The

METROPOLITAN WATER DISTRICT

OF SOUTHERN CALIFORNIA

HISTORY *and* FIRST ANNUAL REPORT

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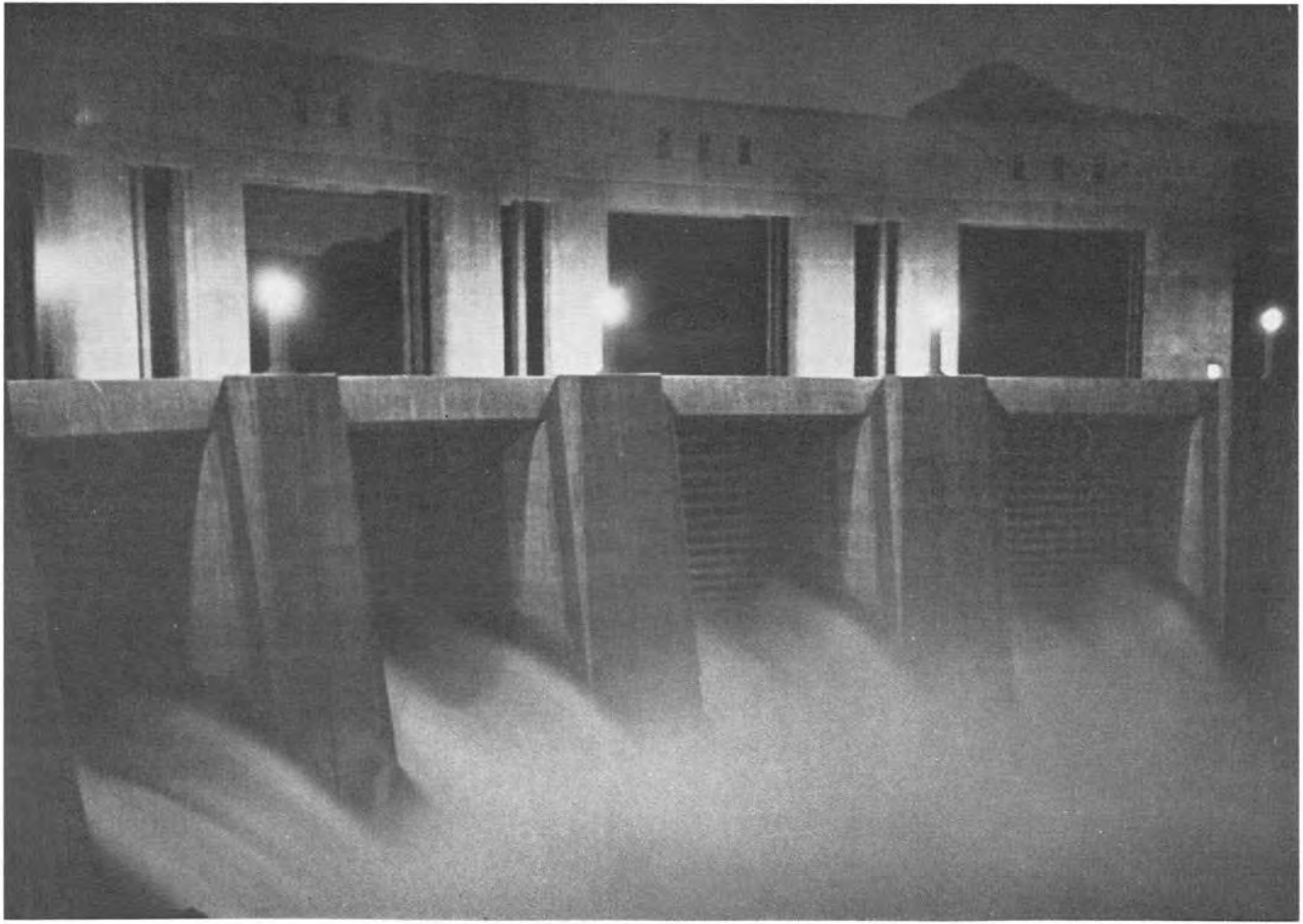

A night view of Parker dam

THE METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA

HISTORY AND FIRST ANNUAL REPORT

For the Period Ending June 30, 1938

F. E. WEYMOUTH
GENERAL MANAGER AND CHIEF ENGINEER

COMPILED AND EDITED BY
CHAS. A. BISSELL

LOS ANGELES
1939

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LETTER OF TRANSMITTAL

Los Angeles, California
January 20, 1939

BOARD OF DIRECTORS,
THE METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA.

Gentlemen:

There is transmitted herewith a copy of the history and first annual report of The Metropolitan Water District of Southern California. This report covers all phases of progress in the construction of the Colorado River aqueduct and distribution system up to June 30, 1938, including a review of the events leading up to the organization of the District in 1928, and an account of its activities since that time.

Very truly yours,

F. E. WEYMOUTH,
General Manager and Chief Engineer

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W. P. WHITSETT............*Chairman, Board of Directors*
LOS ANGELES

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J. M. LUNEY............*Assistant Controller*

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F. E. WEYMOUTH............*General Manager and Chief Engineer*

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Compton	WARREN W. BUTLER
Fullerton	WALTER HUMPHREYS
Glendale	HERMAN NELSON
Long Beach	W. M. COOK
Los Angeles	LOUIS S. NORDLINGER
Los Angeles	OTTO J. EMME
Los Angeles	PERRY H. GREER
Los Angeles	D. W. PONTIUS
Los Angeles	JOHN R. RICHARDS
Los Angeles	V. H. ROSSETTI
Los Angeles	W. P. WHITSETT
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Santa Ana	S. H. FINLEY
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F. E. WEYMOUTH............*General Manager and Chief Engineer*

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Assistant Chief Engineer	JULIAN HINDS
Chief Electrical Engineer	J. M. GAYLORD
Distribution Engineer	R. B. DIEMER
General Superintendent of Construction	JAMES MUNN
Senior Engineer	L. V. BRANCH
Office Engineer	CHAS. A. BISSELL
General Counsel	JAMES H. HOWARD
Assistant General Counsel	ARTHUR A. WEBER
Assistant to General Manager	DON J. KINSEY

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C. C. Elder...Hydrographic Engineer	T. Sheridan Carey...Chief Surgeon-Medical Officer
R. M. Peabody...Mechanical Engineer	S. A. Joseph...Purchasing Agent
E. W. Rockwell...Electrical Engineer	G. D. Smith...Chief of Audits
C. P. Weaver...Superintendent of Operations	A. W. McKinlay...Chief Accountant
L. H. Tuthill...Concrete Technologist	Ira R. Pontius...Disbursing Clerk

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(January 1, 1933 to June 30, 1938)

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R. C. Booth......*Division 1*
John Stearns......*Division 3*
R. B. Diemer......*Division 4*
B. C. Leadbetter......*Divisions 4, 5, and 6*
O. J. Schieber......*Division 4*
J. B. Bond......*Divisions 5 and 6*
Robert N. Allen......*Transmission Division*

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(January 1, 1933 to June 30, 1938)

R. C. Booth......*Coachella tunnels and Eagle Mountain and Hayfield pumping plants*
B. C. Leadbetter......*Coachella and San Jacinto tunnels*
B. H. Martin......*Iron Mountain pumping plant*
R. M. Merriman......*Coachella tunnels*
C. R. Rankin......*San Jacinto tunnel*
T. T. Walsh......*Intake and Gene pumping plants*

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John P. Buwalda

ROLL OF DIRECTORS

Anaheim

A. W. Franzen	December 29, 1928 to	April 11, 1930
O. E. Steward	April 18, 1930 to	April 7, 1935
E. P. Hapgood	May 3, 1935 to	*Present*

Beverly Hills

Paul E. Schwab	December 29, 1928 to	June 19, 1931
George R. Barker	June 19, 1931 to	August 2, 1935
Arthur Taylor	August 2, 1935 to	*Present*

Burbank

Harvey E. Bruce	December 29, 1928 to	February 11, 1933
J. L. Norwood	March 10, 1933 to	*Present*

Compton

C. A. Dickison	July 17, 1931 to	January 20, 1933
William H. Foster	January 20, 1933 to	June 28, 1935
Warren W. Butler	June 28, 1935 to	*Present*

Fullerton

Walter Humphreys	April 10, 1931 to	*Present*

Glendale

W. Turney Fox	December 29, 1928 to	November 27, 1931
Samuel G. McClure	November 27, 1931 to	January 13, 1933
Frank P. Taggart	January 13, 1933 to	August 31, 1934
Bernard C. Brennan	August 31, 1934 to	June 4, 1937
Herman Nelson	June 4, 1937 to	*Present*

Long Beach

Nowland M. Reid	April 10, 1931 to	January 27, 1933
W. M. Cook	January 27, 1933 to	*Present*

Los Angeles

W. P. Whitsett	December 29, 1928 to	*Present*
John R. Richards	December 29, 1928 to	*Present*
John R. Haynes	December 29, 1928 to	February 4, 1930
W. L. Honnold	February 28, 1930 to	July 21, 1933
Perry H. Greer	July 21, 1933 to	*Present*
John G. Bullock	October 25, 1929 to	September 15, 1933
V. H. Rossetti	October 13, 1933 to	*Present*
O. T. Johnson, Jr.	November 5, 1929 to	August 29, 1930
I. Eisner	August 29, 1930 to	July 2, 1937
Walter A. Ham	January 20, 1933 to	January 4, 1935
Otto J. Emme	January 11, 1935 to	*Present*
D. W. Pontius	January 20, 1933 to	*Present*
Louis S. Nordlinger	August 13, 1937 to	*Present*

Names of deceased directors are printed in italics.

Pasadena

Franklin Thomas	December 29, 1928 to	*Present*

San Marino

Harry L. Heffner	December 29, 1928 to	September 29, 1933
John H. Ramboz	September 29, 1933 to	*Present*

Santa Ana

S. H. Finley	December 29, 1928 to	*Present*

Santa Monica

George H. Hutton	December 29, 1928 to	January 16, 1931
Arthur A. Weber	January 16, 1931 to	October 12, 1934
William H. Carter	February 15, 1935 to	March 13, 1936
Edmond S. Gillette	June 12, 1936 to	January 8, 1937
Arthur P. Creel	January 8, 1937 to	*Present*

Torrance

John Dennis	March 17, 1931 to	April 14, 1933
J. R. Jensen	April 14, 1933 to	December 31, 1933
Charles T. Rippy	January 19, 1934 to	*Present*

CITIES COMPRISING THE METROPOLITAN WATER DISTRICT

City	Membership dates from:
Anaheim	December 29, 1928
Beverly Hills	December 29, 1928
Burbank	December 29, 1928
Compton	July 10, 1931
Fullerton	March 13, 1931
Glendale	December 29, 1928
Long Beach	March 13, 1931
Los Angeles	December 29, 1928
Pasadena	December 29, 1928
San Marino	December 29, 1928
Santa Ana	December 29, 1928
Santa Monica	December 29, 1928
Torrance	March 13, 1931

INTRODUCTION

On June 30, 1938 the Colorado River aqueduct project, now under construction by The Metropolitan Water District of Southern California, was 75.9 per cent complete, based upon the estimated cost of $220,000,000. Percentages of completion of the principal construction features completed or under way as of that date were as follows:

Main aqueduct:	
Excavation of tunnels	98.5
Concrete lining of tunnels	95.0
Canals, conduits, and siphons	99.9
Pumping plants	75.0
Dams and appurtenant works	96.0
Power transmission line and telephone line from Boulder dam	100.0
Canal and reservoir fencing	100.0
Terminal storage reservoir	99.0
Distribution system:	
Tunnels	99.0
Upper feeder pipe lines	99.0
Eagle Rock to Palos Verdes cross feeder	26.0

District costs, employment, and percentages of completion by fiscal years since the beginning of construction work in January 1933 are shown in the following:

Fiscal year ending June 30	Total cost to end of fiscal year	Cost for fiscal year	Per cent completion[1]	Maximum monthly employment[2]
1933	$ 10,740,699.47	$	4.9	2,170
1934	30,636,037.75	19,895,338.28	14.0	5,490
1935	57,201,566.76	26,565,529.01	26.2	9,017
1936	96,781,459.65	39,579,892.89	44.4	10,781
1937	138,550,628.94	41,769,169.29	63.5	10,533
1938	167,058,971.86	28,508,342.92	75.9	5,481

The Metropolitan Water District of Southern California is a public corporation, organized in 1928 under the authority of the Metropolitan Water District Act (chap. 429, Calif. Statutes of 1927, p. 694). This act provides a means whereby groups of cities,

[1] $220,000,000 project.
[2] Total reported on all contractors' and District pay rolls.

and certain other governmental subdivisions, such as water districts, not necessarily contiguous, may join together for the development of a water supply. The Metropolitan Water District of Southern California is composed at present of the cities of Anaheim, Beverly Hills, Burbank, Compton, Fullerton, Glendale, Long Beach, Los Angeles, Pasadena, San Marino, Santa Ana, Santa Monica, and Torrance, a total of thirteen. Provision is made in the act for the addition of other areas to the District, as may from time to time be found desirable.

The District was organized for the purpose of supplying the area within its boundaries with water for domestic, industrial and other beneficial uses, and incidentally to provide a means of creating a water supply for such surrounding areas as later may find it advantageous to join in the enterprise. Its first objective is the construction of the Colorado River aqueduct project, consisting of a main aqueduct 242 miles long, extending from the river near Parker, Arizona, to the Cajalco reservoir near Riverside, California, and a distribution system leading to various consumption centers. The following pages contain an account of the conception and planning of the project and a report of construction progress to June 30, 1938.

Government of the District is effected through a board of directors, composed of at least one director from each member city, the voting power being distributed on the basis of one vote for each ten million dollars of assessed valuation, no one city to have more than fifty per cent of the total voting strength of the board. The directors are appointed by the executive officers of the member cities with the consent and approval of the governing bodies. The District has authority to acquire, construct, and operate a water works system, to do all the things incidental to such functions, and to sell water and levy taxes to provide funds for carrying on its business and for paying interest and principal of any bonded indebtedness.

The region within which the cities of the Metropolitan Water District are situated embraces the fertile plain surrounding the City of Los Angeles and extending to Redlands on the east and Newport Beach on the south. The area as a whole is generally referred to as the "south coastal basin" or the "metropolitan area." There are 2,200 square miles, or 1,400,000 acres, of first-class habitable lands within this basin. Citrus fruits and semi-tropical vegetation grow luxuriantly. The climate is delightful

SPENCE AIR PHOTOS

Downtown Los Angeles

and the region is attractive as a place of residence and as the site of an intensive industrial development. Labor is plentiful and foodstuffs are abundant. The oil fields of Southern California provide fuel for all purposes and the Los Angeles-Long Beach harbor is an open door to the markets of the world.

The region is adequately served by three transcontinental railway systems and is covered by a complete grid of paved highways. There are street car, interurban, bus, and truck facilities for every local transportation need. National and international air lines afford quick passenger, mail, and express services to all parts of the American continent. Electric power service is universally available, and gas and domestic water lines are found almost everywhere, even in the rural sections. Educational, religious, and recreational facilities are unsurpassed.

As of January 1, 1938 the population of the metropolitan area was estimated at approximately 3,000,000, or 45 per cent of the population of the State of California. The assessed value of taxable property in the same area was $2,748,000,000, which is 40 per cent of the assessed value of the state. The population and assessed values of the present cities of the District are shown in Table 1. Assessed valuations quoted include the operative property of public utilities but not the property of public corporations exempt from taxation. The assessed values shown theoretically represent about 50 per cent of the real values.

TABLE 1

Population and Assessed Values of District Cities

	Estimated population January, 1938	Assessed value 1937-1938
Anaheim	13,000	$ 9,168,145
Beverly Hills	27,000	56,238,340
Burbank	23,000	22,578,060
Compton	16,000	7,291,780
Fullerton	13,000	14,064,460
Glendale	75,000	57,759,020
Long Beach	175,000	146,220,425
Los Angeles	1,500,000	1,325,178,340
Pasadena	85,000	85,798,355
San Marino	7,000	14,007,340
Santa Ana	35,000	24,309,100
Santa Monica	50,000	45,885,695
Torrance	9,000	19,266,665
Total	2,028,000	$1,827,765,725

Population totals for each census year since 1890, with estimates from reliable local sources for 1938, both for the area as a whole and present District cities, are as follows:

Year	District cities	Entire basin
1890	62,322	140,540
1900	123,294	235,820
1910	391,595	668,038
1920	737,483	1,085,000
1930	1,665,833	2,491,000
1938 (estimated)	2,028,000	3,000,000

The wealth of the basin is derived from many sources; the oldest and perhaps most fundamental resource being agriculture. Southern California oranges are world renowned and other citrus crops are valuable. Deciduous fruits, nuts, grapes, avocados, and other specialized crops also thrive, and all staple vegetables and foodstuffs are produced in abundance.

Petroleum is another basic source of wealth. The basin produced 107,918,000 barrels of oil and 191 billion cubic feet of natural gas in 1937. In addition to this, large quantities of oil and

A Los Angeles County oil field

gas are available from San Joaquin Valley fields in the vicinity of Bakersfield and electrical power at low rates is abundant throughout the area. The amount of electrical energy used in Southern California for the year 1937 totaled approximately 5,350,370,000 kilowatt hours, of which 1,068,570,000 kilowatt hours was produced at the Boulder power plant. The present 330,000-kw installation at Boulder can be increased as required to a capacity of 1,152,000 kw with an annual output of firm energy of 4,330,000,000 kw-hr, a large part of which will flow to Southern California.

The basin is a notable commercial center. In volume of waterborne commerce, as evidenced by total inbound and outbound cargo tonnage, the Los Angeles-Long Beach port stands third in the United States and is one of the world's foremost oil-exporting ports. The combination of harbor facilities, proximity to the Panama Canal, and adequate railway connections, make this the shipping center for the Southwest.

As is brought out in detail in the following pages, this phenomenal growth of population and industry in a naturally semidesert area has overtaxed the water resources appurtenant to the region to such an extent that for the coastal plain outside of Los Angeles the present deficiency of its permanent safe water supply is now computed at from 215 to 300 cubic feet per second, or from one-fourth to one-third of the dependable yield of the region's water resources. The need for a supplemental imported water supply to maintain the continued growth and prosperity of the region was foreseen 15 years ago. The story of the problems solved and the obstacles overcome in the decade-long campaign which culminated in the construction of the Boulder Canyon project by the Federal Government and the authorization by the voters of the District of a $220,000,000 bond issue to build the Colorado River aqueduct is an epic of enterprise of no less interest and importance to an understanding of the project as a whole than is the description of the construction of the works themselves. It has therefore appeared appropriate that this, the first annual report of The Metropolitan Water District of Southern California, should contain more than a passing reference to the history of the early investigations, negotiations, and legislative enactments accompanying the inception and development of the constructive project now approaching completion.

CHAPTER 1

Need for the Colorado River Aqueduct

THE EXTREME aridity of the Southern California climate is not immediately evident to the recently arrived resident or tourist, with only the luxuriant subtropical vegetation of the cultivated areas as a basis for judgment. The sharp contrast with the Sahara-like deserts that must be crossed by every one approaching Los Angeles overland increases the impression of abundant rainfall, until the fact is finally realized that all this vegetation is continuously dependent upon frequent irrigation. The region constitutes in reality a great oasis, sharply bounded in every landward direction by deserts of utter sterility. It derives a limited and extremely variable water supply from the 1,000 square miles of rocky, steeply sloping mountain watersheds which drain into the basin from the north and east. On these mountain slopes the rainfall averages about 30 inches annually, but this rate decreases toward the ocean to only 15 inches at Los Angeles and about 10 inches at the beaches.

These figures for average rainfall, as is often the case with water supply means, are themselves misleading, for one very wet year (with most of its run-off lost as floods into the ocean) outweighs several very dry years in computing the average. As nearly as may be determined from all available data, there have been during the 157 years of Los Angeles history, approximately 94 years with less than average rainfall and more than 100 with less than average stream run-off. The median precipitation during the period has not exceeded 13.5 inches; that is, at least half of the years have yielded less than this amount of rainfall.

Precipitation in Southern California varies widely from year to year, half of the seasons being "unusually" dry, about one in five unusually wet; few are normal or average. Further, when precipitation does occur, it is extremely intermittent; often several months in succession will yield none whatever. Conversely, a single month will sometimes bring one-half the total annual rainfall and occasionally one-half the annual total may fall in a single storm.

Official U. S. Weather Bureau rainfall measurements for Los Angeles are available only since 1877, but earlier records are available from nearby points, including Los Angeles harbor from 1864 and Fort San Diego from 1850. By analyses of old flood records, mission crop reports, miscellaneous notes, diaries of early settlers, and other indirect means, H. B. Lynch, consulting hydraulic engineer of Los Angeles, has extended these records with reasonable dependability back to the year 1769.[1] The results show that there has been no change in mean climatic conditions in Southern California since that date at least, although drought periods are indicated that were both more severe (1822-32) and of longer duration (1842-83) than any that have occurred during the present century.

Early records

A few excerpts from some of these old records may be of interest. Father Juan Crespi reports fording the Los Angeles River on January 7, 1770, and "observing on its sands rubbish, fallen trees, and pools on either side, for a few days previously there had been a great flood which had caused it to leave its bed." Captain de Anza entered in his diary, on January 1, 1776, the following experience with the Santa Ana River, near Riverside: "It was found to be almost unfordable for the people, not so much because of its depth as of the rapidity of its current which upsets most of the saddle animals." In 1780 the annual report of the Mission San Diego recorded: "A few days ago we had a heavy rainfall which filled the river bed and lowlands where the wheat and barley had been planted. * * * The Indians are now working hard to remedy the trouble for the present and to prevent similar disasters in the future."

But periods of drought and extreme low precipitation followed. Father Lasuen wrote on April 26, 1796: "In the year (1795) preceding this we saw ourselves compelled to send one-half of the neophytes for some months into the mountains to search for food, as in the manner of the savages, whilst we maintained those staying here on half rations, and a little milk, until the time of the wheat harvest." This period of drought was unusually severe and protracted, causing difficulties at all of the missions. A letter from Fathers Tapis and Miguel, concerning the Mission Santa Barbara, says: "Repeatedly in the year 1794 the water stopped

[1] Rainfall and Stream Run-off in Southern California; H. B. LYNCH.

to flow at one-quarter of a league from the mission * * * and the harvests are small considering the amount of grain planted." In 1810, which was many years before irrigation had been undertaken in Southern California, Lake Elsinore had shrunk to little more than a swamp about a mile long.[1] This indicates a long preceding period of deficient supply since, according to Lynch, if no water whatever flowed into this lake it would require eleven years for a full lake to evaporate to dryness.

Beginning in 1810 and lasting for eleven years, the records show a period of excessive rainfall. In 1822 another period of extreme drought commenced, lasting until 1832, interrupted only by a large flood in 1825. During this entire period crops almost without exception were very small. Father Fernando Martin, of the Mission San Diego, wrote to Governor Echeandia in January 1829, saying: "In this year of drought, when there is no pasture for the sheep, where shall they be placed?"

Commandante Santiago Arguello wrote Governor Echeandia in January 1831, saying: "The mission (San Gabriel) in sterile years can scarcely support its neophytes, as has happened in the last two years." The year 1833-34 is described as having been a very rainy one and the year 1839-40 equally so. The season of 1840-41 is reported as very dry, and many references to it appear in the records. General Bidwell, who entered the state about this time, is recorded by Royce[2] as saying that there had been no rain for 18 months.

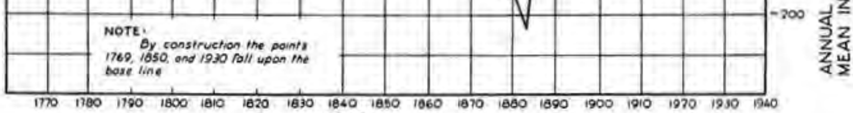

Fig. 1—Rainfall cycles in Southern California

The results of the Lynch study have been combined with the rainfall records of the past 60 years and are shown in the differen-

[1] U.S.G.S. Water Supply Paper 447; p. 321.
[2] John Bidwell, Pioneer; C. C. Royce.

tial mass diagram of Fig. 1. The great variation in precipitation between years and also between months is shown graphically in Fig. 2. Rainfall data for each year since records have been kept in Los Angeles are given in Fig. 3.

Run-off

Sites for the missions and pueblos of the Spaniards were necessarily limited to the banks of the few unfailing surface streams, and the Plaza and Old Town of Los Angeles were so located. For the Los Angeles River, now generally so dry and dusty, a typical southwestern upside down stream, was throughout the nineteenth century a never-failing source of water supply for the potential metropolis. Under Mexican rule the ranchos at an early date preempted throughout the basin the site of every perennial spring or cienega (all now dry so many years that even their sites and former existence seem entirely unknown to present residents). Notable among these were "The Tears of Santa Monica", where ocean-going vessels in earlier years replenished their water supplies and from which the present beach city was named; and Centinella Spring, on the site of which the Inglewood city pumps now draw the municipal water supply from a depth of 150 feet, or well below sea level.

As such springs and the few spring-fed streams were the sole source of water supply during the long, dry summers, irrigation development was very sharply limited. At Los Angeles, an irrigated area of 1,500 acres at the time of the American occupancy had grown to only 8,400 acres a generation later, and in 1879

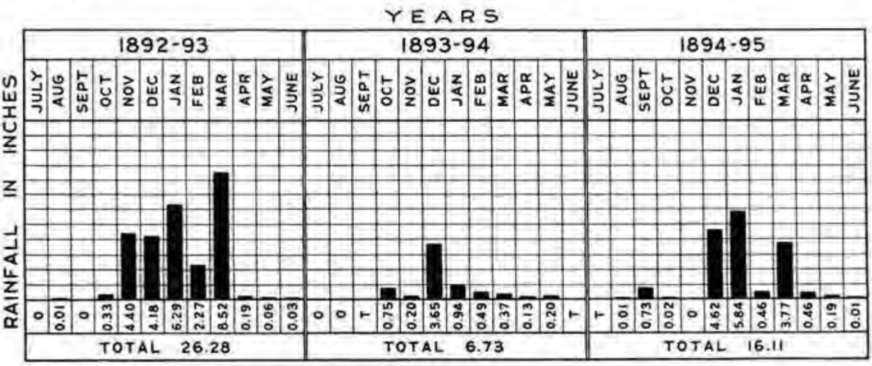

Fig. 2—Typical high, low, and average rainfall years

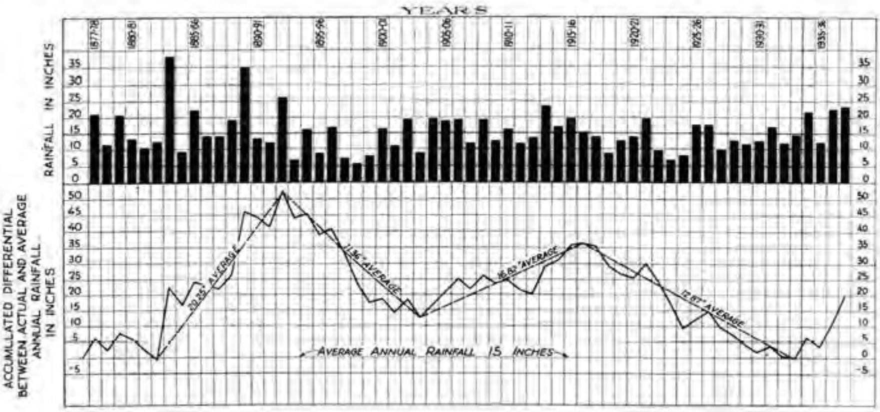

Fig. 3—Annual rainfall records in Los Angeles

even this small oasis suffered seriously from lack of water, much accentuated by increasing upstream diversions. These encroachments on the pueblo's ancient water right, as granted by the King of Spain, and on which the very existence of the settlement depended, became the subject of long drawn out litigation, with the water finally restored to the town.

Practically all surface flows available to the coastal plain are received from the watersheds of the Santa Ana, San Gabriel, and Los Angeles rivers. The areas tributary to each of these streams and the run-offs for different rainfall years are given in Table 2. From this table it will be noted that the mean annual run-off from

TABLE 2

***Run-off from Watersheds of Southern California Coastal Plain*[1]**

	Los Angeles River	San Gabriel River	Santa Ana River	Coastal Plain
Area of mountain and foothill watershed, square miles	342	369	1,167	1,878
Maximum run-off of record, acre feet	418,000	610,000	1,361,000	2,389,000
Equivalent sec-ft.	578	842	1,880	3,300
Minimum run-off of record, acre feet	0	11,800	44,100	55,900
Equivalent sec-ft.	0	16	61	77
Mean run-off, 1924-29, acre feet	26,200	85,700	182,000	293,900
Equivalent sec-ft.	36	118	251	405
Mean run-off, 1919-29, acre feet	52,000	132,000	273,000	457,000
Equivalent sec-ft.	72	182	377	631
Mean run-off, 1889-1929, acre feet	86,000	161,000	323,000	570,000
Equivalent sec-ft.	119	222	446	787

[1]Bulletin No. 25. Report on State water plan. California Division of Water Resources. 1930.

the coastal plain for the 40-year period from 1889 to 1929 was only 24 per cent of the maximum of record. On the other hand the minimum year of record shows less than 10 per cent of the 40-year mean, and the annual flow for the five-year period from 1924 to 1929 averages only 51 per cent of the same 40-year mean.

These large variations in annual run-off might be at least partially equalized if sufficiently large storage at strategic points on each stream could be provided. However, except for the Bear Valley reservoir on the Santa Ana River, built in 1883-84, sites do not exist on these streams where reservoirs could have been constructed in the early days, at a price which the lands could afford and by the time the agricultural development had become sufficiently intensive to justify the construction of expensive storage, all stream flow except flood peaks had been appropriated. Spreading works and other conservation projects have succeeded in equating these river flows to some extent by providing means of recharging the underground basins, but their operation is likewise subject to prior appropriative rights.

The rate of increase in demand can be judged from the data of Table 3 where the increases in irrigated acreage in Los Angeles, Orange, Riverside, and San Bernardino counties are shown for each ten-year period beginning with 1890.

TABLE 3

Areas Irrigated in San Bernardino, Riverside, Orange, and Los Angeles Counties 1889 to 1930 [1]

	1889-90	1899-00	1909-10	1919-20	1929-30
Irrigated farms	4,403	9,215	11,521	18,968	22,967
Area in irrigated farms, acres	139,900	198,000	342,400	547,300	549,900
Irrigated area per farm, acres	31.8	21.5	29.7	28.9	23.9

Water supply and regional development

In 1870 most of Southern California was still included in enormous land holdings, with tens of thousands of acres in single ranchos, and grazing was practically the sole economic activity. Even this industry was unable to survive the vagaries of the region's water supply. One hundred thousand head of cattle were lost in Los Angeles County in the season of 1856-57 because of drought, and in the period from 1862-64 another great drought destroyed even larger numbers, 60,000 head of cattle being reported to have been sold at Santa Barbara for 37½ cents per head,

[1] U. S. Census for Irrigation.

due to lack of water and feed. The ranchos never recovered from these losses. Sheep largely replaced the vanished cattle, but were soon equally hard hit by drought, 22,000 being recorded as lost in 1877 on the Centinella Rancho alone.

It was in this last-named year (1877) that the Southern Pacific railway was connected through to Los Angeles from the East. The incoming tide of settlement thus released found its opportunity in the breakup of the ranchos, and the intense competition which arose between the Southern Pacific and the Santa Fe shortly after the coming of the latter in 1885 started a phenomenal growth in population which has been maintained to the present time. A land boom of unparalleled proportions occurred in 1886 and 1887. Although many regrettable factors accompanied this boom, the stimulus given to immigration was great. In 1880 the population of Los Angeles was 11,183; in 1890 it was 50,395.[1]

Intensive irrigation development

Citrus culture in Southern California was first undertaken about 1854. In 1862 there were 25,000 orange trees in the state, all of which were seedlings derived from Mexico, but no large-scale development occurred until after the navel orange was introduced from Brazil in 1873.[2] Commercial development became important during the following decade, with lemon and grapefruit culture following the navel orange.

The large money returns realized from the citrus groves and from the other specialized crops later introduced furnished the incentive for an intensive development of the region's water resources. The first effect on water supply resulting from this rapid growth was overappropriation of surface supplies. This condition was offset temporarily by well drilling, first with artesian wells, then, after water tables had begun to drop and after commercial electric motors and gas engines became available, by pumped wells, later supplemented or replaced by larger diameter wells with deep-well turbine pumps. The rate of growth in irrigated areas and in the use of wells is shown in Tables 3 and 4.

The census of 1890 reported 1,577 wells used for irrigation in the coastal plain but added that in the large artesian area totalling 315 square miles, every farmer and fruit grower had his own well for domestic use. During a general groundwater survey by the

[1] Reports of U. S. Census Bureau.

[2] The Americana, Vol. 5.

TABLE 4

Growth in Use of Wells in San Bernardino, Riverside, Orange, and Los Angeles Counties 1889 to 1930 [1]

ARTESIAN WELLS	1889-1890	1909-1910	1919-1920	1929-1930
Flowing wells used for irrigation....	1,577	1,596	918	242
Capacity, gpm	....	275,700	165,000	38,000
Capacity per well, gpm	....	173	180	157
PUMPED WELLS				
Used for irrigation	....	3,494	4,886	5,874
Capacity, gpm	....	1,631,300	2,459,100	3,438,800
Capacity per well, gpm	....	466	504	585
H.p. used for pumping	....	61,000	105,800	179,100
H.p. used per 1,000 gpm	....	37.4	43.1	52.2
Mean lift, feet	....	....	61	77

U. S. Geological Survey from 1900 to 1904, 11,000 wells were examined and measured, of which 8,000 were then in active use with 2,500 having an aggregate artesian yield of not less than 300 cubic feet per second. These artesian fields have now practically vanished, except for small areas where toward the end of a wet winter wells sometimes flow again for a short period. The 1930 census found only one artesian well in the Los Angeles River basin, none in the San Gabriel basin, and a total of 21 in all of Orange County.

Meanwhile, the capacity of actively pumped wells for seasonal irrigation use had increased to 5,200 cubic feet per second by 1930 and, including municipal wells and smaller private installations, the total is now estimated at not less than double this amount, or seven times the aqueduct capacity, for use during the peak summer months. Because of nightly and winter shutdowns, the use of many wells for standby purposes only, and the mutual interference of nearby wells when simultaneously operated for considerable periods, the average annual water production of all such coastal plain wells, however, actually totals slightly less than the full rated capacity of the Colorado River aqueduct. Regular measurements of water levels at approximately 10,000 wells in the coastal plain area are being compiled by the state engineer's office. As generally only one well of a group is measured and reported, serving as a reliable index for the others, or only the more easily accessible in a given locality (many being so constructed that measurement is practically impossible), it has been concluded that the number of wells in the Los Angeles area is now not less than 30,000.

The effect of such an accelerated development and increased

[1] U. S. Census for Irrigation.

FAIRCHILD AERIAL SURVEYS, INC.

Horticultural development in Orange County pumping from the underground storage reserves has been only too plainly evident in falling water levels throughout most of the region, particularly since 1916. The situation is complex, as there are in fact not one but 40 or more basins and sub-basins, generally supplied by and in turn spilling over into several others, making quantitative determinations of their relationships difficult and a problem for many years of continued observation and study. Briefly, the overdraft, exclusive of the Los Angeles city area, is variously estimated at from 215 to 300 cubic feet per second as an average over the last ten years.

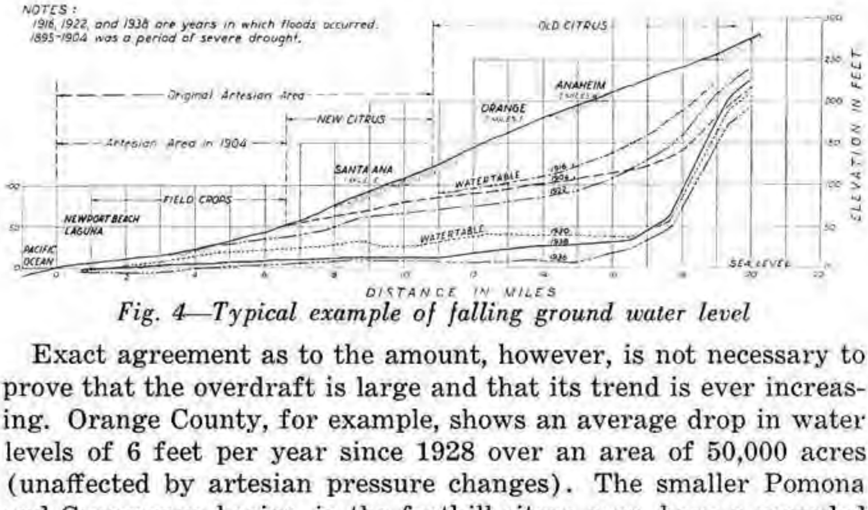

Fig. 4—Typical example of falling ground water level

Exact agreement as to the amount, however, is not necessary to prove that the overdraft is large and that its trend is ever increasing. Orange County, for example, shows an average drop in water levels of 6 feet per year since 1928 over an area of 50,000 acres (unaffected by artesian pressure changes). The smaller Pomona and Cucamonga basins, in the foothill citrus area, have a recorded drop of 10 feet per year for the same period, with individual wells showing even worse conditions. A wet year checks this drop temporarily, and in some cases may even effect a replenishment of the overdraft of a previous year or two, but immediately the downward trend is resumed, to be stopped permanently, and definite recovery accomplished only by means of large-scale importations of water.

Experience with pumped wells is typified by the following extract from the report of the Pasadena Water Department dated May 13, 1929, concerning its San Gabriel project. The Copelin well, with which the extract is concerned, is situated in the west central portion of the City of Pasadena:

> In 1899 an open timbered shaft was sunk to water at a depth of 154 feet at the Copelin well site. A steam plunger

pump was installed in a room excavated in the wall of the shaft just above high water level. This equipment pumped water down to a depth of 187 feet below the surface, furnishing a water supply until 1902 when greater capacity was required. In that year a 12-inch well was drilled from the bottom of the pit to a total depth of 655 feet below ground surface and an additional steam plunger pump was installed. By 1905 the water plane had receded to 166 feet, and the steam plunger pumps could not operate at capacity, so an additional 12-inch well was drilled to a depth of 676 feet, a three-stage vertical centrifugal pump being installed with one suction in each well. Power was supplied by a 200 h.p. steam engine belted to the pump shaft. This equipment operated successfully for 15 years until water levels fell in 1920 to 172 feet below the surface and the pump would not hold suction.

A change was therefore made in 1921 to the deep well type of equipment. The 12-inch wells being too small and crooked, a 26-inch well was drilled to a total depth of 700 feet, with bedrock at 680 feet. A deep well turbine pump was installed at 240 feet below the surface, driven by a direct connected vertical electric motor at the surface. In 1924 the static water level had receded to 190 feet and it became necessary to lower the pump 36 feet to a depth of 276 feet, to add another stage to the pump, and to install a larger thrust bearing at the surface because of the increased lift. In 1926 the static water level had receded to 223 feet and it was again necessary to add 36 feet of column, placing the lower pump runner at 312 feet. This time it was necessary to install an entire new set of pump runners and bowls in order to pump efficiently against the additional head. A new pump head with a still larger thrust bearing was installed. Again in 1929 it became necessary to lower the pump 36 feet to a present depth of 348 feet in order to secure capacity with a lowered static water level of 240 feet.

The history of this well is typical of the general experience in developing ground water from the local supplies during a recession in the water table of 86 feet and a loss of more than one-half the water bearing strata, a much greater drawdown being therefore now required to maintain well capacity.

The experience of Pasadena with the Copelin well is not unique but is typical of experience in other regions.

The Owens River aqueduct

The City of Los Angeles began its history as a Spanish pueblo, founded on September 4, 1781. Nine years later a population of

139 is reported; by 1800 it had grown to 315; and during the next decade, to 365.[1] Even so late as 1850, when California was admitted to the Union, the population was only 1,610.[2] In 1877 its population was about 9,000 and the town dipped its domestic water supply from an open ditch, generally below rather than above where the laundry was beaten clean on the rocks and the boys went in swimming. The late William Mulholland arrived in Los Angeles in the latter year and his first experience in public water supply service came with his employment as superintendent of this system. A wooden flume soon replaced the open ditch, to be replaced in turn by the first steel main in 1901, each under Mr. Mulholland's direction as superintendent for the private water company. In 1902 the city acquired the water system by purchase, retaining Mr. Mulholland as chief engineer, and he continued thereafter in active service with the Water Bureau in this capacity until his retirement in December 1928.

By 1905 the City of Los Angeles had completely diverted the normal run-off of the Los Angeles River, and to augment that supply had constructed underground galleries across the narrows of that river to collect the subterranean flow. In addition, wells were put down on the southern side of the city which drew their supply from underground storage. With opportunity for replenishment during the winter, these withdrawals would have been safe, but the chief source of replacement was being withdrawn upstream by direct diversion. In spite of the use of its entire plant production the City of Los Angeles during July 1905, experienced a withdrawal from storage of more than 3½ million gallons per day. With population increasing at a rate of 150 per cent per decade, this condition caused genuine alarm.

A comprehensive study was made of new supply sources. The Big Tujunga, a tributary of the Los Angeles River, was studied with respect to storage, but storable flows occur on this stream only in periods of unusual rainfall and the amount of recoverable water was much less than that required. The Mojave River was investigated; also the South Fork of the Kern. It was estimated that the Mojave River would yield 60 cubic feet per second of additional supply, but this could be obtained only after costly litigation and by depriving other areas tributary to Los Angeles of their water supply. Kern River was being used as the only

[1] California of the South; McGroarty.

[2] The Americana, Vol. 5.

supply for more than 110,000 acres in the San Joaquin Valley and was insufficient. Piru Creek was studied, but afforded so small an additional supply as to be of little value. The San Gabriel River was also investigated, but it was already overappropriated during most months of each year.

About 1900 the possibility of importing water from the Owens River was suggested. An investigation, ordered in 1904, proved the plan sound. A year later the electorate approved by a majority of fourteen to one a bond issue of $1,500,000 for preliminary engineering and the purchase of water rights and right of way. In June 1907 a $23,000,000 bond issue to cover the entire construction cost of the project was approved by a ten to one majority vote, and in 1913 the Owens River aqueduct was completed with a designed capacity of 400 cubic feet per second.

This new supply was expected to solve the city's water problem for many years to come, but only ten years later another drought proved its Sierra Nevada watershed inadequate to fill the aqueduct during a dry cycle. By 1923 the conditions which obtained prior to construction of the Owens River aqueduct were again imminent. Population growth had continued even more rapidly than before, with no prospect of an early decrease in rate of growth. Los Angeles had become a city of major manufacturing importance and a port of the first magnitude. Demand on the Owens River water system was building up so rapidly that its inadequacy in from ten to fifteen years was foreseen.

Colorado River aqueduct

A search was made for a new source of supply. It was found that about 135 cubic feet per second might be secured by extending the Owens River system into the Mono Basin still farther north. This water could be brought to Los Angeles through the Owens River aqueduct without increasing its size, which was more than sufficient for the transportation of the water available in Owens Valley. But even with such a system the supply would still be inadequate and the basic problem remained unsolved.

Many other communities were in even worse position than Los Angeles, and in addition lacked the resources to make importations such as Los Angeles had accomplished in 1913. The Pasadena experience quoted previously was typical of others. Orange County was experiencing an alarming lowering of water table. The population of the whole Southern California area was increasing along with that of Los Angeles at a rapid rate. Industries were also showing a remarkable growth, the increase in the value of manufactured products being from \$440,800,000 in 1919 to \$1,341,650,000 in 1929, and of water-borne commerce from \$153,-919,000 in 1919 to \$1,055,800,000 in 1929.[1] Agriculture, population, and industries, all growing, demanded more water. With present sources being overdrawn continually, it was clear that a new importation to meet the needs not only of Los Angeles but of the entire Southern California metropolitan area must be made. The only new source found available was the Colorado River.

Estimated ultimate demand

The Colorado River aqueduct was therefore planned not as a Los Angeles project, but as a Southern California enterprise, not on the basis of meeting immediate needs alone, but on the far broader basis of insuring for generations to come an adequate water supply for the region as a whole. The ultimate aqueduct capacity was fixed at 1,500 cubic feet per second in the first instance on the basis of a thorough study of population trends and probable growth of domestic and industrial demands in the metropolitan area. A consideration of the region's water supply problems on the basis of the areas involved serves as a valuable confirmation of the conclusions drawn from the statistical studies.

The habitable area of the south coastal basin is approximately 2,200 square miles, or 1,400,000 acres. The Colorado River aqueduct, after allowing for losses, will deliver approximately 1,000,000 acre-feet per year into local storage reservoirs, or say seven-tenths of an acre-foot per acre. The Los Angeles aqueduct, extended to Mono Basin, can be depended upon (but for use by the City of Los Angeles only) for perhaps the equivalent of two-tenths of an acre-foot per acre, bringing the imported supply up to a depth of nine-tenths of a foot on the average.

The total area of the basin is 3,900 square miles, of which the uninhabitable mountainous and foothill portions comprise 1,700 square miles. The rainfall in the mountains is estimated to average as high as 30 inches. About 20 per cent of this precipitation, as a long-time average, probably reaches the valleys in the form of run-

[1] Latest official figures available show a value of manufactured products of \$1,053,000,000 in 1935 and a total for water-borne commerce in 1937 of \$861,000,000, but with improving business conditions both these figures are confidently expected to reach and pass the 1929 figures at an early date.

SPENCE AIR PHOTOS

Shipping in Los Angeles-Long Beach harbor off. Not all of this run-off can be conserved, allowing for flood seasons as well as normal and dry years. If, as appears to be a reasonable estimate, approximately eight-tenths of this 20-per cent average run-off from the mountains may be saved and spread over the habitable area, an additional four-tenths of an acre-foot per acre is obtained. Percolation on the valley floors is less susceptible of close determination. It is ineffective except in seasons of abnormal precipitation and is generally concluded to add not more than one-tenth of an acre-foot per acre, on the average, to the available pumped water supply.

The total supply then, with all prospective importations, amounts to approximately 1.40 acre-feet per acre. This is a gross figure, with no allowance for losses in handling and distributing. As an irrigation supply, this is a modest amount. As a domestic supply it is low, even for sparsely settled sections and it makes no allowance for the heavy usage in congested and industrial districts. Ultimately this allowance will probably be slightly increased by sewage reclamation and perhaps more notably by return flow from irrigation when a more bountiful primary supply is made available, but from all the evidence that is now available it appears that the adopted capacity of 1,500 cubic feet per second is a reasonable approximation to the needs of the District, so far as they may now be safely predicted.

Quality of Colorado River water

Colorado River water, as regulated by the Boulder Canyon reservoir, is absolutely clear and free from silt, its former suspended and bed loads having been deposited at the head of the reservoir, over 100 miles upstream, and the Parker reservoir capacity of 717,000 acre-feet is more than adequate for the removal of any slight turbidity acquired between Boulder dam and the head of Parker reservoir, thus insuring that at the aqueduct intake the flow of the Colorado River will likewise be clear, sparkling, and entirely potable.

The water is and will probably always remain exceptionally free from bacterial and other contamination, such as industrial wastes, for in the seven-state watershed area of 180,000 square miles above Parker dam there is a population of only about 315,000, or one person for each 370 acres. Of this population, 40 per cent resides in incorporated towns and villages (115 in number or one to each million acres) of which towns but five exceed 5,000

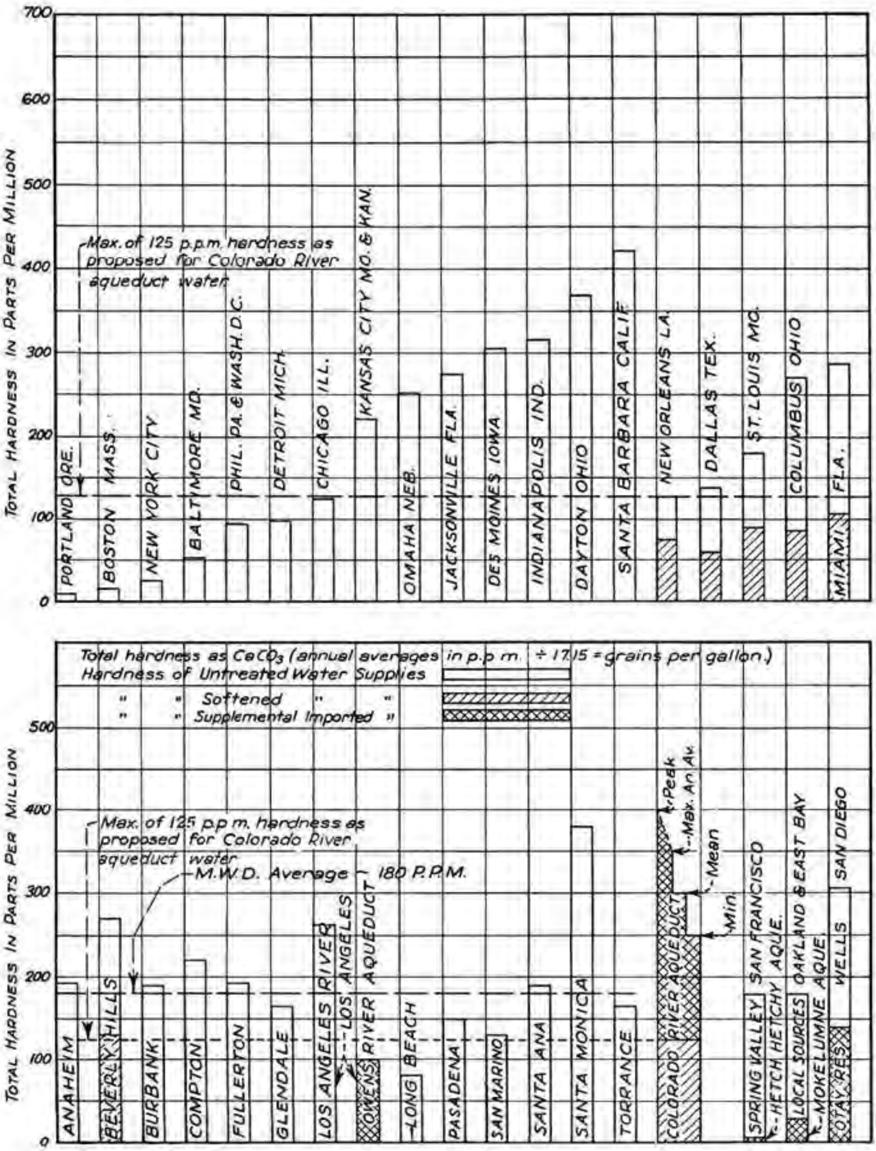

Fig. 5—Colorado River water compared with other water supplies

and only one equals 10,000 population. This extremely low population density of but 1.7 per square mile compares with 120 per square mile for the Hudson River basin, exclusive of New York City; with 150 per square mile for the Connecticut River basin, and with 380 per square mile for the entire Delaware River basin. Furthermore, with the exception of Needles, California, there are no towns or villages upstream from the intake for hundreds of miles. The storage of the river flow for long periods of time in Mead Lake behind Boulder dam, which is only 98 miles above the head of Parker reservoir, will do much to minimize the effect of any local contamination, bacterial or otherwise. Any possible contamination from Needles will, of course, be obviated by suitable sewage disposal works.

Colorado River water has been used for many years in Yuma, Imperial Valley, and elsewhere along the river for every purpose —domestic, municipal, and agricultural—with generally satisfactory results. Since the completion of Boulder dam the storage in this reservoir of the relatively soft flood waters formerly wasted into the ocean has reduced maximum salinity and hardness to less than half the former extremes so that the water in the lower river now compares favorably in hardness and total dissolved solids with waters used for domestic purposes over widespread areas

TABLE 4A

AVERAGE COMPOSITION OF COLORADO RIVER WATER BEFORE AND AFTER TREATMENT

CONSTITUENT	PARTS PER MILLION	
	RAW WATER	TREATED WATER
Total hardness	300.	125.
Carbonate hardness	145.	35.
Noncarbonate hardness	155.	90.
Silica, SiO_2	19.	....
Iron, Fe	0.25	less than 0.01
Calcium, Ca	81.	14.
Magnesium, Mg	25.	23.
Sodium, Na / Potassium, K	87.	117.
Bicarbonate, HCO_3	182.	......
Carbonate, CO_3	......	21.
Sulphate, SO_4	243.	243.
Chloride, Cl	60.	60.
Nitrate, NO_3	2.8	2.8
Total solids	608.	481.

of the Middle West. It is also in these respects superior to supplies from many city wells, and to low-flow supplies from some of the local surface streams. The fact has always been recognized, however, in connection with Colorado River aqueduct investigations, that the water will require softening in order to give the greatest satisfaction for domestic and industrial uses.

Studies extending over several years have resulted in the conclusion that by use of standard softening processes reduction in total hardness of the aqueduct water to 125 parts per million or less can be satisfactorily and economically accomplished, the average composition of Colorado River water before and after the proposed treatment being as shown in Table 4A.

In Figure 5 there is shown for comparison with Colorado River water after treatment, the average hardness of water supplies, both treated and untreated, of representative cities throughout the country. In the lower chart the hardness of the present water supply of each member city of the Metropolitan Water District and of other California cities is plotted for comparison with Colorado River water before and after the recommended treatment. From these charts it appears that the proposed reduction of hardness to 125 p.p.m. should result in an entirely satisfactory supply. Any treatment plant that is constructed will of course be so designed that a maximum hardness as low as 100 or even 80 p.p.m. can be obtained for the additional cost of the larger quantities of the necessary chemicals, if and when found desirable.

CHAPTER 2

Early Developments, Enabling Legislation, Organization, Power and Water Contracts

THE COLORADO RIVER aqueduct project was made possible by three fundamental legislative enactments and three major contracts. These are first, the Colorado River Compact, the Metropolitan Water District Act of California, and the Boulder Canyon Project Act; second, the two contracts between The Metropolitan Water District of Southern California and the United States for power and for water, respectively, and the seven-party agreement between the members of the "agricultural group" and those of the "city group" for the allocation of California's rights in Colorado River water. These enactments and contracts are all so interwoven in interest and objective that some discussion of their background and history is essential to an understanding of the project's place in the history of the Southwest.

Indispensable as they both are to the finally adopted plan, neither the Colorado River aqueduct nor the Boulder Canyon dam was a part of the original conception for utilizing the waters of the Colorado, but both have evolved out of ideas and schemes which first appeared, in more or less elementary form, before the Civil War. During the intervening years interest waxed and waned repeatedly, but gradually became wider and more purposeful, until finally the aqueduct project was developed, devoted to the highest purpose to which the river might be put, namely, providing a metropolitan domestic water supply.

First river diversion

Thomas H. Blythe moved to the Palo Verde Valley in 1856 and commenced the first recorded use of the Colorado River in California. In 1877 he made the first California filing on Colorado River water, claiming 95,000 miner's inches (1,900 cu. ft. per sec.) to be used in the irrigation of 40,000 acres known as the Blythe Rancho. In 1860, seventeen years before the first transcontinental railroad reached Southern California, Dr. O. M. Wozencraft and

Ebenezer Hadley, the latter county surveyor for San Diego County, conceived a project for the irrigation and colonization of 3,000,000 acres in Imperial Valley. They proposed to divert water from the Colorado River by way of the Alamo River and Mexico in much the same way as that finally utilized by the California Development Company forty years later. This project was approved by the California legislature, but failed before the National Congress.

Lieutenant Eric Bergland, Corps of Engineers, U. S. Army, carried out surveys in 1876 to investigate the possibility of reaching the Imperial Valley with a canal which would lie wholly within the United States. After covering the area between Grand Canyon and Needles he reported unfavorably on such an All-American route, but called attention to the natural route available south of the international boundary.

In 1886 a private company was organized which unsuccessfully undertook to irrigate and develop lands in the Imperial Valley. A similar effort in 1892 was also unsuccessful. Real progress was not made until the California Development Company commenced construction of its Imperial canal in 1900. This canal diverted from the river just below the international boundary and followed the general route proposed by Wozencraft, Hadley, and Bergland, its course being through Mexico for about fifty miles. Although the plan was sound from an engineering standpoint, there were many international political obstacles to satisfactory operation and the persistent efforts thereafter to obtain a canal wholly within the United States finally culminated in the construction of the All-American canal under the Boulder Canyon Project Act, passed nearly thirty years later.

Each of these early developments and proposals was based entirely upon utilization of stream flow without storage or regulation and had to be made without benefit of competent data on stream discharge. The first comprehensive engineering work, upon which plans for an extensive development might be based, began in 1894 and 1895, when the first gaging stations were established on the river, thus permitting records to be kept of the stream discharge and, through these, a determination to be made of the water supply available. Following passage of the Federal Reclamation Act in 1902 (32 Stat., 388) a systematic study of the lower river was undertaken. Frequent stream gagings were made, topographic maps prepared, reservoir sites surveyed, and dam sites explored. In 1904 the U. S. Reclamation Service began the construction of the Yuma project.

Need of flood control

The Imperial Valley was created when the encroaching deltaic deposits of the Colorado River finally cut off the ancient northern extension of the Gulf of California, thus forming a vast lake, the remnant of which, with a water surface now 247 feet below sea level, is known as the Salton Sea. In past ages as the delta-building process continued the river undoubtedly discharged sometimes into the lake and for other long periods into the gulf, but when its mouth was first visited by the white man it was flowing to the latter along the rim of the valley in an apparently stabilized channel.

The lower river, before the construction of Boulder dam, was annually subject to long sustained floods from the melting snows of the high mountains in Colorado and Wyoming, whence it takes its source. The tragic menace from these floods, however, was not fully appreciated until 1905, when the river in flood took possession of an unprotected temporary opening which had been cut during the preceding low-water season between the river and the Imperial canal at a point some four miles below the international boundary, abandoned its former gulfward channel and followed the steeper canal route into the Imperial Valley. For 16 months the entire flow of the river poured into the valley, creating a lake 76 feet deep and 488 square miles in area, and threatening permanently to engulf the entire project. The break was finally closed with great difficulty and expense, but about 30,000 acres of arable land were inundated, miles of main-line track of the Southern Pacific railroad had to be moved to higher ground, and tangible damage in excess of $3,000,000 was sustained. Here, in the need for flood control, was the prime motivating reason for the Boulder Canyon Project Act.

In 1909 the river was dammed for the first time upon the completion of Laguna dam but, aside from growth in the development of the Yuma and Imperial valleys and the smaller development in the Palo Verde Valley, little other river utilization occurred for many years. After the disaster of 1905-1907, the affairs of the Imperial Valley became involved with the financial difficulties of its principal developer, the California Development Company, which latter went into receivership in 1909, its properties being sold at auction to the Southern Pacific Company in 1916 for $3,875,000. The Imperial Irrigation District was organized in 1911, following which, in 1916, it purchased the California Development Company properties from the Southern Pacific Company for $3,000,000, only four months after that company had acquired them.

Whistler report

With the organization of the Imperial Irrigation District the development of the valley advanced more rapidly. Interest in the construction of an All-American canal, which had been dormant for many years, was again revived and became more articulate.

In 1914 Congress made a special appropriation for more intensive study of Colorado River problems by the Reclamation Service and followed this with additional allotments. Thus supported, reconnaissance studies were made of available reservoir sites and irrigation projects and data were compiled on water rights and filings within the basin. In a report, made in June 1918, and a supplementary report, in March 1919, both by John T. Whistler, engineer, U. S. Reclamation Service, the following conclusions were reached: (1) that there is sufficient water supply in the Colorado River, if storage is provided, to supply all future irrigation requirements within the drainage basin; (2) that in order to fully utilize the water supply for future irrigation development, storage capacity of 10,000,000 to 12,000,000 acre-feet is required; (3) that it is possible so to distribute this storage as to permit the fullest development feasible, not only in the lower Colorado River basin but in the upper tributary basins; (4) that the ultimate cost of such storage for the fullest irrigation development on the lower Colorado River will be well within the value of such storage to the lands that will be supplied; (5) that the additional area feasible to irrigate in the upper basin is 1,154,000 acres, making the ultimate irrigation development approximately 2,500,000 acres; (6) that the ultimate area feasible to irrigate in the lower Colorado River basin is 2,350,000 acres, of which about 465,000 acres were then under irrigation; (7) that the proposed storage for irrigation would provide a large degree of flood protection and that complete flood regulation to a maximum of 60,000 second-feet may be provided by additional flood-regulating reservoirs on the Grand, San Juan, and Gila rivers, at a cost well within the value of such protection; (8) that there would be in the regulation proposed a material benefit to water-power development in the Colorado River basin as a whole. The principal reservoirs proposed were on the upper river above Lee Ferry.

Following the Whistler report and other reports made during the same year, and after the conclusion of two agreements between the Imperial Irrigation District and the United States, one dated February 16, 1918, providing for surveys and the appointment of a joint board (All-American canal board), and the other dated October 23, 1918, for extension of the Imperial canal to Laguna dam and committing the District to the construction of an All-American canal therefrom, the first Kettner bill was introduced in the 66th Congress in June 1919. This proposed legislation sought to authorize the Secretary of the Interior to accept the District's bonds in payment for funds advanced for the construction of an All-American canal to serve the Imperial and Coachella valleys. Neither this bill nor its successor, introduced in the second session of the same congress, was enacted.

On May 18, 1920, a bill, later known as the Kinkaid Act (41 Stat., 600) was approved, under which the Secretary of the Interior was authorized and directed to make an examination and report on the condition and possible irrigation development of the Imperial Valley. One-half of the cost of this examination and investigation was to be paid by the United States and the other half by local affected agencies.

At about the same time a keen interest in the Colorado River was displayed by various public and private agencies seeking the right to develop hydroelectric power, but proposing to provide storage and flood control incidentally.

Report on problems of Imperial Valley

The study of the Colorado River by the Reclamation Service engineers did not stop with the submission of the Whistler report. As previously stated, the principal reservoir sites discussed in that report were located above the Grand Canyon and would provide adequate flood control of the upper river only. They did not provide that flood protection which was the essential and most urgent need of Imperial Valley. Accordingly investigations were transferred to the lower basin where topographic surveys were continued up the river from Bulls Head and a detailed survey was made of the reservoir site at and above Boulder Canyon. Upon funds becoming available under the Kinkaid Act the scope of the studies was enlarged to include, on account of their interrelation with the problems of the Imperial Valley, a general review of the conditions and water resources of the entire Colorado River basin, requiring data along 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.

A preliminary report was made by Director A. P. Davis to the Secretary of the Interior November 27, 1920, and a final report in July 1921. This latter report, entitled "Problems of Imperial Valley and Vicinity," (S. Doc. 142, 67th Cong., 2nd sess.) gave the results of diamond drill borings, geological investigations, engineering surveys, preliminary plans, and estimates demonstrating the feasibility of Boulder dam from the construction standpoint. It also presented hydrographic studies showing the degree of flood protection that could be provided, the available water supply, and the amount of firm power that could be generated, showing conclusively that the development of this reservoir site was the key to the problem of the proper and orderly development of the resources of the Colorado River basin. All surveys and field investigations for this report were made under the direction of F. E. Weymouth, then chief engineer of the Reclamation Service.

Fall-Davis report

The Kinkaid Act required the Secretary of the Interior to report "what assurance he has been able to secure as to the approval of, participation in, and contribution to the plan or plans proposed by the various contributing agencies." Following receipt of the engineering report by Director A. P. Davis, discussed in the preceding paragraph, the Secretary of the Interior pursuant to the instructions of the act continued inquiry by correspondence, publicity, and public hearings to determine the probable reception of the proposals. These inquiries culminated in a public hearing in San Diego in December 1921, at which time expressed sentiment was virtually unanimous for a large project to provide flood-control, storage and power. In transmitting the report, popularly known as the Fall-Davis report, to the Senate, under date of February 28, 1922, Secretary Fall concurred in the recommendations of Director Davis, and urged favorable action by the Congress. These recommendations were as follows:

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 allot 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 the Federal Government or otherwise be required in both construction and operation to give priority of right and use:
   First. To river regulation and flood control.
   Second. To use of storage water for irrigation.
   Third. To development of power.

Two months after the Fall-Davis report was transmitted to the Senate, Congressman Phil D. Swing introduced a bill seeking to authorize the construction of a project for Colorado River development which would embody the recommendations of that report. A companion bill was introduced in the Senate by Senator Hiram Johnson. This was the first of four Swing-Johnson bills introduced successively in the 67th, 68th, 69th, and 70th congresses, the last of which became the Boulder Canyon Project Act.

Colorado River Compact

The Colorado River, for many years prior to the construction of the first railroad between Yuma and the Pacific Coast, was


SPENCE AIR PHOTOS

Long Beach, Signal Hill, and mountains navigated more or less regularly by steamboats for hundreds of miles above its mouth. In addition to its status thus established as a navigable stream, the fact that its lower delta and mouth are in Mexico gives an international aspect to its problems. But the most pressing difficulties which had to be disposed of before any comprehensive development could be accomplished were not those connected with either navigation or foreign relations. With a watershed reaching into seven states and the main stem of the river traversing or forming part of the boundary of five of these, in an arid region where the extent of the ultimate habitable area is irrevocably determined by the limitations of the dependable water supply and the possibilities for its economic utilization, it is not surprising that the establishment of equitable interstate relationships demanded first consideration.

As a means of solving some of these difficult interstate problems it was proposed by some of these states, early in 1921, that a compact be entered into based upon negotiations and study by their representatives meeting in joint session. Each of the seven basin states adopted appropriate legislation authorizing the appointment of compact commissioners, the last being the State of California on May 12, 1921. On August 19, 1921, the Congress consented to the negotiation of such a compact and provided for the appointment of a commissioner to represent the United States. The commission was organized in Washington, D. C., on January 26, 1922, with Herbert Hoover, then Secretary of Commerce, representing the United States and serving as chairman, and commissioners representing each of the seven basin states, as follows:

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

Following its organization meeting and numerous executive sessions held in Washington in January 1922, the Colorado River Commission met for public hearings in Phoenix, Los Angeles, Salt Lake City, and Grand Junction, Colorado, in March 1922, and in Denver and Cheyenne in the early part of April. Final sessions were held at Santa Fe during November of the same year, culminating on November 24th in the execution of the Colorado River Compact, with the commissioners of each of the seven interested states and of the United States signatory thereto, subject in each case to subsequent ratification by proper legislative authority. This compact provided principally for a division of the available water of the Colorado River system. It did not attempt finally to allocate the water among the states, but made a general division at Lee Ferry between the "upper basin" and the "lower basin." It apportioned to each of these basins in perpetuity a total annual diversion of 7,500,000 acre-feet for beneficial consumptive use and granted the further right to the lower basin to increase its beneficial consumptive use by 1,000,000 acre-feet per annum. The division did not apportion the total annual water yield of the system, but rather the firm amount, leaving the excess for further apportionment between the two basins after October 1, 1963. The compact recognized the Colorado as a navigable stream, but held that this use should be subservient to the use for domestic and agricultural water supply and for power purposes. It declared the policy that the flow of the river might be impounded for power generation, but that agricultural and domestic use should remain forever dominant. The document cleared the way for legislation authorizing construction of a major development. The compact was ratified during the following year (1923) by six of the seven states, but was declined by Arizona. As the act then stood it could not be put into effect until ratified by all.

For the purpose of crystallizing sentiment and furthering the development of the Colorado River an influential group of citizens of California met in Fullerton on May 10, 1923, and formed the Boulder Dam Association, with the expressed objective "to advance by all legitimate means the construction by the Government of Boulder dam and the All-American canal and such other development in Arizona, Nevada, and California as is practicable, all as recommended in the Fall-Davis report." John L. Bacon, mayor of San Diego, was named president; George L. Hoodenpyle, city attorney of Long Beach, was named vice-president; and S. C. Evans, mayor of Riverside, executive director. The membership of this association consisted not of individuals, but of civic and other bodies, including county boards of supervisors, farm bureaus and other agricultural groups, chambers of commerce, ex-servicemen's, and many other civic and service clubs. Over 200 such organizations throughout Southern California, Arizona, and Nevada were represented. The association carried on a systematic and effective campaign of public education, published informative news letters, issued pamphlets and booklets, obtained newspaper publicity, and carried on correspondence and conferences with representatives and public officials in Washington.

Need for additional domestic water

About this same time it was becoming increasingly evident that the phenomenal growth of Southern California and its metropolitan area would soon demand a new importation of water. The City of Los Angeles had seen its safe yield of Owens Valley water absorbed and had studied other sources from which importations might be made. The only adequate feasible source appeared to be the Colorado River, where flood waters, if properly conserved, could be made available for such use. New storage works were needed, as the low flow of the river was often insufficient to meet the existing demands of the Imperial Valley and others dependent upon it. The need for a source of domestic water supply therefore became an additional and potent reason for urging the development of the river.

In October 1923, William Mulholland, then chief engineer of the Water Bureau, recommended to the Department of Public Service of Los Angeles that a survey be authorized to investigate the feasibility of importing water into Southern California from the Colorado River. This recommendation was approved, and on October 29, 1923, the first reconnaissance for a route for the Colorado River aqueduct was undertaken. The general feasibility of such an aqueduct from the Colorado River was soon established, and on June 28, 1924, the City of Los Angeles made a filing with the state authorities on a flow of 1,500 cubic feet per second of water from the Colorado River.

Weymouth report

The results of two years' additional work under the Kinkaid Act were embodied in a report made by Chief Engineer F. E. Weymouth, of the U. S. Bureau of Reclamation, to the Commissioner of Reclamation under date of February 28, 1924. The conclusions of this report were as follows: (1) that there was immediate need of flood protection for river bottom lands in the lower Colorado River basin and for the Imperial Valley, attention being called to the immediate danger, during each flood period, that the river might break into the valley and destroy it; (2) that there was shortage of water in the Imperial Valley in each low-water year, there being only 3,500 second-feet or less available for the entire valley at such times; (3) that it was practicable to build reservoirs on the Colorado River sufficient in capacity to provide reasonably uniform flow from year to year; (4) that the results of the investigation of eight dam sites on the main river indicated that the most advantageous site from the standpoint of river regulation, flood control, storage for irrigation, and power development was that at Boulder Canyon with a dam in Black Canyon; (5) that the immediately urgent problems of river control and utilization in the Colorado River basin could be solved by (a) the construction of Boulder Canyon reservoir with a dam in Black Canyon, raising the water 605 feet and forming a reservoir of 34,000,000 acre-feet capacity; (b) the reservation of 8,000,000 acre-feet at the top of the reservoir for flood control with provision for a decrease of 4,000,000 acre-feet, dependent upon upstream development; (c) provision for priority of use of remaining storage for irrigation over power; (d) construction of a power house with 1,200,000 h.p. installed capacity; (e) construction of an All-American canal from Laguna dam to Imperial Valley.

The Weymouth report also submitted preliminary designs for the Boulder Canyon project and gave the following list of advantages of the recommended site over any other site or combination of sites which had been proposed: (a) accessibility; (b) excellent foundation conditions at the dam site; (c) availability of suitable construction materials; (d) lack of interference with any proposed irrigation project; (e) lower cost of providing storage than at any other known site on the Colorado River, with the exception of a purely flood-control reservoir which could possibly be built at approximately the same cost at Mohave Valley; (f) interception of floods from all important tributaries, with the exception of the Bill Williams and Gila rivers; (g) located nearest to the lands to be benefited.

Metropolitan Water District organized

During 1924 general sentiment for the construction of an aqueduct from the Colorado River which would benefit all of metropolitan Southern California was beginning to develop and, on September 17th of that year, the Colorado River Aqueduct Association was organized in Pasadena to sponsor such a project. This association was somewhat similar in organization to the older

Boulder Dam Association. At the organization meeting, which was attended by representatives of thirty-seven communities, a committee was named to draft "special legislation which will alone permit and make practical joint financing, and, following that, harmonious control of the operation of such great works." The late W. B. Mathews, as special counsel for the Department of Public Service of the City of Los Angeles, and James H. Howard, as city attorney of Pasadena, were prominent in this early organization work. As a result of the work of this association, a bill was introduced in the state senate on January 19, 1925, which sought to authorize the organization of metropolitan water districts. This passed the senate on April 15, 1925, by a vote of 25 to 9, but was defeated in the assembly a week later by a vote of 43 to 32.

The first preliminary surveys having indicated the practicability of an aqueduct from the Colorado River, the electorate of the City of Los Angeles, on June 2, 1925, authorized the issuance of $2,000,000 in bonds for the purpose of providing funds for carrying on additional aqueduct engineering and investigation work. With this financing the Bureau of Waterworks and Supply of the city increased its activities both in the field and office.

On February 27, 1926, the third Swing-Johnson bill was introduced in Congress. In the committee hearings on this bill congressional consideration was for the first time given to the proposal to use the Colorado River for a domestic water supply for Southern California. As previously mentioned, similar bills for the construction of the Boulder Canyon project had failed to come to a vote in the preceding congresses. It was early recognized that to secure favorable consideration the project must be self-supporting and that the power to be generated from any development which was built must find a market which would eventually return all costs of the entire project to the Government. As additional engineering work for a Colorado River aqueduct was done it became evident that any practicable diversion from the river must be made at an elevation lower than that of much of the area to be served, and would involve pumping. Such pumping was practicable only if a large amount of power could be obtained at a low price. This created, at once, a potential market for a substantial part of the power from any major Colorado River development. When these facts, as well as the need for an additional domestic water supply in Southern California were laid before Congress support for the Swing-Johnson measure became easier to obtain.

In January 1927, a second bill providing for the organization of metropolitan water districts was introduced in the California legislature and, after some amendment, was passed in the senate on April 6, 1927, by a vote of 27 to 0. On April 27th the same bill was passed by the assembly by a vote of 63 to 2. The act was approved by the Governor on May 10, 1927, and became effective on July 29th of the same year. Thus the state legislative basis for the organization of The Metropolitan Water District of Southern California was established.

The board of directors of the City of Pasadena, on February 15, 1928, pursuant to the Metropolitan Water District Act of the State of California, adopted an ordinance declaring that public necessity and convenience required the organization and incorporation of a metropolitan water district, and named the following cities as those proposed to be included: Arcadia, Beverly Hills, Burbank, Covina, Culver City, Glendale, Glendora, Los Angeles, Pasadena, San Marino, Santa Monica, and Whittier, in Los Angeles County; Anaheim, Fullerton, Orange, and Santa Ana, in Orange County; Colton, Redlands, Ontario, and San Bernardino, in San Bernardino County; and Riverside, in Riverside County. This was the initial step required under the newly-enacted law, preliminary to organization of the agency which would construct and operate the Colorado River aqueduct.

On August 3, 1928, the Supreme Court of the State of California, in a suit brought by the City of Pasadena against Bessie Chamberlain, city clerk, decided that the Metropolitan Water District Act was constitutional. Following this test, the board of directors of the City of Pasadena on October 16, 1928, called a special election on the incorporation and organization of a metropolitan water district, such election to be consolidated with the general election on November 6th. On that date the electorates of Beverly Hills, Burbank, Glendale, Los Angeles, Pasadena, Santa Monica, San Marino, San Bernardino, Colton, Anaheim, and Santa Ana approved the inclusion of the areas of their cities within the proposed district; two others, namely, Glendora and Orange, did not approve such inclusion. A certificate of incorporation was requested of the secretary of state on December 4th, following which

The Metropolitan Water District of Southern California was incorporated on December 6, 1928.

Following incorporation of the District and subsequent appointment of official representatives by the member municipalities, the board of directors of The Metropolitan Water District of Southern California was called together by Clayton R. Taylor, chairman of the board of directors of the City of Pasadena, at the Huntington Hotel in Pasadena on December 29, 1928, for organization. The directors present were:

A. W. Franzen	Anaheim
Paul E. Schwab	Beverly Hills
Harvey E. Bruce	Burbank
C. A. Hutchinson	Colton
W. Turney Fox	Glendale
W. P. Whitsett	Los Angeles
Franklin Thomas	Pasadena
W. O. Harris	San Bernardino
Harry L. Heffner	San Marino
S. H. Finley	Santa Ana
George H. Hutton	Santa Monica

Two other directors from Los Angeles, John R. Richards and John R. Haynes, were unable to attend.

On February 9, 1929, permanent organization of the District was effected, with W. P. Whitsett, of Los Angeles, chairman; Franklin Thomas, of Pasadena, vice-chairman; and S. H. Finley, of Santa Ana, secretary. The first board meetings were held in the Pasadena City Hall but the permanent organization began its work in the offices of the Los Angeles Department of Water and Power at 222 South Hill Street, Los Angeles. On March 1st, W. O. Harris, of San Bernardino, was appointed temporary controller. On July 1, 1929, F. E. Weymouth undertook direction of all the District's engineering activities as chief engineer.

Fourth Swing-Johnson bill

Progress was being made in Congress during this time on the enactment of the Boulder Canyon Project Act. The fourth Swing-Johnson bill was introduced in the two houses of Congress on December 5 and 6, 1927. The final bill combined the important features proposed in the previous unsuccessful Swing-Johnson bills. As introduced in the Senate, it authorized the Secretary of the Interior "to construct, operate, and maintain a dam and incidental works in the main stream of the Colorado River at Black Canyon or Boulder Canyon adequate to create a storage reservoir of a capacity of not less than 20,000,000 acre-feet of water and a main canal and appurtenant structures located entirely within the United States connecting the Laguna dam, or other suitable diversion dam, * * * with the Imperial and Coachella valleys in California; * * * also to construct and equip, operate, and maintain at or near said dam * * * a complete plant and incidental structures suitable for the fullest economic development of electrical energy from the water discharged from said river * * *." An appropriation of $125,000,000[1] was authorized and 4 per cent interest was stipulated as payable on advances by the Government. No work could be begun and no money expended, nor could water rights be claimed, until the State of California and at least five of the other basin states had approved the Colorado River Compact. Before any money could be appropriated or any construction work done the Secretary of the Interior was required to make provision for revenues, by contract or otherwise, which in his judgment would be adequate to pay all expenses of operation and maintenance and repay within 50 years of the completion of the project all money advanced by the Government for the construction of the dam and incidental works. It was provided that the dam and reservoir should be used: First, for river regulation, improvement of navigation, and flood control; second, for irrigation and domestic uses and satisfaction of present perfected rights; and third, for power.

The contract between the United States and the Imperial Irrigation District entered into on October 23, 1918, covering a connection at Laguna dam and the construction of the All-American canal entirely at the expense of the District, was recognized in the act, but the Secretary was given authority to modify such agreement with the consent of the District.

There had been and still was much opposition to the proposed project, partly because of the great cost and partly on account of the proposed power development. In April 1927, Senator Charles W. Waterman of Colorado, former Governor James G. Scrugham of Nevada, Governor Frank C. Emerson of Wyoming, James R. Garfield, former Secretary of the Interior, and William F. Durand, professor of mechanical engineering, Stanford University, were appointed as special advisers to the Secretary of the Interior "to inquire specifically into the engineering, legal, and economic phases

[1] Later raised to $165,000,000; see page 43.

of the development of the Colorado River, visiting the levees and delta country of the lower Colorado and Boulder, Glen Canyon, and Topock dam sites and any other points of interest involved." Two of these advisers, viz., former Governor Scrugham and Governor Emerson, had been members of the commission which drafted the Colorado River Compact.

The special advisers were requested to submit their reports "severally and individually." Senator Waterman did not prepare any statement; the other four advisers submitted reports which were used in the Senate committee hearings held between January 17 and January 21, 1928.

Colorado River board appointed

After long debate the Boulder Canyon Project Act (Swing-Johnson bill, H. R. 5773), was passed by the House on May 25, 1928. Four days later the Congress, by joint resolution, authorized the appointment of a Colorado River board and commissioned it to report on the following questions concerning the proposed Boulder dam project: Engineering feasibility, earthquakes, plans and estimates, adequacy, water supply, Yuma gagings, stream flow rainfall record, mineral salts, silt in the reservoir, silt below the reservoir, power, and economic feasibility. Thereupon the Secretary of the Interior appointed to this board Charles P. Berkey, Daniel W. Mead, Warren J. Mead, Robert Ridgeway, and Major General William T. Sibert, chairman.

On November 24, 1928, this board submitted its report declaring the proposed dam across the main stream of the Colorado River at Black or Boulder Canyon feasible and stating its opinion that the Black Canyon site was preferable to that in Boulder Canyon. It recommended, however, that the proposed dam be constructed on conservative or ultraconservative lines, proposing that the allowable stress in the dam be reduced from 40 tons per square foot, as allowed by the Bureau of Reclamation, to 30 tons per square foot, thus increasing the amount of material in the dam, and that the diversion tunnel capacity be increased from 100,000 to 200,000 cubic feet per second in order the better to handle flash floods. It also recommended materially increasing the permanent spillway capacity. An estimate was presented in which the cost of the dam and reservoir (for 26,000,000 acre-foot capacity) was placed at $70,600,000; a 1,000,000-h.p. power plant $38,200,000; the All-American canal from Laguna dam to the Imperial Valley

$38,500,000; and interest during construction $17,700,000, or a total estimated cost of $165,000,000.

With regard to economic feasibility the report stated "The board believes that a growing demand for power in Southern California when considered on a conservative basis, will be sufficient to absorb the probable power output of the proposed hydroelectric plant. * * * It is obvious that the power which can be generated from Boulder dam is a valuable resource. If the income from storage can be reasonably increased and the capital investment reduced by the cost of the All-American canal, together with a reduction for all or a part of the cost properly chargeable to flood protection, it would be possible to amortize the remaining cost with the income from power."

In its report the board prescribed some conditions which considerably increased the estimated cost, but it had satisfied the Congress of the project's feasibility. Many of the recommendations were incorporated in amendments to the bill, finally becoming a part of the Boulder Canyon Project Act.

Boulder Canyon Project Act becomes effective

The finally amended bill was passed by the Senate on December 14, 1928; the Senate amendments were concurred in by the House on December 18th; and the bill was approved by President Coolidge on December 21, 1928, thus ending the long campaign for legislation providing for a major Colorado River development, a campaign which began with introduction of the first Kettner bill in the first session of the 66th Congress on June 17, 1919.

Before the Boulder Canyon Project Act could become effective California was required to accept its water allocation as set out therein and ratification of the Colorado River Compact by six states was necessary. Wyoming and Colorado had already ratified the compact on a six-state basis in February 1925, followed by New Mexico and Nevada in March of the same year. On April 8, 1925, the Finney resolution had been passed by the California legislature, ratifying the compact with the proviso that such ratification would be effective when 20,000,000 acre-feet of storage was authorized. This condition having now been met, California accepted the limitations imposed on its use of Colorado River water and ratified the six-state compact March 4, 1929. Utah's ratification followed on March 6th, and on June 25, 1929, President Hoover issued a proclamation, pursuant to the provisions of the act, stating that the states of California, Colorado, Nevada, New Mexico, Utah, and Wyoming had approved the Colorado River Compact without condition; that the State of California had agreed to the limitations of the act with regard to the use of water; that therefore all prescribed conditions had been fulfilled; and that the Boulder Canyon Project Act was now effective.

Thus there had been accomplished the three enabling legislative measures which were necessary to the consummation of the Colorado River aqueduct project, namely (1) the Colorado River Compact, creating a basis of water apportionment; (2) the Metropolitan Water District Act of California, creating the legal means for joint construction of a great water carrier; and (3) the Boulder Canyon Project Act, authorizing a project which would provide the necessary water supply, through storage of otherwise wasted water, and a source of power to enable delivery of the water to the coastal plain.

The latter act, however, imposed certain conditions upon the Secretary of the Interior which he was required to meet before construction of the Boulder dam project could be undertaken. Principal among these was the requirement that he have in hand, before construction was started, contracts sufficient, in his opinion, to insure the payment of all operation and maintenance expense and repayment of all investment costs within fifty years.

In the meantime engineering work, both by the Department of Water and Power of the City of Los Angeles and by the Metropolitan Water District, had proved that it would be uneconomical to build any aqueduct from the Colorado River to Southern California without making use of considerable pumping. It was therefore imperative for the future of the aqueduct project that a large block of cheap power be obtained.

Also, while the Metropolitan Water District had a definite water right, established by the original filing of the City of Los Angeles in 1924, and the Boulder Canyon Project Act had, by providing for storage, established a means of obtaining delivery of this water supply, it was still necessary that this water right be perfected and, to avoid costly and longdrawn out litigation, that an agreement be reached by the District with the other California water users on the allotments to be made to each.

In order to determine the "competitive conditions at distributing points or competitive centers" where Boulder Canyon power might be sold and therefrom the value of such power the Secretary of the Interior named R. F. Walter, chief engineer, U. S. Bureau of Reclamation; L. N. McClellan, chief electrical engineer of the Bureau; and Professor W. F. Durand, of Stanford University, as a special committee to determine the rate at which Boulder Canyon power might be sold. A report was rendered on September 10, 1929, in which the cost of competitive power generated in oil or gas-burning steam electric plants located in Southern California was estimated. From this estimate the value of falling water for use in generating power at Boulder Canyon was determined to be $0.00163 per kilowatt-hour. This estimate was based on the assumption of no revenue from the sale of water or secondary electrical energy.

Power contracts executed

Under date of September 10, 1929, the Secretary of the Interior notified all prospective purchasers of power to be generated at Boulder to file applications therefor with him not later than October 1, 1929. It was required that the quantity of power desired should be stated, also that a general statement be made concerning the purpose and place of use of the power covered by the application. Pursuant to this notice 27 parties submitted applications, some of which were conditional and others indefinite. The three principal applicants were: Department of Water and Power of the City of Los Angeles, the Southern California Edison Company, and The Metropolitan Water District of Southern California. The City of Los Angeles and the Southern California Edison Company each asked for the entire power output of 3,600,000,000 kilowatt-hours, as the firm output was at the time assumed to be. The Metropolitan Water District requested about one-half the total firm energy and the State of Nevada one-third. The total of definite applications was 322 per cent of the amount of power available.

The Secretary was accordingly faced with the problem of allocating among the conflicting applicants the energy available. It was recognized that the absorption of this quantity of power represented a serious problem and that greatest security for the Government required that the risk be spread among several agencies. It was desirable also that as broad a regional benefit be obtained from this power as was consistent with financial soundness. The dam would rest on the border between Arizona and Nevada and it was desired to give these states an opportunity to utilize its energy but neither of them was in a position to make a firm contract for the use of any power within its boundaries. On the other hand, it had to be recognized that the California applicants offered the only definite means of financing the project.

On October 21, 1929, the Secretary announced tentative allocations as follows:

To The Metropolitan Water District of Southern California, 50 per cent, or so much thereof as may be needed and used for the pumping of Colorado River water;
To the City of Los Angeles, 25 per cent; and
To the Southern California Edison and associated companies, 25 per cent.

These allotments were to be subject to certain deductions which might arise through the exercise of preference rights, i.e.,

(a) not exceeding 18 per cent of the total power developed for the State of Nevada for use in Nevada;
(b) not exceeding 18 per cent of the total power for the State of Arizona, for use in Arizona, as above; and should either of the states not exercise its preference rights the other might absorb them up to 4 per cent;
(c) not exceeding 4 per cent for municipalities which had theretofore filed application.

All such preference rights in whole or in part were to be exercised by the execution of valid contracts with the respective states and municipalities satisfactory to the Secretary, and in accordance with certain conditions set forth in the allocation notice. The exercise of such preference rights was to reduce proportionately the above allotments to the District, the city, and the company. Should the 50 per cent allocated to the Metropolitan Water District be not required for pumping, this was to become available to the City of Los Angeles, 66⅔ per cent; to the Southern California Edison and associated companies, 33⅓ per cent.

The charge for storing water for the Metropolitan Water District was set at 25 cents per acre-foot.

A formal hearing on the tentative allocation took place in Washington, D. C., on November 12, 1929, to consider protests. Final allocation was delayed in the hope that an agreement might be reached with Arizona and hence that a seven-state compact might be secured. Conferences to this end were held in Phoenix and Reno during January and February, 1930, without tangible results.

Negotiations were then undertaken in Los Angeles between representatives of the United States, the District, the City of Los Angeles, and the Southern California Edison Company, as a result of which, on March 20, 1930, the following preliminary agreement on power allocations was reached:

> RESOLVED, that we recommend to the Secretary of the Interior that the 64 per cent of total firm power from the Boulder Canyon project available to California interests under his allocation be divided, upon terms hereinafter set forth, as follows:
>
> | | Per cent total firm power |
> |---|---|
> | To the Metropolitan Water District | 36 |
> | To the City of Los Angeles and other municipalities which have filed application | 19 |
> | To the Southern California Edison Co. | 9 |
> | Total (exclusive of unused firm power) | 64 |
>
> and
>
> FURTHER RESOLVED, that we recommend to the Secretary that the Metropolitan Water District be given the first call upon all unused firm power and all unused secondary power up to their total requirements for pumping into and in the aqueduct, and that any unused power of the municipalities be allocated to the City of Los Angeles, and that any remaining unused firm power or unused secondary power be divided one-half to the City of Los Angeles and one-half to the Southern California Edison Company; and,
>
> FURTHER RESOLVED, that all parties hereto agree to cooperate to the fullest extent to make the Boulder Canyon project a success in all its phases; and,
>
> FURTHER RESOLVED, that this agreement is based upon the resolution already passed by The Metropolitan Water District of Southern California and accepted by the board of water and power commissioners of the City of Los Angeles whereby that district requests the City of Los Angeles at cost to generate its power requirements and to operate its transmission lines, which lines are to be paid for and owned by the Metropolitan Water District.

Immediately after conclusion of this allocation agreement, the negotiation of the power contracts necessary to make it effective was initiated and on April 26, 1930, two contracts, carrying an obligation to take and pay for all of the firm energy to be generated at Boulder Canyon, were signed at Los Angeles. The first is a lease of power privileges to which the United States, the City of Los Angeles (through its Department of Water and Power), and the Southern California Edison Company, are parties. The second is a contract for the purchase of electric energy, to which the United States and the Metropolitan Water District are parties.

The general framework of these instruments establishes the city and the company as several (not joint) lessees of the power plant, obligated to generate at cost for certain other allottees, of which the Metropolitan Water District is the major one. Allottees other than the Metropolitan Water District were accorded by these contracts various time periods within which to execute their separate contracts with the United States for purchase of energy. Ultimately the Los Angeles Gas & Electric Corporation, the Southern Sierras Power Company, and the cities of Pasadena, Burbank, and Glendale entered into such contracts. Contracts have not yet been executed on behalf of the states of Arizona and Nevada, and the way is kept clear for the states to exercise their option at any time within 50 years. As of the present writing, therefore, eight contractors are obligated to take Boulder dam's firm energy. The last five of these have acquired their contracts by virtue of "drawback" provisions in the original city, company, and district contracts with the United States. Table 5 shows the ultimate disposition of Boulder dam power by virtue of these contracts.

Seven-party agreement of 1930

The Colorado River Compact, signed at Santa Fe in 1922, made no allocation of water to the several states, the division being between the upper and lower basins. It was provided in the Boulder Canyon Project Act that the legislation should remain ineffective unless and until six states of the Colorado River basin, including California, had approved the compact, and, further, until the State of California, by legislative action, should limit its use of Colorado River water to 4,400,000 acre-feet per annum, plus one-half of the excess and surplus. In order that the dates of the various contracts made by the Secretary of the Interior on behalf of the United States with the several water-using agencies in California might not be deemed to affect the priorities of their respective rights, a contract was entered into, commonly referred to as the Seven-party Water Agreement of 1930, wherein the priorities of the rights of the parties thereto are settled. The parties to the contract are: Palo Verde Irrigation District, Imperial Irrigation District, Coachella Valley County Water District, The Metropolitan Water District of Southern California, City of Los Angeles, City of San Diego, and County of San Diego.

TABLE 5

ULTIMATE DISPOSITION OF BOULDER DAM ENERGY

[From *The Hoover Dam Contracts*, by Wilbur and Ely.]

	Firm energy			Secondary energy
	Minimum which United States must supply	Contractor's obligations if energy is available	Maximum which contractor can demand under various conditions	
	Per cent	*Per cent*	*Per cent*	
Arizona[1]	18		22	None.
Nevada[1]	18		22 (18% plus 4% if not used by other state).	None.
Metropolitan Water District	36	36	72% (its own minimum plus first call on unused state energy).	First call on all secondary energy.
Los Angeles	14.9054 (13% plus uncontracted municipality energy).	32.9054 (its minimum, plus ½ unused state energy, subject to Metropolitan's first call).	32.9054	Call on ½ secondary energy subject to Metropolitan's first call.
Pasadena	1.6183	1.6183	1.6183	None.
Glendale	1.8867	1.8867	1.8867	None.
Burbank	0.5896	0.5896	0.5896	None.
Southern California Edison Co.	7.2	21.6 (7.2% plus 80 % of ½ unused state energy).	21.6	Call on 80% of ½ of secondary energy, subject to Metropolitan's first call.
Los Angeles Gas & Electric Corp.[2]	0.9	2.7 (0.9% plus 10% of ½ unused state energy).	2.7	Call on 10% of ½ of secondary energy, subject to Metropolitan's first call.
Southern Sierras Power Co.	0.9	2.7 (0.9% plus 10% of ½ unused state energy).	2.7	Call on 10% of ½ of secondary energy, subject to Metropolitan's first call.
TOTAL	100	100		

[1] To be contracted for as needed.
[2] Now goes to the City of Los Angeles.

The agreement is dated August 18, 1931. Prior thereto The Metropolitan Water District of Southern California had entered into an agreement with the United States for the storage and delivery of water (April 24, 1930). After the seven-party agreement had been made, the District's contract with the United States was amended in accordance with this seven-party agreement.

As thus amended the present water delivery contract between the District and the United States provides in part as follows:

Delivery of water by the United States

The United States shall, from storage available in the reservoir created by Hoover (Boulder) dam, deliver to the District each year at a point in the Colorado River immediately above the district's point of diversion (at or in the vicinity of the proposed Parker dam) so much water as may be necessary to supply the district a total quantity, including all other waters diverted by the district from the Colorado River, in the amounts and with priorities in accordance with the recommendation of the chief of the division of water resources of the State of California, as follows (subject to the availability thereof for use in California under the Colorado River Compact and the Boulder Canyon Project Act):

The waters of the Colorado River available for use within the State of California under the Colorado River Compact and the Boulder Canyon Project Act shall be apportioned to the respective interests below named and in amounts and with priorities therein named and set forth, as follows:

Section 1.—A first priority to Palo Verde Irrigation District for beneficial use exclusively upon lands in said district as it now exists and upon lands between said district and the Colorado River, aggregating (within and without said district) a gross area of 104,500 acres, such waters as may be required by said lands.

Section 2.—A second priority to Yuma project of United States Bureau of Reclamation for beneficial use upon not exceeding a gross area of 25,000 acres of land located in said project in California, such waters as may be required by said lands.

Section 3.—A third priority (a) to Imperial Irrigation District and other lands under or that will be served from the All-American canal in Imperial and Coachella Valleys, and (b) to Palo Verde Irrigation District for use exclusively on 16,000 acres in that area known as the Lower Palo Verde Mesa, adjacent to Palo Verde Irrigation District, for beneficial consumptive use, 3,850,000 acre-feet of water per annum less the beneficial consumptive use under the priorities designated in sections 1 and 2 above. The rights designated (a) and (b) in this section are equal in priority. The total beneficial consumptive use under priorities stated in sections 1, 2, and 3 of this article shall not exceed 3,850,000 acre-feet of water per annum.

Section 4.—A fourth priority to The Metropolitan Water District of Southern California and/or the City of Los Angeles for beneficial consumptive use, by themselves and/or others, on the coastal plain of Southern California, 550,000 acre-feet of water per annum.

Section 5.—A fifth priority (a) to The Metropolitan Water District of Southern California and/or the City of Los Angeles, for beneficial consumptive use, by themselves and/or others, on the coastal plain of Southern California, 550,000 acre-feet of water per annum and (b) to the City of San

Diego and/or County of San Diego, for beneficial consumptive use, 112,000 acre-feet of water per annum. The rights designated (a) and (b) in this section are equal in priority.

Section 6.—A sixth priority (a) to Imperial Irrigation District and other lands under or that will be served from the All-American canal in Imperial and Coachella Valleys, and (b) to Palo Verde Irrigation District for use exclusively on 16,000 acres in that area known as the Lower Palo Verde Mesa, adjacent to Palo Verde Irrigation District, for beneficial consumptive use, 300,000 acre-feet of water per annum. The rights designated (a) and (b) in this section are equal in priority.

Section 7.—A seventh priority of all remaining water available for use within California, for agricultural use in the Colorado River basin in California, as said basin is designated on map No. 23000 of the Department of the Interior, Bureau of Reclamation.

Section 8.—So far as the rights of the allottees named above are concerned, The Metropolitan Water District of Southern California and/or the City of Los Angeles shall have the exclusive right to withdraw and divert into its aqueduct any water in Boulder Canyon reservoir accumulated to the individual credit of said district and/or said city (not exceeding at any one time 4,750,000 acre-feet in the aggregate) by reason of reduced diversions by said district and/or said city; provided, that accumulations shall be subject to such conditions as to accumulation, retention, release, and withdrawal as the Secretary of the Interior may from time to time prescribe in his discretion, and his determination thereof shall be final; provided further, that the United States of America reserves the right to make similar arrangements with users in others states without distinction in priority, and to determine the correlative relations between said district and/or said city and such users resulting therefrom.

BIBLIOGRAPHY

The published data on the problems of the Colorado River, Imperial Valley, Boulder Canyon, Metropolitan Water District, and collateral matter are very voluminous. Especially noteworthy are the following documents from which was taken a large part of the material presented in this chapter:

Eighteenth annual report of the U. S. Reclamation Service. Department of the Interior. 1918-19.

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Problems of Imperial Valley and vicinity. Senate document 142, 67th Congress, 2nd session. 1922.

Report on the problems of the Colorado River basin. F. E. WEYMOUTH. Department of the Interior. In manuscript, 8 vols. February 1924.

Hearings before the committee on Irrigation and Reclamation. Senate. 70th Congress, 1st session. January 1928.

Colorado River development. GEO. W. MALONE. Senate document 186, 70th Congress, 2nd session. 1928.

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CHAPTER 3

Surveys by the City of Los Angeles

WHEN IT became apparent that an additional source of water supply must be secured for the City of Los Angeles and that the Colorado River was the only adequate source from which it could be imported, William Mulholland, chief engineer of the Bureau of Waterworks and Supply of the city, recommended to the Department of Public Service on October 23, 1923, that the feasibility of such an importation be investigated. Accordingly, that board authorized preliminary surveys, the first of which was a reconnaissance made by William Mulholland, H. A. Van Norman, E. A. Bayley, and party, starting October 29, 1923.

This reconnaissance indicated not only that an aqueduct could be constructed, but that several alternative routes were available, and the organization of field parties for preliminary engineering work was undertaken immediately.

Field surveys were made during the following year, using small crews, the work being paid for from water bureau revenues, but it soon became evident that more extensive work was necessary and that it could not be financed from the relatively small amounts available from such revenues. Consequently, on June 2, 1925, a proposition that the city issue $2,000,000 in bonds for the purpose of acquiring lands and rights of way, and constructing necessary works for an aqueduct from the Colorado River was submitted to the voters of Los Angeles at a special election. The proposal was approved by a vote of 86,154 to 15,846, or approximately 5.4 to one, and the first funds from the sale of these bonds became available in December 1925. Immediately thereafter survey, engineering, and investigation work was expanded. During the period from 1923 until March, 1929 all work for the project was under the direction of William Mulholland and H. A. Van Norman.

Route studies

Between the Colorado River and the mountains surrounding the south coastal plain of Southern California a vast desert area exists which, prior to 1923, when preliminary aqueduct engineering was undertaken, had never been adequately mapped. There were potential routes on many locations with diversions from points scattered from Boulder Canyon to the international boundary, and accordingly it was deemed necessary to cover all of this area with adequate topographic maps. Wherever recent U. S. Geological Survey maps were available these were used and the new work tied into them. Some of the early topography was taken on a scale of 5,000 feet to the inch, but later a scale of 10,000 feet to the inch with 100-foot contours was selected as standard for the first mapping. Wherever greater detail was required, additional mapping was done on a 1,000-foot scale with 10-foot contours. Still smaller areas for reservoir and other special purposes were mapped to larger scales. The following gives the detail of the areas mapped:

Scale of map	Area mapped, square miles
1 inch = 100 feet	8
1 inch = 200 feet	5
1 inch = 500 feet	15
1 inch = 1,000 feet	2,732
1 inch = 5,000 feet	2,252
1 inch = 10,000 feet	19,644
Total	24,656

All topographic maps were prepared by the plane-table method, the originals being made in the field on 20 by 30-inch sheets. Horizontal control was supplied by extending additional triangulation from the California-Texas arc of primary triangulation of the U. S. Coast and Geodetic Survey. This work was also tied to the triangulation system of the U. S. Geological Survey wherever possible. Triangulation control was extended over an area of 27,000 square miles, 1,650 separate stations being established. Vertical control was secured by means of precise level lines extended from established bench marks of the Geological and the Coast and Geodetic Surveys.

Because it appeared to be the shortest practicable route between Los Angeles and the Colorado River, the first route surveyed in detail by the engineers of the city was that from Blythe. There being no suitable site at this point for a diversion dam they proposed that diversion be accomplished through an infiltration gallery to be built along the west bank of the river, the lower end of the gallery being approximately 16 miles north of Blythe.

From the proposed infiltration gallery the Blythe route extended southerly to the Palo Verde Valley and thence westerly by a series of pump lifts and grade conduits through the Chuckwalla Valley and over Shaver's Summit. It then passed through the flanks of the Little San Bernardino Mountains to the east portal of a long tunnel extending from the vicinity of Cabazon to the vicinity of Redlands. From the west portal of this tunnel the proposed route passed along the north side of the Santa Ana and San Gabriel drainage areas to San Gabriel Canyon.

By means of the proposed infiltration gallery it was planned to accomplish both desilting and diversion control without expensive structures. The success of such a plan depended, however, upon the rate at which water would filter into the gallery; and to determine this rate under actual conditions, as they would occur in operating practice, a two-mile section of gallery was built and subjected to pumping tests. The resulting inflow being less than was expected, plans for this type of intake were abandoned and surveys were extended upstream to the Parker dam sites, to investigate the possibility of the use of one of these sites for a diversion dam to be used in connection with the Blythe route. Two alternatives were proposed for this extension. Both followed the river closely from Parker to the Riverside Mountains, where they diverged, one following the river to the Maria Mountains, and connecting with the original Blythe route north of the Palo Verde Valley, the other passing through Grommet and Rice and connecting with the Blythe route in the vicinity of Desert Center.

Most of the area mapped was remote from highways or roads. Some of it was exceedingly rough and could only be crossed on foot or horseback. Some road work of the "scratch" type was done on the southern slopes of the Little San Bernardino Mountains along which it appeared certain that any practicable route for the aqueduct must be located. Approximately 115 miles of such roads, including laterals, were built between the fall of 1925 and the spring of 1927. A road was also built from Earp, California, northerly 16 miles along the west bank of the Colorado River to the upper Parker dam site. This road was later widened and surfaced by the District and incorporated into its permanent road system.

Cost of investigation by the City of Los Angeles

A large amount of other preliminary work was done by the City of Los Angeles both of an engineering and general nature.

The total cost of all work done by the City of Los Angeles on the Colorado River aqueduct project up to December 31, 1928 was $1,129,154.71, but the work continued to be financed from the proceeds of the city's $2,000,000 bond issue up to May 1, 1930 when the project was taken over by the Metropolitan Water District. A summary of the entire costs incurred by the City of Los Angeles in connection with the project is given below, but the description of the work performed subsequent to March 1, 1929 will be found in Chapter 4.

Expenditures by the City of Los Angeles

From 1925 Los Angeles bond funds:		
Rights of way in Riverside County		$ 7,468.85
Buildings and equipment		98,623.75
Construction infiltration gallery at Blythe		84,229.89
Drilling and proving test wells at Blythe		28,491.04
Field surveys		958,795.29
Road, Earp to Parker dam site		193,668.76
Other roads and trails		48,946.47
Water investigations		5,001.50
Terminal storage studies		22,936.27
Relief map and models		27,515.63
Dam site investigations		79,567.64
General engineering expense		424,620.06
Preliminary surveys and investigations paid from city revenue funds prior to availability of city 1925 bond funds	$125,745.72	
Less cash on hand	1,918.52	
Less correction (R/W)	1.95	123,825.24
Total cost, exclusive of interest		$2,103,690.39

Because all of the work represented in the foregoing tabulation of costs was done for the Colorado River aqueduct project, the District, on May 7, 1935, concluded a contract under which it agreed to reimburse the City of Los Angeles therefor and to pay interest thereon as follows:

Net interest on 1925 bonds to January 1, 1933	$ 415,270.67
Interest on costs paid from general funds	25,449.26
Interest on bond interest paid by city	79,221.27
Total interest	$ 519,941.20
Total to be repaid to City of Los Angeles, exclusive of interest subsequent to January 1, 1933	$2,623,631.59

The District's contract with the city for this repayment stipulates that the District will pay to the city, as it becomes due, the money required for payment of all interest not yet due on the 1925 bonds and also that it will pay to the city all of the money necessary for the retirement of these bonds as they come due. As of the date of this report, i.e., June 30, 1938 all of the District's obligation to the city had been paid except that which affects interest and bond amortization not yet due.

CHAPTER 4

Preliminary Engineering Work by the District

PERMANENT ORGANIZATION of The Metropolitan Water District of Southern California was accomplished February 9, 1929, with the election of W. P. Whitsett as chairman of the board of directors; Franklin Thomas, vice chairman; and S. H. Finley, secretary. Until May 1, 1930, however, when funds became available from the District tax levy for the year 1929-1930, and the project was formally taken over by the Metropolitan Water District, all engineering and organization work continued to be financed from the proceeds of the city's $2,000,000 bond issue, as stated in Chapter 3, and all forces utilized on the work were employees of the Bureau of Waterworks and Supply.

In March 1929, F. E. Weymouth was appointed chief engineer of waterworks for the Bureau of Waterworks and Supply of the City of Los Angeles, and took active charge of all engineering work in connection with the Colorado River aqueduct project, becoming chief engineer of the Metropolitan Water District on July 1, 1929 and general manager and chief engineer February 7, 1932.

In June, 1929 the board of directors of The Metropolitan Water District of Southern California approved a report of its finance committee outlining the work to be done by the District during the ensuing 12 months and also the budget for that period. This program proposed that a general aqueduct route be selected and submitted to a board of consulting engineers by November 1929 so that this board could report its recommendations by January 1, 1930. Following this it was proposed that during the period from January to July, 1930 a detailed engineering and economic study of the selected route be made and submitted to this board for final consideration. To finance the year's work it was recommended that the balance of approximately $700,000 available in the Colorado River aqueduct fund of the City of Los Angeles be used and that a District tax of three and one-half cents per $100 of assessed valuation be levied for the year 1929-30.

Board of review appointed

September 27, 1929 the chairman of the District board of directors appointed A. J. Wiley, of Boise, Idaho, Richard R. Lyman, of Salt Lake City, and Thaddeus Merriman, of New York City, as a board of review to select "the most feasible and practicable route for an aqueduct to transport domestic water from the Colorado River to the cities of the coastal plain of Southern California." Chairman W. P. Whitsett, of the District, gave the following instructions to the board:

> 1. Your basic problem is that of selecting an aqueduct route possessing such engineering features as will assure the perpetual delivery of water to the District at the lowest possible unit cost. Cost of construction and cost of operation are both to be given due consideration.
>
> 2. All data thus far secured in a six-year study of the problem will be made available to you. Such other data as you may deem necessary will be furnished you. Engineers working under the direction of the Los Angeles Department of Water and Power and, later, under this board, have surveyed and mapped some 25,000 square miles of territory in the affected area. Numerous diversion points on the river and all routes that have a promise of feasibility have been surveyed and considered. All this material is now being made ready for your study.
>
> 3. You must take into consideration, in reviewing the situation, every possible factor which may affect: (a) practicability of the aqueduct; (b) initial cost of construction; (c) perpetual cost of maintenance and operation; (d) time required for construction.
>
> 4. In particular, you must consider, from every practical angle, the relative merits of gravity aqueduct possibilities as compared to an aqueduct requiring pumping lifts.
>
> 5. You should give careful consideration to (a) the problem of silt elimination; (b) the problem of providing proper storage and regulation at or above the point of diversion on the river; (c) the problem of providing adequate storage along the line and at the western terminus of the aqueduct; (d) the complex financial and engineering task of selecting the most economical grades.
>
> 6. You are requested to give careful attention to each of the routes suggested, and to any other route which you may deem worthy of study. Possible diversion points on the river thus far given consideration by the District engineers include: An intake at Laguna dam near Yuma; an intake at Picacho, twenty miles above Laguna dam;

> an intake near Parker; an intake 16 miles north of Blythe; an intake at Boulder dam reservoir; an intake at Bridge Canyon. From each of these intakes a number of different routes are possible. Many of these routes have been given detailed study.
>
> 7. You are authorized, subject to approval by this board, to employ experts for the consideration of any special features of the undertaking, such as unit costs of tunnel construction under varying conditions, costs and engineering problems in connection with the desilting and clarification of water, or any other phases of the problem where expert technical advice is believed necessary.
>
> 8. Upon your selection of the general route which appears to be the most feasible and practicable, a detailed field survey of the favored line or lines will be made for you by the District engineers. Data covering every phase of the problem will be made available for your study in the preparation of your final recommendations.
>
> 9. Your recommendations embracing the selection of a route for the Colorado River aqueduct are to be submitted to this board in the form of a written report. This report should set forth fully the reasons supporting your selection, and a general review of the entire problem.
>
> Actual construction of the aqueduct is desirable at the earliest possible date. The necessity of securing domestic water from the Colorado River for use in the District is an urgent and pressing one. Local water resources now available will have been developed to their limit by the time the physical job of building the aqueduct has been completed.
>
> It is expected that Frank E. Weymouth, chief engineer of the Metropolitan Water District, will submit to this board in November the data thus far collected in the course of the Colorado River aqueduct surveys. All of this material immediately will be presented to you for your information and use.

In November 1929, the chief engineer submitted a report in which he reviewed the engineering and other work which had been done up to that time. Included were preliminary estimates and details of 54 routes. Twenty-eight of these routes considered diversion from near Black Canyon at Boulder dam, five being for gravity operation, twenty-three for pumping. Seven routes considered diversion from a high dam at Bridge Canyon, 120 miles above Black Canyon, with gravity operation. Seven proposed diversion from Bulls Head dam site, 31 miles upstream from Needles. A total of 42 routes was considered from the upper river.

Twelve routes from the lower river were also estimated and covered in the report. Three of these considered diversion from the site now occupied by the Imperial dam near Yuma; three considered diversion from Picacho; one considered the Blythe route, utilizing upper Parker dam site; and five the same site, but followed a route via Rice.

In addition to a full discussion of each route, the report contained data on assessed valuation, water supply, quality of water, economic use of aqueduct, delivered cost of water, pumping and power problems, design studies, silt and clarification data, filing on Colorado River water, lands withdrawn from entry, reservoir sites on lower Colorado River, test borings, and an index to all available reports, papers, and miscellaneous data on the proposed Colorado River aqueduct.

Preliminary report of board of review

The board of review submitted its report to the board of directors of the District on December 21, 1929. The following quotations indicate the substance of the report:

> Pursuant to your instructions of September 27th, your board of engineers convened at Los Angeles on November 25th and since that time has given continuous attention to the matter of the Colorado River aqueduct. We have made field examinations of the principal features of each of the fifty odd routes which have been proposed and have familiarized ourselves with all of the data available regarding them.
>
> The problem before the District has been clearly stated in your letter of instruction. It is one of great magnitude. An aqueduct for bringing water from the Colorado River to the coastal plain of Southern California must traverse a distance of from 200 to 300 miles and must pass under great mountain ranges. The difficulty of the problem is increased because the Colorado River even at Black Canyon is generally at an elevation lower than the area to be served. Several so-called gravity routes have been proposed and many pump lift plans have been suggested. We have studied them all from the viewpoint of the district as a whole, as well as from the angle of the individual who, in the last analysis, will pay in taxes and assessments the cost of construction and later the cost of maintenance and operation. These matters affect the problem, and we have held them before us during our studies and examinations.
>
> We have visited and examined the dam sites at Bridge Canyon, at Black Canyon, at Bulls Head, at upper Par-

ker, at lower Parker, and at Picacho and have carefully studied the topographic and geologic details at all of the critical points along the many proposed aqueduct locations. In making these field examinations we have traveled over 4,000 miles and have covered every important feature relating to the problem.

We have been greatly impressed by the thoroughness with which the studies of Chief Engineer Weymouth and his assistants have been made and with the vast amount of painstaking care with which this problem has been developed in all of its engineering aspects. In the course of our studies in the field we have also had the advice and assistance of Dr. F. L. Ransome, geologist of the District.

As the result of our studies and examinations, we submit the following preliminary report and recommendations which will later be supplemented when the information and data hereinafter set forth have been obtained and assembled for our consideration:

Recommendations

To the end that strictly comparable estimates of cost may be prepared, we recommend that preliminary location surveys and geological investigations be made along the following routes:

1. From Black Canyon to Puddingstone via Goffs, Ash Hill, Lucerne Valley, and San Bernardino; the same by way of Morongo Valley and also via Barstow.
2. From Bulls Head to Puddingstone via Goffs, Ash Hill, Lucerne Valley, and San Bernardino; the same by way of Morongo Valley and also via Barstow.
3. From upper Parker via Rice and Cadiz to Ash Hill and thence along the several alternates to Puddingstone.
4. From Picacho to Puddingstone via Ruthven, Whitewater, and Colton.

On each of the above routes the pump lifts and drops should be located so as to place the aqueduct location in the most favorable terrain with respect to (a) geological conditions, (b) accessibility to existing transportation lines, (c) value of rights of way, (d) minimum cost of construction, and (e) maximum future safety. These locations should, so far as practicable, further be placed at such elevations as to admit of their adaptation and incorporation as parts of a route taking water from a higher level than Black Canyon with the end in view that all or a large part of the pumping lifts may, at a later time, be eliminated.

All of the above routes are indicated as terminating at Puddingstone but, as the investigations hereinafter suggested for terminal storage are developed the terminal locations may be modified accordingly.

The board of review also reported on four routes proposed by other parties. Two of these proposed a large regulating reservoir above the Grand Canyon with an aqueduct to carry both domestic and irrigation water to Southern California from that point through Utah and Nevada. The reservoir proposed was 850 miles from Southern California. These plans were dismissed with the conclusion that "they are outside the range of present-day possibilities."

Another plan involved a dam 875 feet high at Bridge Canyon, a tunnel 75 miles in length under mountains and valley fills from the reservoir to Yucca, Arizona, a siphon 11 miles long crossing the Colorado River under a maximum head of 1,000 feet, and a second long tunnel carried for 89.5 miles under Lucerne Valley and the San Bernardino Mountains. The board of review pointed out the unprecedented height of the proposed dam; the small capacity of the proposed reservoir, the consequently small storage space available for silt deposition and river regulation; and the low estimates of cost utilized by its proponent; stating that they did not regard the plan as a "practical present solution of the District's problem."

A proposal for a continuous tunnel from Black Canyon to Monrovia was deemed unworthy of further consideration because of the physical and construction hazards involved, particularly because of the great depth at which it would cross the San Andreas fault, also because of the great length under extensive alluvial deposits which were certain to carry water. Shafts up to 2,000 feet in depth and as far apart as 22 miles had been proposed. Shafts 4,000 feet deep would have been required to reduce this spacing to as short a distance as 10 miles.

The board of review stated its opinion that undue prominence had been given to the Virgin Valley salt beds within the Boulder Canyon reservoir site, but recommended that additional study be made by District engineers and geologists. It also recommended that additional data on silt removal be collected and that additional geological studies be made along routes recommended for further consideration. It recommended some additional investigations of dam sites on the river and of sites for terminal storage.

The board report concluded with a statement that in its opinion "there is no pure gravity route over which water can at the present time be brought into the district which will effectively and economically serve its needs * * * The only present practicable supply of water from the Colorado River is to be obtained as a pumped supply through an aqueduct so located as to take full advantage of the topographical features of the country through which it passes, always keeping the pump lifts down to the lowest practicable minimum and bearing in mind the desirability of connections which may be made in the future for the purpose of eliminating all or a large part of the pumping lifts."

Final report of board of review

Following receipt of the board of review report of December 1929, engineering parties were immediately sent into the field to run out the preliminary locations suggested by the board and to collect the additional data requested. The scope and results of this work were reviewed by the chief engineer in his letter of November 10, 1930 to the District's board of directors transmitting a four-volume report. This report was submitted to the board of review, which in turn made a report to the board of directors under date of December 19, 1930 concurring in the chief engineer's conclusion that the best, safest, and most economical location for the aqueduct is the Parker route. Copy of this report, exclusive of supporting appendices, and a copy of the chief engineer's letter summarizing the conclusions of his report will be found at the end of this chapter[1].

By Resolution No. 97, unanimously adopted at its meeting January 16, 1931, the board of directors designated the Parker route, as recommended in the above reports, as the official route for the Colorado River aqueduct, and instructed the chief engineer to proceed with the preparation of final plans for the aqueduct on that basis. The chief engineer was also instructed to continue his surveys and plans in connection with the terminal and local facilities of the project, final conclusions on which had not then been reached.

[1] See Exhibits A and B, pages 64 and 87.

Exhibit A

Chief engineer's letter of November 10, 1930 transmitting his summary report of preliminary surveys, designs, and estimates for the Colorado River aqueduct and terminal storage projects.

LOS ANGELES, CALIFORNIA,
NOVEMBER 10, 1930.

MR. W. P. WHITSETT,
CHAIRMAN, BOARD OF DIRECTORS,
THE METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA,
LOS ANGELES, CALIFORNIA.

DEAR SIR:

In November 1929, a report was prepared setting forth the preliminary work accomplished up to that time, looking toward the final selection and construction of an aqueduct from the Colorado River into the territory of the Metropolitan Water District. This report summarized the results of preliminary estimates for some sixty alternative locations for the aqueduct, pointed out the precariousness and expense of certain proposed all-gravity lines, called attention to the most outstanding physiographical and geological difficulties, showed that at least some pumping was essential on any practicable line into the District and presented data intended to assist in the final problem of route selection.

This report was later submitted to an engineering board of review consisting of Thaddeus Merriman, A. J. Wiley and Richard R. Lyman, with the request that they review it in detail. Under date of December 21, 1929, this board of review submitted a report summarizing the conclusions reached by them from a study of the original report, supplemented by a careful examination of the most salient features of the project in the field. The most essential recommendations made by the board of review at that time are summarized in the following quotation:

> To the end that strictly comparable estimates of cost may be prepared, we recommend that preliminary location surveys and geological investigations be made along the following routes:
>
> 1. From Black Canyon to Puddingstone via Goffs, Ash Hill, Lucerne Valley and San Bernardino;—the same by way of Morongo Valley and also via Barstow.
>
> 2. From Bulls Head to Puddingstone via Goffs, Ash

Hill, Lucerne Valley, and San Bernardino:—the same by way of Morongo Valley and also via Barstow.

3. From upper Parker via Rice and Cadiz to Ash Hill and thence along the several alternates to Puddingstone.

4. From Picacho to Puddingstone via Ruthven, Whitewater and Colton.

On each of the above routes the pump lifts and power drops should be located so as to place the aqueduct location in the most favorable terrain with respect to (a) geological conditions, (b) accessibility to existing transportation lines, (c) value of rights of way, (d) minimum cost of construction, and (e) maximum future safety. These locations should, so far as practicable, further be placed at such elevations as to admit of their adaptation and incorporation as parts of a route taking water from a higher level than Black Canyon with the end in view that all or a large part of the pumping lifts may, at a later time, be eliminated.

Immediately upon receipt of the report from the board of review, parties were put into the field and the selected preliminary lines were located on the ground. It was found possible in many instances to vary the original office locations to better suit topographical features as revealed by the field work. The engineers were followed by experienced geologists who made detailed studies of the regions occupied by each of the various routes. As a result of the geological studies, still further revisions of the lines were found necessary. In many instances the routes or parts of routes which appeared most desirable from topographic considerations were found to be impracticable because of crushed and faulted zones in the rock formations, because of the presence of deep water-bearing alluvials, or because of other objectionable geological features. This process of trial and study was carried forward on all of the most promising line locations for each of the four primary routes recommended for investigation by the board of review, and resulted in a final selection of what is believed to be the most suitable location along each of these primary lines.

Having arrived at this point, studies were begun of proper grades, slopes, pump lifts, and return power drops. Probable unit costs were also investigated individually for each important division of each of the proposed lines. As a result, a great mass of information has been accumulated as to costs of construction, costs of pumping, value of power and cost of operating the aqueduct along the proposed routes.

Careful studies have also been made of the possibility of an all-gravity line from Bridge Canyon, and the possibility of providing, temporarily, a pumping line capable of being extended to Bridge Canyon at some future date. Estimates have been prepared for a possible combination of the Picacho route and the Coachella branch of the All-American canal.

In making preliminary estimates it has generally been assumed that the main aqueduct will be constructed to full size in the beginning, leaving only the pumping plants, pressure lines and storage reservoirs to be added to gradually as the demand for water increases.

There is a possibility of lessening the burden during the first years of operation by building the entire line at first for only part capacity. The ultimate cost under such arrangement would be greater, but if the second development can be deferred for a sufficient time, savings in interest might offset the inefficiency resulting from dividing up the work. Estimates for the Parker route have been prepared for 50, 75, 100 and 125 per cent of the assumed ultimate capacity. These estimates are available but are not included in this report.

In addition to the work done on the aqueduct routes, Bulls Head and upper Parker dam sites on the Colorado River have been surveyed and drilled. Also, a topographic map was made of the Bridge Canyon dam site and all of the dam sites have been subjected to careful geological examination. A large number of sites for local storage reservoirs have likewise been studied, surveyed and examined geologically. The more promising of these sites are now being explored by drilling. Careful studies have also been made showing that the water supply is adequate and of acceptable quality.

The results of all work done have been compiled in the form of reports and drawings and placed in the files of this office. These reports, taken collectively, are very voluminous. They contain not only the data required to substantiate the alternative projects finally selected as most feasible but also detailed studies which resulted in the rejection of the many lines, reservoirs and other features which at one time appeared worthy of investigation. These detailed reports have been condensed and summarized into one report, which it is thought will be more convenient for study and consideration. This report contains separate chapters on water supply, geology, unit costs, aqueduct location, power and pumping plants, and terminal storage.

For convenient reference, the final results of geological studies and route surveys are summarized in the attached map, Fig. 6. This map shows the best location from each of the four major points of diversion suggested by the board of review in 1929, and an additional line from Bridge Canyon. The principal geological faults affecting the project are also shown on the map and areas filled in with deep alluvial material are indicated by stippling. Many of these alluvials are water bearing. None of them is suitable for tunneling at great depth.

A summary of aqueduct cost estimates along the selected lines, together with certain pertinent physical data, is shown on Table 6. The annual operating cost after the end of the amortization period and the corresponding cost per acre foot for water at the point of delivery into terminal storage are also shown. The average estimated water costs throughout the development period, including amortization over a fifty-year period are likewise shown, exclusive of terminal storage costs.

In considering the water costs shown in Table 6, it must be recognized that they represent average values over long periods. If an attempt is made to have the sale of water care for all the investment costs, operating costs and interest, from the first, charges higher than the average shown will be necessary for the first few years, due to the fact that only a portion of the full aqueduct flow can be sold in the beginning. This will be balanced by a cost below the average toward the end of the amortization period. Cost figures shown in Table 6 are exclusive of the cost of terminal storage and of the connecting lines required for the wholesale delivery of water.

Terminal storage is likely to cost from $15,000,000 to $20,000,000 for a first development, depending upon the volume developed, with a similar sum at some future time.

Parker route

The first two columns of Table 6 give data and estimates for lines diverting from the river at the upper Parker dam site a short distance upstream from Parker, Arizona. The Parker site is favorable for the construction of a combined diversion and power dam. The height to which the water can be raised is limited by en-

Fig. 6—Alternative preliminary aqueduct routes

croachment on the City of Needles, California, about 58 miles up the river. A dam raising the water 72 ft. to elevation 450 is contemplated. Foundation conditions at the site are excellent for any type of dam, except for the great depth of overburden in the river channel. This difficulty may be offset, in part, by deferring construction until after the river is under control at Black Canyon.

Alternative estimates for the Parker route, with and without a diversion dam, are shown in the table. The river is confined in a narrow channel at the point of diversion and the water may be withdrawn by direct pumping with no danger of trouble due to change in the course of the stream.

If the dam is built, sufficient reservoir capacity will be provided to care for the clarification of the water for many years, perhaps until a definite regimen of flow has been established below Black Canyon and the transportation of silt has ceased. If the dam is not built, it will be necessary to install clarification works at the point of diversion. In this event, a low head pumping plant will be provided to lift the muddy water into the clarifiers and only clear water will be delivered to the other plants.

The initial construction cost of the project is, naturally, greater if the dam is built. However, the cost of clarification work will be an appreciable percentage of the cost of constructing a diversion dam, so that the difference in first cost for the two plans is not as much as might be expected. Furthermore, it is probable that a dam at this location will be required for other purposes at some future time, in which event the clarification works, the low lift pumping plant and other items, totaling approximately $9,000,000 in value, will become useless.

If the dam is built, the reduced pumping head, the value of the power produced, and improved operating conditions reduce the operating expenses sufficiently to more than offset the additional cost of the dam, thus reducing the ultimate delivered cost of water.

After an initial pump lift of 539 ft. to an elevation of 989 ft. the Parker route (with dam) leaves the river in a 12.3-mile tunnel through the Whipple Mountains. These mountains are of granitic formation, free from important faulting. Beyond this tunnel there is a length of 51 miles of surface conduit which may be cut and cover section or open lined canal. This section is located in granular detrital material, a product of disintegration of the native igneous rock. It offers stable foundation for any type of lined surface channel. In its proposed location, the conduit through this region will be practically free from danger of disturbance by cloud bursts or earth movements.

The above mentioned length of surface conduit leads to a tunnel

Little San Bernardino Mountains

through the Granite Mountains. This tunnel will be largely in solid rock formation although some detrital material will be encountered at the ends. There is little possibility that water will be encountered in the detrital approaches. Leaving the Granite Mountains, the aqueduct lies almost entirely on the surface, with a few short tunnels, to a point east of Shaver's Summit. In this stretch are located the pumping plants required to lift the water up to its final summit elevation of 1817 ft. The spreading out of the pumping plants in this way is not in all respects desirable but in this line it has a beneficial effect upon costs, as it makes it possible to fit the line accurately to the topography.

At the base of the last pumping plant, just before reaching the summit, there exists a natural reservoir of large capacity. This reservoir can be developed at a nominal cost and is available for the equalization of flow or as a protection against possible breakage in case the surface conduit leading to it is of open canal type.

West of Shaver's Summit the line is located principally in tunnel along the face of the Little San Bernardino Mountains. This tunneling is in a stable block of granite, believed to be free from any important or dangerous faulting. The map, Fig. 6, shows that an old fault of uncertain location parallels a part of the line a distance of one or two miles away from it. The geologist finds that this fault shows no evidence of movement in modern times.

Emerging from the Little San Bernardino Mountains, the line crosses the upper end of Coachella Valley in open conduit. The San Andreas fault and its important branches are crossed on the surface under conditions which insure reasonable safety against disastrous damage in case of movement. The line then passes underneath the San Jacinto Mountains in tunnel, emerging near the mouth of Potrero Canyon in the San Jacinto Valley, where the San Jacinto fault line is crossed at the surface. From this point the line may be led to its terminus in Puddingstone or Brea reservoirs by either of several safe and satisfactory routes. A power drop of 406 ft. is available at Colton, if the line is routed that way, which subtracted from the pump lift of 1523 ft. leaves a net lift of 1117 ft.

The tunnels required on this line are shorter and lie at less depth than on most of the other lines. Also, they appear to pass through less dangerous regions. It is impossible to definitely determine from surface examinations all the difficulties likely to be encountered in the construction of any large tunnel project. The actual hazards involved in the construction of the tunnels on this line cannot be predicted with certainty until after the completion of borings and other field tests. However, insofar as can be foreseen, the construction of the Parker route involves less risk than any of the other proposed lines.

Black Canyon route

Column 3 of Table 6 shows data for a line diverting from the Boulder reservoir. This line, it will be noted, is somewhat less economical than the lines from Parker. This is due to the greater length of this line, more expensive tunnel work and to the fact that the Parker estimate contemplates a considerable length of open canal east of Shaver's Summit, while the Black Canyon line is all in covered section. There are several places along the eastern end of the Black Canyon route where open canal could be used to advantage, except that storage facilities similar to those mentioned for the Parker route, are not available for equalization and for protection against canal breaks. Even with the maximum use of open canal, the Black Canyon route will still be less economical than the Parker.

This line is largely in surface conduit to a point near Daggett where it enters a 51.3-mile tunnel through the western end of the Bullion Mountains, under the west end of Lucerne Valley and through the San Bernardino Mountains, emerging at a point just west of San Bernardino, where it crosses the San Andreas fault and its branches in surface conduit. The line then follows comparatively safe location, mostly in surface conduit, to a terminal in the Pine Canyon reservoir.

Up to the beginning of the long tunnel just mentioned, the aqueduct passes through stable formations similar to those described for the eastern end of the Parker route. Considerable faulting exists in the mountains near the outlet end of the long tunnel, and the tunnel passes under the alluvial filled junction between the Lucerne and Mojave valleys. While there is reason to believe that this tunnel can be constructed, it involves an element of uncertainty and risk.

There are two criteria as to the proper elevation for this line. One is the siphon at the Ash Hill saddle, near Ludlow. If the elevation of the line is made too great, the cost of this siphon becomes prohibitive. The other is, if the elevation is reduced, the cost of the tunnel through the San Bernardino Mountains is greatly increased, and the safety of the route is greatly impaired by crossing the San Andreas fault under ground.

A notable feature of this line is a proposal to use direct connected pumping units at Black Canyon for a large proportion of the lift. The first pumping plant lifts the water on an average of 1029 ft. to the elevation of 2170 ft. above sea level. The second plant, which is only a short distance away, provides an additional 633 ft. lift bringing the water up to elevation 2790 ft. There are no other lifts on this line.

Numerous alternative locations for the Black Canyon route were investigated. An important variation contemplated a line from the Ash Hill siphon near Ludlow, through the Morongo Valley to the east end of the Coachella Valley, following from that point a lo-

TABLE 6
SUMMARY OF COST ESTIMATES

Estimate number	73-B	74-B	77-A	78-A	79-B	80-B	62
Line designation	Parker (Canal) Hayfield (Direct Diversion)	Parker (Canal) (Diversion from Reservoir)	Black Canyon High Line	Bulls Head High Line	Picacho High Line	All-American Picacho with Dos Palmas standby	Bridge Canyon low dam. Regulation dev. above dam
Point of diversion	UPPER PARKER	PARKER RESERVOIR	BLACK CANYON	BULLS HEAD	PICACHO	YUMA	BRIDGE CANYON
Via	Rice, Hayfield Res., Shavers Summit, Whitewater, Potrero, Moreno, Perris reservoir, Colton	Rice, Hayfield Res., Shavers Summit, Whitewater, Potrero, Moreno, Perris reservoir, Colton	Goffs, Ash Hill, Daggett, Devil Canyon	Goffs, Ash Hill, Daggett, Devil Canyon	Ruthven, Palm Springs, Potrero, Moreno, Perris reservoir, Colton	Dos Palmas, Palm Springs, Moreno, Perris reservoir, Colton	Topock, Danby, Lucerne, Colton
Point of termination	PUDDINGSTONE	PUDDINGSTONE	PINE CANYON	PINE CANYON	PUDDINGSTONE	PUDDINGSTONE	PUDDINGSTONE
PHYSICAL DATA							
Average diversion, sec-feet	1,500	1,500	1,500	1,500	1,500	1,807	1,500
Seepage and evap losses, acre-feet	99,419	99,245	81,284	68,961	63,531	321,172	85,764
Net terminal delivery, acre-feet	986,531	986,705	1,004,666	1,016,989	1,022,419	986,705	1,000,186
Height of diversion dam, feet	0	72	0	120	0	0	600
Initial elevation, feet	378	450	1,167	640	184	177	1,705
Terminal elevation, feet	1,000	1,000	1,220	1,220	1,000	1,000	1,000
Number of pumping plants	6	4	2	6	7	7	0
Total pump lift, feet	1,601	1,523	1,662	2,051	1,997	1,888	0
Number of return power plants	1	1	1	1	2	1	0
Total power drop, feet	406	406	564	564	620	406	498
Power chargeable to diversion from Black Canyon reservoir, kw	0	0	58,370	0	0	0	58,370
Power for hydraulic units, kw	0	0	173,000	31,000	0	0	0
Elect power reqd for pumping, kw	309,300	291,040	114,320	354,150	394,540	323,760	0
Total power reqd for pumping, kw	309,300	291,040	287,320	385,150	394,540	323,760	0
Power produced at diversion—hyd, kw	0	0	173,000	31,000	0	0	0
Power produced at diversion—elec, kw	0	29,100	0	62,500	0	0	199,180
Return power produced, kw	38,430	38,430	54,730	55,400	61,800	38,430	0
Total power produced, kw	38,430	67,530	227,730	148,900	61,800	38,430	199,180
Kw-hr per yr prod at diver hyd & elec	0	238,329,000	1,416,870,000	765,765,000	0	0	1,744,817,000
Kw-hr per yr return power produced	314,770,000	314,770,000	448,266,000	453,726,000	506,119,000	314,770,000	0
Total kw-hr per year produced	314,770,000	553,099,000	1,865,136,000	1,219,491,000	506,119,000	314,770,000	1,744,817,000
Total kw-hr per yr reqd for pumping	2,533,200,000	2,383,600,000	2,353,151,000	3,154,391,000	3,231,290,000	2,651,600,000	0

TABLE 6 *(Continued)*

SUMMARY OF COST ESTIMATES

Estimate number	**73-B**	**74-B**	**77-A**	**78-A**	**79-B**	**80-B**	**62**
Line designation	Parker (Canal) Hayfield (Direct Diversion)	Parker (Canal) (Diversion from Reservoir)	Black Canyon High Line	Bulls Head High Line	Picacho High Line	All-American Picacho with Dos Palmas standby	Bridge Canyon low dam. Regulation dev. above dam
PHYSICAL DATA *(cont.)*							
Open canal (lined or unlined), miles	74.12	74.12	0	0	0	118.90	0
Closed surface conduit, miles	80.26	80.26	158.47	133.48	158.98	98.67	81.57
Pressure tunnel, miles	2.20	2.20	9.64	1.30	2.20	2.20	0
Grade tunnel with shafts, miles	22.65	22.65	51.33	62.46	29.56	14.22	209.45
Grade tunnel without shafts, miles	63.82	67.75	67.27	42.20	24.95	21.76	16.19
Steel delivery lines, miles	0.99	1.36	0.21	1.49	2.62	2.01	0
Steel penstocks, miles	0.60	0.60	0.10	0.10	0.98	0.60	0
Steel siphons, miles	1.00	0.51	4.39	4.07	0.81	0.81	5.63
Concrete pipe lines, miles	16.27	15.91	7.99	8.91	14.02	12.27	3.06
Total, all tunnels, miles	93.67	92.60	128.24	105.96	56.71	38.18	225.64
Total, all pipe lines, miles	18.86	18.38	12.69	14.57	18.43	15.69	8.69
Total length aqueduct, miles	266.91	265.36	299.40	254.01	234.12	271.44	315.90
Longest tunnel, miles	12.95	12.95	51.33	51.33	15.34	12.95	89.51
Second longest tunnel, miles	9.70	9.70	5.49	11.13	14.22	3.85	75.34
Greatest dist between headings, miles	5.02	5.02	5.78	5.78	5.55	5.45	7.58
Number of shafts	4	4	9	11	4	2	37
Deepest shaft, feet	1,430	1,430	1,840	1,840	1,430	1,430	2,800
Second deepest shaft, feet	615	615	1,510	1,510	615	615	2,670
Total depth of shafts, feet	2,860	2,860	11,825	12,535	2,620	2,045	56,575
Storage, pumping control, acre-feet	65	35	5,000	60	75	75	0
Storage, power control, acre-feet	0	0	0	0	0	0	0
Auxiliary storage space, acre-feet	97,000	97,000	0	0	0	200,000	0
Transmission line, 220-kv, circ-miles	426	424	24	140	654	418	0
Transmission line, 66-kv, circ-miles	14	14	0	46	14	96	0
Years to construct	6	6	6	6	6	6	9

COSTS[3]							
Preliminary investigations	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000
Diversion dam	0	12,958,400	0	13,870,900	0	0	68,000,000
Headworks	593,000	100,000	500,000	100,000	593,000	0	163,000
Clarifiers	3,390,000	0	0	0	3,219,200	3,219,200	0
Total heading	3,983,000	13,058,400	500,000	13,970,900	3,812,200	3,219,200	68,163,000
Open canal (lined or unlined)	15,159,300	15,159,300	0	0	0	29,484,800	0
Closed surface conduit	36,317,700	36,317,700	66,157,700	54,560,600	69,082,800	43,861,400	39,182,200
Pressure tunnel	2,222,600	2,222,600	10,902,300	1,347,800	2,222,600	2,222,600	0
Grade tunnel with shafts	20,791,400	20,791,400	47,103,700	56,959,700	28,912,000	13,018,600	277,618,400
Shafts	894,000	894,000	3,558,700	3,788,800	833,500	625,200	19,670,800
Grade tunnel without shafts	57,390,000	56,560,400	54,520,300	33,590,400	20,757,100	18,264,000	14,574,900
Steel siphons	1,109,500	690,000	6,905,200	6,739,500	908,000	908,000	17,216,000
Concrete siphons	11,568,800	11,299,500	5,151,100	5,834,300	9,701,000	8,559,200	2,202,900
Wasteways, ry crossings, flumes, etc.	488,800	488,800	230,000	230,000	419,800	391,000	511,800
Total aqueduct	145,942,100	144,423,700	194,529,000	163,051,100	132,836,800	117,334,800	370,977,000
Auxiliary storage	76,900	76,900	0	0	0	2,115,000	11,000,000[1]
Pumping plants	13,577,000	12,027,000	9,957,000	13,763,000	16,463,000	15,469,000	0
Delivery lines	2,142,000	1,950,000	2,103,000	2,660,000	2,905,000	2,252,000	0
Transmission lines	10,337,000	10,287,000	587,000	3,788,000	15,562,000	10,600,000	0
Storage basins for pump control	594,000	469,000	400,000	656,000	750,000	844,000	0
Total pumping plants, 1st devel	26,650,000	24,733,000	13,047,000	20,867,000	35,680,000	29,165,000	0
Power plant at diversion	0	0	0	0	0	0	9,709,000
Penstocks	0	516,000	0	705,000	0	0	1,295,000
Transmission lines	0	0	0	0	0	0	0
Total power plants at div, 1st devel	0	516,000	0	705,000	0	0	11,004,000
Return power plants	0	0	1,916,000	1,936,000	3,556,000	1,778,000	0
Penstocks	1,100,000	1,100,000	370,000	370,000	1,471,000	1,100,000	0
Transmission lines	0	0	0	0	0	0	0
Storage basins for power control	0	0	0	0	0	0	0
Total return power plants, 1st devel	1,100,000	1,100,000	2,286,000	2,306,000	5,027,000	2,878,000	0
Total construction cost, 1st devel (a)	180,252,000	186,408,000	212,862,000	203,400,000	179,856,000	157,212,000	463,644,000
Int & taxes during const, 1st devel	19,190,000	19,871,000	26,144,000	23,946,000	19,324,000	17,053,000	94,202,000
Total cost, incl int, 1st devel (b)	199,442,000	206,279,000	239,006,000	227,346,000	199,180,000	174,265,000	557,846,000
Cost of future development (c)	14,112,000	14,256,000	9,724,000	15,768,000	15,552,000	13,320,000	4,284,000
Total, ult dev without int (a)+(c)	194,364,000	200,664,000	222,586,000	219,168,000	195,408,000	170,532,000	467,928,000
Annual net opr charge after amort	6,471,000	5,903,000	6,847,000	6,835,000	7,947,000	6,748,000	4,702,000
Net oper charge per ac-ft after amort	6.56	5.98	6.82	6.72	7.77	6.84	4.70
Aver water cost, int & amort, 40-yr period, per acre-foot[2]	26.66	26.56	28.72	29.51	28.41	24.59	51.25

[1]Development above Bridge Canyon for regulation.
[2]Bond redemption deferred during construction. Obligations during construction paid by taxes.
[3]EDITOR'S NOTE: As stated on page 67, cost figures shown in this table are exclusive of the cost of terminal storage and of the wholesale delivery system.

cation parallel to that shown for the Parker route. This alternative was slightly more expensive than the line shown on Fig. 6, and furthermore it was pronounced unsafe by the geologists because of the broken and faulted nature of the materials through which it was necessary to construct tunnels.

The line as estimated ends at the Pine Canyon reservoir. This is a desirable point of termination, but the storage at this site is inadequate for complete terminal control. This line cannot be conveniently connected to the storage units south of the Santa Ana River, and its adoption would require the development of the Los Nogales reservoir site or the utilization of an expensive combination of miscellaneous reservoirs. The development of the Los Nogales site is considered undesirable for reasons stated in the discussions of terminal storage problems.

Bulls Head route

The fourth column of Table 6 contains data for what is termed the Bulls Head high line. This line contemplates a diversion from a reservoir at Bulls Head about 50 miles down the river from Black Canyon. Except for a short distance at its eastern end, this line is identical with the Black Canyon route just described. A combined power and diversion dam is contemplated at the intake to this line. Excellent rock upon which to found any type of dam exists at the site, subject to the relatively serious difficulty that it is deeply overlain in the river bed with gravel, sand and silt. The height to which a dam can be constructed is limited by the tail water level at Black Canyon. This reservoir would be entirely free from any silting difficulties and is equally as acceptable as the Boulder reservoir as a point of diversion, excepting only its lower elevation and the consequent necessity for a higher pump lift. This line involves six separate pump lifts, five of which are located reasonably close to the dam site. The last lift is at Mile 29 near the junction of the Bulls Head branch with the main Black Canyon route. The total pump lift is 2051 ft. The water surface elevation above the last pump lift is 2605 ft. This route has the same power drop at its western terminus and the same limitations as to storage facilities as the Black Canyon. The total lift, minus the power drop, is greater than for the Black Canyon route because of the lower initial elevation. The first cost is slightly less than for the Black Canyon route but the ultimate cost of water delivered is slightly greater.

Numerous alternative locations for a line from Bulls Head were studied. A low lift line, following approximately the course shown for the Bridge Canyon route, or coming through Morongo Valley, at one time appeared desirable but was later eliminated because of adverse geological conditions. Such a line was proposed because of the possibility of future extension to Bridge Canyon.

Bulls Head is thought to be a possible, but not particularly desirable, point of diversion for the Metropolitan Water District aqueduct.

Picacho route

The fifth route of Table 6 takes out of the Colorado River at the Picacho dam site about 20 miles north of Yuma, Arizona. In the estimate shown, it is contemplated that the water will be diverted by pumping directly from the river. This can be accomplished with safety at the selected site as the river is confined between definite rock walls and has no chance to meander. A low diversion dam could be constructed at this point, but its cost would be prohibitive. In any event, it will be necessary to install and operate some type of desilting equipment, because a storage dam at this site, capable of absorbing all prospective future silt accumulations, is not feasible. The water is elevated from the river through a height to 332 ft. to elevation 516 and delivered into a tunnel leading through the Picacho Mountains to the northern boundary of the Imperial Valley. This tunnel is partly in rock thought to be of a stable character but toward its western end it encounters an alluvial formation for a considerable distance. The difficulties likely to be encountered in this material are problematical.

After emerging from the first tunnel, the line skirts the northern rim of the Imperial and Coachella valleys for a distance of more than a hundred miles. This part of the line is almost entirely in surface conduit and includes 5 pump lifts, making the total lift for the route 1997 ft. At about Mile 75 adverse geological conditions require the introduction of an intermediate power drop of 213 ft. The last pump lift occurs at the western extremity of the Coachella Valley and lifts the water to a summit elevation of 1639 ft. From this point the line pierces the San Jacinto Mountains in a tunnel 15.3 miles long, emerging at a point near Potrero Canyon in the San Jacinto Valley. West of Potrero this line is identical with the Parker route, previously described, and may follow any of several satisfactory and safe locations to a termination at Puddingstone, Brea, or other suitable reservoir. A power drop of 406 ft. is available at Colton, if the line is routed that way.

Fig. 6 shows that the Picacho route is parallel to and near the San Andreas rift for a considerable portion of its total length. This rift, which is known to be a live fault, is characterized by numerous side faults and it has not been possible to find a location for this line which is free of serious danger from earthquake movements. In commenting upon this line, Dr. John P. Buwalda states in part as follows:

> The Picacho route lies entirely in soft materials. This fact would of course make tunneling difficult, and expensive because of necessity of timbering. Even where they are not subject to more violent earthquake disturbance tunnels in unconsolidated materials are less safe than in strong rocks.
>
> This route also follows remarkably closely the most important fault in California, perhaps on the entire earth. Proximity of tunnels to it, and through soft materials, means danger both from failure through collapse and from possible shearing offset of the tunnel along one of the subsidiary or branch faults.
>
> It also does not appear to be safe procedure to build long stretches of conduit almost directly above the fault, or on slices between branches of the fault. It is true that it is necessary to cross certain important faults on any route from the Colorado River to Southern California that can be devised, but from the standpoint of safety, it is certainly far less hazardous to cross a fault once, approximately at right angles, and on the surface, than to follow it very closely for 50 or 100 miles on the surface or to cut it underground.
>
> The conduit of the Picacho route would lie in alluvial fill which probably has considerable depth, resting as it does on a block on one side of the San Andreas fault which has been subsiding while the opposite block, consisting of Indio and Mecca Hills, has been rising and shedding its erosional waste across the fault. Thick alluvium shakes like jelly in a bowl during an earthquake, the alluvium being the jelly and the bed-rock basin in which it lies constituting the bowl. The violence of the earthquake is greatly accentuated in the alluvium; in the San Francisco earthquake of 1906 the deep alluvial basin of the southwestern San Joaquin Valley, 250 miles distant, experienced much more violent shaking than the intervening country. Along the Picacho route we have the combination of presumably deep alluvium and proximity to

> or actual coincidence with the fault. The 1906 shock was probably the fourth, or perhaps the fifth, of comparable intensity along the San Andreas rift within historic times. If a similar movement occurred along about 200 miles of the fault again, with maximum horizontal displacement of about twenty feet, it is quite possible that, aside from the shearing off of the conduit where it crossed the fault or some of its branches, long sections of the concrete shell might be shattered or crushed by the powerful lurching of the alluvium in which it lay.
>
> In short, it appears to be inviting trouble to follow the San Andreas fault closely for long distances.

These statements seem to preclude any possibility of using the Picacho route. In any event, the estimated saving in first cost is more than offset by increased operating expenditures, making the ultimate cost of water delivered by this line higher than the cost of water delivered from the Parker line.

All-American canal route

Column 6, Table 6, presents an estimate for an aqueduct diverting at a point north of the Salton Sea from the western end of the Coachella branch of the proposed All-American canal, the construction of which is under consideration by the Bureau of Reclamation for the Imperial and Coachella irrigation districts. In this plan it is proposed that desilting works be placed at the point of diversion from the canal and that the desilted water be elevated by pumping into a line identical with the western end of the Picacho route, as above described. Assuming that a just division of costs can be arranged between the Metropolitan Water District, the Federal Government, and the Imperial Irrigation District, such a line would apparently reduce both the initial investment and the ultimate cost of water delivered to the Metropolitan Water District. However, there are many difficulties in the way of this project.

In the first place, it is not definitely known when the All-American canal will be constructed, and any attempt at cooperation between the Metropolitan Water District and the irrigation interests might involve delay in the planning and completion of the aqueduct.

It is also possible that a cooperative project will involve some unavoidable operating difficulties. It would probably be necessary that the All-American canal and its branches be under control of the irrigation interests. This would leave the Metropolitan Water District dependent for its supply upon the operation of a long irrigation canal by an outside organization. The operating requirements for irrigation and water supply are not in all respects identical. It is customary in irrigation canals, and especially those carrying a heavy silt burden as will the All-American, to close them down a certain period each year for cleaning and repairs. There is also, in the present case, the possibility of interruption of flow because of breaks in the canal in the cloudburst and earthquake area along the rim of the Imperial Valley. Such interruptions are relatively unimportant from an irrigation supply point of view, but are serious matters in considering the more exacting needs of a water supply project. This difficulty could be offset, to an extent, by a storage reservoir at the end of the canal section.

It would be difficult to enforce necessary sanitary regulations along the irrigation channel. Water in the lower reaches of an irrigation canal usually becomes foul and unfit for domestic consumption. While this condition could be corrected by treatment or by filtration, it is nevertheless considered undesirable.

This line is not shown on Fig. 6, but, as previously stated, it coincides with the Picacho route along the northern rim of the Coachella Valley. This is perhaps the most precarious part of the Picacho route from a geological point of view, and is subject to the objections quoted from Dr. Buwalda's report under the discussion of the Picacho route. The Coachella branch of the All-American canal follows the San Andreas fault closely and is considered by the geologists to be precarious for a domestic supply aqueduct. With particular reference to the All-American canal, Dr. Buwalda offers the following:

> From a geologic standpoint the Picacho and All-American routes do not differ materially as regards the materials through which they would pass but the All-American would follow the San Andreas fault zone more consistently and would be subject to greater danger from fault disturbance.

As now planned by the Bureau of Reclamation, the All-American canal is to be unlined. The losses in such a canal through a sandy region like Imperial Valley would be tremendous, and could not be afforded by the District. The only way to make this project feasible, as regards losses, is for the Metropolitan Water District to line the entire canal at its own expense, with permission in return for this expenditure, to increase its diversion from the canal by the total reduction in losses affected in its own flow and in the flow of the irrigation districts. The practicability of such an arrangement is questionable. The estimates shown assume that this can be done.

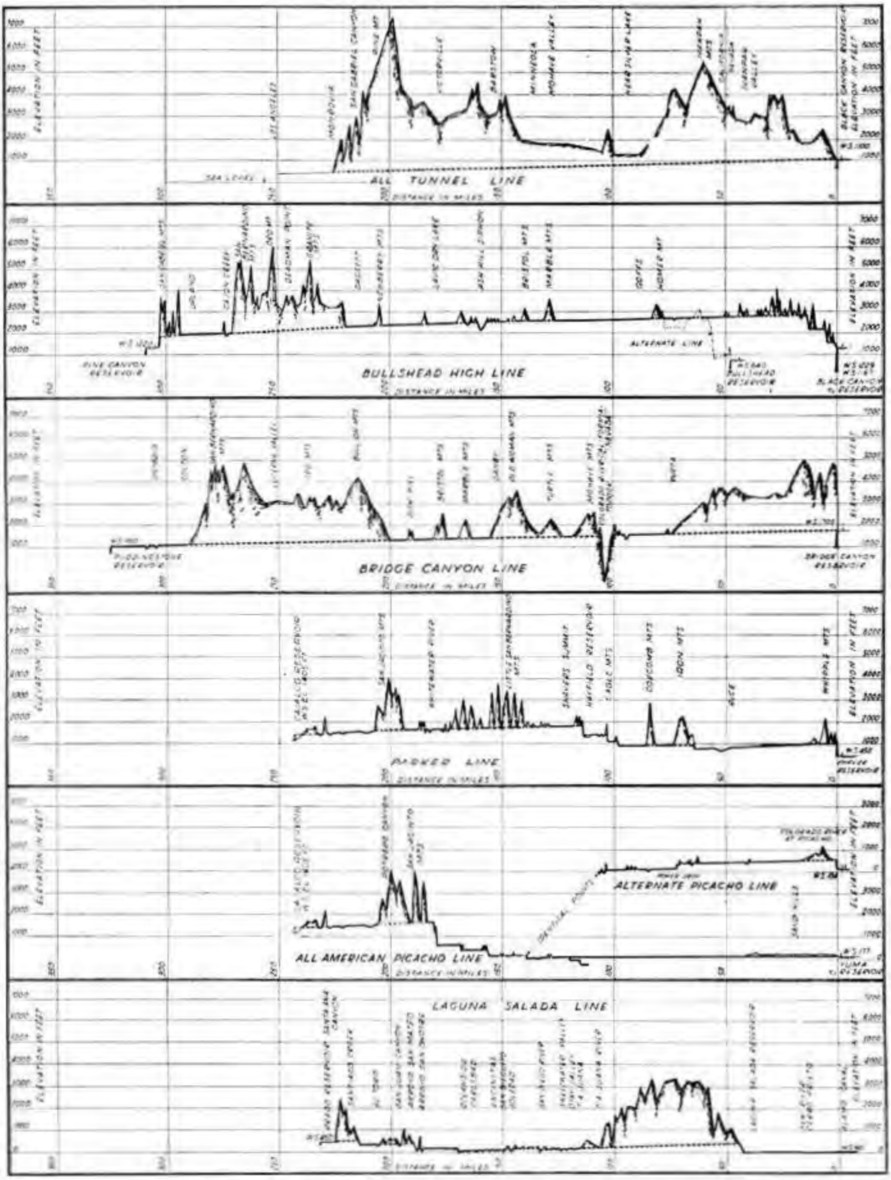


Fig. 7—Profiles of preliminary aqueduct routes

Although the estimated cost of water delivered through this line is slightly less than for some of the more acceptable lines, the difference is not believed to be sufficient to justify the risks involved and the perpetual complications that might result from the lack of control of the system by the District. Filtration and treatment might ultimately become necessary, and this would wholly or partly offset the estimated saving. It is believed that the construction of this line should not be seriously considered.

Bridge Canyon route

In the last column of Table 6 are presented data covering a possible all-gravity line diverting from the Colorado River at the Bridge Canyon dam site about 120 miles upstream from Black Canyon. In this particular estimate it is assumed that a diversion dam 600 ft. high will be constructed at the lower Bridge Canyon dam site. This site is satisfactory for a dam of this height or, perhaps, considerably higher. Estimates were made for lines diverting above dams of various heights up to a maximum of 900 ft. The 600-foot dam appears to offer a slightly more economical development than any other height tried. The plan as presented contemplates the construction of the diversion dam by the District on the assumption that the power development at the dam site will be owned and controlled by the District. It is not probable that such an arrangement would be permitted. A dam 600 ft. high affords only 1,550,000 acre-feet of storage, which is inadequate for the regulation of the Colorado River. This space would be filled in a comparatively short time with silt accumulations. For this reason, any power developed at Bridge Canyon without storage at an upstream point, would be more or less inconstant and would perhaps need to be sold as secondary power. In order to improve the situation, provision is made in the estimates for the development of 3,770,000 acre-feet of regulatory storage at the Dewey and Flaming Gorge dam sites. It is assumed in the estimates that a large portion of the cost of these projects can be absorbed by power development located at the respective sites, leaving only a portion of the upstream storage charges to be borne by the power development at Bridge Canyon. With this provision, an appreciable block of firm power can be developed at Bridge Canyon. However, the two reservoirs proposed do not fully control the Colorado River and a considerable portion of the flow will continue to be available only for the production of secondary power which will probably have little value. This condition will improve as upper basin development proceeds and the river flow becomes more nearly uniform.

The aqueduct leaves Bridge Canyon in a tunnel 75 miles long, under the Grand Wash Cliffs. This tunnel lies at a great depth below the surface. Shafts will be deep and construction of the tunnel will be expensive. Older geological reports indicate considerable faulting in this region but in the preliminary geological work undertaken by the District no serious faults were definitely located. At least some of the shafts will have to be sunk in alluvial material, perhaps through underground water basins of appreciable magnitude. Whether the tunnel location as shown will encounter alluvial material in the deepest parts of the valley fills between the mountain ranges is not known although it is considered probable that some alluvial material will be encountered. The outlet end of the tunnel will certainly be in this material.

Emerging from the tunnel, the line passes in conduit to a point west of Topock where it goes into a steel pressure line and crosses the Colorado River in a pipe line having a maximum head of 1025 ft. West of the river it pierces the Mojave Mountains in tunnel and proceeds along a comparatively safe route, about 45 per cent in surface conduit, to a point near Ludlow. At this point it goes into a tunnel 89.5 miles long under the Bullion Mountains and beneath the water-filled Lucerne Valley, finally emerging at a point in the vicinity of San Bernardino. The outlet end of the tunnel is at a low elevation and for several miles is in the water-bearing gravels along the northern slope of the Santa Ana Valley. The San Andreas fault is crossed deep underground. Numerous other fault zones are also crossed deep underground by this long tunnel. Construction of this line might be possible but it is considered very hazardous.

The arguments in favor of a Bridge Canyon diversion are that it will release for other uses a large block of power at Black Canyon and create an additional supply of salable power at Bridge Canyon and at other points up the river. Furthermore, it is argued, once the amortization period is past, such a route will deliver water perpetually into the District area at practically no cost.

Admittedly, the substitution of this project for any of the pumping projects under consideration would increase the amount of hydroelectric power available for distribution in the Southwest.

However, according to figures available, and considering the immediate prospects for a market for the increased power output, it does not appear that the large increase in cost is justifiable from a power production point of view.

The claim that water will ultimately be delivered practically without cost neglects the requirement for paying taxes on District property outside of California. Inspection of Table 6 shows that the operating cost for the Bridge Canyon line, even after deducting a reasonable amount for the value of the power which could be developed at the Bridge Canyon dam site under the assumed conditions, is not outstandingly lower than the cost of operating the Parker line.

Perhaps the most important point in the consideration of this line is the fact that its construction requires an initial expenditure of some $558,000,000, which would no doubt, be a burden on the present financial capacity of the Metropolitan Water District.

When the upper river shall have been completely developed and controlled and when the demand for power in the Southwest has been largely increased and the supply of cheap steam power has been exhausted, it may be desirable to construct a dam from 600 ft. to 900 ft. high at Bridge Canyon for the purpose of producing hydroelectric energy. When such a dam shall have been constructed and financed by some agency other than the Metropolitan Water District, it may be found feasible to make a gravity connection to it thus eliminating all or part of the pumping necessary to bring the water to Los Angeles over a pumping route.

Terminal storage

Investigations have shown that ample space for terminal storage near the outfall end of the aqueduct is available. Unfortunately, this space is not all located as conveniently as might be desired. However, there are several reasonably promising reservoir combinations from which a development may be chosen. The cheapest and perhaps most convenient combination would be one including the Los Nogales reservoir which lies in the valley west of Pomona. This site is traversed by two transcontinental railroad lines and is very highly developed in many respects. No doubt considerable objection would be raised to its utilization as a reservoir site and it is thought that such utilization should be avoided if possible.

Other promising reservoir combinations involve the use of either the Cajalco site or what has been termed the Perris site, both of which are more remotely located. However, safe connections from either of these reservoirs into the Metropolitan Water District area are possible and it is thought that they offer all the security necessary.

The Perris site is easily reached from any of the proposed aqueduct lines coming in through the San Gorgonio Pass, and it has many features favoring its use as a primary reservoir unit. Perhaps the only undesirable feature of this reservoir is the fact that it lies above the hydraulic gradient of the aqueduct which makes it necessary that the water stored must be pumped into it. This is not thought to be a serious objection as the flow ordinarily will be by-passed and fluctuations taken care of in other units of the storage group of which this reservoir will form a part.

The Cajalco reservoir is slightly more difficult to reach from the proposed aqueduct line but once the connection is made it is believed that it will be more flexible in operation than the Perris site. The difference in desirability and cost between the groups using Perris and those using Cajalco is not great. The present situation may be changed slightly when field explorations on these two sites are completed, but it is not expected that serious physical difficulty will be encountered at either site. Final choice between the two may hinge largely upon the success of right of way negotiations.

RECOMMENDATIONS

In view of the accumulated facts it is desired to make recommendations as follows:

1. The aqueduct should divert from the Colorado River at the upper Parker dam site and should be routed via Rice, Shaver's Summit and Whitewater to Potrero, approximately as shown on Fig. 6.

2. West of Potrero the line should be routed either via Perris reservoir, Colton and Ontario to a point in the vicinity of the Puddingstone reservoir, or via the Cajalco reservoir, Corona and Brea Canyon, depending on the final choice of reservoir groups.

3. A dam at the point of diversion is desirable, and permission for its construction should be sought.

4. Suitable portions of the eastern end of the aqueduct should be of open lined canal, the Hayfield reservoir being utilized as a protection against possible interruptions in flow.

5. Testing of reservoir sites should be continued and negotiations for right of way for the most promising units should be begun as soon as conditions warrant.

The reasons for the choice of the Parker route may be summarized as follows:

a. It will furnish water to the District at less cost per acre foot, all costs considered, than any other safe and satisfactory route.

b. It involves less hazardous construction than any other route, and will be the safest line to operate.

c. It fits terminal storage facilities better than the Black Canyon route, its only serious competitor.

d. It is located entirely in California, and is free from taxation, possibly excepting one end of the diversion dam.

e. If necessary, it can divert directly from the river, leaving it free from outside interference.

f. The cost of this route is believed to be within the financial ability of the District and reasonable in consideration of the value of the service it will render.

F. E. WEYMOUTH,
Chief Engineer.

Exhibit B

Final Report of the Engineering Board of Review

December 19, 1930.

MR. W. P. WHITSETT,
CHAIRMAN, BOARD OF DIRECTORS,
THE METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA,
LOS ANGELES, CALIFORNIA.

DEAR SIR:

On December 21, 1929, the undersigned members of the engineering board of review, after a study of the various routes which had been proposed for an aqueduct from the Colorado River to The Metropolitan Water District of Southern California, submitted a preliminary report recommending the elimination of certain of these routes and designating others for further and more detailed surveys and geological examinations.

On November 14, 1930, after ten months of intensive work on the recommendations of this board, a report was submitted by your chief engineer, Mr. F. E. Weymouth, and on November 25, 1930, this report was referred to us for final review and recommendations together with the following letter of instructions.

TO THE MEMBERS OF THE BOARD OF REVIEW,
THE METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA.
MESSRS. THADDEUS MERRIMAN,
RICHARD R. LYMAN AND
A. J. WILEY.

Gentlemen:

During the time elapsed since the filing of your preliminary report, Chief Engineer Frank E. Weymouth and his staff of engineers have been engaged in securing the engineering and geological data requested. In addition, Mr. Weymouth has directed detailed studies on other phases of the aqueduct project, including an exhaustive investigation of the possibilities of bringing water from the Colorado River to the cities in the District by means of a gravity aqueduct.

On November 14th, Mr. Weymouth filed with this board his report and findings on the problem of selecting the safest, most economical and most practicable route for the aqueduct. In his report he presents the results of his surveys and studies on the four general routes selected by you for further investigation. Data and findings on other alternative routes also were submitted by Mr. Weymouth in his report.

This board, therefore, is prepared to advise you that all of the engineering and geological studies on the Colorado River aqueduct project requested by you in your preliminary report have been made available by the chief engineer of the Metropolitan Water District, and are hereby referred to you for your information and use. Accordingly, all is in readiness for you to resume your study of the aqueduct problem—and to proceed to the making of your recommendations on this project.

As you resume your duties as a board of review on this vitally important task of selecting the best and most economical route for the Colorado River aqueduct, this board desires to place before you the following final instructions and suggestions:

1. At the time you originally were retained by this board you were instructed to recommend to the board an aqueduct plan which would assure the perpetual delivery of an adequate supply of water to the Metropolitan Water District at the lowest possible cost, all elements of construction and operation costs considered. It is desired to reiterate such instructions at this time.

2. All data collected by Chief Engineer Weymouth and his staff of assistants, or secured by the District from any other source, are made available to you. Mr. Weymouth's report and recommendations are referred to you for your information. You are advised, however, that the board expects you to make an independent study of the aqueduct route problem. In no way are you to be bound by Mr. Weymouth's findings and recommendations.

3. Should there be other data desired by you but not made available in the studies conducted by the engineering department of the District, such data will be supplied upon request.

4. You are particularly instructed to give full consideration to the relative physical and economic merits of gravity flow possibilities.

5. You are requested to advise the board definitely upon the cost of constructing, maintaining and operating an aqueduct along the route recommended by you.

6. You are requested to advise the board upon the problem of water storage at the western end of the aqueduct. The board requests in particular your advice as to how much capacity is required for safe regulation and reserve storage; how much of this capacity should be made available in the initial development of the aqueduct, and how much at a later time.

To assist you in your task, the board places at your disposal all of the engineering data and facilities of the District, and whatever additional expert advice may be essential to a proper report on the problem.

Yours very truly,

THE BOARD OF DIRECTORS OF THE
METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA
By W. P. WHITSETT, *Chairman*

Responding to the requests and instructions contained in the letter of instructions we have the honor to present the following report. This report is accompanied by a number of appendices in which the major subjects are discussed each under its own heading. There is also a map showing the main features of the principal routes.

Report of Chief Engineer Weymouth

Mr. Weymouth's report describes in detail the studies made on each of the routes together with the many variations made on each for the purpose of determining the most favorable location. Geological examinations were also conducted under the direction of Consulting Geologist Dr. F. L. Ransome, who was assisted by Dr. John P. Buwalda, Dr. L. F. Noble, Mr. F. M. Murphy, and Mr. Rollin P. Eckis. The results of these studies have been used for the purpose of selecting that route which would encounter the fewest construction difficulties and be the least subject to seismic disturbances.

We find that the investigations recommended in our preliminary report have been carried out by Chief Engineer Weymouth in a most complete and satisfactory manner and that he has given, in the four volumes of his report, a sound basis for reviewing his recommendations and checking the correctness of his conclusions.

Necessity for an increased water supply

The increase in the water requirements of the Metropolitan District will follow its population growth as projected from the United States census reports. This increase can be met only by an additional supply from a source outside the District. Such additions to the supply as are now being made by the extension of the Los Angeles aqueduct and by deeper pumping from the underground basins of the District will meet the increase in demand only for a few years and probably not longer than the period required to bring in a new supply from an outside source.

The Colorado as a source of supply

With one exception all of the many proposals which have been advanced for augmenting the supply of the District agree that the only practical source for an additional supply is to be found in the waters of the Colorado River. The single exception is the proposal to reclaim the water of the sewage. To some extent this may prove to be possible, but none of the water so reclaimed could be used in any municipal system. All of it would necessarily be devoted to manufacturing and irrigation uses.

The flow of the Colorado is ample in volume and it is our understanding that the District has perfected its right to use 1500 cubic feet per second of this water. The storage volume in the Hoover reservoir necessary to regulate the flow of the river has also been arranged for by the District under a contract with the United States.

Aqueduct routes considered

In the order of their location, beginning with the highest on the Colorado River, the routes which we have considered are the following:

1. The San Juan route diverting from the Colorado near the mouth of the San Juan River in Utah. This route would involve the raising of the water by a dam 1080 feet high and the aqueduct would traverse an unsurveyed region in Utah, Nevada and California for a total distance of 850 miles.

2. The Bridge Canyon route would divert from the Colorado at Bridge Canyon about 110 miles by river above the Hoover dam. From this point the water, after being raised by a dam, would flow by gravity to the District, a distance of 316 miles.

3. The Black Canyon route would divert from the reservoir above the Hoover dam by a pump lift of 1662 feet. There would be a return power drop of 564 feet and the length of this route would be 300 miles.

4. The Bulls Head route would divert from the Colorado about 50 miles below the Hoover dam with a pump lift of 2051 feet. The return power drop would be 564 feet. The route would have a total length of 254 miles.

5. The Parker route would divert from the Colorado 150 miles below the Hoover dam with a pump lift of 1523 feet. The return power drop would be 252 feet and the route would be 252 miles long.

6. The Picacho route would divert from the Colorado 275 miles below the Hoover dam and about 20 miles above Yuma with a total pumping lift of 1997 feet. The return power drop would be 620 feet and the total length 234 miles.

7. The All-American route would divert from the All-American canal in the Coachella Valley at a point 119 miles from its head on the Colorado. The total pumping lift would be 1888 feet. The

return power drop would be 406 feet. Its total length, including that part in the All-American canal, would be 271 miles.

8. The southern sea level route would divert from the Colorado below Yuma into a desilting basin, the Laguna Salada, in the Republic of Mexico, from whence it would be diverted by a 70-mile tunnel to San Diego and thence along the ocean front to a point near Santa Monica. The friction loss in the aqueduct and the lift from sea level to the various communities of the Metropolitan District would be supplied by pumping. The length of this route is 277 miles.

Summary of conclusions

Acting under your instructions to recommend an aqueduct plan which will assure the perpetual delivery of an adequate water supply to the Metropolitan District at the lowest possible cost, all elements of construction and operation costs considered, we have made a careful study of the various aqueduct routes described in the report of Chief Engineer Weymouth and have examined all of the most important points and locations in the field.

We have further given extended consideration and study to all of the alternative routes above listed, and present our conclusions as follows:

1. The proposed supply of 1500 second-feet is a correct and conservative forecast of the needs of the future and will cover the requirements up to the year 1980.

2. The water of the Colorado is exceptionally pure and free from contamination. Its sanitary quality is excellent and its mineral content is within the limits of an acceptable supply for domestic use. Its convenience of use for industrial purposes may, as the demands of the future require, be improved through softening processes such as are now in use on other water supplies. The silt content of the Colorado is always high but the water can be clarified either by settling in basins or by mechanical means so as to be of entirely acceptable quality for all purposes. Further discussion on the quality of the water is presented in Appendix I.[1]

3. The salt beds in the Virgin Valley will have no harmful or deleterious effect on the quality of the water stored in the Hoover reservoir. This matter is discussed in Appendix II.

4. After extended examinations and careful analysis of the so-

[1] Appendices not reprinted here; copies may be consulted at the District office in Los Angeles.

called gravity and sea level routes, we are clearly of the opinion that they are not practical solutions of the problem before the District. They would be more expensive to construct, to operate, and to maintain. They would be less safe than the Parker route and hence, would not as effectively serve the best interests of the people. These routes are discussed in detail in Appendices IV, V and VI, while Appendix III presents some of the general principles affecting the choice between a gravity and a pumped supply.

5. We agree with Chief Engineer Weymouth and concur in his conclusion that the best, the safest and the most economical location for the aqueduct from the Colorado River is that known as the Parker route. The geological considerations leading to this conclusion are stated in Appendix VII, while the main reasons and recommendations are presented in Appendix VIII.

6. We have made a careful study and analysis of the cost of constructing, maintaining, and operating an aqueduct along the Parker route, and have concluded that the cost of constructing this aqueduct and all its appurtenant works will be \$199,618,000. Of this total cost the sum of \$25,965,000 may be deferred for about 15 years after the aqueduct first goes into service. The construction cost of the first development of the aqueduct, including arrangements for the clarification of the water, is estimated to be \$181,072,000. (Details of these figures are shown in Appendix IX.)

7. The annual cost of maintaining and operating the Parker route aqueduct after it is in complete commission and delivering 1500 cubic feet per second will be \$6,106,000 per annum. This figure covers all costs and expenses including power for pumping after allowing for the value of the return power. This annual cost, however, does not include either interest on the original investment or the annual payments on account of bond amortization. The interest charges on the complete development will be \$9,500,000. (These conclusions are amplified in Appendix IX.)

8. We have studied the question of the quantity of terminal storage to be provided and, while an ultimate capacity of from 250,000 to 300,000 acre-feet will be required, it is our judgment that the needs during the first 10 or 15 years after the completion of the aqueduct will be reasonably served by from 75,000 to 125,000 acre-feet. We therefore recommend that this quantity of terminal storage be provided and that the dams constructed for this purpose be so designed as to permit of their being raised whenever

greater storage volume becomes necessary. We estimate that the cost of providing 100,000 acre-feet of terminal storage will be $17,500,000. Our conclusions on this question are stated at greater length in Appendix X.

9. Before contracts for construction can be prepared and made ready for advertisement much work must be done in the way of borings and detailed examinations, surveys, and designs. The estimates which have been made include the cost of this work. It should be begun at the earliest possible date so that active construction operations may be immediately put under way on these parts of the aqueduct which will require the longest time for completion. Only in this way will it be possible to realize the bringing in of the Colorado water within the time of six years which has been estimated.

In submitting this report and concluding our services we individually express our appreciation of the aid and assistance which has been rendered in connection with our duties by the directors of the Metropolitan Water District, by Chief Engineer Weymouth, and by the many members of his staff with whom we have been in contact both in the field and in the office.

Respectfully submitted,

THADDEUS MERRIMAN,
A. J. WILEY,
RICHARD R. LYMAN,
Members of the Board of Review
The Metropolitan Water District
of Southern California

EDITOR'S NOTE: The engineering studies summarized in Exhibits A and B were devoted to the determination of the best route for the main aqueduct between the Colorado River and the Southern California coastal plain. Except as noted they do not include estimates either for terminal storage or for distribution lines. When these are added to the costs set up in the table on page 75 and adjustment is made for the shorter main aqueduct line resulting from the adoption of Cajalco as a terminus instead of Puddingstone, the result is the figure used in the bond issue estimate for first development of $218,844,000, or in round numbers, $220,000,000, as shown on page 111.

CHAPTER 5

Location and Design of the Aqueduct

IN THE EARLY stages of the planning of the Colorado River aqueduct, one of the important features of the work was the preparation of comparative estimates of the cost of the project for all the different routes proposed from the various possible points of diversion. To facilitate this work, designs were made for the major types of aqueduct construction such as tunnel, cut-and-cover conduit, canal, and pressure pipes, for the general conditions of location and for a wide range of sizes. For each of these several types and sizes the hydraulic properties were determined and the physical quantities involved in one linear foot of construction computed, from which data tables and charts were prepared for use by the locating and estimating staff. As the various routes were projected on the maps and on the ground, proper sizes of the aqueduct sections for the required capacity and for the available grades were readily selected from these charts and tables, quantities computed and comparative costs obtained. Wherever problems of location and construction departed from the typical conditions, special studies were made and tentative designs and cost estimates prepared for each specific case.

As the choice of routes narrowed down to the Parker route with diversion near Parker, Arizona, and terminal storage at Cajalco, the designs were fitted more closely to the character of the traversed terrain and to the actual conditions of location. The aqueduct was divided into sections in each of which accessibility, general topography, and features of construction were somewhat uniform. For each of these sections, unit costs were determined, based on quantities for a set of tentative sizes. Then variations in unit costs with the sizes of aqueduct sections were analyzed and studies made of the most economical size to use for each unit of construction. These studies were later used in combination in arriving at the final sizes for the entire length of the aqueduct.

The various types of conduit and special structures comprising the aqueduct are basically such as have been successfully used in similar projects in the past, having been evolved through a long period of engineering effort and experience. However, a considerable amount of experimentation and research, as noted later in this chapter, was necessary to meet the unusual conditions of construction and operation in the desert, and to achieve the greatest possible efficiency in the use of construction materials.

Economic factors in location

A number of the first lines investigated involved no pumping. Popular opinion among both hydraulic engineers and laymen naturally favors a gravity supply for a metropolitan area. Such a supply has many advantages, and it was to be expected that many of the schemes for developing a Colorado River water supply should propose gravity delivery. Each of these gravity schemes was carefully considered, but in the end it was necessary that they all be dismissed as physically and financially impossible, or at best as involving expenditures out of all proportion to benefits.

The first step in the study of the pumping projects was the establishment of a basis for determining the economic relationship between cost of pumping, length of aqueduct, percentage of tunnel in the line, and size and type of conduits. It was necessary to provide a pump lift sufficient to permit an economic crossing of the mountain range dividing the coastal area from the desert, and to furnish the fall required to maintain flow in the aqueduct.

In the adopted line the supply is taken from a reservoir created by a dam about 16 miles up the river from Parker, Arizona. The normal water level in this reservoir is to be 450 feet above sea level. The aqueduct flow will be lifted through a total height of 1617 feet. This lift is required to overcome the difference in water surface elevation between Parker reservoir and the critical point in the aqueduct at the outlet of San Jacinto tunnel, and to maintain flow in the aqueduct between these two points. Incidentally, this lift results in a conveniently high delivery elevation for the aqueduct flow, but the same total lift would have been required on this route even though the water had to be delivered at sea level.

Under the prevailing topographical conditions, the general elevation of the line and the total pump lift were determined by end conditions at the San Jacinto tunnel, particularly the outlet. The relation of these conditions to the pump lift was studied with care. First, the "value of a foot of head" or the cost of lifting the specified aqueduct flow of 1500 cubic feet per second (average) an additional foot, was determined. This value is made up of the cost of pumping facilities, including transmission lines and other power producing equipment, plus the cost of perpetual operation which was capitalized at a fixed amount. This latter amount represented a theoretical sum of money, the interest from which would yield an amount sufficient to provide for perpetual power and other operating costs. The total of these factors (pumping facilities plus the capitalized cost of perpetual operation) was estimated at $65,000 per additional foot of head.

Having derived this figure, a cost estimate was made for San Jacinto tunnel in a fairly high trial position. Lowering the tunnel a few feet from this trial elevation added slightly to its length and its cost. If the tunnel were lowered, the aqueduct could be lowered all the way back to the nearest pumping plant and the pumping head at that plant reduced, thus saving on pumping cost. If lowered excessively, the tunnel portals began dipping below the alluvial fills along the mountain slopes, requiring long and deep approach cuts. Also, serious groundwater conditions would be encountered in the approach to the west portal. A point was soon reached where to go a foot deeper added more than $65,000 to the cost of the tunnel and its approaches, thus more than offsetting the saving due to reduced pump lift. The point at which this first occurred marked the economic tunnel elevation.

A similar procedure was followed in determining the size of the aqueduct. If a water conduit is given a very steep slope, the water will flow rapidly, enabling a small channel to deliver a large flow. If the slope is flat, the velocity of flow will be low, requiring a much larger and more expensive conduit. Hence, if there is "plenty of fall", it should be utilized to reduce construction costs. In the case of the Colorado River aqueduct, fall could be provided as required, but its value was $65,000 per vertical foot; hence it had to be used sparingly. If the aqueduct slope were made too steep, much fall was required and the cost of pumping was excessive. A very flat grade reduced the cost of pumping but increased greatly the cost of the waterway. For each type of conduit there was an "economic slope" which gave the smallest combination of construction cost plus capitalized cost of providing the head required to maintain the flow.

Conduit types

The aqueduct is made up of several types of conduit, to suit various topographic situations. The cheapest type acceptable for the service required is a concrete-lined open canal. This type is used across relatively smooth desert areas where the handling of cross-flows from occasional floods is not too serious a problem. A closed concrete conduit built in an open ditch and then back-filled, called "covered conduit", is used in more difficult locations. Concrete-lined tunnels are used where mountains must be pierced or where the topography is so rough that a covered conduit following a grade contour is not feasible. Finally, pressure pipes, or inverted siphons, are required for crossing drainage channels and other depressions.

The costs of these conduit types vary about in the order named. Canals were used wherever possible, then covered conduits. Tunnels and siphons were used only where unavoidable.

The economic slope of each type was determined from cost estimates. Beginning at the established elevation at the San Jacinto tunnel outlet and proceeding eastward, these slopes were added up back to the top of the nearest pump lift at Hayfield, thus determining the peak elevation of 1807 feet above sea level. Although this peak is only 1357 feet above the elevation of the water in Parker reservoir, a pump lift of 1617 feet is required to get the water there. The difference of 260 feet is used up in the slope of the intervening aqueduct.

It would have been desirable, if feasible, to do all the pumping at a single point, i.e., at the intake. However, the desert floor, leading away from the river, is too low to support an aqueduct 1617 feet above the reservoir level. The ground rises in roughly parallel steps from the river to Shaver's Summit, 134 aqueduct miles west of the intake. The pumping was therefore divided between five plants and these were distributed along the line to secure the best possible fit between the aqueduct and the ground.

The first plant is at the river and the second one is nearby, the two having a combined lift of 594 feet, which is sufficient to deliver the water through the Whipple Mountain tunnels onto the tableland in the Vidal-Rice district, and cause it to flow 69 miles by gravity to the foot of Iron Mountain. Here a 144-foot lift provides head for flow through the Iron Mountain and Coxcomb tunnels and across the desert to Eagle Mountain. A fourth lift of 438 feet provides elevation for turning the corner of the mountains northwest of Desert Center and delivering the flow over a divide into the Hayfield Dry Lake area. This old lake bed is to be utilized as a natural reservoir. West of this reservoir, the terrain rises rather rapidly to Shaver's Summit, hence the fifth and last pumping plant is required. This plant lifts the water 441 feet to the peak elevation of 1807 feet. This elevation is somewhat higher than required to clear Shaver's Summit, but is necessary to provide the head needed to pass the controlling elevation at the San Jacinto tunnel outlet.

West of San Jacinto the value of a foot of head is no longer related to the cost of pumping but is dependent upon the value of fall for the maintenance of flow in the remainder of the aqueduct, and the value of elevation in making deliveries to the District cities. The value was somewhat smaller than for the eastern end of the line, hence siphons and tunnels were slightly reduced in size.

Storage facilities

The availability of storage facilities was a further controlling factor in the location and design of the aqueduct. As the maximum demand is reached, it will be necessary to keep the aqueduct running at full capacity day and night, all the year, except for unavoidable interruptions. The result is a constant stream of water. But neither the supply of water at the intake nor the demand at the outlet is naturally constant. The natural flow of the Colorado River is variable and the use of water is much lower in winter than in summer. If the aqueduct is to be used to full efficiency, capacity must be available at both intake and outlet for storage.

Terminal storage is also required for safety. Any waterway as long as the Colorado River aqueduct is subject to accident, due to earthquake, flood, or other natural cause. An interruption of as much as a month is conceivable. Although such interruptions will occur rarely, if ever, it is necessary that such a contingency be provided for by a reserve in local reservoirs. A reserve of two months' supply is about the minimum for safety.

The storage required at the intake is supplied by the Boulder and Parker reservoirs. The latter also serves to clarify the flow before its diversion into the aqueduct. Additional storage is required as near as possible to the delivery end of the aqueduct.

Good reservoir sites are very scarce in Southern California and are generally expensive to develop. The storage possibilities of every "wrinkle" in the topography of the coastal area was investigated, and many apparently possible sites were prospected. Convenience, safety of dams, cost of reservoir, and influence on aqueduct cost, were carefully considered. Finally, the Cajalco site, about ten miles southwest of Riverside, was chosen. The site is very safe and is capable of being developed in stages, as the demand for water grows. The reservoir is formed by an earthern dam across Cajalco Creek, and a long earthern dike along the north rim of the basin. The initial capacity is 100,000 acre-feet, which can be increased as required to a total of 225,000 acre-feet.

As an additional safeguard, and to reduce the capacity required in terminal lines, the District is to acquire Morris reservoir on the San Gabriel River, as soon as Colorado River water is ready for delivery. This reservoir was built by the City of Pasadena. Other small operative reservoirs are contemplated. Use is also to be made of a natural lake bed at Hayfield about the midpoint of the main aqueduct, for additional emergency storage. This basin is west of all the open lined canal and will supply the aqueduct in case the flow in the canal should be interrupted by cloudburst.

Controlling factors in design

The solution of these general problems cleared the way for detailed location and design, which were controlled by considerations of safety, permanence, convenience, and economy, with safety in first place.

The element of safety is divisible into two parts, viz.: Safety against damage to the public and safety against damage to the aqueduct. Where human life is involved, there can be no compromise whatever with safety. The Parker and Cajalco dams, for example, must have an excessive margin of safety, under the worst conditions imaginable. These features and others involving the safety of "life and limb" must be as safe as human ingenuity permits, regardless of cost.

The requirements for safety against damage to private property, other than District property, are only slightly less exacting. It would be theoretically permissible to risk injury to private property if the cost of reimbursing the private individual for the resultant loss is less than the cost of building in such manner as to avoid the risk of injury. However, claims for damage to private individuals cause dissatisfaction and ill-feeling and any possibility of such damage should be eliminated unless the risk is small and the cost of elimination enormous.

Risk of injury to the aqueduct itself can be treated on a more rational basis. There must, of course, be no risk of wholesale destruction, nor must there be any risk of an interruption in excess of the shut-down period provided for in the design of storage works. Within the limits of such provision, risk of damage to the aqueduct itself, where danger to human life is not involved, can be worked out on a mathematical basis. For example, the use of open lined canal instead of covered conduit across favorable portions of the desert, effected a reduction of $20,000,000 in construction and operating costs. Unfortunately, an open canal cannot be made absolutely secure against damage, as by a flood like that which occurred in the coastal area in the spring of 1938. Such a flood, occurring on the desert, would be quite likely to damage the open canal. Complete safety under such extraordinary conditions cannot be attained at any reasonable cost, just as an "absolutely" fireproof house generally is not a good investment. The prudent owner builds his house well, eliminating all needless hazards, and then insures against further risk of loss. Insurance on the aqueduct is provided by building in such a manner that, although occasional difficulties may be encountered, widespread destruction or frequent interruption will not occur. To this end the canal is set deeply into the ground; with only minor exceptions, the concrete-lined waterway is entirely within the firm, undisturbed soil. The concrete lining is very substantial, heavily reinforced with steel bars and from 6 to 8 inches thick. No flood could destroy more than a short length of this structure. The worst that could happen, even under extraordinary storm conditions, would be a moderate repair bill and a short interruption in flow. Service during such interruptions may be maintained by pumping from the Hayfield reservoir, which lies beyond the last open canal section; or by drawing on the Cajalco reservoir at the end of the main aqueduct.

The canal section is thoroughly protected against all ordinary hazards. Great care is taken to exclude storm waters from the canal. The open waterway is interrupted at every drainage channel, the flow being carried across the floodway in pressure pipes, safely buried below the ground surface. Long diagonal drains reach far out on the uphill side to gather small rivulets and sheet drainage into the prepared crossing. Every foot of the uphill bank is protected by substantial embankments and parallel drains. With good luck, these defenses may never be breached and in any event they will resist all but the worst onslaughts of Mother Nature. These open canals are perhaps the most secure open canals ever constructed, yet they involve no element of elaborate extravagance.

The foregoing discussion of safety in the open canals illustrates the type of thinking that went into the planning of the entire aqueduct. The location and design of diversion works, pumping stations, power lines, covered conduit, tunnels, pipe lines, and reservoirs, all were scrutinized with equal care for elements of weakness and hazard.

The elements of "safety" and "permanence" are closely related. An unsafe structure is not likely to be a permanent one. The aqueduct is being built for the future as well as for the present, and must stand and give adequate service for an indefinitely long time. Aqueduct bond redemptions are to extend over a period of fifty years and it is essential that the aqueduct last at least that long. Fortunately, most portions of it, with only nominal expenditures for repairs and replacements, will last much longer than that, in fact, indefinitely. The only important features subject to deterioration are the steel pressure pipes in the distribution system and these are being constructed and protected with such care that a trouble-free life of more than 50 years is confidently expected.

Certain machine parts in the pumping plants may wear out and need replacement. These are covered in all estimates by an allowance for depreciation or replacement. These features are to be carefully maintained and will be delivered to posterity in good order when the bonds have been retired.

"Convenience" is a somewhat less exacting requirement. It is important that the system be planned to permit smooth operation, that deliveries be made at convenient points, that lines be laid out to permit convenient connection to potential future areas, and that in all respects the system be eminently workable. In many respects convenience is relative. For example, it would have been convenient to have the terminal of the aqueduct high enough to serve gravity water to all parts of the District area, but in the higher portions of Pasadena, Los Angeles, and other foothill cities, this was impracticable and expensive. Hence, a compromise was required. The outlet ends of the distributing lines from Cajalco were lowered and consequently cheapened, until an economic balance was reached between the cost of feeder lines and the cost of getting water out of these lines and into the distribution systems of various cities. Similar measures of the value of convenience were applied all along the line.

The requirement for economy pervaded every element of the undertaking. The magnitude of the project was such that success required that the benefits sought should be attained at the minimum possible cost. It does not follow that the cheapest possible line, or the cheapest type of construction, was adopted, but every endeavor has been made to meet the requirements of safety, permanence, and convenience, for the least practicable cost.

Influence of geological conditions

Although portions of Southern California are notably seismic, the location of the aqueduct system is generally such as to avoid the likelihood of damage from earth movement. There is no evidence of faulting in recent geological time in the desert area between the intake and a point in Morongo Canyon, north of Palm Springs. Between this point and Whitewater Canyon the line crosses two faults, the Mission Creek and the San Andreas, lying along the northwesterly rim of the Coachella Valley. The San Andreas, which extends from Imperial Valley to San Francisco and cannot be avoided by the aqueduct line, is one of the world's most important active earthquake faults. It was desirable that both of these faults be crossed approximately at right angles with some flexible type of surface conduit, and for this purpose cast-in-place concrete pressure lines with lead-calked steel bell-and-spigot joints every 20 feet were adopted. Movements on these faults in historical time, although sometimes several feet in magnitude, have all been horizontal, but in order to compensate for any possible adverse vertical movement, an allowance of 2.5 feet, in excess of that required for maintenance of flow, is made at both the San Andreas and the Mission Creek crossings.

From the San Andreas fault to the east portal of the San Jacinto tunnel, the line is continuously in alluvium with no evidence of recent faulting. The 13-mile San Jacinto tunnel traverses granitic formations with numerous faults and fractures, but with no evidence of geologically recent movement.

Just west of the west portal of San Jacinto tunnel, the line crosses the active San Jacinto fault, which lies along the foot of the mountain. Here articulated construction is again resorted to and a similar 2.5-foot allowance made. This flexible construction extends some distance westward to allow for a possible movement on subsidiary faults.

The Valverde tunnel and the Cajalco reservoir are in a stable granite block where the faulting is minor and ancient. The main

Mount San Jacinto

distribution feeder, running north from Cajalco and then west along the foothills to Glendale, crosses no serious fault zones. Furthermore, except for tunnels, it is entirely of precast concrete and welded steel pipe, both resistant to slight displacements. Cross feeders from this line which encounter faults in the metropolitan area are of similar construction and safe from damage unless subjected to a direct earth slip of appreciable magnitude. Protection under such a contingency is afforded by sectionalizing valves and reservoirs.

In addition to the attention given to known faults and fault systems in location of the line, a careful geological study was made of the entire area to be traversed by the aqueduct in order to gain as much information as possible concerning underground conditions at all points. The results of this study were of great value, sometimes in confirming decisions as to location based upon other considerations, at other times in presenting evidence of difficulties which could be avoided only by a relocation of the line. For example, any serious possibility of much heavy ground or of appreciable flows of water in the Coachella group of tunnels might have introduced such hazard as to make the Parker route impracticable. Consequently, the geology of this area was minutely studied. Good ground, slightly broken but dry, was predicted. It was expected that support would be required in not over 10 per cent of the length of the group. Actually, the supported length amounted to 67 per cent. However, the supports were generally light and the percentage of really heavy ground was small. Very satisfactory speed records were made, and the work was completed within the original estimate.

On the other hand, in the vicinity of Iron Mountain the first preliminary plan showed a more direct alignment for the aqueduct, with a tunnel through the north end of Granite Mountain. This original location gave an appreciably shorter line, but the portion in tunnel would have been 12 miles long instead of 8 miles, as in the adopted location, and some increase in siphon work would have been required west of the mountain. Also, the original tunnel would have been principally in alluvium and would have encountered seriously broken formations under the mountain proper. Although the adopted line was longer, neither the cost nor the head required for operation was increased, and construction hazards were greatly reduced.

Initial and final conduit capacities

The District's water right is limited to an ultimate average annual diversion of 1500 cubic feet per second. To allow for inevitable interruptions in flow, the capacity of the main aqueduct was set at 1605 cubic feet per second. This allows 7 per cent outage time for inspection, cleaning, and repairs.

The entire capacity will not be needed immediately upon the completion of the aqueduct. Full development is expected to require from 40 to 50 years. Because of this situation, careful consideration was given to the possibility of building the aqueduct in stages. Comparative estimates were prepared for one-third-capacity, one-half-capacity, and two-thirds-capacity flows. For lined canals, covered conduit, and tunnels, the reduction in estimated costs was relatively small as the capacity was decreased. Estimates for half-capacity construction ran from 80 to 85 per cent of full capacity. Such small savings did not justify divided construction.

In order to check the estimates, alternative bids were called for on full-capacity and half-capacity construction on a number of tunnels. The results were as follows:

Tunnel	Low bidder's total bid price: Full capacity	Low bidder's total bid price: Half capacity	Cost half capacity in percentage of full capacity
Bernasconi	$ 412,055.00	$ 354,097.00	85.93
Valverde	3,286,603.00	2,861,180.00	87.06
Iron Mt.	3,843,504.00	3,190,137.50	83.00
Coxcomb	1,529,400.00	1,368,936.60	89.51
Cottonwood	1,857,062.00	1,521,879.00	81.95

On the basis of this information, any idea of reduced capacity for the three principal conduit types was abandoned. For pressure pipes, however, conditions were different. Where the pipes were long or the heads high, practical considerations made it desirable to use double-barrelled construction, even if the full capacity were required at once. Evidently one barrel could readily be deferred. Hence, all important pressure lines are built to half capacity, with end structures provided for a future second barrel.

Pumping equipment must likewise be divided into a number of units which need be installed only as the demand for water grows. Storage and distribution facilities are similarly subject to progressive development.

Special research problems

In every important undertaking, the engineer is faced with questions which cannot be answered from existing data. Such situations call for special research work unless dependence is to be put on "assumptions." Many such problems were faced by the District.

It was required that more than five million yards of concrete be placed in a long thin line across the desert. Both curing and service conditions were severe. It was necessary to determine the reaction of various available cements to conditions and to consider possible improvements. An extensive program of investigation led to the use of a modified portland cement, with very satisfactory results.

Scarcity of water led to a careful study of surface sealing compounds for curing exposed concrete. Many materials accepted as satisfactory under less severe conditions were found inadequate on the desert. However, two coats of a special coal-tar pitch cutback, carefully applied, gave excellent protection. Single-coat applications were found to be inefficient, regardless of materials used.

Solar heat absorbed by the black tar surfaces notably increased the maximum temperature rise of the setting concrete, thus increasing ultimate shrinkage. This was corrected by applying whitewash over the tar. Maximum temperatures were reduced 20° to 30° by this means.

Before issuing specifications, experimental sections of siphon and cut-and-cover conduit were constructed, backfilled, and tested for stresses and deformations. The results led to certain modifications in design and eventually to the large program of record-size precast concrete pipe in the distribution system. A great deal of effort was expended in the development of spun coal-tar and mortar linings for large steel pipes.

The most ambitious and important research program related to pump design. When aqueduct studies were begun, pump efficiency was estimated at about 85 per cent, and it was thought that for the capacities involved (about 200 cubic feet per second for each unit), double-suction horizontal pumps would be required, with double-stage for the higher lifts. One per cent increase in efficiency means a saving of $50,000 per year in the cost of power. Simplification of pump form meant large savings in installation costs. Careful experimental study was evidently justified. A special laboratory was set up at the California Institute of Technology and a thorough investigation undertaken of the District's pumping problem. This work was carried on cooperatively by the District staff and members of the Institute faculty, with valuable assistance from pump manufacturers. The result is a probable efficiency of 92 per cent or better with single-suction, single-stage vertical units for all lifts up to the maximum of 441 feet. The resultant savings in installation and operating expense make the $150,000 cost of the research program seem insignificant.

Aqueduct sections

Because of the great lengths involved in each type, the design of the aqueduct sections was carried to an unusual degree of refinement. In a short aqueduct, an attempt to save a half dollar per foot of construction could be easily offset by the cost of office work in changing and rearranging structural units to achieve this economy. The same saving of a half dollar per foot, when applied to the full length of the Colorado River aqueduct, amounts to more than a half million dollars, enough to have paid salaries of all the design staff in the District for many years. As a consequence, economy of construction together with structural and hydraulic adequacy were stressed throughout the design work of the aqueduct.

The main aqueduct tunnels are concrete-lined grade tunnels of the conventional horseshoe cross section except that the invert curvature is flattened for construction reasons. However, where yielding soil or large external pressures were expected, the radius of curvature of the invert was reduced to 16 feet, and in some cases where excessive loads were expected, steel reinforcement was provided to strengthen the plain concrete sections. In other portions, where economical and structurally advantageous, the necessary strength was secured by thickening the plain concrete lining and consolidating the surrounding rock with cement grout forced under pressure into the cracks and openings in the rock.

The sizes for these tunnels were determined to give the maximum over-all economy of construction and operation for each individual set of governing conditions and then grouped in optimum average sizes to facilitate construction. All tunnels from the Colorado River to San Jacinto, inclusive, are 16 feet in finished diameter. The Bernasconi and Valverde tunnels are 15 feet 3 inches.

All tunnels in the upper feeder of the distribution system are of the pressure type with either reinforced or plain concrete lining. Circular sections 10 feet in diameter were adopted as the best for over-all economy of construction. Where the excavation is in solid rock with adequate depth of cover, the lining is not reinforced, structural strength and water-tightness being secured, as in the grade tunnels of the main aqueduct, from the backing of the rock which is consolidated with cement grout. Where the distance from the tunnel bore to the surface is less than two and one-half times the head of water on the tunnel, steel reinforcement is provided in the lining for full water head. Tunnels in alluvial sand and gravel are reinforced against both internal and external loads.

The concrete canal lining is of substantial thickness and is continuously reinforced in the longitudinal direction with high elastic limit steel in an amount equal to one-half of one per cent of the concrete area. Transverse reinforcement in an amount equal to one-fourth of one per cent of the cross sectional area of the slab is also provided. To reduce the spacing and the size of cracks, the strength of the concrete was specified not to exceed 2,500 pounds per square inch. The canal section was made smaller and set on a steeper grade than the economic studies indicated, in order to secure in the canal a velocity sufficient to insure the transportation of blow sand or light debris to the sand traps and settling basins provided for their removal.

The standard cut-and-cover conduit section is of unreinforced concrete, built in an open trench, and then backfilled. It consists of the upper arch and an invert which sometimes acts as an inverted arch. The arch is proportioned to resist the external loads imposed upon it. Its abutments are flared to provide a sufficient bearing area and to keep the thrust line within the middle third of the section under varying conditions of loading. In cuts through solid rock, flaring of abutments is not necessary and considerable saving in excavation and concrete is effected by the use of a more slender section poured directly against the sides of the trench. For yielding foundations, excessive depths of cover, and locations under highway or railroad, a heavy reinforced section is designed for each specific condition. In the plain normal section, contraction joints are provided at 35-foot intervals along the conduit. Construction joints at the ends of separate pours are plain butt joints made water-tight by a $\frac{3}{16}$ by 8-inch steel water stop painted with coal tar and extending one foot higher than the normal water surface. The conduit section is backfilled with at least 3 feet of depth over the crest of the arch. It is not subject to damage from any reasonably heavy flood flow.

The crossing of drainage channels, ravines, and other depressions along the aqueduct route requires the use of inverted siphons. There are 144 such structures on the main aqueduct ranging from 175 feet to 26,400 feet in length, and from a few feet to a maximum of 153 feet in operating head. These siphons are all constructed of reinforced concrete. The most predominant construction consists of two independent parallel circular barrels, generally used wherever the length exceeds 400 feet or where the operating head exceeds 25 feet. As previously stated, only one barrel of these siphons has been constructed at the present time, leaving the second to be added when required to meet the growing water demand. Where the siphons are short, the advantages of double-barreled construction are outweighed by the additional cost of the more complicated end structures, and a single circular barrel or a rectangular 3-compartment type is used.

Siphons of the latter type are characterized by extremely low heads and are used where it is necessary to provide artificial waterways for cross-drainage in flat country traversed by canal where the storm run-off is of the so-called sheet-drainage type. Drainage ditches running diagonally to the canal intercept the sheet run-off flow and convey it to places of concentration at and over the low-head siphons. These siphons are spaced at intervals determined by the character and the size of the area contributing to the run-off.

The large-diameter pressure pipes in the upper feeder of the distribution system are of either precast reinforced concrete or welded steel plate. Concrete pipe is used for heads under 300 feet, while steel pipe is used predominantly for heads over 250 feet.

Miscellaneous aqueduct structures

Except at the pumping plants, there is little occasion for controlling the flow between the intake and the Cajalco reservoir, and for this reason special structures are not numerous. Wasteway structures, controlled by radial gates and capable of diverting the entire aqueduct flow into natural drainage channels, are provided at intervals. At each pumping plant overflow and siphon spillways or other automatic devices provide means for discharging the flow in the event of an interruption in pump operation.

Although the open lined canal is well protected with drainage ditches and dikes, it is possible that limited surface flows may be intercepted during heavy storms. To prevent the dangerous accumulation of such flows, paved depressions in the canal banks are provided at intervals, somewhat similar to the standard "dips" of secondary western highways. Sand traps and settling basins along the open canal sections will free the water of light debris. Larger sand traps were built at Iron Mountain, Eagle Mountain, and Hayfield pumping plants. Highway and railway crossings are provided for as required.

Hydraulic features

Friction losses in the entire aqueduct were computed on the basis of Manning's formula:

$$v = \frac{1.486}{n} r^{2/3} s^{1/2}$$

where v is the velocity of water in feet per second, n is the coefficient of roughness, r the hydraulic radius of the channel in feet, and s the hydraulic slope. The value selected for the coefficient of roughness n for the various types of construction were:

Structure	Value of n
Concrete-lined canals	.014
Concrete cut-and-cover conduit and tunnel lining, with steel forms	.013
Concrete cast-in-place siphons	.013
Precast concrete pipe poured standing on end	.012
Welded steel pipe, lined with coal-tar enamel	.014
Welded steel pipe, lined with centrifugally spun cement mortar	.012

To the friction losses in pressure pipe were also added losses caused by bends, which were computed thus:

$$h=0.25\frac{v^2}{2g}\sqrt{\frac{\Delta}{90}}$$

in which h is the head lost in a given bend, in feet; Δ is the angle of bend in degrees; v is the velocity in the pipe in feet per second. At changes between grade conduits and pressure pipes, also between various types of grade conduit, transition structures have been designed to allow a smooth change from one shape and velocity to another. Transitions requiring an increase in velocity were allowed a head loss equal to one-tenth the change in velocity head, transitions involving recovery of the velocity head being allowed a loss equal to two-tenths of the change.

Dams

A noteworthy feature of Parker dam is that while the difference between the upstream and downstream water levels is only about 72 feet, its total height, due to the unusual depth of bedrock below the normal river bed, is 320 feet. Five 50 by 50-foot regulating gates provide for the passage of the river normally and during floods. The maximum capacity of the gate openings is in excess of 200,000 cubic feet per second. These gates impose heavy cantilever stresses on the arch sections and require a stout design. In designing the dam, its height was limited not by structural or economic considerations but by the location of the Santa Fe railroad and the City of Needles, California at the head of the reservoir. Construction of this dam by the U. S. Bureau of Reclamation is covered in Chapter 10.

Gene and Copper Basin reservoirs are created by concrete arch dams very slender in section. These dams were designed using a trial-load method of analysis for a maximum stress of 500 pounds per square inch. The analyses allowed for the effect of tangential shear between the adjacent arches, the effect of twist in vertical blocks, and the effect of foundation deformations. To reduce the effect of temperature drop, the concrete in the dams was designed to be cooled to an average of 50° F prior to the grouting of contraction joints, which were spaced 50 feet apart.

Bond issue estimates

In July 1931 the District published a report[1] presenting the chief engineer's estimates for full- and half-capacity construction of the aqueduct, including terminal storage facilities and distribution system. In this report it was proposed to limit to approximately one-half capacity the initial construction on all readily divisible features, such as the pumping plants and siphons, the distribution lines, and the terminal storage reservoir, but to build the tunnels, covered conduit, and lined canal of the main aqueduct and the diversion dam to full capacity. Under this proposal the cost of the complete system, including deferred items not contemplated to be constructed with funds from the first bond issue, was estimated as follows:

INITIAL CONSTRUCTION	
Diversion dam	$ 13,058,000
Main aqueduct	143,470,000
Terminal storage	17,352,000
Delivery lines	44,964,000
Total initial cost	$218,844,000
DEFERRED ITEMS	
Main aqueduct	$ 12,888,000
Terminal storage	13,320,000
Delivery lines	38,484,000
Total deferred cost	$ 64,692,000
Total ultimate construction cost	283,536,000

Accordingly, it was recommended that a $220,000,000 bond issue to cover the estimated cost of this initial construction be submitted to a vote at the earliest practicable moment. Upon this basis the project was presented to the voters of the District at an election held on September 29, 1931, at which time, as stated in the following chapter, the bond issue was authorized by a vote of nearly five to one.

[1]Report 405. A summary of the Metropolitan Water District aqueduct situation. 1931.

CHAPTER 6

Financing

ON THE 29TH DAY of September 1931, the voters of The Metropolitan Water District of Southern California, by a majority of substantially five to one, authorized the issuance of bonds in the amount of $220,000,000, for the purpose of financing the construction of the Colorado River aqueduct. The law requires merely a majority vote. The election was held two years after the financial crash of 1929 and while the extent and duration of the depression may not have been realized in the fall of 1931, its effects had been definitely felt. Nevertheless, the citizens of the District had sufficient confidence in the future of Southern California to support, by an overwhelming majority, the large bond issue required for aqueduct construction. In this connection it should be remembered also that at the date of this election the idea of Federal financing through the Reconstruction Finance Corporation or Public Works Administration had not developed. The bonds were not voted as a means of securing and expending Federal funds.

Pursuant to the provisions of the Metropolitan Water District Act, within ninety days from the date of the election the board of directors of the District caused to be brought in the name of the District an action in the Superior Court of the State of California, in and for the County of Los Angeles, to determine the validity of the bonds authorized by the electors of the District and the sufficiency of the provision in the act for the collection of an annual tax sufficient to pay the interest on the bonded debt and to constitute a sinking fund for the payment of the principal thereof on or before maturity. By published notice, all interested parties were given the opportunity to appear and contest the validity of the bonds and the sufficiency of the tax levy provisions. The action was contested and carried to the Supreme Court of the state, and in June of 1932 that court rendered its decision declaring such bonds to be valid and the provision for the collection of an annual tax for said purposes to be sufficient.

In the meantime the market for municipal securities had fallen off to a point where it appeared that unless some other source of funds could be developed the District's construction program must be delayed.

In January of 1932 the Reconstruction Finance Corporation had been created by the Congress, for the purpose of financing banks, insurance companies, and railroads. During the spring and early summer of that year the general manager and chief engineer of the District and the general counsel devoted themselves to the then pending Emergency Relief and Construction Act of 1932, designed in part to authorize the R.F.C. to make loans to aid in financing self-liquidating public works projects, a power which had not been granted under the original law. The thought was a new one and the natural inertia of the Congress had to be overcome. Even after the basic idea had been accepted, the tendency was to hedge such lending power with restrictions inconsistent with the limitations imposed by state law upon the District's borrowing power. To enable the District to go ahead upon its long-term financing program, it was necessary that such proposals be defeated. Senator Wagner of New York was in charge of the bill, but it was very largely due to the efforts of Senator Hiram Johnson of California that the text of the amendment was so written that, upon the adoption of the act, the R.F.C. was authorized to buy the long-term bonds issued by public corporations engaged in self-liquidating public works projects. The act became effective in July 1932.

Months before the final enactment of this legislation preliminary negotiations for a loan under its terms had been taken up with the Reconstruction Finance Corporation and the members of the District's engineering and legal staff had been untiring in the compilation and presentation of data demonstrating the physical feasibility and financial soundness of its plans. On July 18, 1932, the new act having been passed by the Congress but not yet approved by the President, the District filed an informal application in accordance with its terms for a loan to finance the construction of the project. This was followed by the filing of a formal application on September 2, 1932.

An advisory board of engineers was appointed by the Reconstruction Finance Corporation for the purpose of studying the engineering and economic feasibility of the project in order to make a determination as to whether it satisfied the definition of self-liquidating public works, as described in the act. The attorneys of the corporation went very thoroughly into the corporate structure and legality of the District's organization and its bond issue. The fundamental soundness of the project plans and the thoroughness and completeness with which the supporting data were assembled and presented made an impregnable case for the District, and after weeks of work a favorable report on both engineering and legal phases of the project was rendered. On the 13th day of September, 1932 the Reconstruction Finance Corporation agreed to bid, at an interest rate not to exceed 5 per cent, on bonds offered by the District up to a total of $40,000,000, in such blocks as might from time to time be offered, thus making it the first project of its type to be approved under the corporation's broadened authority. This and subsequent agreements with the Reconstruction Finance Corporation resulted in the issuance of serial 5-per cent bonds maturing in 36 substantially equal annual amounts from 15 to 50 years after the date of such bonds. Effective April 1, 1934, the Reconstruction Finance Corporation announced that the interest rate would be adjusted to a 4 per cent basis for a period of 5 years, or for such portion of that time as the bonds should remain in its possession, and in May, 1938 as given in detail on page 121, the R.F.C. agreed to exchange the 5 per cent bonds for refunding bonds at an average rate of $4\frac{1}{8}$ per cent.

Following the acceptance by the District of the Reconstruction Finance Corporation's agreement to bid on District bonds an attempt was made to enjoin the loan by action in the District Court of the District of Columbia, on the ground that the project did not come within the statutory definition. The action was decided against the objectors, however, and the initial loan was made.

The fact that the District's project had been carefully planned and was ready for financing in the summer of 1932, all of the engineering and legal work having been completed, enabled the District to proceed with its financing program under extremely favorable conditions. Construction costs were much lower by reason of the fact that the program was commenced in 1932. Had the District been compelled to defer its operations until the money market had become stabilized, the cost of the aqueduct would have been far greater. The combination of circumstances and the cooperation of the R.F.C. have worked greatly to the advantage of the taxpaying public of the District and the prospective users of Colorado River water.

Table 7

CONDENSED BALANCE SHEET
As of June 30, 1938

Assets

Preliminary surveys, engineering, etc.			
By City of L. A. prior to May 1, 1930	$ 2,096,221.54		
Interest on City of L. A. cash expenditures	254,991.00		
By District after May 1, 1930	2,367,333.13	$ 4,718,545.67	
Permanent			
Construction costs to date	153,857,692.00		
Advances a/c condemnation suits	1,046,981.58	154,904,673.58	
Total—Construction cost			$159,623,219.25
Interest during construction			
Interest 1925 bonds		1,655,425.67	
Interest on 1931 bonds		15,108,625.67	16,764,051.34
Cash			
On hand and on deposit		5,503,219.89	
Advances to employees		2,000.00	5,505,219.89
Receivables			
P. W. A. grant		100,000.00	
Unpaid tax assessments		684,054.13	
Miscellaneous accounts		7,408.32	791,462.45
TOTAL ASSETS			$182,683,952.93

Liabilities

Bonded indebtedness			
Bonds sold to R. F. C.	$207,000,000.00		
Less amount not yet delivered	58,524,000.00	$148,476,000.00	
Bonds sold to P. W. A.		1,500,000.00	
Total 1931 bonds outstanding		149,976,000.00	
Accounts payable			
Sundry current accounts	943,005.18		
Contractor's holdback	2,030,537.04		
Installments, City of L. A.	2,267,670.00		
Accrued interest, 1931 bonds, not yet due	2,114,988.33	7,356,200.55	
Reserves			
Compensation and other insurance	1,039,160.75		
Faithful performance bonds	160,300.00		
Unapplied interest refunds	125,000.00	1,324,460.75	
Undistributed revenue			
Interest on bank balances	161,435.63		
Interest refunded by R. F. C.	1,039,658.19	1,201,093.82	
Capital investment—member cities			
Tax assessments, interest credits, etc.	22,812,118.05		
Investment, withdrawn cities	14,079.76	22,826,197.81	
TOTAL LIABILITIES			$182,683,952.93

P.W.A. loan for Parker diversion

With the change of administration in March 1933 new legislation for the purpose of stimulating various agencies of recovery was proposed and on June 16, 1933, the National Industrial Recovery Act (48 Stat. chap. 90, p. 210) was approved. This act terminated the authority of the Reconstruction Finance Corporation to lend money to self-liquidating public works projects and transferred such authority to a new agency, the Federal Emergency Administration of Public Works. It also transferred to the latter all applications for public project financing then on file with the Reconstruction Finance Corporation.

In the meantime the District had filed with the Reconstruction Finance Corporation two applications for additional funds, one (a) in the amount of $59,750,000, the difference between its original application and the $40,000,000 commitment of September 13, 1932; the other (b) in the additional amount of $105,810,000, the sum estimated to be sufficient to complete the project when combined with the original commitment and the amount requested under application (a). No action was taken by the Reconstruction Finance Corporation on either of these applications and they thus automatically became applications to the P.W.A. when the new legislation went into effect.

Because of the long-term commitments required and the large amounts involved, it was found that the District's applications did not fit into the P.W.A. program of expenditure. The administrator was, however, willing to make a commitment for a definite feature of the project involving immediate expenditure of funds found available for application to the work.

On this basis, under date of March 22, 1934, a loan and grant agreement in the amount of $2,000,000 was executed by the P.W.A. and the District for the construction of diversion and outlet works for Parker dam, it being specifically provided that the money would be available only for the construction of diversion tunnels, cofferdams, and outlet structures, and for other and incidental purposes. Pursuant to this agreement, the P.W.A. purchased $1,500,000 District bonds maturing at the rate of $50,000 annually from September 1, 1940 to September 1, 1969, inclusive, and bearing interest at the rate of 4 per cent per annum. Payment for the bonds was made on November 2, 1934, and an interim certificate in the denomination of $1,500,000 was delivered to the P.W.A., evidencing payment for the bonds so purchased. It was the original understanding that upon completion of the $2,000,000 project $100,000 in bonds would be returned to the District along with $500,000 in cash as a grant to stimulate construction, but before final settlement the P.W.A. had sold the entire block of bonds to the R.F.C., and upon a showing that the District's actual expenditures on the works in question had been considerably in excess of $2,100,000 the P.W.A. paid the entire $600,000 grant in cash.

A clause in the original R.F.C. loan agreement permitted that organization to reduce the amount of its commitment by whatever amount of bonds might be sold to other agencies and, pursuant to this, on October 16, 1936, the R.F.C. reduced the amount of the District's first application from $40,000,000 to $38,500,000.

Additional loans by R.F.C.

On June 19, 1934, the Congress granted the R.F.C. authority to make further loans to projects which it had previously undertaken to finance in part and also extended the life of the corporation until February 1, 1935, this being the first of a series of similar extensions. While this legislation was being debated a new application to the R.F.C. had been prepared by the District and this was forwarded to Washington under date of June 22, 1934. In response to this application the board of directors of the R.F.C., on September 26, 1934, authorized the purchase of $15,000,000 of additional District bonds, it being considered that this amount, when added to the $40,000,000 previously committed, would carry the project to the end of the fiscal year 1934-1935. Further commitments were made in succeeding years, the final application for $60,000,000, approved in full on May 14, 1937, bringing the total commitment of the R.F.C. up to $207,000,000.

A tabulation of the various loan commitments follows:

Date of application	Amount of commitment	Date of commitment
Sept. 2, 1932	$40,000,000*	Sept. 13, 1932
May 19, 1933	1,500,000	Mar. 22, 1934
June 22, 1934	15,000,000	Sept. 26, 1934
Apr. 5, 1935	36,000,000	June 1, 1935
Apr. 14, 1936	57,500,000	May 8, 1936
Nov. 27, 1936	60,000,000	May 14, 1937

*Subsequently reduced to $38,500,000 as noted above.

Commitments of the R.F.C. prior to September 1935 had not included authority to use funds received from that corporation for the construction of Parker dam, because of the P.W.A. loan and grant which had previously been made to that work. On March 6, 1936, however, the R.F.C. authorized the expenditure of funds received from it for that purpose.

Bond sales

Under each of the several commitments made by the Reconstruction Finance Corporation, except the final $60,000,000 allocation, the bonds were actually offered for sale and purchased by the R.F.C. in smaller blocks. In lieu of definitive bonds interim certificates were delivered to the Reconstruction Finance Corporation, evidencing payment for the bonds purchased. These interim certificates were in amounts ranging from $1,476,000 to $2,791,000, and were delivered at periodic intervals as funds were required by the District. With expenditures of from $2,500,000 to $4,000,000 per month, interim certificates of these denominations have permitted maintaining close coordination between actual expenditures and funds received. The Reconstruction Finance Corporation, in permitting the District to deliver bonds (interim certificates) in installments as funds were required for the construction of the project, obviated the necessity of the District's carrying large sums of idle money, thus materially minimizing interest costs.

The final issue of $60,000,000 five per cent bonds was sold to the Reconstruction Finance Corporation in one block on March 4, 1938 and interim certificates representing said bonds are being delivered to the Corporation from time to time as funds are required by the District.

The accumulated monthly cost of work accomplished and disbursements of funds received from the Reconstruction Finance Corporation up to June 30, 1938, are shown graphically on Fig. 8, as well as the accumulated fund deliveries from the bond sales to that corporation.

Refinancing operations

Prior to June 10, 1938, all outstanding District bonds were represented by interim certificates in the hands of the Reconstruction Finance Corporation and no definitive bonds had yet been delivered. These interim certificates represented $147,000,000 of 5 per cent and $1,500,000 of 4 per cent Colorado River Waterworks bonds. As previously mentioned, beginning with April 1, 1934, the Reconstruction Finance Corporation has refunded to the District amounts representing one per cent interest on the 5 per cent bonds as this interest became due, thus reducing the effective rate to 4 per cent. This reduction, however, has been voluntary on the part of that corporation and in any event was applicable only up to April 1, 1939. The matter of eventually refinancing its bonded debt at a lower rate of interest had been under consideration by the District for some time. After the Reconstruction Finance Corporation had agreed to the final $60,000,000 commitment, it was decided that the opportune time had arrived to negotiate for a

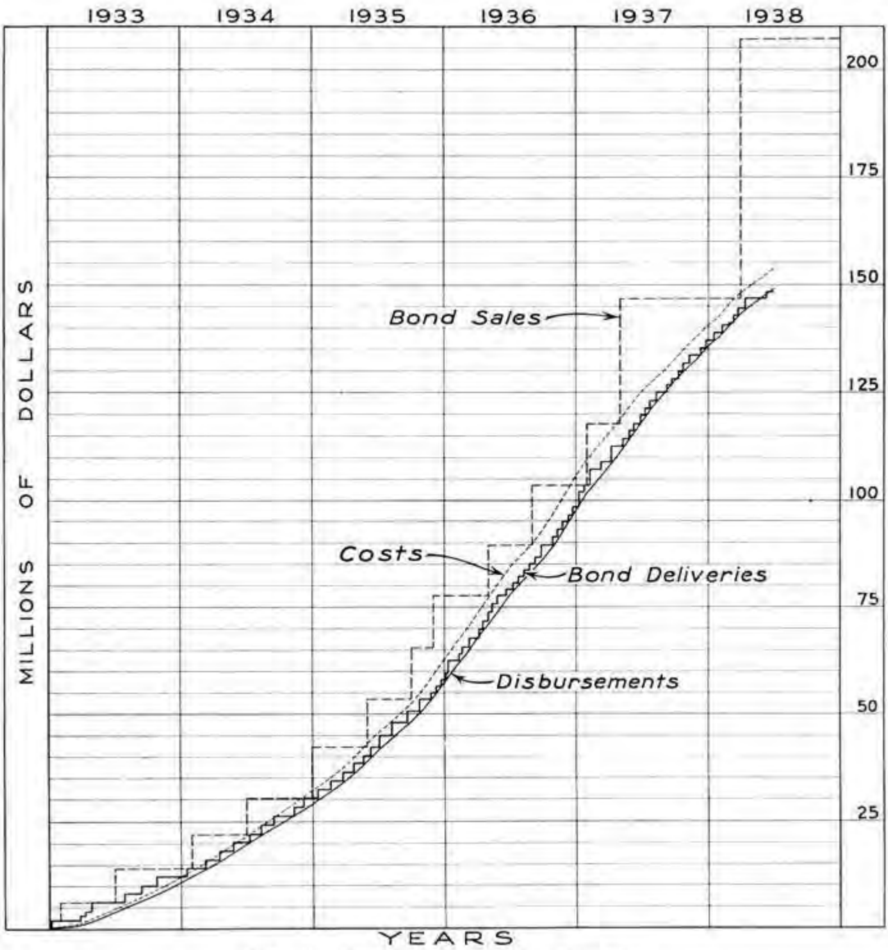


Fig. 8—Bond sales and deliveries

TABLE 8

ANALYSIS OF TOTAL COSTS

Item	Fiscal Year 1937-38		Total to June 30, 1938	
PRELIMINARY ENGINEERING AND ORGANIZATION:				
Prior to May 1, 1930				
Surveys, legal, administration, etc.			$ 2,046,825.92	
Interest on bonds and money advanced for above costs			1,910,416.67	$ 3,957,242.59
After May 1, 1930				
Field investigation expense:				
Dam sites			528.89	
Aqueduct routes			752,593.05	
Reservoir sites			91,111.47	
General water distribution			73,891.50	
Purchase of right of way and land			37,254.04	
Permanent roads			49,646.16	
Subtotal—field expense			$ 1,005,025.11	
General District expense	$ 49,469.04		317,603.41	
General office expense (L.A.)	2,052.42		1,096,358.57	
Subtotal—expense after May 1, 1930	51,521.46		$ 2,418,987.09	
Less cash discounts	8.40	$ 51,513.06	2,258.34	2,416,728.75
Net preliminary expense		$ 51,513.06		$ 6,373,971.34
CONSTRUCTION COSTS:				
Purchase of right of way and land	$ 184,878.08		$ 1,834,909.77	
Construction facilities:				
Roads	6,990.96		903,376.96	
Water	*168.87*		862,028.33	
Power	17,032.82		1,998,026.66	
Telephones	89,905.70		390,357.15	
Operation of facilities:				
Roads	17,135.44		123,921.10	
Water	*15,566.61*		*44,323.00*	
Power	*112,290.04*		*651,148.42*	
Telephones	*10,567.35*		*119,559.30*	
Permanent buildings			67,819.07	
Permanent transmission lines	7,069.77		2,322,402.41	
Permanent pumping plants	7,503,217.97		11,626,501.17	
Parker dam and reservoir	3,471,180.89		6,397,439.69	
Aqueduct construction	9,808,508.05		101,524,742.74	
General water distribution	6,744,474.47		28,653,399.59	
Uncleared administration:				
Engineering	194,889.37		*1,789,047.58*	
Undistributed costs	*93,313.83*		339.93	
Total construction costs	$27,813,376.82		$154,101,186.27	
Less cash discounts, etc.	59,159.71		243,494.27	
Net construction cost		27,754,217.11		153,857,692.00
Total costs		$27,805,730.17		$160,231,663.34

Credit balances are printed in italics.

lower rate of interest on the 5 per cent bonds purchased by the corporation.

In order to reach an understanding, the members of the finance committee of the District's board of directors and the general manager and chief engineer conferred with the chairman of the board of directors of the R.F.C. in Washington on May 2 and 3, 1938. As a result of these conferences, the corporation offered and agreed to exchange the interim certificates held by it, evidencing payment of the purchase price of the five per cent $147,000,000 bonds, for $147,000,000 refunding bonds of the District, $73,556,000 of such refunding bonds to be dated August 1, 1937, and bear interest at the rate of 4 per cent per annum, and $73,444,000 to be dated February 1, 1938, and bear interest at the rate of 4¼ per cent per annum. This offer was accepted and on May 25, 1938, the District's board of directors authorized the issuance of said refunding bonds and the exchange thereof for said original bonds. On June 10, 1938, temporary refunding bonds of the District in the total amount of $147,000,000, dated and bearing interest as above stated, were delivered to the R.F.C. and the corporation delivered to the District the interim certificates evidencing payment for $147,000,000 original bonds of the District. At the time of the exchange an adjustment was made of the accrued interest on the refunding bonds and the interest due to date of exchange on the original bonds, and the interim certificates were duly canceled by the treasurer of the District.

By telegram dated May 19, 1938, the corporation further proposed that it would permit the refunding of $53,000,000 of the aforesaid $60,000,000 bonds on the same basis as that agreed to for the refunding of the $147,000,000 bonds, i.e., substantially one-half of such refunding bonds to bear interest at the rate of 4 per cent and the remainder to bear interest at the rate of 4¼ per cent per annum.

Other financing

In addition to direct financing through the sale of bonds, the District has financed some additional work through the use of tax funds and with credit obtained through the cities of Los Angeles and Pasadena. As has previously been stated, prior to organization of the District a considerable amount of engineering and other work for the project was done by the City of Los Angeles and for this work the District agreed to pay partly in direct cash disbursements from general funds and partly through the assumption of interest and amortization payments on the 1925 Colorado River project bonds of the city when such payments become due. Also prior to the availability of bond funds the District carried on with its own forces extensive engineering and organization work from the proceeds of tax levies, as noted in Chapter 4.

The City of Pasadena in 1932 entered into a contract with the District for the sale of the city's Morris (Pine Canyon) dam, the Morris reservoir to become a major terminal storage reservoir for the District. In payment therefor the District agreed to pay ap-

Table 9

STATEMENT OF TAX ASSESSMENTS AND COLLECTIONS

As of June 30, 1938

Cities	Tax assessments 9 years 1929 - 1938	Adjustment tax assessments[1]	Interest and penalties	Tax refunds	Total collectible	Total collections	Uncollected taxes: Prior years	Uncollected taxes: This fiscal year	Percentage of tax assessment due and uncollected: Prior years	Percentage of tax assessment due and uncollected: This fiscal year
Anaheim	$ 105,083.57	$ 85.28	$ 76.07	*$ 16.46*	$ 105,228.46	$ 102,471.32	$ 1,657.77	$ 1,099.37	2.42	3.01
Beverly Hills	673,480.79	1,988.53	2,206.54	*142.59*	677,533.27	662,731.50	4,661.82	10,139.95	1.03	4.52
Burbank	260,262.64	356.42	1,476.64	*1,217.35*	260,878.35	238,847.50	12,558.76	9,472.09	7.37	10.51
Compton	91,687.08	483.27	499.26	*31.19*	92,638.42	87,969.96	2,614.31	2,054.15	4.14	7.06
Fullerton	162,068.55	92.05	605.72	*10.77*	162,755.55	159,752.75	1,849.25	1,153.55	1.73	2.08
Glendale	706,208.46	7,802.98	87.60	*21.17*	714,077.87	719,080.05	776.42	*5,778.60*	.16	......
Long Beach	1,820,145.80	2,494.98	13,365.57	*2,621.40*	1,833,384.95	1,783,932.33	31,544.76	17,907.86	2.55	3.07
Los Angeles	16,502,652.46	23,952.81	57,716.64	*8,756.48*	16,575,565.43	16,049,780.82	260,391.09	265,393.48	2.31	5.03
Pasadena	1,075,749.22	2,204.79	3,478.87	*129.29*	1,081,303.59	1,056,878.95	13,972.77	10,451.87	1.90	3.05
San Marino	164,254.44	*44.65*	462.37	*7.02*	164,665.14	161,440.99	1,305.77	1,918.38	1.21	3.43
Santa Ana	282,664.68	298.44	272.02	*20.18*	283,214.96	273,341.88	6,008.73	3,864.35	3.23	3.99
Santa Monica	559,783.68	432.45	2,484.41	*150.52*	562,550.02	543,038.28	10,551.84	8,959.94	2.80	4.59
Torrance	235,912.72	.60	1,113.90	*8.67*	237,018.55	227,569.87	5,713.26	3,735.42	3.59	4.85
Subtotal	$22,639,954.09	$40,147.95	$83,845.61	*$13,133.09*	$22,750,814.56	$22,066,836.20	$353,606.55	$330,371.81	2.30	4.54
Withdrawn cities	13,971.94				13,971.94	13,896.17	75.77		.54	
Grand total	$22,653,926.03	$40,147.95	$83,845.61	*$13,133.09*	$22,764,786.50	$22,080,732.37	$353,682.32	$330,371.81	2.29	4.54

[1]Includes $39,854.91 unassessed taxes for all years prior to 1937-38.

Credit balances are printed in italics.

proximately \$1,000,000 in cash and to assume the obligation to pay interest and amortization on \$5,580,000 of San Gabriel project bonds of the City of Pasadena when they became due.

The aggregate of these items which have not required the sale of 1931 Colorado River Waterworks bonds is about \$11,000,000.

CHAPTER 7

Construction Utilities

FROM THE Colorado River westerly to Big Morongo Canyon near the head of the Coachella Valley the aqueduct line for 190 miles is located across a desert terrain, subject to extremes of climatic conditions, and practically devoid of inhabitants. Surface water supplies are nonexistent, and power sources remote. Prior to the period of District activity roads were few and poor, communication facilities rudimentary. Miles to the south, the Southern Pacific railway skirts the Salton Sea on its way to Yuma; east of Mecca the only railroad facilities serving the aqueduct are those afforded by the Phoenix branch of the Santa Fe which crosses the aqueduct line at Freda, some 50 miles west of the river.

The magnitude and diversified character of the work were such that it appeared desirable to divide it for construction purposes into a large number of relatively small schedules, the size of each depending in part upon the length of a feature, as for example a tunnel, or upon its structural unity, as in the case of a dam or pumping plant; and in part upon the financial outlay involved. This policy made it possible to secure competitive bids from many independent contractors, and at the same time by allowing combination bids on any number of related schedules gave full scope to the largest and most adequately financed contracting organizations.

In order to put the bidders more nearly on an equality and avoid wasteful duplication or other uneconomic development of facilities, as well as to make it possible to provide more satisfactorily for the health and comfort of the workmen, a unified program of utility construction and operation was clearly indicated. Among the first contracts to be awarded by the District therefore were those to provide a construction water system, surfaced trunk roads, and power transmission and telephone lines. Use of the District roads is free of toll to all; the other services are supplied to the District contractors under rates and conditions definitely set forth in each case in the construction specifications.

CONSTRUCTION WATER SYSTEM

Prior to beginning construction work, no sources of construction water supply had been developed between the Colorado River and the Coachella Valley. Further west two developed sources were available, the Green well near Long Canyon and springs in the Morongo Valley, both of which sources were subsequently leased by the District. West of Big Morongo Canyon it was practicable to require contractors to purchase water from existing systems or develop their own supplies; eastward a District system was constructed to serve all schedules between that point and the river.

The drilling of water wells was begun by District forces in 1932 and continued until 1935. In some cases 6½-inch test holes were drilled which were reamed out to set and perforate 16-inch casing if potable water in sufficient quantity was developed. In general, however, wells were drilled initially to set 16-inch casing. One shallow dug well was put down in Big Morongo Canyon, later being replaced by a second dug well.

Well pumps are all of the deep-well turbine type, electric motor driven. They vary in capacity from 100 to 750 gallons per minute, with the exception of the small Parker substation pump, and operate under heads up to 530 feet. Each well pump, except at Green well, discharges into a nearby steel tank of 65,000-gallon capacity which is equipped with a float valve for automatic operation of the pump. At Green well the tank capacity is 21,500 gallons. All equipment was installed by District forces.

The main lines consist of continuously welded "gas line" steel pipe in diameters of 5, 6, and 8 inches. The pipe is laid in trench with a minimum cover of 18 inches, except in crossing rocky areas where it is anchored to the rock without cover, and painted with aluminum paint. Expansion joints were not used. In general the pipe lines are located as near as practicable to the aqueduct, in many places on or immediately adjacent to the right of way, with valves installed every four to five miles for convenience in operation and maintenance. Service outlets were set opposite each tunnel working point and at intervals of about two miles opposite canal and conduit schedules. Drain outlets were placed in low spots and air relief valves on all major summits.

The main lines were constructed under three contracts with separate specifications: (1) Big Morongo Canyon to Berdoo Canyon and Fargo Canyon to Yellow Canyon, 33 miles; (2) Yellow Canyon to West Iron Mountain and East Iron Mountain to Sand Draw, 85 miles; (3) Sand Draw to Earp, and Eureka Wash to Copper Basin, 60 miles. These three contracts covered four separate operating sections of the system, as determined by topographic conditions and limitations of the sources of supply. The western section extends from Big Morongo to Berdoo, ending at the latter point to avoid the dip almost to sea level between Berdoo and Fargo can-

Fig. 9—Construction water system

yons. The central section from Fargo to the west portal of Iron Mountain tunnel was carried across the Coxcomb Mountains, through a saddle, because no satisfactory water supply was found between the Coxcomb and Iron mountains. The eastern section extends from the east portal of Iron Mountain tunnel to Earp, and the river section from Eureka Wash to Copper Basin.

The booster stations are designed as transmission boosters and provide delivery pressure only incidentally. Most of the stations are equipped with duplicate pumping units to provide for emergencies. The pumps handle from 55 to 300 gallons per minute under heads varying from 200 to about 900 feet. They are electrically-driven multistage centrifugal units, automatically controlled. An electric timing device closes the motor circuit and starts the pump at predetermined intervals, which can be adjusted to suit conditions. Pumping continues until the filling of the tank closes a float valve at the discharge end of the line and stops the flow of water. When this occurs the electric contacts on the recording flow meter in the pump house operate to open the motor circuit and shut down the pump. If the pump normally in service fails to start, due to motor failure, the control automatically starts the spare pump.

Main line storage is provided by four steel tanks and six reservoirs, each of 300,000-gallon capacity. The tanks are 42 feet in diameter and 29 feet high. The reservoirs are embankment type, gunite lined, of circular shape with top and bottom diameters of 88 and 40 feet, respectively, and 15 feet deep. Their roof framing and sheathing are of redwood. The reservoirs and tanks in some cases float on the line; others act as storage between well pumps and main-line booster pumps. Auxiliary storage is obtained in the well tanks and the booster station tanks, consisting of two 100,000-gallon, thirteen 65,000-gallon, and two 21,500-gallon tanks.

Construction period

The first demand for water was in the Coachella division where camps to start tunnel driving had been established at Fargo and Thousand Palms canyons in January 1933, followed immediately by the opening of four more Coachella camps. By the end of 1933 eighteen tunnel camps altogether were in operation in the desert section, and the headquarters camps of Division 1 and Division 3 had been established.

In the early period of operation temporary gasoline-driven deep-well and booster pumps were used. As electric energy became available these were changed over to electric power drive automatically controlled. In this way water was made available along the various sections of the system on the following dates:

Big Morongo to Berdoo Camp	April 8, 1933
Buried Mountain to Fargo Camp	April 22, 1933
Buried Mountain to West Iron Mountain	June 30, 1933
Sand Draw to East Iron Mountain	July 3, 1933
Sand Draw to Earp	Aug. 25, 1933
Eureka Wash to Copper Basin	Sept. 29, 1933

The demand increased gradually, but completion of virtually the entire main system during the first year was necessary to supply the widely-scattered tunnel and division headquarters camps and transmission line substations. The permanent installation, including all pipe lines, reservoirs, tanks, deep-well pumps, booster pumps, pump houses, and automatic-control apparatus was in operation by December 25, 1933.

Water service

District service extends only to the main-line outlet at which the user makes connection with the system. From this point all storage tanks, pipe lines, and pumps, if required, are installed by the user.

Water is delivered under sufficient pressure to fill a receiving tank. Each outlet is provided with strainer, water meter, by-pass, throttling cock, and a pressure-reducing regulator if necessary. The District reserves the right to limit the delivery at any one outlet to 50 gallons per minute and the operation of pumps to not more than 16 hours per day. Consequently, it is necessary for the user to install sufficient storage to carry over the eight-hour period during which the pumps normally are not operating.

In addition to purely domestic needs in camps, and construction requirements in the mixing, placing, and curing of concrete, large quantities of water were used for incidental purposes. In the shops cooling water was necessary in air compression, in sharpening and tempering of drill steel, and in the recharging of storage batteries. In tunnels, in order to prevent the formation of dust during drilling, water was supplied to the bottom of the hole through hollow drill steel, and during the mucking operation the rock broken by the explosives in blasting was frequently sprayed. Testing of the completed aqueduct sections, particularly the siphons, required large quantities of water.

In the tunnels served by the system the total consumption for camps, shops, excavation, and concrete varied from 123 to 332 cubic feet per linear foot of completed tunnel and averaged 230. On the open work approximate quantities for similar uses were 100 cubic feet per linear foot for cut-and-cover conduit; 50 for canals; and 36 for siphons. All these quantities are exclusive of water used for testing. All water produced by the system has been used for aqueduct purposes with the exception of a small supply delivered to the California State Highway Department.

Metered deliveries by calendar years are given in Table 10. Deliveries up to the end of 1934 were mainly for use in tunneling operations. In 1935 construction was extended to canal and conduit schedules. During the years 1935 and 1936 work was actively in progress at almost all points from the Colorado River to the end of the system at Big Morongo. This activity continued into the early part of 1937 though many features were completed before the end of 1936. About 15 per cent of the water delivered in 1936-37 was for testing purposes.

The quantities listed in Table 10 are those metered for delivery but not necessarily consumed at once. In periods of slack demand water was stored in available completed portions of the aqueduct

TABLE 10

CONSTRUCTION WATER SYSTEM

Costs to June 30, 1938

CALENDAR YEAR	CON-STRUCTION COST	OPERATION AND MAINTE-NANCE COST	WATER SALES, CUBIC FEET	CREDITS	ACCUMULATED NET COST
1933	$646,263.93	$ 27,008.25	5,845,933	$ 8,766.86	$664,505.32
1934	176,782.15	48,087.26	22,566,708	34,034.44	855,340.29
1935	28,320.06	63,416.77	39,415,784	74,859.02	872,218.10
1936	12,242.93	84,695.05	59,797,801	118,477.50	850,678.58
1937	....	68,242.04	49,733,073	99,205.95	819,714.67
To June 30, 1938	....	20,477.74	9,254,147	22,487.08	817,705.33
Total	$863,609.07	$311,927.11	186,613,446	$357,830.85	$817,705.33

Water sales quantities are from the water delivery records of the hydrographic division. Revenue and operation and maintenance costs from cost division.

in order more amply to care for later periods of active demand, which might otherwise have temporarily overtaxed the part of the system involved. Water used for testing was reused when possible for further testing. In addition to the metered supply a small quantity of water has been used by the maintenance crew for flushing pipe lines and tanks.

The average monthly delivery from the beginning of operation of the system up to June 30, 1938, has been 3,034,300 cubic feet, or 22,697,000 gallons. The maximum monthly delivery of 6,234,800 cubic feet, or 46,636,000 gallons, occurred in July 1936. The average monthly delivery during 1936, the maximum year, was 4,983,-150 cubic feet, or 37,274,000 gallons.

Each consumer is billed for water metered into his line at the rate stated in his specifications. For tunnel construction the charge was 15 cents per 100 cubic feet, and for canal, conduit, siphon, and other construction 30 cents. The District supplies to the contractors without charge all water used for testing purposes. The average revenue per 100 cubic feet of water sales to June 30, 1938 is $0.191.

Treatment of water

The water as delivered has carried from 345 to 1,095 parts per million of dissolved solids and from 17 to 472 parts per million of hardness, except the standby wells at Earp and Eureka Wash, which carry somewhat greater amounts. When the wells were developed chemical analyses of the water indicated a satisfactory quality for all purposes without necessity of softening or other treatment. However, after three months of use "red water" became a considerable problem. This trouble eventually appeared in all parts of the system except that portion supplied from the Buried Mountain wells. Investigation disclosed the cause to be one or more of the following:

(a) Excess free carbon dioxide;
(b) Crenothrix, an iron bacterium;
(c) Sulphate-reducing bacteria;
(d) Excess iron in the natural well waters.

In order to overcome this difficulty aerators were constructed at the Big and Little Morongo wells to remove free carbon dioxide, and at Big Morongo a chlorinator was installed as a precautionary measure to treat the surface flow from Morongo Valley. No treatment has been necessary at the Buried Mountain wells. At the Pinto well an aerator, a chlorinator, and a dry-lime feeder were required to eliminate the excess iron and the sulphate-reducing bacteria. At the Vidal Wash, Earp, and Eureka Wash wells the treatment consists of chlorination and the addition of dry lime to correct acidity. The water-treating equipment has operated very satisfactorily.

Operation and maintenance

The entire system is periodically inspected by a supervisor with a crew of from three to five patrolmen, who check the operation of equipment, oil the motors, pumps, and bearings, attend to the flow meters, read water meters, clean and chlorinate reservoirs, tanks, and pipe lines when necessary, and make adjustments or repairs as required. In addition, an inspector from the office of the hydrographic engineer in Los Angeles takes bacteriological samples twice monthly and samples for chemical analysis occasionally. Samples are taken from every source of supply and from the faucets of all camp kitchens in operation on the system.

The construction water system has proven of sufficient capacity and has presented no major operation and maintenance difficulties.

The cost of construction, cost of operation and maintenance, and net cost after credits from water sales are given in Table 10. The figure given for cost to June 30, 1938, is the actual net cost without depreciation and interest.

CONSTRUCTION POWER SYSTEM

Early in 1932, in order to have a basis for negotiations on power rates and for design of the transmission system, estimates were made of the power requirements for the construction program then under consideration. A maximum connected load of 31,000 horsepower was indicated by these studies and, assuming a 5½-year demand period, the energy required was estimated at 235,000,000 kw-hr with a possible maximum of 270,000,000 kw-hr. The various alternatives considered as sources of power supply for aqueduct construction included the following: (1) Existing utilities, with delivery to District transmission lines at one or several points; (2) a District steam-electric plant on the Pacific Coast with a transmission system to and along the aqueduct; (3) a Diesel-electric plant near Colton with transmission system along the aqueduct; (4) six Diesel-electric plants, located at approximately equal distances along the aqueduct; (5) Diesel-electric units and direct Diesel drive, where possible, at each load center.

Using published rates as a basis, without any allowance for the possibility of special municipal rates, power purchased from existing utilities was found to be lowest in cost delivered at the load points followed by the other methods in the order listed in the preceding paragraph. Furthermore, purchased power could be delivered immediately upon completion of the transmission system, whereas to acquire equipment and build a steam-electric plant would have required upwards of 18 months, and to deliver and install large Diesel units from 6 to 12 months. A very important advantage of a purchased power supply lay in the fact that such a power supply could be instantly increased up to the limit of the transformer capacity and, in the event further expansion should be necessary, additional transformers could be obtained in less time than would be required for the purchase and installation of additional Diesel or steam units.

On June 4, 1932 a notice was issued inviting bids for supplying electric power for the construction of the aqueduct, under three alternative items providing for delivery at one or several points in the vicinity of or along the aqueduct route. A joint bid from the Southern California Edison Company, Ltd., Southern Sierras Power Company, and Los Angeles Gas and Electric Corporation was made under one item only of the notice, namely, for delivery at Colton of 23,000 kilowatts (30,800 horsepower) at 66,000 volts, and an additional 4,000 kw upon request of the District made at any time during the life of the contract. The rate bid was $1,500 per month for 66 months after beginning power delivery, plus 95 cents per month per kilowatt of maximum demand, plus 5 mills per kilowatt hour, with a minimum charge of $3,000 per month.

An additional charge was included if fuel oil cost should exceed 75 cents per barrel at the Edison Long Beach steam plant and a credit, up to 10 per cent of the monthly bill, was allowed for high power factor. This bid was accepted by the District and an agreement entered into on July 20, 1932 with the three power companies. The actual cost to date of the power purchased under this contract is 6.25 mills per kw-hr at the Colton substation, and the average delivered cost is 6.78 mills.

Transmission system

The transmission system was designed and built by the District to supply a maximum distributed load of 18,000 kw (24,000 horsepower) but the design was such that the system could be readily reinforced to carry a reasonable excess above this amount. The short period of use indicated the advisability of cheap construction, yet reliability was exceedingly important. A careful study was made to determine the most economic transmission line voltage, giving due consideration to the question of steady-state stability in view of the fact that a large block of power must be transmitted to Parker dam, a distance of 300 miles from the generating plants on the Pacific Coast. As a result of the calculations, transmission at 66,000 volts, the voltage at which power could be received from the Colton substation, was found to be feasible and economical, especially since it did not require the installation of a transformer bank at Colton. Selection of this transmission voltage permitted a flexible design, since one transmission line with two or three 5,000-kva synchronous condensers would be sufficient up to about two-thirds the estimated maximum load of 31,000 hp and other transmission lines and condensers could be added according to the load development.

The principal features of the system are shown in Fig 10. The original 66-kv line extends from Colton via the Lakeview, Cabazon, Fan Hill, and Hayfield substations past the south end of the Coxcomb and over the Granite mountains to the Granite substation, where the 66-kv line ends about 70 miles from the aqueduct intake. An independent 66-kv line was later built on a direct line from Colton through San Timoteo Canyon to the Cabazon substation, making two distinct 66-kv circuits between these points. At the five substations the voltage is reduced to 33-kv to serve the power distribution system, which runs substantially parallel to the 66-kv transmission system as far as the Granite substation. Thence a single 33-kv line extends to the Colorado River, constituting the only source of power supply along this portion of the aqueduct. The 33-kv line west of the Granite substation is normally sectionalized between substations so that it operates on the radial feeder principle. However, during outages of any section of the 66-kv line it is possible to make an emergency by-pass by tying together the 33-kv distribution feeder lines.

Fig. 10—Construction power system

On June 17, 1937 a duplicate power circuit was established from Iron Mountain to Camino station and thence to the Colorado River through the District's newly constructed Boulder transmission line, which had not yet been energized from the Boulder Canyon plant. At this time the Reclamation Bureau contractor, nearing completion of excavation for Parker dam, was encountering a large inflow of water through the river gravels. A power outage of any considerable duration during this period on the single 33-kv line from the Granite substation might have had extremely serious consequences and this use of the Boulder line added greatly to the safety of his operations.

In the construction of the transmission lines butt-treated cedar and full-treated fir poles were used. The 66-kv lines are of H-frame and wooden wishbone construction, the design being varied to meet the different topographic conditions encountered. The H-frame type predominates. Suspension-type insulators are used, carrying No. 4/0 copper conductor. The total length of 66-kv line is 196 miles. In the 33-kv lines single pole, flat construction is typical, but use is made of the H-frame when necessary and joint construction with 66-kv lines where permissible. The 33-kv distribution line is constructed with No. 2/0 copper conductor on pin-type insulators. The 33-kv tap lines carrying current from the 33-kv distribution lines to the 33/2.4-kv substation of each power user are generally of single pole, flat construction with No. 2 copper conductor on pin-type insulators. The total length of 33-kv line is 280.5 miles, consisting of 226.8 miles using No. 2/0 conductor and 53.7 miles using No. 2.

The original transmission lines listed in the preceding paragraph were constructed in 1933 and were all built by contract, the District supplying poles, insulators, and conductor, and the contractors supplying all other material and the necessary equipment and labor to complete the work. Subsequently, 16 miles of 33-kv tap lines required to supply power to tunnel, canal, conduit, siphon, dam, and pumping plant schedules were built by District forces.

Transformer banks of 6,000-kva capacity at Lakeview, Cabazon, Fan Hill, Hayfield, and Granite substations tie the 66-kv and 33-kv systems together. At the 6,000-kva Parker substation the voltage is stepped down from 33 kv to 11.5 kv to operate a 5,000-kva synchronous condenser. To supply power for tunnel, canal, conduit, and siphon operations, aggregate plants, District headquarters camps, wells and boosters, Parker dam, and pumping plant construction, substations ranging in capacity from 20 kva to 2,000 kva deliver power from the 33-kv lines at 2.4 kv.

Synchronous condensers of 5,000-kva capacity were installed in the Lakeview, Fan Hill, and Parker substations to assist in the maintenance of a high-voltage level throughout the system. Tap-changing autotransformers were installed in Fan Hill, Hayfield, and Granite substations as auxiliaries to the regular transformer banks. These make it possible to control voltage conditions on the local distribution systems independently of the operation of the synchronous condensers, which consequently can be operated in a manner best suited to the needs of the power system as a whole.

The lines east of Cabazon are protected by instantaneous overcurrent relays set to operate on faults occurring in 80 per cent of each section. They are supplemented by a conventional installation of inverse-time overcurrent relays. By the use of the instantaneous relays, clearances have been obtained as quickly as 9 cycles, which minimizes the tendency for synchronous equipment to drop off the line on a voltage dip. In the loop between Colton and Cabazon phase directional relays are used, and also ground directional relays receiving their potential from capacity taps in the switch bushings.

Construction period

The original power system from Colton to the Colorado River was built as rapidly as possible, under five contracts in order to supply power to the District water system for pumping and to the District and its contractors for camps and for tunnel-driving operations. Work was started December 27, 1932 and practically completed to the Colorado River on October 8, 1933. During that period 442 miles of circuit were constructed, or about 1½ miles per day. A sixth contract for the construction of the San Timoteo Canyon line, 34.8 miles in length, between Colton and Cabazon, was awarded in August 1933 and construction was completed January 5, 1934.

In doing this work more than 400 carloads of material were transported from the railheads to the point of use. Contractors overcame great difficulties in moving equipment and materials across desert blow-sand areas and over several mountain crossings where roads were extremely poor or entirely lacking. Much of the hauling and construction work was done in the summer with desert temperatures ranging up to 127°. In the Coxcomb area during the entire month of July 1933 daily temperatures above 110° with a maximum of 127° made it necessary to carry on the work in the early hours of the day only.

Operators' cottages

Because of their remote location, it was necessary to erect quarters for the operators of the main line substations and to provide water supply and other conveniences. This work was done under two housing contracts. The first, for cottages and garages at Lakeview, Cabazon, and Fan Hill, was awarded March 24, 1933 and completed May 20, 1933. The second, for similar buildings at Hayfield, Granite, and Parker, was awarded August 18, 1933 and completed November 4, 1933.

Power rates

Energy is furnished to the consumer in the form of 3-phase, 50-cycle current at approximately 2,400 volts, and is delivered at the terminals of oil switches maintained by the District and located at points convenient to the work. Power so furnished must be used on aqueduct construction only, the consumer providing his own distributing system and being required to cooperate with the

District in maintaining the highest practicable power factor and minimum peak demand.

Energy is sold at the rate of one cent per kw-hr, provided the average power factor of the consumer's load is 95 per cent or higher. If the average power factor falls below 95 per cent, .04 of a mill per kw-hr is added to the rate for each one per cent by which the average power factor falls below 95 per cent. This penalty for low power factor has been sufficient to induce nearly all users to install synchronous motors and other equipment of high power factor. The average delivered cost to consumer has been about 1.03 cents per kw-hr.

In supplying electric power for aqueduct construction the District agrees to furnish each consumer the amount necessary for the efficient and economical prosecution of his work, and to exercise reasonable diligence in maintaining a continuous supply. The user is required, whenever practicable, to make use of such power to the exclusion of any other source of electrical energy, except for standby purposes, and to provide at his own expense any standby power which he deems necessary.

Operation and maintenance

The construction power system has a very creditable operating record. Accidental interruptions have affected only small portions of the system and there have been only five general shutdowns with an accumulated duration of 23 minutes due to failure of the power supply at Colton.

The three synchronous condensers located at District substations have been operated as required to reduce the monthly power bills to a minimum. The power factor of the entire District load has been such that the maximum power factor discount of 10 per cent has been applied to all monthly bills. In addition, excellent voltage regulation has resulted from the high power factor of the contractors' loads.

Up to June 30, 1938 the total power purchased by the District amounted to 335,271,267 kw-hrs. Power sales for the same period were 309,094,313 kw-hrs. The difference indicates the average line loss of approximately 7.8 per cent. The maximum monthly consumption of 8,890,000 kw-hrs occurred in January 1936. The peak load on the system was 14,592 kilowatts in April 1937.

The personnel required to operate and maintain the power system, make service extensions and connections, and dismantle and remove unused lines consisted, under active construction conditions, of a superintendent, 6 to 7 substation operators, 2 to 3 electricians, 5 linemen, and part time of five patrol crews with truck drivers, helpers, and clerks, making an average force of 24 men.

The cost of construction, cost of operation and maintenance including power purchased, credits from power sales, and net cost to June 30, 1938 are given in Table 11. The net cost to June 30, 1938 is the actual cost without depreciation and interest.

CONSTRUCTION TELEPHONE SYSTEM

Preliminary studies covering various plans for serving the communication requirements along the aqueduct indicated the desirability of utilizing the telephone initially during the period of construction and later for the operation of the completed project in preference to any other of the standard methods of communication.

Because of the desert and rural types of territory traversed by the aqueduct there were no public exchange telephone systems in the area suitable for serving the work. It was found that a substantial saving could be made if telephone service were rendered over facilities installed and maintained by the District as compared with costs for equivalent services offered by the telephone companies over facilities extended into the area by them.

TABLE 11

CONSTRUCTION POWER SYSTEM

Costs to June 30, 1938

Calendar Year	Construction Cost	Operation and Maintenance Cost[1]	Power Purchased, kw-hr	Power Sales	Accumulated Net Cost
1933	$1,734,014.10	$ 121,200.35	10,209,780	$ *90,206.00*	$1,765,008.45
1934	85,330.17	394,063.98	50,162,630	*512,152.74*	
		17,610.72[3]			1,749,860.58
1935	121,070.32	571,438.19	81,010,560	*771,259.10*	
		227.76[3]			1,670,882.23
1936	50,980.22	592,517.84	82,521,752	*772,142.26*	
	19,609.37[2]	*2,129.69*[3]			1,520,498.97
1937	23,794.67	583,974.16	77,730,065	*709,381.41*	
	574.71[2]	*3,510.75*[3]			1,414,800.93
To June 30, 1938	7,333.06	256,496.96	33,636,480	*321,498.96*	
	4,311.80[2]	*5,941.95*[3]			1,346,878.24
Totals	$2,022,522.54	2,519,691.48	335,271,267	*3,176,640.47*	
	24,495.88[2]	5,800.57[3]			1,346,878.24

[1]Includes cost of purchased power.

[2]Net salvage of lines and equipment removed.

[3]Cost of operation and maintenance equipment less amount of depreciation applied during the year.

Credit balances are printed in italics.

There were already in existence pole lines paralleling the route of the aqueduct from Desert Center to Beaumont which could economically be utilized to support conductors of the District's telephone system. Arrangements were made with the owners of these various lines for joint use of the poles by the District. In some instances an easement was obtained from the owners; in other cases pin space was arranged for on a contact rental basis. Between the field headquarters building in Banning and the general office building in Los Angeles it was found more economical to lease channels from the telephone company than to install District facilities.

Construction period

The first notice to proceed with the construction of the system was given December 21, 1932 for a trunk line with three metallic circuits from Beaumont to the west portal of Bernasconi tunnel and for several tap lines. In March and April, 1933, agreements were made with the Southern California Telephone Company for (1) purchase of a trunk line consisting of five metallic circuits between Banning and Whitewater; (2) purchase of a one-sixth life easement in a company trunk line with five metallic circuits from Whitewater to Desert Center; and (3) construction by the company for the District of tap lines into the camps then open in the Coachella division.

On March 18, 1933, upon completion of the field headquarters building, the Banning switchboard was placed in service. Toll and exchange connections were made over trunk lines of the Southwestern Home Telephone Company until April 26th of the same year, when leased wires to Los Angeles went into use. Early in April an agreement with the Western Union Telegraph Company provided for constructing by its line crew and on its poles between Beaumont and Banning three metallic circuits to connect previously constructed District trunk lines. In June the trunk line circuits to the west portal of Bernasconi tunnel were extended to a point in the Cajalco reservoir area near the west portal of Valverde tunnel, with tap lines to the tunnel camps.

In July 1933 construction was authorized of the remaining trunk lines of the system extending easterly from Desert Center to the Colorado River, with necessary taps to all aqueduct camps not yet served and to the railroad office at Earp. These lines consisted of five metallic circuits between Desert Center and Division No. 3 camp at Eagle Mountain, four circuits thence to East Coxcomb, and three from that point to the Colorado River. The completion of this contract in November 1933 marked virtual completion of the trunk and tap lines of the District's construction telephone system. Later additions consisted of the extension of two circuits westerly from Valverde to Cajalco dam in July 1935, and tap lines to aqueduct camps as new construction was begun.

In July 1933 a switchboard was installed at Berdoo camp, Division 4 headquarters, with direct trunks between it and Banning. The same type of installation was completed in September 1933 to Division 3 headquarters; in January 1934 to Division 1; and in January 1936 to Division 2. The switchboard at Division 3 handled all traffic east of that point until April 4, 1935, when an operator became necessary at Division 1. The operation of the switchboard at Division 2 was begun January 22, 1936. Thereafter service was available throughout the system from 8 to 24 hours daily, depending upon the traffic.

On September 13, 1935 a contract was awarded for construction of telephone lines between Boulder dam and the aqueduct pumping plants. Upon completion of these lines in May 1936 connections were made to the existing District system, extending its service area to every working point on the project. The construction and costs of this line are detailed in connection with the Boulder transmission line.

The following tabulation shows, as of June 30 of each year, the telephone facilities installed and operating as part of the construction communication system:

Item	1934	1935	1936	1937	1938
Switchboards in operation	3	3	5	5	3
Number of instruments—M. W. D.	183	226	237	209	173
Number of instruments—contractors	27	48	57	16	11
Total miles of metallic circuits in operation	1,055	1,060	1,273	1,265	1,206
Miles of M. W. D. pole line in operation	262.5	310.4	450.7	453.2	441
Miles of pole line utilized jointly with others	87.8	87.8	87.8	87.8	81

Type of construction

The trunk lines which are to continue in service after aqueduct construction has been completed have been built according to best modern practice, using full-length-treated southern pine or butt-treated cedar poles and hard-drawn copper wire. Protective devices installed on the system have been generally satisfactory and no cases of acoustic shock or damage to property have occurred.

The system now in use consists of two circuits leased from the Southern California Telephone Company between exchanges in the Los Angeles head office and the Banning field headquarters, trunk lines on District poles and on poles of the Western Union Telegraph Company and the Southern California Telephone Company, necessary switchboards at division headquarters and single-circuit tap lines on both telephone and power poles of the District. The District's system is connected with public toll systems so that communication can be established between any station on the District lines and stations on any public line. The Banning switchboard is the wire center from which circuits radiate to all points along the aqueduct. It is also the point of interconnection between the District system, the toll facilities of the Bell system, and the leased wires to the Los Angeles office.

Operation and maintenance

The District installs and maintains telephones as required for the use of the contractors and the District construction forces, such use being limited to official business, with personal messages transmitted in case of emergency. For each call between stations connected with the same exchange the District toll is ten cents, and fifty cents if the call is transmitted through more than one exchange, the time allowed being three minutes or less with a like charge for each additional three minutes or less. Tolls for service over connecting systems are added to the District charges.

The personnel necessary to operate and maintain the system consists of a supervisor, electricians, switchboard operators, and part time of five patrol crews who maintain the power and telephone systems jointly. No major troubles have been experienced in operating the system and satisfactory transmission has obtained on intra- and inter-system communications.

Ticketing and timing by the operators of all messages transmitted over the system for which a charge is made were started in

August 1933. The tabulation following shows the number of pay calls handled during each fiscal year since ticketing was started:

	1934	1935	1936	1937	1938
Calls charged to M. W. D. forces	65,614	140,624	145,381	160,869	134,800
Calls charged to contractors	11,567	32,605	42,169	35,507	11,950
Total	77,181	173,229	187,550	196,376	146,750

The cost of construction and of operation and maintenance, and the credits of the system by calendar years, are given in Table 12. The operation cost includes all rental and toll charges. The net cost to June 30, 1938 is the actual cost without depreciation and interest.

CONSTRUCTION ROAD SYSTEM

In 1932 the only state highway that could serve any of the construction camps to be built on the aqueduct east of Whitewater was made up of that part of U. S. 99 between San Gorgonio Pass and Coachella, together with its branch from Coachella to Blythe, designated as U. S. 60, or the Sunkist Trail. This route was paved west of Mecca and east of Desert Center and had a graded, graveled surface between these points. Through Coachella Valley this highway is several miles south of the aqueduct and hundreds of feet lower in elevation; at Shaver Canyon it approaches the aqueduct, then leaves it entirely beyond Desert Center. At the eastern end

TABLE 12
CONSTRUCTION TELEPHONE SYSTEM
Costs to June 30, 1938

Calendar Year	Construction Cost	Operation and Maintenance Cost*	Credits	Accumulated Net Cost
1933	$259,623.28	$ 14,411.97	$ 13,731.95	$260,303.30
1934	31,761.53	43,230.67	66,634.10	268,661.40
1935	7,684.36	51,492.35	88,890.62	238,947.49
1936	799.50	65,571.28	101,184.28	204,133.99
1937	461.61	66,440.84	88,670.20	182,366.24
To June 30, 1938	347.02	32,552.74	32,060.59	183,205.41
Total	300,677.30	273,699.85	391,171.74	183,205.41

*Includes all rental and toll charges.

of the aqueduct an unimproved county road paralleled the A.T. & S.F. Railway between Freda and Earp, but east of Grommet it was at a considerable distance from the aqueduct line. From Earp to Parker dam site the river road had been graded but not surfaced by the City of Los Angeles in 1931 and 1932. The only other roads were trails made by prospectors, the 115 miles of light-graded roads built during the survey period by the City of Los Angeles along the south slopes of the Little San Bernardino Mountains, and additional "scratch" roads made by the District.

The District road system is shown in Figure 11. It was planned to provide, in conjunction with state highways, easy access to aqueduct schedules for both District forces and contractors. The system consists of paved trunk roads connecting with state highways, and paved branch roads to the division camps and the aqueduct intake, requiring only the additional construction of short stub roads to complete the service to the individual contractors' camps.

The building of the first section of trunk road, 35.9 miles in length, along the north side of the Coachella Valley between Garnet and Indio was started January 21, 1933 and completed July 26, 1933. The second section, from Desert Center to Earp, a distance of 84 miles, was constructed between February 20, 1933 and August 4, 1933. The final section of the system was completed through to Parker dam site, Division No. 1 camp, and Intake between October 29, 1933 and January 22, 1934 by widening and surfacing to District standards the previously graded 16-mile river road and constructing extensions to the above points. In addition, the District contributed $20,000 toward the cost of a new state highway, extending from a point on the District road near Indio to Shaver's Summit via Mecca Pass. This road was opened to traffic in 1935.

Stub roads connecting all the Division 4, or Coachella, camps with the trunk road from Garnet to Indio were built, either by contract or by District forces driving the Coachella tunnels, for

Fig. 11—Construction roads

their benefit and at their expense. Similarly contractors at their own cost connected their camps and work with the District highways. These stub roads were graded and many were either oil surfaced or treated with calcium chloride, but were built to last the period of construction only.

Prior to beginning work on, and during the erection of, the 230-kv transmission line from Boulder dam to the District pumping plants, 250 miles of additional roads were graded to serve this work and for subsequent use in patrolling the lines. Since these roads were solely for this portion of the project, their cost was charged to this feature and they are described in the chapter on the transmission lines. A paved branch road to be built by District forces from U. S. Highway 60 to the Hayfield pumping plant was authorized April 9, 1937. This road, approximately 3.5 miles in length, was graded in August 1937; the oil mix was prepared and spread in September; and the work completed in November of the same year.

In addition to the desert roads constructed in conjunction with the main aqueduct work, the District has built roads in the Cajalco area to replace county roads closed by the construction and operation of the reservoir. This work is described in the section of the report pertaining to Cajalco reservoir.

Construction and maintenance

The District trunk and branch roads were designed and built with a uniform 20-foot width of oil cake pavement of a minimum thickness of 3 inches when compressed and having a 3½-inch crown. On both sides of the paving, shoulders extend 2 to 6 feet on the same or a slightly increased slope to the ditches, providing a roadway with a minimum width of 24 feet. Upon completion of grading, including cuts and fills, the subgrade was prepared by sprinkling and rolling the native material, or, where the material was blow sand or otherwise unsuitable, by spreading and similarly treating selected materials from borrow pits. Upon this subgrade surfacing materials, native or imported or a mixture of the two, as conditions required, were distributed in windrows and thoroughly mixed with road oil by blading back and forth or by a tractor-propelled mixing machine. The road mix was then spread in layers and compacted by rollers and under traffic, accompanied by dragging and other treatment necessary to produce a smooth, true, and satisfactory wearing surface.

A few timber bridges, corrugated-iron culverts, and occasional timber culverts were used, but in general desert drainage channels were crossed by paved dips with easy vertical curves. The lower side of each dip was protected against scour, in case of flood, by a concrete cut-off wall extending the length of the dip.

The surfaced roads in the District system were graded and paved under seven contracts, except the branch roads to Division 2 camp and to the Hayfield pumping plant, built by District forces, the Earp to Parker dam road graded by the City of Los Angeles, and the stub roads previously mentioned. Lengths of the various roads, dates of completion, and construction costs are given in Table 13.

The District construction road system was built to serve aqueduct construction and operation only. However, since the roads opened extensive but previously inaccessible portions of the California desert, made a shortcut from Coachella Valley to Needles and points north, and provided an access to Arizona through Parker, recreational and commercial traffic has grown to quite important proportions. While the District permitted such use at all times it became necessary to post signs warning travelers that they used all District roads at their own risk.

Each division engineer is responsible for maintaining the District-owned roads within his division. Maintenance has consisted of patching the wearing surface, principally along the edges, protecting the wearing surface by applications of seal-coat oil, or of road oil and gravel, as required, reshaping shoulders and ditches, and clearing dips after storms. A number of severe storms have struck the District system without damage more serious than the partial filling of dips with debris and some gullying of shoulders. Motor patrol graders, light trucks, and other standard equipment are in use.

The cost of maintenance by calendar years is given in Table 13, the amount per mile per month averaging approximately $15.00.

Transfer of roads

On January 28, 1938 the board of directors of the District, by resolution, authorized the transfer to the County of Riverside of its interest in the Coachella Valley-Berdoo Canyon road from Garnet to Indio and the Little Morongo Canyon road. These transfers were made by deeds dated February 7 and February 19, 1938, respectively. By the end of the year 1938 it is anticipated that transfer will be similarly effected to the counties of Riverside and San Bernardino of the respective portions of the Desert Center-Earp road situated in each.

TABLE 13
CONSTRUCTION ROAD SYSTEM
Costs to June 30, 1938

WORK	MILES	DATE COMPLETED		COST
Surveys				$ 9,232.90
Construction				
Garnet to Indio	35.88	July 26, 1933		185,851.80
Desert Center to Earp	83.96	Aug. 15, 1933		389,555.87
Branch to Division 3 headquarters	7.71	Nov. 17, 1933		47,781.28
Earp to Parker dam[1]	15.32	Jan. 22, 1934		53,713.10
Branch to Division 1 headquarters	2.39	Jan. 22, 1934		38,968.72
Branch to Intake pumping plant	1.99	May 23, 1934		140,900.07
Branch to Division 2 headquarters	2.43	Nov. 10, 1934		8,969.83
Training ditches				1,374.51
State Highway Div., (Shaver's Summit road)				20,000.00
Hayfield pumping plant road	3.50	Nov. 29, 1937		7,028.88
Subtotal, construction	153.18			$ 903,376.96
Maintenance		1933	$19,268.22	
		1934	15,896.92	
		1935	19,740.36	
		1936	38,469.46	
		1937	22,589.39	
		To June 30, 1938	7,956.75	$ 123,921.10
GRAND TOTAL	153.18			$1,027,298.06

[1]Grading of road from Earp to Parker dam was done by City of Los Angeles; paved and completed by District. Roads to Division 1 and Intake had heavy rock cuts and fills.

CHAPTER 8

Main Aqueduct Tunnels

THE MAIN AQUEDUCT tunnels are of horseshoe section and are lined with concrete of a minimum thickness of 6 inches on the sides and 9 inches in the arch. All are 16 feet high and 16 feet wide, inside of lining, with the exception of Bernasconi and Valverde, where these dimensions are 15 feet 3 inches. Their designed carrying capacity is 1,605 cubic feet per second. Except for the Colorado River tunnel, which slopes upward from Intake surge chamber to its outlet in Gene reservoir, the Copper Basin No. 1, which rises similarly from the Gene surge chamber, and Copper Basin No. 2, which will be under slight pressure with full level in Copper Basin reservoir, all main aqueduct tunnels are designed to operate as grade tunnels at all times.

The aqueduct route was so located as to reduce the length and hazard of tunnel work to a minimum. Proceeding westerly from the intake to Shaver's Summit, a distance of 134 miles, the terrain rises in roughly parallel north-south steps, marked by the mountain ranges which lie across the route. Beyond this summit a plateau-like area with ridges projecting from its north surface extends to Thermal Canyon at mile 150. There the mountain masses change to a northwesterly direction and their rugged south slopes fall away precipitously into Coachella Valley with few open areas until Fan Hill is reached. Thence approaching the upper end of the valley and San Gorgonio Pass the fan surfaces are at higher elevations and canyons become numerous with crossings possible at aqueduct grade, but with ridges jutting far out into the detrital fans. For nearly 40 miles through this portion of the Little San Bernardino Mountains between Thermal and Big Morongo canyons almost continuous tunnels were necessary.

On the south side of San Gorgonio Pass the barrier formed by the Coast Range is pierced by the aqueduct line in tunnel through the north flank of the San Jacinto Mountains. Emerging from these mountains onto a relatively high shelf forming the southeastern portion of the coastal basin, two low ridges lie across the route, one on either side of the Perris Valley. The westerly of these ridges closes the eastern side of the Cajalco basin, the site of terminal storage for the main aqueduct and of the first of the several reservoirs required on the distributing system.

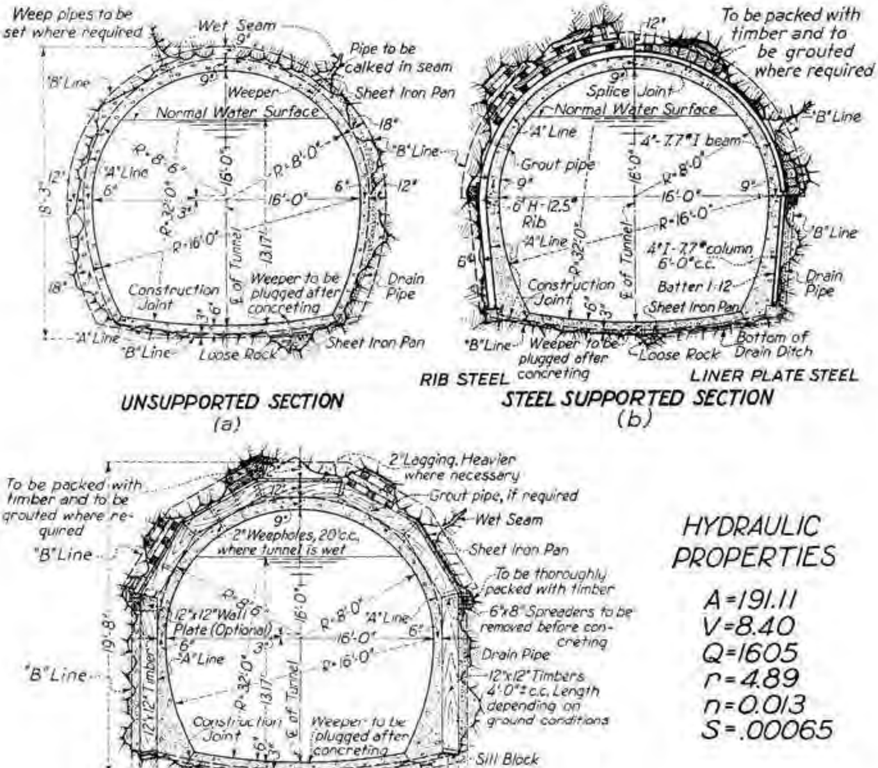


Fig. 12—Tunnel sections

These mountain ranges and masses in the 242 miles from the Colorado River to Cajalco require for their passage 29 tunnels, varying in length from 338 feet in Mecca Pass No. 1 to 96,605 feet, or 18.3 miles, in the East Coachella. The combined length of main aqueduct tunnels is 92.1 miles, or 38 per cent of the total mileage. Data on tunnel lengths and costs are given in Table 14, page 177, and typical unsupported and supported cross sections are shown in Figure 12.

In the drawing of the steel-supported section two kinds of support are shown: On the right, the standard liner plate, used extensively in the early period of tunnel excavation; on the left, rib steel as subsequently developed for the Coachella tunnels and extensively used there and in other tunnels because of its low cost and ease of erection.

The 12 by 12-inch timber set shown on the drawing was subject to variation to suit conditions. The most widely used dimension timber was 10 by 10 inches with an excavated section proportionately smaller than shown. In heavy ground timber sets up to 16 by 16 inches, skin-tight, have been used, in which case the entire section has been enlarged to provide for placing concrete lining up to 24 inches thick inside of the timber.

Specifications

The rate of progress in tunnel construction under the best of conditions is much less than can readily be maintained in the construction of surface conduits of comparable size or capacity. Therefore the tunnels were the first of the aqueduct features to be started. In general the tunnel schedules consisted of units up to approximately two miles in length, which could be economically constructed from the proposed point or points of access. In the longer tunnels, however, particularly those under high mountains where access was limited except at heavy cost, the schedules were of greater length.

All bids were called for on the basis of unit prices for the estimated quantities of each of the various items of work comprising a schedule. Lump sum bids were sometimes called for on single items of a schedule, as for example the access work, but never for an entire schedule. The bidder included in his unit prices all costs of plant and materials except reinforcement steel and other permanent metal work, steel tunnel support, and cement for gunite, grout, and tunnel lining, all of which were supplied by the District.

The first tunnel specifications were issued October 19, 1932 inviting bids for the construction of San Jacinto tunnel to full size and capacity. Bids were opened November 29th and a contract was awarded December 12, 1932 to the Metropolitan Engineering Corporation on the basis of its low bid. This corporation defaulted on its proposal, however, and thereafter the next low bid was reinstated with the consent and at the request of the bidder. On February 10, 1933 a contract for the work was awarded this bidder, Wenzel and Henoch Construction Company, Milwaukee, Wisconsin, and executed March 17th, with the completion date established as December 17, 1938.

The second tunnel job to be authorized but the first to show progress was in the Coachella division, consisting of 18.3 miles in the single East Coachella tunnel and about 8 miles of the adjoining West Coachella tunnels, under six schedules with operations to be carried on from six camps. As a measure to relieve the unemployment situation, at that time extremely acute, and avoid the delay in starting work consequent upon advertising for bids, the board of directors on December 21, 1932 authorized the construction of these six schedules by District forces. Five days later, on December 26, 1932, two superintendents with construction crews were on the ground at Fargo and Thousand Palms camp sites, ready to start work, and within two months' time work was in active progress at all six camp locations on stub roads, grading for camps, erecting buildings, laying water lines, and such excavation in approach cut, adit or tunnel as could be done effectively with temporary equipment. The specifications for construction of the Coachella tunnels were similar in all respects to those for tunnels under contract, and the construction forces of the District were subject to independent inspection in the same manner as were forces of the contractors.

Estimates by District engineers had indicated that the cost of half-capacity tunnels would run not less than 75 per cent of that of full-capacity tunnels, and that there would therefore be no economy in constructing these features to anything less than full size. In order to secure irrefutable evidence on this point, the next tunnel specifications, those for construction of Bernasconi and Valverde tunnels, were issued February 24, 1933 inviting alternative bids on both sizes. When bids were opened on April 3rd it was found that the low bidders on the full capacity were likewise low bidders on half capacity, and on the basis of their bids the smaller size would cost approximately 86 per cent of the full size.

In the meantime specifications had been issued March 13, 1933 inviting bids on the construction of Iron Mountain, Coxcomb, and Cottonwood tunnels to both full and half capacity. Here again on the basis of bids received on April 17th the cost of half-capacity construction would have been 82 per cent or more of the cost of full capacity.

Original conclusions as to the economy of full-capacity tunnel construction having been thus confirmed, succeeding advertisements called for bids on full-capacity tunnels only.

On April 10, 1933 specifications for the East Eagle, West Eagle, Hayfield Nos. 1 and 2, and Mecca Pass Nos. 1, 2, and 3 tunnels were issued, followed on April 24th by specifications for Colorado River, Copper Basin Nos. 1 and 2, and the Whipple Mountain tunnels. By June 16, 1933 the construction of all tunnels, excepting East Eagle, bids on which had been rejected, and Schedules 7 and 8 of the West Coachellas, had been provided for either by contract or by District forces. On December 27, 1933, specifications were issued for this remaining work. On February 2, 1934 a contract was awarded for the East Eagle tunnel, but the bids on the Coachella schedules were rejected, these two schedules aggregating 7.1 miles of tunnel being later added to the adjoining work being done by District forces.

Tunnel-driving operations

In general, contractors, upon receiving notice to proceed with their work, were diligent in organizing forces, assembling equipment and materials, erecting camps, and proceeding with all preparatory work even before power and water were available from the District systems.

The mess accommodations and dormitories in contractors' camps were in some cases operated by the contractor; in others were subcontracted to commissary and catering companies. In the Coachella tunnel camps such operations were carried on by the District, with a steward in charge of all mess halls.

The most common entry to the tunnels was through one or both portals. Five tunnels, however, were driven from horizontal adits, the total length of adits amounting to 10,327 feet. The east portion of Iron Mountain tunnel was driven entirely from one vertical shaft and Valverde from three vertical shafts and one inclined adit. At San Jacinto there are two vertical shafts and three inclined adits, of which the one at the west end has been discontinued with the opening up of the west portal of the tunnel.

Standard methods of excavation have been employed with improvements to take full advantage of modern equipment. In beginning tunnel driving at any point a top heading followed by excavation of the bench was customary for the first few hundred feet. In bad ground small drifts are driven in the top heading section, either on the sides as wall-plate drifts or in the top center, and opened out to full top heading, followed by bench excavation. However, following the early adaptation of the drill carriage or jumbo to these tunnels the method of excavation known as full face has been universally adopted, except in very bad ground, where some variation of heading and bench is generally used.

The estimated rate of tunnel advance was 4 to 5 feet per heading per eight-hour shift. The actual progress was at a much higher rate, as shown in the following tabulation. However, it will be noted that the average for all tunnels in the first period and for San Jacinto in 1937 and 1938 approximates the estimated rate:

	Linear feet of tunnel advance	Linear feet per shift	Linear feet per shift, excl. San Jacinto and Valverde
1933	46,094	4.62	4.71
1934	250,066	6.34	7.17
1935	140,854	6.05	7.84
1936	22,404	5.20	10.50
1937	10,179[1]	4.77	......
1938 (to June 30)	9,903[1]	4.56	......
TOTAL	479,500	5.89	7.04

When conditions remained constant, with the section either continuously supported or entirely unsupported, remarkable progress was made. In a number of tunnels an average daily advance of 30 feet was maintained for long periods. As shown in the above table, the average advance per eight-hour shift up to June 30, 1938 for all tunnel excavation, including the placing of support, was 5.89 feet and, excluding San Jacinto and Valverde, where difficulty was experienced from water and bad ground, was 7.04 feet.

The Whipple tunnel, driven from an adit with two headings or faces, and 19 per cent supported, averaged 44.1 feet per day of elapsed time and 46.9 feet for the actual days worked, or 23.45 feet per actual heading day of three shifts. The Coxcomb tunnel driven from a single heading and 50 per cent supported had corresponding advances of 20.1 and 23.7 feet; Cottonwood tunnel, driven from both portals and 100 per cent supported, made 38.7 and 45.7 feet; Iron Mountain East tunnel, driven with two headings from a vertical shaft and 59 per cent supported, made 28.6 and 36.2 feet.

In the Coachella division the two headings of the East Coachella

[1] San Jacinto only; all other main aqueduct tunnel excavation was completed prior to January 1, 1937.

Tunnel with steel-rib support

Unsupported tunnel in rock

tunnel, driven from the Yellow Canyon adit and 56 per cent supported, averaged 34.8 feet per day of elapsed time and 40.5 feet for the actual days worked. The corresponding progress for single heading at Thousand Palms No. 1 tunnel, 84 per cent supported and one of the first of the aqueduct tunnels to be started, was 17.8 and 20.5 feet, and for single heading at Long Canyon, 83 per cent supported and started in 1934, 21.8 and 24.9 feet. In the driving of the ten Coachella tunnels a total of 178,142 feet from the eight camps the average progress, including the placing of support, was 7.05 feet per actual shift worked.

The best monthly progress in all aqueduct tunnels for a single heading crew was made in May 1936, when at Morongo camp 1,227 feet of fully supported tunnel was driven in 81 shifts. This footage was made in completing Blind Canyon tunnel and beginning Morongo No. 2. The second best single heading progress was 1,101 feet of fully supported tunnel in 78 shifts made in November 1935 in Thousand Palms No. 1 when the crews were working more than 14,000 feet from the portal. The next best progress was 1,084 feet of unsupported tunnel driven in 90 shifts in November 1934 in the west heading of Copper Basin No. 2. This increased speed in tunnel driving was due to many factors, among which are the use of new and improved types of equipment, advances in methods of excavation, freedom from water and bad ground, except in San Jacinto and Valverde, and generally excellent heading crews, which latter in turn was largely attributable to the superior living conditions afforded the men in the camps, high wages, and good working conditions.

Equipment

Drill carriages and drills, mucking machines, and devices for quickly replacing loaded cars with empties at the face during the mucking period, have long been used on tunnel work. Here they were extensively improved and developed. The drill carriages, or jumbos, mounting from 5 to 11 powerful drills operated by compressed air, could be moved by electric locomotive up to the face, their folding side platforms raised to level position, air and water connections made, and drilling started in ten minutes. This made possible the drilling, loading, and blasting of full-face rounds 5 to 12 feet deep with from 25 to 72 holes in from 2 to 4 hours, the depth of round, the number of holes, and the drills necessary to complete the drilling in a given time, being governed by the hardness and tightness of the rock. Removed from the face, with platforms down, the jumbo could be stored on a nearby siding and its equipment serviced for the next round.

In the first tunnels standard hand-feed drills were used, but these were largely displaced by newly developed drills having automatic feeds, providing greatly increased speed of drilling. Heavier and more powerful models were possible because the mounting of the drills in position on the drill carriage obviated the necessity of the crew carrying the drills to and from the face.

Virtually all blasting was done from a power circuit using electric detonators, with no-delay or instantaneous caps in the cuts, and various delays in the remaining holes of the round to secure the proper firing order.

In the adit excavation and some of the tunnel excavation of early 1933 several different types and sizes of muckers were tried. These were found to be inadequate to maintain the time of mucking close to the breaking time of a round in the face of the heading. Demand was made on the manufacturers for larger, sturdier, and faster machines, resulting in the construction of muckers with electric motors up to 60 horsepower with more than double the capacity of the earlier machines.

Muck cars were of the usual types and sizes, but a more extensive use of roller bearings permitted longer trains and more rapid disposal of broken rock. The quick switching of empty and loaded cars behind the mucker was facilitated by use of various devices. One was the "California switch," a portable double track with switches which was moved forward on the tunnel track and kept as close as desired to the face. Another was the "grasshopper," a combination overhead car passer and drill carriage on wide track, in which ramps front and rear made it possible to pass empty cars over the top while the load was hauled out below. A variation of this machine used a belt conveyor with a tilting front section which was raised for the mucker to go through and lowered under the mucker belt when in operation, the machine and conveyor being long enough to load out a full train of cars without switching.

Haulage underground was largely by storage battery locomotives. In some tunnels combination trolley and battery locomotives were used, the batteries serving for travel beyond the ends of the trolley lines. On the surface, gasoline locomotives were utilized for yard and dump work.

Ventilation of the short tunnels presented no unusual problems. In the long tunnels both positive pressure blowers and centrifugal compressors were used, usually blowing fresh air to the face in quantities much in excess of the requirements of the normal crew, but so arranged that by reversing the flow, air could be exhausted after blasting to clear the heading of smoke. Thus within from 15 to 30 minutes after the blast the noxious gases were so completely drawn out that the safety miners, the mucking machine with its crew, and the trainmen were able to return to the heading, make conditions safe, and start mucking the round, this part of the cycle of operations occupying from 1½ to 4 hours.

Geology

In the Colorado River, Copper Basin No. 2, and Whipple Mountain tunnels sedimentary sandstones, and conglomerates were encountered in portions of all three. At the west portal of Iron Mountain 2,949 feet of dry, partially consolidated sand and gravel and at the east portal of Valverde 2,100 feet of moist sand and clay were passed through. The Morongo No. 2 tunnel was in a cemented sand and conglomerate and the nearby Whitewater tunnels were entirely in sedimentary fanglomerate, a hard, well-compacted sand and gravel. A short distance east of the Berdoo adit an old canyon filled with cemented gravel was crossed. With these exceptions all tunnels were excavated through igneous rocks which may be generally classified as granitic, consisting of granite, gneiss, granodiorite, diorite, and porphyry.

The sandstones and conglomerates were excellent for tunnel excavation, breaking to close lines and requiring little support. The alluvial materials, sand, gravel, and clay, were sufficiently consolidated so that their excavation in tunnel section was relatively easy. In the Morongo No. 2 and Whitewater tunnels the cemented and compacted sand and gravel were ideal for tunneling. They required only light blasting and were so dry that sprinkling to lay the dust was necessary. In the two Whitewater tunnels excavation per shift averaged 8.5 feet for their entire length and in the shorter Morongo 14.9 feet. Both the alluvial and cemented materials required full support, though standing well during excavation.

The granitic rocks varied widely. For the most part they were hard, but blocky, loosely jointed, and rather closely fractured. In excavating a section from 17 to 20 feet wide in such rock, joints and fractures were released, so that sooner or later blocks and slabs loosened by subsequent blasting would fall, creating a serious hazard. A large proportion of the support used was placed to prevent such falls of rock and make the headings safe. Air slacking of jointed and fractured rocks was also of frequent occurrence, requiring a large amount of gunite protection. Eight tunnels in granitic rocks were practically 100 per cent supported and approximately 61 per cent of all footage in such rock required support, not including in this figure the gunite-coated areas. Hard, massive, or tightly jointed and slightly blocky granites which required no support were found in some long stretches of tunnel, but this desirable condition was the exception rather than the rule.

The desert tunnels were dry except for occasional slight seepages, and these with few exceptions stopped within a short time. In San Jacinto heavy flows of water have been encountered which after intervals of time have greatly diminished. The Bernasconi tunnel produced small localized seepages of no significance. In Valverde little water was encountered excepting in an alluvium-filled basin between shafts 2 and 3, water stored therein being local to that basin. In none of the aqueduct tunnels was any evidence of mineralization discovered, and none of the fault zones showed any indication of recent movement.

Tunnel lining

In general the proportions of cement, aggregate, and water in the concrete tunnel lining were designed "to produce a concrete of maximum practical economy to the District and having ultimate compressive strength at the age of 28 days of not less than 2,500 pounds per square inch, and capable of being deposited in the forms so as to produce a wall of maximum density and maximum smoothness of surface to be exposed to the flow of water" (specifications). The exact proportions of these materials were varied during the progress of the work as analyses and tests were made of samples of the aggregate and resulting concrete. Samples of concrete for test purposes were taken by the inspectors as placing proceeded and forwarded to the Banning laboratory for testing.

In the lining operations the usual procedure was to place a concrete curb to line and grade, for form support, followed by arch and side walls, and lastly invert. Where a curb was not used a timber sill was set to support the forms. In two cases a fixed length of forms was used and the open end closed by a bulkhead, placing being continuous until the entire form was filled. The more usual method, however, was to use forms fabricated in short sections and bolted together into units of 20 to 30 feet in length, which could be moved forward on a traveler as arch placing proceeded. With this set-up continuous placing of arch lining was possible without bulkheads except at the portals.

For all tunnels from the Colorado River to and including the east portion of San Jacinto, sand, gravel, and rock for concrete were produced from nearby deposits previously tested and approved by the District. Aggregate for the west portion of San Jacinto and for Bernasconi and Valverde tunnels was shipped from commercial pits because of the lack of adequate deposits in the immediate vicinity. In all cases the cost of aggregate was included in the price bid for concrete.

The specifications called for the use of three sizes of aggregate: Fine, or that passing a 3/8-inch screen, and two grades of coarse, viz., 3/8 inch to 1 inch and 1 inch to 2 inches. Some latitude was permitted in order to make the best use of desert deposits, with screening into four sizes to an upper limit of 2½ inches, and making two classes of fines. This last became necessary when an excess of very fine particles existed in the natural deposits. The quantities of the various sizes in a given mix were weighed to within 2 per cent of the specified weights. In approximate figures the aggregate for arch concrete was composed of 37 per cent sand, 28 per cent small rock, and 35 per cent large rock, with slightly different proportions in the invert.

All portland cement used in tunnel lining was furnished by the District and was manufactured by the four Southern California mills in accordance with District specifications[1]. After grinding and storage in a mill silo the cement was sampled and the silo sealed by District inspectors. The samples were tested by District chemists in the Banning laboratory. If the cement met the specification requirements the seals were broken by the inspectors and shipment allowed. Almost the entire quantity was shipped in bulk from the mills by rail and hauled in covered trucks and trailers from the railway siding to the tunnel batching plants. In some cases the District provided for delivery into the contractor's storage; in others the contractor took delivery at the railway and was paid for hauling at his bid price per ton-mile.

The cement for each batch of concrete was weighed in the batch-

[1] See also Chapter 13, p. 277.

Completed 16-foot concrete-lined tunnel

ing plant to within one per cent of the specified weight. The quantity of cement per cubic yard of concrete in the tunnel lining has varied according to conditions from 1.3 to 1.6 barrels with an average for all tunnels of 1.4.

All arch concrete was placed mechanically using either pneumatic or pump types of machines, with discharge pipes extending from the placer up to and along the top of the forms so as to deliver concrete to the highest point of the arch and fill the entire open space outside of the forms. The curing of the arch by water spray was continued for 14 days after the forms were stripped.

In a number of tunnels, using the continuous pour method, records of placement of more than a mile of arch in one month were made with a maximum of 7,647 feet at Whipple in September 1936. Progress at this latter rate involved the daily mixing and placing in the restricted tunnel section of 865 cubic yards of concrete. The one-day maximum of 1,387 cubic yards was placed by District crews in the west portal section of San Jacinto. The maximum monthly footage placed where a fixed length of forms was used, was 3,740 feet.

Invert concrete was likewise placed mechanically, but without the use of forms. Its surface was screeded to final shape and hand trowelled to the required smoothness. Prior to placing invert a general clean-up of the bottom was made so that once started the work could proceed with dispatch. Rates of progress exceeding expectations were attained. The operation, including the taking up, conveying past the concrete equipment, and disposal of all track materials, a final clean-up, shaping, and compacting of the subgrade, and the placing, screeding, and finishing of the concrete was performed at an average speed approximating 250 feet per shift, with many runs exceeding 1,200 feet per day.

Wherever seepage existed in the arch section, sheet iron panning was attached to rock or timber to divert the water from the fresh concrete to the invert. When the invert was placed tile or gravel drains were used as channels to keep water away from the concrete until it had set.

In lining San Jacinto tunnel from Potrero shaft to the west portal it was necessary to change the usual order and place invert first. Because of the water entering the Potrero headings a 30-inch pipe had been suspended along the side between the shaft and portal to carry this water out to the west portal. This pipe prevented the setting of arch forms for lining. Therefore the invert and a portion of the side walls were placed to form a channel, the track was relaid on a low trestle above the invert, the water turned into this channel, and the pipe then removed. Thereafter the remainder of the arch concrete was placed to complete the lining.

In addition to the required samples of mixed concrete taken by the inspectors during placing, cores for strength tests have been cut from lined sections long after the lining was completed, and systematic drilling has been done in the arch to check the thickness of concrete actually placed, particularly where overbreak of rock had occurred. In general, the concrete considerably exceeds the required strength of 2,500 pounds per square inch at 28 days. The thickness of concrete in the arch was rarely found to be less than specified, but regardless of thickness, wherever voids were discovered which indicated necessity of filling, a sand and cement mixture was pumped through the test holes to refusal, or until the grout appeared in nearby control or check holes.

Labor

By action of the board of directors of the District employment on aqueduct construction work, with very few exceptions, was restricted to residents of the District. This requirement did not impede tunnel work. Contractors were allowed their key men and the District found residents qualified to be superintendents and foremen. With a few experienced men to form the nucleus of a crew and under good supervision inexperienced men rapidly developed into most efficient tunnel organizations demonstrating a splendid spirit of rivalry and willingness to work.

The work week for employees on main aqueduct construction was limited by state law to 48 hours. In the beginning one day of rest was taken each week. This plan was soon revised to 12 days' continuous work and 2 days off in a fortnightly period. This proved to be a more satisfactory arrangement, in that it gave employees living in remote camps time in which to visit their homes. At San Jacinto, where utmost speed was necessary, and at a few other tunnels, work was continuous except at the Fourth of July and Christmas seasons, but in all these cases operations were so arranged that the requirements of law as to the 8-hour day and one day of rest in seven were nevertheless complied with in respect to the individual workmen.

COACHELLA TUNNELS

The excavation and lining of the Coachella tunnels were done entirely by District forces. Early in 1933 six camps were opened, four for the East Coachella tunnel and two for the West Coachella tunnels, followed in February 1934 by the establishment of two more West Coachella camps, to construct the remaining tunnels constituting Schedules 7 and 8 of the Coachella division. The District operated dormitories, mess halls, commissaries, recreation rooms, and a base hospital, with air-cooling in summer and heating in winter for most of the living quarters.

The designed length of the ten Coachella tunnels was 175,975 feet and the estimated cost $18,000,000. As constructed the length was increased (2,167 feet) by changes in portal stations, to 178,142 feet, and a much greater footage of tunnels, 67 per cent instead of the anticipated 10 per cent, required support. Though both these factors added appreciably to the yardage and cost of excavation and concrete, the total expenditure at the time of completion in

San Jacinto tunnel scene

1937 amounted to only $17,876,376.26, and as of June 30, 1938 this cost had been reduced by salvage credits to $17,669,132.12, or more than $330,000 under the engineer's estimate.

Access to the 18.3-mile East Coachella tunnel was through adits at each of four camps. These adits increased in length westwardly from 686 feet at Yellow to 891 feet at Fargo, 2,042 feet at Berdoo, and 2,935 feet at Pushawalla; totaling 6,554 feet. Headings were driven east and west from the junction of each adit with the tunnel line. At Yellow Canyon camp the length of tunnel excavated was 21,572 feet, at Fargo 25,261 feet, at Berdoo 29,101 feet, and at Pushawalla 20,671 feet. The stretch with greatest distance between adits and the last to be completed was that from Fargo to

Berdoo, 31,024 feet, in which excavation was completed on January 2, 1936. The Fargo West heading was started in May 1933 using the temporary equipment with which the adit had been driven, was discontinued pending installation of the permanent plant, and then was resumed in July. The Berdoo East heading was begun on August 14, 1933, so that almost six miles of tunnel were driven from these two headings in 2½ years.

Of the West Coachella camps, Thousand Palms and Wide were located in broad canyons, Long and Morongo in narrow canyons between tunnels; work proceeding in both directions from each camp. There were nine tunnels in this group varying in length from 848 feet at Wide No. 2 to 16,730 feet at Seven Palms. The second longest of this group, Thousand Palms No. 1, 16,058 feet, was driven with a single heading from its west portal. The aqueduct record month's footage for one heading, 1,101 feet, was made in this tunnel for the month of November 1935, after the 14,000-foot mark had been passed.

The concrete lining of the East Coachella tunnel was placed from two camps, Fargo and Berdoo. Aggregate pits were opened in both canyons above the tunnel right of way so that sand, gravel, and rock could be hauled down grade to the screening and batching plants located in the canyon over the tunnel where the cover was not deep. At these points openings to the surface, which had been made to improve ventilation during excavation, were utilized to chute dry batches of cement and aggregate into the batch cars on the tunnel siding below.

The Thousand Palms No. 1 tunnel was lined from its west portal easterly, using aggregate and crews from Fan Hill. Northerly of and above the aqueduct line in Wide Canyon a large pit was opened which produced all aggregate used in Thousand Palms No. 2, Wide Nos. 1 and 2, Seven Palms, Long, and Blind tunnels, a total of 57,862 feet. Production of aggregate for the remaining tunnels, Morongo Nos. 1 and 2, with a total length of 7,617 feet, was contracted, the plant being located near the Morongo camp, from which the work of lining was done by District forces.

In the lining of the greater part of the Coachella tunnels each dry batch, as weighed at the batching plant, contained materials for one cubic yard of concrete. Cars with compartments for three batches, in trains of from five to ten cars, were used to transport materials to the lining equipment in the tunnel where mixing was done just prior to placing with a concrete pump. So expert did the crews become in handling forms and equipment for arch lining and in dispatching aggregate to the mixers, where work was continuous, that for a period of nine months, from April to December, 1936, an average of 640 cubic yards was placed in 176 feet of arch every 24 hours by Berdoo crews. This record of lining progress becomes even more noteworthy when it is observed that the rated capacity of these pumps was only 480 cubic yards per 24 hours and that the aggregate plants and the hauling equipment were designed and built for this capacity.

The lining of the tunnels west of Long Canyon was done in 1936 with equipment of larger capacity. This equipment likewise used concrete pumps, but the mixers were of two-yard capacity, and the batch cars had two compartments, each compartment containing materials for two cubic yards of concrete. The entire 15,305 feet of arch in Long Canyon tunnel was placed in 189 eight-hour shifts in June, July, and August, 1936, at an average rate of 81.0 feet, or 297.6 cubic yards per shift. For 144 shifts in July and August the average was 89.1 feet, or 323.3 cubic yards per eight-hour shift. In placing invert after removal of track and final preparation of the subgrade the footage over considerable periods of time exceeded 500 feet per shift.

The placing of concrete in the Coachella tunnels was finished on May 8, 1937 with the completion of the lining of the east heading at Berdoo camp. Upon completion of the lining in the East Coachella tunnel the Yellow and Pushawalla adits were closed off from the tunnel with heavy concrete plugs. At Fargo and Berdoo doors were set in the tunnel lining and the adits are being maintained as entries to the tunnel for inspection. All the adit work was completed in October 1937. Dismantling of the construction plants was completed in December, equipment that was not needed on some other District job and could not be sold on the ground being hauled to storage in the salvage yard at the Banning field headquarters. Buildings which could not economically be moved for further use were sold subject to removal by the buyer.

On December 13, 1937 the Coachella headquarters office was closed, the remaining haulage of equipment to salvage and clean-up of the camp areas being transferred to the salvage division. On June 30, 1938 the Yellow, Fargo, Thousand Palms, and Long Canyon sites were completely cleaned up, with a small amount of work remaining at the other sites.

SAN JACINTO TUNNEL

The contract with Wenzel and Henoch Construction Company, for construction of the 13-mile San Jacinto tunnel was executed March 17, 1933. The contractor under his plan of operation had to complete a 261-foot vertical shaft at Cabazon with a 935-foot horizontal cross drift south to the tunnel line, and a 796-foot vertical shaft to the top of the tunnel at Potrero before he could begin actual tunnel work at these points. The sinking of Potrero shaft was started on May 12, 1933 and of Cabazon shaft on May 25, 1933. At West Portal, where a short adit was required to reach the tunnel and begin excavation, the contractor started the adit approach cut on August 8, 1933. This 237-foot adit was completed to the tunnel section on September 21, 1933, and the first San Jacinto tunnel excavation was made at that point. At Cabazon the shaft was excavated, concrete lined and equipped, and the cross drift finished to the tunnel line by January 17, 1934, but excavation in the tunnel section was not started until the last day of that month. At Potrero sinking and lining of the shaft proceeded slowly, the top of the tunnel being reached April 7, 1934. A shaft station was cut in the tunnel section, with the necessary sumps and skip loading pockets below, and excavation in both directions away from the station was begun May 2, 1934.

Inability to procure progress in excavation resulted in unreasonable and unnecessary delay and the further services of Wenzel and Henoch Construction Company, contractors, were dispensed with by order of the general manager and chief engineer, effective under its terms January 15, 1935. The order did not result in the actual taking over of the work by the District until February 12, 1935. Up to this date the contractor had excavated 12,653 feet of main tunnel, made up of 1,821 feet in Cabazon East, 4,874 in Cabazon West, 160 in Potrero East, 1,137 in Potrero West, and 4,661 in West Portal headings, respectively.

Progress in 1935—District forces

The District immediately made plans for and started the construction of pump chambers at Cabazon and Potrero shafts, in each of which centrifugal pumps were installed with a combined capacity at each point of approximately 16,000 gallons per minute. In the tunnel headings pumps were set at all working faces and ample water discharge pipes were installed; drilling, mucking, and hauling equipment was added, and the ventilation system was en-

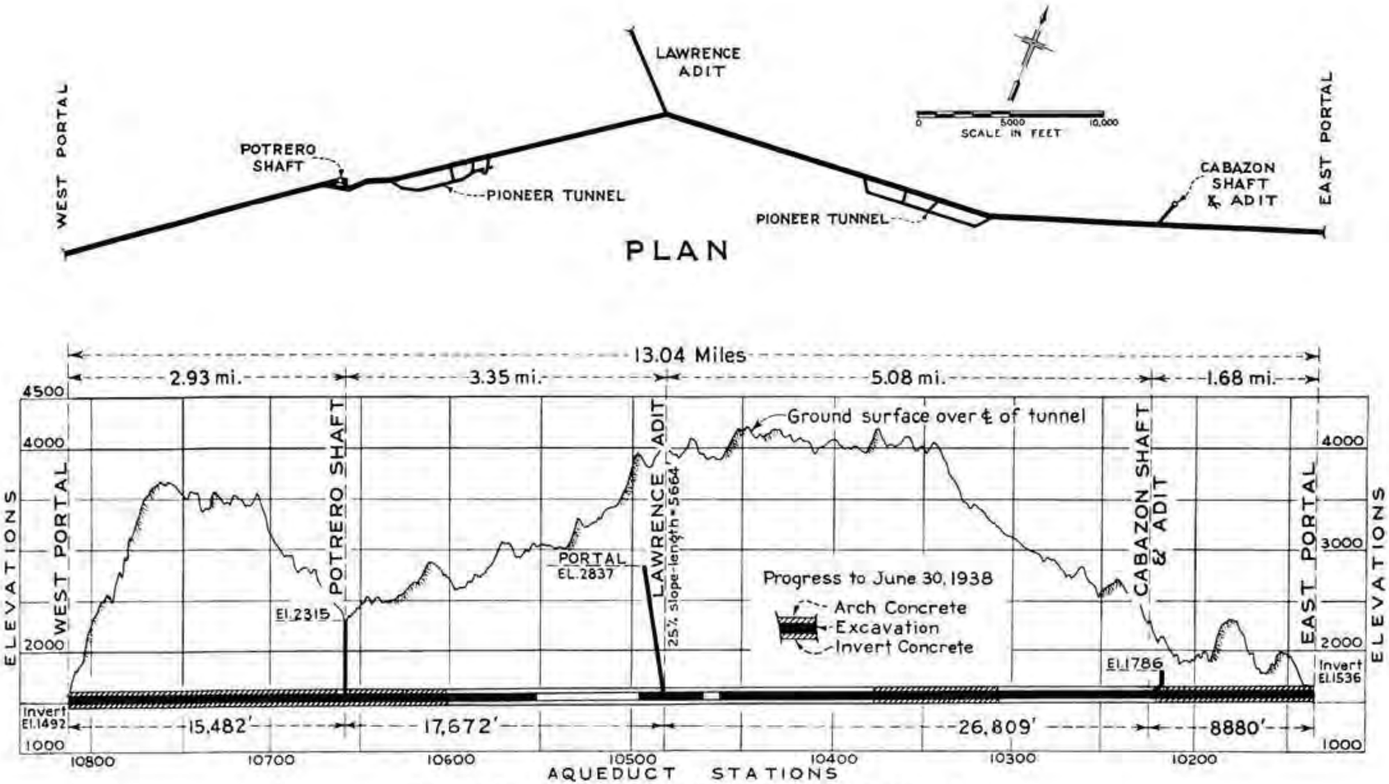


Fig. 12A—Plan and profile of San Jacinto tunnel larged, while on the surface all facilities were expanded, including additional buildings, larger hoists, and more air compressors, ventilation blowers, and power feeder cables.

The excavation of all headings was prosecuted vigorously, particular attention being given to the long leg between Cabazon and Potrero. From February 12, 1935 to the end of the year the footage of tunnel driven by District forces was 15,691, made up of 3,300 in Cabazon East, 2,956 in Cabazon West, 1,930 in Potrero East, 2,995 in Potrero West, and 4,510 in the West Portal. In the Cabazon-Potrero sector much of the excavation was through fractured zones in the granitic formation, where difficult conditions were encountered with some flows of water under pressure. In April 1935, after futile efforts to recover and continue the Potrero East heading which the contractor had lost because of serious caving in a broken zone, and following exploratory diamond drilling both vertically from surface and horizontally from the tunnel, a detour starting 43 feet east of the shaft was driven to the south around the caved area and back to the original line. The drilling had indicated a favorable crossing about 150 feet to the south. At this point the detour intersected the shear zone nearly at right angles and the crossing was made without serious difficulty. Every precaution was taken in excavation and a 24-inch gunite lining was applied to the 18-foot wide shear zone.

At the close of the year it was evident the tunnel would soon be opened from Potrero to the west portal. Plans were therefore made to drive a water drift through the block south of the shaft connecting the detour and Potrero West in order to keep the shaft station clear of any water line discharging to the west portal. This by-pass was enlarged to full size becoming a portion of the main tunnel and reducing the curvature due to the detour. It was completed in February 1936.

Progress in 1936

In 1936 the Potrero West and West Portal faces met on February 21st, and on September 5th the Cabazon East heading reached the location of the east portal, later being connected to the surface on the north side by means of a slope adit, lined with concrete to provide a permanent access to the tunnel. These connections reduced the working faces to three in February and two in September, but the total footage driven during the year was 13,862 with Cabazon West averaging 298 feet, Potrero East 361, and all headings 390 per month. The opening of the tunnel to the west portal removed all danger of flooding the Potrero workings since water could flow to the portal. This was not the case at Cabazon where the west heading was driving down grade and inflowing water would collect at the face. Therefore during the year the pumping capacity at Cabazon shaft was increased by the addition of two 5,000-gpm pumps and a similar increase was made in the pump capacity at the west heading.

The rock in the Cabazon-Potrero sector was better on the average than that in other aqueduct tunnels where rapid progress was being maintained, but water, sometimes under pressure, made excavation difficult and slow. Advance in this 8.4-mile section had been so delayed prior to February 12, 1935 that in 1936 it was determined that working at only two headings the tunnel could not be completed as scheduled. Two measures were adopted to expedite the excavation of this important section. One was to construct an additional adit for access to the tunnel at a point approximately midway of the unexcavated portion, the other to start a pioneer tunnel parallel to and 75 feet south of the main bore. This separation was reduced to 55 feet in the last 919 feet of the Potrero pioneer. Completion of the adit would double the number of points of attack, and pioneer headings pushed well in advance of the main tunnel headings would permit cross connections to be driven from time to time which would further increase the number of working faces in the main tunnel. A pioneer also would permit detouring utilities and traffic around a section of main tunnel being lined concurrently with excavation. Moreover, in the event of meeting of the pioneer tunnel headings long before the main tunnel, the pioneer would be available during the interim as a water carrier to prevent serious loss to the District cities in a drought emergency.

Accordingly, in March 1936, the Lawrence adit portal was located and excavation started on a 25 per cent incline downward to tunnel grade; in May a pioneer heading was turned off at Cabazon West; and in June a similar heading was begun at Potrero East. At the end of 1936 the adit had been excavated a distance of 2,214 feet; the Cabazon pioneer 2,901; and the Potrero pioneer 3,955 feet, the faces of the pioneers being 176 and 189 feet, respectively, ahead of the main tunnel faces.

So far as known the Lawrence adit is the first slope adit in which a drill carriage and a mucking machine were adapted for and suc-

Holing through at San Jacinto tunnel

cessfully used in excavating down a 25 per cent grade. A great saving in time and in the arduous labor of hand mucking under slope conditions resulted. The drill carriage for the 11 by 12-foot adit section was anchored in position at the face during the drilling period, after which it was pulled back and lowered onto a siding by the hoist. The mucker, being unable to retract itself unassisted on a 25 per cent grade, was counterweighted in such a way that its regular equipment could then move it forward and back as when operating on the level. This was accomplished by running a cable from a hoist set on one side of the adit, through sheaves on the mucker frame and back to a counterweight (a loaded car) operating on a track at a short siding opposite the hoist. The purpose of the hoist was to regulate the position of the counterweight as the mucker advanced at the face. It was also necessary to remodel the mucker bucket and boom and flatten the conveyor to compensate for the adit slope. With this adaptation of tunnel equipment to slope work monthly progress increased to a maximum of 523 feet and daily progress exceeding 20 feet was frequently attained.

In the pioneer tunnels drill carriages were built to fit the 10 by 10-foot section and except for small changes in height of mucker conveyors all other equipment was identical with that of the main tunnel to provide complete interchangeability.

Progress in 1937

Despite some delay due to a strike[1] called August 14th, the Cabazon West heading was advanced 7,868 feet during the year 1937, a daily progress of 21.7 feet. Support was required at such times as the rock jointing became loose, or fractured zones occurred, but totaled only 1,220 feet or 15.5 per cent. The remainder of the advance was through hard, tight granodiorite in which a battery of 11 drills was necessary to complete the drilling of a 10-foot round of about 70 holes in two to three hours; the loading with approximately 700 pounds of explosives, blasting, and clearing smoke requiring another hour. Between October 14, 1937 and February 18, 1938 an advance of 3,560 feet was made without support.

During the year progress in Potrero East amounted to 2,297 feet with 1,636 feet supported, more than 1,000 feet of which required 16 by 16-inch timbers, at times skin-tight. Twice during the year cross drifts were driven from the pioneer to the tunnel line and excavation started in one or both directions well in advance of the main heading. In this way progress was made every month with from one to three headings in operation. Here the pioneer was exceedingly advantageous in providing an access for opening up advanced headings and continuing main tunnel progress. In some sections where the granite was badly broken, single 16 by 16-inch timber sets side by side were insufficient to support the ground, and under these conditions double 16 by 16-inch sets were used. Subsequently, in preparation for concrete lining, alternate sets of the inside ring were removed in order further to increase the strength of the concrete lining which in such areas will have a minimum thickness of 24 inches.

The slope excavation in Lawrence adit was completed October 31, 1937 with a length on the incline of 5,462 feet. The station section 8 feet below tunnel grade was then excavated on a slight slope up to the north side of the tunnel, being completed on December 17th, making the total length 5,664 feet. The station deck with tracks was erected at tunnel grade, thus providing sump space for water which might be encountered. By the end of the year the

[1]See page 170.

equivalent of 14 feet of full tunnel section had been excavated at Lawrence.

The total advance in tunnel excavation for 1937 was 10,179 feet, leaving a remaining footage between Cabazon and Lawrence of 7,533 and between Lawrence and Potrero of 9,111.

The Cabazon pioneer tunnel was discontinued at the south wall of the main tunnel on July 26, 1937 with 4,373 feet driven since the first of the year. During this time rock conditions were generally excellent and the high daily average of 21.1 feet was made in the pioneer, but in the same period the main tunnel averaged 20.9. It was evident that in good going the larger section could be driven as rapidly as the smaller, and the possibility of a long run of hard rock ahead indicated the economy of suspending the pioneer, and resuming it later if necessary.

The Potrero pioneer was continued until August 11th for an advance in 1937 of 1,616 feet. At this time it was 528 feet ahead of the main face and 43 feet ahead of the east face driven from the new cross drift No. 3 completed August 7th. The pioneer excavation was not resumed after the brief shutdown incident to the C.I.O. strike in August 1937. The advance heading in the main tunnel being at that time in massive granite without support, it was decided to discontinue the Potrero pioneer and resume its excavation later should main tunnel conditions require it.

C.I.O. strike

In December 1936 an affiliate of the Committee for Industrial Organization, known as Local No. 270, International Union of Mine, Mill, and Smelter Workers, was organized on San Jacinto tunnel and on other aqueduct work. District officials did not oppose or seek to obstruct the organization of this union. On the contrary the board of directors, within two weeks after the union was formed officially set up a staff committee with instructions to treat with union representatives. This committee, by appointment, held 22 meetings with various union committees and conducted many informal conferences. Union representatives appeared before the board of directors and were given full opportunity to present such complaints and proposals as they desired. During this period of negotiations all demands of the union were adjusted, including the granting of wage increases amounting to 16 per cent. In June 1937 a union committee requested a "closed shop" agreement. On July 2nd the board of directors issued a statement of its employment policy as a municipal corporation, in which it stated: "This board cannot and will not restrict employment to members of any single union. Special written agreements will not be made with any particular group of employees." On August 13, 1937 a union delegation appeared before the board and demanded that the board immediately sign a written agreement containing 16 specific demands, including recognition as sole bargaining agency and preferential hiring. The District was unable legally to accede to such demands and the board refused to sign the proposed contract. At 4:00 p.m. the following day the union called a strike and all but 206 of a total working crew of about 1,190 men walked off. However, all pumps and utilities were continuously operated though tunneling progress was temporarily retarded. Camp and housing facilities were supplied where necessary so that crews could be lodged and fed at the work without crossing picket lines, which were continuously maintained on roads leading to the camps. By October 1, 1937 tunnel work was back to normal despite the union's determined effort to stop all progress.

Progress in 1938

In January 1938 the Cabazon main tunnel heading made a San Jacinto record progress of 920 feet and up to May 31st had averaged 25.4 feet daily. In June the formation changed to wet, badly-fractured granodiorite and aplite with mud seams, and advance became slow and cautious. For the six months to June 30th the total advance was 4,357 feet. The daily average was 24.1 feet with 1,166 feet requiring support. At this date the Cabazon West face was 23,629 feet from the Cabazon adit junction, exceeding by more than a mile the greatest distance previously excavated in the aqueduct tunnels from a single access.

At Lawrence adit the rock at the junction was a blocky granodiorite, more or less fractured, with wet seams, and required heavy support. Progress was slow during the first quarter because of ground conditions and delays caused by construction of sumps and installation of pumps and water-discharge lines. Up to April 15th both headings were practically fully supported. Rock conditions then improved in the east heading and much better progress was made until early June, when a zone of soft, fractured rock with mud seams and small flows of water was entered. However, 2,127 feet of tunnel was excavated in this heading during the six months ending June 30, 1938. In the west heading blocky, fractured granodiorite with some water persisted, necessitating for the most part 16 by 16-inch timber support, until the middle of May, when the granodiorite became firm and hard but wet. Water was found in test holes drilled ahead of the face and grouting was frequently resorted to for sealing off these flows. By the end of June an advance of 1,253 feet had been made for the half year.

Two pump installations for Lawrence adit were completed in March, each of a rated capacity of 14,000 gpm. One, located in the station at the bottom of the adit, delivers water to the other located midway of the incline section, whence the water is pumped to the surface. The total difference in elevation between the tunnel grade and the adit portal is 1,324 feet.

At Potrero three main tunnel headings were available during the first three months of 1938, the No. 1 leading directly from the shaft, and two advanced headings, No. 2 driving west to meet No. 1, and No. 3 driving east on line, access to both being gained through a cross-cut from the pioneer. The block between No. 1 and No. 2 consisted of badly crushed and disintegrated granite, with clay and gouge material necessitating extremely cautious excavation. Small drifts were connected through in the top of the section; these were widened out to complete the upper portion of the tunnel, with heavy timber segments set on wall beams resting on the bench, and finally the bench was removed and the beams caught up on posts. This connection was completed on April 16th. In the meantime the rock in the No. 3 heading had improved and the better conditions prevailed to the end of June, total progress in the three headings for six months of 1938 being 2,166 feet, or a daily average of 12 feet. On June 30, 1938 there remained 1,049 feet between Cabazon and Lawrence and 5,692 feet between Lawrence and Potrero to complete all main aqueduct tunnel excavation.

Concrete lining

Following the holing through between Potrero West and West Portal preparations were made to place concrete lining in this section. As previously stated the invert was completed first, after which the arch was placed and then grout under low pressure was pumped outside of the lining. The invert placing was started in March 1936; the arch was completed in January 1937; and the low-pressure grouting in April. This lined portion, 14,953 feet in length, extends from a point near Potrero shaft to the west portal. Final high-pressure grouting in this section was started June 7, 1938 and was in progress at the date of this report, for the purpose both of filling all voids outside of the concrete lining and sealing off any infiltration of ground water from the surrounding rock formation.

The San Jacinto tunnel invert is being placed with a radius of 16 feet instead of the standard 32 feet, thus making a more nearly circular section, and with a much greater thickness than the minimum 6 inches shown in Fig. 12.

In Cabazon East the normal sequence of lining operations was observed except for 130 feet of invert placed in a swelling ground section. Curbs were poured in November and December, 1936; the arch was started in January 1937 and completed to a point near the Cabazon adit in June; and the remaining invert was placed in July, the total distance lined in this heading being 8,484 feet. Drilling of grout holes in preparation for grouting this portion of the tunnel was begun June 20, 1938.

In Cabazon West, after discontinuance of pioneer excavation, all main tunnel traffic was detoured through the pioneer while the parallel section of main tunnel was lined with concrete. The placing of curbs was started in September 1937 and the arch in October. The invert was finished in February 1938, completing the lining of this 6,972-foot section. Clean-up, relocation of utilities, and placing of curbs in preparation for arch lining are now under way in the section westerly from the Cabazon adit.

At Potrero, following completion of the arch lining to the west portal in January 1937, preparations were started for extending the lining into the east heading, concurrently with excavation. In August 1937 concrete curbs and invert were first placed, extending from the existing concrete through the by-pass toward the east face. Concrete placing in curbs, invert, and arch has been continuous since that time to totals of 6,109 feet of curb, 6,112 feet of invert, and 5,361 feet of arch up to June 30, 1938.

CONTRACT TUNNELS

Walsh Construction Company, of Davenport, Iowa, was awarded a contract at its low bid on the six schedules comprising the Colorado River, Copper Basin Nos. 1 and 2, and Whipple Mountain tunnels, which formed a large but compact construction job. The preliminary work included the construction of 6 miles of oil-surfaced road to the Whipple adit, 1½ miles of graded road to the Copper Basin adit, 4½ miles of 4-inch water lines and two complete camps, one at Copper Basin adit the other at Whipple adit. The

Colorado River tunnel, 5,482 feet long, was driven from its west portal near Copper Basin camp. At Copper Basin the contractor elected to enter the No. 2 tunnel by means of an adit 12 feet high by 14 feet wide and 330 feet long, driven at his own expense. From this adit a short section of 1,878 feet was driven to the east portal; the track was extended across a small wash; and the 705-foot No. 1 tunnel was completed. To the west of this adit a leg 9,690 feet in length extended to the west portal in Copper Basin. At the Whipple Mountain tunnel the contractor opened both portals but excavated and lined the entire tunnel from an adit, which was 12 feet by 14 feet in section and 924 feet long. The east leg was 18,336 feet in length and the west 13,902 feet.

Winston Bros. Company, of Minneapolis, Minnesota, was awarded a contract for the east portion of the Iron Mountain tunnel and the two schedules of the Coxcomb tunnel. The access to the former was in a saddle where a 160-foot vertical shaft was sunk to tunnel grade at a point 9,902 feet from the east portal and 13,743 feet from the west end of the schedule. The camp and appurtenant buildings were located near the collar of this shaft, through which all work was carried on.

Utah Construction Company, of San Francisco, excavated the west portion of the Iron Mountain tunnel, 16,208 feet long, from the west portal. A 10-per cent incline was required to reach tunnel grade at the portal station. The first 2,949 feet of the tunnel was through a somewhat compacted alluvium, the remainder in granite.

The Coxcomb tunnel, part of the Winston Bros. Company contract, was opened up at both portals with plans for two complete camps to drive both ways. The first camp was built and tunnel excavation started at the east portal. Consistently good progress was made month after month and the contractor completed the entire 17,795 feet from the one point of attack.

Broderick and Gordon, of Denver, Colorado, had contracts for both East Eagle and the east portion of West Eagle Mountain tunnels. The contract for the latter was awarded and work started in the summer of 1933. Access to the tunnel line was through an adit 1,982 feet long, with all camp buildings near the adit portal. The tunnel was driven 7,871 feet from the adit junction to the east portal and westerly 7,974 feet to a connection with the adjoining contract. Upon award on February 2, 1934, of contract for the East Eagle Mountain tunnel the contractor extended compressed air, water, and telephone lines from his existing plant at the adit to the west portal of this tunnel, from which all work was done, installing only such additional equipment as was necessary. The enlarged crews were quartered in the existing adit camp and transported by bus to and from the East Eagle tunnel. The completion of the East Eagle tunnel, 9,440 feet long, on July 23, 1937 was delayed until the portion of cut-and-cover conduit, immediately adjoining the east portal on a high ridge, was finished, as all concrete material was delivered through the tunnel.

L. E. Dixon Company and Bent Bros., Inc., of Los Angeles, were awarded contract for the construction of the west portion of the West Eagle Mountain tunnel. Later a one-third interest in this contract was acquired by William A. Johnson, of Pasadena, and this group completed the contract, working from their camp at the west portal to the point of connection with the adjoining contractor, Broderick and Gordon; the total length of this schedule being 10,649 feet.

Hunkin-Conkey Construction Company, of Cleveland, Ohio, contractor on Hayfield No. 1 tunnel, elected to drive an adit at its own expense 17 feet in diameter and 300 feet long to the approximate midpoint of this 9,734-foot tunnel, instead of entering at the west portal as had been expected.

Shofner and Gordon, of Denver, Colorado, excavated and lined the Hayfield No. 2 tunnel, 5,435 feet long, through the west portal.

The J. F. Shea Company, Inc., of Portland, Oregon, drove the Cottonwood tunnel from the two portals, with two camps, excavating 9,987 feet through the east portal and 10,118 feet through the west. The lining operations however were carried on from the east portal only.

The contract for the three Mecca Pass tunnels was awarded to the Morrison-Knudsen Company, of Boise, Idaho. Work was carried on from a camp located near the east portal of the 4,605-foot No. 3 tunnel, the longest of the group, and was first started westerly from this portal. The two shorter tunnels, 338 and 997 feet, were driven from their west portals. This was the first of the tunnel contracts to be completed, notice being filed March 11, 1935.

The Whitewater tunnels were driven by West Construction Company, of Boston, Massachusetts, the No. 2 with a length of 8,172 feet being excavated from its east portal, followed by No. 1 from its west portal, a distance of 2,060 feet. The camp was located at the east portal of the No. 2 tunnel. These tunnels being beyond the range of service of the District water system the contractor secured his supply from the Whitewater River line of the Palm Springs Water Company, but received his power and telephone service from the District lines. Lining operations were subcontracted to L. E. Dixon Company, which placed concrete first in No. 2 from west to east, then in No. 1 from east to west, with forms and equipment later used in Hayfield No. 2, west portion of West Eagle, and West Iron Mountain tunnels.

The Bernasconi tunnel was awarded to the Hamilton and Gleason Company, of Denver, Colorado. A small camp was established at the east portal, where entry was made by an incline through the valley fill. Near the location of the west portal the contractor excavated an air shaft to the surface to aid ventilation while completing the excavation and lining of the 6,220 feet of tunnel. The camp water supply was obtained from the Fairview Farms system and power and telephone service from the District lines.

Valverde tunnel, fourth in point of length, was divided into two schedules, both of which were awarded to Dravo Contracting Company, of Pittsburgh, Pennsylvania, on its combination low bid. Excavation was carried on in both directions from three vertical shafts and one inclined adit without opening the portals, except sufficiently at the west end, in conjunction with the adjoining contractor, to permit removal of tunnel lining forms and equipment. The water supply was obtained from the tunnel and from wells on the tunnel right of way, but power and telephone service were supplied from the District systems.

In Table 14 all main aqueduct tunnels are listed with cost and other data for completed features. All tunnels except San Jacinto were completed prior to June 30, 1938. The total cost includes the contract earnings, all materials supplied by the District such as cement and steel support, and all administration and engineering expense in connection with the entire job. The cost per foot includes strictly tunnel items and, also, all costs of access excavation and approach section concrete if any were placed.

Table 14

MAIN AQUEDUCT TUNNELS

Tunnel	Contractor	Contract awarded	Work completed	Length in feet	Total cost	Cost per foot
Colorado River	Walsh Constr. Co.	June 16, 1933	Jan. 29, 1936	5,482	$ 633,345.72	$115.53
Copper Basin Nos. 1 and 2	Walsh Constr. Co.	June 16, 1933	Feb. 23, 1936	12,273	1,348,174.57	109.85
Whipple Mt.	Walsh Constr. Co.	June 16, 1933	Feb. 24, 1937	32,238	3,113,342.46	96.57
Iron Mt. (E. portion)	Winston Bros. Co.	Apr. 21, 1933	Oct. 30, 1936	23,645	3,080,200.68	130.27
Iron Mt. (W. portion)	Utah Constr. Co.	Apr. 21, 1933	Feb. 26, 1937	16,208	2,274,286.06	140.32
Coxcomb	Winston Bros. Co.	Apr. 21, 1933	Apr. 22, 1937	17,795	2,206,957.04	124.02
East Eagle Mt.	Broderick & Gordon	Feb. 2, 1934	July 23, 1937	9,440	1,050,260.79	111.26
W. Eagle Mt. (E. portion)	Broderick & Gordon	June 2, 1933	May 6, 1937	15,845	1,954,611.68	123.36
W. Eagle Mt. (W. portion)	L. E. Dixon & Bent Bros.	June 2, 1933	Mar. 12, 1936	10,649	1,347,563.46	126.54
Hayfield No. 1	Hunkin-Conkey Const. Co.	June 2, 1933	Jan. 9, 1936	9,734	1,176,379.62	120.87
Hayfield No. 2	Shofner & Gordon	June 2, 1933	July 27, 1935	5,435	654,295.43	120.39
Cottonwood	J. F. Shea Co., Inc.	Apr. 21, 1933	Dec. 27, 1935	20,105	2,736,891.18	136.13
Mecca Pass Nos. 1, 2, & 3	Morrison-Knudsen Co.	June 2, 1933	Mar. 1, 1935	5,940	797,968.93	134.34
Whitewater Nos. 1 & 2	West Constr. Co.	June 16, 1933	Apr. 15, 1935	10,232	1,282,924.70	125.38
Bernasconi	Hamilton & Gleason Co.	Apr. 7, 1933	Nov. 18, 1935	6,220	493,174.20	79.29
Valverde	Dravo Contracting Co.	Apr. 7, 1933	Oct. 18, 1936	38,015	4,630,268.18	121.80
	TOTAL			239,256	$28,780,644.70	$120.29
Coachellas	District force account	Dec. 21, 1932	May 8, 1937	178,142	$17,671,717.91	$ 99.20
San Jacinto	Contract and District	Feb. 10, 1933	Uncompleted	68,843	....	....

CHAPTER 9

Canal, Cut-and-Cover Conduit, and Inverted Siphons

IN THE DESERT areas traversed by the aqueduct, from the Whipple Mountains to Hayfield more than half of the surface work consists of lined canal. Between the mountain masses are great valleys and basins characterized by alluvial fans sloping gently from the mountains to the line of contact with opposing fans. There are very few well-defined water courses in these valleys and therefore the fans are relatively smooth, except in occasional areas of blow sand or along dissected mountain slopes. Because of uniformity of cut, regularity of slope, and simplicity of cross drainage problems these fans are ideal locations for canal. Used in combination with cut-and-cover conduit for crossing eroded and blow-sand areas and siphons for crossing washes and extended depressions, 62.02 miles of lined canal have been economically employed for this easterly portion of the aqueduct.

Westerly from Hayfield to San Jacinto tunnel the surface schedules of the aqueduct lie close to the mountains or cross broad canyons between the mountain ridges; between the San Jacinto and Valverde tunnels they cross the San Jacinto and Perris valleys. In these areas ample evidence exists of infrequent but heavy rains with large and rapid run-off. Moreover danger of pollution to water in open channels is present because of proximity to human habitations and to centers of population. Along this portion of the project only closed types of surface construction are used. These consist of cut-and-cover conduit and inverted siphons built well down in the ground, in such a way that floods will flow over the top without damage.

Excavation

The excavation for the surface schedules was predominantly in alluvial materials which could be readily dug by standard machines. In some areas partial cementation of these materials made digging somewhat difficult, while in others the alluvial deposits were sufficiently cemented at varying depths and in varying percentages of the section to be given a rock classification. This latter condition was found west of the Whipple Mountains, along the east slopes of the Eagle Mountains, and on the west side of Bernasconi Mountain. The usual procedure in breaking the cemented material was to sink churn drill holes to subgrade staggered along both sides of the center line and blast in advance of excavation.

Hard granitic rock occurred continuously along the ridge between the top of the Eagle pump lift and East Eagle tunnel, and at numerous isolated points such as the vicinity of the Mecca Hills and the north slopes of the Lakeview Mountains. Drilling in granitic rock was almost universally done with light air-hammer drills. Approximately 10 per cent of the total yardage excavated for the open work schedules was classified as rock.

The all-rock section of cut-and-cover conduit and siphons extending for nearly a mile westerly from the Eagle pump lift was drilled and blasted in benches. Center line depths along the conduit in this stretch varied from 22 to 50 feet, but along the siphons rarely exceeded 12 feet. A $1\frac{3}{4}$-yard shovel was used for the rough excavation. On the steep slopes of the siphons it was necessary to anchor the rear end of the shovel by cable to prevent overturning. Access to this work during the excavation period over a narrow road built on a 25 per cent grade was very difficult. On the north slope of the Lakeview Mountains the rock presented no unusual features.

Draglines with bucket capacities of 1 to 6 cubic yards on 50- to 90-foot booms and with walking or caterpillar traction did the major portion of the open work excavation. They were powered by gasoline or Diesel engines, or by electric motors. In some cases, one dragline on the aqueduct center line made the entire rough excavation; in others two draglines were used, one following the other and each taking half the cross section. In deep cuts, two or more lifts were required and it was then necessary to rehandle the excavated material. Tractor-operated bulldozers and track-type tractors with carryall scrapers were extensively used in grading ahead to facilitate dragline operation and to make the initial excavation at high ridges. Bulldozers also did much of the leveling for the construction roads and the fine grading of the bottom of the trench in preparation for concrete.

Excavation generally was continued through the summer season, particularly on canal work, in order to keep ahead of the concrete operations, which latter proceeded much more rapidly than the trench excavation and the fine grading of the invert foundation.

Concrete

Aggregate for the desert schedules was produced from gravel pits located usually along the line but not necessarily within the limits of the respective schedules. For Schedules 4, 5, and 6, near Rice, aggregate was shipped by rail from a pit near Earp. For the work west of San Jacinto tunnel, aggregate was purchased from commercial pits and shipped by rail to the batching plants of the contractors. The concrete was proportioned by weight and all weighing of aggregate, as well as cement, was closely controlled under constant inspection. Cement was delivered in bulk either directly to contractors' batching plants or to the nearest railhead, in which latter case it was hauled to the work by the contractor at his bid price per ton-mile of haul.

In general, no concrete was placed in the surface work in the desert during the months of June, July, August, and September. At other times of the year when the maximum daily temperature in the shade exceeded 90°, the placing of concrete was restricted to the time beginning two hours before sunset and ending three hours after sunrise. West of San Gorgonio Pass, placing of concrete was permitted during the summer months but only at night.

All mixing, placing, and curing of concrete were subject to rigid inspection. Samples of concrete were taken from the mixers by District inspectors and placed in cylindrical containers. These concrete test cylinders were taken to the Banning laboratory for testing, the results being checked against earlier tests made by the District on cylinders using aggregate from the same sources; also the test results served to control the proportions of the mix.

Exposed surfaces of concrete were treated with two coats of coal-tar pitch cutback sealing compound to retain moisture until the concrete had thoroughly set. These were followed by a heavy coat of whitewash to prevent absorption of the heat of the sun. All interior surfaces in cut-and-cover conduit and inverted siphons, with the exception of conduit invert, which was placed as an exposed slab, were cured by water spraying for a period of not less than 14 days.

Late in 1933, while final designs for the surface schedules were under way, construction of experimental sections was started in order to check assumptions as to distribution of external loads, foundation reactions, and the effects of temperature variation and of various methods of curing and backfilling. These sections, which now form permanent parts of the aqueduct, are located in the Coachella division. They include 890 feet of full-capacity cut-and-cover conduit, and 790 feet of half-capacity cast-in-place siphon with transition structures, all built by District forces in the Fan Hill area; and 660 feet of half-capacity precast siphon, built under contract across Little Morongo Canyon. Observations were made of temperatures in the concrete during setting, after applications of curing compound and of curing compound and whitewash, and finally after being covered with the backfill material. Stresses in the concrete were determined from measurements of strains in various sections with strain gages and meters, or from measured changes in shape under varying conditions of loading. Foundation and earth pressures were measured by means of pressure cells distributed around the entire exterior of the section. In general, the results of the field tests were in close agreement with the design assumptions, and no important changes in design were indicated.

Start of work

First specifications for the surface work, consisting of canal, cut-and-cover conduit, and inverted siphons, were issued August 27, 1934, and covered 16 schedule groups extending from the Whipple Mountain tunnel to the East Coachella tunnel. The total length as given in the specifications was 110.62 miles, and included 62.33 miles of canal, 33.65 miles of cut-and-cover conduit, and 14.64 miles of inverted siphon. Many bids were received for each schedule group, with contractors in some cases bidding for combinations of schedules, resulting in award of the 16 groups in seven contracts.

Construction of the surface work between the East Coachella tunnel and Cajalco, consisting of seven schedule groups comprising 20.42 miles of cut-and-cover conduit, 13.22 miles of inverted siphon, and 0.91 mile of unlined canal leading from Valverde tunnel into the reservoir, was provided for by the end of 1934. Authority was given District forces to build the sections between the Coachella tunnels, and three contracts were awarded for the other six groups.

Certain miscellaneous structures which form a part of the surface work adjacent to the pump lifts were included in the pumping plant contracts. The full-capacity siphon between the Gene reservoir and pumping plant and the similar siphon connecting Copper Basin No. 1 and No. 2 tunnels were awarded with the Gene plant.

The box siphon within the area of the Hayfield pumping plant was awarded with that plant.

The first excavation on the surface work was started November 27, 1934 on Schedule 8, followed by other schedules in December, and after the turn of the year. Concrete placing was begun at the end of January 1935, but on the desert schedules was suspended for the summer period on May 31st.

Camps were set up for all work east of San Jacinto tunnel, but west thereof the contractors' forces found their own quarters in San Jacinto, Lakeview, Nuevo, Perris, and other nearby towns. Some of the desert camps were of the portable type built and operated by commissary companies as subcontractors; others were built by the contractors but operated by commissary companies; still others were built and operated by the contractors themselves; and in several cases men employed on the surface work were cared for in existing tunnel camps. At all points of work many of the men lived with their families in trailers, tents, and cabins adjacent to the contractor's camp where water could be obtained and sometimes electricity.

LINED CANAL

A normal cross section of lined canal with its hydraulic properties is illustrated in Fig. 13. The slope of .00015 or 0.792 of a foot per mile is steeper than the theoretically economic gradient but is necessary to provide sufficient velocity of flow to move sand which may blow into the stream to the sand traps. Lined canal is lowest in cost per linear foot to construct of any aqueduct section. It requires least slope for its operation, which in turn reduces the required pump lift. It was therefore desirable to make use of this section wherever permissible, even though it is more subject than closed and buried conduit to damage from floods. However, with the canal set well down into the ground and protected by embankments, and with diagonal and parallel drains or training ditches on the uphill side to divert water to surface crossings at siphon loca-

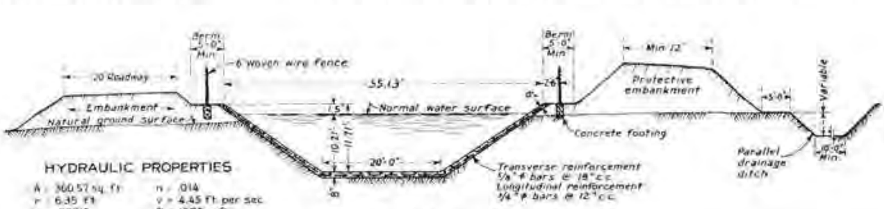
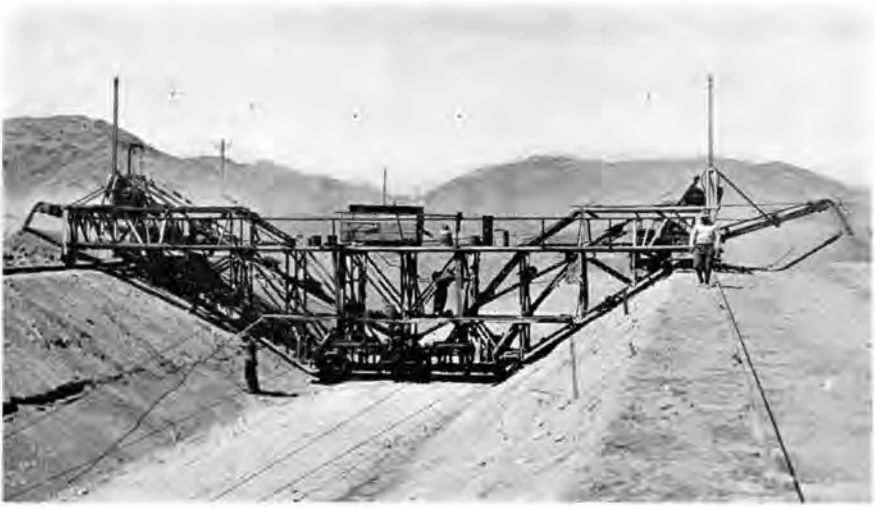


Fig. 13—Canal section in earth

tions, every possible precaution has been taken against flood damage. A freeboard of $1\frac{1}{2}$ feet of concrete lining above normal water surface with full-capacity flow is provided for protection of embankments from scour by water in the canal itself. To maintain this freeboard, particularly during heavy storms directly over and along the canal section, concrete-paved depressions or spillways



Canal trimming machine

are constructed at intervals in the canal embankment. These spillways, with a lip $3\frac{1}{2}$ inches above the normal water surface, are 40 feet wide at the canal lining and extend across the berm and roadway.

Small sand traps with square openings the full width of the canal invert and hopper sides sloping to a well $8\frac{1}{2}$ feet below are used at strategic points along the canal as collectors for such sand as may blow into the stream. At the Iron Mountain, Eagle Mountain, and Hayfield pumping plants large sand traps have been constructed as a final measure of protection for the pumps from any gritty material which might be borne along by the flowing water.

Wasteway structures controlled by radial gates and capable of discharging in event of necessity the entire aqueduct flow into natural drainage channels were built into the canal sections at Vidal Wash in Schedule 3, at Rice in Schedule 5, at Division 2 in Schedule 8, and in the approach to the east portal of Coxcomb tunnel at the end of the canal in Schedule 10. Additional wasteways were built in the conduit sections, as later described.

In the excavation of the canal prism the final trimming was done with care and accuracy to insure the required thickness of lining being placed upon a compact foundation without waste of concrete. Dragline operators became remarkably skillful in taking out the entire rough excavation in alluvial materials to within a few inches of the finished lines. In the beginning of canal work the final trim was made largely by slow and costly hand methods with one exception. On Schedule 8 the contractor, Wood and Bevanda, devised and constructed a canal trimmer to prepare the entire fine grade in one operation. This machine was so successful in fast performance at low cost that other machines of identical or similar pattern were generally adopted for all canal work following the 1935 summer shutdown period.

The estimated average excavation per linear foot of canal was 18.63 cubic yards. The pay average per linear foot was 17.15 cubic yards. The average bid price for common excavation was 20 cents per cubic yard with a low of 16 and high of 25 cents. The average bid price for rock excavation was 60 cents ranging from 55 cents to one dollar per cubic yard.

Canal lining machine

Completed canal in desert

Lining methods

Following close behind the trimming was the placing and tying of reinforcement steel, with the network resting upon concrete pedestals of proper height to fix the position of the reinforcement in the concrete lining. The weight of high elastic limit steel per linear foot of canal is approximately 147 pounds.

The concrete lining followed closely behind the placing of steel. At the start of lining operations early in 1935 various methods were tried. One involved placing the invert slab entirely by hand, followed by the placing of the side slopes which were screeded from a machine built to span the canal section. Another attempted to use a road paver and place the bottom and sides in separate operations similar to highway paving; still another used a machine spanning the canal with buggies to distribute concrete in invert or side slabs, whichever was being placed. These methods all proved too costly and were abandoned for lining with the Wood or similar type paver, designed by the same contractor who had devised a successful canal trimmer. These machines consist essentially of a steel slip form, having the same dimensions as the sides and bottom of the lined canal, suspended in the canal from transverse steel trusses mounted on dollies and supported on tracks laid along the two banks. Concrete of relatively dry consistency is fed from the top, through hoppers, along the front of this form and is vibrated or

Canal transition into Coxcomb tunnel

otherwise worked into place as the form structure is moved forward slowly and continuously by power winches. A dense solidly packed lining results, conforming accurately to the required dimensions. To increase the smoothness and improve the surface texture the entire exposed surface of the lining is hand trowelled, after which it is treated with sealing compound and whitewash.

The quality of the concrete placed by the pavers is generally superior to that possible to obtain by older methods, with the added advantage that there is no construction joint at the junction of the invert slab and side slope paving. Their speed was quite remarkable, more than 530 feet of complete lining being placed per eight-hour shift for long runs and a record run of 3,772 feet being made by a single machine in a seven-shift week.

The actual pay quantity of concrete per linear foot of canal was

1.41 cubic yards, compared with an estimated 1.44, and the average cement content per cubic yard was 1.36 barrels.

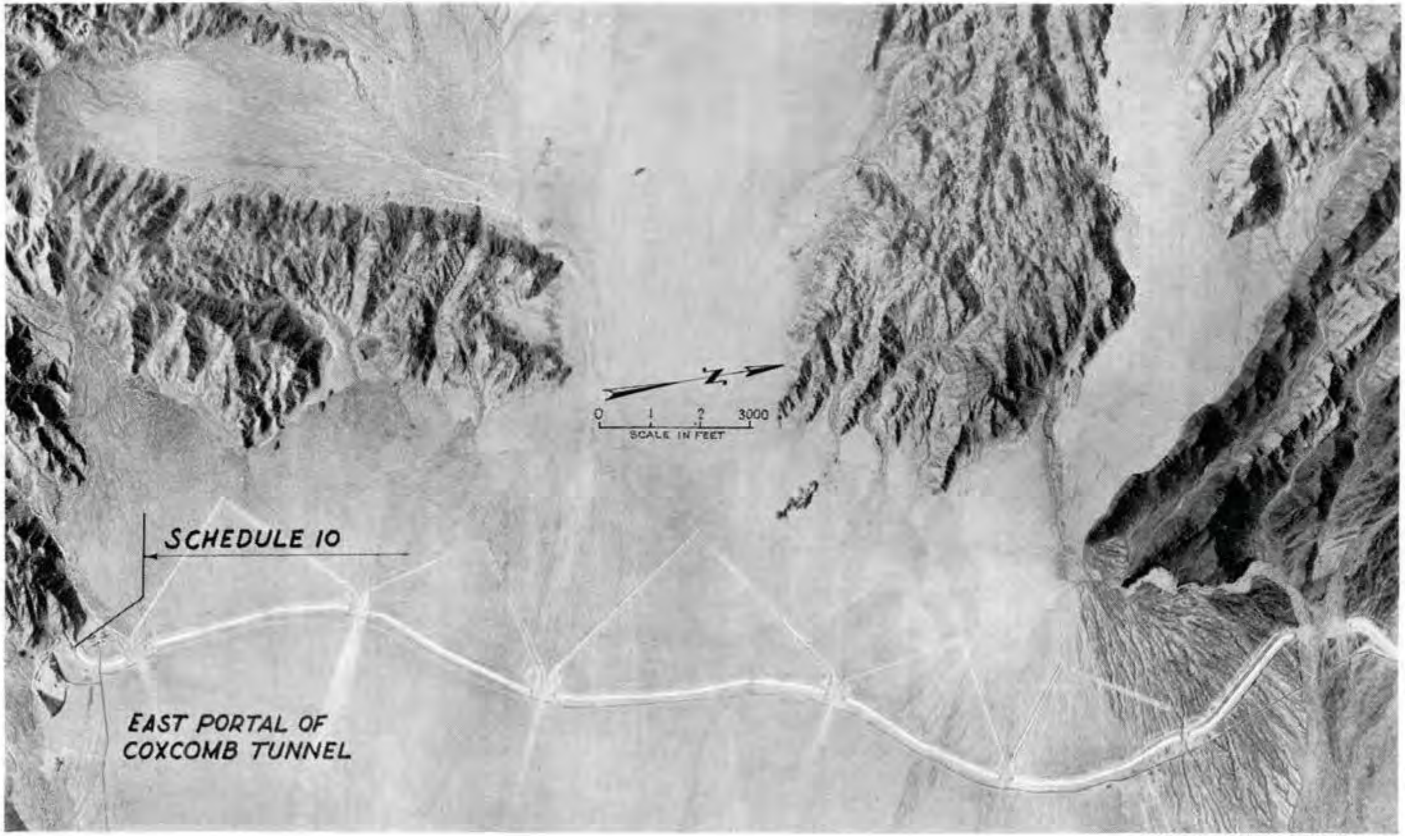
Protective works

For the protection of the canal from floods, diagonal training ditches of varying widths and depths have been excavated on the uphill side to divert water to natural channels where inverted siphons beneath the surface permit flow across the right of way without damage. Where necessary, parallel drains have been excavated along the upper embankment to divert to the siphon crossings any water which comes from the area below the diagonal ditches. At vulnerable points in the drains rock riprap has been dumped to prevent erosion of the alluvial materials. At siphon headwalls riprap was placed as a rock blanket one foot thick held between top and bottom layers of wire mesh securely tied together. This blanket was laid on a carefully dressed slope and extends from the level of the siphon barrel up to the top of the headwall embankment and around the sides to the canal embankments. Where the canal parallels the Santa Fe railroad this latter type of protection was used for canal embankment at points of intersection of the upper embankment with the existing railroad training ditches.

In the final clean-up and shaping of excavated material the embankments on the uphill side of the canal were leveled off with bulldozers and graders to a minimum top width of 12 feet and a height above top of canal lining of not less than 6 feet. The downhill embankment, used as a roadway, was left with a minimum width of 20 feet and a minimum height of 18 inches. The leveled-off tops of the embankments were finished with a slight slope away from the canal. Berms with a width of 5 to 10 feet were left between the canal lining and the bottom of each embankment slope.

Fencing

The canal sections are enclosed their entire length with woven wire mesh and barbed wire attached to steel posts set in concrete, making a fence about 6 feet high. Gates are spaced at convenient intervals for access. The total length of fence is approximately 126 miles and the cost 54.7 cents per foot of fence. This work was done under contracts with the Anchor Post Fence Co., of Baltimore, Maryland, and the Pittsburgh Steel Company, of Pittsburgh, Pennsylvania, and was completed June 14, 1938.



FAIRCHILD AERIAL SURVEYS, INC.

Aerial view of canal and drainage system

Contract and cost data

The table on page 190 lists the aqueduct canal schedules, all of which have been completed, and gives the principal data covering that work. In addition to the schedules given in the table there are short sections of special canal at the Iron Mountain, Eagle Mountain, and Hayfield sand traps and 5,568 feet of unlined channel from the west portal of Valverde tunnel leading into Cajalco reservoir. All canal construction was contracted. In the table the total cost includes all District items, cement, reinforcement steel, gates and valves, curing compound, administration, and engineering.

CUT-AND-COVER CONDUIT

Between the Whipple Mountain tunnel and Hayfield reservoir cut-and-cover conduit is used only to cross areas subject to sudden and extensive flooding or to severe blow-sand conditions, and in deep cuts at tunnel portals. From Hayfield to Valverde, however, all grade flow, with the exception of tunnels, is in cut-and-cover conduit, no lined canal being used. Cross sections of the cut-and-cover conduit in earth and in rock are shown in Fig. 14. These are standard for the schedules east of San Jacinto tunnel, where the slope of .00045 makes a drop per mile of 2.376 feet. To the west of San Jacinto the slope is increased to .00056, or 2.957 feet per mile, and the height decreased from 16 feet to 15 feet 4½ inches.

In general the conduit section was constructed of plain concrete. The invert was placed first, considerably in advance of the arch,

Canal wasteway gates

Table 15

MAIN AQUEDUCT CANALS

Schedule	Contractor	Contract awarded	Work completed	Length in feet	Total cost	Cost per foot
3	Barrett & Hilp and Macco Corp.	Oct. 19, 1934	May 25, 1937	28,154	$ 827,016.60	$29.37
4	Jahn & Bressi Construction Co.	Oct. 19, 1934	Mar. 18, 1937	50,143	1,094,612.36	21.83
5	Jahn & Bressi Construction Co.	Oct. 19, 1934	Nov. 17, 1936	49,568	1,077,345.34	21.73
7A	Barrett & Hilp and Macco Corp.	Oct. 19, 1934	Jan. 25, 1936	15,357	428,303.32	27.89
8	C. W. Wood and M. J. Bevanda	Oct. 19, 1934	July 28, 1937	41,449	962,873.73	23.23
9	Utah Construction Co.	Oct. 19, 1934	May 15, 1937	41,164	1,044,960.82	25.39
10	Aqueduct Construction Co.	Oct. 19, 1934	April 6, 1936	39,655	935,027.58	23.58
11	Aqueduct Construction Co.	Oct. 19, 1934	June 24, 1937	33,682	789,782.02	23.45
13	Aqueduct Construction Co.	Oct. 19, 1934	Jan. 30, 1937	28,300	628,764.49	22.22
	TOTAL			327,472	$ 7,788,686.26	$23.78
Canal section in pumping plant contracts				4,164		
Unlined:						
23A	Griffith Company	Dec. 7, 1934	Oct. 24, 1936	5,568	$ 143,819.38	$25.83

and the arch was placed between inside and outside forms set upon and attached to the invert concrete. The abutments are flared out in alluvial material to provide bearing area, but in solid rock this is unnecessary. Contraction joints, with steel water stops coated with coal-tar paint and extending one foot higher than the normal water surface, occur at 35-foot intervals. The joints are of two kinds, construction and dummy. Their purpose is to confine any

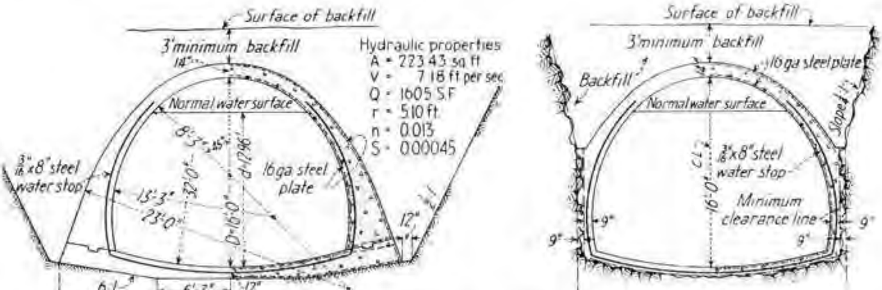


Fig. 14—Conduit sections

cracking of the concrete due to contraction to sections where the water stops will prevent leakage. Construction joints occur at the ends of each placing operation, where a plain steel plate spans the joint. Dummy joints are set at the 35-foot points between the construction joints and are embedded in the concrete as placing proceeds. They consist of a similar coal-tar painted steel plate to which fins of lighter plate are welded at right angles along the mid line. The fins are extended up to the top of the arch. At each joint the plate in the arch section is welded to that previously placed in the invert.

On firm and unyielding foundation the invert acts merely as a strut or tie and needs no reinforcement. On yielding foundations or under great depths of backfill and at railroad and highway crossings two types of reinforced section are provided, one treated as a complete elastic ring with reinforcement throughout the section, the other as a combination of unreinforced arch and reinforced supporting invert.

On the longer reaches of cut-and-cover conduit special means of access to the interior are provided. Rectangular openings 2 feet 6 inches by 8 feet 8 inches in the crown of the arch are spaced 2,000 feet apart, and there are occasional openings through which a truck

Cut-and-cover conduit

can be lowered. These latter openings are located at transitions between conduit and siphons, and other places where the length of the conduit without means of access by truck is greater than four miles. Two wasteway structures were built in the cut-and-cover conduit section, one a short distance west of the Whipple Mountain tunnel, and another near the east portal of San Jacinto tunnel in San Gorgonio Wash.

Excavation

For the normal section of conduit with 3 feet of backfill over the top of the structure the trench excavation in alluvium is a little more than 21 feet deep and 30 feet wide at the bottom. No trimming was necessary on the side slopes but the bottom, which becomes the foundation for the invert slab, was trimmed by hand or machine to the required lines, and sprinkled and rolled, usually with 10-ton rollers, to secure the requisite compaction. In sandy or unconsolidated material excavation progress at the rate of 240 feet per day was not uncommon. In the conduit excavation the pay quantity has averaged 41.4 cubic yards per linear foot, and the average contract prices were 20 cents per cubic yard for common excavation and $1.09 for rock.

Concrete

The invert slab was placed upon a well-moistened subgrade in a manner similar to that used in constructing concrete highways. The portion of the surface to be in contact with flowing water was hand finished by trowelling, while the portions upon which the arch rests and to which it is bonded were thoroughly cleaned and roughened by water-and-air jets before the concrete had entirely set, and then covered with wet burlap until ready to receive the arch pour. The arch forms were of heavy steel construction, the inside forms being collapsible for moving ahead on a traveler running on a track, similar to that used in tunnel lining operations, and the outside forms being extensible for moving out or up from the con-

Constructing conduit in deep cut

crete and forward to a new setting by a gantry running on a track outside the invert. After fixing the forms in position, with a bulkhead at the open end, the concrete was placed as a continuous operation, the length of forms usually being some multiple of 35 feet, which is the specified distance between contraction joints. After the forms were stripped the exterior surface was kept wet until the

Constructing conduit

sealing compound could be applied, followed by a dense coating of whitewash. The inside forms were left in place longer than the outside. After removal of forms the interior surface was given a 14-day curing treatment with water spray or mist. Thorough inspection of the concrete was made after stripping the forms and imperfections were carefully repaired. Satisfactory results have been secured throughout, both in quality of concrete and smoothness of interior surfaces.

The invert and arch placing were generally carried on concurrently, the invert work being kept several hundred feet in advance of the arch. The record progress per day over a six-day period with a single concreting shift each day was 224 feet of completed conduit. Rates of 175 feet and 200 feet per day were readily maintained for long periods. The pay quantity of concrete per linear foot of conduit was 4.20 cubic yards, and the amount of cement per cubic yard of concrete averaged 1.33 barrels.

Backfilling of the trench was generally started as soon as the concrete had acquired sufficient strength to take the load, the fill being brought up fairly uniformly on both sides and in normal section mounded evenly over the right of way.

Contract and cost data

The principal contract and cost data for the cut-and-cover conduit schedules, all of which have been completed, are given in Table 16. The total costs include all District items. The cut-and-cover

Completed conduit before backfill

conduit was contracted with the exception of those portions between the Coachella tunnels, which were built by the District organization constructing these tunnels.

INVERTED SIPHONS

The crossing of drainage channels, ravines, and other depressions along the aqueduct route requires the use of various types of inverted siphons, having for the entire main aqueduct a total

TABLE 16

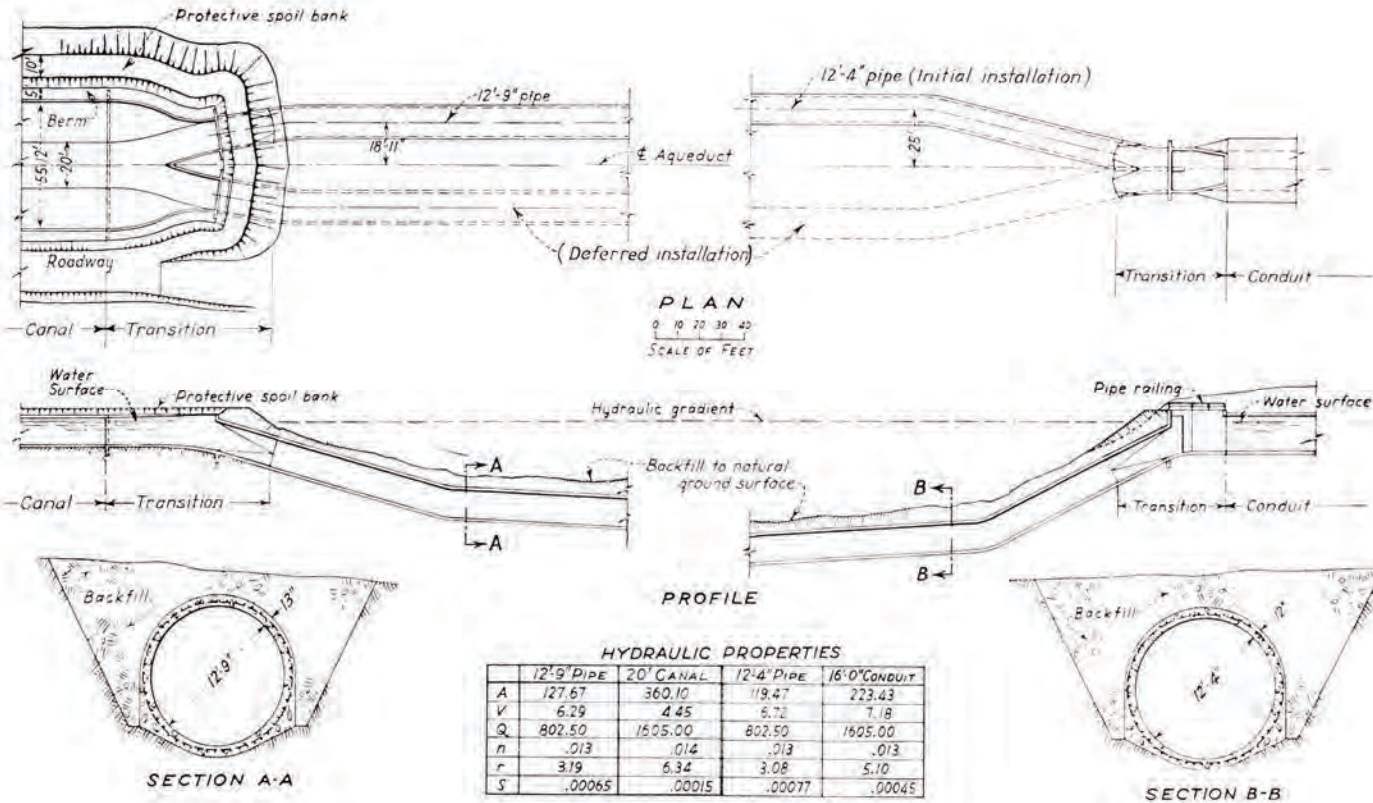
MAIN AQUEDUCT CUT-AND-COVER CONDUITS

SCHEDULE	CONTRACTOR	CONTRACT AWARDED	WORK COMPLETED	LENGTH IN FEET	TOTAL COST	COST PER FOOT
1	Aqueduct Construction Co.	Oct. 19, 1934	July 14, 1936	20,325	$ 1,382,279.31	$68.01
2	Barrett & Hilp and Macco Corp.	Oct. 19, 1934	May 25, 1937	24,584	1,358,341.77	55.25
7	Barrett & Hilp and Macco Corp.	Oct. 19, 1934	Jan. 25, 1936	12,350	785,628.86	63.61
9A	Utah Construction Co.	Oct. 19, 1934	May 15, 1937	3,289	232,779.88	70.78
11A	Aqueduct Construction Co.	Oct. 19, 1934	June 24, 1937	3,188	186,251.79	58.42
12	Three Companies, Inc.	Oct. 19, 1934	Nov. 6, 1937	31,233	1,734,347.59	55.53
13A	Aqueduct Construction Co.	Oct. 19, 1934	Jan. 30, 1937	1,005	65,131.41	64.81
14	Thompson-Starrett Co., Inc.	Oct. 19, 1934	June 3, 1936	30,222	1,290,117.89	42.69
15	Thompson-Starrett Co., Inc.	Oct. 19, 1934	July 31, 1937	33,953	1,396,373.98	41.13
16	Thompson-Starrett Co., Inc.	Oct. 19, 1934	May 20, 1938	17,139	817,848.02	47.72
18	J. F. Shea Co., Inc.	Nov. 9, 1934	Aug. 14, 1937	26,887	1,202,217.37	44.71
19	J. F. Shea Co., Inc.	Nov. 9, 1934	May 30, 1938	34,870	1,606,453.04	46.07
23	Griffith Company	Dec. 7, 1934	Oct. 13, 1936	33,145	1,387,726.60	41.87
Fan Hill	Met. Water District force account	Oct. 13, 1933	Nov. 19, 1934	890	106,558.16	119.73
17 & 17A	Met. Water District force account	Nov. 2, 1934	June 15, 1937	12,331	604,900.75	49.06
	TOTAL			285,411	$14,156,956.42	$49.60
Modified conduit in tunnel contracts				2,111		

length of 28.7 miles. There are 144 inverted siphons ranging in length from 175 feet to 26,400 feet and in operating head from a few feet to 153 feet. All siphons with the exception of the Little Morongo experimental precast pipe are constructed of cast-in-place reinforced concrete and are of three distinct types, a single circular barrel, two parallel circular barrels, and three square barrels. For short siphons of low head between sections of tunnel or cut-and-cover conduit a single 16-foot barrel of full capacity is used. If the siphons are of considerable length and subjected to heads higher than 25 feet the two-barrel type, each of half capacity, is more economical, with construction of one barrel deferred until such time as water demand makes it necessary. The diameter of each barrel in this case varies from 11 feet 5 inches to 12 feet 9 inches according to location and operating conditions. This type, as used with canal, conduit, and tunnel, is shown in Fig. 15. The thickness of shell is approximately one inch for each foot of pipe diameter. Short siphons of low head between canal sections are most economical when designed as a three-barrel rectangular box and constructed as a single unit. The three barrels, each 9 feet 9 inches square, with sufficient capacity to carry the full aqueduct flow are illustrated in Fig. 16. The cost of transition structures at the ends of the siphon had a decided influence on the selection of the type to be used.

Where siphons were comparatively short and occurred within lengths of the aqueduct suitable for a single construction contract, they were combined with the major work in schedule groups, about half the total length of siphon being included with other work in this way. The remainder, consisting entirely of 12 foot 4 inch siphon, generally in long sections, was contracted in six separate siphon schedules.

Estimates of cost of different kinds of construction for the inverted siphons, together with actual experience on the experimental sections at Fan Hill and Little Morongo, indicated the economy of cast-in-place concrete construction under main aqueduct conditions. In general, however, alternative bids were invited for cast-in-place and precast construction for the half-capacity siphons. For several schedules bids were also invited for welded steel pipe. The bids confirmed the decided economic advantage of cast-in-place concrete construction as indicated by the District's estimates.



HYDRAULIC PROPERTIES

	12'-9" Pipe	20' Canal	12'-4" Pipe	16'-0" Conduit
A	127.67	360.10	119.47	223.43
V	6.29	4.45	6.72	7.18
Q	802.50	1605.00	802.50	1605.00
n	.013	.014	.013	.013
r	3.19	6.34	3.08	5.10
S	.00065	.00015	.00077	.00045

Fig. 15—Half-capacity circular siphon

Fault crossings

The desert portion of the aqueduct extending from the river to the northern part of Coachella Valley—nearly 200 miles—is believed to cross no active earthquake faults. Beyond this point, however, major faults are crossed by the Big Morongo, San Andreas, and Casa Loma siphons. Although the cast-in-place type of construction is exceptionally resistant to the vibrations and shocks that may be produced by an earthquake, any actual displacement of ground across a rigid siphon is likely to extend the damage for a considerable distance because of the continuity of the structure. In fault zones therefore the cast-in-place construction was broken every 20 feet by joints capable of transmitting shear but no tension. In case of earthquake disturbance and displacement of ground these joints will give the siphons the desired flexibility, and, should an actual rupture occur in the line, will confine the damage to a short length. As a precaution against possible vertical displacement of the ground an additional drop of 2½ feet over that required by siphon losses was provided in the hydraulic gradient of each of the above siphons.

Siphon construction on Coachella division

Excavation and backfill

In alluvium the sides of the cut were excavated to as steep a slope as would stand, and left rough; the bottom was trimmed and compacted to a finished subgrade. In the wet material encountered in crossing the San Jacinto Valley a blanket of broken rock was shaped to grade in the trench bottom to provide a permeable and stable base which could be kept drained while the concrete was

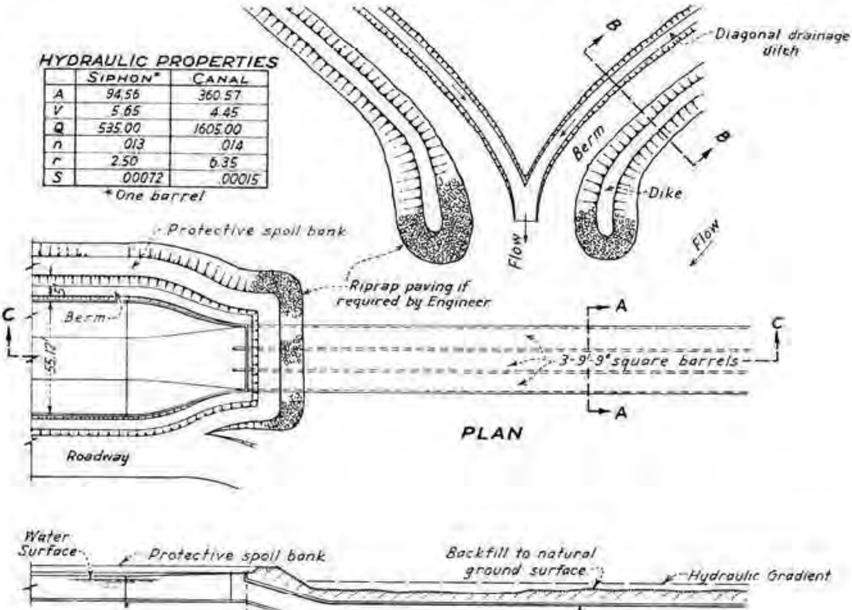


Fig. 16—Square-barreled siphon

being placed upon it. In rock sections the excavation for the future second barrel was done at the same time to avoid the possibility of later damage by blasting alongside the section in use.

Big Morongo siphon

The excavation per linear foot was slightly less than had been estimated, varying from 16.8 cubic yards for the 12-foot 4-inch circular siphon, to 25.4 for the box siphon, and 30.8 for the 16-foot full capacity circular siphon.

Except for the Eagle Mountain siphon, which is in rock cut throughout, all siphon trenches are backfilled, the surplus material being spread over the right of way without filling any existing channel, or being used to build up headwalls and embankments, preparatory to the laying of the riprap blanket for protection of the canal section during flood run-off.

Concrete

The placing of concrete in the siphons involved greater difficulties than in cut-and-cover conduit or canal because of the heavy steel reinforcement, and the steep slopes of some of the depressions which were crossed.

In the circular siphons the transverse reinforcement hoops were formed, butt-welded, and tested by the District before delivery to the contractors. This fabrication was done in two shops, one at Rice, the other at Indio. The longitudinal steel was furnished in commercial lengths and was continuous in all cast-in-place siphons except those crossing active faults and in a 1,700-foot section of the Pinto siphon. The reinforcement cages were supported on concrete piers set into the subgrade, steel bolts being anchored in the

Canal transition to box siphon

piers to support the inside forms. In moving the inside forms the bottom sections which act as track for the form carriage were lifted, moved through the carriage, and set on the pier bolts in an advanced position, after which the top sections were collapsed onto the carriage and moved ahead. The outside forms were moved in much the same way as for the cut-and-cover conduit. The concrete was placed in one continuous operation between bulkheads for varying lengths, depending upon the length of the contractor's forms.

For the box siphons concrete was poured first in the invert, being screeded and hand trowelled except where the walls joined the floor slab. The steel forms were then moved into position and the walls and top slab completed.

Transitions at the ends of the siphons have shapes depending

Eagle Mountain siphon

TABLE 17

MAIN AQUEDUCT FULL-CAPACITY SIPHONS

SCHEDULE	CONTRACTOR	CONTRACT AWARDED	WORK COMPLETED	NO. OF SIPHONS	LENGTH IN FEET	TOTAL COST	COST PER FOOT
			Siphons with single 16′-0″ diameter barrel				
1A	Aqueduct Construction Co	Oct. 19, 1934	July 14, 1936	3	810	$ 92,269.53	$113.91
15B	Thompson-Starrett Co., Inc	Oct. 19, 1934	July 31, 1937	2	495	62,649.72	126.57
16B	Thompson-Starrett Co., Inc.	Oct. 19, 1934	May 20, 1938	4	1,080	125,036.20	115.77
Gene inlet	Winston Bros. Co. & Wm. C. Crowell	Nov. 22, 1935	Apr. 29, 1938	1	1,831	257,524.72	140.65
Copper Basin	Winston Bros. Co. & Wm. C. Crowell	Nov. 22, 1935	Apr. 29, 1938	1	415	52,694.24	126.97
	TOTAL			11	4,631	$ 590,174.41	$127.44
Inlet siphons in pumping plant contracts					890		
			Siphons with three 9′-9″ square barrels				
3A	Barrett & Hilp and Macco Corp.	Oct. 19, 1934	May 25, 1937	12	4,070	$ 380,195.39	$ 93.41
4A	Jahn & Bressi Construction Co.	Oct. 19, 1934	Mar. 18, 1937	10	3,075	242,638.00	78.91
5A	Jahn & Bressi Construction Co.	Oct. 19, 1934	Nov. 17, 1936	12	4,020	343,123.34	85.35
8A	C. W. Wood and M. J. Bevanda	Oct. 19, 1934	July 28, 1937	13	4,930	423,777.59	85.96
9B	Utah Construction Co.	Oct. 19, 1934	May 15, 1937	8	2,910	285,584.55	98.14
10A	Aqueduct Construction Co.	Oct. 19, 1934	April 6, 1936	10	3,750	332,908.03	88.78
11B	Aqueduct Construction Co	Oct. 19, 1934	June 24, 1937	9	3,735	353,854.36	94.74
13B	Aqueduct Construction Co.	Oct. 19, 1934	Jan. 30, 1937	6	2,660	246,381.16	92.62
Hayfield	Dixon Co. and Case Const. Co.	Sept. 4, 1936	July 27, 1937	1	300	34,363.60	114.55
	TOTAL			81	29,450	$2,642,826.02	$ 89.74

Table 18

MAIN AQUEDUCT HALF-CAPACITY SIPHONS

(One of two barrels constructed for initial development)

Schedule	Contractor	Contract awarded	Work completed	No. of siphons	Length in feet	Total cost	Cost per foot
1B	Aqueduct Construction Co.	Oct. 19, 1934	July 14, 1936	2	890	$ 74,310.85	$ 83.50
2B	Barrett & Hilp and Macco Corp.	Oct. 19, 1934	May 25, 1937	7	5,985	352,837.51	58.95
3B*	Barrett & Hilp and Macco Corp.	Oct. 19, 1934	May 25, 1937	8	8,275	448,897.32	54.25
6	C. W. Wood and M. J. Bevanda	Oct. 19, 1934	July 28, 1937	1	15,520	766,137.49	49.36
8B*	C. W. Wood and M. J. Bevanda	Oct. 19, 1934	July 28, 1937	3	2,960	147,904.28	49.97
10B*	Aqueduct Construction Co.	Oct. 19, 1934	April 6, 1936	1	1,100	70,598.19	64.18
11C*	Aqueduct Construction Co.	Oct. 19, 1934	June 24, 1937	1	3,400	176,918.47	52.03
12A	Three Companies, Inc.	Oct. 19, 1934	Nov. 6, 1937	2	1,738	231,120.00	132.98
14A	Thompson-Starrett Co., Inc.	Oct. 19, 1934	June 3, 1936	1	2,150	127,517.69	59.31
15A	Thompson-Starrett Co., Inc.	Oct. 19, 1934	July 31, 1937	2	1,400	99,823.19	71.30
16A	Thompson-Starrett Co., Inc.	Oct. 19, 1934	May 20, 1938	2	1,127	92,156.89	81.77
17B	M. W. D. force account	Nov. 2, 1934	June 15, 1937	10	9,621	878,202.21	91.28
Fan Hill	M. W. D. force account	Oct. 13, 1933	Nov. 19, 1934	1	790	82,894.51	104.93
Little Morongo	United Concrete Pipe Corp.	Nov. 17, 1933	Aug. 20, 1934	1	660	82,620.88	125.18
18A	J. F. Shea Co., Inc.	Nov. 9, 1934	Aug. 14, 1937	2	650	61,612.23	94.79
18J	Morrison-Knudsen Co.	Jan. 11, 1935	Sept. 16, 1936	2	9,811	560,883.73	57.17
19A	J. F. Shea Co., Inc.	Nov. 9, 1934	May 30, 1938	1	2,235	131,298.38	58.75
20	J. F. Shea Co., Inc.	Nov. 9, 1934	Dec. 24, 1935		18,618	937,835.69	50.37
20A & B	Griffith Co.—M. W. D.	Dec. 7, 1934	uncompleted	1	752	....	....
20C	Griffith Co.	Dec. 7, 1934	Sept. 14, 1935		7,000	375,713.12	53.67
21	Griffith Co.	Dec. 7, 1934	Oct. 13, 1936	3	14,608	548,958 55	37.58
22	Griffith Co.	Dec. 7, 1934	Oct. 13, 1936	1	7,229	266,198.25	36.82
	TOTAL			52	116,519	$6,514,439.43	$ 55.91

*12′-9″ circular barrel; the remainder are all 12′-4″ circular barrels; except Little Morongo siphon, which is 12′-0″ diameter, and Schedule 19A, which is 11′-5″ in diameter.

upon the type of adjoining aqueduct section and were constructed using special forms built up for the particular structure involved.

In the long circular siphons, manholes for access to the interior of the barrel were located at regular intervals and blow-off structures with valves were built at low points to permit draining. Air release and vacuum valves are installed on high points of siphons.

SPENCE AIR PHOTOS

Aerial view of box siphons at drainage crossings

The concrete per linear foot, including transitions and structures, averages 1.95 cubic yards in the 12-foot 4-inch circular, 3.5 in the box, and 3.37 in the 16-foot circular siphons, differing only slightly from the estimated quantities. The cement varied from 1.54 to 1.69 barrels per cubic yard of concrete.

The cost of the different types of siphons and other data are given in tables 17 and 18. The length and cost of siphons are inclusive of the transitions. The total cost includes District-furnished cement, reinforcement steel, valves, sealing compound, administration and engineering.

All siphons were contracted, with the exception of the Fan Hill experimental section and the siphons between the Coachella tunnels forming a part of the Schedule 17 group, which were built by District forces, as previously noted, and with the further exception of one short section of the half-capacity Casa Loma siphon at its connection with San Jacinto tunnel. The excavation for this last mentioned siphon section was performed by the siphon contractor at the request of the District, the resulting cut providing access to the west portal of the tunnel during its construction. Upon completion of the work in the tunnel the concrete siphon barrel will be completed and backfilled by the District.

CHAPTER 10

Dams and Reservoirs

PRIMARY storage for the District's water supply is afforded at Boulder dam under contracts with the United States dated April 24, 1930 and September 28, 1931. The stored water is to be delivered in the river at the District's diversion point 155 miles downstream from Boulder dam, where it will be impounded in the reservoir created by Parker dam, and thence pumped into the aqueduct system. Within the first six miles the aqueduct water passes through two more reservoirs, formed by the Gene Wash and Copper Basin dams, respectively. From this latter reservoir until Cajalco is reached no large storage is planned except at the Hayfield pumping plant where a natural reservoir in Hayfield Dry Lake will provide regulation and storage.

In addition to the major terminal storage at Cajalco, Morris reservoir in San Gabriel Canyon, which the District has agreed to purchase from the City of Pasadena, as noted in Chapter 12, will provide 39,300 acre-feet gross capacity of "close-in" storage on the upper feeder. Further regulation and control of flow in the feeder lines and protection against interruption of flow will be provided by the construction of a few small operative reservoirs situated near the ends of the lines. The events leading up to the construction of Boulder dam and the relation of that project to the Colorado River aqueduct are discussed in an earlier chapter, and the construction of the Morris dam has been described in a report issued in 1935 by the Pasadena Water Department.[1] In this chapter an account is given of the other dams and reservoirs enumerated above.

PARKER DAM AND RESERVOIR

The Parker dam is located just below the junction of the Bill Williams and Colorado rivers, about 16 miles northeast of the town of Parker, Arizona. It raises the water surface about 72 feet to an elevation of 450 feet above sea level, creating a storage of 717,000 acre-feet. A power development is planned to be installed

[1] Technical Report on Construction of Morris Dam; VERNE L. PEUGH.

here at some future time, and the present construction program includes the trashrack structure and forebay and a part of the foundations of the proposed power plant.

The dam is of the concrete arch type and has five 50 by 50-foot structural steel regulating gates operating between concrete piers on the crest to control the passage of water. A general plan of the dam and its related features is shown in Fig. 17. Construction has been carried on and completed during the filling of the reservoir above Boulder dam, thus minimizing both the flood hazard and the cost of works for the control of the river during construction. The river flow was carried past the dam site through two 29-foot concrete-lined tunnels on the Arizona side, each with a designed capacity of 30,000 cubic feet per second, with water surface in the reservoir at elevation 435. This was estimated to be sufficient to by-pass the controlled discharge at Boulder dam, plus any probable flood flow from the Bill Williams River.

In accordance with the terms of a contract dated February 10, 1933, the dam is being built by the U. S. Bureau of Reclamation with funds furnished by the District. The United States retains one-half the power privilege at the dam and a limited right to regulate the top 10 feet of reservoir storage. The other half of the power to be developed will belong to the District. Dam and reservoir will remain the property of the United States, and will be operated and maintained by it for the benefit of the District. This operation and maintenance will be entirely at the District's cost and expense until such time as some use shall be made of the reservoir by the United States for water diversion or power development, whereupon these annual costs will be prorated.

Preliminary work

In the preliminary investigation the District test-drilled the dam site area to ascertain the position and character of bedrock. This drilling disclosed a great depth of sand and gravel, with some boulders near the bottom, underlain by excellent rock. At the point selected the river channel fill was about 235 feet deep in a narrow canyon between hard rock walls.

Upon completion of preliminary field work and office studies, in which District engineers cooperated, specifications were issued by the Bureau of Reclamation calling for bids to be received up to July 26, 1934 for construction of the dam and appurtenant works. Six Companies, Inc., builders of Boulder dam, were low

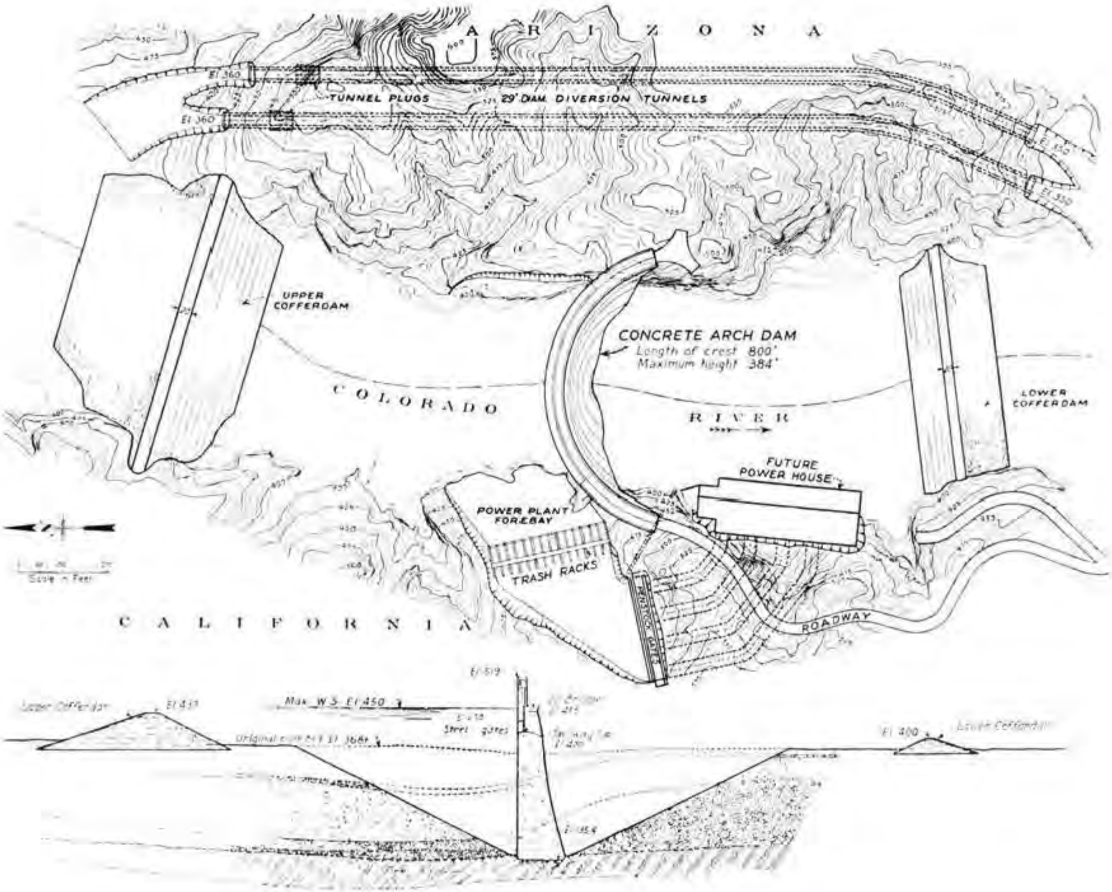


Fig. 17—Parker dam

bidders and on August 25, 1934 a contract was entered into with this organization for the work. Shortly after beginning the preliminary construction Six Companies, Inc. subcontracted the diversion tunnels to one of its constituent companies, J. F. Shea Company, Inc., and subsequently, in March 1936, prior to completion of the tunnels, sublet all remaining work under the contract to the same subcontractor.

On the first of October 1934 construction of a temporary camp was begun on the California side, following which work was started on the main camp, the access roads, and a bridge across the river to reach the outlet portals of the diversion tunnels in Arizona. On November 10, 1934 the Governor of Arizona proclaimed martial law in this portion of the state and dispatched a detachment of the Arizona National Guard to take possession of the dam site area in Arizona, contending that the Congress of the United States had not authorized construction of the dam. Three days later the Secretary of the Interior ordered cessation of work in Arizona, but the contractor completed its camp in California and the Bureau of Reclamation proceeded with the erection of its necessary buildings and utilities in the same area.

The United States immediately brought suit in the Supreme Court seeking to enjoin Arizona from interfering with the construction of the dam, and on February 13, 1935, under a temporary restraining order, the Secretary of the Interior authorized a resumption of construction. The court, however, rendered a decision in the case on April 29, 1935 sustaining the Arizona contention, and all work on the dam was immediately stopped by the contractors with the tunnel portal cuts virtually completed and 104 feet of tunnel excavated. The Bureau continued to completion the construction of the unfinished Government camp.

The Rivers and Harbors Act, approved by the President August 30, 1935, specifically authorized construction of the dam and on the part of the United States ratified all the contracts previously made by it in connection therewith. However, Six Companies, Inc., on its part, was unwilling to ratify its contract without being compensated for the loss and expense incurred by it on account of these delays. A contract was therefore executed under date of September 30, 1935, wherein the District agreed to pay this contractor on April 1, 1938 the sum of $240,000 as full compensation for its losses due to delay to the project from the action of the State of Arizona, and the contractor agreed to ratify the contract and proceed with the work.

On October 1, 1935 the subcontractor resumed operations, unwatered the portal cut and the portions of the diversion tunnels excavated before the shutdown, and proceeded with the excavation, concrete lining, and grouting of these tunnels, using methods similar to those for the aqueduct tunnels but modified to suit the larger diameters involved. The inner tunnel as excavated was 1,759 and the outer 1,704 feet in length. The rock was somewhat blocky and fractured requiring almost continuous support but following 10 to 15 feet behind the full-section excavation. The tunnels were finished in September 1936; the inlet and outlet channels were then opened up, and diversion of the river through the tunnels was accomplished October 22, 1936.

The diversion of the river was effected by temporary earth dikes near the tunnel portals. The area between was unwatered by the end of October 1936, and the cofferdams started, using river bed material excavated from the dam site. Early in February 1937, when the fill of the upper cofferdam was nearly completed but not yet faced with riprap, a flash flood occurred on the Bill Williams River. During a 72-hour period the run-off averaged 20,350 cubic feet per second with a peak discharge of 92,500, creating a lake above the upper cofferdam which extended for miles up both streams. The ponded water rose to elevation 405, forty-five feet over the tunnel invert, at which stage the diversion tunnels discharged 42,200 cubic feet per second. The lower cofferdam was threatened by scouring action of the flood waters issuing from the tunnels, but was saved by strenuous and timely work on the part of the subcontractor.

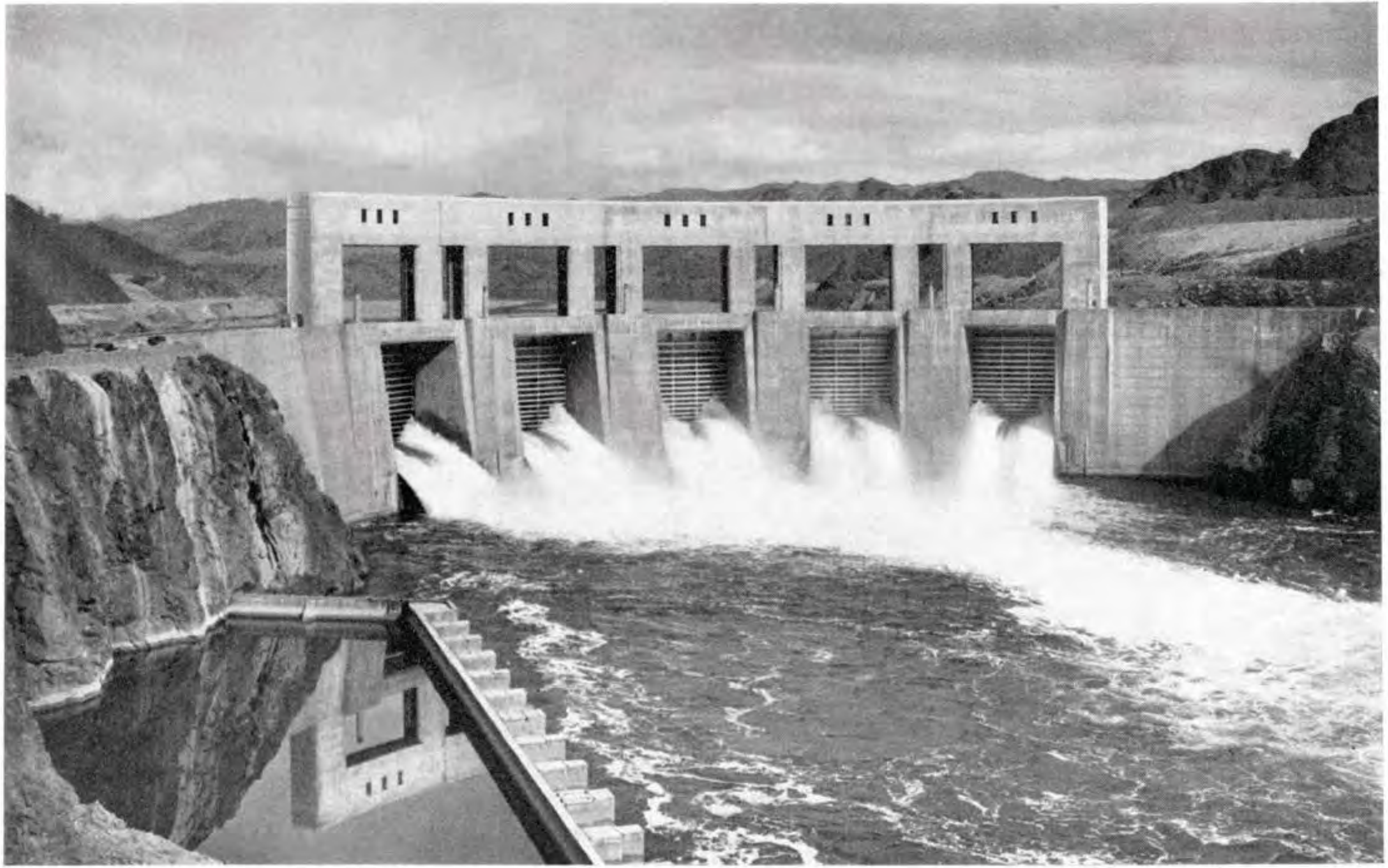
Dam construction

Excavation for Parker dam was started on the Arizona abutment in 1936, prior to completion of the diversion tunnels. After diversion of the river and unwatering of the area between the temporary dams, excavation of both abutments and of river bed material to bedrock was pushed vigorously. When the excavation reached a depth of about 70 feet below streambed late in January 1937 a layer of gravel was passed through which yielded water from both slopes. This flow persisted despite efforts to cut it off, reaching a maximum of 38 cubic feet per second, or 17,000 gallons per minute. Four 26-inch wells were drilled through these water-bearing gravels to bedrock, two on each slope, and pumps installed. Pumping from these wells had the effect of lowering the level at which seepage appeared on the slopes by about 60 feet, but the total pumpage remained fairly constant.

As the depth of the excavation increased, inflowing water caused some sloughing of the material into the excavated area, and rock from the abutment excavation was spread as riprap to stabilize the slopes. As a further measure for the prevention of slides on the downstream side, two rows of steel sheet piling were driven with a river-silt seal when the pit approached bedrock at the great depth of 235 feet.

The excavation in the river bed was carried on with draglines and dump trucks until May 1937, when with the average elevation of the pit bottom at approximately 250 feet above sea level, or 120 feet below the river bed, and the lowest point at elevation 209, it became necessary to use the cableways and 12-yard skips to complete the excavation. Bedrock was first uncovered at elevation 140 in the week ending July 25, 1937. This proved to be the average elevation of bedrock across the channel with the lowest point at elevation 135.4. Bulkheads were erected at the upstream and downstream toes of the dam to exclude water from the foundation area, the foundation was cleaned, and grout holes were drilled. At 5:23 p.m., July 29th, the first concrete was placed in the center portion of the dam foundation area, and by the end of August the average elevation of concrete had reached 206 feet, with grouting completed across the entire foundation.

As concreting proceeded, seepage water was allowed to rise on both sides of the dam. With pumping being done from the downstream pool it was possible to start cooling the concrete below elevation 235 by allowing water from the upstream side to flow through the embedded cooling pipes and discharge on the lower side, the difference in level being kept at approximately 50 feet. In November 1937 a cooling tower and circulating pumps were installed, and cooling of the mass concrete was extended to a greater volume of the dam. At the end of 1937 concrete in the dam had reached the spillway lip in the five gate openings, and was at an average elevation of 409 feet, being 90 per cent complete. Pumping of seepage water from the downstream pool had dropped to 14 cubic feet per second.



Parker dam

The closing of the diversion tunnels with concrete plugs was begun in April 1938, when a section of the tunnel lining forms was lowered sidewise into position at the upper portal of the inside tunnel to act as a curved bulkhead behind which material could be supplied to and work performed within the tunnel. The lower end was closed by dumping rock and fine material into it from the bank; the section was unwatered as far as the plug location and the plug was then completed. The outside tunnel was in process of closure by similar methods at the end of the fiscal year, the bulkhead at the upper end being seated June 29th and the first water flowing over the spillway lip of the dam on July 1st. Removal of the lower cofferdam was started in April, and of the upper in May 1938 and had been completed for both at the end of the fiscal year.

As of June 30, 1938 all work on the Parker dam contract had been completed, with the exception of the concrete plug in the outside diversion tunnel, a small quantity of concrete in the gate house, and general clean-up, including the remaining road work and dismantling of plant and equipment.

Power development

The plan for ultimate power development at Parker dam contemplates four 25,000-kw generators, each utilizing a flow of 5,000 cubic feet per second when operating at full capacity. These generators are to be installed in a power house on the California side of the river, the water being diverted into the penstock tunnels through a forebay excavated in the west abutment of the dam. The original contract included the partial excavation of this forebay and the construction of a concrete trashrack structure across the opening into the reservoir, but no part of the power house structure. After construction work had started, however, it was found that economy could be effected by completing at this time the forebay excavation to the upper end of the penstock tunnels, and constructing immediately downstream from the dam a portion of the substructure of the future power plant. These structures will thus be available for use as cofferdams whenever the construction of the power house and penstock tunnels is undertaken.

Accordingly, the District on September 29, 1936 entered into a supplemental agreement with the United States providing for the performance of this additional work under the existing contract, the cost of the present power plant construction to be divided

TABLE 19
PARKER DAM

FEATURE	UNIT	QUANTITIES	COMPLETION PERCENTAGE
Diversion works			
Approach cuts and channels	cu-yds	105,779	100
East tunnel (No. 2)			
Excavation	lin-ft	1,704	100
Concrete lining	lin-ft	1,654	97
West tunnel (No. 1)			
Excavation	lin-ft	1,759	100
Concrete lining	lin-ft	1,759	100
Upstream cofferdam			
Excavation for foundation	cu-yds	148,282	100
Earthfill and riprap	cu-yds	358,487	100
Removal	cu-yds	142,765	100
Downstream cofferdam			
Excavation for foundation	cu-yds	79,300	100
Earthfill and riprap	cu-yds	106,403	100
Removal	cu-yds	47,755	100
Outlet works			
Excavation—rock	cu-yds	208,498	100
Concrete	cu-yds	5,707	100
Metal work	lbs	642,779	50
Dam			
Excavation—common	cu-yds	1,408,935	100
Excavation—rock	cu-yds	98,401	99
Excav. for spillway approach and road wye	cu-yds	17,000	87
Concrete	cu-yds	290,336	99
Metal works	lbs	6,037,924	88
Roads			
Excavation—common	cu-yds	1,618	99
Excavation—rock	cu-yds	54,004	98
Power house substructure			
Excavation	cu-yds	68,094	100
Concrete	cu-yds	15,418	100

Contract data: U. S. Bureau of Reclamation specifications No. 574; contractor, Six Companies, Inc.; subcontractor, J. F. Shea Co., Inc.

equally between the District and the Bureau of Reclamation. The power house substructure was completed in March and the forebay and trashrack in June 1938.

Equipment

Practically all of the subcontractor's equipment had been previously used on the Six Companies, Inc. contract at Boulder dam. In addition to the customary draglines, shovels, trucks, tractors, etc., two cableways were used. These had a joint tail tower or anchor on the California side, and individual movable head towers on the Arizona bank. The batching and concrete-mixing plants were located adjacent to the head towers with a service track in front of and below the towers for cars handling concrete buckets between mixers and cableways.

Table 19 shows the quantities on the construction of Parker dam and appurtenant works up to June 30, 1938.

Organization

All operations of the U. S. Bureau of Reclamation are under the direction of John C. Page, commissioner. R. F. Walter is chief engineer of the Bureau and J. L. Savage is chief designing engineer. Construction engineers in immediate charge of the work at Parker dam have been as follows: O. Laurgaard, June 22, 1934 to January 26, 1935; E. A. Moritz, January 26, 1935 to January 3, 1938; H. P. Bunger, January 11, 1938 to date.

GENE DAM AND RESERVOIR

Gene reservoir, with a storage capacity of 6,300 acre-feet, is the second reservoir in the aqueduct system. It is located between the Colorado River tunnel and Gene pumping plant and was created by the construction of a dam in a narrow canyon of Gene Wash. Specifications were issued February 12, 1937 inviting bids for the construction of this dam and the Copper Basin dam, with their appurtenant works, under a single contract. The low bidder was J. F. Shea Company, Inc.

The work in Gene Wash consisted of a concrete arch dam with a maximum height of 138 feet and crest length of 430 feet, a concrete ogee spillway dam, and two small rolled earthfill dikes with a maximum height of 25 feet and a total length of 1,300 feet. The reservoir outlet is by way of Gene siphon which leads through a low saddle, closed by the longer of the two earth dikes, to the nearby Gene pumps, the second lift of the aqueduct system.

All features of the Gene Wash reservoir are in close proximity to the District roads near Division 1 headquarters, and a minimum of access work was necessary. During the summer of 1937 the contractor completed the excavation for the dam foundation and abutments and for the spillway, started trenching for the dike cut-off wall and clearing for the dike, and erected a cableway and a concrete-mixing plant. By February 1938 the placing of concrete in the dam was finished, using aggregate batched at the contractor's plant at Parker dam. Foundation grouting followed in March and cooling of the concrete early in April. The earth fill in the dike was completed in March and the concrete in the dike cut-off wall and paving slab was finished in April. With the exception of the clearing of the reservoir site and the placing of a small quantity of miscellaneous metal, construction on this portion of the contract was completed in June 1938.

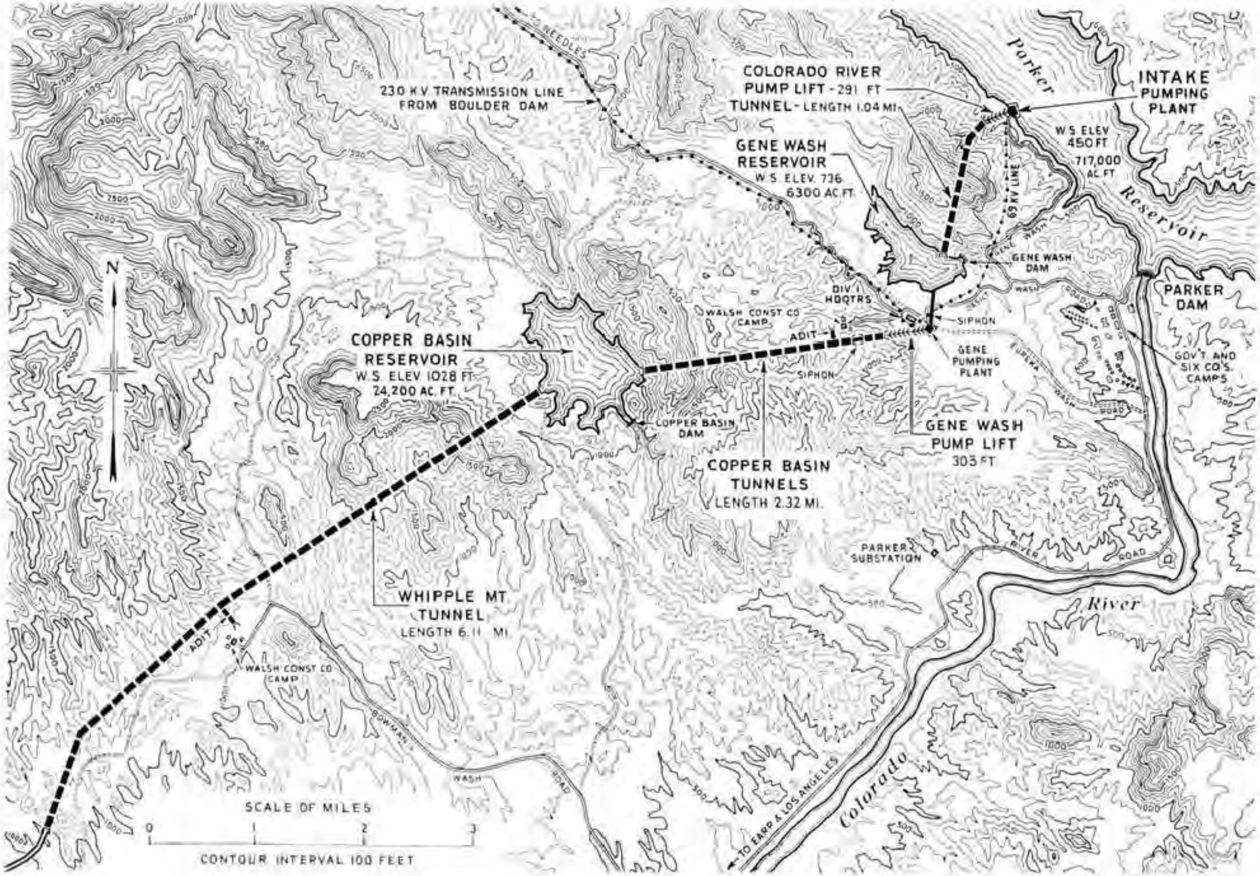


Fig. 18—Gene Wash and Copper Basin reservoirs

COPPER BASIN DAM AND RESERVOIR

The third aqueduct reservoir is in Copper Basin, with a gross capacity of 24,200 acre-feet. The contract work here consisted of a concrete arch dam with a maximum height of 210 feet and crest length of 220 feet, a concrete ogee spillway dam, and a reservoir outlet structure at the entrance to the Whipple Mountain tunnel. The dam is located in a narrow box canyon at the outlet of the basin and the water enters the reservoir from the Copper Basin No. 2 tunnel.

These features were accessible only over very poor mountain roads entering the basin from the east through Bandit Pass and from the west through Barometer Wash. These roads the contractor improved, particularly the one from the east over which he hauled all concrete materials from his batching plant at Parker dam. Starting late in May 1937 work on the various features was carried on intermittently with small crews until the end of September. Work at Copper Basin was then stopped and all efforts concentrated at Gene dam, until October 28th, when operations at Copper Basin were resumed. The first concrete was placed in the dam on December 29, 1937 and the last in April 1938. The

Gene Wash dam

spillway was completed in May and the reservoir outlet works in June 1938. The clearing of the reservoir site was virtually completed and except for minor items all contract work was finished at the end of the fiscal year.

Cooling of concrete in the Copper Basin dam was begun in April, but was discontinued on May 17, 1938 when completion of this operation, together with grouting of the construction joints and embedded cooling system pipes, was eliminated from the work required under the contract. Cooling and grouting will be performed by District forces after the return of cool weather, when the outside temperatures conform more nearly to the desired interior temperatures.

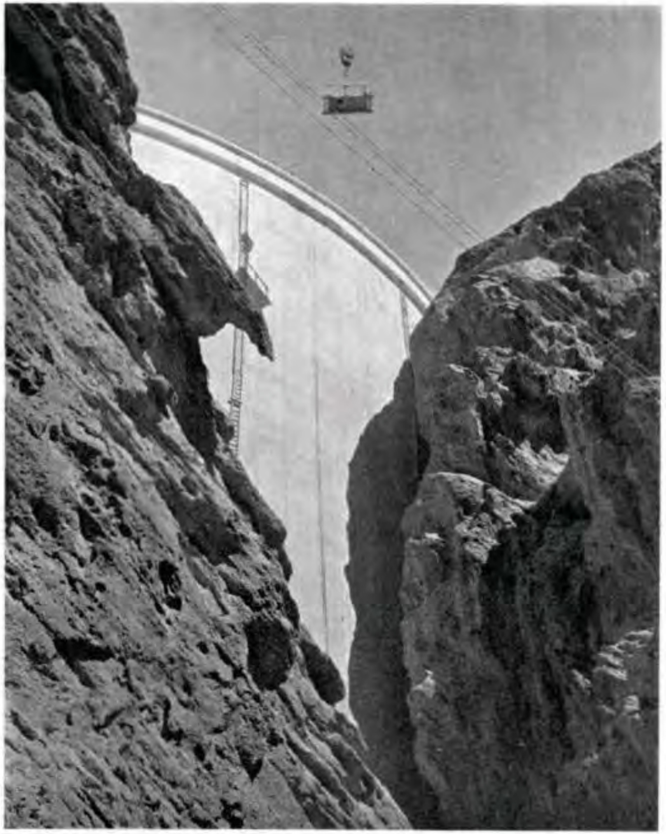
TABLE 20

GENE WASH AND COPPER BASIN DAMS

GENE WASH DAM	UNIT	QUANTITIES	COMPLETION PERCENTAGE
Dam			
Excavation—unclassified	cu-yds	7,500	100
Concrete	cu-yds	14,333	100
Metal work and reinforcement steel	lbs	372,085	99
Install concrete cooling plant	lump sum	....	100
Spillway			
Excavation	cu-yds	4,762	100
Concrete	cu-yds	4,729	100
Backfill	cu-yds	185	74
Metal work and reinforcement steel	lbs	59,603	100
Dike			
Excavation	cu-yds	2,361	100
Earthfill	cu-yds	8,710	100
Concrete	cu-yds	927	100
Reinforcement steel	lbs	72,430	100
Clearing reservoir site	lump sum	....	90
COPPER BASIN DAM			
Dam			
Excavation—unclassified	cu-yds	8,700	100
Concrete	cu-yds	17,986	100
Metal work and reinforcement steel	lbs	443,078	99
Install concrete cooling plant	lump sum	....	100
Spillway			
Excavation	cu-yds	8,000	100
Concrete	cu-yds	2,050	100
Backfill	cu-yds	135	68
Construction outlet works	lump sum	....	98
Clearing reservoir site	lump sum	....	99

Contract data: Contractor, J. F. Shea Co., Inc.; date of award, March 26, 1937; date for completion, Sept. 30, 1938.

Table 20 contains actual quantities and completion percentages to June 30, 1938, on all main items of the contract for Gene Wash and Copper Basin dams and appurtenant works, and other contract data.



Copper Basin dam

Cajalco outlet tower

HAYFIELD RESERVOIR

The Hayfield reservoir area is a natural closed basin and no work is required here except clearing of the site which will be undertaken shortly before priming of the reservoir begins.

CAJALCO RESERVOIR

The aqueduct when operating at its full capacity will have a constant discharge, while the demand will be variable from day to day and from season to season. In order to equalize these differences, storage reservoirs must be provided at the end of the main aqueduct and at strategic points on the larger distribution lines. Furthermore, in an aqueduct of such great length, crossing as it necessarily must several important fault zones and using for pumping large amounts of electric energy delivered over long transmission lines, there are possibilities of temporary interruptions to flow. These stoppages may be of short or long duration but, since the demand is continuous, ample storage is a requisite for protection in case of such interruptions. In the ultimate development, storage capacity of the order of 300,000 acre-feet may be necessary, though in the first stage a portion only of this amount is required.

Cajalco site was selected for storage at the end of the main aqueduct because it is situated at the upper end of the area to be served and has an elevation that will permit gravity delivery to the entire area, is on a stable granite formation at a safe distance from major fault zones, and is suitable for economical development in stages to a maximum capacity of about 225,000 acre-feet. The construction of the reservoir for the initial capacity of 100,000 acre-feet was started in August 1935 and completed in February 1938. This work was done under one general contract by Griffith Company of Los Angeles, and involved the excavation and lining of a diversion tunnel and an outlet tunnel, the construction of two earthfill embankments, namely, the main dam across Cajalco Creek and a dike on a low ridge along a portion of the northerly side of the reservoir, and the construction of a spillway and an outlet tower.

The diversion tunnel, used as a by-pass for storm water in Cajalco Creek during the construction of the dam, is 9 feet in diameter, 2,000 feet long, and lined with concrete. The outlet tunnel with a capacity of 1,500 cubic feet per second is 14 feet in diameter, 2,348 feet long, and lined with a welded steel membrane adequate to withstand the full reservoir head. The steel membrane, or cylinder, is backed with concrete and lined with 2 inches of gunite, reinforced with welded steel mesh. Water will pass through the outlet tunnel to the distribution system lines. Initially it will connect the reservoir to the upper feeder and later will feed all of the distribution lines west of Cajalco.

Means of releasing water from the reservoir into the outlet tunnel is provided by a reinforced concrete outlet tower, adjacent to and directly connected with the inlet end of the tunnel. The tower is circular in shape, 20 feet inside diameter, and 145 feet high. Fifty control valves were installed in the tower at ports on six different levels. These valves are of the double-disc type, 30-inch diameter, and hydraulically operated.

Dam and dike

Cajalco dam and dike were built with earthy materials thoroughly compacted to a high degree of density. Each has an 8-inch slab of reinforced concrete on the upstream slope, and a concrete cut-off wall to sound rock at the base of the slab. Following are the principal dimensions of the two structures:

	Dam	Dike
Maximum height at axis, feet	210	94
Crest width, feet	50	32
Crest length, feet	2,170	7,575
Maximum width at base, feet	1,340	420
Embankment fill, cubic yards	3,092,000	3,857,000

Before any contract work was started at Cajalco, extensive drilling operations and tests were carried on to determine the location and characteristics of earth materials suitable for the fills and to explore the foundations for the embankments. Test holes for fill material were made with dry rotary drilling rigs which put down holes 24 inches in diameter to depths from 5 to 40 feet. Altogether about 1,000 of these holes were drilled, and samples were taken from each at five-foot intervals. Test holes in the foundations were made with diamond drilling machines from which cores were obtained, and by digging shafts to bedrock. Results of the explorations for earthfill materials indicated that there was sufficient satisfactory material within the reservoir area and reasonably close to the sites of the dam and the dike to make the required fills, while the results of the foundation explorations verified the

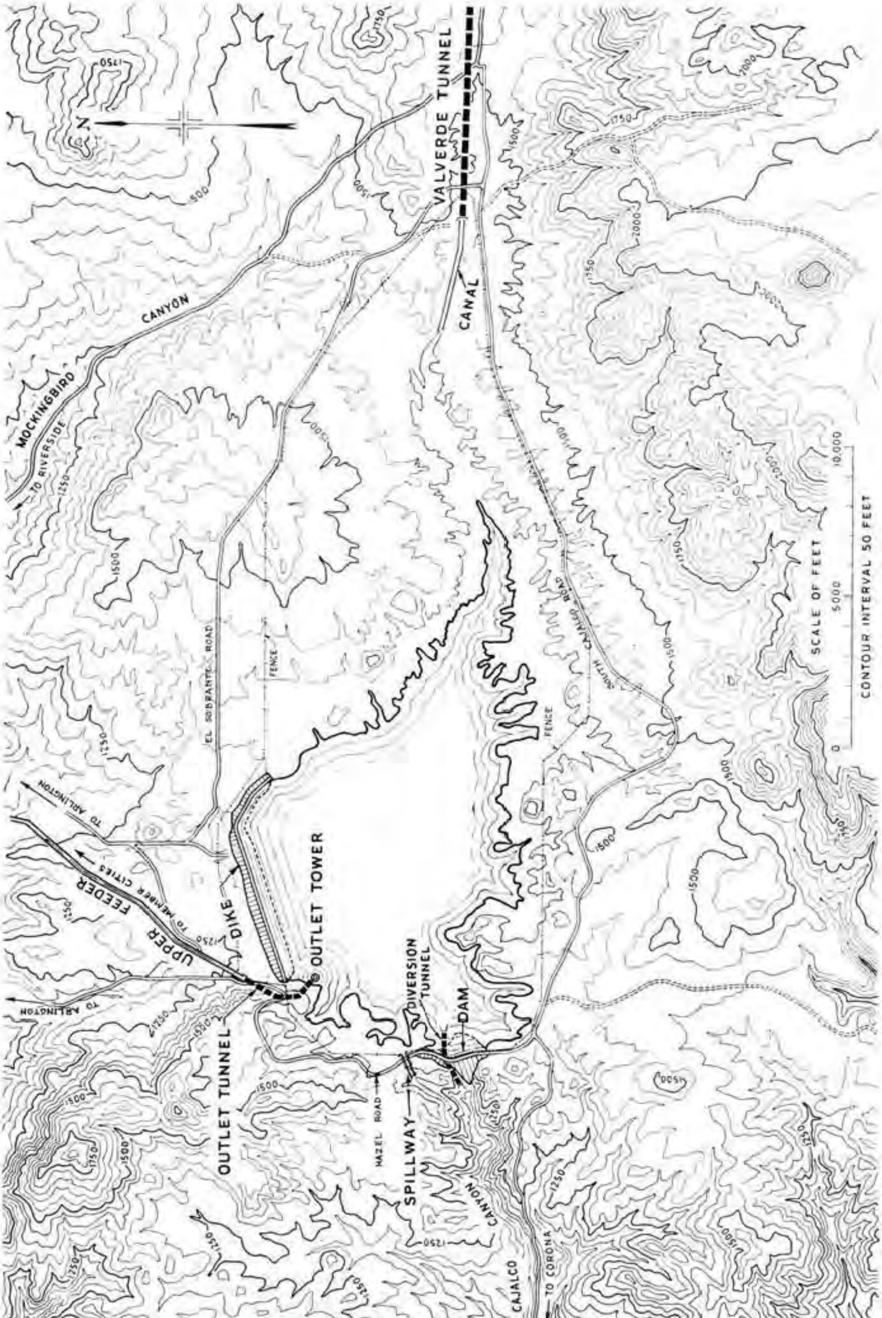


Fig. 19—Cajalco reservoir

preliminary reports of the District's geologists that underlying foundation materials were excellent for earthfill dams.

Considerable preparatory work was required before the embankments were started, involving mainly the removal of earth from the foundations to a depth at which the material in place had a density and imperviousness equal to that which could be obtained in the compacted fill. Economy was effected by stockpiling and using excavated materials whenever they were suitable for use in the embankments or elsewhere. In fact, proper utilization and disposal of excavated materials was one of the most important problems, from an economic standpoint, in connection with the Cajalco construction work. Every cubic yard of material removed from required excavations which was used in the rolled fill meant a direct saving to the District, as such use reduced the amount of material which had to be obtained from borrow pits or quarries at considerably higher unit prices.

At the site of the dike the average depth of excavation was about 3 feet. Excavation for the dam foundation, however, required the removal of material to depths of 4 to 65 feet. In both cases most of the excavated earthy material was redeposited and compacted in the fill. Rocky material from the excavation was passed over a grizzly made of bars spaced 4 inches apart; the rocks were then deposited in the pervious section at the toe of the dam and the fines were incorporated into the rolled section.

Material placed in the embankments, other than that obtained from required excavations, was hauled ½ to 2½ miles from the borrow pits within the reservoir area, using four 2½-yard shovels for excavating and loading the earth and a fleet of thirty 10-yard trucks for transportation. In general, the material was compacted in 6-inch layers in the embankments by tractor-drawn sheepsfoot roller units weighing 30,000 pounds each, which made 16 trips over each 6-inch layer.

Density control

In order to obtain the desired compaction in the embankment it was essential that the earth contain the proper amount of moisture. The materials were all too dry in their natural condition in the borrow pits and were given approximately the proper moisture content prior to excavation by means of an overhead sprinkling system or by flooding small diked areas. Any deficiency in moisture after wetting in the borrow pits was made up by the use of

TABLE 21
CAJALCO DAM AND DIKE

	Unit	Quantities
Dam and spillway		
Excavation	cu-yds	680,928
Fill—earth	cu-yds	3,092,114
rock blanket and crest	cu-yds	43,444
Concrete	cu-yds	27,027
Reinforcement and metal work	lbs	3,196,739
Dike		
Stripping	cu-yds	50,904
Excavation	cu-yds	13,958
Fill—earth	cu-yds	3,856,990
rock, toe trench, and crest	cu-yds	21,687
Concrete	cu-yds	44,166
Reinforcement and metal work	lbs	5,907,176
Tunnels		
Approach cuts	cu-yds	41,463
Excavation[1]	lin-ft	4,432
Steel cylinders	lin-ft	2,341
Concrete	cu-yds	10,972
Outlet tower		
Excavation	cu-yds	201,163
Concrete	cu-yds	3,251
Reinforcement and metal work	lbs	995,066

Contract data: Contractor, Griffith Company; date of award, August 16, 1935; date completed, February 9, 1938; total District cost, $5,454,485.19.

hoses during excavation and sprinkler trucks on the embankment. The average total water content was 12 per cent by weight, and the average dry weight density of the compacted fills was about 125 pounds per cubic foot. Average density of the undisturbed earth in the borrow pits was found to be from 105 to 110 pounds per cubic foot.

A well-equipped soil testing laboratory was maintained by the District at the site of the work, where moisture, compaction, and percolation tests were carried on continuously during the construction period. The effectiveness of the compaction methods employed is indicated by the small amount of settlement which has taken place in the fills, the maximum being 0.10 of a foot in the dike and 0.23 of a foot in the dam.

In order to prevent leakage under the dam the foundation was grouted at the cut-off wall. Holes were drilled below the bottom of the wall to depths of 30 to 200 feet at intervals of about 6 feet, following which grout was forced through these holes into the surrounding ground under pressures of from 30 to 100 pounds per square inch. The arrangement of the holes was such as to assure

[1]Excavated length of outlet tunnel reduced 84 ft. by change in location of outlet tower.

an impervious curtain below the cut-off. The quantity of grout used averaged 0.20 of a cubic foot per linear foot of drill hole.

An overflow spillway and a concrete-lined discharge channel were constructed near the north end of the dam with the spillway lip 14 feet lower than the crest of the dam. The discharge capacity of this spillway with the water halfway to the crest of the dam (6.7 feet over the spillway lip) is 11,000 cubic feet per second. With the water surface at crest elevation the discharge would be in excess of 25,000 cubic feet per second. This spillway capacity, together with the 30,000 acre-feet of freeboard storage between spillway lip and dam crest, is more than ample to protect the dam against the greatest possible flood in the 40 square miles of drainage area tributary to the reservoir.

The pay quantities of the major items for the various features of the Cajalco reservoir work are shown in Table 21.

Additional work

Other work in the Cajalco basin in connection with the reservoir development consists of a steel suspension bridge for access to the outlet tower, necessary roads to replace existing county roads which have been vacated within the reservoir area, fencing, and maintenance.

A contract was awarded December 10, 1937 to the Kyle Steel Construction Company of Los Angeles for the suspension bridge at the outlet tower. The steel erection was begun and completed in the following March, followed by painting and the completion of all work in this contract April 4, 1938.

On December 5, 1935 the District entered into an agreement with Riverside County to replace in new locations certain existing county roads in the reservoir area which it was necessary to vacate. Prior to this agreement the District in November 1935 finished grading 3.1 miles of the main South Cajalco Road involving 54,000 cubic yards of excavation, and furnished road oil and culvert material for this stretch and for an additional 3 miles of the road constructed by Riverside County. Early in 1937 District forces finished grading 3.15 miles of the El Sobrante Road on the north side of the reservoir extending westerly from a point near the Valverde tunnel outlet.

In November and December, 1935 the Griffith Company, in order to provide a more convenient access for construction materials, secured a right of way and graded about 1.5 miles of road southerly from existing county roads at the intersection of Taylor Street and Dufferin Avenue to the west end of the dike. This contractor's road has now become a part of the county system and is linked with the South Cajalco Road by approximately three miles of paved road crossing over the spillway and dam and constructed by the Griffith Company under the Hazel Road contract. Hazel Road has a minimum width of roadway of 26 feet improved with a three-inch layer of oil cake 18 feet wide. A concrete bridge 20 feet wide with a clear span of 66 feet carries the road across the spillway channel.

The total cost to the District of roads in the Cajalco reservoir area to June 30, 1938 amounts to $61,287.28.

PALOS VERDES RESERVOIR

The Eagle Rock-Palos Verdes cross feeder will extend approximately 31 miles from the valve structure at the west portal of San Rafael No. 1 tunnel on the upper feeder to a terminus in the Palos Verdes reservoir to be constructed on the southeasterly slope of the Palos Verdes Hills. This reservoir will have a capacity of approximately 1,000 acre-feet, and will perform essential functions in the efficient regulation not only of the cross feeder but of the lower portion of the upper feeder itself, as well as any future lines which may terminate in the harbor area. The supplemental storage capacity thus provided will also afford protection to the industrial and residential areas south of the Inglewood fault in case of interruption of the cross feeder service by earthquake movement or other causes.

FENCING OF RESERVOIRS

Woven wire fences and gates at Gene Wash, Copper Basin, Hayfield, and Cajalco reservoirs were constructed under contract by the L. A. Fencing Company of Los Angeles. Work was begun in January 1938 at Hayfield and completed June 18, 1938 at Cajalco. The fence consists of 58-inch V-mesh galvanized fabric topped by two strands of barbed wire, all on steel posts set in concrete footings. The total length of 23.3 miles was constructed at a cost of 54 cents per linear foot.

CHAPTER 11

Pumping Plants and Transmission Lines

AT THE POINT of diversion in Parker reservoir the normal water surface elevation will be 450 feet above sea level, while in the Cajalco reservoir maximum ultimate water elevation will be 1,405 feet. The 1,617 feet of pumping lift required to overcome this difference in elevation and provide the necessary slope in the 242 miles of waterway is accomplished in five pumping plants located at points along the route as shown on the map and profile of the aqueduct. The hydraulic grade reaches a maximum elevation of 1,807 feet at the top of the Hayfield lift and from this point the flow is entirely by gravity to the terminal reservoir. The aqueduct was designed and located to require minimum pumping lift and there are no sites on the main aqueduct where recovery of power is possible.

The Intake pumping plant takes water directly from Parker reservoir and raises it 291 feet through the Colorado River tunnel into Gene Wash reservoir. The water is lifted an additional 303 feet by the Gene pumping plant and is discharged through the Copper Basin tunnels into Copper Basin reservoir. Parker reservoir, capacity 717,000 acre-feet, is an excellent settling basin and it is expected that water diverted into the aqueduct will be free from silt. Any temporary turbidity in Parker reservoir, caused by local flood flows, will be removed by the 6,300 acre-feet of reservoir capacity in Gene Wash and the 24,200 acre-feet in Copper Basin so that the outflow from the latter will be clear at all times. Discharge from Copper Basin is regulated by slide gates operated by remote control from Gene pumping plant.

The succeeding lifts are Iron Mountain, 144 feet at Mile 69; Eagle Mountain, 438 feet at Mile 110; and Hayfield, 441 feet, at Mile 126 from Intake. The open canals leading to these three pumping plants at times will collect considerable amounts of blow sand and, while small sand traps are located along the canal at frequent intervals, a large sand trap has been constructed a short distance above each plant as an additional measure for the protection of the pumps from this abrasive material. These three plants are also provided with forebay reservoirs to regulate inequalities in flow and save the water in transit when operation of the plant is interrupted without notice as in the case of power failure. At Iron Mountain and Eagle Mountain, due to lack of natural sites, the reservoirs are limited to a capacity of approximately 100 acre-feet each. At Hayfield an 87,500 acre-foot reservoir being provided in a dry lake bed for other purposes, is available for regulatory uses as well.

The five pumping plants are similar in design. Each plant will contain nine pumps, each with a capacity of 200 cubic feet per second. Eight of these will deliver the full capacity of the aqueduct, leaving one as a spare. Each group of three pumps will be connected ultimately to one of the three discharge pipes to be built at each plant. Inlet manifolds, building substructures, pipeline excavations, and certain other features have been completed for the full nine units of the ultimate installation. The superstructures are complete for five pumps. Initially three pumps and one discharge pipe are being installed in each plant; additional units will be added as required.

The magnitude of the pumping problem, which involves the eventual installation of 45 pumps and the use of nearly 400,000 horsepower of electrical energy offered the possibility of large savings by the selection of equipment of high efficiency and proper operating characteristics, but the almost complete absence of comparable experience in pump design made such a selection difficult. A program of investigation was therefore undertaken in a laboratory installed for the purpose at California Institute of Technology and operated under the joint direction of the District and Institute staffs. The laboratory was designed for rapid and precise testing of model pumps at various speeds and heads, and under a wide range of operating conditions. Many thousands of tests were made to determine the best type of pump, most suitable speed, depth of setting, and other essential characteristics.

Following these preliminary tests specifications were prepared for the 15 pumps of the first installation. A minimum efficiency of 88 per cent was specified with a bonus for higher efficiency to be determined by test of the full-size pumps after installation. Each bidder was required to submit for test in the District's laboratory prior to award of contract a model of one of the pumps offered.

After award of contract each contractor was required to submit for test a model of the pumps he was to furnish. These models showed efficiencies of from 91.5 to 92.5 per cent. Several of the leading pump manufacturers cooperated in the testing program and in the preparation of the specifications.

The pumps are all of the single-suction, single-stage vertical centrifugal type with bronze impellers, and are of extra heavy construction throughout. The pumps are set below the level of the inlet water to minimize the risk of cavitation and insure self-priming. The direct-connected synchronous motors are mounted above the highest inlet water level in order to avoid any possibility of flooding.

At Intake, water enters the pumps through trashracks directly from Parker reservoir. At the other plants steel intake manifolds distribute the flow to each pump. At Iron Mountain, Eagle Mountain, and Hayfield some of the pumps are equipped with selector valves permitting water to be drawn either from the aqueduct or from the reservoir, as may be required. Between each pump and its branch discharge line a rotary plug valve is installed so that any pump can be taken out of service for inspection or repair without interfering with the operation of adjacent units. These valves, under control of a device similar to an hydraulic-turbine governor, serve also to regulate surge pressures in the pipe line upon sudden shutdown due to loss of power or other cause. About 100 feet from the plant the three 6-foot discharge pipes from each group of pumps converge through a special branch fitting into a 10-foot welded steel discharge line leading to the top of the lift where the 10-foot lines discharge into the next section of the aqueduct. The 6-foot branches are encased in concrete and backfilled but the 10-foot pipes are carried in the open air on special rocker supports.

Each pump is driven by a vertical, three-phase, 60-cycle, 6900-volt synchronous motor, totally enclosed and water-cooled. Motor sizes are 4,300 hp at Iron Mountain, 9,000 hp at Intake and Gene, and 12,500 hp at Eagle Mountain and Hayfield. All motors are started at full voltage as induction motors with water in the pump casings and are synchronized automatically by application of field current under control of a relay.

Power for the initial or half-capacity development will be supplied from two 82,500-kva generators at Boulder dam over a single-circuit 230-kv transmission line 237 miles in total length, as

Intake plant on the Colorado

described later. Operating conditions are unique in that the entire load consists of large synchronous motors and continuity of service and close regulation are relatively unimportant. The system, including generators, transmission line and motors, was designed as a unit and the characteristics of the motors adjusted to give the necessary stability under the most adverse conditions of operation. Full voltage starting of motors produces severe voltage dips but greatly simplifies the plants and results in a considerable reduction in cost.

The pumps and all major equipment are controlled from a switchboard where indicators and instruments give the operator knowledge of conditions throughout his plant. Recording meters will register the flow of water through the pumps.

CONSTRUCTION OF PUMPING PLANTS

The first specifications for pumping plants were issued in October 1935, covering the construction of buildings for the Intake and Gene plants and appurtenant structures, the 16-foot inlet siphon, connecting Gene reservoir with the Gene pumping plant, and the Copper Basin siphon, also 16 feet in diameter, between the Copper Basin No. 1 and No. 2 tunnels. A contract was awarded for all this work on a joint bid by Winston Bros. Company and Wm. C. Crowell, the low bidder, on November 22, 1935. On November 29th specifications were issued for the Iron Mountain plant, including the 100 acre-foot regulating reservoir, sand trap, wasteway, and appurtenant works. This contract was awarded January 24, 1936 to Wood & Bevanda, contractors on canal Schedule No. 8 adjoining this plant.

On January 31, 1936 specifications for the Eagle Mountain plant were issued covering the construction of the building itself, a sand trap at the end of the last canal schedule 4½ miles east of the plant, lined regulating reservoir at the plant, and appurtenant works. Award of contract for this work to the L. E. Dixon Company was made on March 27, 1936.

The last pumping plant specifications were those for the work at Hayfield, issued July 17, 1936, calling for bids on the pumping plant, sand trap, approach channel from the Hayfield reservoir, and appurtenant works. Contract for this plant was awarded on September 4, 1936 to L. E. Dixon Company and Case Construction Company, Inc. on their joint bid.

The construction of each pumping plant under these contracts includes the building substructure and superstructure, the inlet structures and manifolds, the pump delivery lines with anchors and piers, the switch and transformer structures, and other appurtenant work. It does not include the installation of the pumps, motors, and other hydraulic and electrical equipment, which is now being done by District forces.

Water, power, and telephone service for construction were supplied at all pumping plants from the District systems. Crews working on the Intake and Gene plants were boarded and lodged at the nearby Parker dam construction camp. At Iron Mountain the contractor's camp for adjacent canal work served also for his crews on the pumping plant. New camps were built and operated by the contractors at Eagle Mountain and at Hayfield. District forces working on installation of mechanical and electrical equipment are quartered in temporary dormitories at the division camps and boarded at the regular messes enlarged to meet requirements.

Table 22 contains engineering and other data relative to the five pumping plants and Figures 20 and 21 illustrate the general features of the Intake plant which, except for the direct inlet from the reservoir to the pump house, is typical of the others. On account of future submergence by Parker reservoir especial attention was given to the foundations for this pump house. Diamond drill holes were put down to a maximum depth of 76 feet below the footings, the cores showing fairly hard but closely fractured quartz-diorite gneiss to the full depth of the holes. Pump pits were continued on a flat grade instead of being stepped, other footings generally were lowered, and in order to increase the factor of safety against flotation the footings were anchored by 1¼-inch reinforcement bars grouted into the rock to a depth of 20 feet.

Intake

The contractor for Intake and Gene plants began preliminary work late in December 1935. Early in January 1936 excavation was started in the Gene area adjacent to Division No. 1 camp and

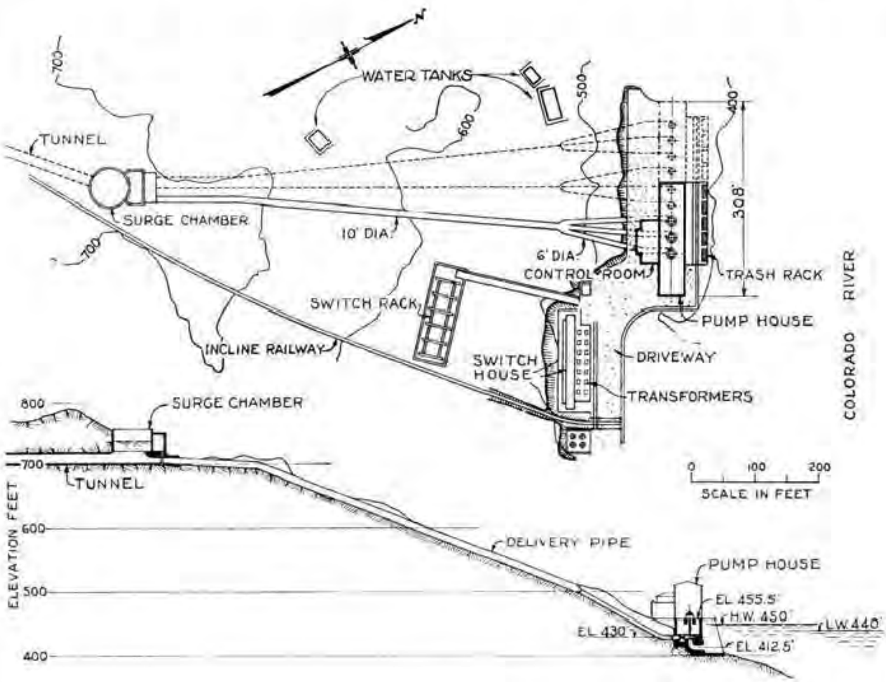


Fig. 20—Plan and profile of Intake plant

at the approach to the Intake site. Access to the latter site was provided by Gene Wash road, finished by the District in May 1934. This road extends from the Desilt Wash road to the west bank of the Colorado River at Intake, a distance of about two miles. The contractor started excavation at the end of this road, dropping the grade to the elevation established for the plant layout as he proceeded into the building area. Excavation for the switch house was first in order, followed by that for pump house, incline railway, and delivery lines, that for the switch house being completed in September and for the pump house in November 1936.

After grouting the foundations and drilling for and setting anchor bolts, the placing of concrete in the substructure of the pump house was begun at the end of November. The excavation for the incline railway was sufficiently advanced by January 1937 to start construction of the track, and in February work of placing concrete piers and installing pipe in the delivery line was begun. In March placing of concrete in the switch house foundations and walls and in the power cable tunnel was commenced, and in April erection of the steel frame of the pump-house superstructure was begun by the Consolidated Steel Corporation, Ltd., subcontractor for this work and for the steel delivery lines at the two plants.

Following a strike of the employees of the contractor in April 1937 all work at Intake plant was stopped, with the exception of steel erection by the subcontractor, who resumed work on May 10th and completed steel construction on both pump house and delivery pipe by the end of the month. Work was resumed by the general contractor September 7, 1937. By October placing of concrete was again under way, followed by erection of structural steel for switch rack and transformer hoist and construction of concrete water tanks, gate house, and surge chamber. On February 19, 1938 a fire of unknown origin destroyed the forms for the top lift of the surge chamber and damaged the concrete wall surfaces, delaying completion. All other contract features were completed in March but the guniting of the damaged surge chamber walls was not finished until April.

District forces began the installation of equipment as soon as this work could be done without delay to the contractor. In January 1938 all contract work was completed inside the pump house and the District proceeded with the assembly of valves and pumps in the pits, the necessary concrete work for valve, pump, and motor foundations and pump enclosure, the assembly of the motors above the pumps, and shaft connection to the pumps. Concurrently with assembly of equipment in the pump house, work has gone forward on the power system from the high-voltage switching station through the transformers and switch house to the motors. The independent water system consisting of pumps, delivery lines, and high-level concrete tanks to supply water for cooling, domestic and fire-protection purposes is under construction; the gates in the gate house at the top of the delivery pipes are being installed; and the landscaping of the area is in progress.

Gene

Excavation for the Gene plant was begun January 23, 1936 and first concrete was placed in some of the pump-house column footings at the end of April. In May construction of concrete cradles for the inlet sphere and manifolds was started. This was completed in June, after which no further concrete work was done until pouring of pump house foundation and substructure concrete was begun October 2, 1936. Thereafter concrete work was continuous throughout the winter months.

Following the strike in April 1937 no further work, except to complete water-curing of concrete, was performed by the contractor until September, when backfilling was resumed at the Gene pump house and preparations made for resumption of concrete work by repair of old and construction of new forms. Concrete work was practically finished at the end of December and steel work in the switch rack and backfill around buildings shortly after.

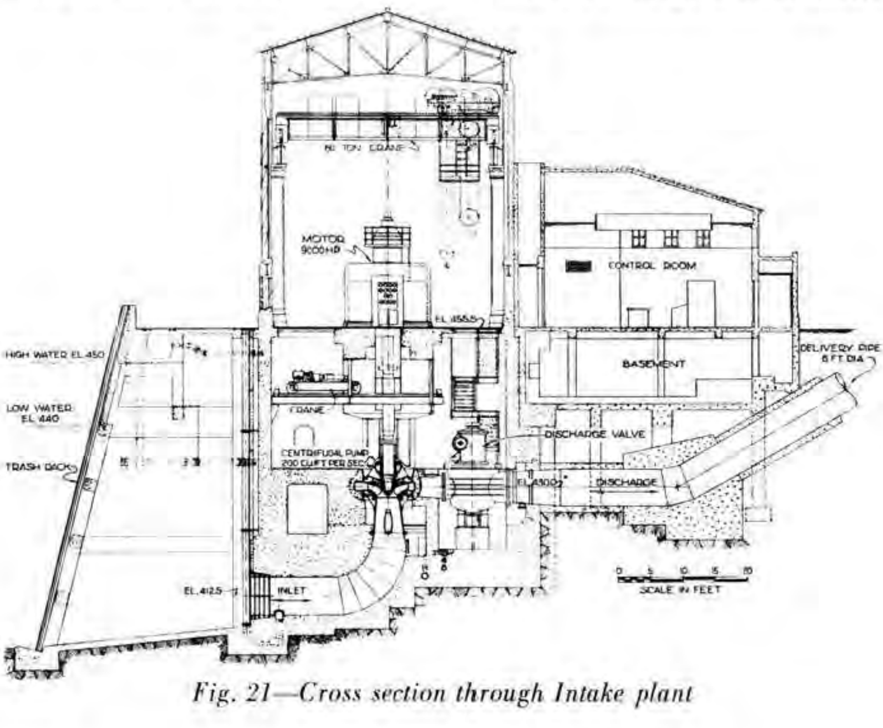


Fig. 21—Cross section through Intake plant

Except for final clean-up, this plant and all other work under the contract were completed in February 1938.

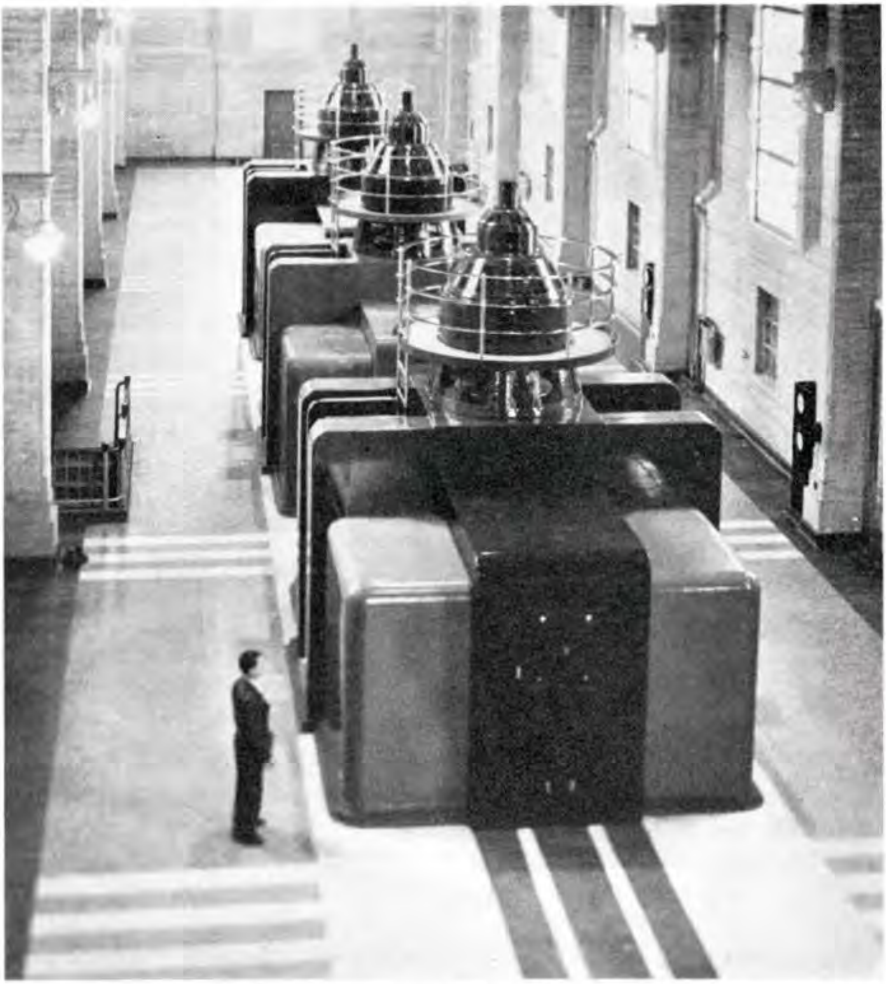
District forces began work at the Gene plant in October 1937 with construction of a temporary machine shop near the pump house and excavation for the transformer hoist foundations. In December the placing of inlet elbows was begun, followed by assembly of pumps in the pits, setting of inlet and discharge valves and other mechanical and electrical equipment necessary in the operation of pumps, motors, and valves. The erection of the motors on the motor floor with their connecting shafts to the pumps was started in April, and at the end of June work was in progress on the entire plant.

Iron Mountain

Excavation for the Iron Mountain pumping plant was started in the pump house area February 14, 1936, using caterpillar tractors and carryall scrapers, and was actively prosecuted on all features until June 16th, when work was suspended for the summer season. Concrete placing was started September 22nd in the pier supports for the inlet manifold, the installing of which was commenced by Western Pipe and Steel Company, steel work subcontractor, in October. Here as at Gene the inlet consists of a sphere and three branches to supply the nine pumps. By November concrete work was under way on all features of the contract.

In February 1937 the pump house substructure was completed, and erection of the steel frame of the superstructure began. This was finished early in March, after which the steel subcontractor proceeded with the construction of the delivery pipes, these being completed and tested in June. All of the major contract features were finished prior to July, but the contractor continued with clean-up and removal of equipment until September 1, 1937, when the contract was completed.

Preparatory to the installation of equipment, District forces in May 1937 began moving in tools, materials, and construction equipment from the force account work in the Coachella division which at this time was nearing completion. In June, the contractor having finished the pump house interior, work was started on the setting of the inlet elbow for the No. 3 pump and the inlet tees for pumps Nos. 1 and 2 and pouring concrete encasement about them. In June, also, the first pump casing arrived and in July was set in No. 3 pit. From this time on installation of valves, pumps,



Pumping plant motors

motors, and all accessories of the plant continued without interruption. The last pump reached the plant in October 1937, and the last motor the following January. Early in March 1938 the assembly of the mechanical parts of all pumps and motors had been finished. In April the tying in of the 230,000-volt switching station to the power line was completed and in May and June work was in progress on pressure piping for control of discharge valves, power and light connections, finish of building and grounds, and general clean-up.

Eagle Mountain

Much of the construction at Eagle Mountain was subcontracted, including excavation, aggregate production, plate steel pipe, structural and reinforcement steel, roofing, and painting. The contractor placed all concrete and backfill and performed such other work as could not readily be subcontracted.

On April 8, 1936 the contractor started the erection of a camp to house his employees, a short distance south of the plant and west of the District road into Division 3 camp. On April 20th stripping of the reservoir area was begun and on May 2nd drilling was started, preparatory to excavation in the inlet channels and pump house foundation. In July excavation was extended to the surge chamber and gate house site at the top of the lift, to the delivery pipe slopes, and to the sand trap. By October trimming to final grade of the pump house foundation rock was under way on the west side, but under the control house and a portion of the main plant the material was so broken that deep excavation was required, it being found necessary at one point to carry the excavation to a depth of 40 feet below the original grade. A good bedrock base was finally secured and the first concrete was placed in the pump house foundation walls and slabs early in January 1937.

In the meantime rough excavation for the sand trap was completed and concrete placing had been started for the surge chamber and gate house. In March the subcontractor set the first sections of the intake manifold and the installation was completed and tested in May. Concrete work in the various structures was continuous through the summer months, that in the sand trap being finished June 24th, and the pump house up to the motor floor in August. With the pump house up to this level it was possible for the subcontractor, Consolidated Steel Corporation, Ltd., to begin erection of the structural steel frame and crane, and this work was completed in October 1937.

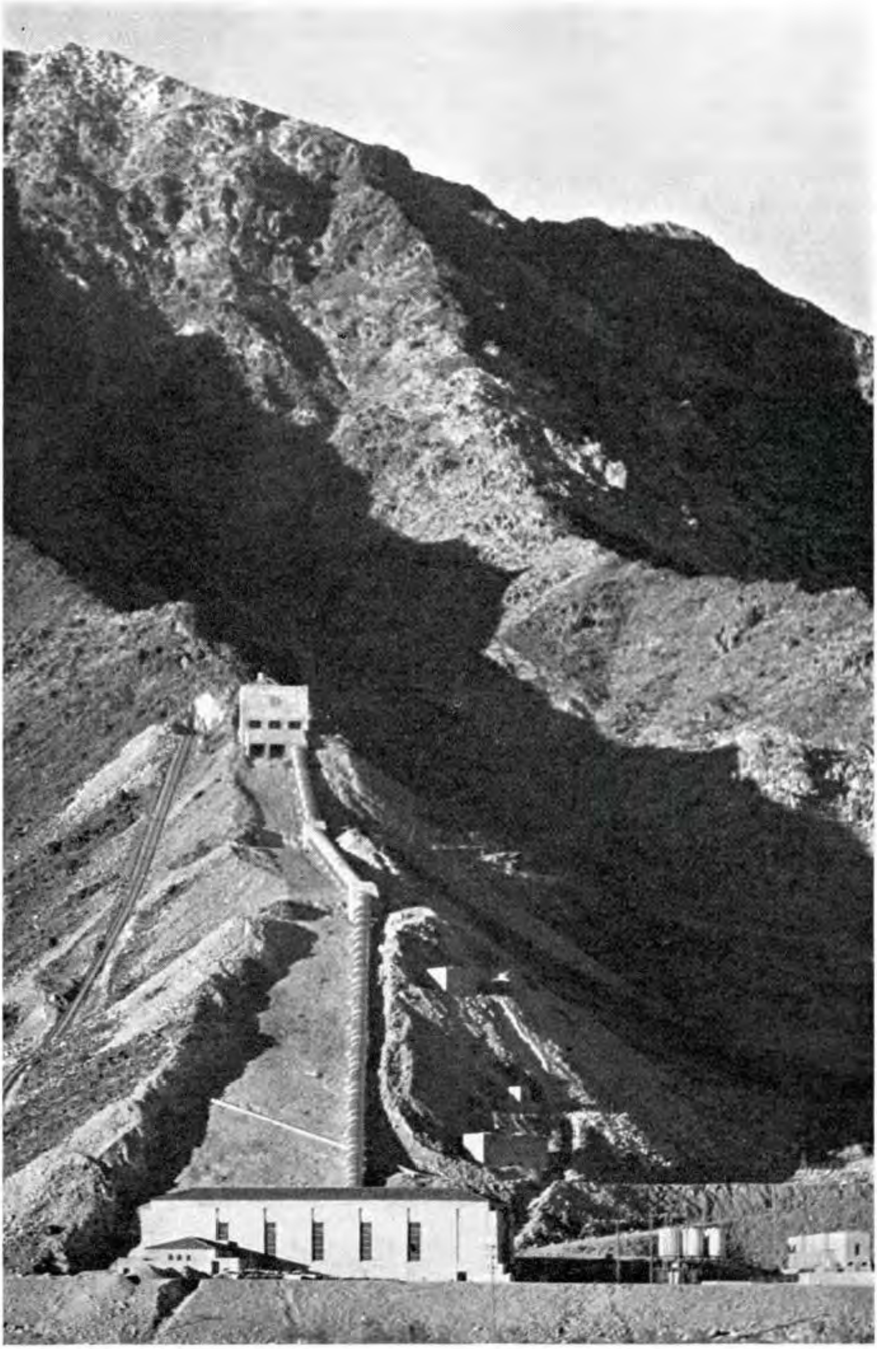
Concreting of the superstructure followed to completion in January 1938, concrete in the switch house and water tanks being fully placed shortly after. The subcontractor on the delivery pipes, Western Pipe and Steel Company, set up rigging and began construction of the pipes in December 1937, finishing the job ready for test two months later. In March 1938 the rolling of the oil-mix reservoir lining was completed; backfill around buildings and in the yard was brought up to grade; and general cleanup was in progress. The contract was completed on April 16, 1938, except for the removal of some of the contractor's camp buildings.

District construction forces were organized in August 1937 to prepare for installation of pumps, motors, and other equipment as soon as the contractor was in the clear. A machine shop was erected from buildings moved from the Coachella camp at Berdoo and some of the existing buildings at Division 3 were enlarged to care for increased crews, and to service construction equipment. In October the transformer hoist footings were placed and when the switch rack steel erection by the contractor was completed in

Eagle Mountain pumping plant

November the District employees began installation of oil circuit breakers and electrical connections.

Following completion and clean-up of the pump house interior early in 1938 the No. 3 inlet elbow, pump casings, and valves were moved out of storage into the building and erection was begun, since which time work has been actively progressing on all items of equipment installation. By April 1938 the pump settings were so far advanced as to require the services of the manufacturer's erecting engineer, and at the end of the fiscal year were nearing completion. In the switch house and at the transformer rack electrical work is well along; gates have been erected in the gate house; construction of the camp water supply is proceeding; and the grounds are being landscaped.



Hayfield pumping plant

Hayfield

On the Hayfield plant the excavation for the various features was subcontracted, likewise the production of concrete aggregates and the steel work in the pump house structure, the two inlet manifolds, and the delivery pipes. All other construction under the contract was performed by the contractor's own forces.

During the week ending September 26, 1936 the contractor began erection of a camp for housing his forces, at the same time starting excavation in the switch yard area. By the end of the year excavation had been extended into the areas covered by the sand trap at the west end of canal Schedule No. 13, the rectangular canal and box siphon leading thence into the plant, the pump house and inlet manifolds, and the delivery pipes.

The first concrete was placed on this contract in the switching station footings in February 1937. In March and April concrete placing followed completion of excavation in canal, siphon, and spillway channel and by June the pump house foundation excavation being sufficiently advanced concrete work was started in the east walls and sump. During the summer concreting operations were continuous in an effort to make up time.

In October, Consolidated Steel Corporation, Ltd., subcontractor, began construction of the lower inlet manifold, followed by the delivery pipes in December and the structural steel of the pump house and upper manifold in January 1938. The delivery pipes were ready for testing in May 1938.

Following the completion in February 1938 of the steel frame of the pump house, the placing of concrete in the structure was resumed in April and was nearing completion at the end of June, at which time also most of the other features, viz., the inlet structures from both aqueduct and reservoir, the delivery pipes and gate house, the incline railway, and the switch rack were completed or nearly so, except for clean-up.

TRANSMISSION LINES

The District has contracted with the United States for a supply of power to operate its pumping plants, as discussed in Chapter 2. This power will be generated at Boulder dam and will be delivered to the points of use by transmission lines which have been built and will be operated by the District. These lines consist of a 230-kv single circuit from Boulder through Searchlight, Nevada, to a midpoint switching station at Camino, whence two branches extend, one to the Gene plant, with a 69-kv extension to Intake;

TABLE 22

PUMPING PLANTS

	INTAKE	GENE	IRON MOUNTAIN	EAGLE MOUNTAIN	HAYFIELD
Miles west of Intake	0	2	69	110	126
Static lift, feet	291	303	144	438	441
Average operating head, feet	294	310	146	440	444
Elev. hydraulic grade at top of lift, feet	740	1,037	1,047	1,404	1,807
General bldg. dimensions (initial), feet	40 x 184	39½ x 179½	39½ x 179	42 x 179	44 x 194½
Delivery lines, slope length in feet	946	2,202	689	947	1,284
Diameter main lines, feet	10	10	10	10	10
Diameter branch lines, feet	6	6	6	6	6
Surge chamber dimensions	60′ dia. x 60′ high	36′ dia. x 30′ high	Transition only	30′ dia. x 82′ high	Transition only
Pump manufacturer	Byron Jackson Co. and Pelton Water Wheel Co.	Byron Jackson Co. and Pelton Water Wheel Co.	Allis-Chalmers Mfg. Co.	Worthington Pump & Mchy. Co.	Worthington Pump & Mchy. Co.
Motor manufacturer	General Elec. Co.	General Elec. Co.	Allis-Chalmers Mfg. Co.	Westinghouse Elec. & Mfg. Co.	Westinghouse Elec. & Mfg. Co.
Horsepower (each motor)	9,000	9,000	4,300	12,500	12,500
Kw-hrs per day required for three pumps	415,000	438,000	206,000	622,000	627,000
Kw-hrs per day required for eight pumps	1,108,000	1,168,000	550,000	1,658,000	1,673,000
Construction contractor	Winston Bros Co. and Wm. C. Crowell		Wood & Bevanda	L. E. Dixon Co.	L. E. Dixon Co. and Case Constr. Co.
Contract awarded	November 22, 1935		Jan. 24, 1936	March 27, 1936	Sept. 4, 1936
Work completed	April 29, 1938		Sept. 1, 1937	April 16, 1938	Uncompleted
Construction cost	$1,215,843.71	$1,040,930.29	$730,519.27	$1,063,594.97	....

the other to the Iron Mountain, Eagle Mountain, and Hayfield plants. The present lines will deliver 165,000 kilowatts, or sufficient power for pumping one-half the ultimate capacity of the aqueduct. In the future a parallel line will be built from Boulder to Camino and probably extended to Hayfield.

Preliminary studies to determine the most economic transmission line included electrical stability calculations, and complete design of towers and cost comparison of lines using two types of conductors. Long-time laboratory tests were made of different makes of insulators to select the one most suitable for the anticipated conditions.

Five types of towers were built, the standard suspension tower weighing 10,200 pounds and being capable of supporting a maximum span of 1,710 feet. The dead end tower used at all angles above 10 degrees is the heaviest and weighs 14,800 pounds. The towers support the three conductors in a horizontal plane 22 feet 3 inches apart and 70 feet 6 inches above the ground. Towers were staked to provide an initial clearance of conductors to ground in mid span of 30 feet, somewhat above the legal requirement, to allow for future stretch in the cable.

The four legs of the steel towers are supported upon footings which must take the thrust or pull of the tower legs under conditions of high wind or with broken conductors. The soil of the desert is generally sufficiently alkaline to corrode exposed galvanized metal, consequently a type of footing was adopted which consists of a central leg angle attached to a structural steel grillage, the whole of which is encased in reinforced concrete. In the dry lake, however, greater precaution was necessary and there the towers were set upon concrete pads, supported by creosoted piling driven deep into the soil. The concrete pad is protected as much as possible from the action of the strong alkalis by a coating of rich asphaltic mastic.

The conductor used uniformly over all the line, except in the 10-mile section across the Danby Dry Lake, where copper conductors were adopted as being more resistant to the corrosive action of alkali dust, is a composite cable made up of 26 aluminum wires stranded over a core of seven galvanized steel wires. The cross section of aluminum is 795,000 circular mils. The outside diameter is 1.108 inches and the weight is 1.09 pounds per linear foot.

The copper conductor used over the Danby Dry Lake is made up of 50 copper wires stranded in two layers over a twisted copper

I-beam section. The cross section of copper is 510,000 circular mils; the over-all diameter 1.004 inches; and the weight 1.62 pounds per linear foot.

The aluminum conductor is supported by strings of thirteen 10-inch insulators having a mechanical strength of 15,000 pounds. The cable is protected at the suspension clamps by armor rods and suitable vibration dampeners are provided. For the copper conductor in the alkali section of the line 17 units of insulators are used to make up for the impaired insulation value of the discs when coated with alkali dust. In this section, also, special towers were used to accommodate these longer strings of insulators.

Vibration dampeners were not specified for the copper conductor but tests made on the completed line showed sufficient vibration to warrant their installation. Consequently, dampeners identical with those used on the aluminum except for copper contact surfaces, were installed by District crews.

Surveys

The first survey work in connection with the transmission lines was accomplished in the spring of 1931, to secure sufficient data for the design of the principal elements of the line and the preparation of preliminary estimates.

In September 1933 the survey of the final line was started. In the rugged Whipple Mountain area northwest from Division No. 1 and the Gene plant an aerial reconnaissance was made, followed by sufficient aerial photography to provide complete coverage of possible locations. This not only proved of great value in locating the patrol road and transmission line through this difficult area but also revealed a desirable relocation of Intake pumping plant which resulted in considerable savings in cost.

By the end of May 1934, the entire 237 miles of final location had been chained, profiled, and tied into U. S. Land Office corners. Profiles were taken on the center line and 25 feet to right and left while additional "shots" were taken at points of questionable clearance. Field books were submitted to the Banning office where profiles were prepared and forwarded to the Los Angeles office for the spotting of towers.

Roads

Since roads were lacking over a large part of the line, a District road crew was organized as soon as possible after the final location was made, and in January 1934 started the construction of a natural surface dirt road along the transmission line right of way. Working northward from Danby Dry Lake about 50 miles to a point five miles north of Camino, then southeastward toward Gene, this crew built 84 miles of temporary road and seven miles of access road, and improved some 25 miles of nearly impassable existing roads in the Whipple Mountain area before work was completed in May 1934.

In addition to the transmission line surveys a location was made for the permanent patrol road through the Whipple Mountain area and profiles and cross sections were taken to permit the preparation of specifications for construction of the road by contract. The contract was let to Bennett and Taylor, Los Angeles, on February 25, 1935. Construction was started shortly thereafter and completed on October 15, 1935. During the winter this same contractor graded the Camino-Searchlight section of the patrol road, completing this work in March 1936.

Contracts

All location surveys were completed early in July 1934, and during the following year specifications covering the construction of the telephone line, and materials for and construction of the transmission lines were prepared and issued for bids. On September 27, 1935 a contract was awarded to Fritz Ziebarth of Long Beach for construction of the 230,000-volt transmission lines, followed by contracts for furnishing the tower steel, aluminum and copper conductor, and porcelain insulators.

The materials for the transmission lines were delivered by the manufacturers to the rail points nearest to the place of installation. The construction contractor received the material and did all the work necessary to complete the lines, including the construction of passable roads along some portions of the line not previously opened by the District. The District field forces placed the center stake at each tower location and gave all the data for assembling each tower. Inspectors followed the various stages of the work and checked accuracy and workmanship.

Construction of 230-kv line

During the first week of December 1935 the contractor started setting up his camp at the site of the Camino switching station and began the driving of piles for the footings in the Danby Dry Lake. On February 1, 1936 excavation for concrete footings was begun at different points along the Camino to Iron Mountain section. An excavator was used where the ground was suitable and the remainder of the excavation was by hand, using compressed-air tools and explosives when needed.

As soon as the excavation was well organized and steel assembled, the setting and concreting of footings was begun. The type of footing generally used consists of a truncated cone base 3 feet 6 inches in diameter at the bottom, set 7 feet 10 inches below the ground line, supporting a round tapering concrete column 17 inches in diameter at the base and 12 inches at the top. In the center of the column and extending down into the base is a 4-inch angle which is joined in the base to a grillage of structural steel. This footing stub angle is set at the tower leg batter and projects sufficiently above the concrete envelope to provide a lap joint at the point of attachment of the tower. In order to provide for bending loads the concrete envelope is reinforced by vertical bars spaced around the stub angle and by a ¼-inch spiral around the top three feet of footing. Placing of concrete was not permitted when the air temperature was above 95° and all work on footings was suspended during the period from June 18th to October 1st due to the intense summer heat.

On May 1, 1936 erection of towers was started immediately south of Camino on the Camino-Hayfield line. On June 10th one crew started erecting towers in the Danby Dry Lake bed. Here great care was exercised to keep the galvanized steel off the alkali ground as it was found that after only a few hours in contact with the moist soil an appreciable amount of galvanizing was removed by the corrosive salts.

On July 21st the stringing of the aluminum conductor was begun south of Camino. Insulators were usually hung by the tower crews but in some cases the stringing crews hung the insulators, lifting both insulators and stringing sheaves at the same time. In all cases when sheaves were lifted ropes were left therein for passing the lead lines back through the sheaves from the layout tractor when stringing.

Aluminum conductor was delivered to the site on reels containing three-fourths of a mile of cable. The reels were spotted in dollies adjacent to the end of the previous "pull" and the cable paid out, three conductors at one time, by lead lines some 200 feet in length attached to a tractor. As each tower was reached the lead lines were passed back over the stringing sheaves by means of the ropes left therein, and the conductor pulled through the tower. When sufficient lengths had been laid out and spliced for a pull, usually 2¼ miles, tension was placed on each cable, singly, by means of a power-driven winch on the tractor, sufficient to permit the release of the cable from the dead-man at the end of the previous pull, and the cable was then prestretched to 12,000 pounds for five minutes. Following this the conductor was sagged to normal tension, about 7,500 pounds at ordinary temperatures, and attached to the new set of dead-men required at the end of each pull to hold tension while the line was being clipped-in to the towers and additional conductor was being laid out and spliced for the next pull.

Transformers and switch house

From October 1, 1936, when concreting operations were resumed after the summer layoff, to the end of the year excavation and concreting of footings were pushed energetically while two crews of men followed closely erecting towers. From 24 to 31 towers were erected by the two crews each week when working under favorable conditions. By the end of 1936 towers had been erected from the Boulder plant to a point near the Iron Mountain pumping plant and from Camino to within 13 miles of Gene. At the same time stringing was finished from Boulder to the Danby Dry Lake and to Mile 27 on the Camino-Gene line.

During January 1937 work of all kinds was slowed down by the unusually cold weather. At Camino the temperature fell to 17° and exposed water pipes were frozen. The cold and the wind at times made tower erection impossible and concrete could not be placed on account of freezing.

Tower erection on the Camino-Gene section was completed late in February 1937, but due to difficulty in handling cable in the rough Whipple Mountain country, stringing was not finished to Gene until two months later.

All of the tower and stringing crews were then concentrated in the Iron Mountain-Hayfield section and by May 12th the towers were all erected. By July 19, 1937 stringing of conductors for the entire line was completed and by August 16, 1937, five months before the date specified in the contract, the clean-up crews had finished and a certificate of completion for the 230-kv transmission line was filed.

When the contractor finished the main lines, switch racks at the pumping plants had not been erected. It was therefore impossible for him to make the required connections between conductors and racks. Minor items also remained on the Parker dam standby loop. After this line had been taken out of service in March 1938 and the switch racks had been constructed District forces proceeded to string all terminal spans at the racks and to finish the Parker loop. The entire 230-kv line was completed May 3, 1938 except the terminal span at the Boulder switch rack which awaits construction of this rack by the Federal Government.

Construction of 69-kv line

The Gene branch of the 230-kv line terminates at the Gene switch rack. From this point power will be transmitted to the Intake rack by a double circuit 69-kv line 2.2 miles in length. The steel towers, except for specially designed bridges, are similar to those of the 230-kv line and the conductor is No. 4/0 copper cable with a cross section of 211,600 circular mils. Bids were received for the construction of this line in March 1937, but were rejected and the work was done by District forces at an appreciable saving in cost. Construction was started late in March 1937 and carried on by a

Operator's cottage at Gene

small crew throughout the summer, the line being completed in September with the exception of the span over the emergency standby loop to Parker dam. Early in December daily shutdown of this standby loop was permitted; the final span was strung and the 69-kv line completed on December 8, 1937.

Camino switching station

The Camino switching station on U. S. Highway 66, about 23 miles west of Needles, California, is designed as headquarters for transmission line operation and maintenance. A completely equipped camp has been built at this point, partly by contract and partly by District forces. It consists of six cottages, garage stalls, warehouses, and shop. A 915-foot well was drilled to develop water; sewer and lighting systems were constructed; and a butane gas plant to supply the camp and the gas engines driving water and power units. An ample supply of spare tower steel is stored here, together with other necessary materials and tools. The entire camp is enclosed by a woven wire fence with an interior fence enclosing the switch yard area.

The initial switching equipment consists of one disconnect switch on the Gene branch and one on the Hayfield. The yard is designed for later installation of a second transmission line, additional disconnect switches, and oil circuit breakers.

Additional road work

Following the construction of the 230-kv line north of Iron Mountain a start was made from that point in February 1937 on the repair and drainage of such portions of the contractor's road as were usable and on construction of a road through the previously omitted sections. This work, when completed in August 1937, provided a continuous patrol road from Boulder to Iron Mountain. Since that time the reconstruction of the contractor's road from Iron Mountain to Hayfield has been nearly completed, so that there is now a total of 250 miles of natural surface dirt roads along the transmission lines, continuous throughout except for a detour around the south end of the Coxcomb Mountains, the west slopes of which are too precipitous to justify the expenditures necessary to close this gap.

Construction costs

The total cost to June 30, 1938 of the permanent transmission line and facilities is given herewith:

Surveys	$ 55,580.56
Roads and water supply	167,396.13
230-kv lines	1,907,622.05
69-kv line	38,354.28
Camino switching station	89,392.76
Stores	64,056.63
Total	$2,322,402.41

TELEPHONE LINE

While transmission line surveys were in progress in 1934 the telephone line to connect Boulder dam and the Camino switching station to the existing District system along the aqueduct, described in Chapter 7, was also located and tied in to U. S. Land Office corners. This necessary addition to the system consisted of 7.8 miles of tap lines connected to trunk lines at Hayfield and Iron

Mountain and 139.4 miles of new trunk line paralleling the transmission line at a distance for the most part of about one mile.

A contract for construction of this additional line according to the specifications was awarded to Newbery Electric Corporation on September 13, 1935. The first line crew started work December 10, 1935 and construction was completed and clean-up and testing of the line finished May 27, 1936. The usual construction methods were followed. In favorable soil, holes were dug with a tractor-mounted mechanical auger, and at other locations by hand. Standard construction consisted of two No. 6 American wire gage copper wires on 5-foot 4-pin crossarms supported by 25-foot butt-treated Douglas fir poles with 220-foot spans.

Permanent connections to the pumping plants and necessary installations in each plant have not been completed.

CHAPTER 12

Distribution System

WHEN THE COLORADO RIVER aqueduct project was first considered, attention was directed particularly to the problem of transporting water from the Colorado River across the desert region lying east of the developed portion of Southern California to a terminal reservoir at some point within or close to the area to be served. As the plans became more definite, it was realized that an important part of the undertaking would be means of economically distributing the water to the various member cities after it had reached the end of the main aqueduct. Consequently definite plans were started, early in 1931, on the design of distributing lines and facilities for this purpose. Taken together, these features are termed the District's distribution system.

This is not a distribution system in the customary meaning, as the District will not deliver to individual users, but will furnish water in wholesale quantities to member cities for distribution by local municipal water departments, to augment supplies obtained from present sources.

While there are thirteen cities in the District at present with a population of more than 2,000,000, the potential service area comprises most of the coastal plain of Southern California. Although growth in water demand in the metropolitan area is inevitable, it cannot be definitely foreseen as to just where the greatest demand will be, or what will be the rate of increase. With this uncertainty in view it was deemed advisable to keep the District's distribution system as flexible as possible in order to economically meet the increasing demands for water where and when they may arise.

Flexibility is to be accomplished by construction in progressive stages, with a first development consisting of adequate features to serve all of the member cities either directly or indirectly for a few years. When the demand for water reaches the capacity of this initial system, additional features will be added as required in accordance with a general predetermined plan until the delivery of the full capacity of the main aqueduct is attained. The District's policy in this respect was published in Report No. 405, dated July 13, 1931 as follows:

> . . . the pumping plants, steel pipe lines, terminal storage works, distribution lines, and other readily divisible features, should have an initial capacity sufficient to supply the water need up to about 1950. This calls for about 100,000 acre-feet storage capacity and approximately half capacity in the other divisible items. The main aqueduct tunnels, covered conduits, and lined canals, should be constructed to full capacity in the beginning.

In regard to deliveries to member cities, the statement of policy adopted by the District on January 9, 1931 reads as follows:

> The Metropolitan Water District will deliver water, either directly or indirectly, through a system provided by the District, to each of the eleven original member cities, and to those cities whose applications for admission prior to March 1, 1931 have been approved, at or near the boundary of each, this point of delivery to be determined by considerations of economy and convenience with respect to the general engineering plans adopted by the District, and to such other points as the Directors may determine.

Principal features

The principal features of the distribution system included in the program for initial construction consist of the Cajalco reservoir, the headworks, a high line or upper feeder between Cajalco reservoir and Glendale, one cross feeder extending southerly from the upper feeder to serve the member cities in Orange County, another to make deliveries to the cities of Los Angeles, Compton, Torrance, and Long Beach, and a lateral westerly from the end of the upper feeder to supply Glendale and Burbank. This lateral will be extended to supply Beverly Hills and Santa Monica, also, unless exchange arrangements with the City of Los Angeles are consummated whereby these last-named cities will be supplied by connections from existing Los Angeles lines. Delivery to San Marino will be through a short lateral from the upper feeder and delivery to Pasadena will be directly from the upper feeder.

The main aqueduct will deliver water at a fairly uniform rate to Cajalco reservoir, but the distribution system must deliver water to meet the varying demands of the thirteen cities, all at different elevational zones. Regulation and control of flow in the feeder lines

SPENCE AIR PHOTOS

Morris dam in San Gabriel Canyon

and protection against interruption of flow are to be effected at Cajalco and Morris reservoirs and at a few small operative reservoirs situated near the ends of the lines. All of the distributing lines will operate under pressure.

The distribution system headworks consist of an outlet manifold with regulating valves at the end of the Cajalco outlet tunnel, a small forebay, and a forebay outlet structure serving the upper feeder, with provision for a connection to a lower feeder planned to extend at some later date westerly from Cajalco. Bids were opened March 15, 1938 for this work. A contract was awarded to The Contracting Engineers Co., of Los Angeles, low bidder, and construction is under way.

The upper feeder, which is now practically completed, has a capacity of 750 cubic feet per second between Cajalco and San Dimas and 510 cubic feet per second between San Dimas and Glendale. A take-out for a future auxiliary line to the central portion of Los Angeles is located in the vicinity of San Dimas. The upper feeder consists of 10.3 miles of welded steel-plate pipe with diameters varying from 9 feet 8 inches to 11 feet 6 inches; 35.7 miles of precast concrete pipe with diameters varying between 9 feet 8 inches and 12 feet 8 inches; 0.3 mile of 10-foot and 7-foot cast-in-place concrete siphons; and 15.7 miles of circular pressure tunnels, most of which are 10 feet in diameter.

The line extends northerly from the headworks at Cajalco to a point near Fontana and thence in a northwesterly direction through Cucamonga, Ontario, Pomona, San Dimas, and Glendora, a total of 41.6 miles to the east portal of the Monrovia No. 1 tunnel, this portion consisting of welded steel and precast concrete pipe. From the east portal of Monrovia No. 1 tunnel to Glendale, a distance of 20.4 miles, the line passes through or along the base of the San Gabriel range and beneath the streets of Sierra Madre and Pasadena and consists of a series of concrete-lined pressure tunnels, alternating with stretches of either precast or cast-in-place concrete pipe. Three major spillway structures have been built at drainage channels crossing the feeder; viz., a needle valve at the Santa Ana River and overflow spillways at the Puddingstone flood control channel near San Dimas and on the westerly side of the Arroyo Seco.

Most of the pipe line portion of the upper feeder traverses thickly settled areas where right of way was expensive and numerous improvements were encountered. Where possible, economy was effected by using streets instead of private right of way notwithstanding the expense for restoring pavements and moving other utility conduits. In general, where the lines traversed private property, easements were taken to avoid excessive severance damage appurtenant to fee purchase, and the pipe was buried a minimum of 4 feet below the ground surface for protection against erosion and to permit owners to use the ground for agricultural purposes after construction had been completed. Easements through cultivated areas provided for the replacement of three feet of top soil.

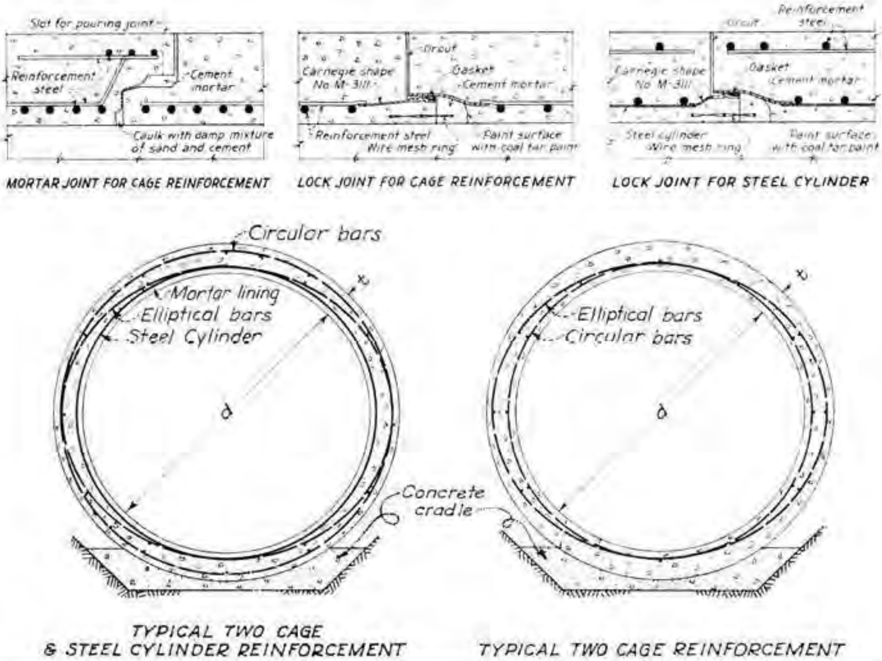
All of the distribution system contracts awarded prior to June 3, 1936, except Cajalco, were made subject to the 30-hour week provision of the Reconstruction Finance Corporation, Cajalco being on the same 48-hour-week basis as the work on the main aqueduct. The contractors, however, found it impossible to secure a sufficient number of skilled workmen during the time the 30-hour provision was in force, since the men were unable to earn wages equalling what they could earn elsewhere in the metropolitan area. Because of this condition the 30-hour regulation was amended on June 3, 1936 permitting a 40-hour week on all distribution system work.

Precast concrete pipe lines

The ten precast concrete pipe schedules of the upper feeder were constructed by three contractors under five separate contracts, varying in length from 4.5 to 11 miles. Nine and one-half miles of line with hydraulic heads of 75 feet or less were constructed with bell-and-spigot joints calked with mortar and grout, while 26 miles under heads greater than 75 feet have steel lock joints with lead gaskets. The maximum head in the precast concrete pipe schedules is 290 feet.

Permission for use by the District and its contractors of the patented lead and steel type of lock joint for precast pipe was secured through a contract with the American Concrete and Steel Pipe Company, the regional licensee. Under this contract the District purchased from the licensee the complete lock-joint assemblies, each consisting of the two matching steel joint rings and a lead and fibre gasket, and furnished these to the respective construction contractors as required.

Complete plants for fabricating the reinforcement and manufacturing and curing the precast pipe were established by the contractors at points convenient to the line. The American Concrete



d	PHYSICAL PROPERTIES				HYDRAULIC PROPERTIES					
	t	Wt of 12' section	Length	Maximum head	Area sq.ft.	r ft.	S	n	V ft. per sec.	Q c.f.s.
9'-8"	10"	33.6 tons	4.42 mi.	292	73.39	2.42	.00097	.012	6.94	509
10'-3"	10"	36.0 "	4.65 "	248	82.52	2.56	.00071	.012	6.17	509
11'-8"	12"	38.4 "	17.00 "	255	106.90	2.92	.00077	.012	7.02	750
12'-8"	13"	42.0 "	9.61 "	75	126.01	3.17	.00050	.012	5.95	750

Fig. 22—Precast concrete pipe details

and Steel Pipe Company plant was located at Rochester, on the Santa Fe railroad east of Ontario near Schedules 4P and 5P. The plant of the J. F. Shea Company, Inc. for Schedules 6P and 7P was located between Claremont and Upland, adjacent to both Santa Fe and Pacific Electric tracks and about a mile north of the pipe line. Subsequent to the award of its first contract the United Concrete Pipe Corporation constructed a permanent plant on the north side of the Arrow Highway east of the San Gabriel River and approximately two miles north of Baldwin Park, where the pipe was cast for Schedules 8P, 9P, 10P, and 11P. Construction procedure at the various plants varied somewhat as to detail but was similar in all essential respects.

For strength against external loads and internal water pressure, steel bar reinforcement was used, either fabricated into hoops or wound spirally on an electrically rotated drum. The hoops or

Precast concrete pipe sections

spirally wound steel bars were welded to the longitudinal steel and to the lock-joint rings, when these were used, to form a complete rigid unit. For heads in excess of 80 feet a thin steel cylinder was added to insure water-tightness and assist the cage reinforcement in resisting internal pressures. These cylinders were formed from flat sheets or plates, with all seams welded. Each cylinder with joint rings attached was tested for leakage, following which the cage reinforcement was fabricated around and welded to the cylinder.

In order to secure a uniformly excellent product, plans and specifications for the forms, as well as for the pipe itself, were included in the construction contracts. Each set of forms consisted of a cast-iron or steel base ring, inner and outer cylindrical steel forms, and a steel tamping platform surmounting the assembled forms and reinforcement, with guide rings and spreaders welded to the frame to hold the reinforcement and forms rigidly in place during the concreting operations.

Concrete for the pipe was mixed at a central mixer and then placed in the forms from a hopper mounted on a movable placing gantry. Electric vibrators were attached to the outside forms and moved upward as the forms were filled. After the concrete was placed it was worked by rotary vibrators consisting of long steel rods actuated by air motors revolving at approximately 500 rpm, the rods being pushed down into the concrete along the faces of the inside and outside forms. Dense concrete with smooth surfaces, free from air and water pockets, was thus obtained.

The forms were left in position for at least 12 hours during which the inside of the pipe was steam cured at a maximum temperature of 130°, to develop high early strength in the concrete. Then 48 hours later the section was laid on its side by some form of gantry and rolled to the adjacent storage yard where curing continued for the remainder of a 14-day period. Due to the weight of the pipe, ranging for the different diameters from 26 to 42 tons for the standard 12-foot lengths, special equipment was developed for handling the sections in the yard, transporting them from the yard to the trench, and installing them in the trench. All the transportation units used for hauling the pipe from the plant to the trench were of one general design, consisting of a truck and a low bed semitrailer.

The placing equipment used for the 11-foot 8-inch and 12-foot 8-inch pipe in the open country east of Ontario consisted of a steam-operated stiff-leg derrick mounted on a frame which spanned the trench. For the 11-foot 8-inch pipe through citrus groves and streets between Ontario and San Dimas an electrically operated

Lowering precast pipe with gantry crane truss-type gantry was used. In laying the 10-foot 3-inch and 9-foot 8-inch pipe west of San Dimas, a large crawler-type crane was used which traveled along the side of the trench.

All of the precast concrete pipe was bedded in a concrete cradle, the placing of which closely followed the laying of the pipe. Backfill was settled by a combination of puddling and flooding.

Lowering precast pipe with special gantry

Under normal conditions pipe laying progressed at a rate of from 12 to 16 sections or 144 to 192 linear feet per eight-hour day, dependent upon the capacity of the manufacturing plant. A record maximum of 30 pipe sections was placed in eight hours on Schedule 10P by the United Concrete Pipe Corporation.

After the trench was backfilled, each schedule was tested for leakage. Bulkheads were constructed, the line filled with water, and pressures equivalent to operating conditions applied. The specifications stipulated that the leakage should not exceed 100 gallons per inch of diameter per mile of pipe in 24 hours. All the schedules tested to date have successfully passed the leakage test.

Table 23 contains essential data on the precast concrete pipe schedules, all of which with the exception of Schedule 9P were completed prior to June 30, 1938.

Cast-in-place pipe lines

The upper feeder line along the base of the San Gabriel Mountains is intersected by three major canyons for the crossing of which special structures were necessary, namely, San Gabriel Canyon, between Monrovia No. 1 and No. 3 tunnels; Monrovia Canyon, between Monrovia No. 3 and No. 4 tunnels; and Eagle Rock Canyon, between San Rafael No. 1 and No. 2 tunnels. Contract for these structures involving 1,122 linear feet of 120-inch and 534 feet of 84-inch cast-in-place pipe, and appurtenant works, was executed March 13, 1937, with Basich Brothers of Los Angeles and work was still in progress at the date of this report.

Santa Ana river siphon and bridge

Steel pipe was used on a 10.3-mile section of the upper feeder extending from a point two miles south of Arlington to the Jurupa Hills, the hydraulic head ranging up to 485 feet, and pipe diameters from 116 to 138 inches. The steel line crosses the Santa Ana River on a bridge composed of eight 50-foot approach spans, and three 181-foot steel-truss bridge spans supported by piers 43 feet high with footings varying in depth from 30 to 50 feet. Rocker arms attached to ring girders are used to support the pipe on the bridge, providing for longitudinal movement due to expansion and contraction. Pipe line and bridge were awarded to the Western Pipe and Steel Company January 10, 1936 as one contract.

The steel pipe was fabricated in the shop in sections 33 feet 4 inches long from plates varying in thickness from $^{17}/_{32}$ to $^{31}/_{32}$ of an inch. All shop joints and seams were butt welded by automatic electric machines. Whenever the plate thickness exceeded $^{5}/_{8}$ of an inch the completed sections were heated in an annealing furnace to eliminate welding stresses. Each section was subjected in the shop to a hydrostatic pressure test, the pressure varying with plate thickness and internal diameter of pipe.

For protection against corrosion, the pipe was given a $^{3}/_{32}$-inch inside coating of coal-tar enamel and a $^{3}/_{4}$-inch outside coating of gunite reinforced with wire mesh. In very corrosive soils, an outside coating of coal-tar enamel was used underneath the gunite. In order to insure a satisfactory bond between the enamel and the

Table 23

DISTRIBUTION SYSTEM PRECAST PIPE LINES

Schedule	Contractor	Contract awarded	Work completed	Length in feet	Total cost	Cost per foot
1P	American Concrete & Steel Pipe Company	Jan. 10, 1936	Dec. 23, 1937	12,277	$ 662,190.19	$53.94
3P	American Concrete & Steel Pipe Company	Jan. 10, 1936	Dec. 23, 1937	20,124	1,236,544.40	61.45
4P	American Concrete & Steel Pipe Company	Nov. 1, 1935	June 18, 1937	25,867	1,312,788.72	50.75
5P	American Concrete & Steel Pipe Company	Nov. 1, 1935	June 18, 1937	24,892	1,164,131.19	46.77
6P	J. F. Shea Co., Inc.	Dec. 20, 1935	May 24, 1938	27,294	1,530,307.51	56.07
7P	J. F. Shea Co., Inc.	Dec. 20, 1935	May 24, 1938	29,950	1,736,366.97	57.97
8P	United Concrete Pipe Corp.	Nov. 1, 1935	Mar. 17, 1937	24,529	1,508,259.43	61.49
9P	United Concrete Pipe Corp.	Aug. 7, 1936	incomplete	8,691	....	......
10P	United Concrete Pipe Corp.	Aug. 7, 1936	Aug. 13, 1937	10,517	539,192.53	51.27
11P	United Concrete Pipe Corp.	Aug. 7, 1936	Nov. 27, 1937	4,127	305,104.84	73.93

Laying steel pipe near Arlington

steel, the pipe was preheated to a temperature of about 190° F for the enameling operation. On straight sections the hot enamel was applied to the interior of the pipe while it was being rotated at a high rate of speed, thus securing a uniform, glossy lining. In bends and branches and at field joints the enamel was applied by daubing. All enameled surfaces were carefully inspected for imperfections by means of an electrical detector.

After the enameling was completed the fabricated sections were shipped by rail to a field plant located in the vicinity of the trench, where the gunite coating was applied and allowed to cure for seven days. A specially designed tractor gantry handled the pipe in the field yard, unloading the railroad cars and loading the trucks, upon which the gunited sections, weighing from 25 to 36 tons, were transported from the field yard to the trench. A heavy crawler-type crane traveling along the roadway beside the trench unloaded the pipe and placed it in the trench. The pipe sections across the bridge at the Santa Ana River were not gunited but were given two coats of aluminum paint over a priming coat of red lead.

Butt-welded joints with butt straps were used for the field joints on the sections of pipe across the Santa Ana River, and bell-and-spigot lap-welded joints on the remainder of the schedule. Each joint was tested by forcing a liquid soap solution into the space between the inside and outside welds at a pressure of 100 pounds per square inch. All joints were then enameled on the inside and gunited on the outside, after which the trench was backfilled and compacted by ponding and flooding. The contractor maintained an average rate of progress of six sections or 200 linear feet per day installed in the trench and welded.

Construction of bridge and piers of the Santa Ana River crossing was sublet. Consolidated Steel Corporation, Ltd. fabricated, erected, and painted the three steel truss spans, furnishing the necessary pedestals and connections to the concrete piers. Morrison-Knudsen Company, subcontractor for all the excavation and concrete on Schedule 2S, also had the concrete and excavation for the piers for Schedule 2B, but in turn sublet to Dan Teters and Company not only the excavation and concrete work for the piers but also the concrete work on the pipe line schedule.

Santa Ana siphon bridge

The final clean-up of the right of way on the two schedules was finished on November 24, 1937, completing the entire contract, the cost of which was as follows:

Work	Total cost to District	Cost per linear foot
54,530 linear feet of steel pipe	$4,565,251	$87.88
Bridge	226,629	

TUNNELS

The distribution system tunnels are all pressure tunnels of circular section, uniformly 10 feet in diameter, except for 2,856 linear feet of 9-foot 9-inch section at the west end of Monrovia No. 4. They fall into two distinct types, tunnels in rock and tunnels in alluvium. The tunnels in rock are situated along the southerly slope of the San Gabriel range from Glendora to the Santa Anita Wash and through the San Rafael Hills west of the Arroyo Seco, including Monrovia Nos. 1, 2, 3, and 4 with an aggregate length of 9.3 miles and the San Rafael Nos. 1 and 2 totaling 1.8 miles in length. The tunnels in alluvium comprise the Sierra Madre and Pasadena tunnels, 1.3 and 3.3 miles in length, respectively. These latter tunnels were constructed at depths from 30 to 70 feet below the ground surface where the upper feeder line was routed through narrow streets in highly developed residential areas of the two cities, thus avoiding interference with improvements and inconvenience to the public.

In both the Sierra Madre and Pasadena tunnels the ground encountered was partially cemented alluvium which was readily excavated without blasting by means of pneumatic spaders and electrically operated mucking machines. The average excavation progress per month was 1,470 feet in the Pasadena tunnel for three shifts per day and 1,250 feet in the Sierra Madre tunnel on a two-

Fig. 23—Distribution system tunnels

shift basis. The maximum monthly progress was 2,185 feet and the maximum daily progress was 93, both in the Pasadena tunnel.

The concrete lining of the tunnels in alluvium was heavily reinforced, mainly with circumferential steel hoops. Concrete was placed in a full circle without longitudinal construction joints, by means of collapsible steel forms supported by a traveling carrier or jumbo. Concrete was placed by means of pneumatic concrete guns in sections 60 to 80 feet long between bulkheads, one section being placed each day. Concrete materials were batched at the portals, and transported into the tunnels to the mixer which discharged into the concrete gun.

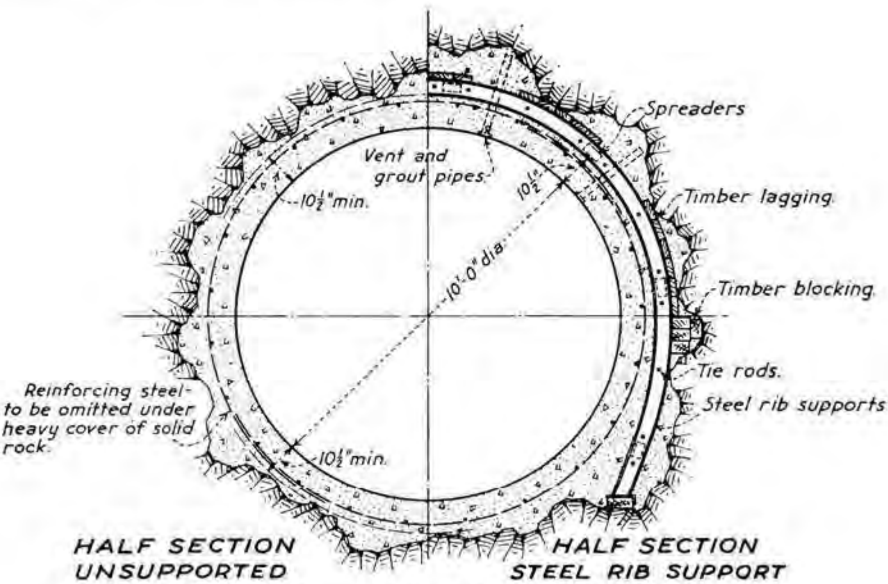


Fig. 24—Cross section of distribution tunnel

It was impossible to remove any lagging or spiling prior to the concreting operations due to the danger of caving and runs of sand. Grout was forced into the voids behind the concrete after the lining had cured sufficiently to permit putting pressure upon it.

Excavation in the rock tunnels involved the usual cycle of drilling, loading, blasting, mucking and, where needed, placing support. In most cases only light support was required, consisting of steel ribs and timber lagging, although timber sets were placed in faulted or soft ground where greater support was necessary.

The average excavation progress in all the rock tunnels for three eight-hour shifts per day was approximately 30 feet, or 800 feet per month for each heading. The greatest monthly progress at one heading was 1,210 feet in the Monrovia No. 3 tunnel.

Concrete lining was placed in the rock tunnels for the full circumference in one operation, except in a portion of Monrovia No. 3 west of the Fish Canyon adit, where the invert concrete was placed in advance of the sides and arch. Reinforcement steel was used in the concrete lining of the rock tunnels where the depth of cover was less than two and one-half times the hydrostatic head to which the tunnel will be subjected, and where soft unstable ground was encountered.

Table 24 contains essential data on the upper feeder tunnels. Monrovia No. 3 and Monrovia No. 4 had not been completed at the end of the fiscal year.

Flood damage along the upper feeder

Two large low-pressure areas passed over Southern California between February 28th and March 4, 1938. The first storm brought a fairly heavy rainfall. The second storm began at approximately 7:30 p.m. March 1st and lasted until 9:45 a.m., March 4th, an unusually heavy precipitation occurring especially in the foothill and mountain areas north of the upper feeder which turned the streams and dry washes into torrents. In many cases there were maximum flows greater than any previous record, the peak flow of all the channels between the Santa Ana River and the Arroyo Seco approximating a total of 200,000 cubic feet per second. In view of the severe test given the conduits and structures of the distribution system the damage was remarkably small. Construction progress of the contractors was practically at a standstill for periods varying from a week to ten days because of the disrupted transportation facilities and the necessary clean-up and repairs to construction equipment.

The damage at Cajalco was slight, a small amount of erosion occurring on the back face of the dike. Along most of the pipe line schedules some backfill erosion occurred and in a few places the pipe was exposed. The contractor's camp at Fish Canyon was destroyed, but operations on Monrovia No. 3 were completed from the west portal. The contractor on the San Gabriel Canyon crossing had completed the cast-in-place pipe except for the valve structure on the east side of the canyon adjacent to the west portal of

TABLE 24
DISTRIBUTION SYSTEM TUNNELS

Tunnel	Contractor	Contract awarded	Work completed	Length in feet	Total cost	Cost per foot
Monrovia No. 1, Monrovia No. 2	West Constr. Co.	Dec. 21, 1934	May 17, 1937	7,868; 940	$ 671,109.61	$76.19
Monrovia No. 3	West Constr. Co.	Dec. 21, 1934	incomplete	32,105	....	....
Monrovia No. 4	L. E. Dixon Co., Bent Bros., Inc., Johnson, Inc.	July 26, 1935	incomplete	8,133	....	....
Sierra Madre	J. F. Shea Co., Inc.	Aug. 9, 1935	Oct. 31, 1936	6,700	465,967.02	69.55
Pasadena extension	L. E. Dixon Co., Bent Bros., Inc., Johnson, Inc.	Aug. 9, 1935	Nov. 24, 1936	5,604	417,028.24	74.42
Pasadena	L. E. Dixon Co., Bent Bros., Inc., Johnson, Inc.	Dec. 21, 1934	Apr. 23, 1937	12,140	1,058,475.78	87.19
San Rafael No. 1, San Rafael No. 2	L. E. Dixon Co., Bent Bros., Inc., Johnson, Inc.	July 26, 1935; July 26, 1935	incomplete; incomplete	4,047; 5,669	....	....

Monrovia No. 1 tunnel. No damage occurred to the line but the contractor's equipment and a quantity of District-furnished materials were washed downstream and buried under the debris. Most of this was subsequently recovered.

Laterals to cities

Contract for the construction of the northerly 17.4 miles of the Palos Verdes feeder, between Eagle Rock and 98th Street, was awarded September 10, 1937 to J. F. Shea Company, Inc. This feeder is a service line for the cities of Los Angeles, Long Beach, Torrance, and Compton and is located principally in city streets at such depths as to be below other utility improvements. The line consists of 55-inch and 51-inch welded steel pipe with plate thicknesses from $\frac{3}{8}$ to $\frac{15}{32}$ of an inch, and the maximum hydraulic head on the line is about 450 feet.

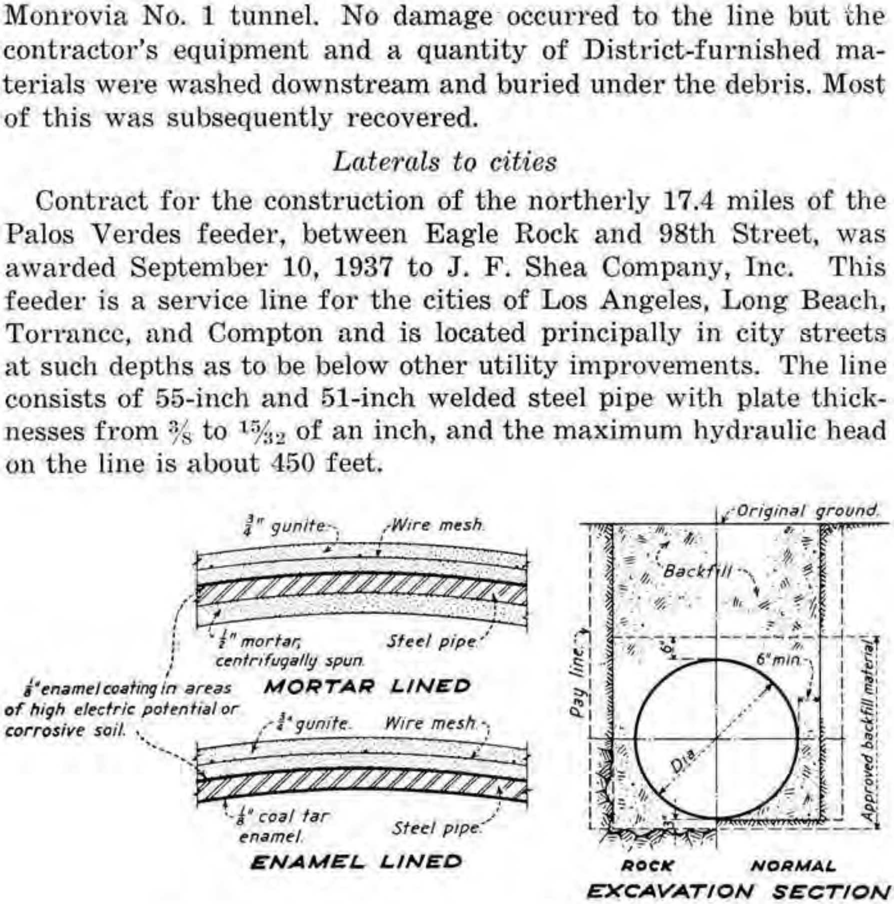


Fig. 25—Welded steel pipe in distribution system

This pipe line, divided into three schedules, takes off from a structure at the west portal of San Rafael tunnel No. 2 at Eagle Rock Canyon in the City of Pasadena and extends in a southerly and westerly direction to 98th Street and Wadsworth Avenue in the City of Los Angeles. It crosses the Arroyo Seco at the Pasadena Avenue bridge, traverses the western end of the City of South Pasadena, passes to the east of the Ascot reservoir of the City of Los Angeles, with a connection thereto, and crosses the Los Angeles River just north of Washington Boulevard. Aside from three short tunnels in the first schedule and numerous railroad crossings accomplished by jacking larger diameter pipe under the tracks, all pipe is being laid in open trench, the backfilling of the trench being kept as close as possible behind the pipe laying. The space outside of the pipe line in tunnels, and between it and the jacked pipe at railroad crossings, is filled with concrete. As of June 30, 1938 excavation had been completed for 6.24 miles and 5.99 miles of pipe had been laid by the contractor.

The inside of the pipe was given a ½-inch cement mortar lining, centrifugally applied by spinning the pipe sections. In practically all other respects fabrication methods were similar to those used on the steel line at the Santa Ana River, including an exterior gunite coating, with coal-tar enamel under the gunite where corrosive soils or electrolytic conditions exist. Both the inside and outside coatings were applied at the plant where the pipe was fabricated. From the fabricating plant the pipe sections, 30 feet long, were trucked to the trench where they were laid by a crawler-type crane. Special precautions were taken to prevent electrolytic action in the steel pipe as the result of numerous street railway and utility line crossings. In addition to insulating the pipe with gunite, and coal-tar enamel where required, two insulating joints and several test connections have been installed on the 17.4-mile stretch.

It is planned to call for bids on the construction of other sections of the distribution system in the near future so that delivery to all of the present thirteen member cities will be provided for by the time that Colorado River water becomes available at Cajalco reservoir. Included in the remaining work is a 14-mile extension of the Eagle Rock-Palos Verdes cross feeder required to reach the member cities in the harbor district, a 1,000 acre-foot operative reservoir to be constructed in the Palos Verdes Hills at the end of the cross feeder, and laterals to the other member cities not reached by the completed parts of the system.

CHAPTER 13

Specifications and Contracts

THE FIRST CALL for bids on permanent construction work in connection with the Colorado River aqueduct was for the construction of the San Jacinto tunnel, bids for which were opened November 29, 1932. The form developed for this set of specifications established a pattern which has been followed more or less closely in all subsequent construction specifications issued by the District. "The contract" is defined in the specifications as consisting of the Notice Inviting Bids, Instructions to Bidders, Proposal, Agreement, Specifications, and Drawings. These documents, together with the bond forms, are bound into a single volume and issued to prospective bidders. Specifications for the construction of permanent buildings or works are issued in printed form; others may be either printed or mimeographed, depending upon their importance and their anticipated circulation. In either case the volumes are 8½ by 11 inches in size; drawings are reduced to a uniform height of 11 inches, reproduced by roto-printing or lithographing, folded, and bound with the text or, if numerous, in a separate volume.

The burden of knowledge of and compliance with all applicable local, state, and Federal laws and regulations rests of course with the contractor, regardless of specification provisions. Certain legislative enactments however are required by state law to be specifically set forth in the specifications, including those relating to the eight-hour law, prevailing rate of per diem wages, and prohibition of employment of alien labor. The Reconstruction Finance Corporation requires the inclusion of provisions relating to prohibition of employment of convict labor, use of domestic materials and machinery, regulations regarding rates of pay for labor, employment preference to ex-servicemen and, west of Cajalco, the 30-hour (now 40-hour) week. In accordance with action by the District's board of directors provisions are included requiring the contractor to give preference in employment to residents of the District, where they are qualified. In order to protect local surety company agents and brokers, attention is called in the instructions to bidders to the law requiring premiums on risks located in California to be paid in and credited to offices located in the state.

Following San Jacinto, specifications for other tunnels were issued in rapid succession, until by the end of 1933 the construction of all main aqueduct tunnels had been provided for. Including the suspended San Jacinto contract, there were 14 contracts (13 of which are now completed) covering 19 separate tunnels, having an aggregate length of 58.4 miles.

Contractor's tunnel camp in Whipple Mountains

The writing of this group of specifications was preceded by months of preparatory work. In addition to the location surveys and geological reports, District engineers experienced in tunnel work made complete designs, plans, estimates, and construction layouts for each job so that the specifications were based upon definite knowledge of the situation at each tunnel, as complete as the most competent contractor would collect as a basis for his bid. As a further guide in the comparison of bids and award of contract thereunder, regulations required that a sealed copy of the engineer's estimate be filed with the board in each case prior to opening bids.

All conduit, canal, and siphon schedules east of the Coachella tunnels, comprising 110.62 miles of surface work, were included in Specifications No. 70, issued in August 1934. Contract awards under these specifications aggregated $14,166,000. The remaining 30.5 miles of main aqueduct surface work was advertised in October of the same year. All surface work was done by contract, except a few short sections constructed by District forces to connect the various units of the Coachella tunnels.

Force account specifications

As an aid in relieving the acute unemployment situation existing in Southern California at that time, construction of Schedules 1 to 6 of the Coachella group of tunnels by District forces was authorized on December 21, 1932. Preparations were quickly made and excavation was actually under way by January 25, 1933. Later the construction of the two remaining schedules of this group, and of the short connecting stretches of conduit and siphon by District forces was authorized. Following the suspension of the Wenzel and Henoch contract for construction of San Jacinto tunnel, that work was taken over by District forces on February 12, 1935. The only other main aqueduct features constructed by District forces are relatively minor isolated items, and include roads at Division 2, Hayfield and Cajalco, wasteways at Coxcomb and Casa Loma, Whipple spillway, the 69-kv transmission line between Gene and Intake pumping plants, buildings and water-supply lines for Camino switching station, and the patrol board for the Boulder transmission line. The pumps, motors, and appurtenant machinery for the pumping plants are also being installed by District forces.

Distribution system

Specifications for the first construction on the distribution system were issued in the latter part of 1934 and contracts were awarded in December of that year for the Pasadena and the Monrovia Nos. 1, 2, and 3 tunnels. The Monrovia No. 4, the San Rafael, the Sierra Madre tunnels, and the last portion of the Pasadena tunnel were advertised during the middle of 1935 and all were under contract by August. The outlet and diversion tunnels for Cajalco reservoir were included as a part of the contract for construction of Cajalco dam.

The first contracts for the construction of distribution system surface lines were awarded in November 1935, based on specifications issued in September. The first contract covered the precast pipe line for the upper feeder, between Fontana and Ontario and between San Dimas and Glendora. Contracts were awarded during the next two months for the remaining sections required between Cajalco and the Monrovia No. 1 tunnel, the last award being made in January 1936, for construction of the Santa Ana River siphon and the two sections of pipe line adjacent thereto. Contracts were later awarded for the additional pipe lines required to connect the various sections of the Monrovia tunnels, the Sierra Madre, the Pasadena, and the San Rafael tunnels, for the crossings of San Gabriel, Monrovia and Eagle Rock Canyons, and for the first schedules of the cross feeder from Eagle Rock to Palos Verdes.

Specifications were issued in July 1935, for construction of the Cajalco dam. For economy and better coordination these specifications provided that the diversion and outlet tunnels, the dike required along the north side of the reservoir, the main dam, and the spillway be constructed by the same contractor. Bids were received in August 1935, and a contract was awarded the same month.

Transmission line and pumping equipment

Specifications were issued in June 1935, for furnishing and erecting steel towers, aluminum and copper conductor, and porcelain insulators for the 230-kv transmission line from Boulder Canyon to the five aqueduct pumping plants. Contracts for the required materials and for construction were awarded in September 1935.

The first specifications for pumping plant construction were issued in October 1935. These resulted in an award of contract in November for the construction of both the Intake and Gene pumping plants and appurtenant works. In January 1936 a contract was awarded for construction of the Iron Mountain pumping plant and the 100 acre-foot forebay reservoir adjacent thereto. Contracts for construction of Eagle Mountain and Hayfield pumping plants were awarded March 27, 1936, and September 4, 1936, respectively. Specifications for construction of each pumping plant include the building substructure and superstructure, pump delivery lines with anchors and piers, switch structures, and other appurtenances; but do not include the installation of hydraulic or electrical machinery.

Following an extensive research conducted by the District's electrical and mechanical engineering staff, in collaboration with the engineering staff of California Institute of Technology, as noted in Chapter 11, specifications for furnishing the pumps to be used in

TABLE 25

CONTRACTS FOR FURNISHING PUMPING PLANT MACHINERY AND EQUIPMENT

	Items	Awarded to	Contract price
6	9,000-hp synchronous motors for Intake and Gene	General Electric Company	$693,759
3	4,300-hp synchronous motors for Iron Mountain	Allis-Chalmers Mfg. Co.	288,400
6	12,500-hp synchronous motors for Eagle Mountain and Hayfield	Westinghouse Elec. & Mfg. Company	784,562
15	5,500, 15,000 and 22,000 kva 230/6.9 kv transformers	General Electric Company	737,295
16	230-kv disconnecting switches	Bowie Switch Company	99,204
8	230-kv disconnecting switches	KPF Electric Company	49,827
12	69-kv disconnecting switches	Pacific Elec. Mfg. Corp.	16,092
70	15-kv disconnecting switches	Railway & Industrial Engineering Corp.	65,133
4	230-kv oil circuit breakers	General Electric Company	148,467
25	15-kv oil circuit breakers	Kelman Elec. & Mfg. Company	38,212
19	butterfly valves for pump intakes (Gene, Iron Mountain, Eagle Mountain and Hayfield)	Koppers Co., Bartlett-Hayward Div'n	113,959
9	Conical plug valves for pump discharges (Intake, Gene, Iron Mountain)	S. Morgan Smith Co.	219,075
6	Conical plug valves for pump discharges (Eagle Mountain and Hayfield)	Pelton Water Wheel Co.	138,994
5	Traveling cranes	Cyclops Iron Works	84,928
5	Transformer cranes	Cyclops Iron Works	74,804

aqueduct pumping plants were completed late in 1935 and contracts were awarded in January 1936. These contracts provided for furnishing three pumps for each plant. The pumps for the Intake and Gene plants were furnished by Byron-Jackson Company; those for the Iron Mountain plant by Allis-Chalmers Manufacturing Company; and those for the Eagle Mountain and Hayfield plants by the Worthington Pump and Machinery Corporation. The contract prices in each of these awards were respectively, $215,451, $101,249, and $256,830.

Other important awards for pumping plant machinery and equipment are listed in Table 25.

Construction materials

Subject to exceptions as found necessary to suit varying conditions, the rule under construction contracts is for the District to furnish cement, reinforcement steel, and in general all the articles and materials that the contractor is required to incorporate in the finished work, except water and aggregate for concrete, steel plates for welded steel pipe, and steel cylinders and bars for precast concrete pipe. The District also furnishes all steel ribs (but not timber) for permanent tunnel support. This arrangement has required the purchase by the District under formal specifications of large quantities of construction materials for use by District contractors, in addition to the explosives, drill steel, mucking machines, battery locomotives, and all the other materials and machines required for the prosecution of the District's force account work on the Coachella division and at San Jacinto tunnel. Under such specifications there have been delivered to date 6,891,000 barrels of portland cement, 61,500 tons of reinforcement steel, 21,500 tons of steel tunnel support, 700 miles of steel reinforced aluminum and 35 miles of copper conductor cable, and hundreds of items of slide gates, radial gates, valves, steel forms, and other fabricated articles too numerous to mention. For construction operations by District forces 4,500 tons of explosives and 485 tons of drill steel have been purchased.

An extensive investigation of California portland cements carried on at the Banning laboratory by the District's testing engineer in cooperation with the cement companies and the University of California resulted in the preparation of specifications for five different types of cement for District use, each differing in greater or less degree from the then current American Society for Testing Materials standard and each especially adapted to definite requirements of some part of the aqueduct work. For the bulk of the work a cement was specified meeting in general the requirements of a standard portland but somewhat more finely ground and more closely restricted as to allowable percentages of the less desirable compounds. The other cement specifications include sulphate-resistant cement for use where soil samples indicate that corrosive ground waters will be encountered, high early strength cement for temporary gunite support in tunnels and for grouting to cut off water ahead of tunnel excavation, low-heat cement for mass concrete in dams, and a portland-pozzuolan cement for a short test section of tunnel lining.

The District's major cement contract was awarded in December 1934 under Specifications 79 to California Portland Cement Company, Riverside Cement Company, Southwestern Portland Cement Company, and Monolith Portland Cement Company, bidding jointly. Under this contract a total of 5,999,775 barrels was delivered at an average price f.o.b. mills of $1.3523, transportation charges and sales tax paid by the District. The base price under the contract was $1.40 per barrel in bulk, at the mills, but provisions were included for price adjustments with variations in labor, power, and fuel costs and a further proviso was included that the price under District specifications during any calendar month should not exceed the average wholesale price of ordinary portland cement to other consumers during that month by more than the 4-cent differential obtaining at the date of contract. The application of these factors resulted in the average net price stated in the first part of this paragraph.

Deliveries under the above contract were completed October 27, 1937, but prior to that time a contract had been awarded to Monolith Portland Cement Company for 425,000 barrels, plus or minus 25 per cent, at a price of $1.19 f.o.b. Monolith, subject to adjustments as in the earlier contract. Subsequently, a short-time contract with the other three Southern California cement companies, bidding jointly, provided for the delivery f.o.b. mills of 250,000 barrels, plus or minus 20 per cent, at a firm price of $1.50 per barrel, and a contract was awarded Southwestern Portland Cement Company, May 31, 1938, for 80,000 barrels, plus or minus 20 per cent, delivered in the District's bins at the west portal of San Jacinto tunnel at $1.60. Total job requirements are now estimated at 7,200,000 barrels.

For the portions of the aqueduct served by the Southern Pacific railway, cement is hauled in bulk to the railhead in cars and delivered thence into bins at the various sites of work by railway company trucks, under transportation contracts dated October 9, 1934 and March 13, 1935. For the work at other points, except at the west portal of San Jacinto tunnel supplied under the 80,000-barrel contract previously mentioned, cement generally is shipped to the railhead by the District and hauled thence to the site of the work by the construction contractors. The average cost for transportation of cement from the mills to the work for the entire job has been approximately $0.50 per barrel.

All reinforcement steel required for the work, except that used in precast concrete pipe, is purchased by the District and furnished to the contractors f.o.b. railhead, or, in the case of fabricated bars, at some specified convenient point. The straight bars are purchased under contracts with local jobbers, awarded in August 1935, covering the delivery of 83,790 tons of reinforcement steel as required throughout the full construction period. Net prices of straight bars f.o.b. cars at points of use, exclusive of taxes, vary from $45.50 per ton for rail steel to $53.30 per ton for billet steel. Steel hoops for the circular concrete siphons were bent and welded by the District in fabricating plants located at Indio and Freda, then reshipped to points of use on a "fabrication-in-transit" arrangement. Except for one contract, where the contractor did his own work, bent bars for main aqueduct structures were fabricated by the District at Indio and Freda, and for some schedules by Wood & Bevanda at Rice. Steel reinforcement for precast pipe on the distribution system was furnished and fabricated by the pipe contractors.

To June 30, 1938 the District had issued 281 major specifications for construction and for furnishing materials, supplies, and equipment. These resulted in 405 formal contracts, involving total expenditures of $107,082,382.44. A large number of minor specifications providing for miscellaneous materials and equipment have also been issued.

List of construction contracts

Table 26 on the following pages gives a list of the principal construction contracts on the main aqueduct and distribution system, together with the names of the construction superintendents employed during the course of the work. In general the District's contractors and the key men in their organizations were of high calibre, experienced in their respective lines of work, resourceful, and efficient. The morale of the employees was well maintained throughout. Relations between the contractors and the District organization were excellent. A mutually satisfactory settlement of completed contracts was reached in practically every case without resort to the courts. Aside from the litigation in connection with the suspended Wenzel and Henoch Construction Company contract, there has been only one instance in which a contractor has brought suit against the District in connection with a construction contract, and in that case a compromise was effected before the suit came to trial.

TABLE 26

PRINCIPAL CONSTRUCTION CONTRACTS AND CONTRACTORS' PERSONNEL

CONSTRUCTION FEATURE	CONTRACT AWARDED	CONTRACTOR	HOME OFFICE	CONSTRUCTION SUPERINTENDENTS	WORK COMPLETED
		Main aqueduct tunnels			
Colorado River, Copper Basin Nos. 1 and 2, and Whipple Mt.	June 16, 1933	Walsh Construction Co.	Davenport, Iowa	Floyd Huntington and J. H. Gill	Feb. 24, 1937
Iron Mountain; east portion	April 21, 1933	Winston Brothers Co.	Minneapolis, Minn.	E. A. Bernard, excav; R. V. Johnson, conc.	Oct. 30, 1936
Iron Mountain; west portion	April 21, 1933	The Utah Construction Co.	San Francisco and Ogden	Ben Arp	Feb. 26, 1937
Coxcomb	April 21, 1933	Winston Brothers Co.	Minneapolis, Minn.	E. A. Bernard, excav; R. V. Johnson, conc.	April 22, 1937
East Eagle Mountain	Feb. 2, 1934	Broderick and Gordon	Denver, Colo.	C. J. Kavanagh, excav.	July 23, 1937
West Eagle Mt.; east portion	June 2, 1933	Broderick and Gordon	Denver, Colo.	John Will, conc.	May 6, 1937
West Eagle Mt.; west portion	June 2, 1933	L. E. Dixon and Bent Bros., Inc.	Los Angeles	Paul C. Guinn	Mar. 12, 1936
Hayfield No. 1	June 2, 1933	The Hunkin Conkey Constr. Co.	Cleveland, Ohio	Geo. B. Hoag	Jan. 9, 1936
Hayfield No. 2	June 2, 1933	Shofner and Gordon	Los Angeles	H. E. Warden	July 27, 1935
Cottonwood	April 21, 1933	J. F. Shea Co., Inc.	Los Angeles	Gilbert J. Shea	Dec. 27, 1935
Mecca Pass Nos. 1, 2, and 3	June 2, 1933	Morrison-Knudsen Co.	Boise, Idaho	S. A. Dahlberg, excav; Geo. Fortier, conc.	Mar. 1, 1935
Whitewater Nos. 1 and 2	June 16, 1933	West Construction Co.	Boston, Mass.	H. E. Carleton	April 15, 1935
San Jacinto	Feb. 10, 1933	Wenzel and Henoch Construction Co. (by M. W. D. on force account since Feb. 12, 1935)	Milwaukee, Wis.	Otto Seefeld	....
Bernasconi	April 7, 1933	Hamilton & Gleason Co.	Denver, Colo.	H. J. King, excav; H. S. Stocker, conc.	Nov. 18, 1935
Valverde	April 7, 1933	The Dravo Contracting Co.	Pittsburgh, Pa.	R. W. Remp	Oct. 18, 1936
		Main aqueduct surface work			
Canal; conduit; siphon	Oct. 19, 1934	Aqueduct Construction Co.	San Francisco and Los Angeles	C. M. Elliott and S. T. Corfield	June 24, 1937

Canal; conduit; siphon	Oct. 19, 1934	Barrett & Hilp and Macco Corp.	San Francisco and Los Angeles	H. W. McKinley	May 25, 1937
Canal; siphon	Oct. 19, 1934	Jahn & Bressi Constr. Co.	Los Angeles	Joseph Muscolo	Mar. 18, 1937
Canal; siphon	Oct. 19, 1934	C. W. Wood and M. J. Bevanda	Stockton, Calif.	A. F. Weesner	July 28, 1937
Canal; conduit	Oct. 19, 1934	The Utah Construction Co.	San Francisco and Ogden	Ben Arp	May 15, 1937
Conduit; siphon	Oct. 19, 1934	Three Companies, Inc.	Denver and Albuquerque	C. G. Clapp and C. J. Kavanagh	Nov. 6, 1937
Conduit; siphon	Oct. 19, 1934	Thompson-Starrett Co., Inc.	New York, N. Y.	Rodney J. Smith	May 20, 1938
Little Morongo siphon	Nov. 17, 1933	United Concrete Pipe Corp.	Los Angeles	Fred Jenkins	Aug. 20, 1934
Conduit; siphon	Nov. 9, 1934	J. F. Shea Co., Inc.	Los Angeles	W. F. Rennebohm	May 30, 1938
Siphon	Jan. 11, 1935	Morrison-Knudsen Co.	Boise, Idaho	J. O. Young	Sept. 16, 1936
Conduit; siphon	Dec. 7, 1934	Griffith Company	Los Angeles	Harry Davis	Oct. 13, 1936

Main aqueduct dams, pumping plants, and appurtenant works

Parker dam[1]	Aug. 25, 1934	Six Companies, Inc.	San Francisco	F. T. Crowe	
Intake and Gene pumping plant buildings	Nov. 22, 1935	Winston Bros. Co. and William C. Crowell	Minneapolis and Pasadena	R. A. Crowell	Apr. 29, 1938
Iron Mountain pumping plant buildings	Jan. 24, 1936	Wood and Bevanda	Stockton, Calif.	A. F. Weesner	Sept. 1, 1937
Eagle Mountain pumping plant buildings	Mar. 27, 1936	L. E. Dixon Co.	Los Angeles	F. H. Strohecker and J. H. Larkin	Apr. 16, 1938
Hayfield pumping plant buildings	Sept. 4, 1936	L. E. Dixon Co. and Case Const. Co., Inc.	Los Angeles and Alhambra	Crawford Strohecker and W. N. Evans	
Gene Wash and Copper Basin dams	Mar. 26, 1937	J. F. Shea Co., Inc.	Los Angeles	F. T. Crowe	
230-kv Boulder transmission line	Sept. 27, 1935	Fritz Ziebarth	Long Beach, Cal.	M. S. Elliott	Aug. 16, 1937
Whipple patrol road	Feb. 25, 1935	Bennett and Taylor	Los Angeles	Knight Bennett	Oct. 15, 1935
Boulder telephone line	Sept. 13, 1935	Newbery Electric Corp.	Los Angeles	Jack Sager	May 27, 1936
Fence schedule No. 1	Nov. 19, 1937	Anchor Post Fence Co.	Los Angeles	W. H. Mendell	June 14, 1938
Fence schedule No. 2	Nov. 19, 1937	Pittsburgh Steel Co.	Pittsburgh, Pa.	H. W. M. Coleman	June 5, 1938
Fence schedules Nos. 3, 4, and 5	Nov. 19, 1937	L. A. Fencing Co.	Los Angeles	H. Henderson	June 18, 1938

[1]Constructed under cooperative agreement with U. S. Bureau of Reclamation.

TABLE 26 *(Continued)*

CONSTRUCTION FEATURE	CONTRACT AWARDED	CONTRACTOR	HOME OFFICE	CONSTRUCTION SUPERINTENDENTS	WORK COMPLETED
		Distribution tunnels			
Monrovia Nos. 1, 2, and 3	Dec. 21, 1934	West Construction Co.	Boston, Mass.	H. E. Carleton	....
Monrovia No. 4; San Rafael Nos. 1 and 2	July 26, 1935	L. E. Dixon Co., Bent Bros., Inc. and Johnson, Inc.	Los Angeles	Paul C. Guinn and W. N. Evans	....
Sierra Madre	Aug. 9, 1935	J. F. Shea Co., Inc.	Los Angeles	Ed. H. Shea	Oct. 31, 1936
Pasadena	Dec. 21, 1934	L. E. Dixon Co., Bent Bros., Inc. and Johnson, Inc.	Los Angeles	H. J. King	April 23, 1937
Pasadena extension	Aug. 9, 1935	L. E. Dixon Co., Bent Bros., Inc. and Johnson, Inc.	Los Angeles	H. J. King	Nov. 24, 1936
		Cajalco reservoir, distribution pipe lines, and appurtenant works			
Cajalco reservoir	Aug. 16, 1935	Griffith Company	Los Angeles	R. B. Sawyer, Harry Davis, and Franz Fohl	Feb. 9, 1938
Distribution headworks structure	Mar. 25, 1938	The Contracting Engineers Co.	Los Angeles	Julian Huddelston	....
Precast concrete pipe	Jan. 10, 1936	American Concrete and Steel Pipe Co.	Los Angeles	D. H. Rankin	Dec. 23, 1937
Steel pipe and steel bridge	Jan. 10, 1936	Western Pipe & Steel Co.	Los Angeles	L. L. White	Nov. 24, 1937
Precast concrete pipe	Nov. 1, 1935	American Concrete and Steel Pipe Co.	Los Angeles	J. C. Connell	June 18, 1937
Precast concrete pipe	Dec. 20, 1935	J. F. Shea Co., Inc.	Los Angeles	Ed. H. Shea	May 24, 1938
Precast concrete pipe	Nov. 1, 1935	United Concrete Pipe Corp.	Los Angeles	Charles Johnston	Mar. 17, 1937
Canyon crossings	Feb. 19, 1937	Basich Bros.	Torrance, Calif.	Dick Noble	....
Precast concrete pipe	Aug. 7, 1936	United Concrete Pipe Corp.	Los Angeles	Roy Richards	....
Mortar-lined steel pipe	Sept. 10, 1937	J. F. Shea Co., Inc.	Los Angeles	W. F. Rennebohm and Charles A. Shea, Jr.	....

CHAPTER 14

Testing and Inspection

IN FEBRUARY 1931, within 60 days after the Parker route had been finally adopted for the Colorado River aqueduct, prospecting was begun in the vicinity of this line for deposits of sand and coarse aggregate which might prove suitable for concrete. At this time roads were few and poor, consequently many new tracks were made in the desert and, where a Ford would not go, many canyons and wash areas were explored on foot.

In August 1931, pending construction of the field headquarters at Banning, a testing laboratory was set up in the basement of the District's office building in Los Angeles, in order to begin investigation of the properties of test pit samples which gave promise of being suitable for concrete aggregate. This laboratory was equipped with screens, scales, mixer, equipment for impermeability and freezing and thawing tests, and a moist-room without temperature control. Compression tests were made at the Los Angeles City Bureau of Standards but a machine was provided in the District laboratory for tensile tests of briquets.

Hundreds of concrete cylinders were made in this laboratory in the study of complete aggregate combinations from desert sources, but as facilities were limited the principal effort was devoted to a thorough study of sands from the prospective sources because this procedure would give the maximum volume of significant data in return for the time and money expended. Hundreds of mortar batches of the different sands were made into thousands of briquets for tensile and sodium sulphate tests; 2 by 4-inch cylinders for compression, absorption, and freezing and thawing tests; and 6 by 2-inch discs for impermeability tests, using all the four local brands of cement at various water-cement ratios within the range most likely to be required for construction.

Pertinent physical properties of all samples were investigated during this first period of laboratory work. Sieve analyses and determinations of specific gravity, voids, silt content, and organic matter were made as a routine part of the study of materials from every source.

It was early recognized that the percentage of sand and pea gravel in most of the deposits was in excess of that required for the desired concrete proportions in combination with the complementary coarse aggregate. Consequently many small drifts, aggregating several hundred feet in length, were driven into solid rock at numerous points in the vicinity of the tunnel portals in the Little San Bernardino Mountains and in the Turtle Mountains north of Rice, and considerable effort was expended during 1932 in collecting and crushing samples of the best rock from many of these locations and making up concretes, using local fine aggregate. The principal conclusion from these tests was that, in order to obtain sufficient workability and flowability for tunnel lining concrete, considerably more sand, cement, and water per cubic yard of concrete would have to be used with the harsh crushed rock than with natural coarse aggregate. Hence the latter was used in practically all cases, even at the cost of rejection of large quantities of surplus fine material.

The proper curing of exposed surfaces of fresh concrete in the Colorado desert presented a serious problem and, because water was scarce, attention was directed to the determination of the most efficient materials and methods for curing the concrete by sealing in its original moisture. Early in the summer of 1931, before a laboratory was established, slabs were cast on the desert floor near Mission Creek, cured by various treatments, and later tested. During the summers of 1932 and 1933, field testing for evaluation of sealing compounds was continued, but on the more directly and definitely comparable basis of determining by weight the amount of water lost at the age of 24 hours from 6 by 12-inch concrete cylinders coated when green and moist. In these tests several hundred specimens were exposed and observed at Hayfield.

In May 1933 the laboratory was moved from Los Angeles to a new building at Banning, the principal features of which were a controlled-temperature standard moist-curing room; and general work and equipment space divided into three rooms for special physical tests, fineness tests, and chemical tests of cements.

The principal item of new equipment placed in operation at this time was a 300,000-pound universal testing machine with automatic rate-of-load controller and hydraulic support. This machine will test in compression specimens from 2 inches to 10 inches in diameter, provided the larger specimens are not stronger than 3,800 pounds per square inch, and will test bars in tension up to a total pull of 200,000 pounds. It is estimated that approximately 60,000 tests have been made on this machine to date. Annual calibrations have shown it to be accurate within one-third of one per cent of the actual load on the specimen.

Other new equipment in the Banning laboratory included a mechanical screen for quantity separation of aggregate so as to secure accurate grading when reassembled in test batches. An optical comparator was installed to study length changes in bars of mortar and of concrete.

The first year and one-half at Banning, through 1934, was largely spent in the continuation and extension of the investigation and study of materials and methods which had been commenced in Los Angeles. An important extension of the investigation of aggregate quality was completed during this period, particularly in reference to the coarse aggregate. Materials from 42 locations were given freezing and thawing and standard sodium sulphate durability tests, rattler tests, and comparative tests in concretes in which a mortar of constant quality was used.

Another important group of tests, which had been started while the laboratory was located in Los Angeles, was the investigation looking toward the development of a sulphate-resistant cement. Several thousand briquets and cylinders were made and tested after immersion for different periods in sodium sulphate solutions. Samples of every available cement differing even slightly in characteristics from others tested were included in these tests.

By far the most extensive investigation, however, was directed toward the determination of the most suitable composition for cement to be used under desert conditions. This investigation, begun in 1934, led to the adoption of the District's Specifications No. 79, for a finely ground, limited tricalcium aluminate content cement for all aqueduct work, except where special cements were required. These special cements were sulphate-resistant, for structures in alkali ground waters; quick-setting, for guniting and grouting in tunnels; and low-heat, for use in Gene Wash and Copper Basin dams. Specifications for these special cements were likewise based on careful and extensive tests.

Materials and acceptance tests

Exclusive of Parker dam, the Colorado River aqueduct, upon completion, will have required approximately seven million barrels of cement and eight million tons of aggregate in five million cubic yards of plain and reinforced concrete. Each of the several types of cement specified is made at one or more of the four Southern California mills and the aggregate has been obtained from at least 45 different sources along the aqueduct route. A total of 450,000 gallons of coal-tar pitch cutback sealing compound and 1,100 tons of whitewash materials has been used in the curing of exposed concrete surfaces. At least 100,000 tons of steel plates were required for constructing the distribution system pipe lines and the delivery lines rising from the main aqueduct pumping plants. To protect the surfaces of this steel from corrosion, 2,300 tons of coal-tar enamel and 7,800 gallons of primer have been purchased.

For plates and reinforcement bars manufactured in the East under unmodified standard specifications, testing and inspection are performed for the District by commercial laboratories and inspection bureaus located near the steel mills. All the other enumerated materials, locally produced or made elsewhere under special performance specifications, are tested and inspected by District personnel, except as hereinafter noted.

Cement

At the cement mills the District maintains resident inspectors. They sample the cement as it is manufactured, certify that each shipment is made from bins which have been approved and released, and see that the cement is handled and loaded without contamination. After a newly filled bin or "silo" is sampled it is sealed until the samples are tested. These seals may be broken only by the District inspector. This he does only immediately prior to the first shipment from the bin, or immediately upon advice from the laboratory that the lot is rejected and is to be returned to the mill for correction or other disposal.

The cement samples, each representing 300 barrels of cement, are forwarded to the District's testing laboratory, where the specified tests are performed under carefully controlled conditions. In the course of cement acceptance testing to June 30, 1938 not less than 2,250 complete chemical analyses, 27,000 briquets, 4,500 turbidimeter fineness tests, and 4,500 pats for time of set and soundness tests have been made and 4,500 four-pound samples have been stored for future reference. This thorough procedure in cement testing and mill inspection proved to be relatively inexpensive as the large quantities involved made an efficient and economical organization possible. The average total cost for both testing and inspection has been approximately two-thirds of a cent per barrel of cement.

Aggregate

As a basis for the preparation of aggregate specifications, and to determine the suitability of previously undeveloped deposits for use in aqueduct concrete, an extensive preliminary program of aggregate quality tests was conducted at the Banning laboratory as previously mentioned. Due to the necessity for prompt analysis and inspection of the aggregate when produced for construction purposes, however, it was not feasible for this laboratory to do the field testing for so many widely separated operations, after actual construction began. Consequently, small field laboratories were established at every aggregate and batching plant along the aqueduct line, each provided with equipment for the standard physical tests of fine and coarse aggregate. It is estimated that at least 50,000 such tests have been made. These tests supplied data for the acceptance or rejection of the aggregate produced, and for the determination of concrete proportions.

Specifications required accurate separation of the material into either three or four size groups, depending on its use, and also called for washing wherever water was available. Fortunately, where water was not available the deposits were for the most part bone-dry and the surfaces of the particles as screened were clean. In many such locations, however, the sand contained excessive amounts of very fine, clean particles passing the 100- and even the 200-mesh screen. These surplus fines were successfully removed by air separators developed to a high degree of efficiency during the progress of the work.

Concrete design and inspection

In the space here available it is possible only briefly to outline the characteristics of the concretes used. The 28-day strengths specified for concrete in principal structures are 2,500 pounds per square inch for canal lining and embankment paving, cut-and-cover conduit, and tunnel lining; 3,000 pounds per square inch for reinforced concrete and siphons; and 4,000 pounds per square inch for precast pipe. For these three classes of concrete the maximum sizes of aggregate in inches are 2½ and 2, 1½, and 1, respectively; and the usual range of cement content in barrels per cubic yard is 1.06 to 1.50, 1.375 to 1.625, and 1.56 to 1.69, respectively. The wide variation in the amount of cement used in the first two classes is due to the variation in consistency which is necessary under the different conditions encountered for placing the concrete in the several structures. The wetter concretes require more cement if they are to be of the same strength. Since vibration is used to aid in compacting and consolidating the concrete, it has not been necessary to make so wet a mixture as has been the usual practice when only hand methods of compaction were available. In general, mushy, plastic consistencies, with slumps of from 3 to 6 inches according to the requirements of the work, have been used.

Workability or "placeability" of the freshly mixed concrete has been an important consideration in determining concrete proportions, because good workmanship and a good quality of concrete in place cannot be secured if this property is lacking. On the other hand, excessive amounts of cement, sand, and water are guarded against in order to obtain the maximum durability and freedom from shrinkage cracking. The principal factors contributing to these optimum proportions for adequate workability were the increased fineness of the cement and a constant endeavor to approach, so far as practicable, ideal grading of the aggregate, particularly of the sand. In this latter connection, although there was frequently an excess in the sand of particles below 100 mesh, there was often also a marked deficiency of those between 50 and 100 mesh, particularly after removal of the excess below 100 mesh. It was found that, by blending with the pit sand a fine blow sand from nearby locations which contained 50 to 65 per cent between 50 and 100 mesh, a marked improvement was made in the grading of the sand and the workability of the concrete at very little increase in cost.

Samples taken from the concrete as placed were cast into 6 by 12-inch compression test cylinders. These cylinders were moulded in tin cans with friction tops, which were left in place until the specimen reached the laboratory, to avoid or reduce drying out. In the laboratory the cans were removed, and the sample moist-cured until tested. In addition to the moulded specimens, many test cylinders were core-drilled from the finished concrete, at various ages up to a year after placement. These cored samples uniformly have run appreciably stronger than moulded samples of the same age. Approximately 28,000 field specimens were tested prior to June 30, 1938, at an average cost of about 50 cents each.

Sealing compound

Before preparing specifications for the compound to be used for seal-coating concrete in canal lining, the outside surfaces of conduit and siphon, and other exposed concrete, extensive investigations and tests were made to determine for the existing arid conditions of exposure the most effective sealing compound that could be economically obtained. It was found that a coal-tar pitch cutback applied in two coats was most effective. The specifications are simple, being primarily a requirement of performance of sealing value designated as percentage of weight lost by coated green concrete cylinders after periods of exposure of 4 and 8 days in an atmosphere of 100° F and a relative humidity of about 15 per cent.

Inasmuch as this material is furnished from plants in New Jersey and Indiana, arrangements were made for commercial laboratories to take samples, certify as to the proportions of pitch and solvent naphtha, stamp the drums as being filled from approved lots of the compound, and forward a small can of the material by air mail to the District's laboratory for the performance test.

Coal-tar primer and enamel

Samples of coal-tar primer and enamel purchased for coating steel pipe are applied on 4 by 10-inch steel test panels in the manner designated by the manufacturer for field application and tested for performance under specified test conditions. Sagging of more than $\frac{1}{32}$ of an inch after 24 hours in a near vertical position at 160° F is cause for rejection, as is cracking or checking when the plates are stored at — 8° F for 5 hours. It must not be possible to peel the sheet of enamel from the plates after 4 hours at a temperature of 150° F. Panels coated with freshly heated enamel, and others coated after cooking the enamel two hours at application temperature, are stored for 4 hours at 40° F and then subjected to cold-bend tests at that temperature. If more than the specified permissible area of enamel is loosened from the plates in this test the enamel is rejected.

As the primer and enamel are also made in the East, the services of a commercial laboratory are utilized to take samples of each lot as produced and to certify and mark all drums as filled. These samples are forwarded to the District's laboratory for test, and on completion of the tests, advice of acceptance or rejection of each lot is sent to the vendor's representative in Los Angeles.

Whitewash materials

It was found that a durable whitewash, when applied by an air spray in an arid and frequently windy atmosphere, requires, in addition to the powdered hydrated lime, sufficient hygroscopic material to control water loss during placement, and a soapy ingredient to give the mixture cohesion and keep it from running or separating before it dries. The District's specifications for dry whitewash materials were therefore written to require for the above purposes, in addition to the lime, 17 per cent of anhydrous calcium chloride and 1.6 per cent of calcium stearate. The fineness of the materials used, their general suitability, and their ability to remain in suspension without constant agitation, are controlled by a specification requirement that after one hour, settlement shall not leave over 10 per cent of clear supernatant liquid above the turbid solution. Although the whitewash purchased has been prepared in relatively small plants using materials from various sources, generally satisfactory results have been obtained where the application procedure has been competently performed.

Inspection of aggregate production and concrete work was performed by "plant" and "placing" inspectors reporting through chief inspectors, assistant engineers, and resident engineers to the division engineers. The plant inspector was responsible for aggregate preparation and batching. The placing inspector was responsible for the consistency of the mixed concrete at the forms and for its handling, placing, finishing, and curing. Over the construction period more than 300 men have been employed in the above positions. It could not be expected that such a group of men, rapidly assembled, with a wide variety of previous experience, ability, knowledge of the subject, personality, and opinion, would automatically conform in the performance of their duties to a uniform, well coordinated procedure. To overcome this difficulty a 62-page printed manual of instructions, based on the specifications for and conditions applying to aqueduct concrete work, was prepared and a copy issued to each.

As a further and invaluable aid to this end, a school for inspectors was established at the Banning laboratory. The manual and the specifications were used as text books, and the intent and purpose of each part of the concrete specifications were fully explained. The men were taught the simple physics and arithmetic involved in making and computing sieve analyses and specific gravity tests and how to use this information to determine the proper weight of each ingredient to be proportioned into a concrete batch. There were demonstration and practice periods in which each man performed the field tests essential to proper control of aggregate and concrete production, and had practice in the proper making of and caring for a concrete test cylinder. Demonstrations were given of the correct procedure in finishing and troweling of surfaces, clean-up of horizontal construction joints for a satisfactory bond, and application of sealing compound and whitewash. In order to fix the essentials more firmly in their minds the men were given three written quizzes and a batch-computation problem during the course. Seventeen classes of one week each were held during the construction seasons of 1935 and 1936, with a total attendance of 258 men.

Inspection of metalwork

In 1935 an inspection section in the design division of the Los Angeles office was organized to provide inspection at point of manufacture for the very large quantity of fabricated structural steel, welded steel pipe, reinforcement steel hoops, valves, gates, and miscellaneous material and equipment required for the aqueduct. This force, which varied with the amount of work in progress, for a considerable period during 1936 included 17 employees. Two of these were located in the San Francisco area, and one in the East.

The major activity of this group was the inspection of plates, arc welding, and shop hydrostatic tests of 50 miles of welded steel pipe of large sizes for the pumping plant discharge lines, Santa Ana siphon, and pressure conduits. Every inch of arc welded joint was covered by careful visual inspection of each welding pass, including back chipping of any doubtful portion of the weld. In addition, the welding on the pumping plant discharge lines was inspected by standard radiographic acceptance tests. All shop welded sections in the pumping plant discharge lines and pipe with shell thickness exceeding ⅝ of an inch for the 9-foot 8-inch to 11-foot 6-inch diameter Santa Ana siphon were stress relieved.

Inspection was also made of approximately 28,500 tons of steel bars and 5,800 tons of plates and sheets furnished by the pipe contractors on the distribution system for the circumferential reinforcement of 35 miles of precast concrete pipe in diameters up to 12 feet 8 inches. In addition to making the specified tests on the materials, each bar weld was subjected to full tension test in the welding shop, and the cylinder welds were given an inspection similar to that provided for the welded steel pipe.

Inspection during fabrication was furnished also for the following:

- Structural steel work for transmission line towers.
- Structural and ornamental steel and metal work for the five pumping plants.
- Outlet valves and fittings for the Cajalco, Gene Wash, and Copper Basin dams.
- Galvanized woven wire and metal posts for 153 miles of fencing.
- Manhole frames and covers, relief valves, and miscellaneous metal for aqueduct structures.
- Special equipment used on District force account construction.

The steel plate, reinforcement steel, and equipment purchased at eastern manufacturing centers that could not be covered by the one District inspector located in the East was handled through the established engineering inspection bureaus.

CHAPTER 15

Purchasing, Right of Way, Medical, Safety, Personnel, and Miscellaneous Activities

PURCHASING

THE PURCHASE of such equipment, materials, and supplies as were required in the preliminary survey and planning stage of the Colorado River project was on a small scale and therefore a relatively simple matter. It was done by one man, in the office of the assistant controller, following a procedure similar to standard governmental practice.

When construction was authorized in December 1932, Saul A. Joseph of Los Angeles was appointed purchasing agent and a force was immediately organized to purchase building materials, equipment, and supplies and arrange for their transportation to the District forces beginning work on the Coachella tunnels. Large quantities of District-furnished materials required by the contractors on the construction of roads, water, power, and telephone systems, and division headquarters buildings also had to be purchased and delivered to the job.

As aqueduct work progressed the activities of the purchasing division were expanded to cover the procurement of materials for the eight Coachella camps, for contractors who required District-furnished materials for tunnel and surface work, and for San Jacinto tunnel after the latter was taken over by District forces in February 1935. These purchases of equipment, tools, repair parts, miscellaneous supplies, lumber, petroleum products, and food stuffs, for the Coachella and San Jacinto operations and for division headquarters camps, and of merchandise for resale in commissary stores, between January 1, 1933 and June 30, 1938 amounted to more than $13,000,000. Included in this amount are quite extensive purchases of fresh and smoked meats, fruit, vegetables, and dairy products in Riverside County, principally from the Coachella and Palo Verde valleys, and of other supplies from local dealers along the line. The number of purchase orders issued in this 66-month period was 96,426, an average of 1,461 per month.

Working under the purchasing agent was an experienced traffic clerk; all shipments being routed so as to secure the advantage of the lowest shipping rates and resultant least cost to the District, using rail, boat, or truck, or combinations of these transportation systems. The traffic clerk also handled for the most part the transportation and delivery of equipment and materials purchased under formal specifications and contracts aggregating $27,500,000 additional. The total transportation requirements during the period involved the shipment of the equivalent of 48,273 carloads and more than 25,000 truckloads of freight, the amount expended by the District for freight, express, and cartage up to June 30, 1938 approximating $4,307,000.

During the period in the early Coachella operations when it was essential to deliver all kinds of materials and supplies immediately in order to avoid delay in construction at the eight District camps, a special car was loaded each week day afternoon in Los Angeles, attached to a fast Southern Pacific train and spotted on the Indio warehouse siding ready for unloading and delivery the following morning. Equally valuable cooperation was extended by the Santa Fe railway in connection with the work in its territory, and all other transportation agencies cooperated most effectively with the District at all times.

Purchases in excess of $500 are made on competitive bidding, and where the amount involved is in excess of $5,000 bids in writing must be secured by posting notice inviting bids in a public place within the District for at least 72 hours before the time of opening bids. Newspaper advertising is also used when considered advisable. In general, printed or mimeographed formal specifications, prepared as outlined in Chapter 13, are required for construction work and for equipment and materials of a special nature or if the estimated cost is over $10,000. Contracts for the purchase of equipment, materials, and supplies involving an expenditure in excess of $10,000 and all contracts covering the construction of permanent buildings and works are executed by the general manager and chief engineer only after approval by the board in each particular instance.

With the completion in 1937 of the Coachella work by District forces all camp buildings and a large amount of equipment and tools became available for sale as salvage property, and as the San Jacinto work approaches completion additional surplus equipment must be disposed of from time to time. Prior to sale the appraised value of all salvaged material and equipment, whose original cost per unit exceeded $5,000, is determined by a committee appointed from the board of directors. For all other salvage a fair value based on present physical condition is set in the field by a committee of three appointed by the division head, this appraisal being referred to a resurvey board which may concur or may revalue the salvaged material or equipment to an amount consistent with present market conditions. Sales must be made at not less than the appraised value, except with the consent of the board of directors. Up to June 30, 1938 the total of sales amounted to $146,450.14, and the total appraised value of transfers to other District work aggregated $102,270.78.

RIGHT OF WAY

At all times from the beginning of the early main aqueduct studies to the completion of the location for the present development of the distribution system careful consideration has been given to the cost of right of way. Maximum use of public lands and highways was kept constantly in mind, in order to minimize costs, particularly in the high value, cultivated areas of the Southern California coastal plain.

Upon the selection of the general route of the aqueduct there was secured a withdrawal from entry of all public lands within an area of sufficient width to permit a final aqueduct location along the most feasible route. This withdrawal is effective until such time as the District has filled its construction needs when, upon assent of the District, the lands are to be restored to entry. By act of Congress of June 18, 1932 there was granted to the District free of cost the public lands needed for the main aqueduct right of way, including the right to take therefrom stone, gravel, sand, and other materials of like character necessary or useful in the construction of the aqueduct. The act also provides that the District may acquire such additional lands as are required for power transmission and telephone lines, roads, reservoirs, camp sites, diagonal drains, and water lines at a fixed price of $1.25 per acre.

In locating and purchasing the right of way for the aqueduct close attention is given to right of way conditions and future needs. Before a location is definitely fixed it must meet the requirements for use of the interested divisions, that is, the design, electrical-mechanical, and construction. A general right of way strip map is then prepared showing the line superimposed upon the topography and land subdivisions. This map, accompanied by a concise statement of use, reason for size, or shape, or width of right of way, and approximate cost, is transmitted to the general manager and chief engineer for approval. When the general map and accompanying data have been approved detail plats, or atlas sheets, are prepared. These show the type of structure, ownership of land, dimensions and ties of the required parcels, and such other information as is essential to the right of way agent and the District's appraisal board. Each parcel must be examined on the atlas sheet and in the field by the appraisers and their findings as to value are reported to the board of directors, who may then grant authority to acquire the necessary land at prices fixed by the board.

In July 1931 Daniel F. McGarry, of Los Angeles, was appointed right of way agent and acted in that capacity until ill health caused his resignation in January 1932. His successor, George R. LeBaron, also of Los Angeles, was appointed to the office in April 1932 and proceeded with such work as was necessary pending the financing of the project. The acquisition of necessary rights of way for the main aqueduct features was commenced in October 1932. By June 30, 1938 more than 3,100 transactions, exclusive of filings on Federal and state lands, had been completed, involving about 27,500 acres and payments to private owners of approximately $1,800,000. These transactions covered the entire right of way field, comprising purchases of land in fee and of easements for power transmission and telephone lines, roads, water supply lines, well sites, camp sites, reservoirs, tunnels, and surface conduits, the securing of permits and settlement of damage claims. Property has been purchased in Yuma and Mohave counties in Arizona, in Clark County, Nevada, and in Los Angeles, Riverside, and San Bernardino counties in California, and in 22 cities and towns. In the purchase of property, escrows were closed through title companies in the above named counties and in Phoenix, Arizona.

Filings on public lands of the United States have been made to the number of 155, whereby 38,791 acres have been acquired by the District at a cost of $30,625, and in addition, approximately 19,200 acres have been provided by the Federal Government from its public lands for Parker reservoir. Under the provisions of the Metropolitan Water District Act 1,843 acres have been acquired from the State of California at a cost of $1,602.

Powwows were held with the Chemehuevi, Mohave, Colorado River, Morongo, and Soboba Indians, and, with the assistance of the Indian agents, many miles of required easements were purchased through Indian reservations.

The upper feeder pipe line of the distribution system traverses for many miles some of the finest developed citrus land in Southern California. The required easements for this line were obtained without resort to condemnation proceedings except in two instances.

In all cases of right of way acquisition the District policy has been to secure either fee title to the land or easements at the lowest cost consistent with a fair deal for the owner, and to use the right of way so acquired in such a way as to cause least damage to the owner of private lands and least inconvenience to him and to the general public.

MEDICAL, SURGICAL, AND HOSPITAL SERVICES

In January 1931, the board of directors authorized the provision of medical services for office and field employees of the District. For cases of illness or injury not covered by the Workmen's Compensation Insurance and Safety Acts of California this was accomplished by establishing an employees' medical fund to which each employee member contributed five cents per eight-hour shift worked, deductions being made on the pay rolls. Membership in this fund was optional for employees located in Los Angeles or other centers of population where medical services were available, but in remote areas of operation all employees contributed to the fund. In return members were assured of competent medical care at minimum cost in case of noncompensable sickness or injury.

When specifications were prepared for the construction of various features of the aqueduct, provisions were inserted covering the care of the contractor's employees. It was required not only that proper facilities for housing and boarding be furnished but also that adequate medical, surgical, and hospital care be provided for employees, permitting the contractor to furnish and operate his own hospital or to arrange with established private hospitals convenient to the work. Emergency hospitals or first-aid stations were required at all tunnel entrances and at other remote points of construction. To care for illness or injury not covered by the Workmen's Compensation Insurance Act, contractors were allowed to collect five cents per eight-hour shift from those employees who desired the services, in order to extend to all employees on the project the opportunity to have full medical care at minimum cost.

Contractors' hospitals were established at Parker dam, at Whipple Mountain camp, and near Desert Center for work in the eastern aqueduct area and were operated as long as need for them existed. From San Gorgonio Pass westward use was generally made of existing hospital facilities in nearby towns and cities.

When the District forces began work in December 1932 on the Coachella tunnels at Fargo and Thousand Palms camps, plans were instituted for adequate medical services for all Coachella forces. In February 1933, T. Sheridan Carey, M.D., of Los Angeles, was appointed chief surgeon-medical officer for the District's force account work. A complete medical department was quickly organized and a 12-bed modern hospital constructed at Berdoo camp. This hospital was practically completed about June 1, 1933, and received its first serious injury case a few days later. With increase in the construction forces the number of patients also increased, and in October 1933, it was necessary to expand the hospital to 27 beds, more than doubling its original capacity.

The Berdoo hospital was completely equipped with a modern operating room, X-ray plant, physiotherapy department, treatment rooms, diet kitchen, general offices, and store rooms. The hospital building was adequately insulated, and air conditioned. The air-conditioning equipment maintained a comfortable temperature within the building at all times, even during the intense summer heat. The nursing personnel were all graduate nurses. Every type of surgical operation was performed and patients were cared for in Berdoo hospital for necessary periods of time. The men received excellent medical and nursing care, were well fed, and no difficulty was experienced in hospitalizing them remote from their homes. From its opening in 1933 to its closing in October 1936, the hospital had 12,000 admissions, including both the clinic and the actual hospital bed cases, the latter numbering approximately 3,000 during the above period.

In each of the camps on the Coachella and San Jacinto divisions a complete first-aid station was maintained in charge of a competent graduate nurse. Each station contained four emergency beds where the men could be cared for in camp during temporary illnesses. The District maintained three to four ambulances ready for instant service during the construction of the Coachella and the San Jacinto tunnels.

All applicants for employment with the District were required to pass a physical examination in Los Angeles before going out on the job. For this purpose the District organized and maintained medical offices in Los Angeles where all applicants were examined. From 1933 to 1934 Dr. J. W. Neighbor was in charge; since 1934 Dr. Hugh M. Mason has carried on this work.

In February 1935, when the San Jacinto tunnel was taken over by the District, a small medical unit was established at Banning with a doctor in charge, and one nurse, but injured men requiring hospital attention were transported to Berdoo hospital. As the work on the Coachella tunnels progressed toward completion, several camps were closed, and it was decided to expand the medical facilities at Banning. Accordingly in October 1936, Berdoo hospital was closed and all of the surgical and X-ray equipment removed and set up in the south wing of the District headquarters building at Banning. No attempt was made however to conduct a regular hospital at this point, and patients requiring hospitalization are transported to the Hospital of The Good Samaritan in Los Angeles where they come under the care of Dr. Carey.

The operation of the medical department in the field, including its hospital facilities, was satisfactory to all concerned. Due to careful regulations and frequent inspections, the health of the construction forces was adequately maintained. In general the incidence of morbidity was low. No outbreaks of communicable disease occurred. All major and minor injuries were cared for immediately at the District's own modern hospital without the delay caused by transportation over long distances. In 1935 the District's medical facilities were inspected and approved by the American College of Surgeons.

From February 1933 to date 22,461 applicants for employment have been examined. Approximately 20,000 clinic and hospital admissions have been made for medical and compensable cases. This number does not include various admissions at the first-aid stations. Patients to the number of 3,500 have been hospitalized for medical and surgical conditions, approximately 40 per cent under the employees' medical fund and 60 per cent under the compensation fund.

SAFETY

From the beginning of aqueduct planning, safety has been considered one of the important features of the project. The attitude of the board of directors and of the executive officers of the District was early expressed in the policy, "The application of every possible safety measure shall be practiced." Accordingly, Specifications No. 1, issued in January 1932 for construction of Entrance Hill road, required the contractor to "keep himself fully informed of all laws, ordinances, and regulations in any manner affecting those engaged or employed in the work"; to "take out and at all times during the prosecution of the work and until the final completion and acceptance thereof maintain in full force and effect compensation insurance * * * in accordance with the provisions of the Workmen's Compensation, Insurance and Safety Acts of the State of California" and further required that "The Contractor and all his subcontractors and employees shall observe all the safety provisions of the said Workmen's Compensation Insurance and Safety Acts and other state laws and shall at all times fully comply with the requirements of all applicable general or special orders, rules, or regulations issued by the Industrial Accident Commission of the State of California under the authority of said acts." The safety of the public was also provided for in that the contractor was required to erect such barriers and put up such lights and signals and take such other steps as were necessary to protect both person and property.

Subsequently all construction specifications carried a clause requiring the contractor to carry out promptly and fully the safety, sanitary, and medical requirements stated in the specifications or prescribed by the engineer from time to time, "that the safety and health of the employees and of the local communities may be conserved and safeguarded."

T. W. Osgood, at that time assistant superintendent, Department of Safety, of the State Industrial Accident Commission, an engineer of broad experience in accident prevention, was appointed safety engineer for the District on April 1, 1933, soon after construction was started.

On July 10, 1933 a general safety committee, consisting of the assistant general manager, general superintendent, construction engineer, division engineers, superintendent of the Coachella division, and the safety engineer, was organized to develop and promote safe practices on the aqueduct construction. A contractors' executive safety committee, for similar purposes, was formed November 3, 1933, made up of executive officers and principal supervisors of the contractors' organizations, with representatives from the California Industrial Accident Commission, the U. S. Bureau of Mines, and the compensation insurance companies. These committees operated separately until March 1935, when they were merged in the interest of further expediting the safety work. Committee meetings were held monthly, with few exceptions, affording an opportunity for helpful discussions of safety problems and keeping the members safety-minded.

The work progressed twenty-four hours a day, in eight-hour shifts, with increasing momentum until a maximum force in excess of 10,000 men was employed, the operations being carried on from many camps located at strategic points on the line. The safety work, with its principal purpose to protect the employees from accidental injuries, has extended concurrently with construction activities along the entire front from the Colorado River to the District cities.

Safety rules and regulations were compiled and distributed among the construction forces covering the multitude of activities in shafts, tunnels, shops, handling high explosives, surface excavation and concreting, automobile and truck operation and electrical work, as well as fire protection, sanitation and hygiene, and care of the injured.

Safety committees and safety clubs, consisting largely of workmen, with supervisors and safety engineers and inspectors lending all possible help, were organized and have been maintained in aqueduct camps. Monthly meetings were held and these groups contributed greatly to the cause of safety.

Literature published by the U. S. Bureau of Mines, the U. S. Public Health Service, the National Safety Council, and other recognized authorities on safety has been extensively distributed in the camps and to the construction forces.

The safety engineer and his staff of assistants covered all points of construction activity and, aided by the engineers and inspectors of each division, pointed out unsafe practices to division engineers and followed up with reinspection to assure removal of hazardous conditions.

Safety engineers from the State Industrial Accident Commission made periodic inspections of aqueduct work, issuing written reports to employers requiring the removal of any hazards found to exist. Members and staff of this commission have frequently given advice and cooperation on the numerous safety problems arising in connection with the project. The compensation insurance companies also took an active and constructive part in safety work.

The State Division of Housing and Sanitation inspected aqueduct camps from time to time to insure the maintenance of safe and sanitary conditions therein.

As an aid in safety work first-aid training has been conducted in aqueduct camps and large numbers of men availed themselves of the opportunity to learn first aid. This training proved its worth in cases of injury and helped in making the men more safety conscious. The United States Bureau of Mines, in cooperation with the District's safety engineer, conducted this training, held examinations, and awarded first-aid certificates to all men who completed the course.

A complete mine-rescue station, under direct supervision of the safety engineer, was maintained by the District. Six five-man rescue squads were available, all trained by the U. S. Bureau of Mines. Fortunately no tunnel fire or other major emergency has occurred to necessitate placing this unit in service.

The safety program resulted in a very gratifying decrease in the number of lost-time accidents. The new man, especially the inexperienced one, is always an accident hazard, yet during the five years of greatest construction activity, 1933-1937, during which upwards of 35,000 individuals were employed or reemployed for aqueduct work, the accident rate was steadily reduced.

PERSONNEL

When the District on May 1, 1930, took over the control and operation of the Colorado River aqueduct project, it likewise employed the clerical, legal, technical, and engineering forces required to carry forward the work under way. Previously, the persons engaged in this work had been in the employ of the Department of Water and Power of the City of Los Angeles. Many of these employees were taken into the District's organization. Others required from time to time to engage in District work were employed from among the residents of the District cities.

In the conduct of its affairs relating to employment, the District acted in accordance with the provisions of the Metropolitan Water District Act, which provides that the board of directors shall have power to prescribe by ordinance a system of civil service. Accordingly, on August 7, 1931, an ordinance was adopted which established a merit system of employment. Under this system, all classified and unclassified positions were defined, and there was

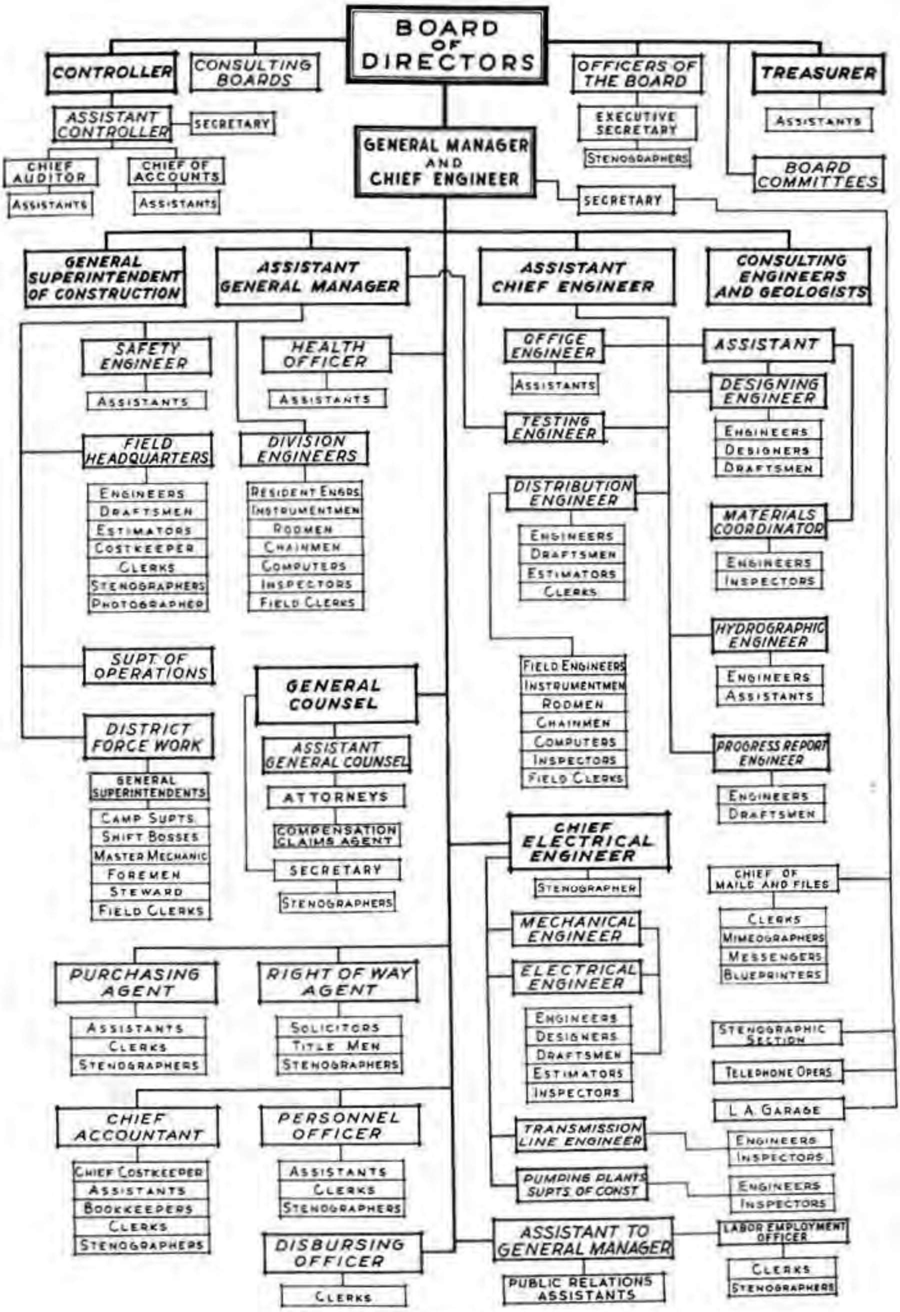


Fig. 26—Organization chart

placed in operation a system of procedure governing the classification and grading of applicants. The residence qualifications of District employees were also defined.

In the operation of its personnel organization it was the determination of the board and the management that the District's merit system must be made to assure (1) the selection of the best qualified applicant, without regard to personal or political influence and, (2) the employment of persons who were bona fide residents of the District. In specifically defining the residence qualifications of District employees the board, on October 13, 1931, adopted a resolution which provided that, "from and after October 13, 1931, no person (shall) be employed by said District, who is not at the time a resident of said District and has been a resident thereof, or of territory comprised therein, for at least one (1) year next preceding * * * ."

The District has continued to operate under this policy. In its determinations concerning the residence qualifications of applicants, the District has imposed rigid requirements of proof. The unsupported claim of residence on the part of the applicant is not accepted as sufficient. Other substantial documentary proof is required, and in cases where fraud or misrepresentation is suspected thorough investigations are made.

In addition to its requirements relating to personal and residence qualifications, the District, since the commencement of aqueduct construction work, has given employment preference to ex-service men.

Immediately following the bond election of September 29, 1931, the District began to accept through its personnel office applications for both classified and unclassified positions. In December 1932, when aqueduct construction work was first set under way, there was established a labor employment office, located at 770 South San Pedro Street, Los Angeles. Branch offices were also established in each member city of the District, and at these conveniently located offices labor applications were received and forwarded to the central labor employment office in Los Angeles.

The labor employment office receives, checks, and rates applications for all classes of construction work up to and including the grade of foreman, while all applications for classified positions are handled through the personnel office, located in the District's Los Angeles office building at 306 West Third Street.

With the inception of aqueduct construction work, Horace A. Beall became personnel officer in charge of classified service, and Col. N. F. Jamieson was made labor employment officer in charge of the District's central labor employment office.

District regulations relating to residence qualifications and employment preference to veterans were made to apply to all persons employed by aqueduct construction contractors, as well as to those employed directly by the District. In order to make this ruling effective, all contractors were required to employ only such persons as had made application through the District's labor employment office and had been certified as bona fide residents and as to their status with regard to military service.

Many of the contracting firms had their home offices in localities far distant from the District territory. In such instances the District exempted a limited number of key positions from its residence requirements, but such exemptions were extremely few.

To facilitate the employment of qualified residents by contracting firms, the District early in 1934 instituted a system of issuing identification certificates to employment applicants found to meet the District's residence requirements. This certificate was issued to the applicant in the form of a small card. It certified the applicant to be a bona fide resident of the District; it indicated whether he was a veteran or a non-veteran; and it carried, on one side, the applicant's photograph, his physical description and his signature, and, on the other side, his right thumb print. Identification certificates to the number of 25,877 have been issued.

In the District's labor employment office, 151,842 applicants have registered for construction work, and 206,139 interviews have been held. A total of 19,261 men was sent out to District jobs and 28,001 to contract jobs, the peak of requests for men for District operations being in July 1936, and for contract in October of the same year. It is estimated that approximately 35,000 individuals have thus far been employed on aqueduct construction work.

Up to June 30, 1938, a total of 25,711 applications have been received for positions in the classified service. Of this number, 15,729 were sufficiently complete to permit of being graded and approved in accord with the established procedure for determining eligibility under the merit system. Applicants came in or were called in for approximately 140,000 interviews, and more than 3,400 classified positions have been filled from the lists of those qualified by residence and requisite education and experience. In addition, during this period many applicants were directed to positions entirely outside the District organization, in response to employers' inquiries for recommendations.

In both branches of the personnel service, the established merit system of employment has been closely adhered to, assuring impartiality and fairness in employee selections. This policy has secured exceptionally well-qualified employees in the classified service, and a high type of labor, both skilled and unskilled, for construction operations.

With the completion of many features of the project it has been necessary to terminate the employment of all who could not be transferred to other District work. Every aid in making new contacts has been given those who desired it, and many have been sent to prospective employers from whom inquiries have been received or who were known to have positions to be filled.

MISCELLANEOUS ACTIVITIES

Construction of the aqueduct has necessitated the shipment, storage and use of vast quantities of materials, equipment, and supplies to construction points located remote from established centers of population, and the housing of workmen in 38 construction camps along a 250-mile line of operation. Recognizing the hazards involved under these conditions, the District has taken steps to insure the competent and continuous maintenance of law and order all along the aqueduct right of way, and in all localities where workmen were concentrated.

The aqueduct route traverses or extends into four counties of the State of California, namely, San Bernardino, Riverside, Orange and Los Angeles. In each of these counties the District has sought and received the full cooperation of constituted peace authorities. In addition, the District has maintained a small group of special officers who have patrolled the aqueduct camps and right of way, working under the authority of the sheriffs of the four counties.

The high standard of personal conduct on the part of the workmen, maintained since the start of the work, is an indication of the good character of the average aqueduct employee and the vigilance of the peace authorities on the job.

In addition to its insistence upon the highest standards of housing, feeding, and medical care for all aqueduct employees, the District has taken steps to build the morale and maintain the general well-being of these workmen. To this end, the establishment of recreation facilities has been encouraged. On the District's two large force account jobs, the Coachella and San Jacinto tunnels, recreation halls were built. Employee committees were formed to arrange athletic and entertainment programs. Circulating libraries were established in many of the camps.

In January 1934, the District began the issuance of the *Colorado River Aqueduct News*, a semi-monthly publication devoted to the progress of the job and the interests of the employees. This publication has been regularly distributed to every employee on the aqueduct, and to a large number of interested citizens, as well.

It has always been the policy of the officers of the District that the citizens and taxpayers should be fully advised at all times concerning the plans, problems, and work of the District. Accordingly, every reasonable step has been taken to make available to the public all of the facts relating to the District's operations. In seeking to place before the people full information concerning its business, the District has sought and secured the cooperation and assistance of all of the legitimate and modern channels of news.

To the press, the District regularly reports the acts and decisions of the board of directors relating to all important issues and developments. Representatives of the newspapers and magazines are given every possible assistance in the securing of factual material concerning the District and the aqueduct. Since the organization of the District, the press of Southern California has printed many thousands of column inches of news and editorial comment bearing directly upon the work and plans of the District.

Technical magazines have followed closely the development of the aqueduct project and have published hundreds of articles relative to the many engineering and technical phases of the undertaking. National magazines, including *The Saturday Evening Post* and *Fortune*, have published illustrated articles giving information on the aqueduct and the District to their millions of readers.

During the period of aqueduct construction, the District has maintained a staff photographer who has made a detailed record of the project in still and motion pictures. These still photographs have been made available to newspapers and magazines and hundreds of such pictures have been printed in newspapers and magazines throughout the world.

From time to time the District's motion picture records of aqueduct construction have been assembled in the form of short educational films. These films have been exhibited in most of the motion picture theaters in Southern California. In addition, the District has made these films available to universities and school systems throughout California, and to many universities throughout the United States, Canada, and Mexico. Motion pictures of the Colorado River aqueduct have been included in the regular class studies of the Los Angeles city schools and many other school systems. Civic, commercial and patriotic organizations have requested the showing of these films, and in response to these requests the District has exhibited a series of aqueduct films to many hundreds of such citizen groups.

In response to inquiries for representatives from the District to appear before citizen groups and describe the progress of work on the aqueduct, a number of employees have volunteered their services as speakers. These employees have trained themselves as competent speakers and have filled several hundred speaking engagements, thus materially assisting in the important task of keeping the public fully advised as to the affairs of the District.

For the purpose of making available authentic and official printed information relating to the District, there have been printed a number of different kinds and types of folders, booklets, and reports. These have been distributed to interested citizens and have been made available to all educational organizations.

At the San Diego International Exposition of 1935 and 1936, the District, acting in cooperation with the Los Angeles Department of Water and Power and the Imperial Irrigation District, built and maintained a Water Palace exhibit. This exhibit included a gigantic topographic map of the aqueduct system showing its relation to other Colorado River development projects and the manner in which it serves the District cities. The Water Palace exhibit was visited by approximately 1,600,000 visitors.

Nationwide radio broadcasting systems have shown an active interest in the progress of work on the aqueduct, with the result that a number of broadcasting periods have been devoted to the project by the Columbia broadcasting system and the Mutual broadcasting system.

Among the notable aqueduct construction developments which have been nationally broadcast were the start of work on San

Jacinto tunnel, the holing through of the East Coachella tunnel, the pouring of the first concrete at Parker dam, the excavation of one of the most difficult sections of the San Jacinto tunnel, and, on one occasion, a broadcast from the entire aqueduct system with six announcers stationed at various points along the system, from Parker dam to 98th and Wadsworth Street, in Los Angeles. In addition to these nationwide broadcasts there have been several local broadcasts of various phases of the District's work.

CHAPTER 16

Corporate Organization, Purposes, and Powers of the District

STATUTORY PROVISIONS

THE METROPOLITAN WATER DISTRICT of Southern California was incorporated December 6, 1928, under the provisions of the Metropolitan Water District Act of the State of California, Stats. 1927, page 694, Deering's General Laws, Act 9129. This act has been amended by Stats. 1929, page 1613, Stats. 1931, page 814, Stats. 1933, page 1289, and by Stats. 1937, page 381[1].

The District is organized "for the purpose of developing, storing and distributing water for domestic purposes" and is declared by the legislature to be "a separate and independent political corporate entity." [Metropolitan Water District Act, Sec. 3.] The District has perpetual succession, and may sue and be sued; may adopt a corporate seal and alter it; may take by grant, purchase, bequest, devise or lease, and hold, lease, sell, or otherwise dispose of, any and all real and personal property necessary or convenient to the full exercise of its powers. [Sec. 5, subds. (1) to (4).] The District also possesses the power of eminent domain to be exercised in the manner provided by law, respecting municipal corporations. [Sec. 5, subd. (5).] The District is authorized, subject to certain limitations, "to borrow money and incur indebtedness and to issue bonds or other evidence of such indebtedness" and "to levy and collect taxes for the purposes of carrying on the operations and paying the obligations of the District". The taxing power is without limitation as to rate or amount for the purpose of meeting both principal and interest requirements of the bonded indebtedness and payment of District obligations to the United States or to any board, department or agency thereof, but is subject to a limitation of five cents on each $100 of assessed valuation for all other purposes. [Sec. 5, subds. (7) and (8).] The District is given power "to join with one or more public corporations for the purpose of carrying out any of its powers". [Sec. 5, subd. (9).]

[1]For text of the act as amended see p. 333.

All bonds issued by the District are general tax obligations, and the board of directors is under a statutory duty to levy sufficient taxes upon all taxable property, both real and personal, within the District, to meet the principal and interest requirements thereon. [Sec. 5, subd. (8); Sec. 7, subd. (j).] The procedure for levying such taxes, together with any taxes levied for general District purposes, is prescribed. [Sec. 8.]

The powers of the District are vested in a board of directors consisting of at least one representative from each municipality, the area of which lies within the District, the representatives being appointed by the chief executive officers with the consent of the governing bodies of the respective municipalities. The board of directors is given power to provide for the holding of meetings, to pass ordinances, resolutions and orders, all ordinances, except those of specified categories, to be subject to referendum by the electors of the District. The board further is authorized to prescribe by ordinance a system of business administration, and to create necessary offices, including those of controller and treasurer, and to prescribe by ordinance a system of civil service. [Sec. 6, especially subds. (1), (2), (4), and (5).] The board is authorized to provide by ordinance for all matters and things necessary for the proper administration of the District's affairs, which are not provided for in the act. [Sec. 13.] Under this statutory authority the board of directors has created the office of general manager and chief engineer, such officer being generally in charge of all administrative matters (Ordinance No. 29). The offices of treasurer, controller, and general counsel also were established by ordinance.

The procedure for incurring bonded indebtedness and for issuing, selling, and refunding such bonds is set out with great particularity in Sec. 7 and also in subdiv. (12) of Sec. 5. This procedure is modeled on the act providing for general obligations of cities and municipalities (Stats. 1901, page 27, Deering's General Laws, Act 5178, as amended), a majority vote, however, being sufficient to authorize bonded debt.

The District may enter into contracts and employ the necessary personnel (Sec. 5, subd. (8)), but any contract involving $10,000 or more must be let upon competitive bidding (Sec. 6, subd. (7)).

The District has the power to acquire water and water rights within or without the state; to develop, store, and transport water; to sell and deliver the same at wholesale for municipal and domestic uses and purposes; to contract with the United States or any board, department or agency thereof, or with the State of California, for furnishing water for any use or purpose and on terms fixed in the contract, subject to revision as to rates, at stated intervals; to sell and deliver surplus water not needed or required by municipalities within the District for domestic or municipal uses within such municipalities, such surplus water being thus available for sale for beneficial purposes but giving preference to uses within the District; provided that all such surplus water shall be subject to recapture by the District upon one year's written notice whenever the board of directors by two-thirds vote shall determine that such surplus water is needed or required by any municipality within the District for domestic or municipal uses within such municipality. [Sec. 5, subd. (10).]

Each municipality, whose corporate area is included within the District, has a preferential right to purchase from the District for distribution by such municipality, or any public utility therein empowered for the purpose, for domestic or municipal uses within such municipality, the proportion of the water served by the District that, from time to time, shall bear the same ratio to all of the water supply of the District as the total accumulation of amounts paid by such municipality to the District on tax assessments and otherwise, excepting the purchase of water, toward the capital cost and operating expense of the District's works shall bear to the total of such payments received by the District from all of its municipalities. [Sec. 5½.]

The District has the power to fix water rates (Sec. 5, subd. (10)), which function is to be performed by the board of directors subject to the requirement that rates shall be uniform for like classes of service throughout the District (Sec. 6, subd. (8)). So far as practicable, the board shall fix such rates as will result in revenue which will pay the operating expenses, provide for repairs and maintenance, and meet the interest and principal requirements of the bonded debt. [Sec. 7, subd. (j).]

The treasurer is authorized to deposit all District funds in banks in the manner provided by law for the deposit of monies of a municipality or other public or municipal corporation (Sec. 13¾). The applicable statute is the Municipal Deposits Act, Stats. 1933, page 642, as amended, Deering's General Laws, Act 2834a.

The Metropolitan Water District Act is a general law, and Section 4 thereof provides the machinery for incorporation of any district thereunder. A method of annexation of additional territory is provided in Section 9 of the act. Withdrawal of area from the District may be brought about as provided in Section 10.

LEGAL DEVELOPMENT

At its 1927 session the California legislature enacted the Metropolitan Water District Act (Stats. 1927, page 694). As required by the State Constitution (Article XI, Sec. 6), this statute is a general law under which any number of metropolitan water districts could be organized by complying with the statutory requirements. However, the act was specifically designed to furnish the means by which a public corporation could be formed for bringing water from the Colorado River for use on the coastal plain of Southern California.

In order, as far as possible, to test the act in the preliminary stage, the city clerk of the City of Pasadena refused to certify certain action necessary to the incorporation of the District, whereupon the City of Pasadena sought an original writ of mandate in the State Supreme Court. The writ was issued *(City of Pasadena v. Chamberlain,* 204 Cal. 653 (1928)), the following principles being decided in this case:

> (1) A city formed under a freeholders' charter may initiate proceedings for the incorporation of a metropolitan water district, as by so doing the chartered city is not performing a municipal affair within the meaning of Article XI, Sec. 6, of the California Constitution.
>
> (2) A metropolitan water district is not an assessment district but is a quasi-municipal corporation, and therefore may impose general taxes without opportunity for hearing as to benefits.
>
> (3) The board of directors of a metropolitan water district, as the governing body of such district, may be vested by the legislature with the power to levy taxes without infringing Sec. 13 of Article XI of the California Constitution, prohibiting the legislature from delegating to any special commission the power to levy taxes or to perform any municipal function.

Subsequent to this decision, on December 6, 1928, The Metropolitan Water District of Southern California was incorporated. The District as originally incorporated was composed of the corporate areas of eleven municipalities, of which seven were situated in the County of Los Angeles, namely: Beverly Hills, Burbank, Glendale, Los Angeles, Pasadena, San Marino, and Santa Monica;

two in the County of Orange, namely: Anaheim and Santa Ana; and two in the County of San Bernardino, namely: Colton and San Bernardino. Prior to the bond election in 1931 the cities of Colton and San Bernardino withdrew from the District and the corporate areas of four cities were annexed, namely: the cities of Compton, Long Beach, and Torrance in the County of Los Angeles, and the City of Fullerton in the County of Orange. No subsequent change in composition of the District has occurred, except the automatic enlargement which occurs when territory is annexed to any one of the component municipalities.

On September 29, 1931, an election was held throughout the District pursuant to action taken under Section 7 of the act, to vote upon the proposition of incurring a bonded indebtedness in the sum of $220,000,000 for the purpose of acquiring and constructing works for bringing water from the Colorado River to the District. The proposition was carried by an affirmative vote of approximately five to one. In compliance with the requirements of subdivision (i) of Sec. 7 of the act, proceedings were instituted promptly in the Superior Court of the County of Los Angeles to adjudicate the validity of the election and of the bonds so authorized and of taxes to be levied for payment thereof. A favorable judgment was obtained in the trial court, and upon appeal the judgment was affirmed *(In re Metropolitan Water District,* 215 Cal. 582 (1932)). This case established the following propositions:

> (1) Under Sec. 7, subd. (i) of the Metropolitan Water District Act, the bond validation proceedings brought by the board of directors may be heard by the proper superior court after a lapse of ten days after full publication of summons without waiting for the lapse of ninety days from the date of the bond election, but a taxpayer or other interested person may not initiate proceedings contesting the validity of the bonds after the expiration of ninety days from such election.
>
> (2) The ordinance declaring the necessity for the particular improvement need not specify the precise location of the works, nor contain a particular description thereof.
>
> (3) The appointive board of directors of the District may be vested with power to levy general *ad valorem* taxes.
>
> (4) Reference in the ordinance determining the necessity for the public improvement and calling the bond election, to provision for the levy of taxes, in the language of the statute, is proper.

(5) The decision of the board of directors, expressed in the ordinance declaring the necessity for the public improvement and calling the bond election, whereby general plans and estimates of costs were made, is subject to judicial review only upon pleading and proof of fraud or bad faith on the part of the board of directors.

As soon as the bonds were validated the District obtained a commitment from the Reconstruction Finance Corporation whereby the latter agreed to bid for a certain amount of District bonds which would be offered from time to time for public sale pursuant to published notice inviting bids as required by Sec. 7 of the act. The first loan agreement was made in September 1932, and four additional loan agreements were entered into subsequently, pursuant to which the Reconstruction Finance Corporation has bid for, and purchased, District bonds in the aggregate amount of \$207,000,000, in addition to \$1,500,000 purchased by the Public Works Administration and later acquired by the Reconstruction Finance Corporation. An unsuccessful attempt was made to prevent the Reconstruction Finance Corporation from carrying out its first agreement, the suit being dismissed by the Supreme Court of the District of Columbia, in response to a contested motion *(Burnham v. R.F.C.*, Equity No. 54845 (1932)).

The bonds having been validated and arrangements for financing having been made, the District undertook to commence actual construction work at the earliest opportunity. However, at the 1931 session of the state legislature, there had been enacted the Prevailing Wage Act (Stats. 1931, page 910) and it was not known whether this act was applicable to District work. Therefore a test suit was brought *(Metropolitan Water District v. Whitsett*, 215 Cal. 400 (1932)), which resulted in a holding that the Prevailing Wage Act applied, the court stating that:

(1) A metropolitan water district is a public instrumentality of legislative creation and is subject to complete legislative regulation and control, limited only by constitutional restrictions.

(2) The Prevailing Wage Act is not void for uncertainty in the terminology employed therein.

(3) The burden imposed by the Prevailing Wage Act is not a tax, and therefore the statute does not violate Section 12 of Article XI of the California Constitution, prohibiting the legislature from imposing taxes upon public or municipal corporations or their inhabitants for municipal purposes.

(4) The Prevailing Wage Act does not unlawfully delegate legislative power to the public body charged with determining the prevailing wages, as such power is administrative and may be exercised within the discretion of such public body.

(5) The Prevailing Wage Act applies to a metropolitan water district, although it does not apply to a city operating under a freeholders' charter, since the construction of public improvements and the payment of wages thereon are municipal affairs.

In 1932 certain groups endeavored to bring about an election in the City of Long Beach for the purpose of voting on the withdrawal of that municipality from the District. Failing in their endeavor to have the City Council call such election, an initiative petition was circulated, but the City Clerk, at the instance of a taxpayer, was enjoined by the Superior Court from certifying the same to the Council on the ground that such petition was ineffectual. Mandamus proceedings then were brought in the Supreme Court by another taxpayer, to compel the City Clerk to take action, but the court denied the writ *(Riedman v. Brison,* 217 Cal. 383 (1933)). This case held that withdrawal from the Metropolitan Water District of the area included in a constituent municipality is not a municipal affair of that municipality, the procedure for withdrawal being prescribed solely by the Metropolitan Water District Act, under which only the city council may call such election, and the charter provisions of the constituent municipality for initiative procedure are inapplicable. Subsequently the City Council proceeded to grant the request and call an election, at which, however, the proposition of withdrawal was defeated.

As an aid to the financing of the District's project, the State legislature, at its session in 1933, amended subdiv. (h) of Sec. 7 of the Metropolitan Water District Act to provide specifically that interest during construction and for one year thereafter might be paid out of the proceeds of the sale of bonds. Doubt arose as to the constitutionality of this amendment, in view of the previous election authorizing the issuance of bonds and the actual sale and delivery of certain bonds prior to the amendment. In an original proceeding in mandamus in the Supreme Court of the State, the validity of this amendment was upheld on the ground that it clarified the previously-existing statutory authority. [*Metropolitan Water District v. Toll,* 1 Cal. (2d) 421 (1934).]

During the summer of 1934, a condemnation action by the District to acquire needed rights of way was brought to issue, ready for trial in the Superior Court of Riverside County. The judges of this court feared that they were disqualified from presiding at the trial by the provisions of Subsec. 6 of Sec. 170 of the Code of Civil Procedure, disqualifying local judges in actions involving certain-named entities, including "any public agency," if the action affect real property or an easement or right of way. The California Supreme Court issued an original writ of mandate directing the respondent judges of the Superior Court to proceed with the trial of the District's condemnation action, holding that the Metropolitan Water District is a quasi-municipal corporation within the exception of general municipal corporations from the disqualifying provisions of the Code of Civil Procedure, the term "any public agency" referring only to entities of the same character as the other entities named in the subsection and not referring to municipal or quasi-municipal corporations. [*Metropolitan Water District v. Superior Court*, 2 Cal. (2d) 4 (1934).] This case further establishes the status of the District as a municipal corporation.

The Metropolitan Water District Act provides that the directors shall be appointed by the chief executive officers with the consent and approval of the governing bodies of the various municipalities, whose corporate areas are included within the District. In one of the cities the mayor, who himself was a member of the City Council, was appointed director from that city. In proceedings in *quo warranto* it was held that he was the authorized representative of that city as there was no incompatibility between the offices of director and city councilman, and it was further held that the requirement of the city charter that a councilman devote his whole time to the duties of his office did not disqualify him from performing the duties of a director of the District. [*People v. Carter*, 12 Cal. App. (2d) 105 (1936).]

The character, powers, and functions of the Metropolitan Water District have been defined and established with some particularity and completeness by the foregoing cases. Contemporaneously with this development of judicial precedents in California, cases were arising in the Supreme Court of the United States which directly affected the District's activities. These were the cases involving the Boulder Canyon Project.

In 1930 the United States Supreme Court dismissed the Bill of Complaint brought by the State of Arizona to enjoin the Secretary of the Interior and the states of California, Nevada, Utah, New Mexico, Colorado, and Wyoming from carrying out the Boulder Canyon Project Act, the Colorado River Compact, and three certain contracts entered into by the Secretary of the Interior pursuant to the project act, of which two of said contracts were with the Metropolitan Water District for water and power, respectively (*Arizona v. California,* 283 U. S. 423, 75 L. Ed. 1154 (1930)). The opinion contains the following propositions:

> (1) The United States may perform its functions without conforming to the police regulations of a state, and an improvement validly authorized by Congress may be constructed in a state without submitting the plans and specifications to the state officials for approval.
>
> (2) The court takes judicial notice that the Colorado River is navigable and a contrary allegation in the bill of complaint will be disregarded on motion to dismiss.
>
> (3) Congress has constitutional power to authorize the Boulder Canyon Project for improvement of navigation of the navigable Colorado River.
>
> (4) The court will not inquire into the motives inducing Congress to enact the Boulder Canyon Project Act, wherein it is recited that the improvement is authorized for the purpose of "improving navigation and regulating the flow of the river."
>
> (5) The improvements provided in the Boulder Canyon Project Act not being unrelated to the control of navigation, the fact that other purposes will be served incidentally, will not invalidate the act, which is within the constitutional power of Congress.
>
> (6) The power of Congress to construct dams and reservoirs on interstate streams for the purpose of irrigating public lands of the United States, or for flood control, or for conserving and apportioning the waters among the states equitably entitled thereto, or for performing international obligations, is not passed upon.
>
> (7) The enactment of the Boulder Canyon Project Act does not invade any rights of the State of Arizona entitling it to equitable relief prior to any actual or threatened impairment of Arizona's rights in and to the waters of the Colorado River.
>
> (8) Bill dismissed without prejudice to future application for relief in case stored water be used in manner interfering with the enjoyment by Arizona or those claiming under it of any rights already perfected, or with the

right of Arizona to make additional legal appropriations and to enjoy the same.

Again, in 1933, the State of Arizona endeavored to prepare the groundwork for asserting rights in the waters of the Colorado River in excess of her appropriated rights, by asking leave to file an original bill to perpetuate testimony concerning the execution of the Colorado River Compact. Leave was refused, the opinion stating *(Arizona v. California,* 292 U. S. 341, 78 L. Ed. 1298 (1933)):

(1) A bill to perpetuate testimony may be entertained in the Supreme Court, although there is no prior precedent.

(2) Requirements for bill to perpetuate testimony are: that the facts expected to be proven by the perpetuated testimony will be material in the determination of the matter in controversy; that the testimony will be competent evidence; that depositions of the witnesses cannot be taken and perpetuated in the ordinary legal methods, because the then condition of the suit (if pending) renders it impossible, or (if no suit be pending) because plaintiff is not in position to start suit in which the issue may be determined; and that the taking of the testimony is necessary by reason of the danger that the testimony will be lost by delay.

(3) Arizona asserts rights under the Boulder Canyon Project Act and the California Limitation Act, but not under the Colorado River Compact, which cannot be considered as a contract in determining the rights of Arizona, which has never ratified the Compact.

(4) The Colorado River Compact does not apportion, as between the Upper and Lower Basins, the surplus waters in excess of the amounts specifically allocated, but recognizes that such surplus may exist applicable to the Lower Basin.

(5) Section 4(a) of the Boulder Canyon Project Act and the California statute enacted pursuant thereto (Stats. 1929, p. 38) place limitations upon California's consumptive use of waters apportioned by Article III(a) of the Colorado River Compact (not to exceed 4,400,000 acre-feet per annum), and the excess or surplus waters unapportioned by the Compact (not to exceed one-half).

(6) Arizona contends that Article III(b) of the Compact confers upon her the exclusive use of the 1,000,000 acre-feet per annum of additional waters which the Lower Basin is authorized by the Compact to use.

(7) Testimony of statements by persons in 1922 in ne-

gotiating the Colorado River Compact for submission to the state legislatures and to Congress is not relevant in determining the meaning of the Boulder Canyon Project Act enacted by Congress in 1928, or the 1929 limitation statute of California.

(8) Question as to whether the United States is necessary party is not passed upon.

Having failed by court action to impede the project, Arizona next offered physical opposition to the construction of Parker dam. This dam was being constructed by the United States to furnish subsidiary regulation of the river and to produce power, and was a Government project, although the cost thereof was being paid to the United States by the Metropolitan Water District. The United States in 1934 brought original suit to enjoin the State of Arizona from such interference, but on the return of the order to show cause why a restraining order *pendente lite* should not issue, a motion to dismiss was made and granted, and the bill dismissed on the ground that proper authority for the construction of the dam was lacking. [*United States v. Arizona*, 295 U. S. 174, 79 L. Ed. 1371 (1934).] The opinion set forth the following:

(1) The Colorado River Compact was approved by Section 13(a) of the Boulder Canyon Project Act, and by presidential proclamation, it took effect June 25, 1929 (46 Stat. at L. 3000).

(2) Arizona's jurisdiction respecting the appropriation, use, and distribution of an equitable share of Colorado River waters is unaffected by the Colorado River Compact or by Federal reclamation law, but Arizona's title is held subject to the power granted to Congress by the commerce clause to regulate the river in aid of navigation.

(3) The Act of March 3, 1899, Sec. 9, forbidding construction of any bridge, etc., in any navigable river or navigable water of the United States until the plans therefor shall have been approved by the Chief of Engineers and by the Secretary of War, and the consent of Congress obtained, applies to Federal and State officers, as well as to private persons, and therefore prohibits the construction of Parker Dam by the United States unless the requisite approval be given or statutory waiver be made.

(4) The reclamation law, Act of April 21, 1904, Sec. 25, 33 Stat. at L. 224, merely extends the reclamation law to the Indian reservations therein named and does not authorize the construction of Parker Dam.

(5) The Boulder Canyon Project Act, Sec. 1, does not authorize the construction of Parker Dam.

(6) Parker Dam was not approved by the President in the manner required by Sec. 4 of the Act of June 25, 1910, U. S. C. A., Title 43, Sec. 413, which requirement was not modified by the National Industrial Recovery Act, Secs. 201a, 202, and 203.

(7) The Parker Dam Project may be deemed to have been begun on February 10, 1933, when the contract was entered into between the United States and the Metropolitan Water District.

(8) The National Industrial Recovery Act does not authorize the construction of Parker Dam, as the Congress did not adopt that dam, nor was the dam recommended by the Chief of Engineers in accordance with established practice dating from the Rivers and Harbors Act of June 13, 1902, and subsequent acts governing the practice of the Chief of Engineers.

This want of authority was corrected by Rivers and Harbors Act of August 30, 1935, 74th Congress, 1st session, Chapter 831, Sec. 2, specifically approving and authorizing construction of Parker dam.

The next step in the history of Colorado River litigation was taken by the State of Arizona which, in 1935, sought leave to file an original bill in the United States Supreme Court against the other Colorado River Basin states to adjudicate the *quantum* of Arizona's equitable share of Colorado River waters. Leave to file was denied, the opinion declaring that *(Arizona v. California,* 298 U. S. 558, 80 L. Ed. 1331 (1935)):

(1) The bill of complaint does not assert any right in Arizona arising from her appropriation of the waters of the Colorado River, as no infringement of such rights is alleged.

(2) Arizona disclaims assertion of any rights under the Boulder Canyon Project Act, the Colorado River Compact or the Boulder Project itself, and does not assert any right to the benefit of the undertaking of California pursuant to the Project Act to restrict California's use of the water.

(3) A justiciable controversy is presented by the proposed bill of complaint only if Arizona, as a sovereign state or as representative of her citizens, has present rights in the unappropriated waters of the river, or if the privilege to appropriate river waters is capable of division and judicial protection from appropriations by others pending its exercise.

(4) The question as to whether the rule of appropriation or the rule of equitable apportionment of unappropriated waters will be applied by the court is not decided.

(5) Arizona cannot obtain adjudication of rights in the unappropriated waters of the Colorado River under the circumstances disclosed in her proposed bill of complaint without joining the United States as a party.

(6) The Colorado River is a navigable stream, and the privilege of the states through which it flows and their inhabitants to appropriate and use its waters is subject to the paramount power of the United States to control the river for the purpose of improving navigation.

(7) The United States, by congressional legislation and by acts of its officers thereby authorized, has undertaken, in the exercise of authority to control navigation, to impound, and control the disposition of, the surplus water in the river not already appropriated.

(8) Determination of Arizona's asserted rights to an equitable apportionment of the unappropriated waters of the Colorado River cannot be made until determination of the superiority of the rights of the United States to impound and control the disposition of such water in aid of navigation, and a suit cannot be maintained without the presence of the United States, which cannot be sued without its consent.

(9) Question as to whether an equitable division of the unappropriated water of the river can be decreed in a suit in which the United States and the interested states are parties, is left undecided.

(10) Petition to file proposed bill denied because of absence of the United States as party, with leave to Arizona to assert any rights she may have acquired, whether under the Boulder Canyon Project Act or California's undertaking to restrict that state's use of water or otherwise, and to challenge, in any appropriate judicial proceeding, any act of the Secretary of the Interior or others, injurious to Arizona.

In addition to the cases mentioned, the District has prosecuted numerous condemnation actions and has been involved in various damage suits growing out of its construction activities. With relatively few exceptions this litigation has resulted favorably to the District or has been settled by satisfactory compromise agreements. Not many cases were brought involving the District's contractors, as the work performed in most instances was satisfactory and differences could be adjusted without suit.

The history of these types of litigation is not set forth here, but the foregoing statement will indicate the development of judicial precedents establishing the status of the District as a municipal corporation, clarifying its powers, and defining the scope of the Boulder Canyon Project undertaken by the United States, with which the District's project is interrelated.

CHRONOLOGY

Historical synopsis of events affecting The Metropolitan Water District of Southern California and the Colorado River aqueduct project

1856

Thos. H. Blythe settled in Palo Verde Valley, probably making first California use of Colorado River water.

1860

O. M. Wozencraft and Ebenezer Hadley proposed irrigation and colonization of 3,000,000 acres in Imperial Valley, using canal route through Mexico via Alamo River.

1876

Lieutenant Eric Bergland investigated and reported unfavorably on routes for an All-American canal from Colorado River to Imperial Valley; pointed to natural route through Mexico.

1877

July 17. Thos. H. Blythe made first California filing on Colorado River water for use on his Blythe Rancho in Palo Verde Valley.

1900

Construction of Imperial Canal started by California Development Company, following Wozencraft-Hadley route via Alamo River for 50 miles through Mexico.

1902

June 17. Reclamation Act (32 Stat. 388) approved.

1904

May 10. U. S. Reclamation Service (Bureau of Reclamation) authorized to begin construction of Yuma project.

1905

November. Colorado River broke through into Imperial Valley causing large damage and creating widespread consciousness of need for flood control.

1907

February 10. Colorado River break finally closed.

1911

July 25. Imperial Irrigation District organized.

1914

Congress appropriated $50,000 for study of entire Colorado River basin, thereby financing work leading up to Whistler report.

1918

February 16. Agreement executed between United States and Imperial Irrigation District for construction of the All-American canal.

June 11. Issuance of report by John T. Whistler, engineer, U. S. Bureau of Reclamation, recommending storage projects on upper Colorado River totaling 10,000,000 to 12,000,000 acre-feet.

1919

June 17. First Kettner bill seeking to authorize construction of an All-American canal introduced in Congress.

1920

January 7. Second Kettner bill introduced in Congress seeking authority for construction of an All-American canal, plus tributary canals and reservoirs necessary for irrigation in Imperial and Coachella valleys.

May 18. Kinkaid Act (41 Stat. 600) approved. Congress authorized and directed examination and report on the condition and possible irrigation development of the Imperial Valley in California.

November 27. Preliminary report on problems of the Imperial Valley and vicinity transmitted by Director A. P. Davis, of the U. S. Bureau of Reclamation, to Secretary of the Interior, pursuant to authority of the Kinkaid Act.

1921

May 26. Report issued by board of engineers (A. J. Wiley, James Munn, J. L. Savage, and W. R. Young) declaring Boulder Dam physically practicable and financially feasible.

August 19. Act passed, permitting compact between the states regarding the disposition and apportionment of Colorado River water.

December 12. Secretary of the Interior Fall began public hearings in San Diego at which expressed opinion was practically unanimous for a large project to develop the Colorado River.

1922

January 26. Colorado River Commission organized at Washington, D. C.

February 28. Fall-Davis report on problems of the Imperial Valley and vicinity transmitted to Senate; subsequently published as Senate document No. 142, 67th Congress, 2nd session.

April 25. First Swing-Johnson bill to authorize construction of Boulder Canyon dam and All-American canal introduced by Phil D. Swing, to carry out recommendations of Fall-Davis report on Imperial Valley.

Colorado River Commission held meetings:

January	26-30	Washington, D. C.
March	15-17	Phoenix, Arizona
March	20	Los Angeles, California
March	27-28	Salt Lake City, Utah
March	29	Grand Junction, Colorado
April	1	Denver, Colorado
April	2	Cheyenne, Wyoming
November	9-24	Santa Fe, New Mexico

November 24. Colorado River Compact executed by the Colorado River Commission at Santa Fe, New Mexico.

1923

May 10. Boulder Dam Association formed at Fullerton, California.

October 23. Board of Public Service, Los Angeles, authorized chief engineer of the Bureau of Water Works and Supply to make surveys to determine feasibility of an aqueduct from the Colorado River to Los Angeles.

October 29. Chief Engineer Mulholland, of the Los Angeles Bureau of Water Works and Supply, H. A. Van Norman, E. A. Bayley, and party started first reconnaissance for the Colorado River aqueduct.

November. Preliminary surveys and investigations for Colorado River aqueduct were started.

December 10. Second Swing-Johnson bill for the construction of Boulder Canyon dam and All-American canal introduced by Congressman Swing; companion bills introduced in Senate by Senator Johnson. Successively introduced in 67th, 68th, 69th, and 70th congresses. Failed to come to vote in all but 70th Congress.

California, Nevada, Utah, Wyoming, Colorado, and New Mexico ratify Colorado River Compact as written.

1924

February 28. Report on the problems of the Colorado River basin submitted to D. W. Davis, Commissioner of Reclamation, by F. E. Weymouth.

June 28. Application 4056 to appropriate a maximum of 1500 cubic feet per second from the surplus waters of the Colorado River filed with State Division of Water Rights by the City of Los Angeles.

September 17. Colorado River Aqueduct Association organized at Pasadena, California.

1925

January 19. First bill (S. 178) providing for the organization and operation of metropolitan water districts in California introduced in state senate by Senators A. B. Johnson and Ralph Swing.

February 25. Wyoming ratified Six-state Compact.

February 26. Colorado ratified Six-state Compact.

March 17. New Mexico ratified Six-state Compact.

March 18. Nevada ratified Six-state Compact.

April 8. Finney resolution passed by California legislature, making California ratification of Six-state Compact effective when 20,000,000 acre-foot storage on the Colorado River was authorized by the Government.

April 15. California senate bill No. 178 providing for organization of metropolitan water districts passed senate by vote of 25 to 9 and transmitted to assembly.

April 22. California senate bill No. 178 for metropolitan water districts refused passage in assembly by vote of 43 to 32.

June 2. Los Angeles electorate authorized issue of $2,000,000 Colorado River project bonds.

October. Funds became available from the $2,000,000 bond issue voted in June, and aqueduct survey work was immediately expedited.

1926

February 27. Boulder Canyon Project Act introduced in 69th Congress by Congressman Phil D. Swing with companion bill by Senator Hiram Johnson. Failed to come to a vote. This was third Swing-Johnson bill.

1927

January 17. Second bill providing for organization of metropolitan water districts introduced in California senate (S. 132).

April 6. California senate bill No. 132, providing for organization of metropolitan water districts passed by senate, 27 to 0 and transmitted to assembly.

April 27. California senate bill No. 132 for metropolitan water districts passed in assembly by a vote of 63 to 2 and transmitted to senate for approval.

April 29. Metropolitan Water District Act approved by senate and presented to governor for signature.

May 10. Metropolitan Water District Act approved by the governor of California.

May 17. Act of California legislature approved, creating California-Colorado River Commission for purpose of negotiating agreements, compacts, etc. with other states and the United States.

July 29. Metropolitan Water District Act (California Statutes of 1927, p. 694) became effective.

August 22, September 2, September 19-29, and October 4. Conference of governors held in Denver in effort to agree on state apportionment of water. Meetings called by Governor Dern of Utah. Attended by Governors Dern, Emerson of Wyoming, Adams of Colorado, Dillon of New Mexico, representing upper basin; Governors Hunt of Arizona, Balzar of Nevada, and Young of California, representing lower basin.

December 5 and 6. Boulder Canyon Project Act authorizing construction Boulder Canyon dam introduced in both houses of 70th Congress. This was fourth Swing-Johnson bill.

December 16. Special advisers appointed by the Secretary of the Interior, to act as a fact-finding committee on the Boulder Canyon project, made their separate reports.

1928

February 15. Board of directors of City of Pasadena adopted ordinance No. 2636 declaring public necessity and convenience require organization and incorporation of a metropolitan water district, also naming cities proposed to be included.

May 25. Boulder Canyon Project Act (Swing-Johnson bill, H.R. 5773) passed by the House.

May 29. Colorado River board, known as the Sibert board, created by joint resolution of Congress to examine and report upon the dam to be constructed under the Boulder dam bill.

August 3. Supreme Court of California decided Metropolitan Water District Act constitutional *(City of Pasadena v. Chamberlain*, 204 Cal. 653, 655).

October 16. Board of directors, City of Pasadena, calls special election on incorporation and organization of Metropolitan Water District, election to be consolidated with general election on November 6, 1928.

November 6. Electorates of Beverly Hills, Burbank, Glendale, Glendora, Los Angeles, Pasadena, Santa Monica, San Marino, San Bernardino, Colton, Anaheim, Orange, and Santa Ana voted on inclusion of their respective city areas in Metropolitan Water District. All approved except Glendora and Orange.

November 24. Colorado River board renders its report to the Secretary of the Interior, reporting favorably on the feasibility of the Boulder Canyon project.

December 4. Certificate of incorporation requested of secretary of state by The Metropolitan Water District of Southern California.

December 6. The Metropolitan Water District of Southern California incorporated.

December 14. Amended House bill (Boulder Canyon Project Act) passed by the United States Senate.

December 18. Senate bill (Boulder Canyon Project Act), as passed by Senate agreed to by House.

December 21. President Coolidge approved the Boulder Canyon Project Act (45 Stat. 1057).

December 29. First meeting held of board of directors, The Metropolitan Water District of Southern California, with Anaheim, Beverly Hills, Burbank, Colton, Glendale, Los Angeles, Pasadena, San Bernardino, San Marino, Santa Ana, and Santa Monica represented.

1929

January 10. California legislature accepts limitation of water as allocated by the Colorado River Compact.

March 4. California ratified Six-state Compact.

March 6. Utah ratified Six-state Compact.

June 13. Amendments to the Metropolitan Water District Act approved by the governor of California.

June 25. President Hoover issued proclamation making Boulder Canyon Project Act and Six-state Compact effective.

July 1. F. E. Weymouth made chief engineer for The Metropolitan Water District of Southern California.

August 30. Metropolitan Water District board of directors authorized employment of A. J. Wiley, R. R. Lyman, and Thaddeus Merriman as an engineering board of review.

September 10. McClellan-Durand report issued on rate which public and private corporations could pay for power, and rate which will produce sufficient revenue to repay cost of Boulder Canyon project.

September 10. Secretary of the Interior Wilbur issued notice that all applications of prospective purchasers of power from Boulder project must be filed by October 1, 1929.

October 2. Secretary of the Interior announced requests for power from Boulder Canyon project insured that all power would be taken, thus assuring repayment of cost of dam as required by law.

October 21. Tentative allocation of Boulder Canyon power announced by Secretary of Interior.

November 12. Formal hearings by Secretary of the Interior on protests against allocation of power to various applicants.

November 14. First report on Colorado River water supply project issued by Chief Engineer Weymouth.

December 21. Board of review submitted preliminary report to board of directors of The Metropolitan Water District of Southern California, recommending surveys, investigations, and comparable estimates of four possible routes for the Colorado River aqueduct.

December 26. Attorney general upheld constitutionality of Boulder Canyon Project Act.

1930

January 9. Conference held in office of Secretary of the Interior on price for power, division of water, and storage charge for water to The Metropolitan Water District of Southern California.

February 21. Preliminary agreement on division of water reached by The Metropolitan Water District of Southern California, Imperial Irrigation District, Coachella Valley County Water District, and Palo Verde Irrigation District.

March 20. Preliminary agreement reached among major California applicants for allocation of Boulder Canyon project power.

March 23. Secretary of the Interior announced agreement had been reached regarding power allocation.

April 7. Agreement reached by eleven municipalities of Southern California for allocation of Boulder Canyon project power.

April 16. Colorado River board (Sibert board) made second report covering Boulder Canyon storage dam with reference to increasing height of crest from 575 feet to 582 feet.

April 24. Contract signed with Secretary of the Interior for delivery of water to The Metropolitan Water District of Southern California.

April 26. Power contract signed by The Metropolitan Water District of Southern California and the Secretary of the Interior.

May 1. The Metropolitan Water District took over all engineering and other work for the Colorado River aqueduct which up to that time had been done under the jurisdiction of the Bureau of Water Works and Supply of the City of Los Angeles.

May 31. Contract for electrical energy, between the United States and The Metropolitan Water District of Southern California, amended.

June 21. Second agreement made on division of water, amending previous agreement of February 21, 1930, between The Metropolitan Water District of Southern California, Imperial Irrigation District, Coachella Valley County Water District, and Palo Verde Irrigation District.

July 3. First appropriation, $10,660,000, for Boulder Canyon project construction approved by President Hoover.

July 7. Secretary of the Interior Wilbur directed Commissioner of Reclamation Elwood Mead "to commence construction on Boulder Dam today."

September 17. Commencement of construction of Boulder Canyon project celebrated by driving silver spike in construction railroad near Las Vegas, Nevada.

October 13. Arizona filed bill of complaint with the United States Supreme Court charging that construction of Boulder Canyon project was invasion of its rights.

November 10. Chief Engineer Weymouth reported to the board of directors of the Metropolitan Water District on preliminary surveys, designs, and estimates and recommended Parker route for Colorado River aqueduct.

December 19. Board of review submitted its second and final report to the board of directors of the Metropolitan Water District.

1931

February 27. Cities of Fullerton, Long Beach, and Torrance annexed to the Metropolitan Water District.

March 4. Bids opened at Denver for construction of Boulder dam, power plant, and appurtenant works.

March 11. Contract for construction of Boulder dam awarded by Secretary of the Interior to Six Companies, Inc.

May 18. United States Supreme Court dismissed bill of complaint in suit brought by Arizona against Secretary of the Interior and signatories to the Six-state Compact.

June 23. City of Compton annexed to District.

August 18. Cities of Colton and San Bernardino withdrew from the Metropolitan Water District.

August 18. Seven-party agreement executed, covering final allocation of water among California claimants.

September 11. Special election ordered by District's board of directors on proposal to issue $220,000,000 of bonds for construction of Colorado River aqueduct project (M. W. D. ordinance 23).

September 28. Section 6 of contract of April 24, 1930 between District and U. S. for delivery of water to the Metropolitan Water District amended to specifically recognize interests of other claimants.

September 29. $220,000,000 bond issue approved by electorate of The Metropolitan Water District of Southern California by a 4.85 to 1 vote.

1932

January 22. Reconstruction Finance Corporation Act approved, as amended.

April 18. Decision of Supreme Court of State of California rendered holding California prevailing wage act constitutional and valid, and applicable to District operations *(Metropolitan Water District v. Whitsett*, 215 Cal. 400).

June 2. California Supreme Court declared $220,000,000 Colorado River aqueduct bond issue valid *(In re Metropolitan Water District*, 215 Cal. 582).

June 18. Congress granted to the District right of way over public lands (H.R. 10048).

July 21. Emergency Relief and Construction Act of 1932 approved, granting Reconstruction Finance Corporation power to lend to self-liquidating projects of political subdivisions of states.

September 2. Application made to the Reconstruction Finance Corporation for a loan of $99,750,000 to finance initial construction of the Colorado River aqueduct.

September 13. Reconstruction Finance Corporation agreed to bid on $40,000,000 bonds to be offered for sale by The Metropolitan Water District of Southern California.

October 19. Specifications No. 3 for construction of San Jacinto tunnel issued.

November 15. Supreme Court of District of Columbia dismissed suit brought by Burnham to enjoin Reconstruction Finance Corporation from lending money to Metropolitan Water District for Colorado River aqueduct construction.

November 23. Contract executed between The Metropolitan Water District of Southern California and City of Pasadena for purchase of Morris (Pine Canyon) dam by District.

November 29. Bids opened for the construction of San Jacinto tunnel.

December 12. First block of bonds amounting to $2,016,000 sold to the Reconstruction Finance Corporation.

December 21. Board of directors authorized construction of Coachella tunnels by District forces.

1933

January 25. First excavation on aqueduct construction at Fargo adit and on Thousand Palms section of Coachella tunnels.

February 10. Contract executed between The Metropolitan Water District of Southern California and United States for construction and operation of Parker dam.

March 17. Contract executed with Wenzel & Henoch Construction Company for the construction of San Jacinto tunnel.

May 19. Application for $59,750,000 additional financing made to the Reconstruction Finance Corporation. (Transferred to the Public Works Administration pursuant to the National Industrial Recovery Act.)

June 2. Application for $105,810,000 additional financing, to complete project, made to Reconstruction Finance Corporation. (Transferred to Public Works Administration pursuant to the National Industrial Recovery Act.)

June 16. National Industrial Recovery Act approved, limiting power of Reconstruction Finance Corporation to make new loans and transferring applications to newly created Federal Emergency Administration of Public Works.

1934

March 22. Public Works Administration executed loan and grant agreement totaling $2,000,000 for construction of diversion and outlet works at Parker dam.

April 16. Reconstruction Finance Corporation granted one per cent interest refund for five years on all bonds of the District held in its portfolio, effective April 1, 1934.

June 15. United States Bureau of Reclamation issued specifications (No. 574) for construction of Parker dam.

June 19. Reconstruction Finance Corporation Act amended permitting the corporation to make further loans to projects financed by it prior to June 26, 1933.

June 22. Application made to Reconstruction Finance Corporation for $77,000,000 additional financing.

July 26. Bids opened in Los Angeles for the construction of Parker dam.

August 25. Contract for the construction of Parker dam awarded to Six Companies, Inc.

September 26. Agreement for $15,000,000 additional loan executed by Reconstruction Finance Corporation.

October 1. Construction of contractor's camp started at Parker dam.

October 19. Contracts awarded for first open work along the aqueduct.

November 10. Governor of Arizona declared Parker dam construction area in Arizona to be under martial law.

November 12. Construction work at Parker dam ordered suspended by Secretary of the Interior.

November 27. First construction operations started on open-work sections of the aqueduct.

December 21. First contracts awarded for distribution system tunnels; including Monrovia Nos. 1, 2, and 3 and Pasadena tunnels.

1935

January 15. Contract with Wenzel & Henoch Construction Company, for construction of San Jacinto tunnel, suspended.

January 29. Construction work started on distribution system tunnels.

February 10. First main aqueduct contract completed—Mecca Pass tunnels.

February 11. Supreme Court of United States enjoined Governor of Arizona from use of militia or from other interference with work on Parker dam.

February 12. District formally took over, from the contractor, the construction of San Jacinto tunnel.

February 14. Parker dam construction resumed.

April 5. Application filed with Reconstruction Finance Corporation for funds ($100,000,000) required during 1935-1936.

April 29. United States Supreme Court ruled that contract between District and United States for construction of Parker dam required congressional approval.

April 30. Work at Parker dam suspended.

June 1. Reconstruction Finance Corporation authorized third loan ($36,000,000).

August 16. Contract awarded to Griffith Company for construction of Cajalco dam and dike.

August 30. Construction work started at Cajalco.

August 30. Rivers and Harbors bill passed by Congress and approved by the President; validated contract of February 10, 1933, between United States and District, also construction contract between United States Bureau of Reclamation and Six Companies, Inc., for the construction and operation of Parker dam.

August 31. Work on Parker dam ordered resumed.

September 4. Application filed with Public Works Administration (State Engineer for California) for $6,805,000 for construction of Parker dam.

September 30. Finance committee and General Manager and Chief Engineer Weymouth of the District conferred with the President and Secretary Ickes at Boulder regarding Parker dam financing.

September 30. Agreement reached between Six Companies, Inc., and District for payment of $240,000 damages resulting from delay in construction of Parker dam caused by Arizona interference.

October 1. Construction work at Parker again resumed.

November 1. First contract awarded for construction of distribution system pipe lines.

November 22. Contract awarded for building the first pumping plants—Intake and Gene.

December 2. Construction work started on Boulder transmission line.

1936

January 6. Construction work started on Gene pumping plant.

January 17. Construction work started on distribution system pipe lines.

January 24. Contracts awarded for furnishing the first fifteen pumps to be installed in the pumping plants.

March 6. Use of funds secured from sale of District bonds to Reconstruction Finance Corporation authorized for Parker dam construction.

March 22. Construction started on Lawrence adit, San Jacinto tunnel.

April 14. Application filed with Reconstruction Finance Corporation for additional $57,500,000 to finance work through the fiscal year 1936-37.

May 15. Contracts awarded for furnishing synchronous motors for the first fifteen pumps.

June 6. Reconstruction Finance Corporation authorized fourth loan ($57,500,000).

September 29. Supplemental contract executed between the District and Bureau of Reclamation regarding construction of substructure for Parker power house.

October 22. Colorado River first diverted through tunnels at Parker dam.

November 27. Application made to Reconstruction Finance Corporation for $60,000,000 additional funds required to complete the Colorado River aqueduct project.

1937

May 8. Concrete lining completed in Coachella tunnels.

May 14. Loan of additional funds, up to $60,000,000, authorized by Reconstruction Finance Corporation.

July 19. Completed stringing conductor on 230-kv transmission line from Boulder dam to the pumping plants.

July 29. First concrete placed in Parker dam.

September 1. Construction of first pumping plant completed (Iron Mountain).

September 10. Contract awarded for first 17 miles of the Palos Verdes cross feeder.

November 15. Work started on Eagle Rock to Palos Verdes cross feeder.

November 19. Contracts awarded for constructing 152 miles of aqueduct fences.

1938

February 9. Cajalco dam and dike completed.

March 1. Most severe storm in Southern California in past 61 years; aqueduct not damaged.

May 30. Main aqueduct cut-and-cover conduits completed.

June 10. $147,000,000 of refunding bonds issued to Reconstruction Finance Corporation, in exchange for an equal amount in interim certificates.

June 29. Parker diversion tunnels closed.

July 1. First water over Parker dam.

METROPOLITAN WATER DISTRICT ACT

STATE OF CALIFORNIA

An act providing for the incorporation, government and management of metropolitan water districts, authorizing such districts to incur bonded debt and to acquire, construct, operate and manage works and property, providing for the taxation of property therein and the performance of certain functions relating thereto by officers of counties, providing for the addition of area thereto and the exclusion of area therefrom and authorizing municipal corporations to aid and participate in the incorporation of such districts.

[Chapter 429, Statutes 1927, p. 694; approved by the Governor May 10, 1927; in effect July 29, 1927. Amended by Chapter 796, Statutes 1929, p. 1613; approved by the Governor June 13, 1929; in effect August 14, 1929. Amended by Chapter 323, Statutes 1931, p. 814; approved by the Governor, and in effect, May 12, 1931. Amended by Chapter 507, Statutes 1933, p. 1289; approved by the Governor, and in effect, May 24, 1933. Amended by Chapter 140, Statutes 1937, p. 381; approved by the Governor April 29, 1937; in effect August 27, 1937.]

The people of the State of California do enact as follows:

Section 1. This act shall be known as the "Metropolitan water district act" and shall apply to the incorporation, organization, government, maintenance and operation of the water districts herein provided for and described, and to the board of directors herein referred to.

Sec. 2. As used herein the term "municipality" or "city" shall be deemed to mean and include any municipal corporation of the State of California, whether organized under a freeholders' charter or under the provisions of general law; and for the purposes of this act such words "municipality" and "city" shall also include and mean any municipal water district incorporated under an act entitled "An act to provide for the incorporation and organization and management of municipal water districts and to provide for the acquisition or construction by said districts of water works, and for the acquisition of all property necessary therefor, and also to provide for the distribution and sale of water by said districts," approved May 1, 1911, as amended, and all further amendments thereof or supplements thereto; any municipal utility district incorporated under an act entitled "An act to provide for the organization, incorporation, and government of municipal utility districts, authorizing such districts to incur bonded indebtedness for the acquisition and construction of works and property, and to levy and collect taxes to pay the principal and interest thereon," approved May 23, 1921, as amended, and all further amendments thereof or supplements thereto; any public utility district incorporated under any of the following acts, namely, an act entitled "An act to provide for the incorporation and organization of public utility districts, authorizing such districts to incur bonded indebtedness for the purpose of the construction of works and the acquisition of property, and to levy and collect taxes to pay the principal and interest on bonds and for carrying on their operations, and providing for the powers, management and government of such districts," approved June 5, 1913; an act entitled "An act providing for the incorporation of public utility districts by municipalities and unincorporated territory, authorizing such districts to incur bonded indebtedness for the purpose of the construction of works and the acquisition of property, and to levy and collect taxes to pay the principal and interest on bonds and for carrying on their operations, and providing for the powers, management and government of such districts, and imposing certain duties and functions in connection with such districts upon certain county officers," approved May 27, 1915, as amended; and an act entitled "An act providing for the incorporation of public utility districts in unincorporated territory, authorizing such districts to incur bonded indebtedness for the purpose of the construction of works and the acquisition of property, and to levy and collect taxes to pay the principal and interest on bonds and for carrying on their operations, and providing for the powers, management and government of such districts, and imposing certain duties and functions in connection with such districts upon certain county officers," approved May 31, 1921, as amended, and all further amendments thereof or supplements thereto; and any county water district incorporated under the County Water District Act, as amended, and all further amendments thereof or supplements thereto.

The terms "board" and "board of directors" shall be deemed to refer to the directors created under section 6 hereof.

[Amendment approved April 29, 1937; Stats. 1937, Chap. 140.]

Sec. 3. Metropolitan water districts may be organized hereunder for the purpose of developing, storing and distributing water for domestic purposes, and may be formed of the territory included within the corporate boundaries of any two or more municipalities, which need not be contiguous, and may be incorporated and organized and thereafter governed, maintained and operated as herein provided, and when so incorporated shall have and exercise such powers as are herein expressly granted, together with such powers as are reasonably implied therefrom and necessary and proper to carry out the objects and purposes of such incorporated districts. Each such district when so incorporated shall be a separate and independent political corporate entity.

Sec. 4. Such metropolitan water districts shall be organized and incorporated in the following manner:

(a) The legislative body of any municipality may pass an ordinance declaring that the public convenience and necessity require the incorporation of a metropolitan water district, which ordinance shall state: (a) that it is proposed to incorporate a metropolitan water district under the provisions of this act; (b) the names of the cities proposed to be included within the district to be incorporated; (c) the name of the proposed district; and (d) an estimate of the preliminary costs and expenses of incorporating and organizing the proposed district and an apportionment of such costs and expenses among the several municipalities proposed to be included within such district. Such apportionment shall be substantially in accordance with population as shown by the most recent federal census.

(b) It shall be the duty of the clerk of the legislative body, upon the taking effect of such ordinance, to forthwith transmit a certified copy thereof by registered mail to the chief executive officer of each of the other municipalities named therein.

(c) Within sixty days after the receipt by any municipality named therein of a certified copy of such ordinance, the legislative body of such municipality shall by order either approve or reject such ordinance without alteration or amendment. In the event that the legislative body of any municipality shall fail to act upon such ordinance as herein provided within such period of sixty days after receipt of a certified copy thereof, such municipality shall be deemed to have rejected said ordinance.

(d) Immediately upon the approval or rejection of said ordinance by the legislative body of any municipality, the clerk thereof shall forward to the clerk of the municipality initiating the proceedings a certified copy of the order approving or rejecting such ordinance, as the case may be. Each municipality thus approving such ordinance shall promptly pay over to the municipality initiating the procedure hereunder, the sum of money apportioned to it by the municipality initiating the proceedings as its share of the preliminary costs and expenses of the incorporation and organization of such district, and the money so paid shall constitute a fund for the purpose of defraying such costs and expenses of conducting the election herein provided for as are not met by the respective municipalities, and such incidental expenses as may be properly incurred in connection therewith. Each municipality contributing money as herein provided shall be entitled to credit with the district for the amount contributed.

(e) Within one hundred twenty days after the transmission of said original ordinance, as provided in subdivision (b) of this section, but not until each municipality named therein shall have acted thereon or said sixty day periods shall have expired, the legislative body of the initiating city shall call and provide for the holding of a special election in all of the municipalities, the legislative bodies of which shall have approved said original ordinance as herein provided, including the initiating city, at which election the proposition of the incorporation of such metropolitan water district shall be submitted to the electors residing within such municipalities for ratification or rejection. Such election may be held separately or may be consolidated or held concurrently with any other election or elections authorized by law at which the electors residing in all of the cities wherein such election is called to be held are entitled to vote.

(f) Such election shall be called by ordinance by the governing body of the initiating city. Such ordinance shall contain, (1) the names of all cities, the governing bodies of which shall have approved the original ordinance as provided in subdivision (c) of this section, in which cities such election shall be called to be held, (2) the day upon which such election shall be held, (3) the time for opening and closing polls, and (4) the manner of voting for or against the proposition. (5) Such ordinance shall also designate the precincts and polling places and shall appoint the officers of such election, which officers shall consist of one inspector, one judge and two clerks in each precinct. The description of precincts may be made by reference to any order or orders of the board of supervisors of the county or counties in which the proposed metropolitan water district, or any part thereof, shall be situated, or by reference to any provisions, order or ordinance of the legislative body of any municipality proposed to be included in the incorporation of such metropolitan water district, or by detailed description of such precincts. Precincts established by the boards of supervisors of the various counties to a number of not exceeding six may be consolidated for special elections held hereunder.

Whenever any election held hereunder shall be held concurrently with or shall be consolidated with any primary or general election, the precincts, polling places and officers of election shall be those designated and appointed for such primary or general election, and the ordinance calling the election hereunder need not designate precincts or polling places or name the election officers, but shall refer to the order or orders, or act or acts, by which such other election shall have been called, and by which the precincts and polling places thereof shall have been fixed and the officers of election appointed.

(g) The ordinance calling such election shall be published once at least ten days before the date of the election therein called in a newspaper of general circulation printed and published in each county within the proposed metropolitan water district, and no other or further notice of such election or publication of the names of election officers or of the precincts or polling places need be given or made.

(h) The ballot used at such election shall contain the words "Shall the territory embraced within the corporate boundaries of the city of.............................. become a part of the..............................metropolitan water district" (inserting the name of the city or water district as the case may be wherein such ballot shall be used and the name of the metropolitan water district as stated in the initiating ordinance) and the words "Yes" and "No" accompanied by voting squares set opposite thereto so that any elector may record his vote either for or against the propositions.

(i) When such election shall be held separately or shall be conducted concurrently with any other election but by the use of separate ballots, such ballots shall be counted by the respective election boards and the returns thereof shall be made to the governing board of the initiating city, which body, at its first regular meeting occurring five days after such election, shall canvass the returns and declare the result thereof.

In the event that any election held hereunder shall be consolidated with any primary or general election and the proposition herein provided for shall be printed upon a ballot containing other propositions, the returns of the election held hereunder shall be made with the returns of the primary or general election to the boards of supervisors or other bodies whose duty it shall be to canvass the returns thereof, and the results of the election held hereunder shall be canvassed at the time and in the manner provided by law for the canvass of the returns of such primary or general election. It shall be the duty of such canvassing body or bodies to promptly certify and transmit to the governing body of the initiating city a statement of the result of the vote upon the proposition submitted hereunder in each of the respective cities, the returns for which shall have been made to such canvassing bodies. Upon the receipt of such certificates it shall be the duty of the governing body of the initiating city to tabulate and declare the result thereof.

The governing body of the initiating city shall certify to the secretary of state the proceedings had together with the result of the election, separately stating the names of the cities in which a majority of the electors voting upon the proposition shall have voted affirmatively; *provided, however*, that the total assessed valuation in such approving municipalities as shown by county assessment records, shall be not less than two-thirds of the total assessed valuation within the district as proposed in the original ordinance according to the records of the county or counties.

The secretary of state shall within ten days after the receipt of such certificate of election issue a certificate of incorporation reciting that the district named in such certificate of election has been duly incorporated according to the laws of the State of California, and naming the municipalities of which said district shall be composed as shown by such certificate of election, which municipalities shall be those in which the majority of electors voting on the proposition of incorporation shall have voted affirmatively. The secretary of state shall transmit to each such municipality a copy of said certificate of incorporation. The incorporation of any metropolitan water district shall be and become effective from and after the date of the issuance of such certificate of incorporation, and such district shall thereupon and thereafter become vested with all of the rights, privileges, and powers in this act provided.

(j) The validity of the incorporation of any such district shall be incontestable in any suit or proceeding which shall not have been commenced within three months from the date of the issuance of the certificate of incorporation thereof; and no invalidity or irregularity in any proceeding which does not substantially and adversely affect the interests of the electors or citizens of the district, or any municipality therein, shall be held to invalidate the incorporation of any such district.

[Amendment approved June 13, 1929; Stats. 1929, Chap. 796.]

Sec. 5. Any district incorporated as herein provided shall have power:

(1) To have perpetual succession.

(2) To sue and be sued in all actions and proceedings and in all courts and tribunals of competent jurisdiction.

(3) To adopt a corporate seal and alter it at pleasure.

(4) To take by grant, purchase, bequest, devise or lease, and to hold, enjoy, lease, sell or otherwise dispose of, any and all real and personal property of any kind within or without the district and within or without the State necessary or convenient to the full exercise of its powers; also to acquire, construct or operate, control and use any and all works, facilities and means necessary or convenient to the exercise of its powers, both within and without and within or without the district and within and without the State, and to do and perform any and all things necessary or convenient to the full exercise of the powers herein granted.

(5) To have and exercise the power of eminent domain and in the manner provided by law for the condemnation of private property for public use to take any property necessary to the exercise of the powers herein granted except water and water rights already devoted to beneficial use and power plants devoted to public use; and provided, further, that any district organized under the provisions of this act shall not have or exercise the power of eminent domain for the purpose of condemning or taking any water or right to water conserved or stored behind any flood control dam that has been or may hereafter be built or constructed by any flood control district created by act of Legislature of this State. Subject to the express limitations hereinbefore set out, in any proceeding relative to the exercise of such power of eminent domain, the district shall have the same rights, powers and privileges as a municipal corporation.

(6) To construct and maintain works and establish and maintain facilities across or along any public street or highway and in, upon or over any vacant public lands which are now, or may become, the property of the State of California, and to construct works and establish and maintain facilities across any stream of water or water course; provided, however, that the district shall promptly restore any such street or highway to its former state of usefulness as nearly as may be, and shall not use the same in such manner as to completely or unnecessarily impair the usefulness thereof. The grant of the right to use such vacant State lands shall be effective upon the filing by such district with the Division of State Lands of the Department of Finance, of an application showing the boundaries, extent and locations of the lands, rights of way, or easements desired for such purposes. If the land, rights of way or easement for which application shall be made is for the construction of any aqueduct, ditch, pipe line, conduit, tunnel or other works for the conveyance of water, or for roads, or for poles, or towers and wires for the conveyance of electrical energy or for telephonic or telegraphic communication, no compensation shall be charged the district therefor, unless, in the opinion of the Chief of such Division of State Lands the construction of such works will render the remainder of the legal subdivision through which such works are to be constructed valueless or unsalable, in which event the district shall pay for the lands to be taken and for such portion of any legal subdivision which, in the opinion of said Chief of the Division of State Lands, are rendered valueless or unsalable, at the rate of one dollar and twenty-five cents per acre. If the lands for which application is made are for purposes other than the construction of roads or for works for the con-

veyance of water, or electricity or telephonic or telegraphic communication, such district shall pay to the State for such lands at the rate of one dollar and twenty-five cents per acre. Upon filing such application, accompanied by map or plat showing the location or proposed location of such works and/or facilities, the fee title to so much of such State lands as shall be found by the Chief of the Division of State Lands of the Department of Finance to be necessary or convenient to enable such district to construct or maintain its works and/or to establish or maintain its facilities, shall be conveyed to such district by patent executed by the Governor of the State of California, attested by the Secretary of State with the great seal of said State affixed, and countersigned by the register of State lands; if an easement or right of way only over such lands be sought by such district, such easement or right of way shall be evidenced by permit or grant executed by such Chief of the Division of State Lands. The Chief of the Division of State Lands may reserve in such patents, grants or permits, easements and rights of way across any lands therein described for the construction of streets, roads and highways. Before any such patent, grant or permit shall be executed any compensation due to the State under the provisions hereof, must be paid. In the event that the duties or titles of any of the officers herein mentioned shall be changed by lawful authority, the functions herein required to be performed shall be performed by the appropriate officer or officers of the State of California. No fee shall be exacted from such district for any patent, permit or grant so issued or for any service rendered hereunder. In the use of streets the district shall be subject to the reasonable rules and regulations of the county or city wherein such streets lie, concerning excavations and the refilling of excavations, the relaying of pavements and the protection of the public during periods of construction; provided, that the district shall not be required to pay any license or permit fees, or file any bonds. The district may be required to pay reasonable inspection fees.

(7) To borrow money and incur indebtedness and to issue bonds or other evidence of such indebtedness; provided, however, that no district incorporated hereunder shall incur indebtedness which, in the aggregate, shall exceed fifteen (15) per cent of the assessed valuation of all the taxable property included within the district, as shown by the assessment records of the county or counties.

(8) To levy and collect taxes for the purposes of carrying on the operations and paying the obligations of the district; provided, however, that such taxes levied under this section exclusive of any tax levied to meet the bonded indebtedness of such district and the interest thereon and exclusive of any tax levied to meet any obligation to the United States of America or to any board, department or agency thereof, shall not exceed five cents on each such one hundred dollars of assessed valuation; to enter into contracts, employ and retain personal services and employ laborers; to create, establish and maintain such offices and positions as shall be necessary and convenient for the transaction of the business of the district, and to elect, appoint and employ such officers, attorneys, agents and employees therefor as shall be found by the board of directors to be necessary and convenient.

(9) To join with one or more other public corporations for the purpose of carrying out any of its powers, and for that purpose to contract with such other public corporation or corporations for the purpose of financing such acquisitions, constructions and operations. Such contracts may provide for contributions to be made by each party thereto and for the division and apportionment of the expenses of such acquisitions and operations, and the division and apportionment of the benefits, the services and products therefrom, and may provide for an agency to effect such acquisitions and carry on such operations, and shall provide in the powers and methods of procedure for such agency the method by

which such agency may contract. Such contract may contain such other and further covenants and agreements as may be necessary and convenient to accomplish the purposes hereof. The term "public corporation" as used in this subdivision shall be deemed to mean and include the United States or any other public agency thereof or this or any other State or any political district or subdivision thereof.

(10) To acquire water and water rights within or without the State; to develop, store and transport water; to provide, sell and deliver water at wholesale for municipal and domestic uses and purposes; to provide, sell, and deliver water and water service to the United States of America, or to any board, department or agency thereof, or to the State of California, for any use or purpose, pursuant to contract therefor, which contract may be for permanent service, but shall provide for the furnishing of such water or water service upon terms and conditions and at rates which will apportion an equitable share of the capital cost and operating expense of the district's works to the contractee, and every such contract shall provide that at the end of five years from the date of its execution and every three years thereafter there shall be such readjustment of the contract, upon the demand of either party thereto, either upward or downward as to rates, as the board of directors of the district may find to be just and reasonable in order to effectuate such equitable apportionment of the said capital cost and operating expense, and all water so contracted to be furnished by the district shall be deemed not to be surplus water available for sale pursuant to the following provisions of this paragraph; also to provide, sell and deliver surplus water of the district not needed or required by municipalities, the corporate area of which is included in such district, for domestic or municipal uses therein, for beneficial purposes, but giving preference to uses within the district; provided, that the supplying of such surplus water shall, in every case, be subject to the paramount right of the district to discontinue the same, in whole or in part, and to take and hold, or to provide, sell and deliver, such water for domestic or municipal uses within the district, upon one year's written notice to the purchaser or user of such surplus water, such notice to be given by the board of directors of the district whenever it shall be determined and declared by resolution adopted by said board of directors by a two-thirds vote thereof that such water is needed or required by any municipality, the corporate area of which is included within said district, for domestic or municipal uses therein; to fix the rates therefor, and to acquire, construct, operate and maintain any and all works, facilities, improvements and property necessary or convenient therefor.

(11) To invest any surplus money in the district treasury, including such money in any sinking fund established for the purpose of providing for the payment of the principal or interest of any bonded or other indebtedness or for any other purpose, not required for the immediate necessities of the district, in its own bonds, or in treasury notes, or bonds, of the United States, or of this State, and such investment may be made by direct purchase of any issue of such bonds or treasury notes, or part thereof, at the original sale of the same, or by the subsequent purchase of such bonds or treasury notes. Any bonds or treasury notes thus purchased and held may, from time to time, be sold and the proceeds reinvested in bonds or treasury notes, as above provided. Sales of any bonds or treasury notes thus purchased and held shall, from time to time, be made in season so that the proceeds may be applied to the purposes for which the money, with which the bonds or treasury notes were originally purchased, was placed in the treasury of the district. The functions and duties authorized by this paragraph shall be performed by joint action of the Controller and Treasurer, with the approval of the attorney, under such rules and regulations as shall be prescribed by the board of directors of the district.

(12) To refund bonded indebtedness incurred by the district under and pursuant to the provisions of section 7 of this act, such refunding to be made in the following manner:

(a) The board of directors by a two-thirds vote may refund such bonded indebtedness, or any portion thereof, and issue refunding bonds of the district therefor maturing not later than fifty (50) years from the date of the first issue of the refunded bonds, if said refunded bonds shall have been issued in one block, or from the date of the respective installment of such refunded bonds, if the same shall have been issued in installments, and bearing interest at a rate not exceeding the interest rate on the refunded bonds. The provisions of subsections (e), (f), (j), (k) and (l) of section 7 of this act, subject to the limitations and modifications imposed by this paragraph, shall apply to such refunding bonds. The provision in said subsection (e) for deferring the date of the earliest maturity of the principal of the bonds shall be construed to authorize the board of directors, in its discretion, to determine and fix the date for the earliest maturity of the principal of said refunding bonds, which date shall be not later than fifteen (15) years from the date of the first issue of the refunded bonds, or from the date of the respective installment of the refunded bonds, as the case may be.

(b) Said refunding bonds may be sold by the board of directors as it shall determine, in the manner provided in subsection (g) of section 7 of this act for the sale of the bonds to be refunded, and the proceeds of the sale of such refunding bonds, excepting premium and accrued interest, shall be placed in the treasury of the district to the credit of the "Refunding fund" and shall be applied only to the purchase, at not more than par and accrued interest, of the bonded indebtedness for which said refunding bonds shall have been issued. Premium and accrued interest shall be placed in the fund to be applied to the payment of interest on, and the retirement of, the refunding bonds so sold. In lieu of selling such refunding bonds and purchasing with the proceeds thereof the bonds to be refunded, the board of directors of the district may exchange refunding bonds at not less than par and accrued interest for the bonds so refunded.

(c) Whenever such outstanding bonds shall be refunded, they shall be surrendered to the treasurer of the district, who shall proceed to cancel the same by indorsing on the face thereof the manner in which the refunding shall have been effected (whether by exchange or purchase, and the amount for which so purchased, if any) and by perforating through each bond and each coupon attached thereto, the word "canceled" together with the date of cancellation. He shall keep a record of such bonds so refunded, and shall make a report to the board of directors at least once a month.

(d) All moneys which shall remain in said "Refunding fund" after all outstanding bonds which were proposed to be refunded therefrom have been taken up and canceled, shall be paid into the sinking fund of such district and become a part thereof.

[Amendment approved April 29, 1937; Stats. 1937, Chap. 140.]

Sec. 5½. Each city, the area of which shall be a part of any district incorporated hereunder, shall have a preferential right to purchase from the district for distribution by such city, or any public utility therein empowered by said city for the purpose, for domestic and municipal uses within such city a portion of the water served by the district which shall, from time to time, bear the same ratio to all of the water supply of the district as the total accumulation of amounts paid by such city to the district on tax assessments and otherwise, excepting purchase of water, toward the capital cost and operating expense of the district's works shall bear to the total payments received by the district on account of tax assessments and otherwise, excepting purchase of water, toward such capital cost and operating expense.

[Amendment approved May 12, 1931; Stats. 1931, Chap. 323.]

Sec. 6. All powers, privileges and duties vested in or imposed upon any district incorporated hereunder shall be exercised and performed by and through a board of directors; provided, however, that the exercise of any and all executive, administrative and ministerial powers may be by said board of directors delegated and redelegated to any of the offices created hereby or by the board of directors acting hereunder.

The board of directors herein referred to shall consist of at least one representative from each municipality, the area of which shall lie within the metropolitan water district. Such representatives shall serve without compensation from the district and shall be designated and appointed by the chief executive officers of municipalities, respectively, with the consent and approval of the governing bodies of the municipalities, respectively. As a member of the board of directors, each representative shall be entitled to vote on all questions, orders, resolutions and ordinances coming before the board, and shall be entitled to cast one vote for each ten million dollars, or major fractional part thereof, of assessed valuation of property taxable for district purposes in the city represented by him as shown by the assessment records of the county and evidenced by the certificate of the county auditor; provided, that each representative shall have at least one vote and no municipality shall have votes exceeding in number the total number of votes of all the other municipalities whose corporate areas are included in such district. In lieu of one representative any city may at its option designate and appoint several representatives not exceeding one additional representative for each two hundred million dollars of assessed valuation, but such representatives shall cast the vote to which such city would otherwise be entitled as a unit and as a majority of such representatives present shall determine. The affirmative votes of members representing more than fifty (50) per cent of the total number of votes of all the members shall be necessary and, except as otherwise herein provided, shall be sufficient to carry any order, resolution or ordinance coming before the board of directors. Any meeting may be adjourned or recessed from day to day or from time to time, by vote of the director or directors present, irrespective of the number of directors present or the number of votes represented at such meeting. For the purposes of this section, the term "major fractional part" shall be deemed to mean a fractional part larger than one-half. Members of the board of directors so constituted shall convene at the time and place fixed by the chief executive officer of the municipality initiating the proceedings hereunder, and immediately upon convening, such board of directors shall elect from its membership a chairman, a vice chairman, and a secretary, who shall serve for a period of two years, or until their respective successors shall be elected and qualified.

The board of directors shall have power:

(1) To fix the time and place or places at which its regular meetings shall be held, and shall provide for the calling and holding of special meetings.

(2) To make and pass ordinances, resolutions and orders not repugnant to the Constitution of the United States or of the State of California, or to the provisions of this act, necessary for the government and management of the affairs of the district, for the execution of the powers vested in the district and for carrying into effect the provisions of this act. On all ordinances the roll shall be called and the ayes and noes recorded. Resolutions and orders may be adopted by viva voce, but on demand of any member the roll shall be called. No ordinance shall be adopted unless it shall have been introduced on a day previous to the time of such adoption except by unanimous vote of all the members of the board

of directors present, provided there shall be present directors from not less than three-fourths of all cities whose corporate areas are included in said metropolitan water district and representing not less than three-fourths of the total votes of said district; provided, that in lieu of such previous introduction or unanimous vote any ordinance may be mailed by registered mail, postage prepaid to each member of the board of directors at least five (5) days prior to the day upon which such ordinance shall be presented for adoption. No ordinance adopted by the board of directors shall take effect until the expiration of thirty (30) days following the adoption thereof, except an ordinance ordering or otherwise relating to an election or to the issuance or sale of bonds or to the levying or collection of taxes or the fixing of water rates; and an ordinance necessary for the immediate preservation or protection of the property, interests or welfare of the district, which shall contain a specific statement showing its urgency, and is passed by three-fourths of the total vote of the board of directors but all ordinances of any of the classes heretofore excepted by this section shall take effect upon their adoption. All ordinances except those which shall take effect upon their adoption as provided in this section shall be subject to referendum in the manner provided by law for the legislative acts of boards of supervisors of counties.

(3) To fix the location of the principal place of business of the district and the location of all offices and departments maintained hereunder.

(4) To prescribe by ordinance a system of business administration and to create any and all necessary offices which shall include the offices of controller and of treasurer and to establish and reestablish the powers and duties and compensation of all officers and employees and to require and fix the amount of all official bonds necessary for the protection of the funds and property of the district.

(5) To prescribe by ordinance a system of civil service.

(6) To delegate and redelegate by ordinance to officers of the district power to employ clerical, legal and engineering assistants and labor, and under such conditions and restrictions as shall be fixed by the directors, power to bind the district by contract.

(7) To prescribe a method of auditing and allowing or rejecting claims and demands; also to prescribe methods for the construction of works and for the letting of contracts for the construction of works, structures or equipment, or the performance or furnishing of labor, materials or supplies, required for the carrying out of any of the purposes of this act; provided that, in cases where work is not to be done by the district itself by force account, and the amount involved shall be ten thousand dollars, or more, the board of directors shall provide for the letting of contracts to the lowest responsible bidder, after publication of notices inviting bids, subject to the right of said board to reject any and all proposals. Provided, likewise, that the board of directors in advertising for bids and in letting contracts as above provided, may require all articles to be furnished to the district thereunder to be manufactured, produced or fabricated in the United States or its Territories, and may prohibit the use in, or employment in connection with, the carrying out of such contracts by the contractor or any subcontractor, of all machinery or materials except such as shall have been manufactured, produced or fabricated in the United States or its Territories, if such are available, the question of such availability to be determined by the board of directors. Provided, further, that contracts, in writing or otherwise, may be let without advertising for or inviting bids, when any repairs, alterations, or other work, or the purchase of materials, supplies, equipment or other property, shall be deemed by the board of directors to be of urgent necessity, and shall be authorized by a two-thirds vote thereof.

(8) To fix the rates at which water shall be sold; provided, however, that rates shall be uniform for like classes of service throughout the district. [Amendment approved April 29, 1937; Stats. 1937, Chap. 140.]

Sec. 7. (a) Whenever the board of directors of any metropolitan water district incorporated under this act shall, by ordinance adopted by a vote of a majority of the aggregate number of votes of all the members of the board of directors, determine that the interests of said district and the public interest or necessity demand the acquisition, construction or completion of any public improvement or works, or the incurring of any preliminary expenses, necessary or convenient to carry out the objects or purposes of said district the cost of which will be too great to be paid out of the ordinary annual income and revenue of the district, said board of directors may order the submission of the proposition of incurring bonded indebtedness, for the purposes set forth in the said ordinance, to the qualified voters of such district, at an election held for that purpose. Any election held for the purpose of submitting any proposition or propositions of incurring such bonded indebtedness may be held separately, or may be consolidated or held concurrently with any other election authorized by law at which the qualified electors of the district are entitled to vote. The declaration of public interest or necessity herein required and the provision for the holding of such election may be included within one and the same ordinance, which ordinance, in addition to such declaration of public interest or necessity, shall recite the objects and purposes for which the indebtedness is proposed to be incurred, the estimated cost of the public works or improvements, or the estimated amount of preliminary expenses, as the case may be, the amount of the principal of the indebtedness to be incurred therefor and the maximum rate of interest to be paid on such indebtedness, which rate shall not exceed six (6) per cent per annum payable semiannually. Such ordinance shall also fix the date upon which such election shall be held and the manner of holding the same and the method of voting for or against incurring the proposed indebtedness. Such ordinance shall also fix the compensation to be paid the officers of the election and shall designate the precincts and polling places and shall appoint the officers of such election, which officers shall consist of one inspector, one judge and two clerks in each precinct. The description of precincts may be made by reference to any order or orders of the board of supervisors of the county or counties in which the district or any part thereof is situated, or by reference to any previous order or ordinance of the legislative body of the municipality, or by detailed description of such precincts. Precincts established by the boards of supervisors of the various counties, to a number not exceeding six (6) may be consolidated for special elections held hereunder. In the event any bond election shall be called to be held concurrently with any other election or shall be consolidated therewith, the ordinance calling the election hereunder need not designate precincts or polling places or the names of officers of election, but shall contain reference to the act or order calling such other election and fixing the precincts and polling places and appointing election officers therefor.

(b) The ordinance provided for in subdivision (a) of this section shall be published once, at least ten (10) days before the date of the election therein called, in a newspaper of general circulation printed and published within the district, and no other or further notice of such election or publication of the names of election officers or of the precincts or polling places need be given or made.

(c) The respective election boards shall conduct the election in their respective precincts in the manner prescribed by law for the holding of general elections, and shall make their returns to the secretary of the district. At any regular or special meeting of the board of directors held not earlier than five

(5) days following the date of such election, the returns thereof shall be canvassed and the results thereof declared. In the event that any election held hereunder shall be consolidated with any primary or general election and the proposition to incur indebtedness shall be printed upon a ballot containing other propositions, the returns of the election held hereunder shall be made with the returns of the primary or general election to the board of supervisors or other bodies whose duty it shall be to canvass the returns thereof, and the results of the election held hereunder shall be canvassed at the time and in the manner provided by law for the canvass of the returns of such primary or general election. It shall be the duty of such canvassing body or bodies to promptly certify and transmit to the board of directors of the district a statement of the result of the vote upon the proposition submitted hereunder. Upon receipt of such certificates, it shall be the duty of the board of directors to tabulate and declare the results of the election held hereunder.

(d) In the event that it shall appear from said returns that a majority of the electors voting on any proposition submitted hereunder at such election voted in favor of such proposition, the district shall thereupon be authorized to issue and sell bonds of the district in the amount and for the purpose or purposes and object or objects provided for such proposition in such ordinance, and at a rate of interest, not exceeding the rate recited in said ordinance.

(e) All bonds of such district, issued under the provisions of this act, shall be payable substantially in the following manner: A part to be determined by the board of directors which shall not be less than one-fiftieth (1/50) part of the whole amount of such indebtedness, shall be payable each and every year on a day and date, and at a place or places to be fixed by said board of directors, together with the interest on all sums unpaid at such date; provided, that, in case such bonds are issued in installments at different times, each installment shall be payable substantially in the following manner: A part to be determined by the board of directors which shall not be less than one-fiftieth (1/50) part of the whole amount of such installment, shall be payable each and every year on a day and date, and at a place or places to be fixed by said board of directors, together with the interest on all sums unpaid at such date; provided, however, that said board may, in its discretion, determine and fix the date for the earliest maturity of the principal of the whole amount of such bonded indebtedness, or of each installment of such bonds, as the case may be, not more than fifteen years from the date of the first issue of such bonds, or of the respective installment of such bonds, as the case may be; in this event, the whole amount of such bonded indebtedness, or of the respective installment of such bonds, as the case may be, must be made payable in substantially equal annual parts in not to exceed fifty (50) years from the date of the first issue of such bonds, when the bonds are issued in one block, or from the date of the respective installment of such bonds, when the bonds are issued in installments. The bonds shall be issued in such denominations as the board of directors may determine, except that no bonds shall be of less denomination than one hundred (100) dollars, nor of a greater denomination than fifty thousand (50,000) dollars, and shall be payable on the day and at the place or places fixed in such bonds and with interest at the rate specified therein, which rate shall not be in excess of six per cent (6%) per annum, and shall be payable semiannually. Such bonds shall be signed by the chairman of said board of directors, or by such other officer as said board of directors shall, by resolution adopted by a majority vote of its members, authorize and designate for that purpose, and such bonds shall also be signed by the Controller, or Assistant Controller, and countersigned by the secretary of said board of directors. The coupons of said bonds shall be numbered consecutively, and signed by said Controller, or Assistant Controller. All such signatures and countersignatures excepting that of the Controller, or Assistant Controller, on said bonds, may be printed, lithographed or engraved.

(f) In case any of such officers, whose signatures or countersignatures appear on the bonds or coupons, shall cease to be such officer before the delivery of such bonds to the purchaser, such signatures or countersignatures shall nevertheless be valid and sufficient for all purposes, the same as if they had remained in office until the delivery of such bonds.

(g) Such bonds shall not be sold at a price less than the par value thereof, together with accrued interest to the date of delivery, nor until notice calling for bids therefor shall have been published in a newspaper of general circulation published and circulated in the county wherein the principal place of business of said district shall be located. Said notice, calling for bids, shall state the time for the receipt of such bids, which shall not be less than ten (10) days after the first publication thereof. Such notice may offer the bonds at a fixed interest rate or with the interest rate undetermined, in which event the bids shall contain a statement of the lowest rate of interest at which the bidder will take the bonds and pay par value or more therefor, together with accrued interest. Bids for such bonds shall be opened publicly and the results thereof publicly announced. Such bonds shall be sold to the highest bidder. Temporary, or interim, bonds or certificates, of any denomination whatsoever, to be signed by the Controller, or Assistant Controller, may be issued until the definitive bonds are executed and available for delivery.

(h) Such bonds may be issued and sold by said board of directors as they shall determine, and the proceeds thereof, excepting premium and accrued interest, shall be placed in the treasury of said district to the credit of the proper improvement fund, and shall be applied exclusively to the purposes and objects mentioned in said ordinance; provided, that the interest on said bonds accruing during the construction period and for one year thereafter shall be deemed to be a construction cost within the meaning of the purposes and objects mentioned in said ordinance, and such interest may be paid from said proceeds of the sales of such bonds. Premium and accrued interest shall be placed in the fund to be applied to the payment of interest on, and the retirement of, the bonds so sold. For the purposes of this section, the construction period shall be deemed to end when the works, the construction of which shall have been authorized from the proceeds of any such bond issue, shall have been placed in operation to such extent as to result in the sale and delivery in the district, of water transported and provided by means of such works.

(i) The board of directors shall, within ninety (90) days from the date of the election authorizing the issuance of bonds, cause to be brought in the name of the district an action in the superior court of the county in which said district, or the greater portion of the property subject to taxation by said district, according to the most recent assessment, is located, to determine the validity of any such bonds and the sufficiency of the provision for the collection of an annual tax sufficient to pay the interest on such indebtedness as it falls due and to constitute a sinking fund for the payment of the principal thereof on or before maturity. Such action shall be in the nature of a proceeding in rem, and jurisdiction of all parties interested may be had by publication of summons for at least once a week for three (3) weeks in some paper of general circulation published in the county where the action is pending, such paper to be designated by the court having jurisdiction of the proceedings. Jurisdiction shall be complete within ten (10) days after the full publication of such summons in the manner herein provided. Anyone interested may at any time before the expiration of said ten (10) days appear and by proper proceedings contest the validity of such bonds and the sufficiency of the provision for the collection of an annual tax sufficient to pay the interest on such indebtedness as it falls due and to constitute a sinking fund for the payment of the principal thereof on or before maturity. Such action shall be speedily tried and judgment rendered declaring such bonds to be valid or invalid, and declaring the provision for the collection of an annual tax for said purposes, to be sufficient or insufficient. Either party may have the right to appeal to the Supreme Court at any time within thirty (30) days after the rendition of such judgment, which appeal must be heard and determined within three months from the time of taking such appeal. After the expiration of ninety (90) days from the date of the election authorizing the issuance of bonds, no action may be brought to contest or question the validity of said bonds and proceedings in relation thereto or the sufficiency of the provision for the collection of an annual tax sufficient to pay the interest on such indebtedness as it falls due and to constitute a sinking fund for the payment of the principal thereof on or before maturity. If there be more than one action or proceeding involving the validity of any of such bonds, or the sufficiency of the provision for the collection of an annual tax sufficient for the said purposes, they shall be consolidated and tried together. The court hearing any proceeding or action inquiring into the regularity, legality or correctness of the proceedings leading up to the issuance of bonds or the validity of such bonds or the sufficiency of such provision for the collection of an annual tax, must disregard any error, irregularity or omission which does not affect the substantial rights of the parties to said action or proceeding. The rules of pleading and practice provided by the Code of Civil Procedure, which are not inconsistent with the provisions of this act, are applicable to all actions or proceedings herein provided for. The motion for a new trial of any such action or proceeding must be heard and determined within ten (10) days from the filing of the notice of intention. The costs on any proceeding or action herein provided for may be allowed and apportioned between the parties or taxed to the losing party, in the discretion of the court.

(j) The board of directors, so far as practicable, shall fix such rate or rates for water as will result in revenue which will pay the operating expenses of the district, provide for repairs and maintenance, and provide for the payment of the interest and principal of the bonded debt. If, however, from any cause, the revenues of the district shall be inadequate to pay the interest or principal of any bonded debt as the same becomes due, the board of directors shall, at the time of fixing the tax levy and in the manner for such tax levy provided, levy and collect annually until said bonds are paid or until there shall be a sum in the treasury of the district set apart for that purpose sufficient to meet all sums coming due for principal and interest on such bonds, a tax sufficient to pay the annual interest on such bonds, or such part thereof as shall not be met from revenues of the district, and also sufficient to pay such part of the principal of such bonds as shall become due before the time when money will be available from the next general tax levy, or such portion thereof as shall not be met from revenues of the district; provided, however, that if the maturity of the indebtedness created by the issue of bonds be made to begin more than one year after the date of the issuance of such bonds, such tax shall be levied and collected at the time and in the manner aforesaid annually sufficient when added to revenues of the district available for that purpose to pay the interest on such indebtedness as it falls due and also to constitute, together with the revenues of the district available for such purpose, a sinking fund for the payment of the principal of such bonds on or before maturity. The taxes herein required to be levied and collected shall be in addition to all other taxes levied for district purposes and shall be collected at the time and in the same manner as other district taxes are collected and shall be used for no purpose other than the payment of such bonds and accruing interest.

(k) Coupon bonds issued hereunder, at the request of the holder, may be registered as to principal and interest in the holder's name on the books of the treasurer of the district, and the coupons surrendered and the principal and interest made payable only to the registered holder of the bond. For that purpose the treasurer of the district shall detach and cancel the coupons, and shall endorse a statement on the bonds that the coupon sheet issued therewith has been surrendered by the holder, and the coupons canceled by such treasurer, and that the principal and the semiannual interest are thereafter to be paid to the registered holder, or order, by draft, check or warrant drawn payable at a place of payment specified in the bond, after which no transfer shall be valid unless made on such treasurer's books by the registered holder, or by his attorney duly authorized, and similarly noted on the bond. After such registration, the principal and interest of such bond shall be payable only to the registered owner. Bonds registered under this paragraph may, with the consent of the district and the holders of the bonds, be reconverted into coupon bonds at the expense of the holder thereof, and again reconverted into registered bonds from time to time, as the board of directors of the district and the holders of the bonds may determine. In converting coupon bonds into registered bonds, coupon bonds may be exchanged for registered bonds of one hundred dollars ($100) each, or multiples thereof, but not exceeding fifty thousand dollars ($50,000) each, in which event new registered bonds shall be issued at the expense of the holder. Coupon bonds may be exchanged for other coupon bonds of one hundred dollars ($100) each, or multiples thereof, but not exceeding fifty thousand dollars ($50,000) each, in which event new coupon bonds shall be issued at the expense of the holder.

For each conversion or reconversion of a coupon or registered bond, the treasurer of the district shall be entitled to charge and collect such fee as the board of directors of the district may prescribe from time to time.

(l) All bonds heretofore or hereafter issued by any metropolitan water district shall be legal investments for all trust funds, and for the funds of all insurance companies, banks, both commercial and savings and trust companies, and for the State school funds, and for all sinking funds under the control of the State Treasurer, and whenever any moneys or funds may by law now or hereafter enacted be invested in, or loaned upon the security of, bonds of cities, cities and counties, counties, or school districts in the State of California, such moneys or funds may be invested in, or loaned upon the security of, the bonds of such metropolitan water district; and whenever bonds of cities, cities and counties, counties, or school districts, by any law now or hereafter enacted, may be used as security for the faithful performance or execution of any court or private trust or of any other act, bonds of such metropolitan water district may be so used.

[Amendment approved April 29, 1937; Stats. 1937, Chap. 140.]

Sec. 8. (a) Immediately after equalization and not later than the fifteenth day of August of each year, it shall be the duty of the auditor of each county wherein such district or any part thereof shall lie, to prepare and deliver to the controller of the district a certificate showing the assessed valuation of all property within the district lying in the county, and also such assessed valuation segregated according to cities, the area of which lie within the district.

(b) On or before the twentieth day of August the board of directors of the district shall by resolution determine the amount of money necessary to be raised by taxation during the fiscal year beginning the first day of July next preceding and shall fix the rate of taxation of the district, designating the number of cents upon each one hundred dollars assessed valuation of taxable property in each county and shall levy a tax accordingly:

(1) Sufficient, when taken with other revenues available for the purpose, to meet interest and sinking fund requirements on all outstanding bonded indebtedness of said district; and sufficient, when taken with other revenues available for the purpose, to meet the payment of the principal and interest on any refunding bonds, or on any bonds the issuance of which may have been authorized by the electors, and which bonds have not been sold but which, in the judgment of the board of directors, will be sold prior to the time when money will be available from the next subsequent tax levy, and in case such bonds are not so issued and sold or such tax for any other reason is not required for said purpose, the tax so levied shall be applied to the payment of interest and/or principal on any refunding bonds, or on any bonds authorized by the electors, then outstanding or subsequently issued and/or sold; and

(2) For all other district purposes.

(c) The board of directors shall also cause to be computed and shall declare in said resolution the amount of money to be derived from the area of the district lying within each separate municipality by virtue of the tax levy. In such resolution the board shall also fix and determine the times and proportional amounts of installments in which any city may elect to make payment in lieu of taxes as hereinafter provided. The board shall immediately cause certified copies of such resolution to be transmitted to the presiding officer of the governing body of each such city.

(d) On or before the twenty-fifth day of August of each year the governing body of each such city may elect to pay out of the municipal funds all or any portion of the amount of tax which would otherwise be levied upon property within such city. Such election shall be made by order upon motion, which order shall recite that such payment shall be made in cash concurrently with the certification of such order to the controller of the district, or that such payment shall be made in installments and the times wherein such installments shall be payable and the amounts thereof, which amounts shall be in accordance with the requirements of the board of directors of the district as approved by resolution. In the event that any city shall elect to pay in cash, or by deferred installments, money or any part thereof which would otherwise be levied upon property within the city, it shall immediately certify to the controller of the district a copy of such order and a statement showing its financial condition, the funds from which such payments shall be made and the sources of revenue to be used therefor. Provided, however, that in the event any city shall elect to pay in cash all or any portion of the amount of tax which would otherwise be levied upon property within such city to meet interest and sinking fund requirements on the outstanding bonded indebtedness of said district, such amount so elected to be paid shall be deposited with the treasurer of said district on or before the twenty-seventh day of August next following such election; and provided, also, that unless such payment is so made in the case of interest and sinking fund requirements, and unless such election, as to all other taxes, shall provide for payments in accordance with the resolution of the board of directors as hereinbefore provided for, then such election shall be ineffective for any purpose.

(e) Before the first day of September the controller of the district shall cause to be prepared and transmitted to the auditor of each county in which the district shall lie, a statement showing the tax rate to be applied to assessed property in each city, which rate shall be the rate fixed by resolution of the board of directors modified to the extent necessary to produce from each city only the amount of money apportioned thereto in said resolution, less any amount paid or undertaken to be paid by such city, or credited thereto as herein provided, but if any fraction of a cent occur, it must be taken as a full cent on each one hundred dollars.

(f) Upon receipt by the auditor of each county wherein such district, or any part thereof, shall lie, of a certified copy of the controller's statement showing the tax rate to be applied to assessed property in each city, and showing the cities, the assessed property in which is exempt therefrom, if any, it shall be the duty of the county officers to collect taxes for the benefit of the district at the rate specified as herein provided. The taxes so levied shall be computed and collected at the time and in the manner required by law for the computation and collection of taxes for county purposes, and the property subject to such tax shall be subject to the same penalties for delinquency, and the same provisions of law relating to the sale of property for nonpayment of county taxes and redemption thereof shall apply to the tax herein authorized. When so collected, such taxes shall be paid over to the treasurer of the district, subject to the deduction herein authorized.

In consideration of services rendered hereunder, any county shall annually be entitled to deduct and withhold an amount not exceeding one per cent on the first twenty-five thousand dollars collected hereunder, and one-fourth of one per cent of any amount in excess of twenty-five thousand dollars collected hereunder. The board of supervisors of each such county may provide such extra help as in their judgment may be necessary for the proper performance of duties hereunder.

(g) Whenever any real property situated in any district organized hereunder and upon which a tax shall have been levied, as herein provided, shall be sold for taxes and shall be redeemed, the money paid for such redemption, except advertising costs, shall be apportioned and paid in part to such district in the proportion which the tax due to such district shall bear to the total tax for which such property shall have been sold. All taxes levied under the provisions of this act shall be a lien upon the property upon which levied, and the enforcement of the collection of such tax shall be had in the same manner and by the same means as is or shall be provided by law for the enforcement of liens for State and county taxes, and all of the provisions of law relating to the enforcement of such taxes are hereby made a part of this act so far as applicable.

(h) Cities, the areas of which are included within metropolitan water districts incorporated hereunder, are hereby authorized to pay to such districts, out of funds derived from the sale of water or other funds not appropriated to some other use, such amounts as may be determined upon by the governing bodies, or other bodies, boards, commissioners or officers having control of such funds, thereof, respectively. Such payments may be made in avoidance of taxes as herein provided, or otherwise, and shall not be deemed gratuitous or in the nature of gifts, but shall be deemed payments for water or services in connection with the distribution of water. Any city making any such payment to any district incorporated hereunder, whether in avoidance of taxes or otherwise, shall receive credit therefor and the amount of the payment so made by any city shall be deducted from the amount of taxes which would otherwise be levied against property lying therein as herein provided. In the event that payment so made by any city shall exceed the amount of taxes which would otherwise have been levied against property within such city, the amount of such excess without interest shall be carried over and applied in reduction of taxes levied, or which would otherwise have been levied during the ensuing year or years. Any city, or body, board, commission or officer thereof having control of funds, which shall have incurred expenses (for which such funds have been, or will be, expended) in the investigation of or preliminary work upon any works or projects taken over by the district, may receive, and the district so taking over any such works or projects may make to such city, body, board, commission or officer thereof, reimbursement for all such sums so expended, or to be expended, for expenses incurred in such investigation of or preliminary work upon the works or projects so taken over by the district, to the extent that the board of directors of the district shall find that such expenditures have benefited such district, it being the intention of this provision to permit the district to purchase, and the city or body, board, commission or officer thereof, to sell, such works or projects taken over by such district, and for which such city, body, board, commission or officer thereof, has no further use or need. The sum so to be paid by such district to such city or body, board, commission or officer thereof, shall be mutually agreed upon, and if the expenses, for which such reimbursement is to be made by the district, shall have been incurred by a body, board, commission or officer, of the city, having control of the funds so expended, or to be expended, for such expenses, then the district shall pay such sum to said body, board, commission or officer, or if ordered so to do by such body, board, commission or officer, the district shall pay such sum to the city.

As an alternative to the purchase and sale of any works or projects taken over by the district, as hereinabove provided, any city, or body, board, commission or officer thereof having control of funds, which shall have incurred expenses for which such funds have been, or will be, expended in the investigation of or preliminary work upon any such works or projects taken over by the district, may certify the amount thereof, without interest, to the board of directors of said district at any time within four (4) years from the date of the incorporation of such district, or the incurring of such expenses, if such district be already incorporated, and if allowed by the board of directors, such amount shall be credited to the city, which itself, or whose body, board, commission or officer, incurred the same, and such expenditures shall be considered as a payment of money made as herein provided for which deduction shall be made from the amount of taxes which would otherwise be levied against property lying within such city.

Any city which shall incur expenses in preliminary work in preparing for the incorporation of or in the incorporation of any district hereunder likewise may certify the amount thereof, without interest, to the board of directors of said district at any time within four (4) years from the date of the incorporation of such district, and if allowed by the board of directors, such amount shall be credited to the city incurring the same, and shall be considered as a payment of money made as herein provided, for which deduction shall be made from the amount of taxes which would otherwise be levied against property lying within such city.

No such payments of money made in avoidance of taxes or otherwise, or such credit allowed by such board of directors, as hereinabove provided, shall apply to reduce the amount of taxes which would otherwise be levied against the property within such cities respectively, to meet interest and sinking fund requirements on outstanding bonded indebtedness of such district.

Such certification and allowance shall be made on or before the first Monday in July, and the amount of money to be raised by taxation shall be computed with reference to the credit to be allowed as herein provided, but such credit may, in the discretion of the board of directors, be considered in connection with the amount of money to be raised by the next tax levy, or may be spread over subsequent years, not to exceed five.

(i) If any city shall fail to comply with the terms of the order relating to payments to be made to the district in lieu of taxation, or if any city annexed to the district shall fail to comply with the terms and conditions fixed by the board of directors and upon which such annexation occurred, the amount of the delinquency, plus a penalty of eight per cent shall be added to the taxes to be collected during the ensuing fiscal year, from the property within such delinquent city, and thereafter for a period of two (2) years no order or ordinance shall be sufficient to exempt the property in said city from taxation hereunder unless it be accompanied by payment in cash of the amount which would otherwise be collected from owners of property within the city, together with all moneys due but unpaid under any previous order, or annexation provision.

(j) All provisions herein, or in any ordinance adopted pursuant hereto, relating to the respective times when the various acts pertaining to the levy of taxes are to be performed, are directory only, and failure to perform any such act or acts within the time so specified shall not impair the authority herein conferred to perform all subsequent acts relating to the levy of such taxes. In the event that any of the provisions of law respecting the time and manner of assessing property for purposes of taxation, of equalizing such assessments, of certifying such assessed valuations to the taxing authorities, of making the tax levies, of certifying such tax levies to the proper authorities for extension upon the tax rolls, and for enforcement and collection of such taxes or of performing any other act regarding the assessment, levy or collection of taxes be amended, changed, repealed or newly enacted, and as a result thereof, it should appear to the board of directors of the district that the time schedule provided herein respecting the levy of district taxes be no longer consistent with such modified tax procedure, then said board of directors by ordinance may prescribe a new schedule setting forth the times when the various acts herein required to be done in levying district taxes shall be performed. Nothing contained in this paragraph shall relieve the board of directors of its duty to provide adequate funds, by annual tax levies if necessary, to meet the interest and principal requirements of the bonded debt as they fall due.

[Amendment approved April 29, 1937; Stats. 1937, Chap. 140.]

Sec. 9. Annexation to the territory of any district organized hereunder may be effected by either of the following methods:

(a) Whenever any area shall be annexed to or consolidated with any city, the area of which shall be a part of any district organized hereunder, such annexed or consolidated area shall by virtue of its annexation or consolidation to such city become and be a part of such district and shall be taxable equally with other parts of such district to pay the indebtedness of the district outstanding at the time of such annexation or consolidation.

(b) The governing or legislative body of any municipality may apply to the controller of any metropolitan water district for a statement showing the amount of the bonded and other indebtedness of the district, the assessed value of the taxable property therein according to the most recent assessment, and the names of all municipalities, the areas of which are included within the district, and it shall thereupon be the duty of the controller to furnish such information to the applicant. After consideration of such statement the governing body of such municipality may apply to the board of directors of such metropolitan water district for consent to annex such municipality to the metropolitan water district. The board of directors may grant or deny such application and in granting the same may fix the terms and conditions upon which such city may be annexed to and become a part of the metropolitan water district, to the end that burdens, including the bonded debt, shall be equitably distributed over all parts of the district, having due regard to benefits. The action of the board of directors evidenced by order made on motion shall be promptly transmitted to the governing body of such applying city, which governing body may thereupon submit to the qualified electors of such city, at any general or special election held therein, the proposition of such annexation subject to the terms and conditions fixed as herein provided. Notice of such election shall be given by posting or publication; when given by posting such notice shall be posted at least ten days and in three public places in the city; when given by publication such notice shall be published once at least ten days before the date fixed for the election in a newspaper of general circulation published in the city. Such notice shall contain the substance of the terms and conditions fixed by the board of directors, as herein provided. Such election shall be conducted and the returns thereof canvassed in the manner provided by law for municipal elections in such city. If such proposition shall receive the affirmative vote of a majority of electors of such city voting thereon at such election, the governing body of such municipality shall certify the result of such election on said proposition to the board of directors of said district and a certificate of proceedings hereunder shall be made by the secretary of the district and filed with the secretary of state. Upon the filing thereof in the office of the secretary of state, such municipality shall become, and be, an integral part of such metropolitan water district, and the taxable property therein shall be subject to taxation thereafter for the purposes of said metropolitan water district, including the payment of bonds and other obligations of such district at the time authorized or outstanding.

(c) The validity of any proceedings for the annexation of a municipality or city to any district organized hereunder, shall not be contested in any action unless such action shall have been brought within three months after the completion of such proceedings, or, in case such proceedings are completed prior to the time that this paragraph takes effect, then within three months after this paragraph shall have become effective.

[Amendment approved May 12, 1931; Stats. 1931, Chap. 323.]

Sec. 10. Any municipality whose corporate area has become or is a part of any water district may withdraw therefrom in the following manner:

The governing body of any such municipality may submit to the electors thereof at any general or special election the proposition of withdrawing from any water district incorporated thereunder. Notice of such election shall be given in the manner provided in subdivision (b) of section 9 hereof. Such election shall be conducted and the returns thereof canvassed in the manner provided by law for the conduct of municipal elections in said city. In the event that the majority of the electors voting thereon vote in favor of such withdrawal, the result thereof shall be certified by the governing body of such municipality to the board of directors of the district. A certificate of the proceedings hereunder shall be made by the secretary of the district and filed with the Secretary of State, and upon the filing of such certificate the area of the municipality so withdrawing shall be excluded from the said water district, and shall no longer be a part thereof; provided, however, that the property within the said municipality as it shall exist at the time of such exclusion shall continue taxable for the purpose of paying said bonded and other indebtedness outstanding or contracted for, at the time of such exclusion and until such bonded or other indebtedness shall have been satisfied.

[Amendment approved May 24, 1933; Stats. 1933, Chap. 507.]

Sec. 11. Except as herein provided, no director or any other officer or employee of the district shall in any manner be interested, directly or indirectly, in any contract awarded or to be awarded by the board of directors, or made or to be made by such officer or employee pursuant to discretionary authority vested in him, or in the profits to be derived therefrom. Notwithstanding the fact that such director or other officer or employee of the district may be a stockholder or bondholder or director or other officer or employee of a corporation contracting with the district, contracts may be made with such corporation for its general benefit unless such director or officer or employee of the district shall own or control, directly or indirectly, stock or bonds to an amount exceeding five per centum (5%) of the total amount of the stock or bonds, respectively, of such contracting corporation issued and outstanding. For any violation of this section such director or other officer or employee of the district shall be deemed guilty of a misdemeanor, and such conviction shall work a forfeiture of his office, or employment, and he shall be punished by a

fine not exceeding five hundred dollars ($500), or by imprisonment in the county jail not exceeding six (6) months, or by both such fine and imprisonment.
[Amendment approved May 24, 1933; Stats. 1933, Chap. 507.]

Sec. 12. Every member of the board of directors of a metropolitan water district formed hereunder shall be subject to recall by the voters of the municipality from which such member is appointed in accordance with the recall provisions of the freeholders' charter, or other law applicable to such municipality.
[Amendment approved June 13, 1929; Stats. 1929, Chap. 796.]

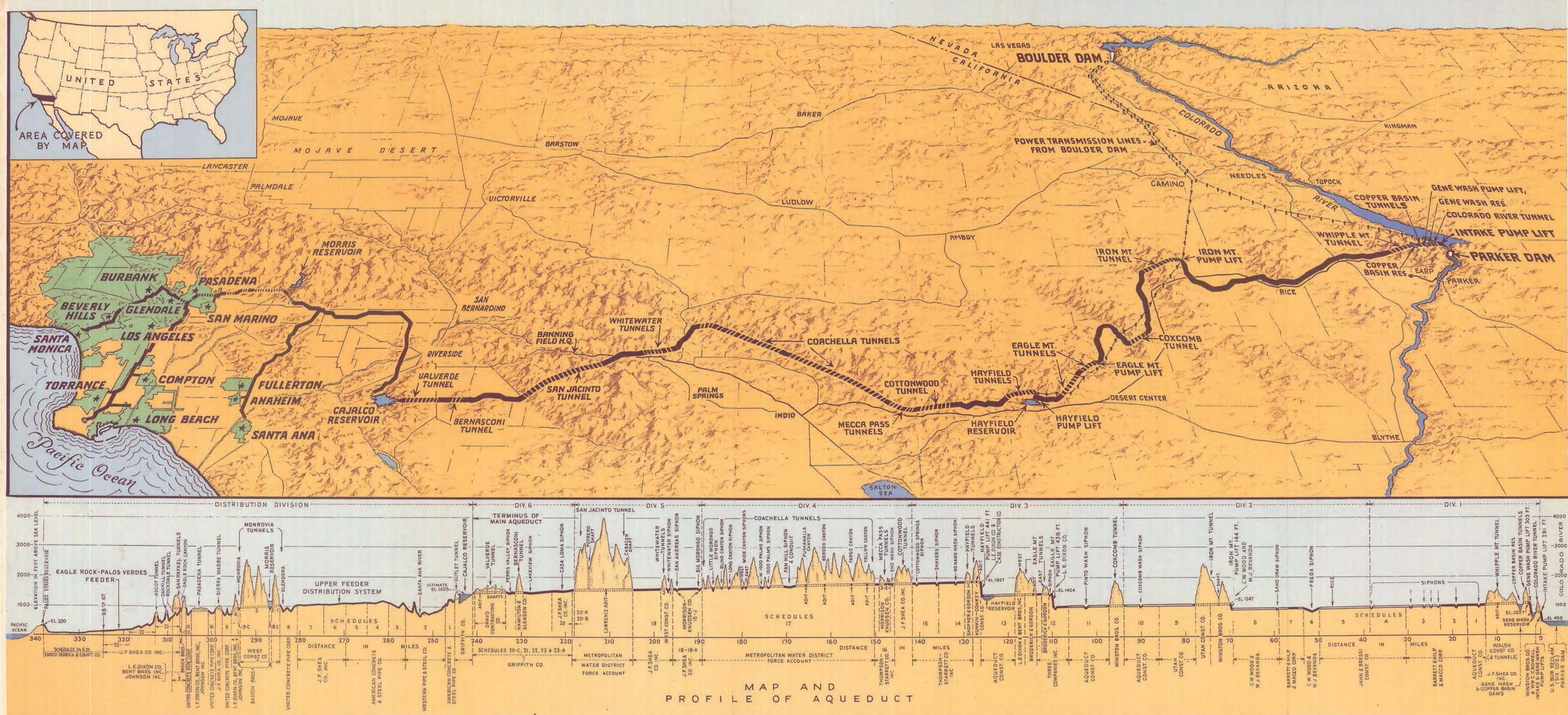
Sec. 13. All matters and things necessary for the proper administration of the affairs of said district which are not provided for in this act shall be provided for by the board of directors of the district by ordinance.

Sec. 13½. Any action required by this act to be done by resolution may be done, with equal validity, by ordinance.
[New section added June 13, 1929; Stats. 1929, Chap. 796.]

Sec. 13¾. The treasurer of any district organized under the provisions of this act is hereby expressly authorized to deposit funds of such district in banks in the manner provided by law for the deposit of moneys of a municipality or other public or municipal corporation.
[Amendment approved May 24, 1933; Stats. 1933, Chap. 507.]

Sec. 14. The fiscal year of any metropolitan water district incorporated hereunder shall commence on the first day of July of each year and shall continue until the close of the thirtieth day of June of the year following. As promptly as shall be possible after the close of each fiscal year, it shall be the duty of the controller of the district to prepare and transmit to the chief executive officer of each municipality, the area of which shall lie within the district, a statement of revenues and expenditures in such detail as shall be prescribed by the board of directors; also a statement of the amount of water stored by the district and the amounts used by the respective cities, the areas of which shall lie within the district.

Sec. 15. If any section, subsection, sentence, clause or phrase of this act is for any reason held to be unconstitutional, such decision shall not affect the validity of the remaining portions of this act. The Legislature hereby declares that it would have passed this act, and each section, subsection, sentence, clause and phrase thereof, irrespective of the fact that any one or more other sections, subsections, sentences, clauses or phrases be declared unconstitutional.



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