THE METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA

10/20/30

A Summary of The Metropolitan Water District Aqueduct Situation

by

F. E. WEYMOUTH
Chief Engineer

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The Need for Water in Southern California

The Metropolitan Water District, and the city of Los Angeles before it, have been studying the Colorado River aqueduct problem for many years. This problem has been gone into exhaustively in all its phases, and it is evident that some new source of water supply must soon be provided for Southern California. Studies made by the Metropolitan Water District lead inescapably to the conclusion that the time for beginning such a project has arrived.

General Water Supply Situation

It is well known that Southern California is naturally a semi-desert. The rainfall is light and irregularly distributed. It is sufficient for only a partial degree of development. However, even with the sparse precipitation, there is a certain amount of run-off, especially in the hills and mountains. This is due to the fact that precipitation often comes in heavy downpours, falling too fast to soak into the ground. Present development in Southern California has been made possible by the saving of these waste waters from the surrounding mountains, and by the prevention of wastes in the valleys themselves. This conservation is made feasible by the fact that the foundation underlying the soil surface is not solid rock, but is porous gravel. The voids in this material form a vessel of vast extent in which the excess waters of heavy floods may be stored and held for use in time of drought. The natural tendency of flood waters to enter these underground basins has been assisted by conservation works, until now very little water escapes down the rivers into the sea.

In addition to the local waters, an important importation is made by Los Angeles from the Owens River basin through the present aqueduct. This supply is conserved at its source in much the same way as the local supplies. The flow of the Owens River is very irregular. When the run-off is high, the waste waters fill the gravels of Owens Valley. In dry periods this water is pumped out again to maintain the flow in the aqueduct.

Water from these sources constitutes the foundation upon which the prosperity of Southern California is built. This foundation is now overloaded. More water is being used than is being replaced each year. This is being accomplished by pumping down into the depths of the underlying gravels and extracting the waters which have accumulated throughout past ages before the efficient modern electrical pump was invented.

That the use is exceeding the inflow is evident to even the casual observer. Not many years ago bountiful supplies of ground water were available almost everywhere at reasonable depths. Over an area of 315 square miles water flowed from wells under artesian pressure. Artesian flow has now practically disappeared, and water levels have dropped everywhere. Levels along the coast have been pumped down below sea level, causing salt water to flow landward, and wells in the foothill regions have been lowered to bedrock. There is evidently less water in the ground now than there was a few years ago, and levels are dropping more rapidly than ever before.

To whatever extent overdraft is due to a temporary condition of drought, it is permissible. These underground basins are one of the principal assets of

Southern California, and it is entirely proper that they should be used to equalize the fluctuating water supply. But they are now being drawn down too deeply. Supported by an inflow which will keep them sufficiently well filled in normal times, these underground reservoirs are valuable insurance against temporary failure of other sources. Empty, they are a detriment to proper utilization of normal local supplies.

It is not difficult to see that some increase in water supply is needed immediately. However, to determine the ultimate amount of new water that will be needed, the rate at which it should be made available, and the extent to which this need can be supplied by the improvement of existing sources, requires the careful balancing of many factors.

ESTIMATED DEMAND FOR WATER IN THE METROPOLITAN AREA

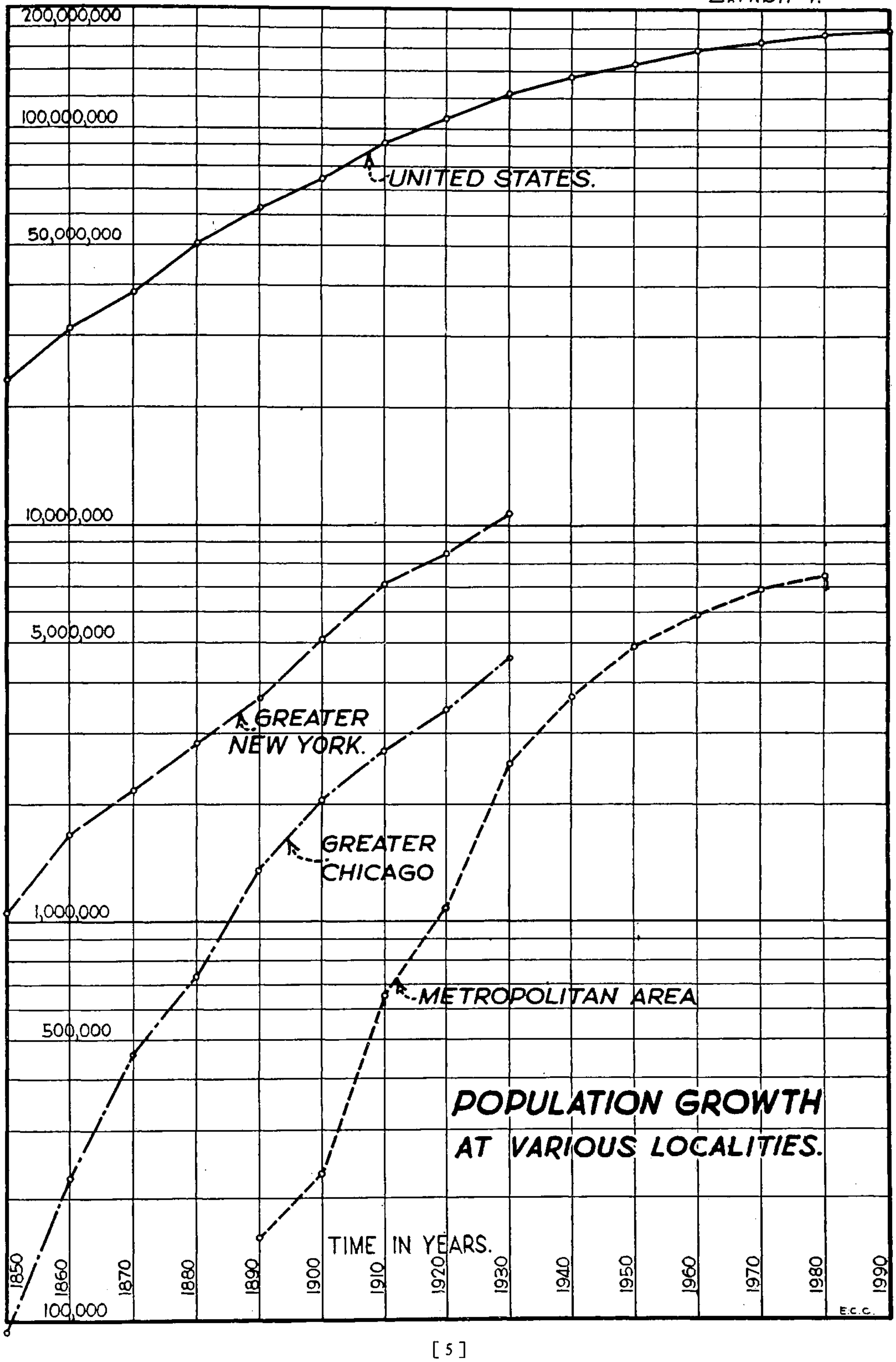
The probable demand on the Colorado River aqueduct is determined by first estimating the total future water needs of the metropolitan area, and then deducting the estimated supply from other sources. The total demand is determined from the predicted population, probable agricultural development or retrogression, and the expected growth of industry. Each of these factors must be carefully analyzed separately.

Population

The number of people in the Metropolitan District area has been doubling, on the average, each ten years since 1890. It is evident that this process cannot continue indefinitely, as the resulting population growth would be unprecedented. Between 1920 and 1930 the population increased from 1,080,000 to 2,497,000, an increase of 1,417,000 people, or 131%. The same ratio of increase from 1930 to 1940 would add 3,263,000 people, bringing the population up to 5,760,000. Such an increase is thought to be unlikely. However, it is reasonable to assume that the same **number** of people will be added to the population in the present decade as in the 1920-1930 period. This would mean the addition of another 1,417,000 people, bringing the population in 1940 up to 3,914,000. This would give a 56.6% increase for the present decade as against a 131% increase from 1920 to 1930. It is believed that such an increase may reasonably be expected to occur, and to continue for some time into the future. The possibility of a maximum rate of growth at least as great as this assumption should be considered in plans for the future. The possibility of a slower rate of growth also needs to be considered. The ideal project should not be so large as to be a financial burden should a minimum rate of growth prevail, nor so small that it cannot be economically enlarged to care for the maximum.

After carefully considering all factors, the rate of growth shown in Table 1 has been chosen as the basis of all planning. The numerical increase for the present decade is 1,220,000 against 1,417,000 for 1920-1930. The estimated increase is less for each succeeding period. The estimated percentage of increase from 1930 to 1940 is 49%, as against 131% for 1920 to 1930. The percentage of increase drops down rapidly to 10% in the 1970-1980 period. The data of Table 1 are also shown graphically on Exhibit 1, in comparison with the recorded growths of similar areas embracing New York and Chicago. The past growth of the United States, and the future growth as predicted by Raymond Pearl, of Johns Hopkins University, an authority on population growths, are likewise shown on Exhibit 1. This exhibit is platted

Exhibit I.



200,000,000
100,000,000
50,000,000
10,000,000
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UNITED STATES.
GREATER NEW YORK.
GREATER CHICAGO
METROPOLITAN AREA
POPULATION GROWTH AT VARIOUS LOCALITIES.
TIME IN YEARS.
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
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on ratio paper to accentuate the fact that the percentage of growth decreases for each successive decade.

For equal populations the growth curves for the three cities are more or less parallel, signifying approximately equal growths. Prior to 1930 the metropolitan curve is somewhat steeper than the others. The predicted curve bends over rapidly and if carried slightly further would become parallel to the predicted curve for the United States as a whole. This means that eventually Southern California is assumed to grow at approximately the same rate, or percentage, as the country in general. Southern California being without question the most desirable residence section of the country, this can occur only because of the exhaustion of opportunity. Consideration of these facts leads to the conclusion that the estimated rate of growth shown in Table 1 is a minimum value, and that planning a water supply for a lesser growth would be unwise.

TABLE 1

Past and Predicted Growth

Year	Population	Numerical Increase	Percentage Increase
1890	160,000		
		70,000	44
1900	230,000		
		420,000	183
1910	650,000		
		430,000	66
1920	1,080,000		
		1,417,000	131
1930	2,497,000		
		1,220,000	49
1940	3,717,000		
		1,223,000	33
1950	4,940,000		
		995,000	20
1960	5,935,000		
		925,000	16
1970	6,860,000		
		662,000	10
1980	7,525,000		

Per Capita Use——Domestic Waters

The water requirement of a given population for domestic uses is determined by multiplying the number of people by some arbitrary rate of use per day. The per capita use of water varies with general climatic conditions, abundance of supply, retail cost, general living standards, and other factors. The domestic use at present in the metropolitan area varies from about 120 gallons per capita per day in Los Angeles to 266 gallons per capita per day in Beverly Hills. The average for the Los Angeles County area is 135, and 155 for the Santa Ana watershed. There has been for some time a general tendency for the per capita use to increase, due to improvement in the scale of living. It is thought likely that the peak has not yet been reached. However, to be conservative, a future average domestic use of 120 gallons has been assumed for the District. The domestic demand is obtained by multiplying the estimated population by this rate of use, and making certain minor corrections for special conditions and overlapping uses.

The Industrial Demand

There are today 2150 industries in Los Angeles County of such magnitude as to require segregation into industrial zones. This is about one industry for each 1000 inhabitants. Industrial development has been a prime factor in the growth of Southern California for the past ten years. With the assurance of a sufficient water supply available there is every reason to believe that its influence will be increased in the years to come. The present industrial use is 18% of the total. It is expected that this percentage of use will gradually increase to an average of about 27% in 1950, perhaps remaining constant after that date. Industrial uses in other cities are as follows:

Baltimore, Md.	25%
Bridgeport, Conn.	52
Chicago, Ill.	19
Kansas City, Mo.	35
Milwaukee, Wis.	65
New York City	22
Rochester, N. Y.	26
Springfield, Mass.	30
Average	34%

The estimated rate for Southern California is well below the average for these cities. This estimate is thought to be reasonable, and failure to provide for it would be unwise.

Agricultural Development

The agriculture of the region is best considered under two headings—general agriculture and citrus culture. It is usually assumed that general agriculture, which consists of alfalfa, truck gardens, general field crops, etc., will not increase in this area. There are considerable areas of vacant lands which may eventually be devoted to general crops, but it is assumed that some areas now irrigated will be converted to urban uses. As a net result, the area devoted to general crops is assumed to decrease gradually throughout the amortization period. It appears likely that some areas now devoted to citrus will likewise be converted to city uses. Other marginal citrus areas are likely to be abandoned to general agriculture, but careful study leads to the conclusion that the net citrus acreage is likely to increase slowly for the next few decades. The estimated total acreages likely to be devoted to agriculture are as follows:

Year	General farming and deciduous acres	Citrus acres	Total acres
1930	302,000	188,000	490,000
1940	287,000	193,000	480,000
1950	256,000*	252,000	508,000*
1960	247,000*	264,000	511,000*
1970	234,000*	256,000	490,000*
1980	219,000*	249,000	468,000*

* Does not include 50,000 acres of temporary use in San Jacinto Valley.

On the average the gross agricultural area is expected to decrease. A small temporary increase is shown from 1930 to 1960 due to the citrus development, but this is lost later.

Total Demand for Water—All Uses, All Sources

The estimated population multiplied by the per capita use, plus agricultural and industrial development, multiplied by the proper use factors, gives a total estimated use of water in the metropolitan area as follows:

Year	General agriculture sec-ft.	Citrus culture sec-ft.	Industrial sec-ft.	Domestic sec-ft.	Total sec-ft.
1930	464	376	103	477	1420
1940	440	385	205	708	1738
1950	491*	490	341	943	2265
1960	496	490	410	1129	2525
1970	472	490	474	1304	2740
1980	432	478	520	1429	2859

* New agricultural area added in San Jacinto Valley.

Safe Yield From Present Sources

Determination of the safe yield from present sources of water supply is equally as important as estimating the total future need, and is only slightly less difficult. The yield from present sources is obtained by adding together the measured uses and wastes, and subtracting any water that may be withdrawn from the underground storage basins. The waters produced by the principal cities of the District are generally carefully measured and recorded. Also certain private companies selling water for both agricultural and domestic uses keep reasonably dependable records. However, much water is pumped by individual farmers and industries without any definite record of its production being made. This subject of water use has been carefully studied by the State Department of Water Resources, the Metropolitan Water District, the city of Los Angeles, and other agencies, and a figure for the total water used has been arrived at which is believed to be correct within a relatively small percentage of error. Records are also being kept of the water wasting into the sea. It may be assumed that these two factors have been determined with all the accuracy required. The matter of withdrawals from underground basins is less definitely known. The computations for these withdrawals involve assumptions as to the porosity of the underground strata. Considerable study has been devoted to this part of the problem, and figures which are sufficiently accurate for the present purpose have been deduced.

It is generally agreed that the present use is in excess of the long time average yield. Assuming all local streams fully controlled, and the Los Angeles aqueduct brought up to full capacity by the addition of the Mono Basin water, it is thought that supply and demand would now be about balanced. There may be a small margin of excess, under long time average conditions over the 1930 needs, but insufficient to support growth until 1940.

Estimates of average yield by various authorities agree reasonably well. Nevertheless, they should not be taken too seriously because of the short time that the present rate of use has prevailed. It is a notable fact that with an average use much lower than the present, ground waters have been steadily decreasing for many years. It is also necessary to use so-called "long term averages" with care. Direct measurements of rainfall are available for only 53 years. During that time the rainfall rate has been going up and down in alternating wet and dry cycles, which plot graphically like the teeth on a saw. It is certain that an "unusual" drought will occur sooner or later. If such an event should happen now, by a continuation of the present dry period, great damage would result.

The city of Los Angeles is today using a peak summer flow of 700 sec-ft. Of this flow 260 sec-ft. are being pumped from the underground basins of Owens Valley, and 160 sec-ft. are being pumped from local gravel beds. A bare 10%, or 70 sec-ft., is derived from the natural surface flow. The remainder comes from reservoir storage waters accumulated through the winter months, largely also pumped from the gravels. The small surface flow, which is the only "new water" coming into the system, is rapidly decreasing, and may become negligible before the end of the summer. Ground water levels are also going down, not only temporarily, but progressively.

Similar signs of distress are evident in other places. Only those communities adjacent to enormous underground basins have an adequate protection against a continuation of the present drought for even two or three years. Much longer and more severe droughts have been known to occur in the past. Whether the present average figures, based upon meager data, should be implicitly relied upon as an indication of safe yield is doubtful. It may be stated with certainty that a yield estimated upon the present record will not be materially exceeded on the average, and an appreciable reduction in a prolonged period of drought is possible.

The best available estimate places the fully developed yield of present sources at 1540 sec-ft., computed as the long time average after all local waters are conserved and after Mono Basin has been developed. This figure is believed to be reasonable, subject to the limitations just named.

Shortages Must be Met by Overdraft

Present use being practically equal to the full average yield of present sources, continued development of the region will cause an inevitable shortage in supply, even assuming normal water conditions. With continued low rainfall the shortages will be severe. If no remedy were at hand, this would be a very serious matter. However, if the construction of the aqueduct is not too long delayed, relief can be afforded by continuing to overdraw the underground basins. The required drafts can perhaps be maintained without serious difficulty up to 1938, if the rainfall is normal, or perhaps even to 1940. Whatever the circumstances as to rainfall, this procedure cannot be continued indefinitely without causing complete exhaustion of the underground basins, and by 1940 there will be urgent cause to stop this overdraft in many localities. Also, in many places depletion will have reached a point where extraction of even the average safe yield will be expensive, and it will be desirable temporarily to buy Colorado River water while the overdrawn basins are permitted to refill from natural inflows.

This possibility of overdraft on the underground waters is peculiar to this region, and is a very fortunate circumstance. It permits the building up in advance of a demand upon the aqueduct with less risk of a disastrous water shortage due to a prolonged drought than would otherwise be incurred.

If this vast store of water were not at hand, there would be serious danger of shortage at the present time, and the Colorado River aqueduct would need to be in service already. Excepting in a few isolated cases, it will probably be possible to manage on borrowed water until a new supply can be obtained, assuming a normal rainfall and all possible additions to present supplies completed as planned.

Demands on the Colorado River Aqueduct

After the Colorado River aqueduct is completed, it will no longer be necessary to resort to overdraft. The difference between the demand and the local supply can be made up from the new source. The demand on the Colorado River aqueduct will be the difference between the total estimated demand and the supply from other sources. For the first few years it is assumed that the draft on the local supply will be reduced, allowing recovery from the accumulated overdraft which will occur during the construction period. Normal pumping of present sources is assumed to be re-established by 1950. The resulting estimates are as follows:

Year	Total demand sec-ft.	Supply from present sources sec-ft.	Demand on Colo. River aqueduct sec-ft.	Diversion from Colo. River to provide demand sec-ft.
1940	1738	1331*	407	529
1950	2265	1540	725	879
1960	2525	1540	985	1161
1970	2740	1540	1200	1401
1980	2859	1540	1286**	1500

* Reduction due to depletion of underground basins.
** Maximum available. Estimated demand is 1319 sec-ft.

A TENTATIVE PLAN FOR THE REPAYMENT OF THE AQUEDUCT COSTS

The foregoing estimates as to the water required from the aqueduct can be realized only if the costs of the aqueduct and its operation are distributed in some just and equitable manner which will encourage utilization of the aqueduct. It is not feasible or advisable to make detailed commitments as to water prices at the present time. This can be done more accurately when the aqueduct is put into operation and afterwards as conditions change from time to time. However, it is possible to propose the essential elements of a plan of procedure, and to estimate the probable effect of such a plan on water prices. Several possible plans have been suggested.

In the most desirable plan it is proposed that the obligations to be met annually by the District be divided into two parts. The first part represents ownership in the project—that is, it covers interest on bonds and bond repayments, and is to be allocated to the various political units of the District on the basis of assessed valuation. The second part covers maintenance, operation, purchase of power for pumping, storage charges for water, and all other expenses except interest on bonds and bond redemptions, and is to be allocated to the various cities, or other wholesale purchasers of water, on the basis of aqueduct water used—that is, at so much per acre ft., or 100 cu. ft.

These charges can be passed on to the ultimate consumer in any convenient manner to suit local conditions in each individual case. The operating charge will no doubt in all cases be collected through the sale of water. The capital charge can likewise be added to the retail price of water if desired. This latter charge would necessarily be spread over the water used from all sources, rather than against Colorado River water only, as the capital charges must be paid regardless of demand on the aqueduct. The Colorado River water will not be isolated and sold to a special group of ultimate consumers, but will be mingled with other waters, and the whole sold at a price which will repay the cost of the combined supply. Theoretically, the Colorado River aqueduct is strictly a domestic supply project. The sale of irrigation water is a secondary consideration. For this reason it is assumed for the present that agricultural waters will bear no part of the capital charge. Citrus water might, in certain cases where a right to permanent use is granted, be able to bear some part of this cost.

In studying the effect of such a plan on water prices, it is assumed that the construction program will be adjusted to provide facilities for delivering water in accordance with the estimated demand. This requirement is fulfilled most economically by limiting the initial construction to approximately half capacity on all readily divisible features, such as distributing lines, pumping plants, siphons and storage reservoirs, but building the tunnels, covered conduit and lined canals of the main aqueduct, and the diversion dam to full capacity in the beginning. Additions are assumed to be made to the deferred features from time to time as required.

The initial construction is assumed to require six years. The total estimated cost of the completed system is 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

It is proposed to finance the initial installation by the sale of 50-year bonds, with the first redemption deferred 15 years from date of issue. The deferred items may be financed by similar bonds, or from revenues. Assuming that deferred items will be built from bond sales, and figuring interest at 4¾%, the total annual capital charge begins at $10,395,000 in the first year of operation, which is all interest, and remains constant until the 9th year, when redemption begins. This charge increases to a maximum of $17,289,000 in the 15th year, and then reduces gradually to the end of the amortization period, when it disappears.

If this expense is assumed to be distributed uniformly over the domestic and industrial water sold by the cities of the District, the estimated increase in rates necessary for this purpose in 1940 will be 4.18c per 100 cu. ft. ($18.20 per acre ft.). This decreases to 3.22c per 100 cu. ft. ($14.01 per acre ft.) in 1947, increases again to a maximum of 4.51c per 100 cu. ft. ($19.64 per acre ft.) in 1954, and then gradually decreases to the end of the amortization period, when it disappears. The average increase in rates for capital costs for the first 41 years of operation is estimated to be 3.33c per 100 cu. ft. ($14.55 per acre ft.). Beyond that time it soon becomes negligible.

These items of cost are independent of the water delivered through the Colorado River aqueduct. Also, they are computed on the basis of the water used by the cities which are actually members of the District, with certain apparently inevitable additions, and not on the total water needs as given on a preceding page. The rates shown are not water charges to be assessed by the District, but are estimates of the average additions to water rates in the individual cities to reimburse the cities for lump sum payments on account of their respective shares in the capital expenses. This means of repayment is not intended to be compulsory. Any individual city may meet any part or all of this expense in any legal manner it may see fit.

There will also be an operating charge for water delivered from the aqueduct. This will include the operating and maintenance of the aqueduct, pumping plants, reservoirs, distributing lines, the purchase of power for pumping, insurance, taxes on lands and on investments outside of California, and all other obligations of the District, except interest on bonds and bond redemptions, with a small credit for return power from the distributing system. This item is estimated to start at $4,731,000 in 1940, and to increase gradually with the growing demand for Colorado River water to a maximum of $7,401,000 in 1980. The corresponding unit cost of Colorado River water is 3.69c per 100 cu. ft. ($16.06 per acre ft.) in 1940, 2.52c in 1950, 1.99c in 1960, and 1.83c in 1980. This charge applies to Colorado River water only, and not to all of the water used by the member cities.

If it is assumed that the deferred items are financed from revenues, the interest and amortization charges will be reduced in the latter years of the development, but an additional item must be added to create a sinking fund which will provide money for building the additional units as needed. The result is that the obligations are slightly increased in the early years, with a corresponding reduction later. The total capital charge for 1940 is changed to $13,072,000, which remains constant until 1949, and then gradually increases to a maximum of $17,945,000 in 1954, after which it reduces, and disappears at the end of the amortization period. The corresponding additions to water prices are 5.25c in 1940, 3.72c in 1950, 4.68c in 1954, and gradually reducing thereafter to the end of the bond period. The operating cost would be the same as given above.

SIZE OF INITIAL DEVELOPMENT

The Colorado River aqueduct once it is constructed will serve the community indefinitely. For this reason an extended bond repayment period is justified. Fifty-year bonds are contemplated. No repayment of capital charges is to be made in the first 15 years. In other words, the project is to be paid for almost entirely by coming generations. It would clearly be unjust to proceed with a plan adequate for 15 to 20 years, but not suited to expansion, to care for the needs of the people who must pay for it. The project should be planned, as far as is practicable, to be fair to the entire group upon which the burden of repayment must fall.

Under a given set of assumptions, the best plan can be computed with mathematical accuracy, but in using such computations many practical factors must be considered. The present generation must not be bankrupted in order to make a large, but less essential, saving at some future time. On the other hand, the future of the project should not be jeopardized for the sake of a relatively small present reduction in annual expense.

If a half-sized aqueduct could be constructed and operated at half the cost of a full capacity one, then adoption of such a size would save the interest on half of the investment for a number of years. Such a saving could be balanced against the reduced certainty in final perfection of water rights, the disadvantage of having to go through another period of shortage and other disadvantages of a partial development. But actually, half capacity construction in certain features, costs much more than half as much as full capacity.

A large proportion of the work can be subdivided without appreciable increase in construction cost. The pumping plants, and steel pipe lines must be built in parallel units, for practical reasons. Units not needed at first may be deferred with no appreciable increase in the ultimate cost of the project. Also, these units can be added to quickly as additional needs develop. This makes it easy to take care of unforeseen emergencies.

A main line tunnel of half capacity is estimated to cost approximately 70% as much to construct as one of full capacity. Also, the construction of a second unit would require a considerable period of time. The same is true of the covered conduits and lined canals. The cost of constructing the power lines and pumping plants will be increased, due to the necessity for more pumping plant houses and other duplications. To get an idea of the relative merits of the two plans it is necessary to compare costs on the complete project. The economic pump lift is greater on the divided line, and operation and maintenance costs are increased due to the division of the works. As a result, the operating charge for half capacity construction will always be more than for full capacity initial construction. Amortized at 4¾%, this increased annual expense is equivalent to an investment of $13,287,000. In making comparisons this must be added to the cost of the divided line.

The comparative figures are as follows:

	Full-Sized	Half-Sized	Difference
Initial Construction			
Diversion dam	$ 13,058,000	$ 13,058,000	———
Main aqueduct	143,470,000	108,076,800	$—35,393,200
Terminal storage	17,352,000	17,352,000	———
Distribution	44,964,000	44,964,000	———
Total initial cost	$218,844,000	$183,450,800	$—35,393,200
Deferred Items			
Main aqueduct	$ 12,888,000	$104,477,200	$+91,589,200
Terminal Storage	13,320,000	13,320,000	———
Distribution	38,484,000	38,484,000	———
Total deferred cost	$ 64,692,000	$156,281,200	$+91,589,200
Total ultimate construction cost	$283,536,000	$339,732,000	$+56,196,000
Amortization of excess operation costs	———	13,287,000	+13,287,000
Total	$283,536,000	$353,019,000	$ 69,483,000

The reduction in initial expenditure due to a half-sized line is $35,393,000. This is not a true saving but is merely a deferment for a few years of a part of the bonded indebtedness. The real saving is the interest on this amount between the time of initial construction and the time that the second unit must be built. If accumulated for a sufficiently long time, this interest would tend to overbalance the excess cost of divided construction. However, a deferment of more than 23 years is required before the accumulated interest on the $35,393,000 saving becomes equal to the $56,196,000 increased construction cost plus the $13,287,000 value of the increased operating cost.

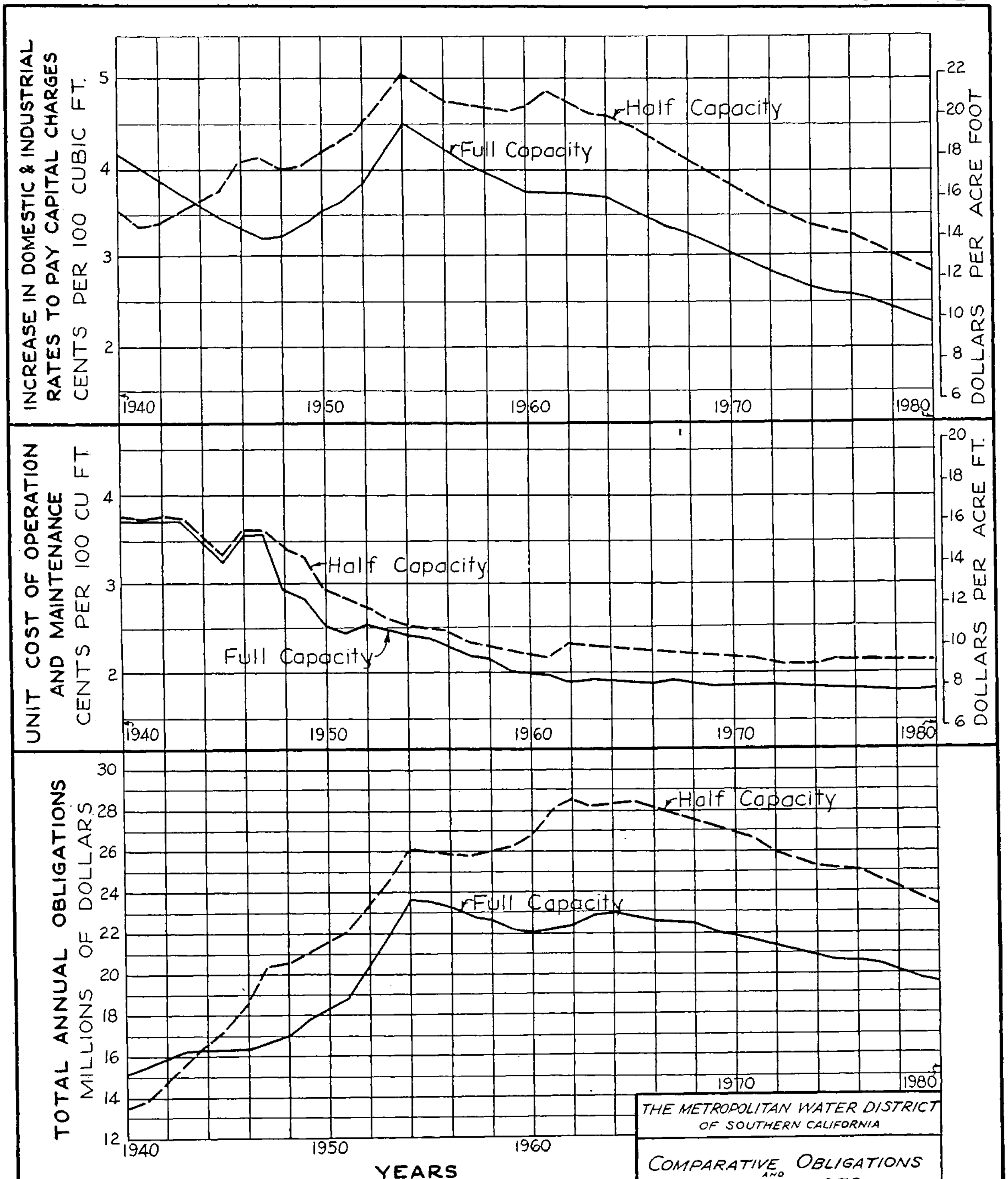
A comparison of rate increases and total obligations for full capacity and half capacity main features is shown on Exhibit 2. It will be noted that the half capacity line shows a slightly reduced capital charge for the first four years, after which time this charge is higher than for the full-sized line, until the end of the amortization period. The construction of the duplicate half capacity project must be completed by the eighth year and is assumed to be begun in the third year. The operating charge is higher for the half capacity project at all times. The total obligation is slightly lower on the half-sized line for the first four years, after which time it is permanently higher, due to the necessity of preparing for a second barrel.

The increase in operating cost on the half-sized line is due to the increased economic slope, requiring a higher pump lift, and to the division of works, requiring a larger operating personnel. The slopes could, of course, be made the same as for the full capacity line, but the capital cost would thereby be appreciably increased. The amortized present value of the excess operating costs is $13,287,000. This item cannot be reduced without increasing the capital cost by an amount which exceeds the reduction in the item.

There are many factors which cause a half capacity tunnel or lined conduit to cost more than half as much as a full capacity one. In the first place, for the same slope water runs slower in a half capacity channel, and area of the water prism must be more than half as large as for a full capacity line. This is partly, but not fully, offset by using steeper slopes, and increasing the pumping costs. In the case of a canal in rough country, considerable portions of the line are in relatively deep cut. The part of the cut above the water surface is only slightly affected by increase in the capacity of the canal. On the average the half-sized canal requires more than three-fourths as much excavation as the full-sized. The concrete lining in the reduced section is proportionately higher than the excavation. This is due to the fact that the perimeter of the section, which requires lining, is proportionately greater for the smaller sizes. The canal lining for the half-sized conduit is 80% of that of the full-sized.

For a covered surface conduit the situation is more or less the same as for a canal. The cover required to protect the conduits is constant. Also, a practically constant clearance outside of the conduit structure is required for the construction of forms, and in deep cuts the portions of the excavation above the top of the conduit do not vary greatly with the capacity. As a result, it is found that the half-sized conduit requires 65% as much excavation as the full-sized conduit.

Departure from theoretical in the case of tunnel excavation is due to the increase in water prism, caused by a reduced hydraulic efficiency and to the effect of certain arbitrary limitations as to thickness of lining. The excess excavation is less than for either the canal or conduits. The variation in concrete for the tunnel is affected by the slower velocity and arbitrary limits in thickness of lining. A percentage of 67 is estimated for the half-sized lines.



NOTE:-"Full Capacity" construction refers only ~~to Diversion~~ Dam, Main Aqueduct tunnels, covered conduit, and lined canals. Other features will be built only as needed in any case. The "Half Capacity" line requires duplication in the 8th year

THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

COMPARATIVE OBLIGATIONS AND WATER COSTS HALF & FULL SIZE AQUEDUCTS

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Checked Appr.

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In the shafts where size is dependent upon equipment requirements and is the same in all cases, the excavation is practically the same for a large as for a small tunnel.

The quantities of other conduits, such as siphons and steel pipe lines, are affected in a similar manner.

The percentages of primary quantities may be summarized as follows:

Item	Full capacity	Half capacity
Capacity	100%	50%
Excavation—canal	100	77
Excavation—conduit	100	65
Excavation—tunnel	100	56
Concrete—canal	100	80
Concrete—conduit	100	57
Concrete—tunnel	100	67

Unit costs are also higher for the smaller line. A large part of the plant equipment depends upon length as well as size, and is not materially reduced for a half-sized line. Many items of labor are also more or less constant, regardless of size, within the limits under discussion. Rights of way, roads, telephones, water supply, fences, drains, diversion dam, headworks, auxiliary storage, pump control basins, preliminary investigations and overhead are substantially constant for any size.

Taking all these factors into consideration, a half-sized line is economically infeasible unless the completion of the duplicate installation can be deferred until about 1960. Such deferment is out of the question.

SUMMARY

In conclusion, it appears that the construction of a Colorado River aqueduct should be started at once.

Provision should be made for an ultimate diversion of 1500 sec-ft., of water from the river.

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 ft. 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.

The diversion dam, if constructed at the beginning, will necessarily be built full size. If it is found necessary, for any reason, to defer the construction of the diversion dam, then the substitute temporary clarification and pumping works should be held to the minimum installation that will satisfy the water demand. These works will consist of units which can be added to as required.

A bond issue of $220,000,000 to cover the estimated cost of the required diversion works, pumping plants, aqueduct, terminal storage and delivery lines should be submitted to a vote at the earliest practicable moment.

Whether the deferred construction work, amounting to $64,692,000, should be financed by a future bond issue, or from revenue, should be left for future determination.