State of California
THE RESOURCES AGENCY
Department of Water Resources

BULLETIN No. 104

PLANNED UTILIZATION OF GROUND WATER BASINS: COASTAL PLAIN OF LOS ANGELES COUNTY

Appendix C: OPERATION AND ECONOMICS

DECEMBER 1966

FOREWORD

At present, more than half of the water supply of the South Coastal area of Southern California is furnished by water from the ground water basins of the area. In general, extractions from these basins exceed the replenishment, thus resulting in the decline of ground water level elevation. In some areas, this decline has caused sea-water intrusion. Unless proper steps are taken, lowering of ground water level elevations is expected to become worse because of increasing future water demands.

Many local water leaders, in recognition of the potentially serious nature of the decline of water levels, requested that detailed information be provided to assist them in overcoming, or at least alleviating, the detrimental effects. As a result of these requests, many by way of formal resolutions, the Department of Water Resources formulated a comprehensive program for an investigation of the planned utilization of major ground water basins of Southern California.

Statutory authority for the Department to conduct investigations of surface and underground water conditions is contained in Section 226 of the California Water Code. Item 262 of the Budget Act of 1959 delegates broad authority to the Department to use the appropriation "for conducting water resources investigations, surveys and studies, preparing plans and estimates, making reports thereon, and otherwise performing all work and doing all things required thereto ...."

The general objective of this program is to formulate and present operational-economic information on a wide range of plans that will assist local agencies to achieve the maximum utilization of ground water basins in coordination with surface storage and transmission facilities. To attain this objective, the work program for each area of the investigation is divided into three phases: geology, hydrology, and operation-economics. The first two phases provide the basic information required to develop a mathematical model of a ground water basin that simulates the basin's water level responses under various assumed plans of basin operation. The model is then used in the operational-economic phase of the investigation to determine the cost of operation. The results of this phase for the Coastal Plain are presented in this appendix. The results of the geologic and hydrologic phases have been reported in Appendixes A and B. The bulletin, which is to follow soon, will present the summary of results of all three phases of the investigation.

William E. Warne

William E. Warne, Director
Department of Water Resources
The Resources Agency
State of California

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State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

ENGINEERING CERTIFICATION

This report has been prepared under my direction as the professional engineer in direct responsible charge of the work, in accordance with the provisions of the Civil and Professional Engineers' Act of the State of California.

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State Agencies

Public Utilities Commission
Water Rights Board

Los Angeles County Agencies

County Assessor
County Regional Planning Commission
County Flood Control District
County Waterworks Districts 10, 13, and 16

Special Districts

Central and West Basin Water Replenishment District
Downey County Water District
The Metropolitan Water District of Southern California
Orchard Dale County Water District
South Montebello Irrigation District
Central Basin Municipal Water District

City Water Departments

Bellflower
Beverly Hills
Compton
El Segundo
Hawthorne
Huntington Park
Inglewood
Lakewood
Long Beach
Los Angeles
Lynwood
Manhattan Beach
Santa Monica
Signal Hill
South Gate
Torrance
Vernon
Whittier

Private Water Companies

California Water Service Company
Conservative Water Company
Dominguez Water Corporation
Investment Water Company
Laguna-Maywood Mutual Water Company
La Habra Heights Mutual Water Company No. 3
La Mirada Water Company
Maywood Mutual Water Company No. 3
Montebello Land and Water Company
Pacific Water Company
Park Water Company
Peerless Land and Water Company
San Gabriel Valley Water Company
Somerset Mutual Water Company
Southern California Water Company
Southwest Water Company
Suburban Water Systems
Tract 180 Mutual Water Company
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Other Companies

Continental Can Company, Inc.
Douglas Aircraft Company, Inc.
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The Flinkote Company
International Business Machines Corporation
Mobil Oil Company
Richfield Oil Corporation
Shell Oil Company
Standard Oil Company of California
Texaco, Inc.
Union Oil Company of California

ABSTRACT

This appendix presents the results of detailed operational-economic analyses of a wide range of plans for utilizing ground water resources in coordination with surface water resources of the Coastal Plain of Los Angeles County. / The plans of operation studied in detail include both those that require immediate commencement of safe-yield operation of the ground water basins and those that permit the deferment of safe-yield operations until 1991. The accumulated ground water reduction for these plans during the period ranges from zero to 4,000,000 acre-feet. / The results of those studies showed that, from the local point of view, the price of imported water is the most critical variable affecting the economics of water service of the area. / Nomographs are provided for estimating the cost of water service for the selected plans of operation under any combination of conditions that affect the pricing schedule of imported water. / New techniques were developed, including techniques for estimating the amount of deep percolation to the ground water basins, formulating mathematical models of primary surface distribution systems and ground water basins, and determining the most economical combination of pumps and storage tanks. Details of these techniques and tabulations of data related to the facilities and costs of five of the operational plans are also presented. / Foldout plates show the study area, the operational and economic subareas, existing and projected primary distribution systems, change in ground water level elevations under the 5 plans of operation and the amounts of extractions under these plans of operation, and storage and transmissibility factors.

CHAPTER I. INTRODUCTION

The existing level of economic development in the Coastal Plain of Los Angeles County can be attributed, in large measure, to the availability and utilization of the underground water resources of the area. Forward-looking leaders in local water management agencies, realizing the vital role of water in the future development of the area, have undertaken projects which provide for replenishment of the ground water basin and prevention of saline intrusion. These groups have also actively supported the planning, authorization, and construction of the State Water Project, which will insure the continuing availability of adequate imported water to supplement local ground water supplies.

Through these pioneering activities--basin replenishment by spreading and injection, and creation of freshwater barriers to prevent saline intrusion--local agencies have acquired a wealth of experience in basin management. However, because of the lack of knowledge, especially in geology and economics, there was a desire for more knowledge than was available. The local agencies in the Coastal Plain of Los Angeles County requested and helped to pass a budget augmentation through the Legislature so the Department might use its expert knowledge in extending the accomplishments of "local pioneers" and future water requirements could be met most economically.

Because the State of California is interested in providing the most effective water plan, effective use of ground water is considered to be a part of the California Water Plan. From this point of view, the study conducted for the Coastal Plain of Los Angeles County has enjoyed the limelight in the eyes of the many key engineers in the Department of Water Resources.

The area (Plate 1) encompasses about 600 square miles. About 490 square miles is underlain by the Central, Hollywood, Santa Monica, and West Coast ground water basins. In this appendix, the study area will be referred to as the Coastal Plain.

Concepts of Planned Utilization of Ground Water Basins

The Department of Water Resources conducted the planned utilization studies reported in this bulletin under the presumption that all institutional obstacles would be overcome and that the necessary institutional structure would be made available to implement any physically possible plan of operation. This approach makes possible the formulation and analysis of a wide range of plans, with specific emphasis on comprehensive operation and economic aspects, so that, in the future, the optimum plan of basin operation can be achieved. Before this is possible, many important legal and organizational changes will be required. These problems and the steps involved in their eventual solution are being evaluated as the final phase of this investigation.

Planned utilization of ground water basins involves the use of the basins for transmitting and storing varying portions of the area's water supply by coordinating these transmission and storage functions with man-made facilities, such as reservoirs and pipelines, to meet the water requirements of the area. It also connotes the optimum utilization of these surface and ground water supplies. In arriving at the most efficient and economical plan of coordinated operation, many complex and interrelated elements must be considered. These include: water demands, water supplies, alternative plans of operation, physical responses of ground water basins and surface distribution systems, cost of supply facilities and operations, and comparison of costs of various plans of operation.

The most significant attributes of ground water basins are the amount of fresh ground water in storage, the basin storage capacity, and the transmissive characteristics of the basins. Alternative plans of operation must be studied to assure the optimum use of these attributes to satisfy the physical demands for water. At extreme ends of the operational spectrum, these demands could be met with selected amounts of water delivered through either man-made surface facilities only, or through the natural ground water basin. Between these two extremes, local and imported water supplies could be delivered to water users by many possible systems which would use surface facilities combined with the ground water basins.

Before defining the coordinated operation of ground water basins, the analogy between physical characteristics of the ground water basins and surface distribution systems should be emphasized. The rate of deep percolation and subsurface inflow into the ground water reservoir is equivalent to the rate of inflow into the surface reservoirs. The storage capacity of the ground water basins is comparable to the storage capacity of the surface reservoirs. The transmissive characteristics of the aquifers of the ground water basins may be compared to the delivery characteristics of the distribution system. Finally, the piezometric pressure and ground water table in the ground water basins are analogous to the hydraulic grade-line elevations in the surface distribution system. Using equations that numerically describe the flow characteristics of ground water basins and surface distribution networks, it is possible to calculate and integrate capabilities of these water delivery media to meet the physical objectives of the investigation.

To meet physical demands for water satisfactorily, facilities must be provided in such a way that the largest flow rate requirement is satisfied at all locations at required pressures. This provision insures that all lesser flow rate requirements are satisfied. Then, in brief, a study of the coordinated operation of the ground water basins may be considered as determining the changing requirements for surface and ground water supplies and facilities to meet the largest flow rate requirement of each year and the associated cost of those supplies and facilities, including maintenance and operation costs.

Logical selection of the scheme of operation to be implemented requires that the relative costs of each scheme of operation be known. Further, these costs must be determined in such a way that all of the items that affect the total cost associated with meeting total water demands are considered.

Because the water demand of the Coastal Plain is met by the use of both imported water and locally pumped ground water, changes in the use of locally pumped ground water necessarily affect the amount of imported water required. At the same time, capacities of facilities for delivering imported water through the surface system also affect the capacities of pumping and storage facilities required for regulating the water supplies to meet the fluctuating water demand. The cost of operation depends on the number and type of facilities provided, the manner of operating these facilities, and the amounts of water used both from imported and ground sources.

Objective and Scope of Investigation

The objective of the investigation of Planned Utilization of Ground Water Basins, Coastal Plain of Los Angeles County, was to develop, analyze, compare, and publish operational-economic information on the present plan of operation and on a wide range of plans, to be used as a guide by local agencies for managing the ground water basins in the Coastal Plain in coordination with surface storage and transmission facilities. These plans were designed to:

1. Meet the increasing and fluctuating future water demands of the area with local and imported water supplies at the lowest overall cost to the local area.

2. Affect economical conservation and optimum use of locally available surface and ground water supplies.

3. Correct or minimize the undesirable effects of overdraft.

The study was conducted under the presumption that all legal obstacles could and would be overcome and that the necessary management organization would be made available to implement any physically possible plan of operation. Therefore, only the operational and economic factors were considered in the study. Other factors which might be of importance to those local agencies having decision-making authority were not evaluated in this phase of the investigation. These factors, however, are being considered and will be included in the main text of this bulletin.

The study of the Coastal Plain of Los Angeles County was detailed and comprehensive but is considered to be at the reconnaissance level. For each year up to 1990, water demand, water supply, required facilities, the physical reactions of both surface and subsurface systems, and cost were determined and carefully analyzed to evaluate annual variation in the operational and economic effects of various schemes. The study period, between 1963 and 1990, was selected because the State Water Project aqueduct facilities that will import additional water supplies to Southern California have been sized to meet the area's 1990 water demands, thus assuring a firm supplemental water supply to the Coastal Plain to meet its growing demand for water. Further, it was considered that a detailed year-by-year study beyond 1990 was unwarranted because no information was available about water projects to be constructed to meet the water needs of the area beyond 1990. To make the study even more meaningful, economic analyses for selected schemes were extended beyond 1990 to perpetuity.

Fifty-eight alternative plans, encompassing a wide range of possible methods of operating the ground water basins in the study area, were investigated. Detailed operational and economic information was developed under assumed conditions affecting the cost of water services. In recognition of the fact that these conditions will change in the future, the effects of changes on the cost of water service were analyzed.

Conduct of Investigation

The study area was divided into 10 operational and economic subareas to evaluate better the physical and economic effects of various schemes of ground water basin operation on these subareas. The operational area breakdown was used for physical evaluation of various alternative plans of basin operation and the economic area breakdown was used for economic evaluation of the plans. The operational area breakdown shown on Plate 2 was governed by geologic and hydrologic characteristics of the area, the method of operation of the ground and surface water facilities. The economic area breakdown was governed primarily by water service area boundaries.

To simplify the economic analyses, the area served by the City of Los Angeles Department of Water and Power (Plate 2), which occupies parts of many operational areas, was deleted from all operational areas except operational area 3, and the entire area served by the City of Los Angeles was referred to as economic area 3. Also, the area served by the City of Whittier, which was found to be common to all plans of operation, was taken out of operational area 5 and handled independently; the remaining area was referred to as economic area 5. The remaining portions of other operational areas were also referred to as economic areas, but the same numbers were retained for identification.

In this phase of the Coastal Plain investigation, data developed in the earlier geologic and hydrologic phases were utilized extensively. Data on aquifers and transmissive and storage characteristics of these aquifers were used to develop a mathematical model of the ground water basins of the Coastal Plain. Hydrologic information, including data on deep percolation of precipitation and applied water, was used to verify the mathematical model. In addition, past data on water requirements were used in projecting future applied water demands and in estimating future water supplies to ground water basins; and the data on past deep percolation of precipitation and applied water were used.

For the study of the operation of the ground water basins in coordination with the surface storage and transmission system, operational information was obtained from a large number of major water agencies in the area. In addition, available technical literature was perused for methods and techniques of conducting a study of this type. However, it was found that previous investigators had not presented any method or techniques that met the needs of these studies. Therefore, original procedures were developed to complete the study. Some of the approaches that have been developed and incorporated in these studies are:

1. Simulation of hydraulic responses in the basins by a mathematical model on a digital computer.

2. Determination of maximum delivery capacities of pipeline networks.

3. Determination of the most economical combination of pumping and storage facilities.

4. Determination of the relationship between flow rates from storage and storage volume requirements.

5. Determination of facilities required for coordinated operation of surface and subsurface facilities.

The general steps taken in the investigation of planned utilization of ground water basins are shown as a simplified flow chart in Figure 1. This chart gives the general sequence and relationship of contributing studies, some conducted concurrently, but all providing essential information for succeeding steps. Similar information is presented in greater detail in Plate 3.

Figure 1 shows that the basic information that was directly used in the operational-economic phase was obtained in the geologic and hydrologic phases. Historical water supply, use, and disposal data were used to estimate the future water supply and the deep percolation of this water supply. Future water demands were determined on the basis of studies of historical water delivery, projected population growth, and the unit applied water use factor of the area. Alternative plans were made to evaluate relative merits of various schemes of using the surface and ground water resources.

A mathematical model of the distribution system was also developed and subsequently used for estimating the maximum delivery capacity of the distribution system, under the condition in which proper pressures are provided at control structures and takeout connectors. In analyzing the system, consideration was limited to that portion of the system in which

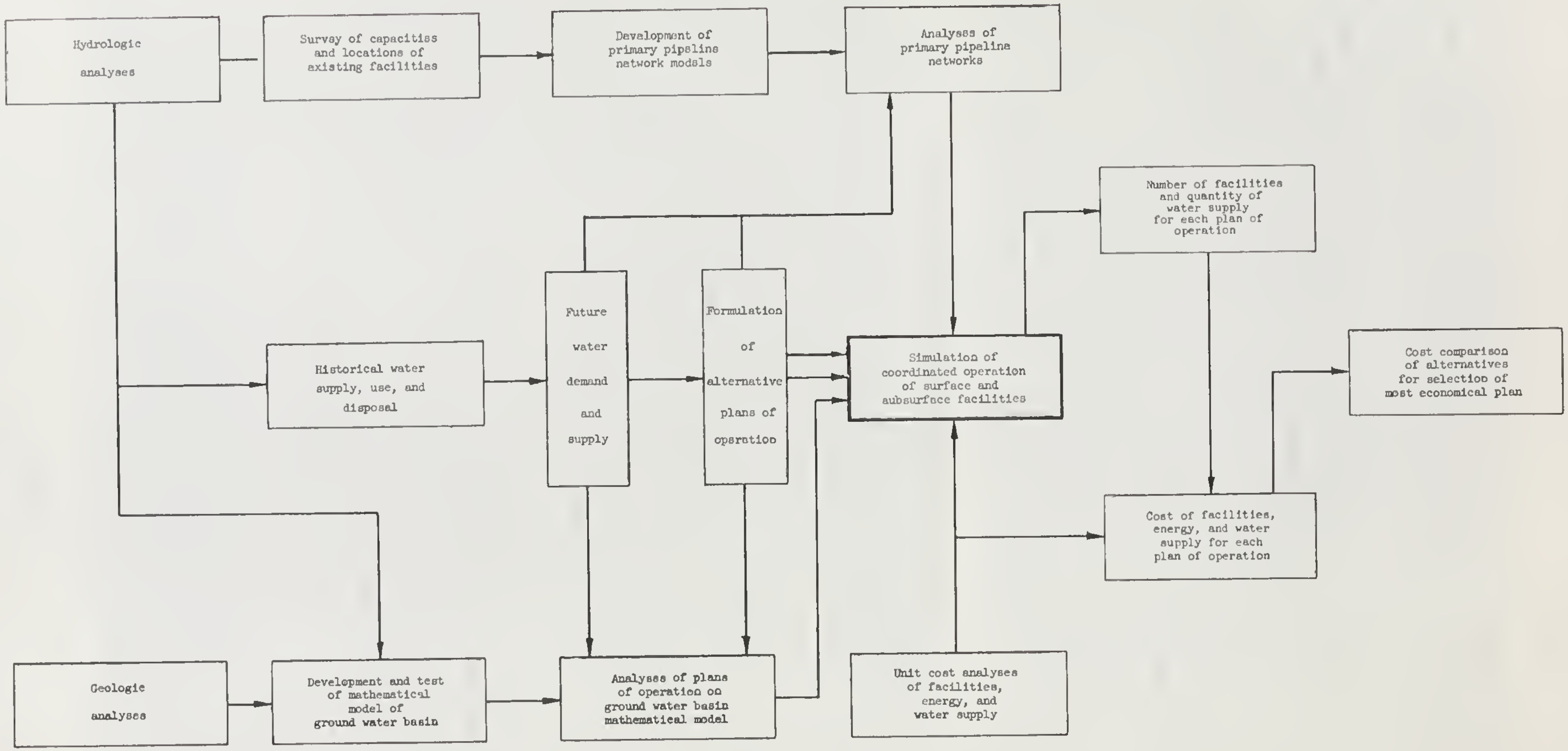


Figure I— SIMPLIFIED FLOW CHART OF INVESTIGATION OF PLANNED UTILIZATION OF GROUND WATER BASINS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

meaningful variations in deliveries of water would occur with alternative plans. The portion of the system that was common to all plans, such as secondary pipelines making distribution to houses, was excluded from comparative analyses.

The heavy-outlined block in Figure 1 is the point in the investigation at which the results of specific analyses described earlier were integrated with the results of surveys of existing facilities and unit cost analyses of facilities, energy, and water supply. In this step, the number of future facilities and the quantity of water supply and treatment required for each plan of operations were determined. Finally, the costs of facilities, energy, and water supply of each plan of operation were determined and costs of alternatives were compared.

Both digital and analog computers were used to evaluate the physical and economic effects of a large number of possible alternatives. This use of computers enabled the engineers and geologists to conduct complex computations rapidly and to process huge amounts of data economically.

The ground water problems and objectives contained in this prototype study were recognized to be applicable to other ground water basins in California. Therefore, the solutions, including the computer programs for the solutions, were written in general terms so they might apply with minimum modification to any other problem area where there is a need for planned utilization of ground water basins.

Related Investigations and Reports

A number of important investigations to develop information on operation and protection of ground water basins have been conducted by the Department of Water Resources, the Central and West Basin Water Associations, the Central and West Basin Water Replenishment District, the Los Angeles County Flood Control District, and other agencies. A bibliography of related investigations is presented in Attachment No. 1. These publications provide information on the control and reduction of ground water pumpage, the facilities and water supply required for replenishment and protection of the ground water basins, and other items related to the management of the water resources of the Coastal Plain.

CHAPTER II. DETERMINATION OF OPERATIONAL AND UNIT COST DATA

The objective of this phase of the investigation was to develop, analyze, compare and present operational-economic information on the present plan of ground water basin operation and on a wide range of other plans. This information was to be used as a guide by local agencies for managing the ground water basins in coordination with surface storage and transmission facilities. The study conducted herein for the Coastal Plain reflects the agreement between the water purveyors in San Gabriel Valley and the Central Basin.

To obtain the operational information, all components of the surface and ground water supplies and facilities of the Coastal Plain were identified, simplified, and separately analyzed. The results of these individual analyses were brought together to formulate and analyze alternative plans of operation to determine the required water services, facilities, and costs of each alternative.

The major study components are: determination of future water demands; determination of future water supply and water quality; survey of existing and proposed surface and ground water facilities; hydraulic analyses of the primary distribution system; hydraulic analyses of ground water basins; and analyses of unit costs of water supplies, facilities, and electrical energy. The analyses of these components are presented in this chapter, and detailed discussions of some of the components are presented as attachments to this report. The interrelationship between the major study components and the sequence of the study are illustrated in detail on Plate 3.

Determination of Future Water Demand

The total demand for delivered water in the Coastal Plain comprises demands for applied water, injection water, and spreading water. The applied water is mainly for municipal and industrial consumption. The injection water is for protection of the ground water basins against sea-water intrusion and for replenishment of the ground water basins. The spreading water is also for replenishment of the ground water basins.

Applied Water

The applied water demand of the Coastal Plain was projected for a study period extending from 1963 through 1990. The projected amounts were allocated to each of the 10 economic areas. These demands for applied water were established in terms of annual, monthly, and hourly water demands.

The future annual applied water demand was estimated on the basis of past and present water uses, plus projected incremental increases in future annual water demand. The historic rate of increase of annual water demand

and the present use of applied water were determined by applying the data developed for the safe yield studies published in Bulletin No. 104, Appendix B. Incremental annual increases were based on the future population and unit values of urban water use contained in the basic data for Appendix D, "Economic Demand for Imported Water", Department of Water Resources Bulletin No. 78, "Investigation of Alternative Aqueduct Systems to Serve Southern California". The projected rate of increase in applied water demand approximates the historic rate of increase.

To determine the future annual applied water demands for each economic area, the present and future applied water demands of the Coastal Plain were first distributed to each of the four ground water basins within the study area. The distribution was made to each basin in proportion to the present applied water demand and according to the historic trend of increase. These applied water demands were then apportioned to economic areas within each basin in proportion to the magnitude of population as projected in a map entitled, "Preliminary 1980 Population Distribution, South Portion, Los Angeles", published by the Los Angeles County Regional Planning Commission. The Planning Commission's estimate of population distribution was considered to be more accurate than other available data when applied to small areas. Future population estimates for the Coastal Plain, based on Appendix D to Bulletin No. 78, checked closely with values obtained from the Los Angeles County Regional Planning Commission's population distribution map.

Projected population and annual applied water demand for the total Coastal Plain are:

Year	Population	Annual applied water demand (acre-feet)
1960	3,700,000	800,000
1970	4,500,000	1,001,000
1980	5,100,000	1,163,000
1990	5,200,000	1,218,000

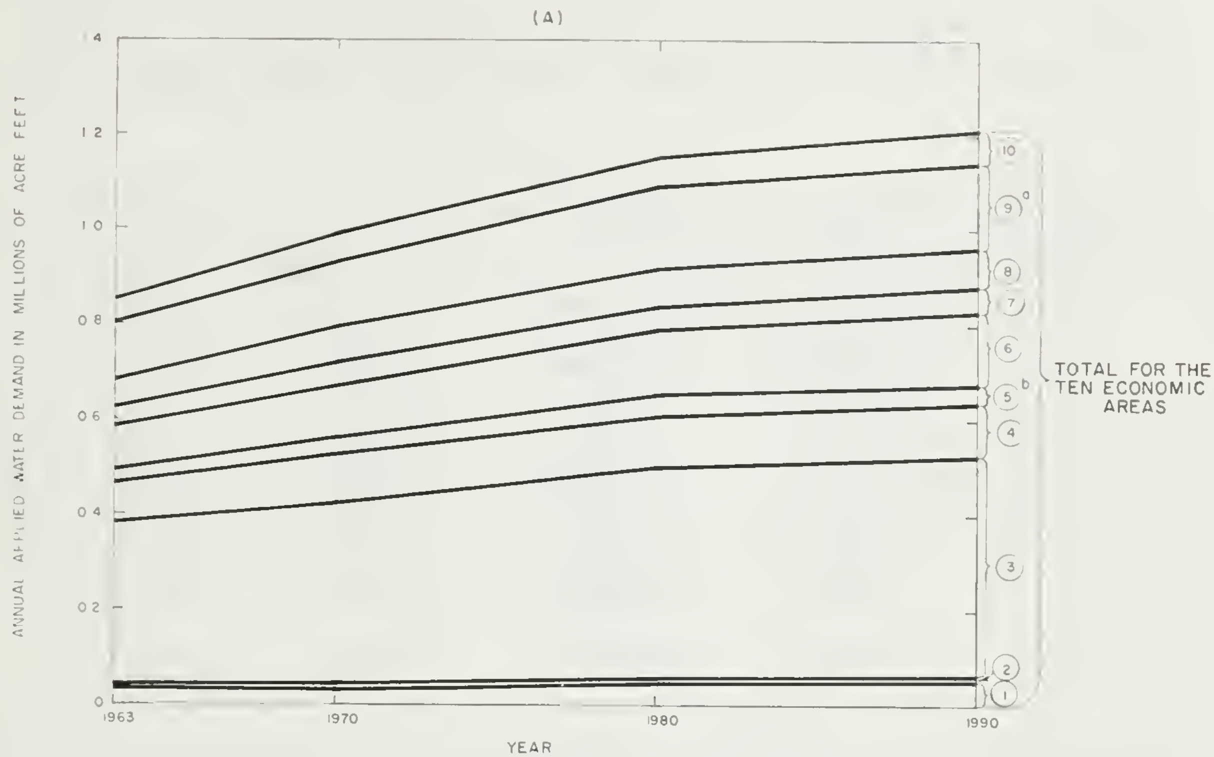
The annual applied water demands for each economic area of the Coastal Plain, projected to 1990, are presented in Table 1 and are illustrated on Figure 2A.

To determine the short-term peaking requirements of the Coastal Plain and of each economic area, information on monthly demand and on hourly demand on a day of maximum water demand was obtained from the City of Los Angeles, the City of Long Beach, the City of Santa Monica, the Southern California Water Company, and other agencies. These data were analyzed, and representative monthly and hourly variations in water demand were established. This study indicated that the peak monthly demand is about 130 percent of the average annual monthly demand; the average demand on a day of maximum use is about 180 percent of the average annual daily demand; and the peak hourly water demand is about 200 percent of average hourly demand on a day of maximum use, or 360 percent of the average annual

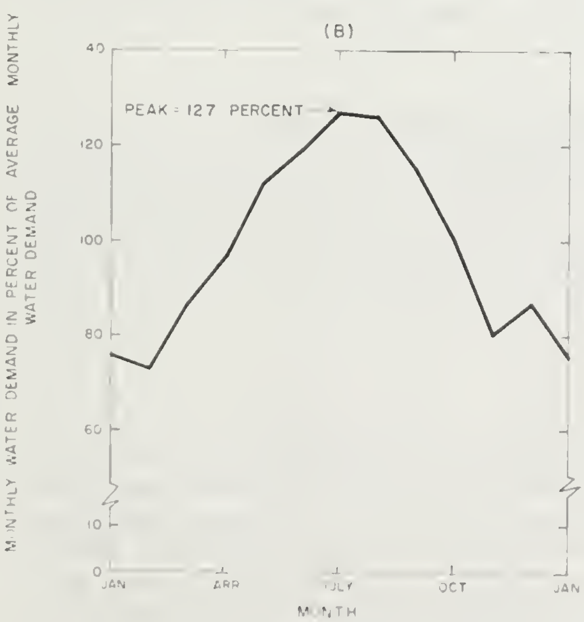
NOTE ① ECONOMIC AREA NUMBER—SEE PLATE 2 FOR LOCATION OF ECONOMIC AREAS

a INCLUDES NONWATER BEARING PORTION OF THE CITY OF LONG BEACH AND PALOS VERDES HILLS

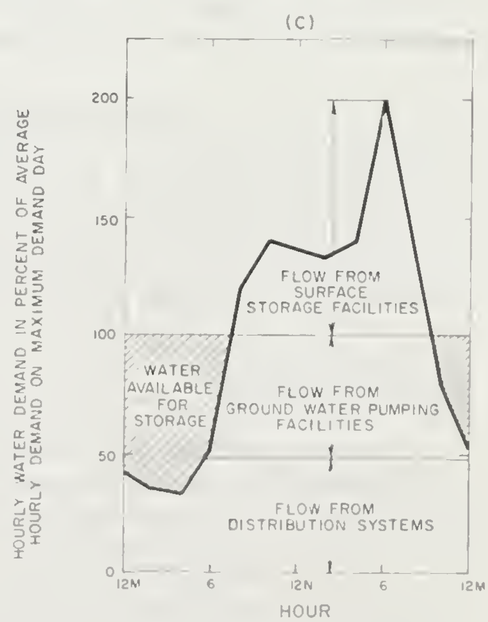
b INCLUDES THE CITY OF WHITTIER



PROJECTED APPLIED WATER DEMAND FOR ECONOMIC AREAS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY



AVERAGE MONTHLY WATER DEMAND



TYPICAL HOURLY WATER DEMAND ON A MAXIMUM WATER DEMAND DAY

Figure 2 - WATER DEMAND

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT.

TABLE 1

PROJECTION OF ANNUAL APPLIED WATER DEMAND IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

In acre-feet

Economic area	1963	1970	1980	1990
1	31,000	36,000	45,000	47,000
2	9,000	10,000	11,000	12,000
3	342,000	378,000	444,000	464,000
4	81,000	99,000	109,000	113,000
5	37,000	45,000	49,000	51,000
6	92,000	112,000	141,000	148,000
7	39,000	47,000	50,000	52,000
8	61,000	75,000	80,000	83,000
9	120,000	141,000	170,000	180,000
10	49,000	58,000	64,000	68,000
TOTAL	861,000	1,001,000	1,163,000	1,218,000

hourly demand. The average monthly variations in water demand, based on historical data and assumed to be applicable to the future, are shown on Figure 2B. The typical hourly water demand variations on the maximum water-demand day in the Coastal Plain are shown on Figure 2C. Also shown in this figure is the division of flow into three components--flow from distribution systems, flow from ground water pumping facilities, and flow from surface storage facilities. The procedure followed in splitting the flow is described in the next chapter.

From the typical hourly water demand variation, the maximum hourly water demand for each economic area was also determined for subsequent analyses to obtain the capacity of required surface and ground water facilities. In determining the maximum hourly demand, the fire-flow requirements were added to the peak hourly water flow on the day of greatest water use in the Coastal Plain. The maximum hourly water demand will be discussed in greater detail in the next chapter.

Injection Water

In addition to the requirement for applied water, there will also be a requirement for water to meet the future needs of the existing and proposed artificial recharge projects shown on Plate 4. One such requirement is for imported water to be used in the injection projects, which will assure continued protection of the ground water basins by the maintenance of fresh water barriers in the Coastal Plain. This injection requirement varies with ground water level elevations resulting from each plan of operation. The amounts required for existing and proposed projects adjacent to Santa Monica Bay and Los Alamitos Bay were estimated by utilizing the information on ground water level responses developed by a mathematical model of the ground water basins that was formulated and verified for this investigation.

For a proposed injection-barrier project in the Wilmington area, the amounts required for injection were estimated without direct use of the model because the ocean is not in direct hydraulic continuity with the deeper aquifers, which are the major water-producing zones in this area. However, based on hydraulic information obtained during the verification of the mathematical model of the ground water basins, it was believed that a relatively small amount of fresh water (approximately 4,000 acre-feet annually) will flow into the deep aquifers from shallow aquifers if a fresh water mound is established in the shallower aquifers, as proposed by the Los Angeles County Flood Control District, and if major extractions are continued from the deeper aquifers. An initial amount of 17,000 acre-feet was estimated to be required to establish a mound in the shallow aquifer, and an annual amount of 4,000 acre-feet was estimated to be required for injection thereafter, to 1990.

Spreading Water

There is also a requirement for imported water to be spread in the Montebello Forebay Area for placing water in storage or for transmitting it through the ground water basin to the point of ground water use. This requirement was handled as an operational variable, and a spreading schedule was prepared for each plan of operation. Further discussions on the spreading schedules as an operational variable are presented in Chapter III.

Determination of Future Water Supply and Water Quality

Water supplies to meet the various water demands in the Coastal Plain consist of imported surface and ground water and locally pumped ground water. Present (1965) sources of imported water include Colorado River water, Owens River-Mono Basin water commingled with ground water of the San Fernando Valley, and ground water and reclaimed waste water from the San Gabriel Valley. In the future, these supplies will be augmented by water from the State Water Project. Ground water is currently extracted from the four ground water basins. These basins are replenished naturally by deep percolation of applied water and precipitation and by subsurface inflow of fresh water at the boundaries of the Coastal Plain. In addition, spread or injected imported surface water constitutes artificial replenishment of the local ground water supply.

Studies of water supply sources also included consideration of the quality of water. A review of available information and projections, for different plans, of the past trend in the water quality change of the area indicated that the variations in water quality under those plans of operation would be minor and would have no significant effect on the comparative economics of the alternative plans. Those different plans encompassed the full range of operational variation in the area.

Imported Water Supply

Colorado River water, which is distributed by The Metropolitan Water District of Southern California, is a major source of imported water to the Coastal Plain. Softened, filtered, and untreated waters are now available for use from the District. Softened and filtered waters are used for applied water, filtered water for injection, and untreated waters for spreading.

The future delivery of imported water to the Coastal Plain by the District was assumed to be limited either by the capacity of the delivery system to provide water at specified pressures or by the available supply from the Colorado River before 1972. This water was allocated among member agencies of the Metropolitan District by each agency's preferential rights in case of water shortage, and the combined water supply from the Colorado River and the State Water Project after 1972. The preferential rights of member agencies, which become effective in the event of water shortages, are based on all payments made by each agency to the District, exclusive of payments for purchased water.

The State Water Project will begin delivering water supplies to Southern California in 1971. In that year, the District will begin importing a portion of this water supply to the Coastal Plain through a planned increase in the delivery capacity of its distribution system. It is anticipated that this system will again be expanded by 1983. The expansion schedule of the District's distribution system used in this study was based upon its Report No. 802, "Comparative Economic Study of the East Branch and West Branch of the California Aqueduct and of Additional Distribution Facilities Required in the Southern California Coastal Plain by 1990", March 1962, because it was the latest report at the time of this study.

The maximum delivery capabilities of the expanded system for the Coastal Plain were determined by formulating and analyzing a mathematical model of the distribution system. The system was simulated by three pipeline networks, each representing the distribution system existing during a given period of time: 1963 to 1972, 1972 to 1983, and 1983 to 1990. These networks are shown on Plate 5. The hydraulic analyses of these networks will be described in a later section of this chapter.

Water imported by the Metropolitan Water District is a supplemental source of supply to the Los Angeles Department of Water and Power, which utilizes two primary sources, the Owens River-Mono Basin and ground water from San Fernando Valley, to supply the Coastal Plain. In view of the anticipated rate of development in the San Fernando Valley, which will result in more local ground water being used in the area of origin and will also require additional water from the Owens River-Mono Basin, the City of Los Angeles, in 1964, initiated construction of the second Los Angeles Aqueduct to meet the water needs of the Coastal Plain.

Because it was assumed that all the water supply for the city would be utilized in each plan of operation, the change in the cost of water service for each plan of operation would remain the same. Consequently, comparative ranking of the cost of water service of the plans will not change. Therefore, the revised schedule below of water importation was adopted for use only in that portion of this study which considers the effect of changing conditions on the cost of water service.

The Los Angeles Department of Water and Power service area within the Coastal Plain now relies almost completely on surface water importations, with less than 15,000 acre-feet of ground water being extracted annually. For this study it was assumed that this amount of extraction will remain essentially the same in the future. Table 2 shows the estimated importation schedules of ground water and Owens River-Mono Basin water, with one aqueduct and with two aqueducts. The total amount of water used in the study area does not change. The second aqueduct's importation is in lieu of water from supplemental Metropolitan Water District import sources.

TABLE 2

ASSUMED* IMPORT SCHEDULE OF WATER
BY THE LOS ANGELES DEPARTMENT OF WATER AND POWER
TO THE COASTAL PLAIN OF LOS ANGELES COUNTY
FROM 1963 THROUGH 1990

Ground water and one aqueduct		Ground water and two aqueducts	
Year	Quantity in acre-feet	Year	Quantity in acre-feet
1963	197,300	1963	197,300
1965	177,500	1965	177,500
1969	137,900	1969	309,000**
1970	128,000	1970	300,000
1975	127,000	1975	260,000
1980	126,000	1980	221,000
1985	126,500	1985	181,000
1990	127,000	1990	141,000

*By the Department of Water and Power, City of Los Angeles.
**Second aqueduct delivery added.

In addition to the water imported into the Coastal Plain by the Metropolitan Water District and the Los Angeles Department of Water and Power, approximately 23,000 acre-feet of water annually has been pumped or diverted from streams in the San Gabriel Valley and imported to the Coastal Plain in recent years. For this study, it was assumed that during the study period, 10,000 acre-feet annually would be used in the economic areas of the Coastal Plain. (The City of Whittier was excluded from these economic areas because the water service in that city would be the same under any alternative plan of operation adopted for the Coastal Plain.) The balance of this amount, 13,000 acre-feet, is considered to be used in the City of Whittier and in communities in Orange County.

Ground Water Supply

In 1963, about 40 percent of the demand of the Coastal Plain for applied water is met by water pumped from ground water basins. Over 20 million acre-feet of fresh water is now in storage in the basins and this is continuously replenished by deep percolation and subsurface inflow. However, the usable amount of water presently in storage may be limited to a considerably smaller amount, depending upon operational, economic, organizational, and legal limitations. In this investigation, some of the water presently in storage, as well as water from deep percolation and subsurface inflow, was considered as a potential ground water supply from the beginning, and the ground water basin was treated as a part of a total storage and distribution system.

The ground water basins are replenished by deep percolation of water from various sources. Sources of deep percolation from pervious areas outside of streambeds are precipitation and delivered water applied to lawns and ornamental shrubs. Sources of deep percolation of local water from streambeds and spreading grounds are storm runoff, rising water, and reclaimed water. Imported untreated water is spread in the streambeds and spreading grounds, and imported filtered water is injected in a sea-water barrier project along the coast.

Deep Percolation of Applied Water and Precipitation. Deep percolation of applied water and precipitation is believed to take place throughout the water-bearing portion of the Coastal Plain, in amounts which vary with the natural and man-made physical conditions of the area. Hydrologists generally agree that it is extremely difficult to determine the distribution of deep percolation within such an area as the Los Angeles Forebay. In studies made to date, investigators have been unable to establish, by direct means, the volume of percolation. Nevertheless, for this study, it was necessary to estimate both the amount and the location of deep percolation.

To meet this need, a method was developed which gives primary consideration to insuring the validity and reliability of the product. To minimize the degree of error in the estimates, the method included independent estimates of all hydrologic items, simultaneous checks on the reasonableness of the annual values of all those items, and the adjustment of the estimates to be consistent with the overall balance of hydrologic items. This was a significant improvement over methods previously available.

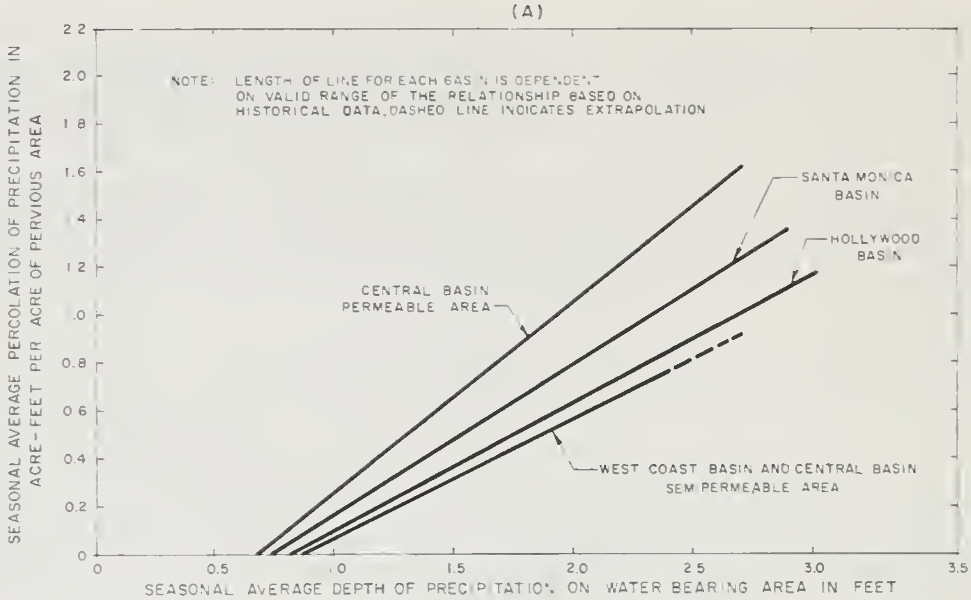
For use in estimating future amounts of percolation of applied water and precipitation within the zone of aeration, percolation criteria were developed for each basin, using the data presented in Appendix B. These criteria were expressed as curves.

Two sets of curves were developed. The first set (Figure 3A) shows the relation between the amount of seasonal percolation of precipitation in an acre of pervious area and the seasonal depth of precipitation on an acre of water-bearing area. The second set of curves (Figure 3B) shows the relation between the amount of seasonal percolation of applied water in an acre of irrigated area and the product of seasonal depths of irrigation water and indexes of wetness. The index of wetness is a unitless number showing the ratio of an annual precipitation to an average precipitation for a long period.

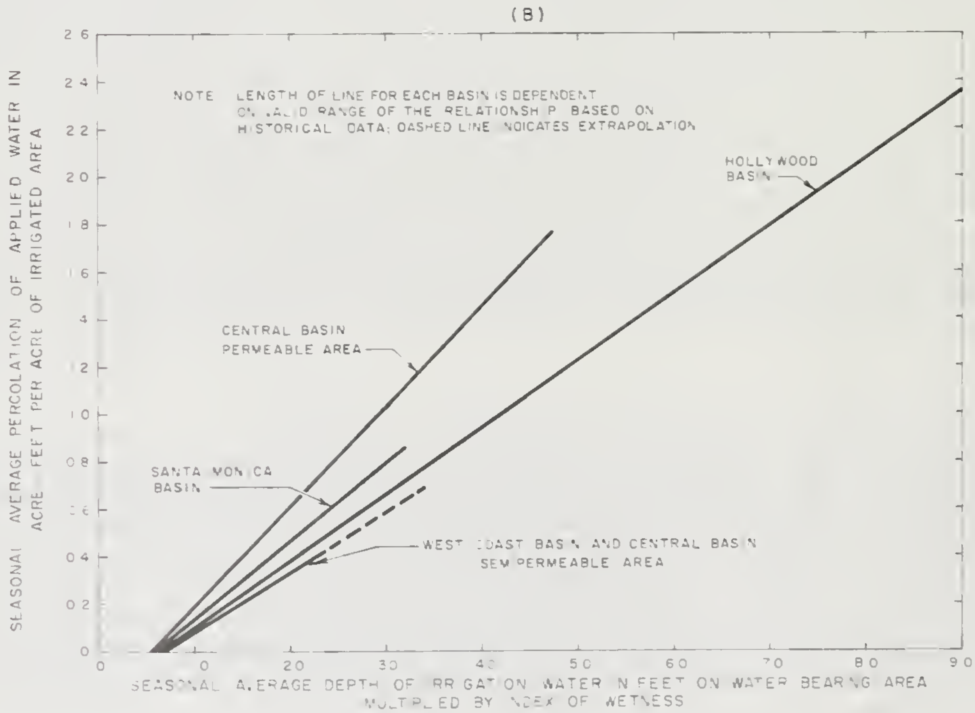
By applying these curves to estimates of future pervious and irrigated areas, annual amounts of percolation from precipitation and applied water to the zone of aeration were established. These amounts were then converted to annual amounts of deep percolation of applied water and precipitation to the zone of saturation. The latter determination was based on studies of historical hydrologic data, which indicated that the fluctuation in the rate of infiltration of precipitation and applied water during the cyclic period from 1934-35 through 1956-57 was attenuated by the zone of aeration. The rate of deep percolation into the zone of saturation was nearly constant during the cyclic period. These analyses are described in detail in Attachment No. 3. The estimated average annual amounts of future deep percolation to the zone of saturation from the beginning of the study period to 1990 are: applied water, 53,000 acre-feet; precipitation, 29,000 acre-feet.

Artificial Recharge and Deep Percolation in Streambeds. Significant amounts of deep percolation of local and imported waters can occur in a portion of the San Gabriel River streambed located in the forebay portion of the Central Basin, in the existing spreading grounds adjacent to the Rio Hondo and San Gabriel River in the Montebello Forebay, and also in the existing spreading grounds adjacent to the Los Angeles River in the Dominguez Gap. The deep percolation of local water in streambeds and spreading grounds consists of storm runoff; rising water, ground water that reappears on ground surface because of higher water table than the ground surface; and reclaimed water.

The future average annual amount of deep percolation in streambeds, under mean precipitation conditions, was assumed to be 53,000 acre-feet--10,000 acre-feet of storm runoff and 43,000 acre-feet of rising water. The storm runoff estimate is based on results of flood routing studies by the



CRITERIA CURVE FOR PERCOLATION OF PRECIPITATION WITHIN ZONE OF AERATION



CRITERIA CURVE FOR PERCOLATION OF APPLIED WATER WITHIN ZONE OF AERATION

Figure 3 - CRITERIA CURVES - PERCOLATION

Los Angeles County Flood Control District. The amount of rising water is the average annual amount estimated to have occurred during the cyclic period, 1934-35 through 1956-57, based on historical hydrologic data from Appendix B. Analysis of these data also indicates that storm runoff and rising water conserved in the streambeds and spreading grounds reach the zone of saturation within a year, regardless of the water level.

The amount of storm runoff and rising water estimated to be conserved annually is 53,000 acre-feet; however, an estimate of 48,000 acre-feet is used in this study as the average annual amount of firm water supply from these sources. This reduction of 5,000 acre-feet reflects the effect of an agreement between the water users in the Upper and Lower Areas of the San Gabriel River system, based on anticipated future conditions in the Upper Area.

On May 12, 1959, a complaint (amended June 8, 1961) was filed in the Superior Court in and for the County of Los Angeles, by the City of Long Beach, the Central Basin Municipal Water District and the City of Compton. This complaint alleged that the water producers in the Main San Gabriel Basin (Upper Area) were using more than their share of the waters of the San Gabriel River.

In an effort to reach a physical solution, two negotiating committees of five members each were appointed, one to represent the plaintiffs and one to represent the major group of defendants.

A proposed Stipulation for Judgment and Judgment were approved by the joint negotiating committees on December 7, 1964, and thereafter were approved by all parties. On September 24, 1965, Judgment was entered.

Under the terms of the agreement, the Central Basin area (Lower Area) is guaranteed an average amount of 98,415 acre-feet of water over a long-term period of normal rainfall for the upper area. For any specific year, the entitlement of the lower area will be based on the average rainfall for a 10-year period that ends with the year in which the entitlement is to be calculated. The determination of the debit or credit of the Upper Area in the future will be based on the difference between the entitlement and actual amounts of usable surface flow, subsurface flow, or export that pass through the Whittier Narrows. If the usable water passing the Whittier Narrows during the water year is less than the entitlement, the Upper Area will be obliged, periodically, to provide sufficient water, or compensating funds, to make up the difference. The average annual entitlement of the Lower Area was derived by using the average amounts of the export, usable surface flow, and usable subsurface flow for the period 1934-35 through 1958-59, minus a stipulated deduction of 5,000 acre-feet.

In addition to runoff from storms and rising waters, water reclaimed from waste water originating in the San Gabriel Valley is available for conservation by spreading in the Coastal Plain. The annual amount presently available for spreading is 13,000 acre-feet, which is about equal to the existing capacity of the Whittier Narrows Reclamation Plant.

It was assumed that untreated imported water will be supplied for future spreading in the spreading grounds to supplement the ground water in storage. It was also assumed that filtered water will be supplied for injection into freshwater barriers adjacent to the coast to prevent sea-water intrusion. The location of these artificial recharge projects is shown on Plate 4. The amounts of untreated water to be delivered to spreading grounds in the future were postulated in spreading schedules for each plan of operation and are described in detail in Chapter III. The amounts of filtered water to be delivered to injection wells along the sea-water barriers were computed as requirements for selected plans of operation by using the mathematical model of the ground water basins. In determining the amount of injection water added as a potential ground water supply, the portion of injected water that flows toward the ocean was subtracted from the total amount of injected water.

In addition to operational-economic studies based on mean seasonal amounts of inflow and outflow, a separate analysis was made to gain an insight into the water level fluctuation that may occur in the future, particularly in the Montebello Forebay area of the Central Basin. An analysis of historical hydrologic data indicated that the ground water levels in the Coastal Plain varied cyclically with cyclic variations in rainfall and subsequent conservation of local water in the streambeds and spreading grounds. For this study, the annual amounts of rising water and storm runoff that percolated during 1934-35 through 1956-57 were assumed to be conserved during the study period. These annual amounts are presented in Table 3.

This assumption was made because the annual amounts of rising water and flood runoff that can be conserved in the future, though related to precipitation, will be affected by the operational conditions in both the Coastal Plain and in the San Gabriel Valley, and reliable predictions cannot be made.

Subsurface Inflow. Subsurface inflow also adds to the ground water supply of the area. Subsurface inflow of fresh water has occurred in the past, and is assumed to occur in the future, at the Los Angeles Narrows, Whittier Narrows, and the Los Angeles-Orange County boundary line. The amounts of inflow at each location will vary with each plan of operation. At the Los Angeles-Orange County boundary, the direction of flow may also vary.

Because it was not possible to correlate the plans of operation considered for the Coastal Plain with any definite future plans of operation for adjoining ground water basins, it was necessary to make assumptions regarding future subsurface inflows. For this investigation, the average annual subsurface inflow assumed to occur at the Los Angeles-Orange County line was 29,000 acre-feet, the estimated inflow which occurred at

TABLE 3

ANNUAL AMOUNTS OF STORM RUNOFF AND RISING WATER
ESTIMATED TO BE CONSERVED IN THE MONTEBELLO FOREBAY

In acre-feet

Year	Quantity of water
1934-35	53,000
1935-36	32,000
1936-37	67,000
1937-38	101,000
1938-39	62,000
1939-40	57,000
1940-41	98,000
1941-42	57,000
1942-43	68,000
1943-44	78,000
1944-45	63,000
1945-46	69,000
1946-47	69,000
1947-48	46,000
1948-49	30,000
1949-50	30,000
1950-51	23,000
1951-52	57,000
1952-53	42,000
1953-54	34,000
1954-55	23,000
1955-56	26,000
1956-57	30,000

Note: These assumed amounts, used in determining ground water level fluctuations resulting from cyclical variations in precipitation, are based on the annual amounts of storm runoff and rising water conserved in the Coastal Plain during the 23-year base period, 1934-35 through 1956-57.

this location in 1960-61. Because subsurface flow varies with changing physical conditions in the area adjacent to the line, the figure of 29,000 acre-feet, adopted for use here, is a working estimate only.

For the Los Angeles Narrows, the assumed future average annual subsurface inflow was 200 acre-feet based on the most recent year of record, 1960-61.

For Whittier Narrows, the assumed future subsurface inflow was 28,000 acre-feet annually, the average amount estimated to have occurred during the base period, 1934-35 through 1956-57. This amount approximates the quantity of inflow stated in the principles of agreement between the water users of the Upper and Lower Areas of the San Gabriel River System. It is subject to some variation, in accordance with a stipulation signed by both parties in 1965.

To account for the annual increase or decrease of fresh ground water in storage during the study period, annual inventories were taken of all items of ground water inflow and outflow to and from the zone of saturation for each plan of operation. Also, cumulative amounts were determined for the period from 1963 through 1990. Tables showing inventory information for selected plans of operation are presented in Chapter IV.

Water Quality

On the basis of studies of past levels of quality of water imported from the Colorado and Owens Rivers, it was assumed that the quality of these supplies would continue to be at about 1963 levels. After 1972, when higher quality water from northern rivers will be available through the State Water Project, the supply from these combined sources is expected to continue to be sufficiently high in future years so that no treatment, other than chlorination, filtration, and softening will be required. An analysis was also made to estimate the change in the quality of ground water in the study area during the study period. For this estimate, historical average values of total dissolved solids were plotted as a function of time. Trends of change, based on the plot, were determined for each of the four ground water basins. The periods of analysis were based on the availability and reliability of basic water quality data on concentrations of total dissolved solids in each basin; these periods varied from 7 years for the Central Basin to 12 years for the Hollywood Basin. The data showed no significant rise or fall in total dissolved solids during the period of study. Furthermore, the annual average values of total dissolved solids for all the basins were well below the 1,000 parts per million permitted by the United States Public Health Service for domestic water. Average values of total dissolved solids, in parts per million, were 400 for the Hollywood and West Coast Basins, 450 for the Central Basin, and less than 700 for the Santa Monica Basin. The values of total dissolved solids in those portions where sea water has intruded in the West Coast Basin and also in the Santa Monica Basin were much higher than mentioned.

As for pollution and contamination of ground water from various deleterious matters and chemicals, the Los Angeles Regional Water Quality Control Board, State Department of Public Health, and the State Department of Water Resources maintain constant vigilance. In cases that could lead to threatening situations, it was assumed, for the purpose of this study, that sufficient steps would be taken in time to prevent any significant damage to the valuable water resource.

Survey of Existing and Proposed Water Supply Facilities

Water supply facilities within the Coastal Plain are those required for transmission and storage of surface and ground water to directly meet the fluctuating demand for applied water and for the artificial recharge projects. The ground water basins also were considered as a part of these facilities in this study. A highly developed network of both surface and ground water facilities for storage, transmission, and extraction of water exists within the Coastal Plain to meet the applied water demands of municipal, industrial, commercial entities, and very small amount of agricultural water requirement. Many of these facilities are required for service of water irrespective of the source; this group of facilities was excluded from consideration so that the investigation could be limited to consideration of those facilities that varied with the source of supply.

The elimination of these facilities limited the study of surface water facilities to the primary distribution system, takeout connectors, and surface storage facilities. Even though surface storage facilities are used for storing both surface water and pumped ground water, all of these storage facilities were categorized as surface facilities for convenience in this study. Ground water facilities considered in the study were spreading facilities, wells and pumps, booster pumps, injection wells, and related barrier facilities required to protect the basins against further intrusion of sea water.

Operational information on these facilities, including their existing capabilities and related costs, were obtained from the major water agencies in the study area. The capabilities of existing connectors, pumps, booster pumps, and surface storage reservoirs were estimated, based on data obtained from virtually all water agencies of the area. These estimates are shown in Table 4 for each of the 10 economic areas. The distribution system analyzed in this study is shown on Plate 5.

The facilities considered to be related to delivery of both imported and ground waters were those downstream of the connectors. It was concluded, after a brief analysis, that valves, meters, house connections, and distribution mains were common to all plans of operation. A relatively detailed analysis showed that secondary distribution systems were also common to delivery of water from both sources, if the systems were constructed to meet accepted design standards of American Water Works Association. Accordingly, these categories of facilities were excluded from further operational and economic analyses.

The distribution systems owned and operated by both private and municipal agencies, such as pipeline networks of the City of Los Angeles and the City of Long Beach, were also considered to be common to all plans of operation, and they, too, were not considered in the economic analyses. However, all the existing and proposed facilities of the Metropolitan Water District and State Water Project were considered in the economic analyses as parts of the cost and, subsequently, the unit price of

TABLE 4

ESTIMATED EXISTING CAPABILITIES OF PUMPS, BOOSTERS, CONNECTORS, AND STORAGE RESERVOIRS IN THE COASTAL PLAIN OF LOS ANGELES COUNTY BY ECONOMIC AREAS

Economic area	Total rated well pump horsepower	Total rated booster horsepower	Existing connection capacity, in cubic feet per second	Volume of existing storage, in cubic feet
1	2,520	1,020	122	6,979,000
2	620	0	25	3,717,000
3	2,310	1,540	419	923,632,000
4	15,500	1,250	125	6,667,000
5	6,140	1,350	22	731,000
6	5,340	1,140	271	5,237,000
7	5,040	150	100	294,000
8	10,320	420	129	2,784,000
9	8,370	850	300	9,668,000
10	6,440	190	85	14,893,000
TOTALS	62,600	7,910	1,598	974,593,000

imported water. Also, those District's facilities which affected operations in the study area but which were not included in the cost of imported water, such as the feeders required in addition to those in the District's plan, were considered both operationally and economically.

In addition to the San Gabriel riverbed, which is a natural spreading facility with an approximate capacity of 120 cubic feet per second, four man-made spreading facilities exist in the permeable area adjacent to the Rio Hondo and San Gabriel Rivers in the Montebello Forebay, and adjacent to the Los Angeles River in the Dominquez Gap area. The total infiltration capacity of the spreading grounds in the forebay is 565 cubic feet per second, which is equivalent to about 400,000 acre-feet per year, provided that the infiltration rate is not reduced by a ground water mound that could develop beneath the spreading site. The locations of the spreading facilities are shown on Plate 4, and information on the recharge capacity of each spreading project is given in Table 5.

The existing facilities were assumed to be available for use up to their spreading capacity in each plan of operation. No additional imported water spreading projects were considered for this investigation. Studies made with the mathematical model indicated that large amounts of sustained spreading cannot be done simultaneously in the Montebello Forebay and in the Los Angeles Forebay, which is the only potential additional spreading ground site of any significant size. Since there is a large amount of

TABLE 5

OPERATIONAL DATA ON EXISTING MAN-MADE SPREADING FACILITIES WITHIN THE COASTAL PLAIN OF LOS ANGELES COUNTY

Name of spreading grounds[a]	Type	Area, in acres		Year first used	Percolation capacity[b], in cfs
		Gross	Wetted		
San Gabriel Coastal	Shallow basins	127	96	1938-39	80
Rio Hondo Coastal (eastside)	Shallow basins	423	370	1937-38	350
Rio Hondo stream-bed development (westside)	Shallow basins	151	89	1955-56	135
Dominguez Gap	Deep basins	54	26	1957-58	6
TOTALS		755	581		571

a. Excludes that portion of the San Gabriel River channel between the Whittier Narrows Dam and Florence Avenue, which has an infiltration rate of about 120 cfs.

b. These capacities are for the condition in which the ground water tables below and adjacent to the spreading grounds are low enough not to disturb passage of water through the surface of the spreading ground. The infiltration capacities shown represent the nominal short-term maximum rates as controlled by the infiltration across the soil-water interface. The month-to-month rates can vary considerably depending upon the total amount of water being applied and the turbidity as controlled by the amount of local storm water conserved within any given period.

ground water in storage--more than 20 million acre-feet--as shown in Appendix A, it is possible to consider delaying safe yield operation* of the ground water basin until some future date. Under such an alternative, the cost of pumping ground water for use now should be compared

*For this study, safe yield operation is defined as a plan under which the amount of output from, and input to the ground water basin over a long period of time is equal.

with the cost of developing, operating, and maintaining a spreading site, purchasing and spreading imported water, and subsequently pumping it for use.

Under a plan of operation in which safe-yield operation was deferred, water levels would gradually decline and pumping costs would gradually increase. Some additional injection water would also be required to repel saline intrusion. These additional costs were included in the analysis of cost of water service for each operational alternative evaluated in this study. Chapter IV discusses the selected plans of operation studied and presents techniques that can be used by local water management agencies to determine the period during which use of ground water would be of economic advantage.

To test the effectiveness of freshwater barriers in protecting the ground water basins, a 1.5-mile reach of wells has been constructed parallel to the coastline near Manhattan Beach as part of the West Coast Basin Barrier Project. At the time of the study, the Los Angeles County Flood Control District proposed to complete an extension of this system by 1965 to provide protection for about 11 miles of the coast from the Ballona escarpment on the north to a point near Redondo Beach on the south. Additional barrier projects in the vicinity of Dominguez Gap and Alamitos Gap are also proposed. Since that time, the extension of the West Coast Basin Barrier Project and the Alamitos Gap Project have been essentially completed and are now operational. The design length and capacity of each project proposed by the Flood Control District are given in Table 6, and the locations of these projects are shown on Plate 4.

To examine a wide range of possible operational plans, injection projects were assumed to be enlarged and extended for some plans in this study. The proposed West Coast Basin Barrier Project and Alamitos Barrier Project were assumed to be enlarged at selected times. Costs during the study period of these enlarged projects were developed for plans of operation that would require injection facilities larger than those designed for the proposed projects, and these costs were included in the total cost of operation. In addition, the proposed Dominguez Gap Barrier Project was extended about 3 miles and a barrier project was extended from the terminus of the West Coast Basin Barrier Project about 8 miles northerly along the Santa Monica Bay; the latter extension will be referred to as the Santa Monica Basin Barrier Project in this study. The extensions considered necessary for some plans of operation are shown on Plate 4. A detailed discussion of the timing, sizing, and the cost of expanded injection barriers is presented in Attachment 8.

The ground water basin also acts as a facility that both stores and transmits ground water from points of recharge and from existing water in storage to points where water is required. The areal extent of the basins is depicted on Plate 1, and a physical description of the hydraulic characteristics of the basins is presented in the latter portion of this chapter.

TABLE 6

INJECTION CAPACITY AND LENGTH OF INJECTION BARRIER PROJECTS WITHIN THE COASTAL PLAIN OF LOS ANGELES COUNTY

Name of barrier project	Length of barrier project, in miles			(4)[a] Design injection capacity as proposed by the Los Angeles County Flood Control District, in cfs[b]
	(1) As proposed by Los Angeles County Flood Control District	(2) Additional project assumed for operational study	(3)=(1)+(2) Total considered for study	
West Coast Basin[c]	11	0	11	69
Alamitos[d]	2	0	2	15
Dominguez Gap	4	3	7	16
Santa Monica Basin	0	8	8	0
TOTALS	17	11	28	100

a. Stabilized rates after a freshwater mound is built.
b. The capacities shown here do not include those of additional projects over and above those proposed by the Los Angeles County Flood Control District.
c. Includes 1.5 miles of existing barrier near City of Manhattan Beach.
d. Los Angeles County portion only.

Hydraulic Analyses of Ground Water Basins

A mathematical model of the ground water basins of the Coastal Plain was developed to integrate the storage and transmissive capabilities of the basins in the operational and economic evaluation of alternative schemes of meeting applied water demands. This model was subsequently verified for reliability by adjusting the storage and transmissive factors within reasonable limits so that the model could reproduce historical ground water conditions when historical amounts of inflow and outflow of the ground water basins were imposed. The verified model was used to generate annual changes in water level elevations from the present to 1990 under various operational plans. In these plans, amounts and locations of future replenishment and extraction varied, and information such as cost of pumping was estimated through a determination of facilities and electrical energy requirements. A detailed discussion of the formulation and verification of the model on the analog computer is presented in Attachment No. 5.

In the formulation and verification of the model, complex elements of the ground water basins and their water supply, use, and disposal were simplified sufficiently so that they could be handled with available knowledge, equipment, and experience. The general steps taken in the formulation and verification of the model follow:

1. A generalized ground water equation was derived that could define the storage, transmissive, and surface water inflow-outflow characteristics. This equation takes the form:

$$\Sigma_i \, (h_i - h_B) \frac{T_{i,B} \, W_{i,B}}{L_{i,B}} + A_B Q_B = A_B S_B \frac{dh_B}{dt}$$

where:

h_i = representative ground water level, in feet, of unit area i, adjacent to area B

h_B = representative ground water level (head), in feet, of the general unit area B

$T_{i,B}$ = representative transmissibility between areas B and i, in acre-feet per year per foot of width

$W_{i,B}$ = width, in feet, through which the subsurface flow occurs between areas B and i

$L_{i,B}$ = distance, in feet, between the nodal points of areas B and i. Therefore, $(h_i - h_B)/L_{i,B}$ is an average slope of a ground water surface between the unit areas B and i.

A_B = area, in acres, of general unit area B

Q_B = rate of net surface inflow and outflow, in acre-feet per year per acre of general unit area B

S_B = representative specific yield of sediments in general area B

t = time, in years

A unit area of interest is expressed by subscript B and all the surrounding units by subscript i. The first term on the left-hand side of the equation is the summation of the subsurface flows between a given unit area and its surrounding areas. The second term describes the surface flow into or out of the zone of saturation of the given area. The change in storage is given by the right-hand expression. A set of these differential equations, with proper values of coefficients, is referred to as a mathematical model of ground water basins.

2. A set of assumptions was made that was consistent with the equation, with the geologic and hydrologic data, and with an analog computer system. Assumptions were made to make the handling of computer equations simple or to provide physical data which were not available. For specific assumptions, refer to the attachment.

3. The entire Coastal Plain was divided into 82 subareas, called polygons, by using the Thiessen Method of polygon construction. The complex system of aquifers within the Coastal Plain was represented by one "equivalent aquifer".

4. Water levels were held constant at 9 of the 82 polygons--8 along the coast at sea level and one in the area of rising water in the Montebello Forebay at 190 feet elevation.

5. Geologic data were analyzed and the "transmissive factor" between polygons and "storage factor" within each polygon was estimated.

6. Historical surface hydrologic data were analyzed and the "surface inflow-outflow factors" at each polygon were determined for the period 1946-47 through 1956-57. Also, hydrographs of representative ground water level fluctuations during the same period were prepared for each polygon, based on the measurements of historical ground water level elevations.

7. A circuit diagram was drawn, illustrating the electrical components of the analog computer and their interconnections. Using this diagram, "patch panels" of the analog computer were wired.

8. A circuit of the analog computer and the proper initial setting of transmissive, storage, and surface inflow-outflow factors in the computer were checked by the dynamic and equilibrium check techniques that were developed in this program. Precalculated water level elevations for each polygon were used in the dynamic check of the analog computer.

9. The "checked" analog computer circuit, with its initial "best values" of transmissibility, storage, and surface inflow-outflow factors, was used to verify the reliability of the mathematical model. The water level elevations generated by the computer were plotted by using X-Y plotters attached to the analog computer, and these plots were compared with the hydrographs of historical water level elevations of the ground water basins. The historical water levels were matched with the computed values by making reasonable adjustments to the values of the transmissibility, storage, and surface inflow-outflow factors as required. Decisions and adjustments were made by hydrologists and geologists, who

isolated and quantified the basic information used to formulate the mathematical model.

The verified model made it possible to formulate plans within the bounds of the physical characteristics of the basins and to obtain operational information required for those plans. Specifically, the model was used to estimate future water level elevations at many locations in the Coastal Plain for numerous combinations of planned replenishment and extraction. These water level elevations were converted to pumping lifts, changes in the amounts of ground water in storage, and subsurface flows among various areas to determine the number of facilities required and the cost of constructing, operating, and maintaining the facilities.

The mathematical model of the Coastal Plain was a linear system, because the transmissibility and storage factors were fixed and did not vary with the change of water level elevations. This simplifying approach was taken because it would provide satisfactory operational and economic results for the range of water level fluctuations in the past, and also because it would use a model that could be developed within the time allotted. Consequently, the water level elevations varied on a linear basis with the rate of net surface water inflow-outflow. For this reason, the technique of superpositioning, which is explained below, was selected to estimate the required water level elevations for each alternative plan of operation.

A set of master influence functions for superpositioning was first developed on a digital computer by using the verified mathematical model. A master influence function is defined as the water level elevation response at each polygon from an action of 100,000 acre-feet per year rate of net inflow-outflow from the surface to the zone of saturation in a selected polygon or a group of polygons. Because the ground water basin system in the Coastal Plain was treated as a linear system, the master influence functions were additive, multiplicable, and relocatable with respect to time. Therefore, the technique of superpositioning could be used.

Under the technique of superpositioning, the master influence functions were multiplied by the ratio of annual amounts of inflow or outflow to the 100,000 acre-feet of subsurface inflow or outflow to adjust the functions representing the effects of amounts of planned extraction or replenishment. The adjusted influence functions corresponding to planned annual extraction or replenishment were then added with other adjusted functions representing all the other operational actions to obtain the resulting water level elevations. In this process, the adjusted functions were so arranged that the adjusted functions of certain years were added to adjusted functions of other operational actions to take place during corresponding years. This technique afforded a simple and flexible tool for generating future average annual water level elevations from the present through 1990 under any combination of replenishment and extraction.

For each plan analyzed, representative annual water level elevations at each polygon were determined for the period from the present through 1990, and the pumping lifts at the polygons were determined by taking the difference between average ground surface elevations and representative ground water level elevations. Superpositioning of master influence functions is explained in detail in Attachment No. 6.

Hydraulic Analyses of the Primary Distribution System

The maximum delivery capacity of the primary distribution system within the Coastal Plain is an important factor in the operational and economic analyses of the coordinated operation of surface and ground water systems. As mentioned earlier in this chapter, the Metropolitan Water District's distribution system is the primary facility for conveying imported surface water within the Coastal Plain; accordingly, this system was closely analyzed.

Data on the maximum delivery capacity were needed for the determination of facilities required under coordinated operation of surface and ground water supplies and facilities.

To obtain the required information, a mathematical model of the District's existing distribution system was formulated, as were models for the expanded system expected to be available for distribution of imported water in the Coastal Plain in 1972 and 1983. In 1972, the first major expansion is scheduled to be completed when water is first estimated to be available through the West Branch Aqueduct of the State Water Project. In 1983, a minor expansion of the system is scheduled for completion in the West Coast Basin.

The expanding distribution system serving the Coastal Plain is shown on Plate 5. It consists of that part of the District's system which is located west of the F. E. Weymouth Softening and Filtration Plant on the Upper Feeder and the R. B. Diemer Filtration Plant on the Lower Feeder. These treatment plants were selected as boundary controls in the hydraulic analyses of the primary distribution system leading into and within the Coastal Plain. The pressure requirements at takeout connectors and control structures were checked in the process of approximating the maximum delivery at adequate pressure.

The general steps taken to formulate and use the mathematical model of the distribution system are as follows:

1. Boundary control and internal control structures were analyzed, and the dimensions of the pipelines in the primary distribution system were determined. Also, the locations of takeout connectors and the areas which they serve were determined.

2. The complex system of pipelines, controls, and takeout connectors was represented by a set of 80 equivalent takeout connectors and 95 equivalent

pipelines of various lengths and diameters. This equivalent system hydraulically represented the existing and proposed networks of the primary distribution system.

3. The "roughness factors" for all equivalent pipelines were determined on the basis of normal operating conditions of the distribution system.

4. A generalized pipeline network equation that defined the transmissive and water takeout characteristics of the pipeline networks was derived. This equation was developed by using the continuity equation, as it is related to pipeline networks and the Hazen-Williams flow relationship. The generalized pipeline network equation takes the form:

$$\Sigma_i (h_i - h_B) Y_{i,B} + Q_B = 0.$$

Q represents the rate of takeout at connectors and h represents the pressure head at the connectors. Y is a conductance factor which is a function of the physical characteristics of pipelines. The takeout connector of interest is expressed by subscript B, and all the surrounding takeout connectors by subscript i. The first term on the left-hand side of the equation is the summation of pipe flows between a takeout connector B and its surrounding connectors i. The second term describes the amount of takeout from connector B. A set of these equations representing the hydraulic relationship among all the takeout connectors in the study area, with proper values of coefficients, is referred to as a mathematical model of the surface distribution system.

5. A set of assumptions was made for various factors, such as roughness of pipes and head loss at connectors, to represent physical and dynamic characteristics of the primary surface distribution system.

6. A digital computer program was developed for computing rapidly the dynamic pressure responses in the equivalent network under different amounts of takeout from the connectors of the system.

7. The maximum conveyance capacity of each of the equivalent networks representing the surface distribution system at the different periods specified in the study, from 1963 to 1972, from 1972 to 1983, and from 1983 to 1990, was determined.

In approximating the maximum delivery rate of pipeline networks, the following criteria for maximum delivery were established: (1) pressures at all or nearly all of the takeout connectors must be equal to or more than 65 pounds per square inch, and (2) a larger delivery rate will not satisfy the pressure requirements for any assumed takeout patterns. Amounts of takeout then were assumed for various connectors, and pressure responses at all takeout connectors and control structures were computed on a digital computer by using the mathematical model of the equivalent distribution system. When resulting pressure responses were lower than the desired pressure, the pattern of takeout was changed, but the total amount of delivery was kept the same so that the pressure could be raised. Pressure analyses were made for a number of takeout patterns until the pressure requirement was satisfied, or until it became apparent that, with the assumed rate of delivery, there was no pattern that could satisfy the pressure requirement. When the computed pressures at all connectors were higher than the desired pressure, the total amount of takeout was increased and the pressure analyses were again made. This process was continued until the established criteria were satisfied. The final selected delivery rates represent an approximation of the maximum delivery rates of the pipeline network analyzed.

The maximum amount of delivery to each economic area was then assumed to be equal to the amount which was used for the connectors in that area in establishing the pattern of maximum takeout. Results of these analyses are shown in Table 7. Detailed information on the formulation and application of the mathematical model of pipeline networks is presented in Attachment No. 4.

Analyses of Unit Cost of Water Supplies, Facilities and Electrical Energy

To arrive at a cost of each plan of operation, unit price and cost of water supplies and unit costs of facilities and electrical energy were estimated. Annual unit costs of facilities and electrical energy were used in arriving at the most economical combination of pumping, boosting, and storage facilities required to meet the future demand for applied water, as is described in Chapter III. A detailed discussion of the unit cost analyses of water supply facilities and electrical energy that are summarized here is presented in Attachment Nos. 7 and 8.

It is emphasized that the costs of the primary distribution system within the Coastal Plain are included in the cost of water imported by various agencies. The only exception is the cost of laterals required in addition to existing and proposed distribution pipelines in the eastern portion of the Coastal Plain, since the cost determination of the laterals and projects could not be made readily through unit cost analysis. The cost determination for these laterals is discussed later in this chapter.

Unit Prices and Unit Costs of Imported Water Supplies

Unit costs were determined for water imported by the Los Angeles Department of Water and Power, reclaimed water and ground water imported from the San Gabriel Valley by various agencies, and water imported by The Metropolitan Water District of Southern California.

Water imported by the City of Los Angeles from the Mono-Owens Valley and the San Fernando Valley costs approximately $20 per acre-foot, based on information obtained from the city. This cost represents the average total cost of water from the two sources. It includes capital costs of

TABLE 7

COMPUTED MAXIMUM DELIVERY CAPACITY AVAILABLE TO
THE COASTAL PLAIN OF LOS ANGELES COUNTY
FROM THE PRIMARY DISTRIBUTION SYSTEM

Economic area	Period of delivery	Computed maximum delivery capacity	
		Gallons per minute	Cubic feet per second
1	1963-72	23,000	51
	1972-83	75,000	167
	1983-90	81,000	182
2	1963-72	11,000	25
	1972-83	11,000	25
	1983-90	11,000	25
3	1963-72	172,000	385
	1972-83	201,000	449
	1983-90	199,000	445
4	1963-72	44,000	99
	1972-83	70,000	156
	1983-90	73,000	162
5	1963-72	19,000	42
	1972-83	23,000	51
	1983-90	26,000	57
6	1963-72	86,000	192
	1972-83	156,000	348
	1983-90	184,000	411
7	1963-72	14,000	31
	1972-83	42,000	94
	1983-90	45,000	100
8	1963-72	43,000	95
	1972-83	140,000	312
	1983-90	142,000	318
9	1963-72	92,000	206
	1972-83	166,000	371
	1983-90	177,000	394
10	1963-72	26,000	57
	1972-83	48,000	108
	1983-90	52,000	116
TOTAL DELIVERY	1963-72	530,000	1,183
	1972-83	932,000	2,081
	1983-90	990,000	2,210

all water facilities and fixed and variable operation and maintenance expenses associated with those facilities. It does not include distribution costs to consumers, which were considered to be common to all plans.

Information concerning extraction costs at well sites in the San Gabriel Valley was obtained from the agencies extracting and importing the ground water to the Coastal Plain. Estimated unit costs of distribution pipelines, including capital costs and fixed and variable operation and maintenance costs, were added to the extraction costs. This total amounted to about $20 per acre-foot. Based on the present price paid by the Central and West Basin Water Replenishment District, the charge for water reclaimed at the Whittier Narrows Water Reclamation Plant was considered to be the same as the Metropolitan Water District's price of untreated water for spreading.

For this study, the unit cost of Metropolitan Water District water was considered to be the price charged by the District to water purveyors in the Coastal Plain. These prices vary with the type of treatment required for each use: softened water for domestic use, filtered water for injection, and untreated water for spreading.

In addition to the direct payment made to the Metropolitan Water District by member agencies for each acre-foot of water used by those agencies, the District levies an ad valorem tax to raise part of its revenues for meeting debt service and operating requirements. In this study, the tax revenues originating from the Coastal Plain were not included in the unit costs of water, but were added to the total cost of operation after the cost of all other items was determined. Specifically, total cost of water service was determined by first computing the present worth of revenues from water sales, based on assumed pricing schedule, and then adding the present worth of the ad valorem water taxes paid.

The pricing schedules applicable up to 1967 had been established by the District when this study was conducted, but no definite schedule or pricing policy had been announced for the subsequent years. To meet the needs of this investigation, alternative pricing schedules for the period after 1967 were developed on the basis of three different sets of assumptions, representing a wide range of possible variations in the total money paid by the Coastal Plain for water service from the District. These three price schedules were used to provide comparative economic information on the five plans of operation selected for detailed analysis. A discussion of the analyses of these five plans of operation is given in Chapter IV and further discussion is made regarding the impact of changing conditions on the price of water.

Because each set of assumptions under which the price schedules were determined entails a lengthy description, these assumptions are not given in detail each time the specific price schedule is mentioned. Also, for convenience, the studies are referred to as price-of-water studies No. I, II, and III. A summary of the assumptions is shown in Table 8, and the

TABLE 8

SUMMARY OF ASSUMPTIONS FOR PRICE-OF-WATER STUDY

Assumptions common to all three price-of-water studies

1. The State Water Project aqueduct system will be constructed according to the schedule outlined in Plan 3 of the Department of Water Resources office report, "A Study of the Optimum Division and Timing of Water Deliveries Between East and West Branches of the California Aqueduct," March 1962.

2. The distribution system will be constructed according to the construction schedule outlined in case No. 7 of The Metropolitan Water District of Southern California Report No. 802.

3. All users will be charged an equal unit rate for untreated water, and cost of treating raw water will be charged only to the users of treated water.

4. The water rates until 1967 will be those already established by the District.

Assumptions for Price-of-Water Study No. I	Assumptions for Price-of-Water Study No. II	Assumptions for Price-of-Water Study No. III
I-1 The amount of water imported by the District to its service area will be as specified in the District's Report No. 802.	II-1 The amount of water imported by the District to its service area will vary in direct proportion to the variation in amount of imported water to the Coastal Plain.	III-1 The amount of water imported by the District to its service area will vary in direct proportion to the variation in amount of imported water to the Coastal Plain.
I-2 The price of water after 1967 will increase at the historical rate until 1969 at which time the price is to be equal to the cost of importing water.	II-2 The prices of water will be as established in Price-of-Water Study No. I. Deficiency in revenue will be borne by ad valorem tax revenue.	III-2 Fifty percent of the capital cost will be borne by ad valorem tax revenue, and the remaining cost of importing water will be borne by sales revenue.

established and estimated pricing schedules of the District's water under price-of-water studies No. I and II are shown in Table 9.

The pricing schedule under price-of-water No. III, from 1963 to 1967, is the same as that shown in Table 9 beginning in 1967, however, the pricing schedule will depend on the plan of operation. For the five selected plans of operation, the price per acre-foot ranged from $33.14 to $35.42 for untreated waters, $37.14 to $39.42 for filtered water, and $42.14 to $43.42 for softened and filtered water.

Unit Costs of Facilities to Meet Applied Water Demand

Annual unit costs were determined for elevated storage tanks, connectors to the primary distribution system, well pumping plants, and booster plants in each of the 10 economic subareas. The unit annual cost of each of these groups of facilities represents a combination of cost components as follows:

TABLE 9

ESTABLISHED AND ESTIMATED PRICE OF WATER SCHEDULE OF THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA FROM 1963 THROUGH 1990 IN THE OPERATIONAL-ECONOMIC STUDY OF THE GROUND WATER BASINS IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FOR PRICE-OF-WATER STUDY Nos. I AND II

In dollars per acre-foot

From	To	For agriculture and ground water replenishment			For other purposes including domestic use		
		Untreated	Filtered	Filtered and softened	Untreated	Filtered	Filtered and softened
1-1-62	1-1-63	$13.50	--	$21.50	$19.00	--	$27.00
1-1-63	7-1-63	14.25	--	22.25	21.00	--	29.00
7-1-63	1-1-64	14.25	$22.25	22.25	21.00	$29.00	29.00
1-1-64	7-1-64	15.00	20.00	23.00	24.00	29.00	32.00
1964	1965	15.25	20.25	24.25	25.00	30.00	34.00
1965	1966	16.00	21.00	25.00	28.00	33.00	37.00
1966	1967	17.00	22.00	26.00	31.00	36.00	40.00
1967	1968	34.00	39.00	43.00	34.00	39.00	43.00
1968	1969	37.00	42.00	47.00	37.00	42.00	47.00
1969	1990	41.00	45.00	49.00	41.00	45.00	49.00

1. Annual unit cost of a pumping plant included costs of well and casing, motor and pump, meters, valves, housing, electrical wiring, right-of-way, and maintenance. The pumping unit was assumed to be rated at 100 horsepower and to have an economic life of 20 years.

2. Annual unit cost of a booster plant included costs of motor, pump, valves, meters, control housing, and maintenance. The booster unit was assumed to be rated at 100 horsepower, and to have an economic life of 20 years.

3. Annual unit cost of elevated storage tanks included costs of fabrication, erection, piping, normal accessories, right-of-way, and maintenance. The elevated storage tank unit was assumed to have a capacity of 500,000 gallons and to have an economic life of 100 years.

4. Annual unit cost of connectors included costs of excavation, backfill, concrete and steel, resurfacing, side outlet, meter, valves, pipes, other accessories, and maintenance. The connector unit was assumed to be rated at 10 cubic feet per second and to have an economic life of 100 years.

The annual unit costs of facilities were determined by first obtaining the average unit capacity of different facilities and subsequently obtaining average fabrication and installation costs from surveys of cost information obtained from various manufacturers and water agencies. Assumptions used in determination of the annual unit costs include interest rates of 4.5 percent and the appropriate average life spans of facilities, based on data from local water supply agencies. All annual unit costs were adjusted to 1963 cost level by using the Engineering News-Record Construction Cost Index. The annual unit costs of each of these facilities are presented, by economic areas, in Table 10.

TABLE 10

ANNUAL UNIT COSTS OF WATER SUPPLY FACILITIES BY ECONOMIC AREAS IN THE COASTAL PLAIN OF LOS ANGELES COUNTY

Economic area	Pump[a]	Booster	Connector	Storage[b]
1	$1,800	$460	$1,850	$5,800
2	2,300	460	1,850	6,000
3	2,400	460	1,850	6,000
4	1,960	460	1,850	5,700
5	1,200	460	1,850	5,500
6	1,500	460	1,850	5,700
7	1,500	460	1,850	5,600
8	1,400	460	1,850	5,500
9	1,400	460	1,850	5,500
10	1,700	460	1,850	5,600

a. Variations in annual unit costs were due to differences in right-of-way costs, average depth of well, and average diameter of well.
b. Variations in annual unit costs were due to differences in right-of-way costs.

Unit Cost of Electrical Energy

Annual unit cost of electrical energy and electrical service connection charges were determined from the current rate schedules of the Southern California Edison Company, a major supplier of electrical energy in the area. These cost data were subsequently used to determine the annual cost of energy and the charge for service connection of pumping and booster units, each having a 100-horsepower rated capacity.

These rate schedules were translated into three cost equations to account for the changes in rates with increasing electrical energy use. Each equation is related to use factors for a 100-horsepower booster or pumping unit. These equations are presented below:

1. For use factors (UF) from 0 to 15 percent,

$$U_{e1} = \left[\left(\frac{0.0136 \text{ Dollars}}{\text{KWHR}}\right)\left(\frac{6530 \text{ KWHR}}{\text{HP-YR}}\right)(UF)(HP_u)\right]$$

2. For use factors from 15 to 30 percent,

$$U_{e2} = \left[\left(\frac{0.0082 \text{ Dollars}}{\text{KWHR}}\right)\left(\frac{6530 \text{ KWHR}}{\text{HP-YR}}\right)(UF) + 5.4\right](HP_u)$$

3. For use factors from 30 to 100 percent,

$$U_{e3} = \left[\left(\frac{0.0064 \text{ Dollars}}{\text{KWHR}}\right)\left(\frac{6530 \text{ KWHR}}{\text{HP-YR}}\right)(UF) + 9.0\right](HP_u)$$

Derivation of the above three equations, together with a detailed discussion of unit costs, is presented in Attachment No. 7.

For estimating the annual service charge for electrical connections for pumps and boosters, an annual unit connection charge equal to $650 for each 100-horsepower unit of pump or booster was used in this study.

Annual Cost of Laterals

Annual costs for laterals in the Coastal Plain were determined to complete the total cost of proposed future facilities. These laterals supplement the existing and proposed future primary distribution system. The annual costs of laterals were based on an average unit cost of $1.90 per foot of pipe per inch of diameter. This unit cost includes the cost of all appurtenances and regulation stations and is based on costs of past construction projects compiled by the City of Los Angeles Department of Water and Power. The annual costs of laterals from 1963 to 1990, for the five selected plans of operation, ranged from $180,000 to $360,000 annually.

The method used to determine annual costs and 1963 present worths of costs is shown in more detail in Attachment No. 8.

Annual Costs of Recharge Facilities

Annual costs were determined for the existing spreading grounds and injection barriers, and proposed or potential injection barriers that are assumed to be operated by the Los Angeles County Flood Control District. Annual costs for the West Coast Basin, Santa Monica Basin, Dominguez Gap, and Los Alamitos Gap Barrier Projects were estimated by analyzing cost estimates presented in feasibility reports by the Flood Control District. Items considered in the cost analyses of barrier projects included connection to the primary distribution system, distribution lines from the connectors to injection wells, recharge wells, observation wells, measuring equipment, and chlorination facilities. The costs for each of these four projects are given in Table 11.

TABLE 11

ESTIMATED ANNUAL COSTS OF INJECTION BARRIERS IN THE COASTAL PLAIN OF LOS ANGELES COUNTY[a]

Barrier project	Estimated range of annual costs[b]
West Coast Basin	$253,000 to $327,000
Los Alamitos	$139,000 to $234,000
Dominguez Gap	$100,000 to $144,000
Santa Monica	0 to $ 47,000

a. Includes the costs of existing, proposed, and assumed facilities.
b. Varies with each plan of operation.

The method used to determine the cost of assumed barrier facilities is presented in Attachment No. 8.

For spreading of untreated water in the existing recharge basins in the Montebello Forebay, a nominal cost of $1.25 per acre-foot for operation and maintenance of these spreading grounds was included in this study. This amount is based on estimates made by the Los Angeles County Flood Control District.

CHAPTER III. FORMULATION AND ANALYSES OF ALTERNATIVE PLANS OF OPERATION

The operational and unit cost data were used in the analyses of alternative plans of operation for determining the required surface and ground water supplies and facilities and related costs. This information, along with cost comparisons of alternative plans, forms the basis for selection of an optimum plan of operation.

Described in this chapter are the formulation of alternative plans of operation, the simulation of coordinated operation of surface and ground water facilities in the analyses of each plan of operation; the economic comparison of alternative plans; and finally, the selection of five plans of operation for detailed analysis.

Formulation of Alternative Plans of Operation

Alternative plans of operation were formulated within certain bounds. The first requirement was that the usefulness of ground water basins as media for the storage and transmission of fresh water would be preserved. The second requirement was that, under each plan, ground water supplies and related facilities must be used in coordination with surface supplies and facilities to satisfy the physical demands specified in the objective of the investigation. The coordinated use of surface and ground water supplies and facilities is schematically illustrated on Plate 6. Another requirement was that each plan must be expressed in terms of a water supply schedule that was designed to meet identical schedules of water demands. The identical schedule was assumed because of the anticipated small changes in demand with change in price of water.

Furthermore, all plans of operation were handled in the same manner for consistency and convenience. Each alternative plan for meeting the future water demand schedules was expressed in terms of a schedule of annual ground water extractions from the study area. The remaining demand to be met by imported surface water was identified as a complementary schedule to the corresponding plan of ground water extraction.

Because the required product of this phase of the investigation was the development of operational and economic information that would be used as a guide in postulating the optimum management of ground water basins, it was necessary to describe the relationship between operational variables and the operational-economic effects of such variables. To obtain the required information, the variable factors of operation were identified and the operating limits for each variable were established. Within these limitations, operational schedules were established for each variable, and these schedules were combined to formulate alternative plans of operation.

The range of operational possibilities for meeting the water demands of the study area is wide with respect to combining the use of surface and ground water supplies and facilities. All the demands for delivered water during the study period could be met either with imported surface water or with locally pumped ground water presently stored in the aquifers and supplemented by annual deep percolation of freshwater and subsurface inflow. The imported water could be delivered through an all-surface distribution system or by an all-ground-water system. Between these extremes, the water demands could be met by many variations of coordinated use of surface and ground water supplies and facilities.

Operational possibilities for utilizing the ground water in storage are also wide. Under a plan of operation designed to halt saline intrusion by the creation of a seaward freshwater gradient in the aquifers, the amount of ground water in storage would increase, because the present water levels are far below sea level in most of the Coastal Plain. In the plans where freshwater barriers would be used to halt saline intrusion, the amount of ground water in storage could either increase, remain unchanged, or decrease. The alternative plans of operation that were studied in the investigation encompasses the entire range of possible variations.

Operational Variables

The controllable factors in the operation of the ground water basins are the timing, amounts, and location of both extraction and artificial replenishment. However, in this study, the locations of spreading and injection projects were fixed. In addition, the method of preventing saline intrusion was a factor of major consideration. These factors were expressed in terms of four operational variables: (1) spreading schedule of imported water at Montebello Forebay, (2) methods of preventing saline intrusion, (3) pattern of ground water extraction, and (4) schedules of ground water extraction.

A group of fixed factors--the deep percolation of applied water, precipitation, stormflow, rising water, and reclaimed water--were also expressed as schedules of future ground water replenishment. These schedules of uncontrollable, or fixed, ground water replenishment were applied to all plans of operation without variation, along with subsurface inflow schedules at the Orange County-Los Angeles County boundary, the Whittier Narrows, and the Los Angeles Narrows.

Limitations on Operational Variables

Before combining the operational variables to formulate alternative plans of operation, operational limitations on some of the variables were established, where applicable, to assure that all the plans studied were physically possible. These limits also reduced the number of plans to be studied to a reasonable range. Limitations were established on the spreading at Montebello Forebay, method of preventing sea-water intrusion, and the pattern and amounts of extraction.

Spreading at Montebello Forebay. As mentioned in Chapter II, it was concluded that there would be no advantage in constructing additional spreading grounds. The feasibility and necessity of establishing limits on the annual amounts of spreading of local and imported waters at Montebello Forebay, therefore, were based on continued use of existing spreading grounds which have more spreading capacity than the amount of spreading considered for this study. Two conditions were analyzed in studying possible limitations: (1) the availability of imported water to be spread and (2) the waterlogging that might result from sustained spreading of large amounts of water.

The availability of imported water to be spread at Montebello Forebay would be limited by the total amount of imported water deliverable to the Coastal Plain and the varying need to meet applied water demands with imported water. This availability varies with each plan of operation. The limitation was determined by first computing the upper limit of imported water that could be delivered, by analyses of delivery systems, and then determining, for each plan, the amount of imported water required to meet the applied water demand and the injection demand to prevent saline intrusion. The difference between the two amounts was considered to be available for spreading. Alternative plans were formulated that would keep the annual amounts of spreading equal to or less than the annual amount of imported water available for spreading.

The spreading of imported water would also be limited by high water tables that may cause waterlogged conditions in or away from the spreading area. The waterlogging limitation on spreading varies with the amounts and locations of extraction. An approximate relation between waterlogged conditions and the combination of spreading and extraction schedules was established by preliminary analyses of water level elevation responses of many plans of operation under the 1956-57 pumping pattern.

This relationship was determined by plotting the maximum sustained annual amounts of spreading for each of the selected extraction schedules that would not cause waterlogging. A line of best fit was drawn through the plotted points to represent the approximate relationship. The graph showing this relationship is shown on Figure 4.

Figure 4 also shows the approximate mandatory minimum amount of pumping that has to be continued to prevent waterlogging that would result from natural recharge, without spreading of imported water. This amount was approximately 127,000 acre-feet, which is 40 percent of 318,000 acre-feet, the amount extracted in the water year 1956-57.

By using the graph, plans of operation were formulated that apparently did not produce waterlogging; however, a further check was needed. For

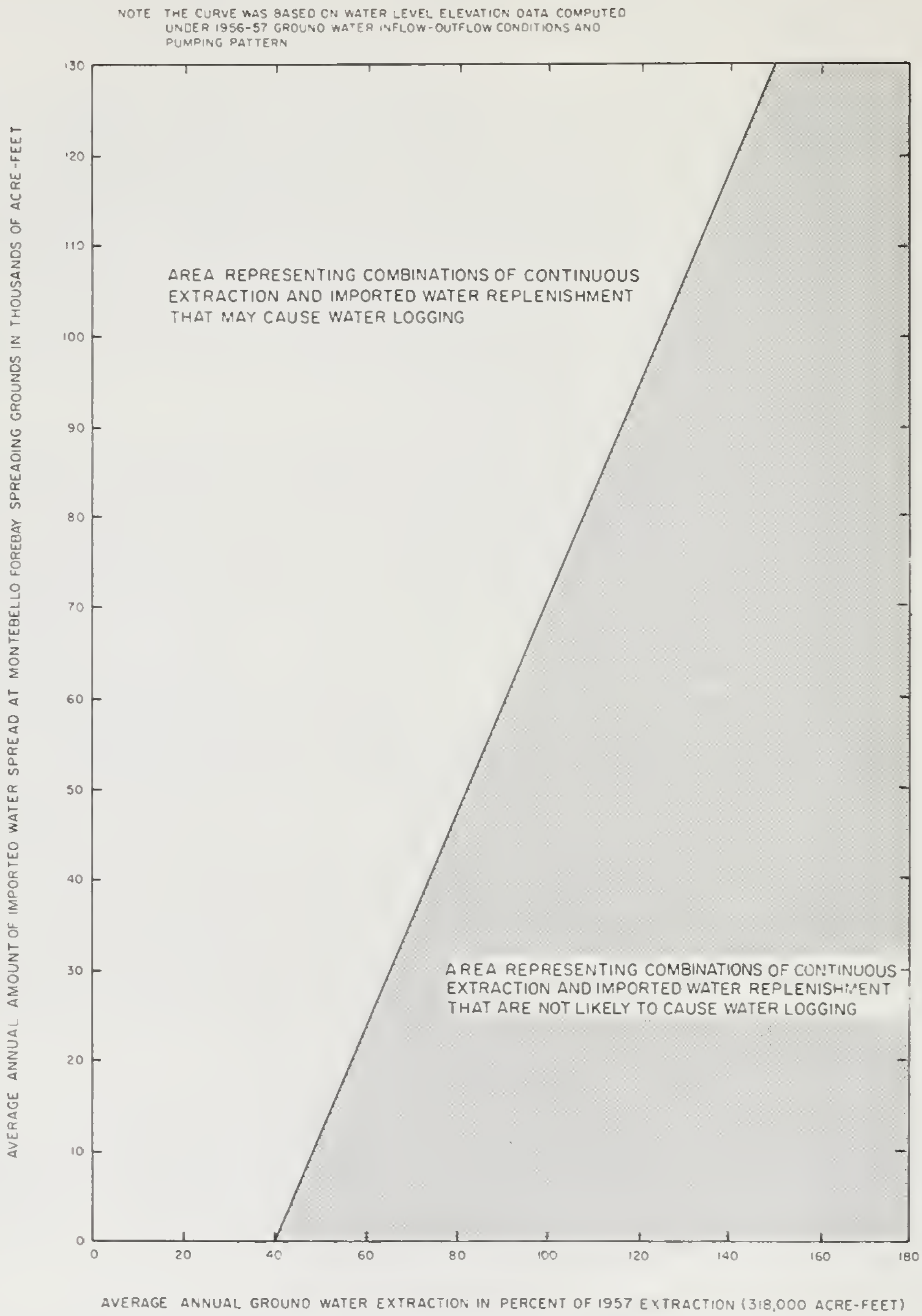


Figure 4

RELATION BETWEEN APPROXIMATE LIMITATION ON SPREADING OF IMPORTED WATER AT MONTEBELLO FOREBAY SPREADING GROUNDS AND THE AMOUNT OF GROUND WATER EXTRACTION this purpose, a computer program was written that checked for waterlogging and modified spreading schedules downward until waterlogging in the Coastal Plain was eliminated. For this check, the annual average water level elevations in all nodes in the unconfined areas were investigated during the study period. When the water level elevations rose to within 20 feet of the average ground surface elevations of the nodes, waterlogging was considered to occur. All plans of operation studied were checked by this procedure.

Methods of Preventing Sea-Water Intrusion. As stated earlier, one of the physical objectives was to halt sea-water intrusion into the Coastal Plain, thus preserving the functional usefulness of the ground water basins. To be consistent with this objective, schemes of operation that would allow continued sea-water intrusion were discarded, and alternatives were limited to operational plans which prevented sea-water intrusion.

A cursory study of various methods of preventing sea-water intrusion indicated that the method using freshwater-injection barriers would be more economical in the Coastal Plain than the methods in which pumping troughs are developed or impervious materials are placed in the aquifers along the seacoast. Accordingly, the freshwater-injection barrier was adopted as the only barrier approach incorporated in the plans of operation.

Another method of preventing sea-water intrusion is to develop a seaward gradient in the water levels within the basin's aquifers. An analysis of this procedure as compared with constructing a barrier could not be performed simply, because of the many complex factors involved. This method of halting sea-water intrusion was, therefore, incorporated in the alternative plans of operation, and the operational-economic significance of both methods was evaluated.

Pumping Pattern. Among the variables that affect the cost of operating the ground water basins is the pumping pattern or the relative location of various extractions. If heavy pumping is concentrated in an area where inflow of ground water is limited by low transmissive characteristics of the ground water basins, pumping costs for a given amount of water would be more than the pumping cost resulting from concentrated pumping in an area where the flow of ground water is relatively unrestricted. This is because water levels would decline more rapidly in the area of limited transmissibility. On the other hand, a concentration of heavy pumping at locations adjacent to the spreading grounds in the forebay area (an area of high transmissive characteristics) would minimize the use of the transmissive and storage capacities of ground water basins, thus affecting overall costs. In addition, if extractions are large near the ocean, costs of freshwater barriers would be correspondingly increased.

An infinite number of variations in the distribution of pumping throughout the Coastal Plain is possible. However, to keep the analyses of this variable within a manageable number, simplifying limitations that were found to be valid for the Coastal Plain were imposed. Variations in relative magnitude of pumping were assumed to occur only between operational areas, with each operational area being operated as a unit, and the existing pattern within any operational area was assumed to be the same in the future. In other words, the relative magnitude of pumping occurring in each node would remain the same with respect to the pumping done in other nodes within each operational area.

A limited number of pumping patterns, adequate to derive a general relationship between the total cost of operation and the pumping pattern, were selected. This selection was based on evaluation of operational and economic effects of extreme variations in pumping patterns.

<u>Ground Water Extraction</u>. An important variable in a study of management of ground water basins is the annual amount of ground water used. This variable significantly affects the cost of meeting the applied water demand because the difference between the applied water demand and local ground water production must be met by imported surface waters. At the same time, the annual amounts of pumping and replenishment affect pumping lifts, pumping plant requirements, use factors of pumping plants, and surface storage tank needs.

Earlier, it was mentioned that continuous extraction of less than about 40 percent of the 1956-57 extractions would cause waterlogging in several areas of the Coastal Plain. This finding established that the lower limit of the amounts of extraction would be about 40 percent of the 1956-57 amount.

Operational requirements also imposed a limitation on the annual amount of sustained extraction. As discussed previously, for each of the three periods considered for installed capacity of the primary distribution system, the maximum amount of imported water that can be delivered was established, the applied water demands by years were projected, and the schedule of total delivered water demands was established. The amount of extraction had to be sufficient so that the total amount of water supply, comprising extracted ground water and imported water, was equal to the total demand for delivered water. For the period before 1972, the lower limit on the annual amount of extractions was, coincidently, found to be approximately 40 percent of the extractions in 1956-57.

For the upper range, no physical limitation could be found except as an operational limit. To be consistent with the assumption previously mentioned, that each economic area would be operated as a unit, the amounts of ground water extraction in one economic area could not be larger than the amount of the applied water demand within that area less the net import from and export to other economic areas or from outside the study area. This amount was determined by subtracting the total amount of water estimated to be delivered to the area during a given year from the applied water demand for that year. All plans of operation were formulated so that the varying annual amounts of extraction did not exceed this limitation throughout the study period.

Schedules of Operational Variables

Within the limitations discussed previously, schedules were prepared for each operational variable and were combined for the formulation of alternative plans of operation. These schedules are described in this section.

Spreading at Montebello Forebay. The sources and average annual amounts of water conserved in the spreading grounds and streambed at Montebello Forebay are:

1. Rising water and storm runoff, 48,000 acre-feet.

2. Reclaimed water, 13,000 acre-feet.

3. Untreated imported water, in amounts that vary with each plan of operation.

The minimum annual total of 61,000 acre-feet of water from the first two sources would be spread in the Montebello Forebay. This amount was considered to be the minimum limit for all plans of operation. In addition, varying amounts of imported water would be spread. Five spreading schedules for imported water in the Montebello Forebay are shown in Table 12.

TABLE 12

SCHEDULES OF IMPORTED WATER SPREADING AT MONTEBELLO FOREBAY, COASTAL PLAIN OF LOS ANGELES COUNTY, FROM 1963 THROUGH 1990

In acre-feet per year

Schedule number	Average amount of imported water spread
1	0 - 15,000
2	15,000 - 30,000
3	30,000 - 45,000
4	45,000 - 60,000
5	More than 60,000

Note that the schedules for spreading were classified according to ranges of average amounts of spreading rather than the specific amounts of spreading, even though the spreading of imported water is a controllable factor in the actual operation of ground water basins. The use of ranges was adopted because selected spreading schedules were annually adjusted so that the economic evaluation and the resulting water level elevations of the alternatives would be consistent with the assumption that the subsurface flow into the Montebello Forebay and the water level in a boundary node in the forebay would remain fixed.

In addition, although this assumption was valid when the change in the water level elevation in the Montebello Forebay remained within the historical variation, it was recognized that the water level at the boundary of the forebay might not remain fixed for plans with a larger recession of water levels in the future. Under these plans which result in lower water levels than those which historically occurred, the subsurface inflow determined by the mathematical model could be significantly higher than the actual subsurface flows which might arise at the Whittier Narrows. To eliminate the effect of these variations, the original spreading schedule was increased by the amount of the difference between the assumed fixed flow and the computed flow for these plans. This addition was made because, in the operational analysis of alternative plans, these differences in the amount of subsurface flow had the same physical and economic significance as the imported water spread. The amount of subsurface flow from the model varied within a range; thus, schedules of spreading could be presented only as a range of amounts, rather than as schedules of specific amounts. This approach permitted the handling of subsurface flows with the minimum error.

Methods of Preventing Sea-Water Intrusion. As mentioned before, two methods for preventing sea-water intrusion were selected for study. These methods are further discussed as method 1 and method 2:

> Method 1--Utilize the existing freshwater barriers and, in addition, construct the freshwater-injection barriers proposed by the Los Angeles County Flood Control District and additional barriers as needed. The amount of ground water in storage under this method may be increased, unchanged, or decreased, thus allowing a wide range of operation.
>
> Method 2--Utilize the existing freshwater barrier, consisting of about 1-1/2 miles of injection wells, but do not construct any additional barriers. The amount of ground water in storage must be increased to create a seaward gradient of freshwater by imposing only small amounts of pumping and large amounts of artificial recharge.

Pumping Pattern. A very large number of different pumping patterns is possible. For this study, however, analysis was limited to 17, which are representative of a wide range of possible patterns. Of these, four were ultimately selected for detailed study in evaluating the operational and economic effects of pumping patterns on the plans of operation.

The 17 pumping patterns that were analyzed are presented in Table 13, in terms of a percentage of the total extractions from the ten operational areas. Note that a variation in a pumping pattern represents a shift in the relative amount of the total extractions which would be pumped in each operational area; the present pattern of pumping within each operational area was assumed to continue in the future.

TABLE 13

PUMPING PATTERN FOR EACH OPERATIONAL AREA IN THE COASTAL PLAIN OF LOS ANGELES COUNTY

In percent of total extraction

Pumping pattern number / Operational area number	1[a]	2	3	4	5	6	7[b]	8	9	10	11	12	13	14	15	16	17[c]
1	1.95	2	3	2	2	4	1	2	3	6	5	2	4	2	2	6	1
2	1.32	2	2	2	2	1	0	1	0	0	0	1	2	1	1	0	0
3	11.84	15	6	12	20	9	22	11	11	20	18	12	7	11	19	16	22
4	20.44	25	17	15	25	19	24	20	13	23	19	22	20	14	24	20	24
5	7.50	8	7	10	7	6	8	7	4	7	6	8	8	9	7	6	8
6	6.29	2	10	7	7	7	b	7	23	11	4	5	5	6	6	4	c
7	9.50	14	9	6	14	9	11	9	6	0	9	10	11	6	13	9	11
8	13.20	15	12	20	7	15	19	13	9	16	14	14	14	18	7	15	19
9	15.60	5	20	6	10	16	b	18	22	0	11	13	13	15	15	10	c
10	12.36	12	14	20	6	14	15	12	9	17	14	13	16	18	6	14	15
TOTALS	100.00	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

a. Pumping pattern that existed in 1956-57.
b. Pumping amount in the West Coast Basin, which is roughly represented by Operational Areas 6 and 9, is held at the 1956-57 amount (approximately 69,700 acre-feet) throughout the study period and the percent of pumping in Operational Areas 6 and 9 with respect to the total amount pumped in the West Coast Basin is 30 to 70 percent, respectively.
c. Pumping amount in the West Coast Basin, which is roughly represented by Operational Areas 6 and 9, is held at a constant amount throughout the study period but varies with each operational plan and the percent of pumping is approximately equally divided between Operational Areas 6 and 9.

Pumping pattern No. 1 (Plate 4) represents the pattern that existed in 1956-57. For that year, a detailed study of the extractions in the Coastal Plain was conducted with respect to locations and amounts, and the results were presented in Appendix B. This pumping pattern approximates the pattern that existed in 1962 before the voluntary pumping cutback was initiated in the Central Basin. Examination of pumping pattern No. 1 in Table 13 shows that the largest percentage of extractions occur in operational areas 4, 8, and 9, with 20 percent, 13 percent, and 16 percent of the total extraction, respectively.

To note the effects of pumping pattern variations, other pumping patterns were compared with pumping pattern No. 1, which is based on the historical pumping pattern of the study area. Pumping pattern variations are presented in Table 13.

<u>Schedule of Ground Water Extraction</u>. Imposed on each plan was a specific schedule of extractions, which in most cases, was held at a constant annual amount throughout the study period. The average annual amounts of extraction during the study period for the plans studied were varied over a wide range. For convenience in identification, the average annual amounts of extraction for the plans were grouped into 10 percent increments of the amount extracted in 1956-57. These increments were sufficiently small to meet the requirement for identification. The code numbers for 20 consecutive increments and corresponding amounts of extraction used in this investigation are presented in Table 14. The schedule of average annual extraction was limited to 20 consecutive increments to stay within the physically feasible range.

TABLE 14

SCHEDULES OF AVERAGE ANNUAL EXTRACTION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

Extraction code number	Extraction, in percent of total 1956-57 extraction	Average annual extraction, in thousands of acre-feet
1	40- 50	127-160
2	50- 60	160-190
3	60- 70	190-223
4	70- 80	223-254
5	80- 90	254-286
6	90-100	286-318
7	100-110	318-350
8	110-120	350-381
9	120-130	381-413
10	130-140	413-445
11	140-150	445-477
12	150-160	477-509
13	160-170	509-540
14	170-180	540-572
15	180-190	572-604
16	190-200	604-636
17	200-210	636-668
18	210-220	668-699
19	220-230	699-731
20	230-240	731-763

The possibility of varying the annual rate of extraction between 1972 and 1990 was considered as a feasible mode of operation in the determination of a schedule of ground water extraction. However, it was decided to make the economic evaluation of approximately constant extraction schedules because it was possible to evaluate qualitatively the economics of varying the extraction schedule. It was known through the qualitative evaluation that larger amounts of annual extraction in the forebay area would provide more economic advantage to the water users than the extraction of ground water specified in the selected schedule. This is because of a saving that is made in providing water service in the near future and because under the present worth concept the impact of this saving is larger than the impact of the saving to be made in some later years. If detailed information is needed by local agencies, however, it is recommended that local agencies make a detailed feasibility study of ground water basin management under this approach.

It was mentioned earlier that if pumping is cut back to 40 percent of 1956-57 extraction, waterlogging is likely to occur in portions of the Coastal Plain. At the other extreme, the upper limit of annual extractions is related to the applied water demands for a particular year; this limit reaches a peak of approximately 340 percent of 1956-57 extractions in 1990, if the annual amount of extraction is varied throughout the study period.

For the period prior to 1972, the lower limit on the amount of annual extraction was also influenced by the delivery capacities of the imported water facilities. As previously discussed, a schedule showing the upper limit of deliverable amount of imported water supply was established for the study period after analyses of feeder systems. Because the applied water demand was assumed to be fixed, the difference between the applied water demand and the imported water schedule for each year had to be made up by ground water.

The maximum amounts of imported water concluded to be available during the study period are shown in Table 15. The schedule of minimum amounts of ground water extractions needed to satisfy the applied water demand in the Coastal Plain is shown in Table 16. The increase in the minimum amount of extractions required in the Coastal Plain (Table 16) is due to the increase in applied water demand and the fixed delivery capacity of the imported water facilities up to the year 1972.

It was previously stated that the imposed extraction amount, in most plans of operation, was held constant throughout the study period. However, when the imposed amount of extraction was less than the lower limits of ground water extraction, the lower limits were used. For those plans, the established coding system (Table 14) still applies because the average annual extraction over the 28-year study period would not be changed significantly.

Numbering System for Combined Schedules

For ease of identification of each of the alternative plans of operation with respect to replenishments, methods of preventing sea-water intrusion,

TABLE 15

MAXIMUM AMOUNT OF IMPORTED WATER SUPPLY FROM
THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA
ESTIMATED TO BE AVAILABLE FOR USE IN THE
COASTAL PLAIN OF LOS ANGELES COUNTY
DURING THE STUDY PERIOD*

In acre-feet

Year	Quantity
1962-63	659,000
63-64	659,000
64-65	659,000
65-66	659,000
66-67	659,000
1967-68	659,000
68-69	659,000
69-70	659,000
70-71	659,000
71-72	1,158,000
1972-73	1,158,000
73-74	1,158,000
74-75	1,158,000
75-76	1,158,000
76-77	1,158,000
1977-78	1,158,000
78-79	1,158,000
79-80	1,158,000
80-81	1,158,000
81-82	1,158,000
1982-83	1,231,000
83-84	1,231,000
84-85	1,231,000
85-86	1,231,000
86-87	1,231,000
1987-88	1,231,000
88-89	1,231,000
89-90	1,231,000

*Estimated amounts were limited by the delivery capacity of the primary distribution system which was assumed to be operated under criteria selected for this investigation.

TABLE 16

MINIMUM EXTRACTION REQUIRED FOR THE
COASTAL PLAIN OF LOS ANGELES COUNTY
ESTIMATED FOR PERIOD BETWEEN 1963 AND 1972

In thousands of acre-feet

Year	Minimum required extraction*
1963	0
64	36
65	89
66	138
67	178
1968	213
69	230
70	260
71	276
72	292

*Minimum amount required to meet applied water demand when the scheduled amounts of waters imported by the City of Los Angeles and from the San Gabriel Valley are fully utilized and when the injection schedule proposed by the Los Angeles County Flood Control District is used.

pumping patterns, and annual amounts of extraction, the schedule numbers for each variable shown in Tables 12, 13, and 14 were combined to make up a four-digit number or, in some cases, five- and six-digit numbers. The first number identifies a spreading schedule at Montebello Forebay; the second, the method of preventing sea-water intrusion; the third, the pumping pattern, in some cases consisting of two digits; and the last, the pumping schedule in the Coastal Plain, also in some cases comprising two digits and separated by a hyphen. For example, the code of Plan 113-4 provides an identification number for the operational plan and identifies the variables of the plan as: spreading schedule _1_, which specifies a range of spreading between 0 and 15,000 acre-feet; method _1_, in which sea-water intrusion is prevented by additional and existing freshwater barriers; pumping pattern _3_, in which the extractions are concentrated in operational areas 4, 6, 8, 9, and 10; and pumping schedule _4_, in which the average annual total extraction was between 223,000 and 254,000 acre-feet.

There could be a total of 3,400 different plans of operation if all possible combinations were made of all schedules of operational variables. However, by interpreting results of preliminary analyses of many plans, it was possible to limit the number of alternative plans studied to 58 and still obtain the needed information. The operational and economic results of the 58 plans were further analyzed to select five plans for additional refinement.

Operational Analyses of Alternative Plans

In this portion of the study, essential results of all the separate analyses of surface and ground water supplies and facilities that were described earlier were integrated for determining the requirements of all items affecting the comparison of costs of each alternative plan of operation. The determination of requirements of these items was accomplished in three major phases. In the first phase, the required annual amounts of imported water to meet the demands for applied water and for artificial recharge projects were determined and subsequently the annual cost of each component of imported water was obtained. In the second phase, the requirements for surface and ground water facilities considered in this study to meet the applied water demand were determined, as were the costs of those facilities. In the final phase, required injection barriers and their related costs were determined. The work for these three phases was particularly suited for data processing machines and electronic computers because the solutions required handling of a large number of. operational data and making lengthy computations.

The methods for determining the annual amounts of water supplies and facilities, and their related costs, required through 1990 are presented in the following discussions. This is followed by a brief discussion on the application of a digital computer to handle the compilation, computation, and tabulation of operational and economic data that were required for this investigation.

Methods for Determining Water Supplies and Facilities

In presenting the methods used for determining the annual amounts of water supplies and facilities, and their related costs, the discussion has been divided into imported water supplies, facilities required to meet applied water demand, and facilities required to meet artificial recharge requirements.

Imported Water Supplies

In determining the amounts of water imported to meet annual applied water demands, the water supplies imported from the Owens-Mono area and the San Fernando and San Gabriel Valleys, as well as the water supply from the ground water basins within the Coastal Plain, were subtracted from the annual applied water demand of the Coastal Plain. The remaining applied water demand was considered to be met with the Metropolitan Water District's softened water, filtered water, and untreated water, in that order. For each of the imported waters from different sources and for each different type of Metropolitan Water District water, upper limits of the amounts that could be depended on were established for this computation. The upper limits for the District's total water supply to the Coastal Plain are shown in Table 15.

The annual amounts of filtered water required for injection along Santa Monica Bay and Los Alamitos Bay were computed for each operational plan. The annual amount of filtered water required by the Dominguez Gap injection facilities to establish a mound to halt sea-water intrusion was presumed to be 17,000 acre-feet in 1968 and 4,000 acre-feet each year thereafter to maintain the mound. The amount of untreated imported water supplied to spreading grounds at Montebello Forebay is an operational variable for each plan. Thus, the annual amounts are reflected by spreading schedules for the alternative plans of operation.

By the above procedure, the annual amounts of imported water, from the present through 1990, were determined for each of the following seven components: (1) water imported by the Los Angeles Department of Water and Power, (2) pumped water imported from the San Gabriel Valley, (3) reclaimed water from the San Gabriel Valley, (4) the Metropolitan Water District's softened water for domestic use, (5) the District's filtered water for domestic use, (6) the District's filtered water for injection, and (7) the District's untreated water for spreading.

The annual cost of each component of water supply was determined by multiplying the annual amount of each component with the corresponding unit cost of water. In addition, to develop and analyze a wide range of economic information for the selected plans of operation, the annual costs of water supplied by the Metropolitan Water District were determined under three different price-of-water assumptions. These assumptions are briefly discussed in Chapter II and are fully described in Attachment No. 7.

Facilities Required to Meet Applied Water Demand

In analyzing the plans of operation comparatively, surface storage, primary distribution facilities, and well pumping facilities were combined so as to meet, most economically, the maximum hourly water demand which was determined by analyses of data relating to past water requirements. This water demand is the sum of fire flow requirements and the peak hourly water demand on a maximum water demand day and conforms with the requirements of the National Board of Fire Underwriters. A separate study was conducted on the fire flow requirements in addition to the peak hourly water demand. Figure 2C (page 11), illustrates the combination of facilities employed to meet the peak hourly demand on a maximum water demand day. During this hour of peak flow, it was assumed that the primary distribution system would be utilized to its maximum flow capacity. As shown on the figure, the remaining portion of the maximum hourly demand was presumed to be met by combined flow from surface storage and well pumping facilities which may include boosting facilities. Boosting facilities were considered because the well pumping facilities are comprised of two types: those pumping directly to operating head and those pumping first to atmospheric pressure for aeration, filtration, and treatment of water with subsequent boosting to operating head.

Many possible combinations of storage, pumping, and boosting facilities could satisfy this remaining portion of the maximum hourly water demand. However, the most economical combination was derived and used to insure the validity of the cost comparisons of alternative plans of operation.

To obtain the most economical combination of facilities, a general cost equation was written that includes pumping, boosting, and storage cost components. This cost equation takes the form:

$$C_t = C_p + C_b + C_s;$$

where C_t is a total cost, C_p is a pumping cost, C_b is a boosting cost, and C_s is a surface storage cost. To formulate this equation, each of the three cost components was reduced to the number and unit costs of facilities, electrical energy costs, and service connection charges. A detailed discussion of the annual unit cost data used in the determination was presented in Chapter II, and an expanded discussion of the above equation is presented in Attachment No. 9.

In this study, it was found to be most convenient to express the number of pumping, boosting, and storage facilities in terms of flow capacity of boosters (Q_b) that lift water from the ground surface to operating head. This was possible because flows from boosters, pumps, and storage tanks are interrelated, and this relationship could be expressed by a series of equations. After making the necessary combinations and substitutions, the cost equation shown above was transformed to the equation shown below:

$$Q_b = \frac{(D_m - Q_f)}{F} - \left(\frac{D_d}{0.416F^2U_s}\right)\left[(L_d + L_g)(X + 0.00349U_p) + Y + \frac{U_b}{3.82}\right]$$

Where:

Q_b = Rate of pumping booster units, in cubic feet per second

D_m = Maximum flow rate of water required under peak conditions with maximum flow equal to the peak hourly demand on the day of maximum water demand, plus the fire flow, in cubic feet per second

Q_f = Rate of peak flow from feeder supply, in cubic feet per second

F = Head relationship between the total pump capacity and the capacity of pumps pumping to sumps only

D_d = Average water demand flow rate on day of maximum demand, in cubic feet per second

U_s = Average annual cost of a surface storage unit, in dollars

L_d = Well drawdown, in feet

L_g = Distance between static water level and ground surface, in feet

X, Y = Factors substituted for constants that vary with pump use factors in energy cost equations

U_p = Average annual cost of pump units in dollars

U_b = Unit annual cost of booster pump, in dollars

The above equation gives the most economical combination of pumping, boosting, and storage facilities for cases where existing surface storage capacities were less than, or equal to, the storage capacity indirectly determined by the above equation.

However, if a comparison showed that the existing surface storage capacity was larger than that determined by the above equation, the maximum possible use of existing storage capacity was made, and the pumps and boosters were sized in a manner that would permit the combined facilities to meet the water demand for five consecutive maximum water demand days, at adequate pressure, a rating criterion of the National Board of Fire Underwriters. This criterion was imposed on each plan of operation as a minimum requirement.

When the combined capacities of the feeders and pumps thus determined were equal to or greater than 100 percent of the average hourly demand on the maximum water demand day, sufficient water was available during nonpeaking hours to fill the existing surface storage space; thus, the total existing storage space was considered to be fully utilized on the day of maximum water demand. However, when the combined capacities of feeders and pumps were less than 100 percent of the average hourly demand on the maximum day, there was not sufficient water during nonpeaking hours to completely fill the existing storage space on that day; thus, only part of the existing storage space would be utilized during any one day to meet the fire rating criterion expressed above. This portion of the existing storage capacity was called the effective existing storage capacity and was made equal to the amount of water available for storage during nonpeaking hours by the combined and continued use of pumping and feeder facilities, plus one-fifth of the remaining existing surface storage capacity that could be filled and carried over from prior "lesser demand" days. The other four-fifths was released at equal rates during the four succeeding maximum water demand days.

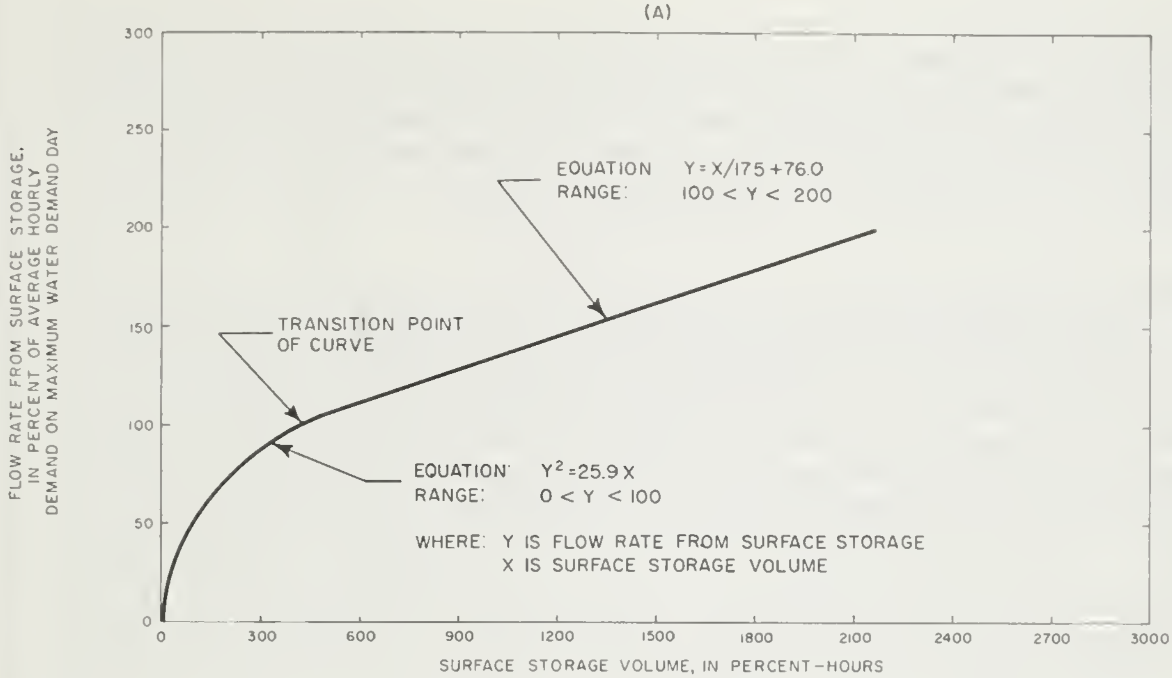
Either the existing storage capacity or the effective existing storage capacity, whichever was applicable, was converted to a release rate from storage by use of a set of equations that approximates the relation between flow rates from surface storage and surface storage volume requirements on the maximum water demand day in the Coastal Plain. This relationship and the equations are shown on Figure 5A and additional information on this relationship can be found in Attachment No. 9. The flow rates from storage and the primary distribution system were subtracted from the maximum hourly water demand to determine the required pumping or boosting capacity.

The most economical combination of pumping, boosting, and surface storage facilities can also be described in terms of the use factor of well pumping facilities. For each alternative plan of operation, a schedule of annual ground water extraction was specified for each operational area. The most economical use factor in a particular year is the specified average pumping rate divided by the peak hourly rate of pumping for the same year, as determined through the use of the equation mentioned above. For each selected use factor, there is a corresponding surface storage requirement. Figure 5B illustrates the increase in costs of surface storage facilities and the decrease in costs of pumping facilities with increasing use factor expressed in percent. The change in the costs of these two facilities is due to the necessity for increasing the volume of storage with the increase in use factor which requires a lesser number of pumps to extract a given amount of water than the lower use factor. It also illustrates the minimum combined costs, which occur at a use factor equal to 60 percent for the particular set of conditions selected for this illustration. For further details see Attachment No. 9.

For some of the plans of operation, laterals were found to be required in economic areas 4, 5, and 8, which are in the eastern portion of the Coastal Plain, in addition to feeders and laterals existing and proposed for the Coastal Plain. To determine the cost of these additional laterals, approximate alignments were set, and the laterals were sized to meet 1990 surface supply delivery requirement under various plans of operation. Based on these alignments and lateral sizes, cost estimates were made and a graph was developed showing the annual costs of additional laterals required to supply varying percentages of 1990 water demand. A graph was prepared for each affected economic area. The percentage of water demand shown on these graphs was keyed to each plan of operation because the amount of imported water required for a particular plan is equal to the water demand minus the amount of ground water extraction selected for the same plan. Thus, for each plan of operation, costs of additional laterals were estimated by using these graphs after a schedule of annual extractions was selected. Costs of additional laterals were converted to annual costs by using appropriate factors related to proper interest rates and economic life of the lateral. The costs of additional laterals included costs of excavation, pipe, installation, regulators, and other normal accessories, resurfacing, and maintenance. The analysis of additional laterals is presented in detail in Attachment No. 8.

Facilities Required to Meet Artificial Recharge Requirements

The facilities required to meet artificial recharge requirements included spreading grounds and sea-water intrusion barrier project facilities.



RELATION BETWEEN FLOW RATE FROM SURFACE STORAGE AND SURFACE STORAGE VOLUME ON MAXIMUM WATER DEMAND DAY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY

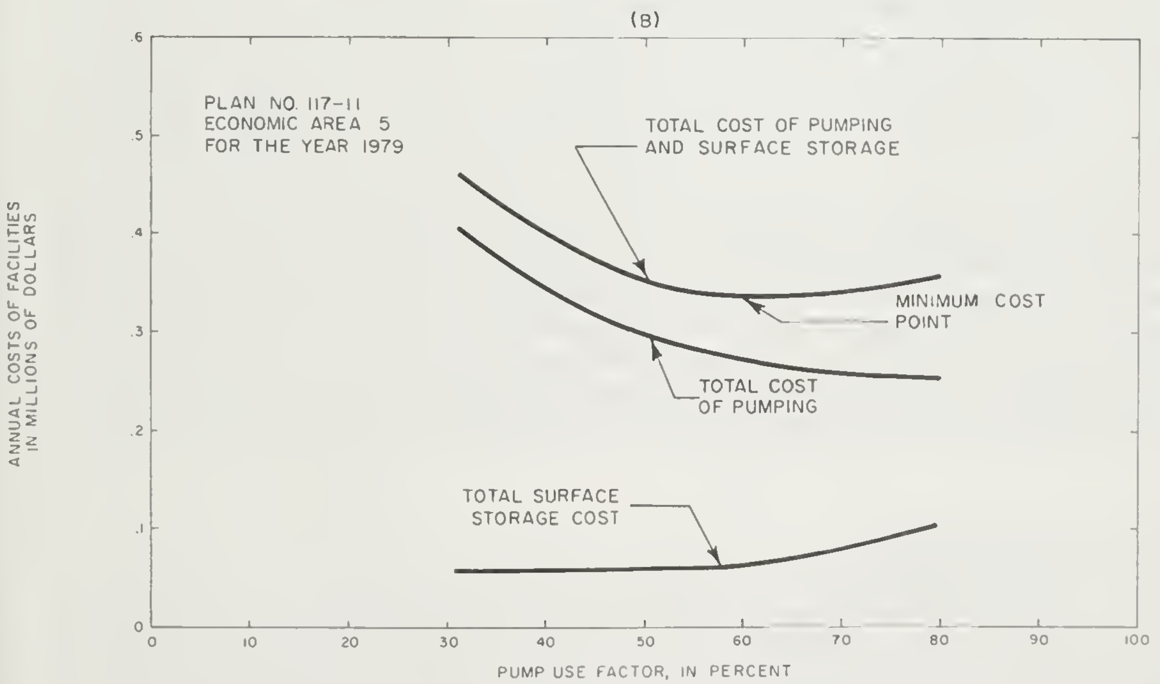


Figure 5— STORAGE CRITERIA AND PUMP USE FACTOR

As stated in Chapter II, it was assumed that the spreading ground facilities now in existence will be adequate to meet future spreading requirements and that the unit cost for the operation and maintenance of these existing spreading grounds would be $1.25 per acre-foot of imported spread water. The additional sea-water intrusion barrier facilities necessary to protect the basins against sea-water intrusion will also serve to meet additional recharge requirements.

Some of the plans of operation that would result in a landward gradient of the water level elevations adjacent to the coast would require the sea-water intrusion barrier projects proposed by the Los Angeles County Flood Control District in addition to existing projects. The proposed projects now under construction are the West Coast Basin Barrier Project, Dominguez Gap Barrier Project, and the Alamitos Barrier Project. Each of these projects was based on the hydraulic conditions which existed at the time the projects were designed. For this study, it was assumed that these proposed projects would be completed as scheduled by the Los Angeles County Flood Control District, and they would be sufficient to handle the requirements of all plans of operation which require amounts of recharge that are less than or equal to the design capacity of each project.

Costs of additional barrier facilities were approximated for the Alamitos Barrier Project, West Coast Basin Barrier Project, and a barrier project along the coast in the Santa Monica Basin. For each of these projects, designs of additional barriers and the necessary laterals extending from the primary distribution system were approximated for four selected injection rates, cost estimates were made for each of these four sets of facilities, and finally, the annual costs of facilities were computed. The selected injection rates for the Alamitos Barrier Project and the West Coast Basin Barrier Project were greater than the design injection rates of the facilities proposed by the Flood Control District to allow evaluations of plans that would require larger amounts of freshwater injection. Finally, a graph was developed for each of the three projects, showing the annual cost of each additional project for varying injection rates. The fourth project, the Dominguez Gap Barrier Project, was assumed to require barrier extensions on both termini, and the project's annual cost was treated as a fixed amount because the schedule of injection was presumed to be fixed as explained earlier in this chapter. A detailed discussion of the location of additional barriers and the manner in which the costs of these projects were determined is presented in Attachment No. 8.

Computer Application

The determination of the required amounts of water supplies, facilities, and electrical energy and their related costs was made for each of the ten economic areas, for each year from the present through 1990. The determination required handling voluminous amounts of data and a large number of lengthy computations, even for the solution of a single plan of operation. Data processing machines and electronic computers were capable of handling these computations. For rapid analyses on computers, the data were processed, all procedures and equations were arranged in logical sequences, translated into computer language, and integrated. The results of the computer analyses were arranged and tabulated. The computer analyses of the plans of operation are summarized in Attachment No. 10.

For use in the computer, the following operational data were prepared: (1) schedules of annual water demands, fire flow requirements, ground water extractions, imported water recharge, pumping lifts, and maximum feeder capacities; (2) existing capacities of wells, pumps, boosters, storage facilities, connectors to feeders, and proposed injection projects; (3) annual unit cost of all the components of imported water supply, and unit annual costs of boosters, pumps, electrical energy and service connection charges; (4) equations describing the cost relationships of additional laterals and injection facilities; and (5) assumed unit capacities of facilities.

By use of these input data and computer programs, determinations were made of pump use factors, flow rates required from each of the facilities, and amounts of imported water delivered. In many cases, flow rates of facilities were subsequently converted to the number of facilities required for each year during the period of investigation.

For the economic analyses of plans of operation, a computer was also used to determine the annual costs of water supply, facilities, and electrical energy. In the cases of additional lateral and injection facilities, annual costs were obtained directly by using cost equations developed from the relationships described earlier. Finally, annual costs were converted by the computer into present worths of costs of water supplies, facilities, and electrical energy for use in the economic comparison of alternative plans.

The operational input data as well as resulting operational-economic data were tabulated by the further use of data processing machines. As anticipated, the number of tabulations, even for one plan of operation, was very large because of the nature of the study, in that the required water supplies, facilities, and costs were itemized for each year during a 28-year study period for ten economic areas. In addition, annual water level elevations and pumping lifts of the equivalent aquifer of the Coastal Plain were tabulated for 73 polygons as well as for each of the ten economic areas.

A complete set of 12 sheets for each plan of operation contains 63 pages of tabulation. Because presenting complete sets of tables of all plans of operation in this report would be impractical, partial sets of tables are presented in Attachments No. 11 through 15. In these, summary data for the total Coastal Plain are presented for the five selected plans of operation. All tables for these plans of operation are available in the files of the Department of Water Resources. Table 17 gives

TABLE 17

TITLES OF SHEETS MAKING UP A COMPLETE SET OF DATA FOR A PLAN OF OPERATION, ATTACHMENTS NO. 11-15

Sheet number	Title of sheet
1	Summary of present worths of future costs of water supply, facilities, and electrical energy in the Coastal Plain of Los Angeles County from 1963 through 1990.
2	Estimated annual amounts of replenishment, common to all plans of operation, to the zone of saturation in the Coastal Plain of Los Angeles County under water supply conditions of mean precipitation from 1963 through 1990.
3	Estimated annual amounts of inflow and outflow at the zone of saturation in the Coastal Plain of Los Angeles County from 1963 through 1990.
4	Estimated annual amounts of water demand and water supply in the Coastal Plain of Los Angeles County from 1963 through 1990.
5	Computed annual costs of water supply in the Coastal Plain of Los Angeles County from 1963 through 1990.
6	Operational data and computed flow requirements of facilities in the Coastal Plain of Los Angeles County from 1963 through 1990.
7	Computed number of required, available, and additional facilities in the Coastal Plain of Los Angeles County from 1963 through 1990.
8	Computed annual costs of required ground water facilities in the Coastal Plain of Los Angeles County from 1963 through 1990.
9	Computed annual costs of required ground water facilities in the Coastal Plain of Los Angeles County from 1963 through 1990.
10	Computed annual charges of required electrical energy and electrical service connection in the Coastal Plain of Los Angeles County from 1963 through 1990.
11	Summary of computed annual costs of water supply, facilities, and electrical energy in the Coastal Plain of Los Angeles County from 1963 through 1990.
12	Computed biennial average ground water level elevations at each node in the Coastal Plain of Los Angeles County from 1962 through 1990.

Note: All sheets reflect data for the entire Coastal Plain; Sheets 6 through 10, showing data by economic areas, are also available but are not included in this report.

the titles and the items of data presented in the 12 sheets that form a complete set for a single plan of operation.

Economic Analyses of Alternative Plans of Operation

Using the information derived from the study of coordinated operation, the future total annual costs for each alternative plan of operation were determined as the sum of the annual costs of water supply, surface and ground water facilities, and electrical energy and service connections. These total annual costs extending through 1990 were converted into total present worth for economic comparison for all alternative plans of operation. As mentioned before, the initial economic analyses of all plans were conducted, using only one cost schedule of imported water prior to selection of alternatives for further study.

Comparison of Present Worths

A present worth of future expenditures may be regarded as the sum of money which, if now invested at a given interest rate, would provide the funds needed to pay the future costs. Thus, comparison of the present worth of costs of alternative plans of operation may be thought of as the comparison of sums needed now to provide a service for a given number of years in the future. A present worth of any future expenditures is obtained by applying the correct single-payment present-worth factor to the expenditure. In this study, present worths of all costs incurred by local agencies were based upon an interest rate of 4.5 percent.

The present worth of the capital cost of existing facilities such as feeder connectors and storage facilities were added to the present worth developed for comparison. Even though these present worths for the existing facilities represented sunk cost and did not affect the comparison, they were added to the present worth developed for comparison so that better evaluation of annual cost per acre-foot of water supply could be made. The determination of annual cost per acre-foot of total water supply was made by dividing the present worth of the total cost of water service by the discounted volume of water delivered throughout the study period.

In determining the present worths of existing storage reservoirs of the City of Los Angeles, costs of construction based on the 1963 construction cost index were determined, and the annual costs of these facilities were determined for assumed lives of the facilities. Subsequently, present worths of annual costs for the study period were determined and summed. For storage tanks and connectors, prevailing construction costs per unit of modular size storage tanks and connectors were applied to the total equivalent number of modular size facilities.

Additional present-worth data were developed for the five alternatives selected for detailed operational and economic comparisons. To provide economic information for these five plans, present worths of cost of operation from 1991 to perpetuity were estimated and added to the present worths of the cost of operation from 1963 through 1990 for corresponding alternatives.

The present worths of water service from 1991 to perpetuity were based on the assumption that the ground water basins would be operated on a safe-yield basis beginning in 1991. This assumption was made to provide common basis for comparison. However, it was known that the extension of the initiation of the safe-yield operation beyond 1990 would provide more economical water service than initiating it in 1990 under a certain combination of conditions. However, the economic evaluation of the alternatives in which a safe-yield operation would be initiated after 1991 was not made because the evaluation would provide meaningless results due to a large number of unknown and unpredictable factors. In other words, the fresh water annual inflow to the ground water in storage would be equal to the fresh water outflow from storage beginning in 1991. Furthermore, the amounts of spreading and injection were assumed to be the same as these amounts in 1990 before the safe-yield operation commences for each plan. Based on these assumptions, the amounts of average annual extractions of ground water for each plan of operation were adjusted so that the difference between fresh water inflow and outflow in the zone of saturation would be zero for each year after 1990.

After determination of the annual costs of operation for the year 1991 under these water supply conditions, the annual costs were assumed to continue to perpetuity. While this condition will not actually happen, the annual cost for the portion of the area for which water requirement is satisfied up to 1991 could be approximately equal. This is because the unit cost of water from the next unit of The California Water Plan will increase only slightly and the effect of increase in unit price is further decreased by the present worth factor. The water requirement over and above that which will exist in 1991 and considered to be met from a source common to all plans of operation and the cost consequently of that portion will be the same for each plan of operation. The annual cost from 1991 to perpetuity was converted to present worth by dividing the annual cost by the interest rate and multiplying with the correct single-payment present-worth factor. This was added to the present worth of water service from the present to 1990, to arrive at the total present worth of perpetual water service for the selected plans of operation.

In all these determinations, the 1963 cost level was assumed to be fixed during the study period. Historical costs were brought up to 1963 cost levels by applying the Engineering News Record Construction Costs Index.

Economic Comparison of Alternative Plans

In the economic comparison, the alternative plan with the least total present worth, under a particular assumption made for determination of the costs of water, was selected as the most economical plan. Because all plans were formulated to satisfy identical physical requirements, equal benefits were provided by each of the plans. Therefore, the plan with the least total present worth had the greatest benefit-to-cost ratio.

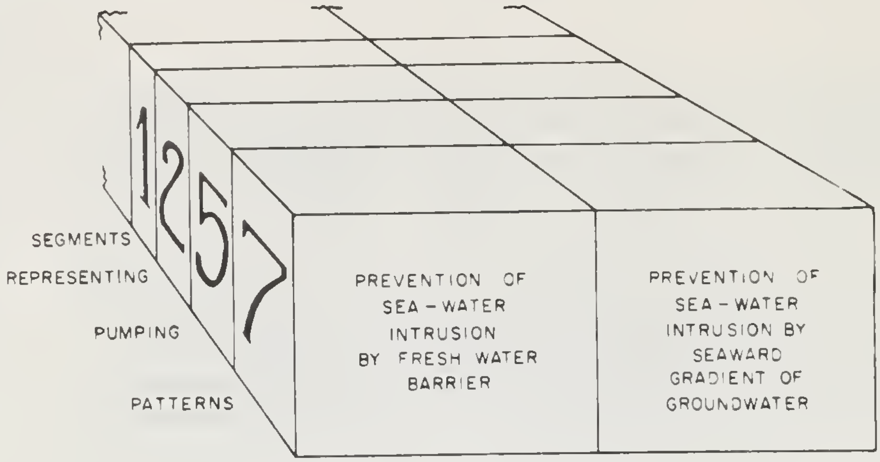
Total present worths of future costs during the study period for a large number of alternatives were compared. As previously mentioned, each alternative was made up of four variables--method of preventing sea-water intrusion, pumping pattern, spreading schedule, and extraction schedule. Figure 6 illustrates how this comparison could be systematically conducted.

Assume an infinitely long bar, a part of which is shown in the upper left-hand side of this figure. This bar has been divided into many segments; in turn, each of the segments has been further subdivided into halves. Each segment represents a pumping pattern and each half of the segment represents one of the two methods of preventing sea-water intrusion: by a freshwater barrier, or by the seaward gradient of ground water. One of these pumping pattern segments has been enlarged in the lower portion of the figure for additional clarification.

Within each half segment, three perpendicular axes are shown. The vertical axis represents the total present worth, in dollars, of each alternative plan of operation. The other two axes represent a spreading schedule of imported water and an extraction schedule of ground water for each corresponding alternative plan of operation within any one pumping pattern.

Present worths can be plotted for alternative plans of operation defined by a constant spreading schedule and a number of varying extraction schedules. In a plane of the segment representing the constant spreading schedule, a line connecting the plotted points will then represent a curve of present worths of alternatives as a function of the amounts of extractions. By using a different spreading schedule, which represents another plane parallel to the first plane, the present worth of other constant recharge alternatives can also be plotted as functions of amounts of extraction. The same procedure can be repeated for many spreading schedules. When all plotted points are connected, the three-dimensional cost surface may take the shape of a bowl, as shown on the figure. The lowest point of the bowl indicates the most economical set of spreading and extraction schedules for a specified pumping pattern and for a particular method of preventing sea-water intrusion. Similar analyses can be conducted for other pumping patterns and methods of preventing sea-water intrusion.

Finally, by comparing the minimum cost points within the half segments, one of the methods of preventing sea-water intrusion can be selected as the more economical. Inspection of the cost curves for the more economical method of preventing sea-water intrusion will suggest the operating plan under which the present worth of future costs would be



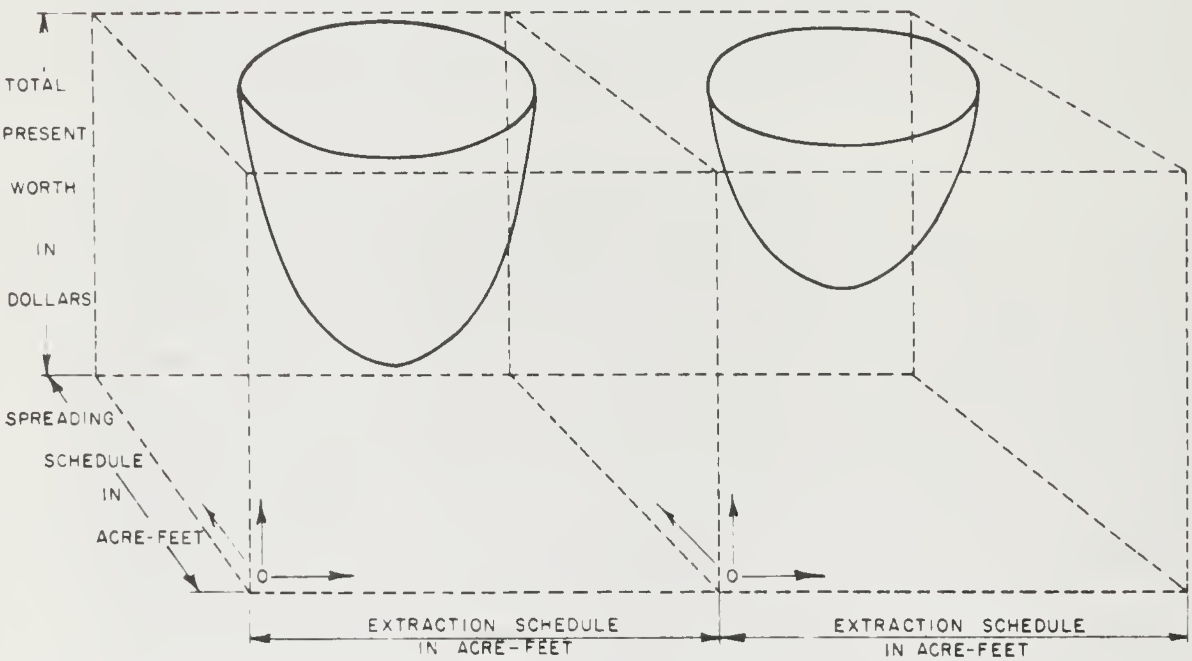


Figure 6

SCHEMATIC REPRESENTATION OF ECONOMIC COMPARISON OF PLANS OF COORDINATED OPERATION

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

at a minimum. Through this process, all the four variables were considered in the determination of the most economical plan of operation.

The amounts of replenishment and extraction investigated, however, were limited on both the upper and lower sides by physical boundary conditions which have been previously described in this chapter. Thus, the economic analysis did not encompass an entire cost surface of the bowl, as is shown on Figure 6, but was limited to only a small portion of that bowl. The missing portion included the lowest point of the bowl, and the significance of this omission is discussed in the following section.

Selection of Five Plans of Operation for Detailed Discussion

A total of 58 plans of operation were analyzed, based on the price of water schedule shown on Table 9. The operational and economic information developed for each plan was voluminous. Therefore, the number of plans selected for detailed discussion had to be limited. Five plans were chosen.

In selecting these plans, it was concluded that, for comparison, one plan of operation should be the one which would provide water service at the lowest cost from a regional point of view. Three of the other plans selected were identical to this least-cost plan in all but one of the operational variables. For all four plans, the method of preventing sea-water intrusion, the schedules of imported water spreading, and the pumping patterns were identical: the amount of extraction varied with each plan. The fifth plan of operation approximates 1963 operating conditions and has schedules which are not identical to the other four plans.

For determining the basic least-cost plan of operation, relationships were established between the total cost of operation and identifiable elements of operation that affect the cost of operation significantly. The isolated relationships were those between total cost of operation and method of preventing sea-water intrusion, amount of spreading, amount of ground water utilized, and pumping pattern. Plans of operation were formulated to incorporate these relationships, and they were successively analyzed.

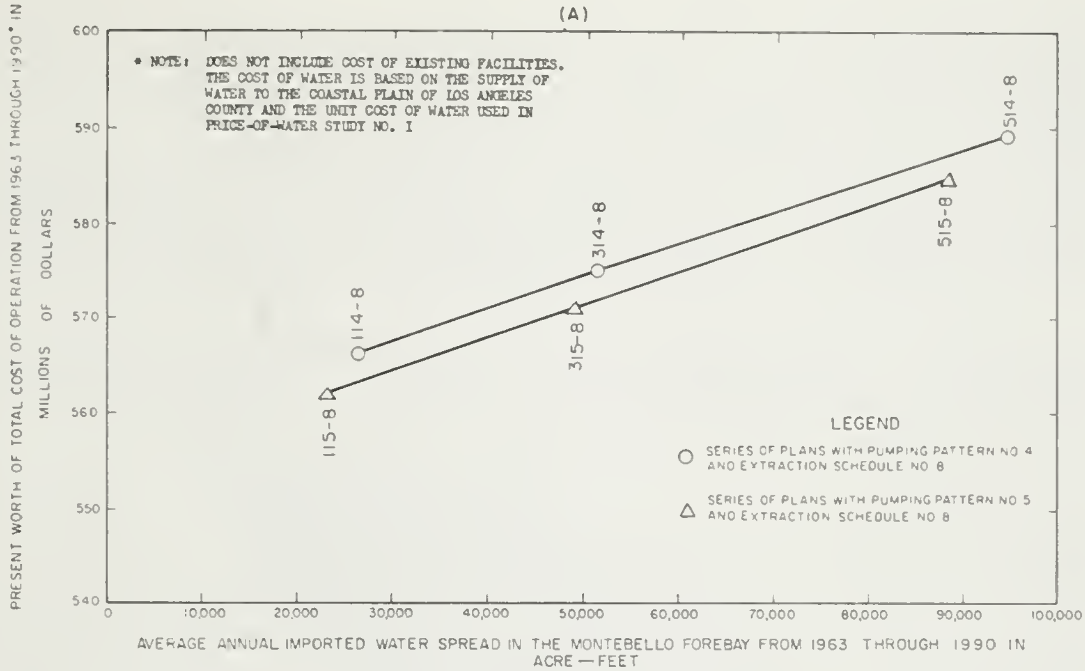
The more economical of the two methods of preventing saline intrusion was determined by comparing the present worth of the total cost of operation for a number of plans. First, from among a number of plans requiring seaward gradients of fresh water, the most economical was selected. Then the present worth for this selected plan was compared with the present worths of plans that use additional freshwater barriers. In this comparison, it was found that the present worth of future cost of the most economical seaward gradient plan was much larger than those of other plans requiring freshwater barriers. During this phase of the study, it was also found that seaward gradients of fresh water could not be created in a short time by reasonable reductions in ground water extractions along the coast, even if large amounts of replenishment water were spread at existing spreading grounds. Therefore, the plans requiring seaward gradients were eliminated from further consideration.

In analyzing the relationship between the total cost of operation and the annual amount of spreading, two groups of plans were compared. Plans within each group were designed so that identical pumping schedules and pumping patterns were imposed and the only difference among the plans was the spreading schedules. The results of the comparison are shown on Figure 7A. As shown by this figure, irrespective of other operational variables, the present worth of the total cost of operation increases as the amount of spreading of imported water increases. For the two groups of plans analyzed, the cost of operation ranged from $560 to $590 million, while the average annual amount of spreading ranged from 20,000 to 95,000 acre-feet.

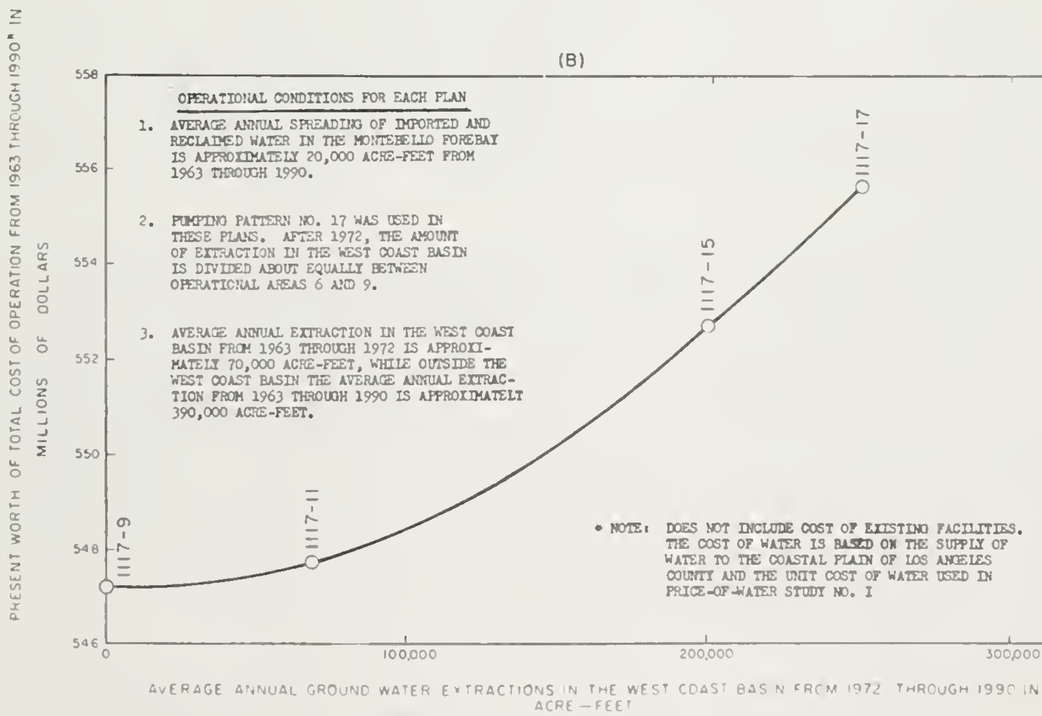
The relation between the total cost of operation and amounts of extraction was analyzed by plotting present worths of the total cost of operation for many plans of operation as a function of the cumulative decrease or increase of fresh ground water in the zone of saturation. A comparison of these plots showed that water service becomes more economical with a greater use of the ground water in storage. This relationship is seen by curve Ia of Figure 13 (page 95), which shows the present worths of selected alternatives for the study period. This relationship was confirmed by further analysis of several plans, which indicated that the amount of ground water utilized is the largest element that affects the total cost of operation.

On the basis of this conclusion, plans of operation that would use as much ground water as possible were formulated for further study. The amount of ground water utilization, however, was limited by pumping patterns. As discussed previously, the upper limit of extraction for each economic area was set by the applied water demand and assumed water delivery from outside sources. To utilize large amounts of ground water, a pumping pattern had to be selected so that the amount of extraction in each operational area did not exceed the upper limit. Although it was known that as ground water use increased, the plan of operation became more economical, it was also found that large amounts of extractions along the coast, where the aquifers are in hydraulic continuity with the ocean, would tend to increase the cost of operation due to the resulting increased cost of preventing sea-water intrusion. This relationship was found by comparing the present worths of several plans of operation with identical operational variables except for pumping schedules in the West Coast Basin. As shown on Figure 7B, the present worths of the total costs of operation for the study period for the plans studied rise as the annual amount of extraction is increased in the West Coast Basin.

These analyses indicated that the most economical plan would be one that included freshwater-injection barriers for protection of the basin against sea-water intrusion, the least amount of spread imported water, a pumping pattern allowing only a small amount of extractions along the



RELATION BETWEEN PRESENT WORTH OF TOTAL COST OF OPERATION AND ANNUAL IMPORTED WATER SPREAD IN THE MONTEBELLO FOREBAY



RELATION BETWEEN PRESENT WORTH OF TOTAL COST OF OPERATION AND ANNUAL GROUND WATER EXTRACTION IN THE WEST COAST BASIN

Figure 7— TREND FOR COST OF WATER SERVICE

coast, and a pumping schedule that permits as much use of ground water as possible in the remaining area. In applying these conclusions, however, the amount of extractions in the West Coast Basin throughout the study period was held arbitrarily to the same amount as that extracted in 1956-57. So that meaningful evaluations might be made for the condition which exists in the West Coast Basin, the pumping pattern was selected to impose the largest amount of uniform annual pumping in the remaining area, even though it was recognized at the time of study that adjudication and subsequent limitation on pumping might be forthcoming.

Several plans of operation using the above criteria were analyzed to determine the most economical plan of operation. For those plans, the only variable was the total amount of extraction in the area outside the West Coast Basin. Plan 117-11 was found to be most economical.

Plans 117-4, 117-5, and 117-7 have the same amounts for each operational variable as plan 117-11 except for the annual amount of extraction. Therefore, these four plans were selected for detailed discussion in the next chapter. In addition, plan 318-5 was selected for further discussion. This plan approximates most closely the present (1963) plan of operating the basins without increasing or decreasing freshwater supply in the ground water basins. This plan is the result of years of planning and effort on the part of local water agencies and it has been operating satisfactorily.

Curve Ia on Figure 13 (page 95) shows the plot of the present worths of total cost of operation for the selected plans of operation. Note that, during the study period, even with the use of the maximum amount of ground water, under the pumping schedule that calls for equal annual amounts of extraction after 1972, the present worth of the total costs of operation has not reached the bottom of the bowl envisioned for cost comparison, which was described earlier.

In fact, the cost surface bounded by the lines delineating the extent of physical possibilities resembles a rectangular sheet of paper that has been tilted so that one of the corners is lower than any other part of the sheet and whose edges are curved as shown schematically on Figure 8. Curve Ia on Figure 13 may be thought as representing the lowest edge of the cost surface on Figure 8. The curve indicating the present worths of the alternatives with varying extraction schedules and the largest spreading schedules may be considered to be represented by the opposite edge. The two remaining edges represent the curves that indicate the present worths of the alternatives with varying spreading schedules and the upper and lower limits of extraction schedules. The curvature of the opposite edge and the remaining edges can be deduced from the curves and the relationships between the present worths and the spreading and extraction schedules that have been presented heretofore.

The cost surface for a physically possible plan of operation, which was compared to a rectangular sheet of paper, occupies only a very small

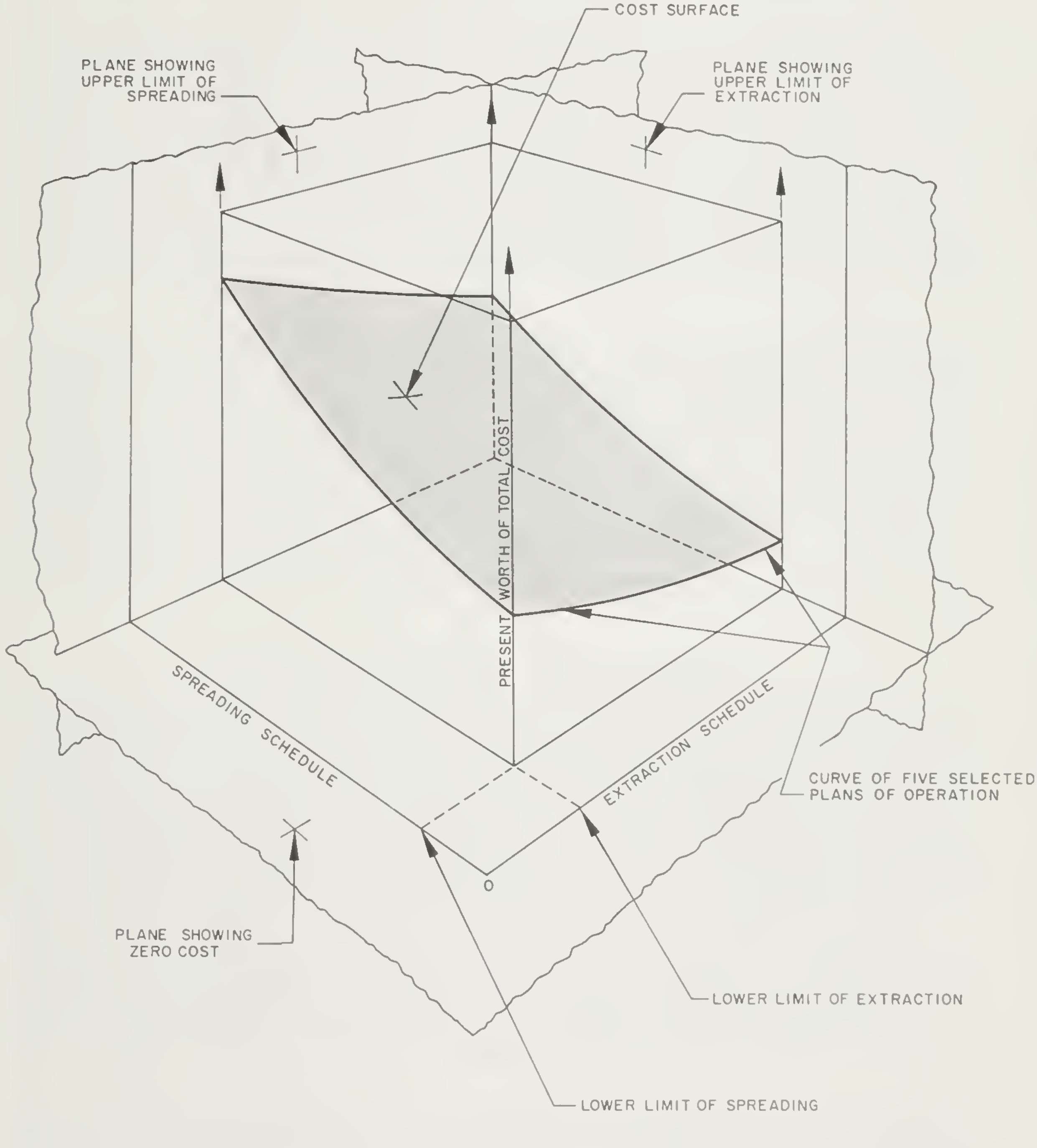


Figure 8

SCHEMATIC REPRESENTATION OF THE COST SURFACE COMPOSED OF PHYSICALLY POSSIBLE PLANS OF OPERATION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY

PARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966 portion of the bowl shown on Figure 6. The remaining portion of the bowl, including the lowest point, lies in the area of physical impossibilities according to the criteria adopted for this investigation.

CHAPTER IV. DETAILED ANALYSES OF SELECTED PLANS OF OPERATION

Five plans of operation, representing a wide range of possible alternative plans, were selected for detailed analysis. The basis of this selection is given in Chapter III. Chapter IV presents the results of the detailed analysis of each of the plans, including data on water demands, surface water and ground water supplies, ground water level elevations, surface water and ground water facilities, electrical energy requirements, and economics. As will be shown in this chapter, the price of imported water is an overwhelming factor in the economics of water service in the study area. Therefore, the economic analyses of the five selected plans of operation were based on three different sets of assumptions affecting the price of imported water.

During the period of this study, the assumed conditions affecting the economics of water service changed significantly, and they will probably continue to change in the future. To evaluate the validity of the results of the investigation on the basis of these changed assumptions, analyses were made of the effect of the changes on the findings of the investigation. These analyses indicated that the changes in assumed conditions did not alter the original findings. The results of these analyses are discussed here with respect to the economics of operation as affected by the four independent variables of ground water basin operation, as well as the price of imported water.

Description of Selected Plans of Operation

For the five selected plans, sea-water intrusion was prevented by construction and operation of freshwater barriers, because this method was found to be most economical. This substantiates the decision made by the Los Angeles County Flood Control District to construct freshwater barriers to repel sea-water intrusion. Also, the average amounts of annual spreading of imported water at the spreading grounds at Montebello Forebay for all plans, except plan 318-5, were kept less than 9,500 acre-feet, and selected annual amounts of pumping after 1972 were held constant for all plans. However, the magnitude of the selected annual pumping was varied for each plan so that the accumulated change in storage of fresh water in the zone of saturation would vary widely. This permitted obtaining of information on a wide range of basin operation. The annual amounts of extractions, from 1972 to 1990, by operational area for the selected plans of operation are shown on Plate 7.

The average annual amounts of controllable items of ground water basin operation (extraction and replenishment) are shown for each plan of operation in Table 18. The pumping pattern, as percent of total extraction for each operational area, is shown on Plate 8. The items of basin operation that were common for all plans of operation are not shown annually in the table. The difference between the total extraction

TABLE 18

EXTRACTION AND REPLENISHMENT SCHEDULE IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FOR THE STUDY PERIOD 1963 THROUGH 1990

In thousands of acre-feet

Year	Plan number									
	318-5		117-4		117-5		117-7		117-11	
	Extraction	Replenishment*	Extraction	Replenishment*	Extraction	Replenishment*	Extraction	Replenishment*	Extraction	Replenishment*
1963	304	65	293	64	317	65	344	66	368	67
1964	291	78	264	55	301	51	340	48	388	51
1965	278	79	236	38	284	35	336	33	408	40
1966	280	103	237	64	286	64	336	65	416	74
1967	281	102	239	62	287	66	336	71	424	85
1968	282	117	245	79	288	82	336	90	432	104
1969	283	103	252	66	290	69	336	80	439	94
1970	283	102	255	65	291	68	337	82	447	97
1971	284	101	258	65	292	67	338	85	455	100
1972	281	100	247	66	287	69	337	85	457	106
1973	278	98	237	65	282	68	336	84	459	111
1974	278	98	232	63	282	67	336	85	459	114
1975	278	96	228	62	282	67	336	85	459	118
1976	278	95	228	60	282	68	336	86	459	122
1977	278	95	228	59	282	68	336	87	459	124
1978	278	94	228	58	282	69	336	87	459	127
1979	278	94	228	57	282	68	336	87	459	131
1980	278	94	228	57	282	69	336	88	459	132
1981	278	93	228	57	282	69	336	89	459	135
1982	278	93	228	55	282	69	336	90	459	137
1983	278	93	228	55	282	70	336	89	459	140
1984	278	93	228	55	282	70	336	91	459	141
1985	278	93	228	54	282	69	336	91	459	144
1986	278	92	228	54	282	69	336	91	459	145
1987	278	92	228	54	282	70	336	92	459	146
1988	278	92	228	54	282	70	336	92	459	148
1989	278	92	228	54	282	70	336	93	459	150
1990	278	92	228	53	282	74	336	95	459	151
Subtotals	7,851	2,639	6,643	1,650	7,999	1,880	9,424	2,307	12,496	3,234
Replenishment common to all plans	—	5,250	—	5,250	—	5,250	—	5,250	—	5,250
TOTALS	7,851	7,889	6,643	6,900	7,999	7,130	9,424	7,557	12,496	8,484

*Figure includes both spreading and injection demands.

and total replenishment indicates the increase or reduction of fresh water in storage in the ground water basins. The detailed information on both the controllable items and the items of replenishment common to all plans are presented in Sheets 2 and 3 of Attachments 11 through 15, respectively, for the five selected plans.

For plan 318-5, the amounts of annual spreading were made large and the amounts of annual extraction were varied so that there would be little change in the amount of ground water in storage. Plan 318-5 represents the current operational scheme in the Coastal Plain. Although the pumping pattern and spreading schedule for this plan are not the same as for the other four plans, it was selected to show operational and economic information on this plan in comparison with that of the other plans.

These plans of operation were related to the four operational variables described in Chapter III. However, for identification, the plans also could be related to the amount of increase or reduction of fresh water in the zone of saturation, which is a measure of the combined effects of controllable and common elements of basin operation under various plans of operation. Specifically, for plans 117-4, 117-5, 117-7, and 117-11, the accumulated reduction in the ground water in storage, during 1963 through 1990, also is a measure of ground water extractions, since amounts of annual spreading were made small for each plan and amounts of injection of fresh water to prevent sea-water intrusion were varied according to needs. The resulting accumulated reduction in ground water in storage ranged from approximately zero to 4,000,000 acre-feet. In subsequent discussions, this means of identifying each plan will often be used to permit easy identification of the relative magnitude of ground water extracted under the various plans.

For plan 117-11, the accumulated reduction of ground water in storage was approximately 4,000,000 acre-feet. This plan represents the operational scheme that allows the largest use of ground water and the smallest use of imported surface water for the series of plans with constant annual amounts of extraction after 1972. On the average, approximately 7,000 acre-feet of imported water was scheduled to be spread annually, in addition to the 13,000 acre-feet of reclaimed water that was assumed to be spread for all plans. The computed required amounts of annual injection varied from 12,000 acre-feet in 1963 to 140,000 acre-feet in 1990. Annual amounts of extraction in the Coastal Plain were gradually increased, from 368,000 acre-feet in 1963 to 457,000 acre-feet in 1972. The annual extraction after 1972 was 459,000 acre-feet, representing 144 percent of the amount extracted in 1957*.

An average extraction rate of 175,000 acre-feet annually was imposed in operational areas 3 and 4, and an average extraction rate of 69,700 acre-feet annually was imposed in operational areas 6 and 9. These latter two areas essentially represent the West Coast Basin.

For plan 117-7, the accumulated reduction of ground water in storage was approximately 2,000,000 acre-feet. An annual average of about 6,400 acre-feet of imported water was spread at Montebello Forebay. Required

*The last year of the 23-year base period of hydrologic history used for this study.

amounts of annual injection of fresh water varied from 12,000 acre-feet in 1963 to 84,000 acre-feet in 1990. As in plan 117-11. the annual amount of extraction in the West Coast Basin was approximately 69,600 acre-feet; the pumping pattern was the same for plan 117-11. Annual extraction was approximately 340,000 acre-feet before 1972; annual extraction after 1972 was 335,600 acre-feet or 105 percent of the amount of 1957 extraction.

For plan 117-5, the accumulated reduction of ground water in storage was approximately 1,000,000 acre-feet. The average annual amount of spreading was about 6,300 acre-feet, and the required amount of annual injection varied from 11,000 acre-feet to 60,000 acre-feet. The amount of annual extraction before 1972 varied from 317,000 to 287,000 acre-feet. After 1972, the annual extraction was 282,000 acre-feet, or approximately 90 percent of the 1956-57 extractions. The pumping pattern was kept the same as that for plan 117-11.

For plan 117-4, the accumulated change in the amount of ground water in storage was approximately zero. About 9,500 acre-feet annually of imported water was presumed to be spread in the soreading grounds. Amounts of required annual injection of fresh water varied from 11,000 acre-feet in 1963 to 49,000 acre-feet in 1990. The pumping pattern was also the same as for plan 117-11. The annual extraction after 1972 was 228,000 acre-feet. This amount represents approximately 70 percent of the amount of 1957 extraction and is about half the extraction schedule of plan 117-11.

For plan 318-5, the accumulated change in the amount of ground water in storage was also approximately zero. About 42,700 acre-feet of imported water was spread annually. Amounts of required annual injection were varied from 11,000 acre-feet to 48,000 acre-feet. The pumping pattern represents the existing pumping pattern in the Coastal Plain. The amounts of annual extraction were varied from 304,000 to 281,000 acre-feet before 1972 and were held constant at 278,000 acre-feet after 1972. This represents the course presently being pursued in the Coastal Plain.

Water Demand and Water Supply

For each of the five plans, inventories were kept of annual amounts of each item of water demand and water supply. These components of water demand and supply from 1963 through 1990 are shown in Sheet 4 of Attachments 11 through 15.

Total water demand varied with each plan of operation. As shown in Table 19, the total water demand was comprised of the applied water demand, the injection demand, and the spreading demand. From 1963 to 1990, applied water demand schedules were the same for each plan of operation. However, demand for injection water was determined as a dependent variable by use of the mathematical model, and the amount of spreading of imported water was one of the independent variables selected within the physical limitations of the basins.

TABLE 19

TOTAL AMOUNTS OF COMPONENTS OF WATER DEMAND AND SUPPLY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FOR THE STUDY PERIOD 1963 THROUGH 1990 FOR SELECTED PLANS OF OPERATION

In thousands of acre-feet

Component	Plan number				
	318-5	117-4	117-5	117-7	117-11
Water demand					
Applied water demand	30,010	30,010	30,010	30,010	30,010
Injection demand	1,080	1,020	1,340	1,760	2,670
Spreading demand	1,560	630	540	550	560
TOTAL WATER DEMAND	32,650	31,660	31,890	32,320	33,240
Water supply					
Import by Los Angeles Department of Water and Power	3,840	3,840	3,840	3,840	3,840
Import from San Gabriel Valley	280	280	280	280	280
Import by MWD					
Softened industrial and domestic	6,480	6,480	6,480	6,480	6,410
Filtered industrial and domestic	11,560	12,770	11,420	10,000	6,990
Filtered injection water	1,090	1,020	1,340	1,760	2,670
Raw spread water	1,190	270	170	180	200
Reclaimed waste water	360	360	360	360	360
Ground water extraction	7,850	6,640	8,000	9,420	12,490
TOTAL WATER SUPPLY	32,650	31,660	31,890	32,320	33,240

Apparently the differences in the total water demand are mainly due to the differences in requirements for injection of fresh water. Table 19 shows that plan 117-4 requires an accumulated amount of 1,020,000 acre-feet of injected water but that plan 117-11 requires about 2,670,000 acre-feet, or more than one and one-half times that of plan 117-4. To further illustrate the differences in injection requirements, annual accumulated amounts of injection demands were plotted for Figure 9. The slopes of the curves change in 1966. This change reflects the increased injection requirements in that year due to commencement of the operation of required additional injection barriers. After 1966, the change of slope of the curves is greater when the use of ground water is greater. For plans 117-11 and 117-7, the change of slope became negligible at about 1985. This indicates that the water levels along the coast were approximately stabilized from that year on.

In each year during the study period, total water demands were met by imported water from various sources, reclaimed waste water, and locally extracted ground water. This relationship is shown in Table 19.

This table shows that the schedule of imports by the City of Los Angeles, imports from the San Gabriel Valley, and the supplies from reclaimed waste water were the same for all plans of operation. However, imports by the Metropolitan Water District and ground water extractions varied with each plan of operation. Scheduling of ground water extractions was one of the independent variables, and the District's import schedule was varied so as to supply the remaining portion of the total water demand not supplied by the other sources of water supply. The amount of softened water available for domestic and industrial uses was assumed to be the same for each plan of operation. For plan 117-11, because of the large amount of ground water utilized and smaller applied water demands during the earlier years, no filtered water use was projected for the first three years. This is reflected in the smaller amount of filtered water used in plan 117-11 compared with the other selected plans.

Fresh Water Supply in Ground Water Basins

To keep an inventory of total amount of fresh water supply in the zone of saturation, annual amounts of inflow into and outflow from the zone of saturation were accounted for and the annual increase or reduction of fresh water supply in the ground water basins was determined. To determine the total increase or reduction of fresh water during the study period, the annual values were then accumulated for the study period.

Items of inflow to and outflow from the zone of saturation were grouped for convenience of reference. Group 1 (items of replenishment common to all plans of operation) consists of subsurface ground water inflow and deep percolation of surface water supplies. Average annual amounts of these items are summarized in Table 20. Group 2 (items not common to

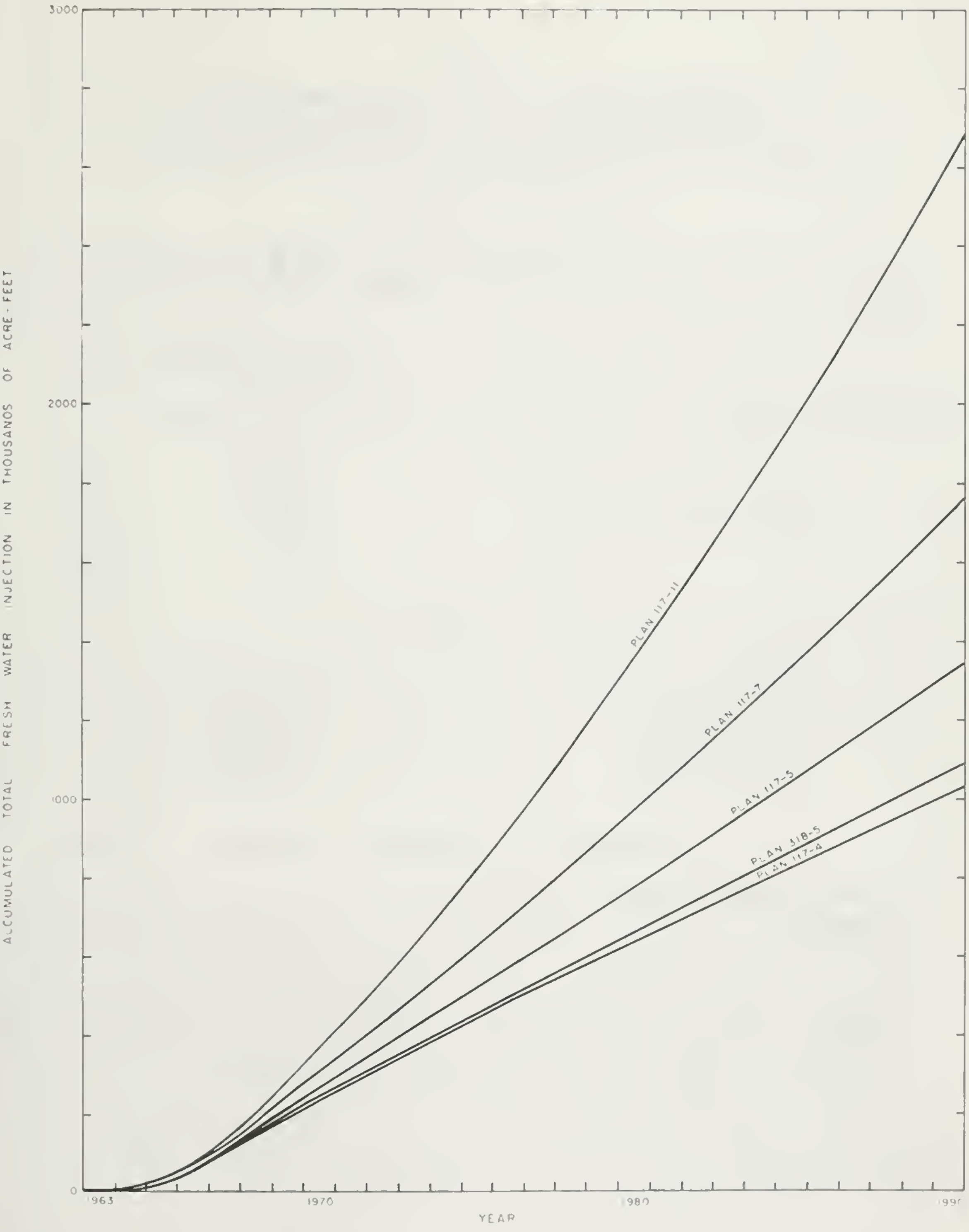


Figure 9
ACCUMULATED TOTAL FRESH WATER INJECTION
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY
FOR SELECTED PLANS OF OPERATION

TABLE 20

ESTIMATED ANNUAL AMOUNTS OF REPLENISHMENT
TO THE ZONE OF SATURATION, COASTAL PLAIN OF LOS ANGELES COUNTY,
UNDER WATER SUPPLY CONDITIONS OF MEAN PRECIPITATION
FROM 1963 THROUGH 1990

In acre-feet per year

(GROUP 1. ITEMS OF REPLENISHMENT, COMMON TO ALL PLANS OF OPERATION)

Items	Amounts	
Subsurface ground water inflow		
Orange-Los Angeles County	29,000*	
Los Angeles Forebay	0	
Whittier Narrows	28,000	
Subtotal		57,000
Deep percolation of surface water supplies		
Reclaimed water	13,000	
Rising water	38,000	
Storm runoff	10,000	
Precipitation	29,000	
Applied water	53,000	
Subtotal		143,000
Total replenishment common to all plans of operation		200,000

*Estimated inflow in 1960-61, adopted for use in this investigation. Because subsurface flow varies with changing physical conditions, this figure is a working estimate only. It is not a forecast of future physical conditions. (See also Chapter II, page 20.)

all plans) consists of extracted ground water and imported water for spreading and injection. Average annual amounts of these items, for each selected plan of operation, are summarized in Table 21.

As described in Chapter II, the amounts of spreading and extraction were independent variables, while the amount of injection was determined as an item dependent on the combined effects of all other controllable or common items of ground water basin operation. Annual variations in each item for the selected plans are given in Sheets 2 and 3 of Attachments 11 through 15.

TABLE 21

SUMMARY OF TOTAL AMOUNTS OF CONTROLLABLE ITEMS OF WATER SUPPLY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

In thousands of acre-feet

(GROUP 2. ITEMS NOT COMMON TO ALL PLANS OF OPERATION)

Plan number	Items		
	Imported water spread at Montebello Forebay	Fresh water injected at barrier projects	Ground water extraction
318-5	1,194	1,081	7,851
117-4	265	1,021	6,643
117-5	173	1,343	7,999
117-7	182	1,761	9,424
117-11	197	2,673	12,496

Of primary interest in ground water basin operation is the change in the amount of fresh ground water in storage. Figure 10 shows annual values of accumulated change in storage for each plan. As stated before, the range of variation for the study period is from approximately zero to a reduction of about four million acre-feet.

Change in Ground Water Level Elevations

Changes in the amount of fresh ground water in storage affect water level elevations in the ground water basins. Changes in water levels also are the manifestation of the integrated effect of all items of basin operation, and are accordingly the key items for measuring these effects. Predicted water level elevations in the equivalent aquifers for all plans were estimated by superpositioning of master influence functions, explained in Attachment 6; the functions were developed by using the mathematical model of the ground water basins. The estimated future water level elevations at nodes of the mathematical model for the five selected plans are presented in Sheet 12 of Attachments 11 through 15. The water level elevation contour map presented on Plate 9, shows the initial ground water level elevations of the mathematical model which approximate the elevations that existed in 1962.

The initial ground water level elevations were determined by imposing historical variations in items of inflow and outflow on the mathematical model, starting from the model elevations from 1956-57. Consequently, the initial ground water level elevations for the year 1962 are mathematically balanced elevations with respect to the model. A comparison of

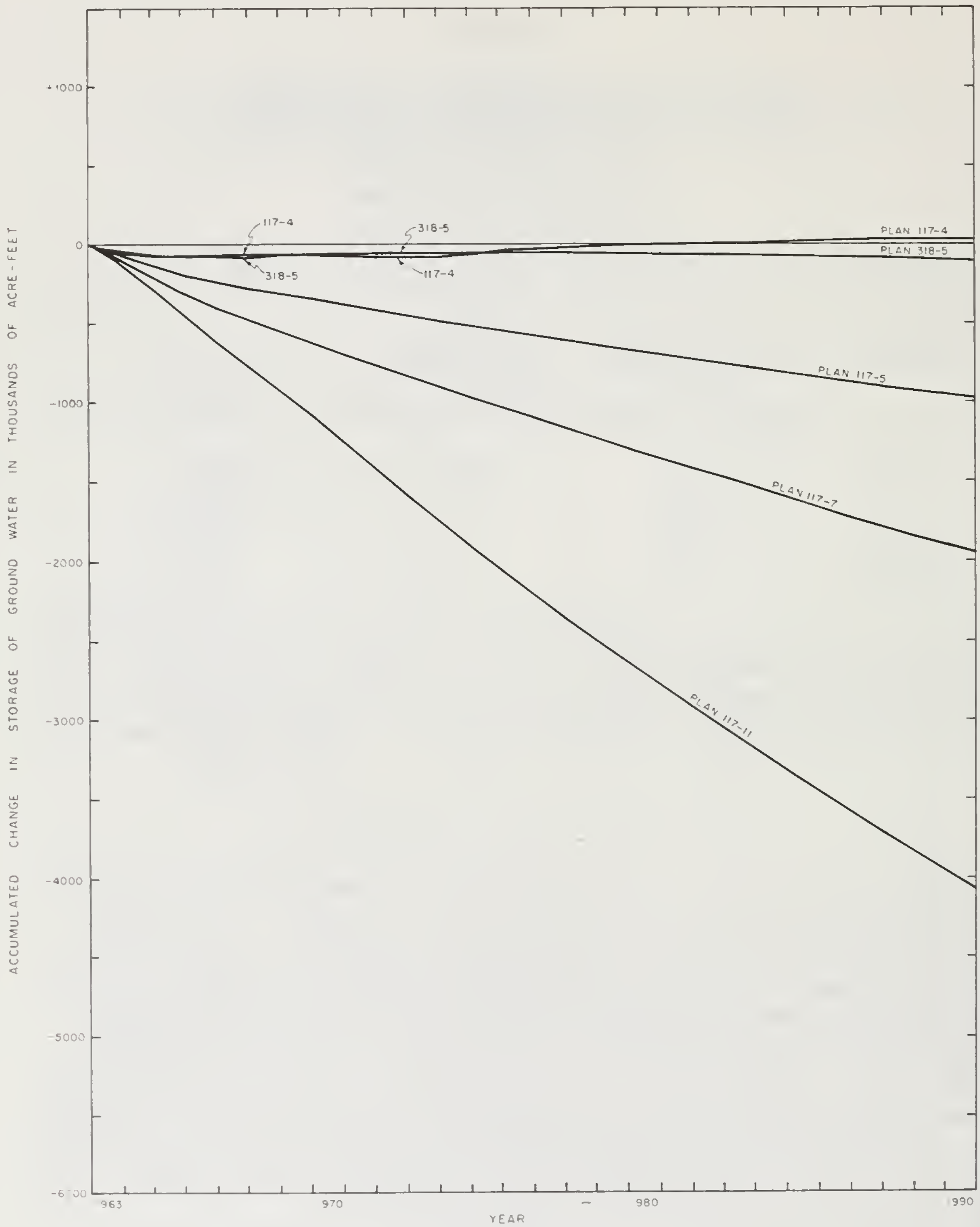


Figure 10

ACCUMULATED CHANGE IN THE STORAGE OF FRESH GROUND WATER IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FOR SELECTED PLANS OF OPERATION the initial elevations and the actual elevations shown by well hydrographs indicated that the water level elevations determined by the mathematical model were close to the actual elevations in the major portion of the Coastal Plain. An example of a good match is shown on Figure 5-4, Attachment 5.

Maps showing contour lines of computed equal changes in ground water levels between 1962 and 1990 for each selected plan are shown on Plates 10 through 14. Plate 10 shows the changes in piezometric levels for plan 117-4, the plan with almost no net change in storage during this period. As shown on Plate 10, water levels in the West Coast Basin were projected to rise as much as 40 feet. In the Montebello Forebay Area, the rise in water levels was projected to be roughly 10 feet, and in the Central Basin, the plate shows a forecast maximum rise of 70 feet in the southeastern end and a maximum fall of 40 feet in the northern end. The rise in the southern end is mainly due to the subsurface flow from Orange County, assumed as a boundary condition for the investigation.

When the water levels in the southerly portion of the Central Basin rise, the subsurface flow at the Los Angeles-Orange County boundary may change with the mode of operation in both counties and the assumed 29,000 acre-feet of subsurface flow may be reduced. If the probable change is such that the subsurface flow would be reduced to zero in 1970 and remain zero until 1990, the magnitude of water level rise in the southeastern portion of the Central Basin would be approximately 30 feet less than shown on Plate 10 for plan 117-4.

Plate 13 shows the changes in ground water levels for plan 117-11--the plan with about 4,000,000 acre-feet of accumulated reduction in fresh ground water in storage. As shown on Plate 13, ground water levels in the Santa Monica Basin would decline about 140 feet adjacent to the Hollywood Basin boundary. The decline in the Hollywood Basin would range from 160 to 180 feet, and the water levels in the southeastern portion of the West Coast Basin would decline as much as 140 feet. The general decline in water levels in the West Coast Basin is due to subsurface outflow from the basin into the Central Basin, caused by heavy pumping and little replenishment in the Central Basin.

The heavy pumping and small replenishment resulted in a significant forecasted decline of water levels in the Central Basin. Plate 13 shows that the ground water levels in the Montebello Forebay Area would decline as much as 280 feet and that, in the remaining area of the Central Basin, the decline would range from 60 feet in the southern portion to 280 feet in the central portion. The general decline in water levels in the Central Basin is also due to heavy pumping imposed in this area during the study period. This decline would result in large amounts of subsurface inflow from the West Coast Basin, which would contribute to the decline of water levels in that area also. The smaller decline in the southern portion of the Central Basin, as compared with the decline in the forebay area and northern portion of the basin, is due to the 29,000 acre-feet of subsurface inflow from Orange County assumed as a boundary condition for the investigation. The amount assumed would be valid if water level elevations in Orange County declined slightly less than those in the Coastal Plain. If the water level in Orange County should remain high, the subsurface flow would be larger than the assumed amount and the decline in water level would be smaller than the decline shown on Plate 13.

The amounts of accumulated reductions of ground water in storage for plans 117-5 (1,000,000 acre-feet) and 117-7 (2,000,000 acre-feet) are between the extremes of plans 117-4 and 117-11. As is seen from Plates 11 and 12, the changes in water levels for plans 117-5 and 117-7 are between those of plans 117-4 and 117-11 in all areas, and these changes are in proportion to the changes in the amount of ground water in storage.

In addition to the analyses of five selected plans, described above, the changes in ground water level elevations were approximated for fluctuations of water supply due to long-term cyclic precipitation. This study was made to estimate the ground water storage space needed in the Montebello Forebay Area for conservation of rising water and flood runoff from San Gabriel Valley under cyclically changing precipitation. In this study, the annually changing amounts of water conserved during the period 1933-34 through 1956-57 in the forebay area were adopted for use as the amounts which would be conserved in the future. The fluctuation in water level elevations due to this conservation was determined by superpositioning. A map showing lines of equal change in water level elevations in the Coastal Plain between the beginning and the time when the water level elevations are at the highest level, a ten-year period, is shown on Plate 15. The rise in ground water levels, showing the effect of cyclical variation in amounts of rising water and flood runoff, was as much as 60 feet in the forebay area. The figure of 60 feet was derived for the purpose of giving the approximate volume of storage capacity needed to store the rising water and flood runoff during the study period.

Land Subsidence

As described earlier, under plan 117-11 ground water levels declined about 280 feet in a portion of the Montebello Forebay Area and about 280 feet in the central portion of the Central Basin. With a decline of water levels of this magnitude, it is reasonable to assume that some subsidence of land would take place. Without a comprehensive survey, it is not possible to establish a reliable relationship between a specific plan of ground water basin operation and a specific degree of land subsidence or to evaluate the economic effects of such subsidence. Although such a comprehensive survey was beyond the scope and cost limitations of this investigation, a limited study of the subsidence problem was made. To our knowledge, no investigation has been conducted by public agencies to estimate the magnitude and manner of subsidence in the Coastal Plain caused by declining ground water levels.

Some land movements of tectonic origin have been reported in Southern California; however, isolation of tectonic movements from movements due to the change in ground water level is impossible with the extent of data available at present.

Even though it is not possible to forecast the magnitude of land subsidence under any selected ground water conditions, it is believed that some subsidence may be expected under a large and continued drawdown of ground water levels in the Coastal Plain. Subsidence may take place in the coastal region or in the inland region. Under the alternatives that were investigated, freshwater barriers were assumed to be maintained along the coastal region and significant lowering of water levels was avoided. Therefore, it was assumed that economically significant subsidence would not occur under any plan of operation in this region.

As to the subsidence in the inland region, the magnitude was expected to be very small. Since 1933, the ground water levels have alternately risen and declined in the Coastal Plain. The rise was approximately 40 feet and the decline was approximately 110 feet in the areas of extreme water level fluctuations. No physical damages traceable to land subsidence due to decline of ground water levels in the Coastal Plain have been reported, to our knowledge. It is assumed that the land movement has been economically insignificant in the Coastal Plain, and it is concluded that the subsidence would affect the future economics of ground water basins of the Coastal Plain very slightly. For this reason, land subsidence was not evaluated either operationally or economically in this investigation. However, if ground water levels are allowed to recede beyond the historical low, a careful vigilance should be kept on land movements in all areas of the Coastal Plain.

Physical change in water-bearing aquifers is possible as the result of drawdown of water levels. However, under the plans of operation discussed in this report, the maximum withdrawal would be 4 million acre-feet out of the more than 20 million acre-feet in storage and a maximum reduction in water levels of 280 feet. Historically, water levels have been reduced about 130 feet with no apparent effect on storage and transmissive characteristics. Thus, it was assumed that the effect of the additional 150 feet of drawdown would also be negligible.

Reliability of Mathematical Model

In Chapter III, it was stated that the mathematical model, on which future water level elevations were estimated, was verified with historical water inflow-outflow data and water level elevations. The model, and consequently, the result of the study, are most reliable for the plans under which water level elevations will fluctuate within the historical variation. The reliability would diminish as water level elevations fluctuate beyond the historical variation. After careful analyses, it was concluded that the model was reliable for this study for the conditions in which water level elevations remain above the base of the Lynwood aquifer.

The Lynwood aquifer extends over the entire Central Basin, the east half of the West Coast Basin, and a small area in the western part of the Hollywood Basin. The base of the aquifer ranges in elevation from 200 to 950 feet below mean sea level in the Central Basin and from 200 to 550 feet below mean sea level in the West Coast Basin. The thickness of the aquifer ranges from 50 to 150 feet. Detailed information on the Lynwood aquifer is presented in Appendix A.

Under plan 117-7, water level elevations in 1990 reach the top of the Lynwood aquifer in the boundary areas, and this plan results in an accumulative reduction in the amount of ground water in storage of approximately 2,000,000 acre-feet from 1963 through 1990.

Plan 117-11, which results in a 4,000,000 acre-foot reduction in the amount of ground water in storage, would result in conditions in which water levels would be below the base of the Lynwood aquifer. However, inaccuracy in physical responses predicted by the model in this case probably would be too small to affect the results of economic analysis. This is because significant errors in the estimated water level elevations would not occur until after 1975, when the reduction in the amount in storage would be larger than 2,000,000 acre-feet, and would then occur in the area where pumping costs would be relatively small with respect to the difference in the total costs of operation of the alternatives.

The linear mathematical model of the ground water basins used in this investigation was formulated and verified in the fall of 1960, and it represents the best knowledge and computer technique available at that time. A nonlinear model, in which storage and transmissive factors are changed as water levels change, would make possible very reliable operational studies of plans that would result in an accumulated reduction of fresh ground water in storage larger than 2,000,000 acre-feet. Large computers, economical and fast enough to handle a complex program for a nonlinear model, have subsequently become available. Following this advancement in computer technology, a technique of formulating a nonlinear model has been developed by the Department for studies of other ground water basins.

In the event of a need for more accurate operational evaluations of plans that involve large amounts of fresh water deficiency, a nonlinear model of the ground water basins in the Coastal Plain could be and should be formulated.

Because the mathematical model must be constructed on the basis of known hydrologic and geologic conditions, the output from the model can establish the feasibility of operational plans only within the framework of water levels which have occurred historically in the basin. The selected plan would then require field testing by actual lowering of the water levels to the indicated depths, accompanied by careful observation of the effects. The mathematical model, however, is an inexpensive and practical tool for evaluating the effects of changing ground water levels and determining the mode of operation to be used as the basis for further empirical testing. It also provides a reliable basis of comparative economic evaluation of basin management plans to be made within acceptable limits of accuracy.

Facilities Required to Meet Applied Water Demands

The determination of facilities required to meet applied water demands was made in two steps. The first step was the determination of facility flow capacity requirements, and the second was the determination of the additional number of facilities required. The capacity and number requirements were determined for all the facilities considered for economic comparison. As mentioned previously, the facility requirements were determined to meet the maximum hourly applied water demand for each of the ten economic areas as well as for the entire Coastal Plain. The method for this determination is discussed in detail in Attachments 9 and 10.

It was realized that the facility requirements for preventing sea-water intrusion along the coastline vary according to each plan of operation. However, in the economic analysis, design of facilities was not made for each different alternative plan of operation. Instead, curves were developed to show the relation between the cost of providing injection facilities and the amount of fresh water injection requirement along the coastline. A detailed discussion of this determination is presented in Attachment No. 8; the curves are shown on Figure 8-1.

For comparison of facility flow requirements in the Coastal Plain, values of annual capacity requirements for connectors, pumping facilities, and surface storage facilities for plans with the largest and the smallest use of ground water were plotted as a function of time. These plots are shown on Figure 11 and are based on the detailed data shown in Sheet 6 of Attachments 11 through 15. Figure 11 (A) shows the breakdown for plan 117-11, in which the reduction in the amount of ground water in storage is about 4,000,000 acre-feet. Figure 11 (B) shows the capacity requirement breakdown for plan 117-4, in which the change in storage of fresh water in the zone of saturation is kept at or near zero during the study period.

These figures show that the surface storage requirement does not vary appreciably for the two plans. However, the pumping and connector capacities are noticeably different between the two plans. The combined capacity of pumping and connector facilities for plan 117-11 is approximately the same as for plan 117-4, and the total capacity of the facilities in any year equals the maximum hourly water demands for the particular year.

Previously it was mentioned that the use factor of pumps and boosters is the major factor affecting the cost of extracting ground water and that the use factor is the ratio of actual use to the total capability for use.

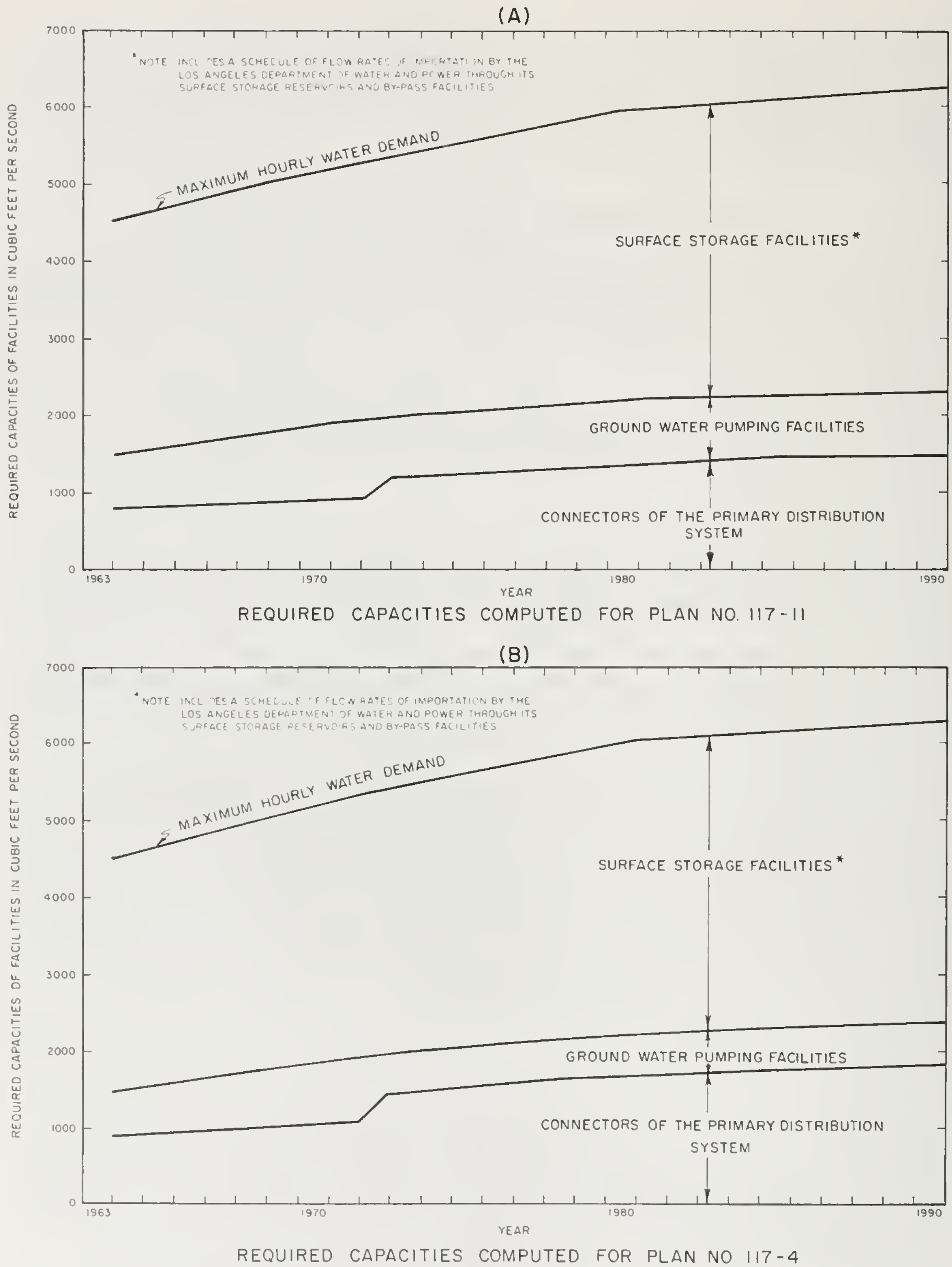


Figure 11

REQUIRED CAPACITIES OF FACILITIES TO MEET MAXIMUM HOURLY WATER DEMAND IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

In this investigation, the most economical combination of facilities resulting in the most economical pump use factor was used, and criteria for such use were imposed in each plan of operation. Figure 12 shows a representation of the annually changing values of use factors for the selected plans of operation which are contained in Sheet 6 of Attachments 11 through 15. The use factor shown for each plan is the average for the ten economic areas. The use factors range between 48 and 77 percent. These relatively high values reflect the assumption that the facilities are provided and operated according to the criteria for the most economic use factor and also the assumption that the use of all facilities within an economic area will be coordinated to meet the water requirement of that area.

Figure 12 shows that the use factors decline about 20 percent between 1963 and 1972 but rise sharply about 20 percent in 1972 and begin to decline again around 1975. This decline continues until 1982, when the factors suddenly rise about 5 percent. The declines are due to limitation on the delivery capacity of the assumed primary distribution system and the resulting requirement for increasing pumping capacities to meet increasing peaking demands and less increases of the applied water demand. The sudden rises are responses to increases in delivery capacities of the primary distribution system predicated on the expected expansion of the system in 1972 and 1983.

Additional numbers of facilities required are shown in Sheet 7 of Attachments 11 through 15 for the five selected plans. These were determined by taking the difference between the total number required each year and the number available in the corresponding year. The number was determined for each economic area independently, to be consistent with the assumptions previously mentioned.

In Table 22, the computed total number of new or replacement facilities required for each plan of operation during the study period is summarized.

TABLE 22

COMPUTED TOTAL NUMBER OF NEW OR REPLACEMENT UNITS NEEDED IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

Facility	Plan number				
	318-5	117-4	117-5	117-7	117-11
Connectors	23	22	20	16	12
Surface storage units	8	9	12	13	31
Booster units	194	179	182	189	235
Pumping units	313	293	418	557	1,039

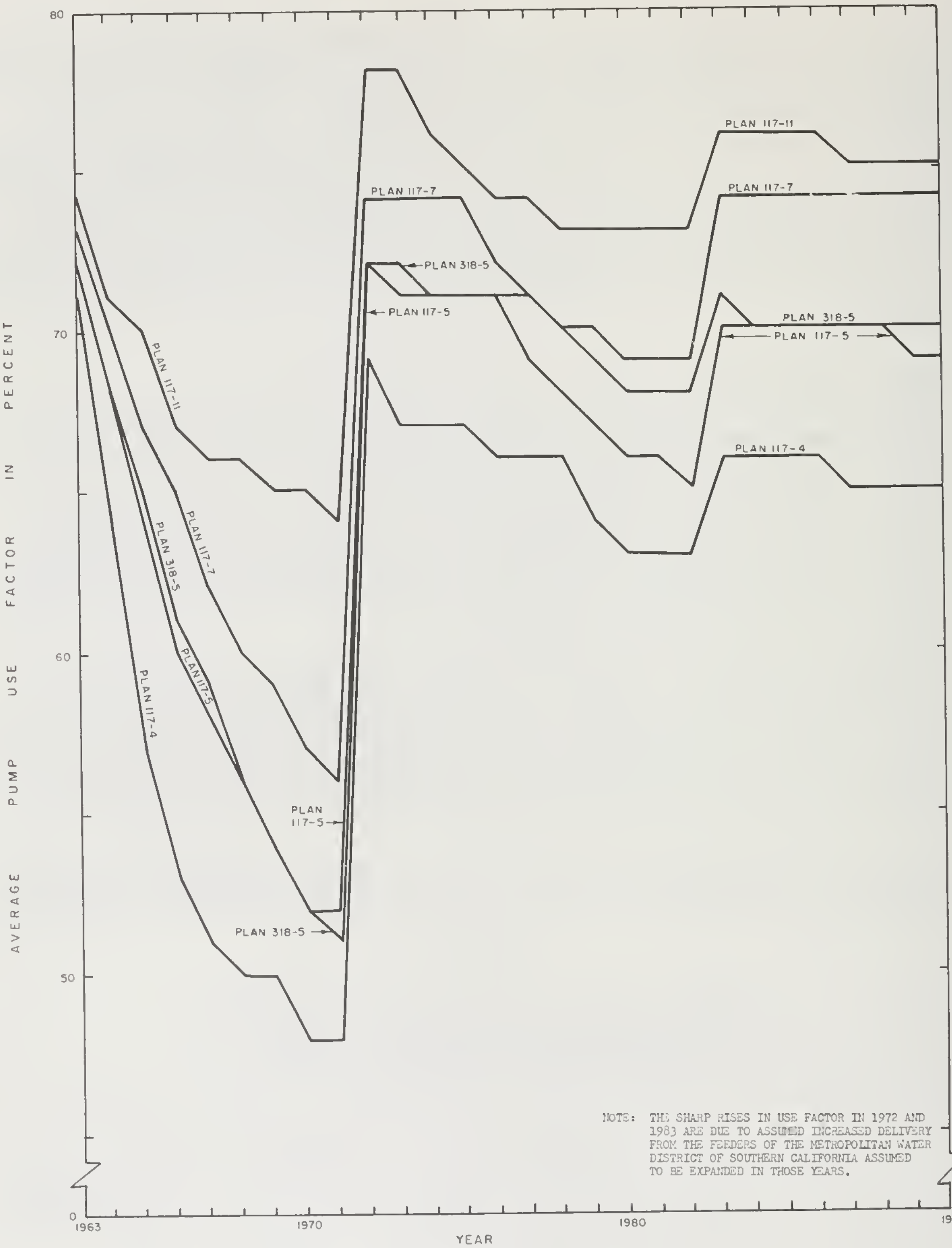


Figure 12

AVERAGE ANNUAL VALUES OF MOST ECONOMIC PUMP USE FACTOR FOR THE COASTAL PLAIN OF LOS ANGELES COUNTY FOR SELECTED PLANS OF OPERATION

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

The required additional number of connectors to feeders ranged from 12 to 23 (added capacities of 120 to 230 cubic feet per second), with the greater increase being required for the plans that require larger amounts of imported water. The number of additional surface storage units ranged between 9 and 31, with the larger numbers for the plans that require large amounts of extracted ground water. The number of new or replacement pumps ranged between 293 and 1,039, while the number of new or replacement boosters ranged between 179 and 235. By increasing the use factor through efficient, coordinated operations of all facilities, the number of pumping units by 1990 may be reduced to approximately one-third of the present number, under plan 117-4.

Cost of Coordinated Operation

To facilitate comparison of the economic effects of the individual items that were considered in determining the total cost to the Coastal Plain for meeting applied water demands, the items were grouped into four categories; surface water facilities, ground water facilities, electrical energy requirements, and imported water supplies. The costs of each of these major divisions comprised lesser cost components. Costs of surface water facilities included those of additional laterals, connectors, and surface storage facilities. Costs of ground water facilities included pumping, boosting, spreading, and injection facilities. Costs of electrical energy included both the energy cost and connected load charge for well pumps and boosters. Costs of imported water supplies to the Coastal Plain were predicated on the prices charged by the Metropolitan Water District for the various types of raw and treated water.

Detailed cost information on items comprising the four categories is shown, for the period 1963 through 1990, in Sheets 5, 8, 9 and 10 of Attachments 11 through 15 for the five selected plans of operation.

A summary of the data contained in those tables is presented in Table 23. Present worths of the total cost for each of the four categories during the study period are shown for each selected plan of operation. Price-of-water study No. 1 is used because it gives the best evaluation of the true cost of water and also it presents information related to the statewide economic impact of ground water management in this area. The range in cost is approximately 7 percent, or a difference of \$48 million. Cost of imported water supply ranges between \$463 and \$554 million, cost of ground water facilities ranges between \$18 and \$32 million, and cost of electrical energy and service connections ranges between \$23 and \$50 million. The maximum cost of surface water facilities is approximately \$247 million (plan 117-4), of which about \$240 million represents the cost of existing storage facilities and connectors. Consequently, the present worth of the future cost of additional surface storage facilities, additional laterals of the primary distribution system not included in the cost of water, and additional connectors is about \$7 million.

TABLE 23

SUMMARY OF PRESENT WORTHS OF FUTURE COSTS OF WATER SUPPLY, FACILITIES, AND ELECTRICAL ENERGY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

(In thousands of dollars)

Category	Plan number				
	318-5	117-4	117-5	117-7	117-11
Imported water supply*	548,403	554,269	530,145	509,484	462,968
Surface water facilities	245,904	246,556	246,202	245,882	244,439
Ground water facilities	18,203	17,944	21,194	24,075	32,444
Electrical energy and service connection charges	25,445	22,665	27,923	34,048	50,064
TOTAL	837,955	841,434	825,464	813,489	789,915

*Based on price-of-water study No. 1, which assumes no ad valorem tax.

Because imported water supply is the largest element in the cost of water service to the Coastal Plain, this factor has the greatest impact on the total cost of each of the alternative plans of operation. However, the cost of ground water facilities and the electrical energy and service connection charges also affect the cost comparison of alternative plans appreciably.

Economic Analyses of Selected Plans

As mentioned above, the price of imported water is a major factor in the economics of water service in the Coastal Plain. Because the prices for imported water have been set by the Metropolitan Water District only up to 1967, economic analyses were conducted for the five selected plans of operation under three different sets of price-of-water assumptions--price-of-water studies No. I, II, and III--for the period from 1963 through 1990. In addition, economic evaluation of the selected plans of operation for the period from 1990 to perpetuity was made so that the selected plans could be compared with respect to the costs of perpetual water services that were computed under the three different sets of assumptions.

In making this estimate, it was assumed that the prices of imported water would remain the same as the prices that are assumed to prevail in 1990. Because the future assumption was that a safe-yield operation would be initiated in 1991 for each plan, the amounts of imported water for direct use would be the same as each of the plans considered after 1990. Thus, the cost of imported water for direct use would be the same for all plans. However, that portion of imported water which is used for maintaining the freshwater barrier to prevent sea-water intrusion would be different. In the event that the price of imported water is increased substantially after 1990, due to additional water projects such as a regional water plan, the cost of water service for a plan of operation in which stored ground water is depleted would be increased much more than the cost of water service under a safe-yield plan of operation. Also, the discussion on the impact of changing conditions on the findings of the study is presented in the latter part of this chapter.

The unit price schedules of the District's water under the three sets of assumptions and a summary of assumptions for the three price-of-water studies are given in Table 8 (page 36), and Tables 7-7, 7-8, and 7-9.

The three sets of assumptions regarding amount and price of imported water from the Metropolitan Water District are presented below:

For price-of-water study No. I, it was assumed that the water will be imported by the Metropolitan Water District in the same amount as a water requirement schedule presented in the District's Report No. 802, "Comparative Economic Study of the East Branch and West Branch of the California Aqueduct and of Additional Distribution Facilities Required in the Southern California Coastal Plain by 1990", and that variations in the amount of water imported to the Coastal Plain will not cause variations in the amount of water imported by the Metropolitan Water District. Also, it was assumed that there will be no price differential between the water used for agricultural or ground water replenishment and the water used for domestic and industrial purposes after 1967.

For price-of-water study No. II, it was assumed that the amount of water imported to the Metropolitan Water District will change in proportion to the variation of imports to the Coastal Plain, the pricing schedule for raw water will be the same as for price-of-water study No. I, and any revenue deficiency will be made up by an ad valorem tax. The variation of imported water is due to the greater utilization of ground water in storage.

For price-of-water study No. III, it was assumed that the quantity of water imported will be the same as that in price-of-water study No. II, but the ad valorem tax revenue will be fixed so that 50 percent of the capital cost of facilities will be borne by tax revenues, and the price of water will be modified for each different amount of import so that the remaining cost of obtaining water will be completely paid for by the revenue from the sale of water.

The present worths of the total cost of water service for the five selecte plans are presented on Figure 13 and Table 24. The present worths of the alternatives under the interest rate of 4-1/2 percent for the period between 1963 and 1990 developed under price-of-water studies No. I, II, and III, are represented by curves Ia, IIa, and IIIa. The costs range from $844 million to $964 million, or a difference of 14 percent, as shown in Table 24. Also shown on Figure 13 are curves Ib, IIb, and IIIb, which represent the present worths of the total cost of water service from 1963 to perpetuity for selected plans of operation under the three price-of-water assumptions. The present worths range from about $1,179 million to about $1,299 million or a difference of 10 percent, as shown in Table 24.

TABLE 24

PRESENT WORTH OF TOTAL COST OF WATER SERVICE
UNDER THREE PRICE-OF-WATER STUDIES

Operational plan number	Price-of-Water Study No. I Present worth of total cost of operation, in millions of dollars			Price-of-Water Study No. II Present worth of total cost of operation, in millions of dollars			Price-of-Water Study No. III Present worth of total cost of operation, in millions of dollars		
	1963 through 1990	1991 to perpetuity	1963 to perpetuity	1963 through 1990	1991 to perpetuity	1963 to perpetuity	1963 through 1990	1991 to perpetuity	1963 to perpetui
318- 5	892	315	1,207	959	315	1,274	928	351	1,279
117- 4	895	315	1,210	959	315	1,274	928	350	1,278
117- 5	879	317	1,196	957	317	1,274	923	353	1,276
117-7	867	321	1,188	958	321	1,279	921	356	1,277
117-11	844	335	1,179	964	335	1,299	918	371	1,289

The present worth of the cost of water service between 1991 and perpetuity can be obtained graphically from Figure 13. For a selected plan of operation, determine the present worth of the total cost of water service from 1963 to perpetuity and then subtract the present worth of the total cost of water service from 1963 to 1990.

Since the applied water demand schedules were common to all plans and equally small amounts of imported water spreading were imposed on all selected plans except for plan 318-5, the curves also show the relation between the present worth of the total cost of water service and the amounts of ground water and imported water used. In plan 117-4, use of ground water was limited to the relatively small amount that is replenished annually, and a large amount of the Metropolitan Water District's water was imported for use. In plan 117-11, a large amount of ground water in storage was utilized and a relatively small amount of the District's water was imported during the study period.

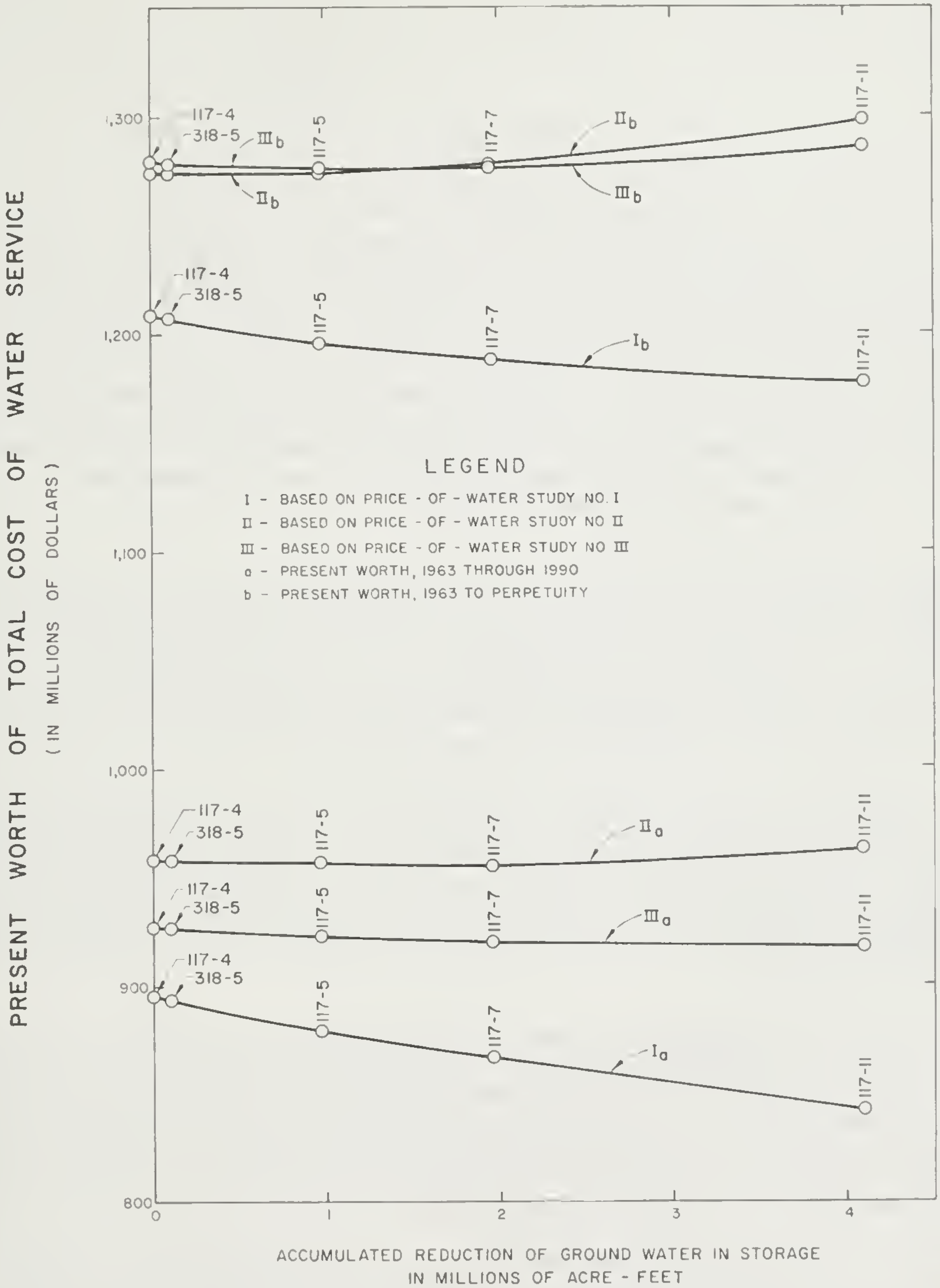


Figure 13. RELATION BETWEEN PRESENT WORTH OF TOTAL COST OF WATER SERVICE AND ACCUMULATED REDUCTION OF GROUND WATER IN STORAGE IN THE COASTAL PLAIN OF LOS ANGELES COUNTY

Curve Ib indicates that plan 117-4 is $31 million more than 117-11. This indicates that the present worths decrease as the amount of ground water use increases. On the other hand, plan 117-11 is approximately $25 million more than 117-4, as shown on curve IIb; plan 117-11 is $11 million more than plan 117-4, as shown on curve IIIb. The latter two curves indicated that the present worths become higher as the use of ground water in storage is increased.

For plan 117-4, the present worth of the cost of perpetual water service is about $64 million higher under price-of-water study No. II than under study No. I (curves IIb and Ib). The difference is the additional cost that is incurred by the Coastal Plain when the cost of water service is partially borne by taxation, and the amount of water imported into the entire Metropolitan Water District is reduced below the volume assumed for the expansion of District's and State's water facilities. A part of the cost of water service in the study area is borne by taxation. The Coastal Plain's share of water service is increased when a larger portion of the cost is derived from taxation because the assessed valuation in the area is proportionately larger.

These interpretations of the total cost of perpetual water service for each alternative are based on the assumption that there would not be drastic changes in the technology of water service. Consequently, the effects of technological advancements, such as a breakthrough in sea-water conversion technique, are not included. A cursory analysis of the effect of very inexpensive conversion of sea water indicates that the findings made in this investigation would remain valid.

The present worths as shown by curves Ia and IIIa decline with reduction in the amount of ground water in storage in the basins. This indicates that the cost of water service between 1963 and 1990 is smaller for a plan of operation that requires larger amounts of ground water and lesser amounts of imported water. However, under price-of-water study No. II (curve IIa), the cost of water service increases as the use of ground water increases.

From 1991 to perpetuity, the cost of water service increases as the use of ground water increases between 1963 and 1990, for all price-of-water studies. (As the use of ground water is increased, the costs of extracting ground water and injecting fresh water at the barriers increase. These increases are partially offset by a decrease in the cost of purchasing filtered water, because there is a reduction in the amount of filtered water purchased for urban use.)

Figure 13 shows that the difference between the present worth (1963) of the total cost of water service from 1991 to perpetuity for plan 117-11, as compared with plan 117-4, is relatively minor, ranging between $10 and $30 million, depending on the price-of-water study used as a base.

Because these two plans represent the maximum and the minimum amounts of ground water withdrawal considered, and because the operating criteria assumed for all five plans were the same after 1990, these amounts of money may also be considered to represent the present worth of the 4 million acre-feet of additional water which would be left in storage in 1990 if plan 117-4 were adopted for use.

As stated previously, for all of the price-of-water studies, it was assumed that there would be no differential in the unit water rates charged for like water used for different purposes after 1967. A cursory study was made, however, to evaluate the effects of differential unit water rates on the cost comparisons of the selected plans of operation. The study was made for the three price-of-water studies by assuming a differential of $13 between agricultural-replenishment-use water and urban-use water. When the total cost of operation, which included the additional cost incurred by the Coastal Plain because of the differential--in terms of added cost of urban-use water and an ad valorem tax--were evaluated, the present worths for the plans of operation under all price-of-water studies were found to be higher; also, the rate of cost reduction with the accumulated reduction of ground water in storage became steeper than that shown for the studies depicted on Figure 13.

The above analysis showed that there was no economic advantage for the Coastal Plain to spread a large amount of imported water for the purpose of increasing the amount of ground water that can be extracted annually under price-of-water study No. III. However, the results of the study also indicated that there may be a long range economic advantage in spreading as much imported water as possible, if the imported water could be obtained at prices equal to the variable operation and maintenance costs during the period when the surplus capacity of the transmission facility is available. This additional amount of ground water could be advantageously used to delay the construction of additional imported water facilities. However, the economic advantage of this type of operation is primarily dependent on proper timing. Before a decision for implementation of such an operation is made an economic analysis is needed with full consideration of the cost of the next water project.

Effect of Changing Conditions on Findings

The operational-economic study of ground water basins in the Coastal Plain is a study dealing with the future water service in the study area. There were a number of factors affecting the cost of water service for which conclusive predictions could not be made. Nevertheless, in order to complete the investigation, it was necessary to assume the future condition of these factors. During the period of the investigation, some of these conditions changed, and they are expected to continue to change. To determine the effect of changing conditions on the findings of this investigation, an evaluation was made of the impact of changes in the three most significant elements of the cost of water service. These three elements are:

1. Energy charges for imported water as it is related to the State Water Project (cost of pumping over the Tehachapi Mountains which reflects the revenue from power generation).

2. Pricing differentials between domestic-industrial and agricultural-replenishment waters sold by the Metropolitan Water District.

3. Ad valorem tax to the member agencies of the District.

The effect of changes in these factors to date (1965) was evaluated by plotting curves that show the relationships between the cost of water service and each of these three factors. The first step in preparing the curves was to determine the cost of water service for four* of the five selected plans of operation under a number of assumed conditions of these factors. All of the previous cost components were included in this study also. Because changes in the three factors under consideration would not affect the cost of ground water production and the cost of other facilities, only the variation in the cost associated with the use of imported water was considered for each different assumed condition. This cost was determined and added to the cost of ground water production and other facilities.

In determining the cost of imported water to the study area, the most recent (1965) information related to the delivery schedules of imported water from the Colorado River, Owens-Mono Area and the State Water Project were integrated in the study. The assumed schedule of Colorado River delivery to the District (Table 25) is based on estimates made by the Colorado River Board. This schedule reflects the possible curtailments of available water from the Colorado River to the service area of the Metropolitan Water District as a result of the recent court decision establishing rights to water from the Colorado River.

The maximum annual entitlements of the Metropolitan Water District to water from the State Water Project are shown in the schedule presented in Table 26. This schedule reflects the increasing capacity of the State Water Project and the resultant increase in the allotment to the District, as shown in the Department of Water Resources Bulletin No. 132-65, "The California State Water Project in 1965".

The Department of Water and Power of the City of Los Angeles was assumed to import water into the Coastal Plain according to the schedule shown in Table 27. This schedule reflects the additional capacity made possible by the second aqueduct now under construction. This schedule is also shown in Table 2 (page 15).

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*Both plans 117-5 and 117-7 were considered representative of the middle range of operations. Plan 117-5 was eliminated, leaving four plans for analysis.

TABLE 25

ASSUMED SCHEDULE OF ANNUAL DELIVERIES OF COLORADO RIVER WATER TO THE METROPOLITAN WATER DISTRICT

Year	Old in acre-feet	New in acre-feet
1962-63	1,180,000	1,020,820[a]
63-64	1,180,000	1,064,380[a]
64-65	1,180,000	1,180,000
65-66	1,180,000	1,180,000
66-67	1,180,000	1,180,000
67-68	1,180,000	1,180,000
68-69	1,180,000	1,180,000
69-70	1,180,000	1,180,000
70-71	1,180,000	1,180,000
71-72	1,180,000	1,180,000
72-73	1,180,000	1,180,000
73-74	1,180,000	1,180,000
74-75	1,180,000	1,180,000
75-76	1,180,000	1,180,000
76-77	1,180,000	1,180,000
77-78	1,180,000	962,000[b]
78-79	1,180,000	744,000[b]
79-80	1,180,000	525,000[c]
80-81	1,180,000	525,000
81-82	1,180,000	525,000
82-83	1,180,000	525,000
83-84	1,180,000	525,000
84-85	1,180,000	525,000
85-86	1,180,000	525,000
86-87	1,180,000	525,000
87-88	1,180,000	525,000
88-89	1,180,000	525,000
89-90	1,180,000	525,000
1990-2039	1,180,000	1,180,000[d]

a. Actual deliveries from the District's annual reports.
b. Calculated using straight line interpolation between 1,180,000 and 525,000.
c. Amount and timing of reduction is based on estimates made by the Colorado River Board.
d. The Colorado River Aqueduct is assumed to be full, due to a regional water plan in this year.

TABLE 26

ESTIMATED MAXIMUM ANNUAL ENTITLEMENTS FOR THE METROPOLITAN WATER DISTRICT FROM THE STATE WATER PROJECT

Year	Old[a]	New[b]
	in acre-feet	in acre-feet
1971	110,400	250,000
1972	198,900	350,000
1973	287,300	450,000
1974	375,800	550,000
1975	464,300	650,000
1976	552,900	750,000
1977	641,400	850,000
1978	729,800	950,000
1979	818,300	1,050,000
1980	906,800	1,150,000
1981	966,100	1,250,000
1982	1,025,400	1,350,000
1983	1,084,700	1,450,000
1984	1,144,000	1,550,000
1985	1,203,400	1,650,000
1986	1,262,800	1,750,000
1987	1,322,100	1,850,000
1988	1,381,400	1,950,000
1989	1,440,800	2,000,000
1990	1,500,000	2,000,000
1990-2039	1,500,000	2,000,000

a. Based on Bulletin No. 132-64, "The California State Water Project in 1964".

b. Based on Bulletin No. 132-65, "The California State Water Project in 1965".

In addition to making assumptions as to the maximum amount of imported water available to the District's service area, assumptions were made on the delivery of imported water. These assumptions were:

1. The City of Los Angeles will import water from the Owens-Mono Area according to the new schedule shown in Table 27.

2. Because the variable cost of water from the Colorado River will be less than the cost of water from the State Water Project, the Metropolitan Water District will use all of

TABLE 27

ASSUMED IMPORT SCHEDULE OF WATER
BY THE LOS ANGELES DEPARTMENT OF WATER AND POWER
TO THE COASTAL PLAIN OF LOS ANGELES COUNTY

Old: Ground water and one aqueduct		New: Ground water and two aqueducts	
Year	Quantity, in acre-feet	Year	Quantity, in acre-feet
1963	197,300	1963	197,300
1965	177,500	1965	177,500
1969	137,900	1969	309,000*
1970	128,000	1970	300,000
1975	127,000	1975	260,000
1980	126,000	1980	221,000
1985	126,500	1985	181,000
1990	127,000	1990	141,000

*Second aqueduct delivery added.

Note: The above values are obtained from the Los Angeles Department of Water and Power.

its Colorado River water entitlement under all plans of ground water basin operation implemented in the Coastal Plain of Los Angeles County.

3. After 1990, under all plans of ground water basin operation, the District's water entitlements from both the Colorado River and the State Water Project will be fully used throughout the District's service area. (This is based on the present thinking of the District with respect to the spreading of imported water.)

4. The amount of water imported annually to the District service area will vary in direct proportion to the variation in amount of water delivered in the Coastal Plain of Los Angeles County. The schedule of delivery to meet domestic, industrial, agricultural, and replenishment water requirements is based upon data published in the District's report No. 818.

5. Any reduction in the delivery of imported water by the District will be a reduction in the amount of agricultural-replenishment water. However, if the amount of agricultural-replenishment water is not large enough to accommodate the total assumed reduction in the delivery of imported water, the balance of the reduction

will be considered to occur in water for domestic and industrial use.

The cost of water service in the Coastal Plain was determined for each of the four plans of operation under ranges of variation for the three factors considered. These ranges are:

Energy Charge. Upper limit - $23 per acre-foot.
Lower limit - $12 per acre-foot.

The upper limit represents the results of the analyses of different energy charges applicable to the East and West Branches of the State Water Project, based on data published in Bulletin No. 132-64. The lower limit is the estimated energy charge given in Bulletin No. 132-65. For this study, the energy charge included the variable operation, maintenance, replacement, and power costs.

Price Differential. Upper limit - $25 per acre-foot.
Lower limit - $0 per acre-foot.

The upper limit represents the maximum amount of constant differential between the rates charged for domestic-industrial water and agricultural-replenishment water which could be applied if costs are spread over the full scheduled repayment period, 1969 to 2039. This value was determined on the basis of the energy rates published by the Department of Water Resources and the estimate of domestic-industrial water supply requirements provided by the Metropolitan Water District.

Tax Revenue. Upper limit - 100 percent.
Lower limit - 0 percent.

The full range of possible variations in the rate of taxation, based on the assessed valuation of properties in the District service area, was considered in establishing the relationship between the ad valorem tax and cost of water service.

A detailed discussion of the items considered in determining the prices of water imported by the District and in determining the tax revenue required under various assumed pricing schedules is presented in Chapter II and Attachment 7. The present worth of the total cost of water service in the study area was computed for the four selected plans of operation under three sets of assumed conditions of the variable factors.

Three sets of curves were developed to show the relationships of the three variable factors. The first set, which shows the relationship between the energy charge and the present worth of the total cost of water service, is shown on Figure 14.

The second set of curves, shown on Figure 15, represents the relationship between the water price differential and the present worth of the total cost of water service.

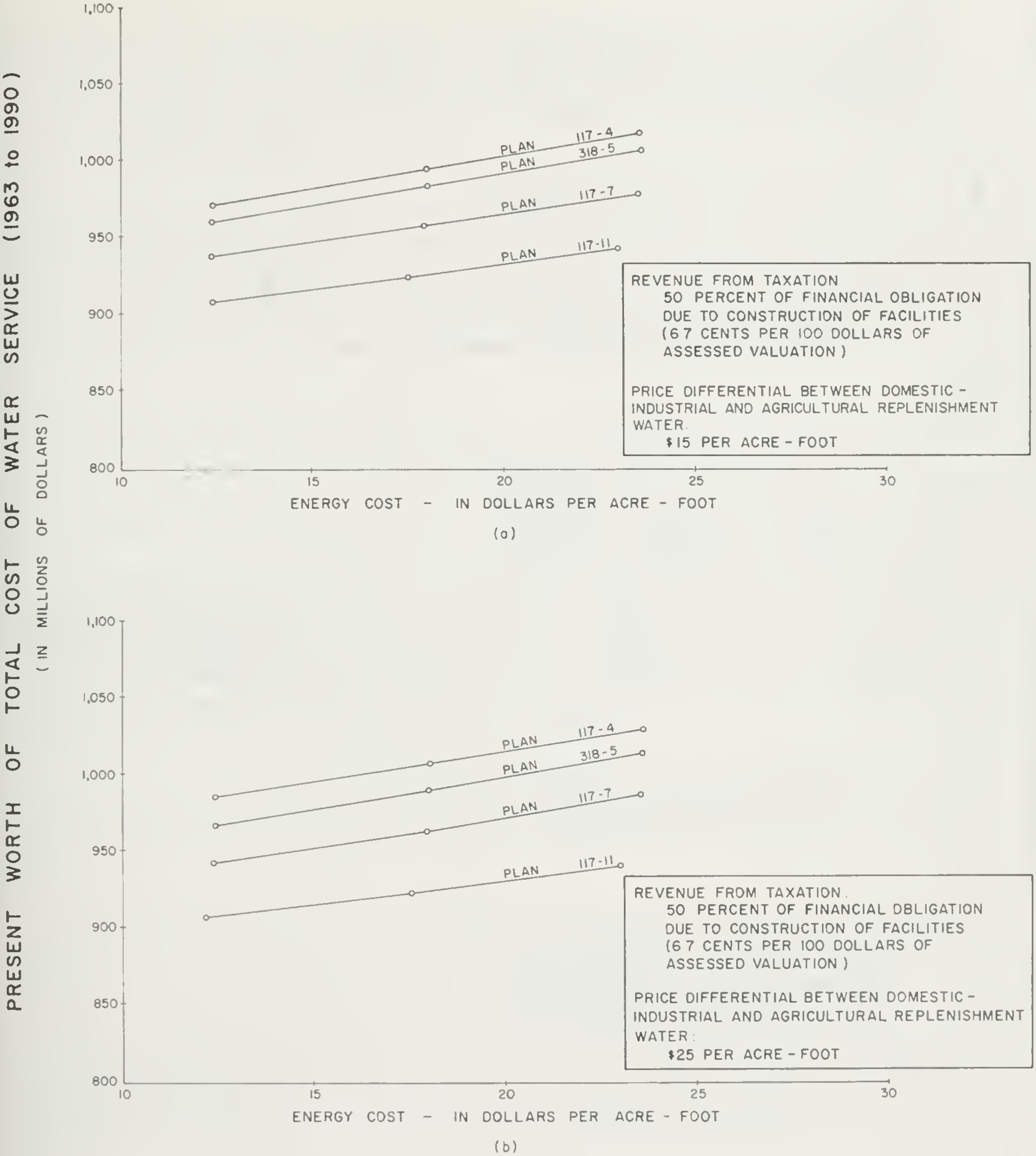

Figure 14. RELATION BETWEEN PRESENT WORTH OF TOTAL COST OF WATER SERVICE AND ENERGY COST

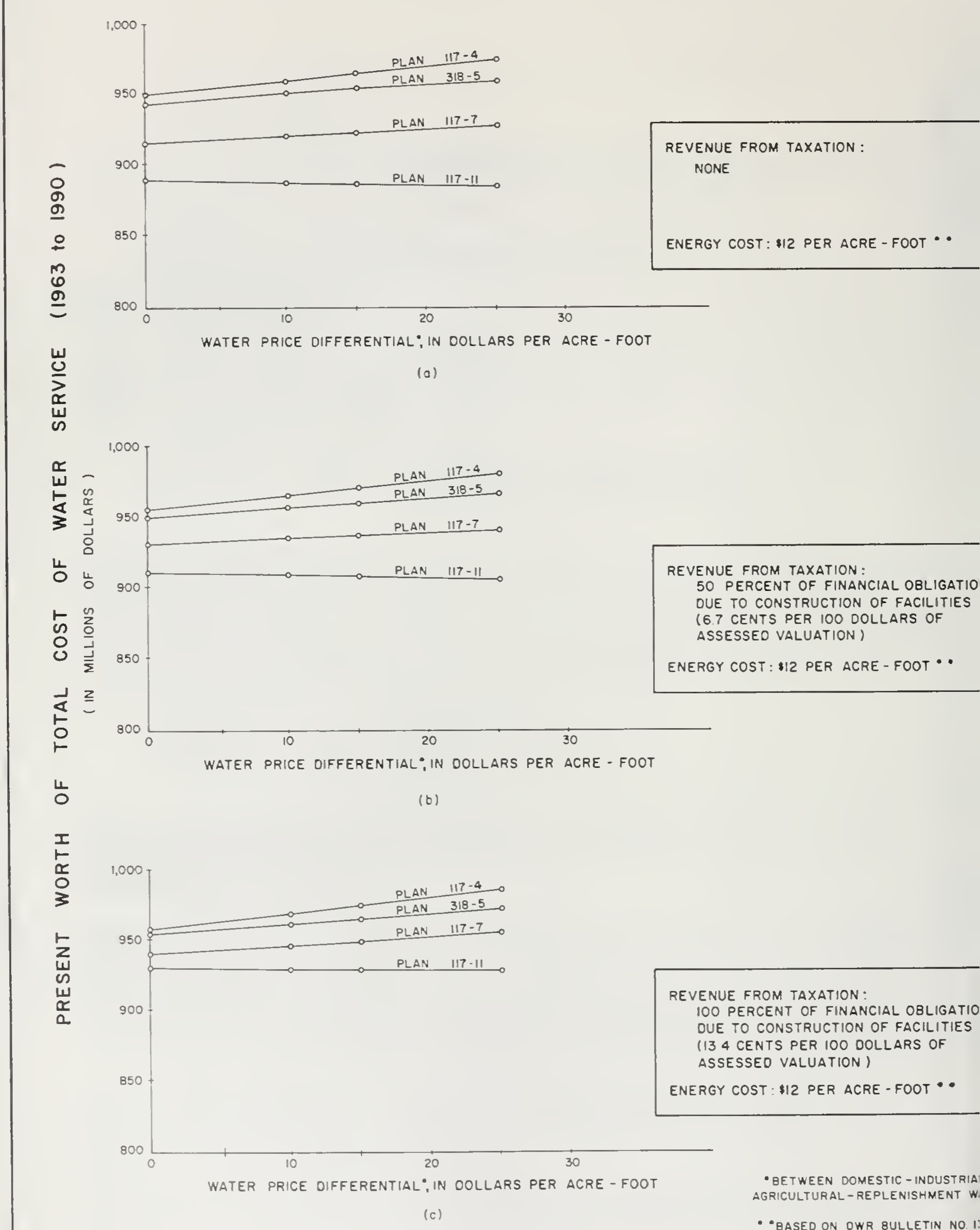

Figure 15. RELATION BETWEEN PRESENT WORTH OF TOTAL COST OF WATER SERVICE AND PRICE DIFFERENTIAL*

The third set of curves (Figures 16 and 17) represents the relationship between the ad valorem tax rate and the present worth of the total cost of water service in the study area. The ad valorem tax rate is indicated on the abscissa of the curves as percent of financial obligation paid by taxes.

With these curves, the effect of changes in one factor on the cost of water service from 1963 to 1990 can readily be evaluated; however, to facilitate the more complex evaluation of the effect of changes in more than one factor, three nomographs were developed. With the nomographs, it is possible to make a reliable simultaneous evaluation of the effect of all three factors within the range shown on the present worth of the total cost of water service under each of the four selected plans of operation.

The present worth of the total cost of water service for the period 1963 through 1990 can be determined from the first nomograph, Figure 18, for all four plans--117-4, 117-7, 117-11, and 318-5. The present worth of the total cost of water service for the period 1991 to perpetuity can be determined from the two additional nomographs, Figures 19 and 20.

The nomograph was constructed by selecting, from Figures 14, 15, 16, and 17, the positions and scales of lines that represent the factors considered in this study: (1) energy cost of water from the State Water Project, (2) price differential between the domestic-industrial and agricultural-replenishment waters, (3) ad valorem tax rate applicable to the member agencies in the Metropolitan Water District's area, and (4) present worth of the total cost of operation.

Analysis of the relationships represented in the curves on Figures 14, 15, 16, and 17 brings out additional information contributory to the findings of this investigation. These relationships are interpreted in the following paragraphs.

On Figure 14, the relationship between the present worth of the cost of water service and the cost of energy for State Water Project water delivered to the study area is shown in the two sets of curves developed for assumed price differentials of $15 and $25 per acre-foot between domestic-industrial and agricultural-replenishment water. For both cases, a rate of taxation which would meet 50 percent of the total financial obligations due to construction of District facilities was assumed. Comparison of the relationship under the two different price differentials shows that the cost of the corresponding plan of operation is smaller when the price differential is $15 than when the differential is $25 per acre-foot.

This is because the money the Coastal Plain has to pay for each acre-foot of water increases as the differential increases. For all the plans studied, the amount of imported water spread was kept to the minimum within the Coastal Plain while a large amount, approximately 350,000 acre-feet, was assumed to be spread in the outside area. In addition, there

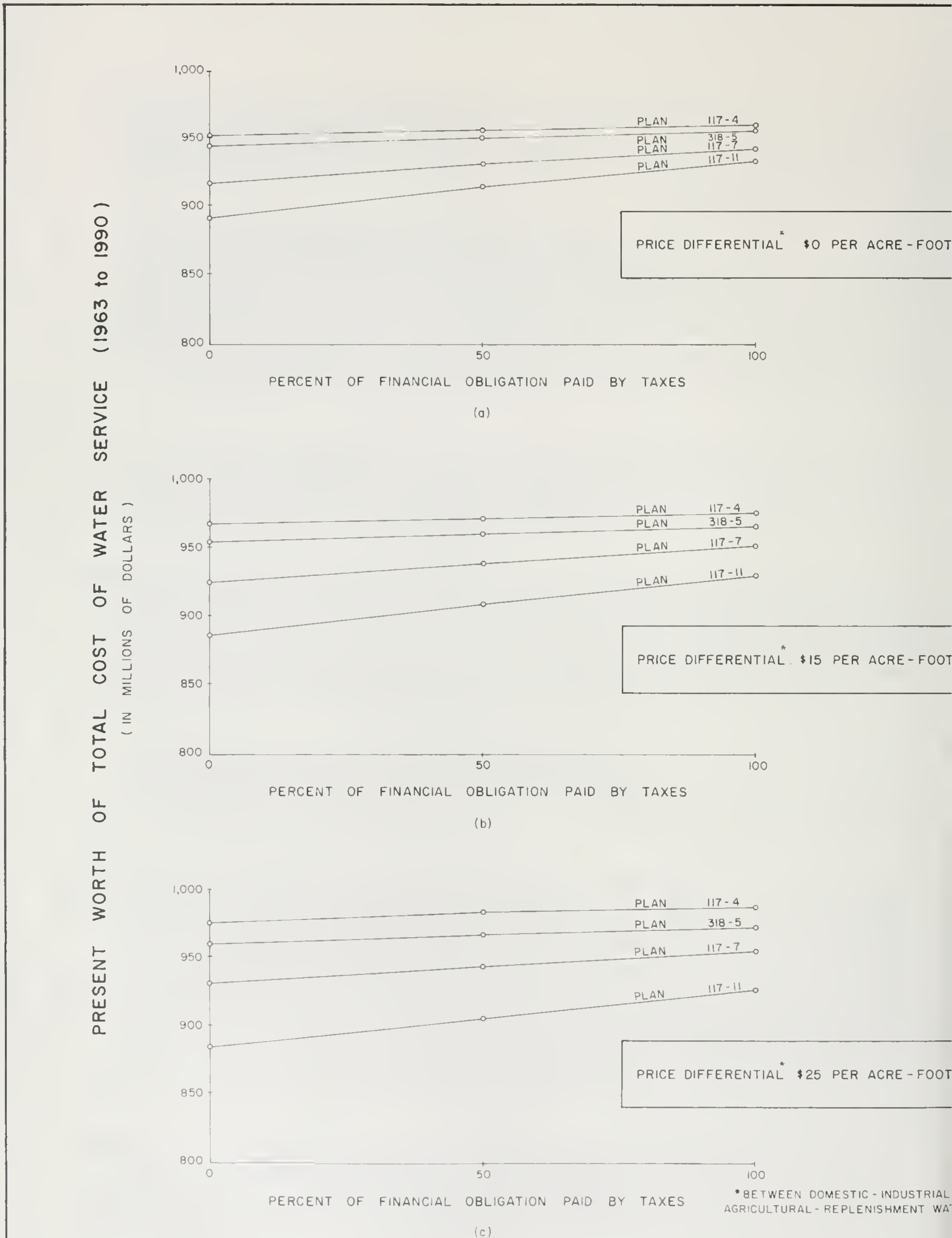

Figure 16. RELATION BETWEEN PRESENT WORTH OF TOTAL COST OF WATER SERVICE AND REVENUE FROM TAXATION (ENERGY COST - $12 Per Acre-Foot **)

** BASED ON DWR BULLETIN NO. 132-65

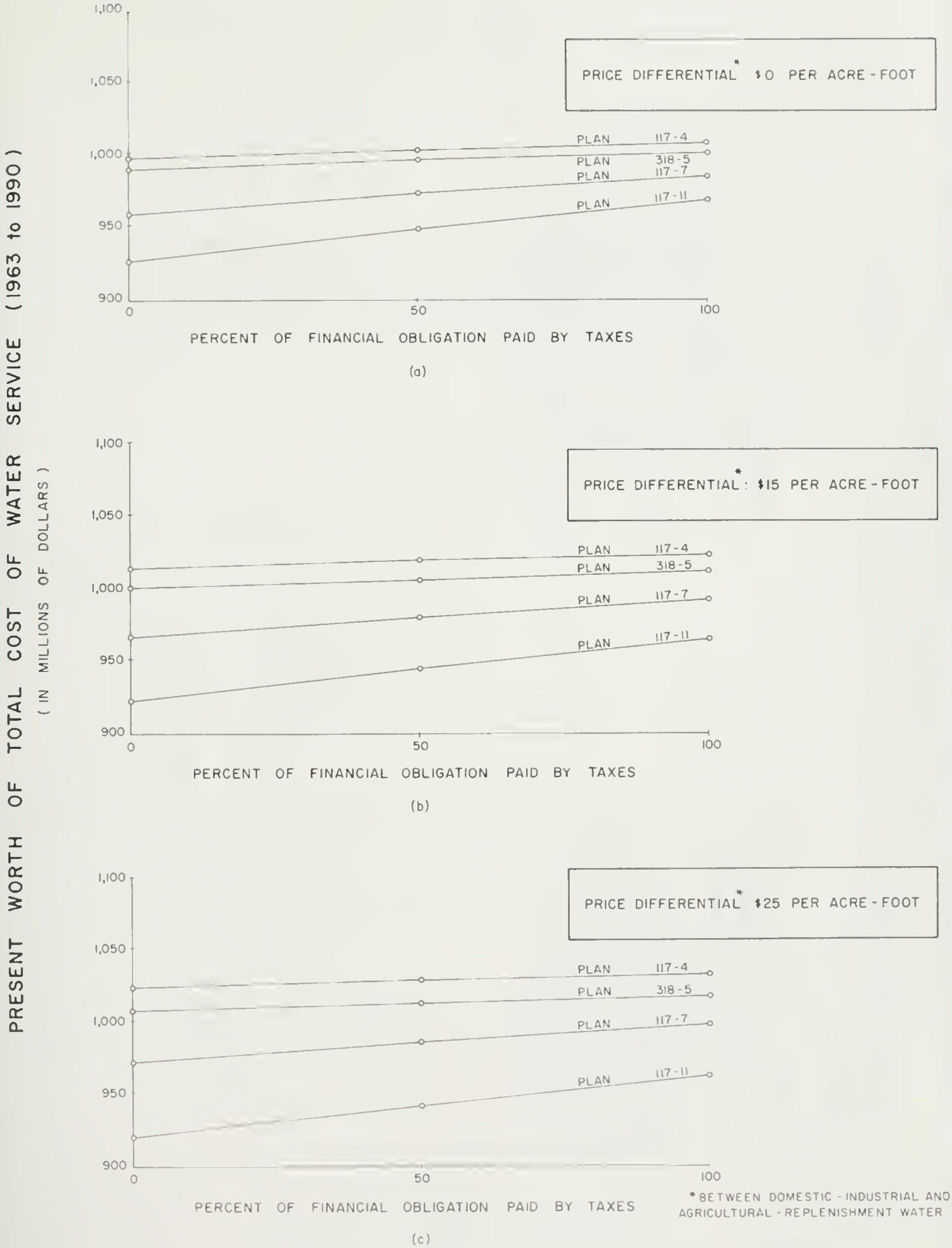

Figure 17. RELATION BETWEEN PRESENT WORTH OF TOTAL COST OF WATER SERVICE AND REVENUE FROM TAXATION (ENERGY COST - $23 Per Acre-Foot**)

** BASED ON DWR BULLETIN NO. 132-64

USE OF THE NOMOGRAPH

1. Select plan of operation.
2. Connect appropriate points on tax scale and differential scale. Mark intersection of this line with turning line.
3. Connect point of turning line with energy cost point. Where this line intersects present worth line, read the present worth of total cost of water service for the selected plan.

DEFINITIONS

Tax. % of financial obligation for Metropolitan Water District facilities borne by property tax.

Differential. Difference in price between domestic-industrial and agricultural-replenishment water imported to the Coastal Plain.

Energy Cost. Energy charge (including operation, maintenance, replacement, and power costs) for State Water Project water delivered to Southern California.

Present Worth. Present worth of total cost of water service, 1963 through 1990.

EXAMPLE

Plan 117-4

Tax - 50%

Differential - $10

Energy cost - $12

Present Worth- $967 million

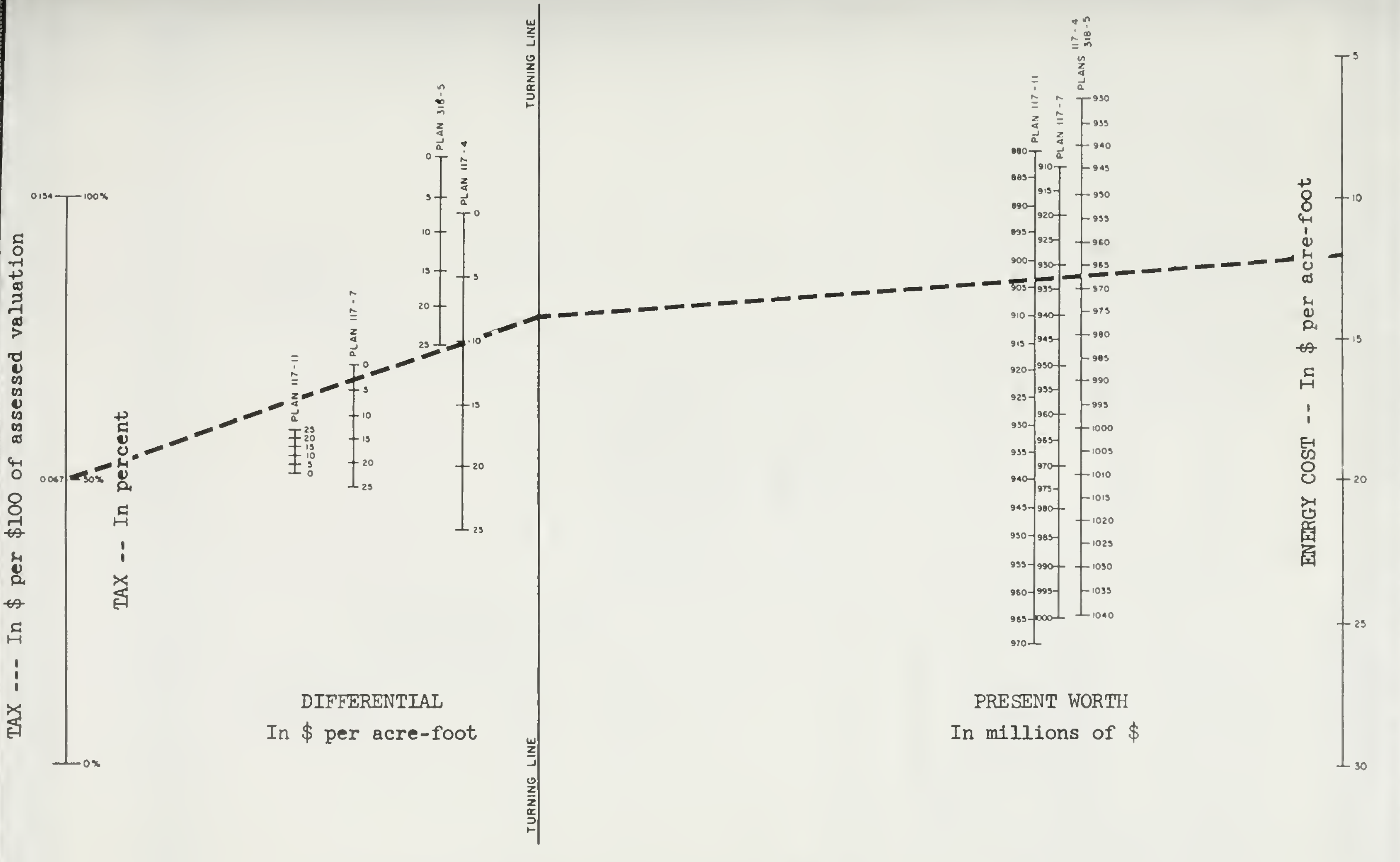

Figure 18. NOMOGRAPH TO DETERMINE PRESENT WORTH OF TOTAL COST OF WATER SERVICE IN THE COASTAL PLAIN UNDER VARIABLE CONDITIONS AFFECTING THE PRICE OF IMPORTED WATER - 1963 THROUGH 1990

USE OF THE NOMOGRAPH	DEFINITIONS
1. Select plan of operation. 2. Connect appropriate points on tax scale and differential scale. Mark intersection of this line with turning line. 3. Connect point of turning line with energy cost point. Where this line intersects present worth line, read the present worth of total cost of water service for the selected plan (See EXAMPLE - - - below)	Tax. % of financial obligation for Metropolitan Water District facilities borne by property tax. Differential. Difference in price between domestic-industrial and agricultural-replenishment water imported to the Coastal Plain. Energy Cost. Energy charge (including operation, maintenance, replacement, and power costs) for State Water Project water delivered to Southern California. Present Worth. Present worth of total cost of water service, 1991 to perpetuity.

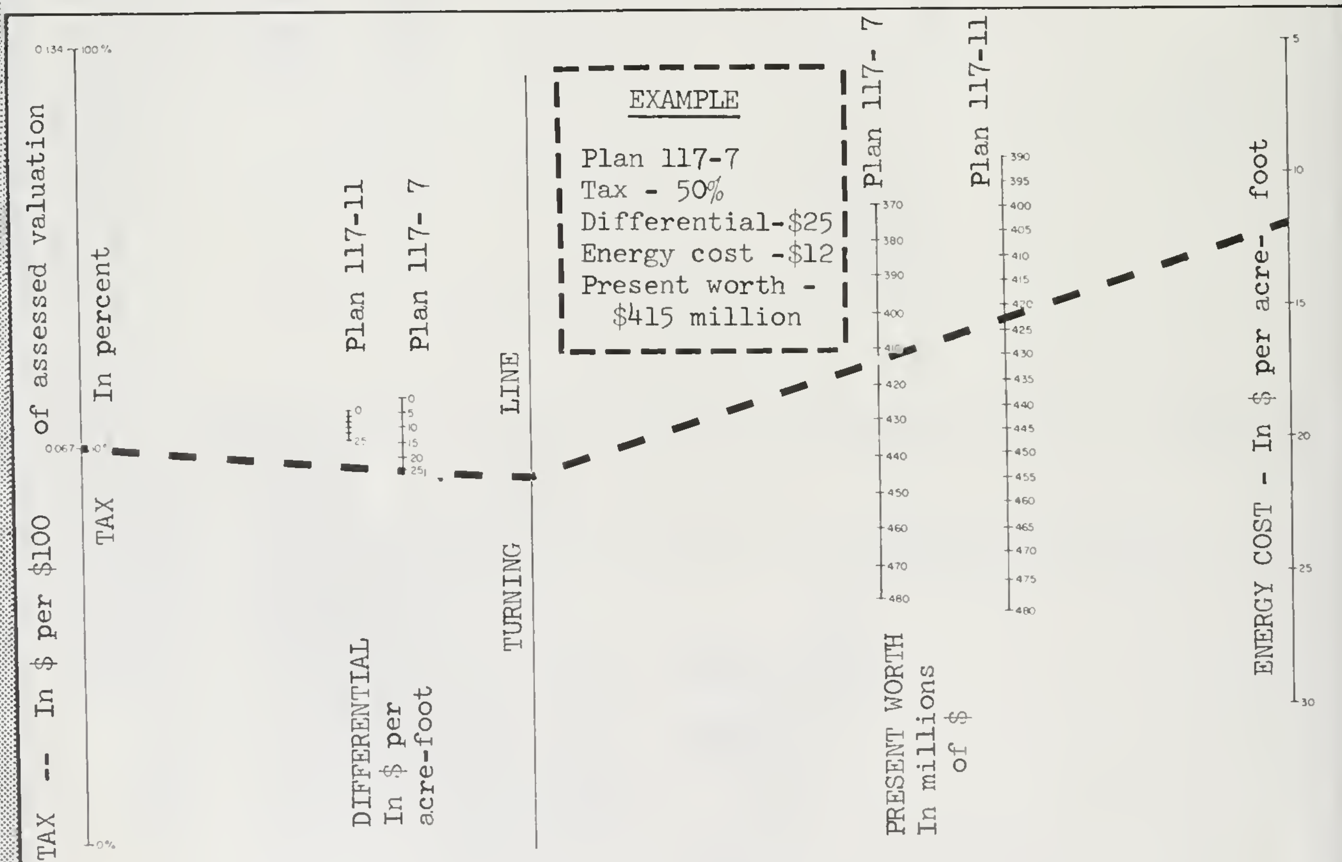

Figure 19. NOMOGRAPH TO DETERMINE PRESENT WORTH OF TOTAL COST OF WATER SERVICE IN THE COASTAL PLAIN UNDER VARIABLE CONDITIONS AFFECTING THE PRICE OF IMPORTED WATER 1991 TO PERPETUITY - - PLANS 117-7 AND 117-11

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

USE OF THE NOMOGRAPH

1. Select plan of operation.
2. Connect appropriate points on tax scale and differential scale. Mark intersection of this line with turning line.
3. Connect point of turning line with energy cost point. Where this line intersects present worth line, read the present worth of total cost of water service for the selected plan.

(See EXAMPLE ---below)

DEFINITIONS

Tax. % of financial obligation for Metropolitan Water District facilities borne by property tax.

Differential. Difference in price between domestic-industrial and agricultural-replenishment water imported to the Coastal Plain.

Energy Cost. Energy charge including operation, maintenance replacement, and power costs for State Water Project water delivered to Southern California.

Present Worth. Present worth of total cost of water service, 1991 to perpetuity.

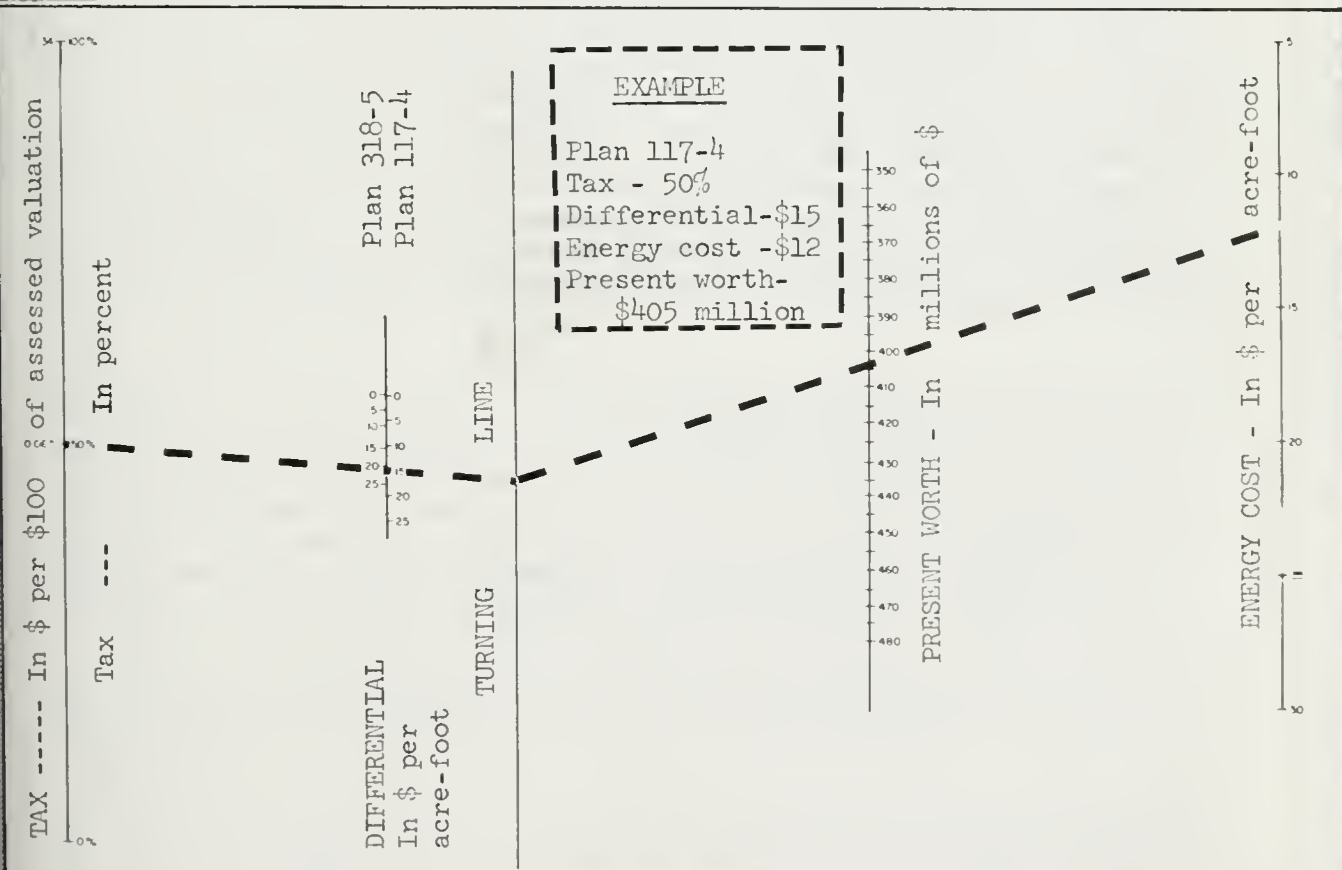

Figure 20. NOMOGRAPH TO DETERMINE PRESENT WORTH OF TOTAL COST OF WATER SERVICE IN THE COASTAL PLAIN UNDER VARIABLE CONDITIONS AFFECTING THE PRICE OF IMPORTED WATER 1991 TO PERPETUITY - - PLANS 117-4 AND 318-5

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

is water used for agricultural purposes outside the Coastal Plain. When the differential between agriculture and urban water is increased, the revenue deficit resulting from selling water cheaply for agricultural and spreading use must be made up by urban water users.

In each case, as anticipated, the present worth of the total cost of water service increases as the cost of energy increases because a higher unit price is charged for water used for domestic-industrial use. Because two of the factors were fixed, the price of imported water for domestic and industrial purposes, as well as the price of imported water for agricultural and replenishment, must be increased to bring in enough revenue to accommodate the increase of the cost to the Metropolitan Water District.

Under both pricing differentials, the cost of water service under plan 117-4, a safe-yield plan, is greater than the cost for plan 318-5, another safe-yield plan. Plan 318-5 uses more imported water for spreading and also pumps more water from the ground water basin than plan 117-4; thus, the cost of water service under plan 318-5 is low because the larger portion of imported water is agricultural-replenishment water, obtained at reduced price. Conversely, plan 117-4 uses a large amount of imported water purchased at the higher domestic-industrial price. The curves on Figure 14 show that, between the two safe-yield plans of operation, the plan which utilizes more imported water for spreading is cheaper than a plan in which more of the imported water is purchased for direct consumption by the users. The curves also show that the difference in the cost of water service between plan 117-4 and 318-5 increases as the differential in water price increases. Comparison of plans 117-4, 117-7, and 117-11 under both the $15 and the $25 price differential shows that the more ground water is utilized, the less expensive the cost of water service becomes.

The relationship between the present worth of the total cost of water service and the price differential for imported water is shown on Figure 15 for three assumed rates of ad valorem tax--0, 50 percent, and 100 percent. In each case, $12 was assumed to be the energy rate for transporting water through the State Water Project. Here, as on Figure 14, it is evident that the cost of water service increases as the amount of imported water used increases. This is seen by comparing the cost of water service for plans 117-11, 117-7, and 117-4. Figure 15 also shows that the cost of water service is less for plan 318-5 than for plan 117-4. In the upper two groups of curves on Figure 15, the cost of water service increases as the differential in water prices increases for plans 117-4, 318-5, and 117-7. However, the cost of water service decreases as the differential in water prices increases for plan 117-11. The tendency for the cost of water service for plan 117-11 to decline is due to the advantage obtained by increasing amounts of differential in the cost of purchasing imported water to be injected along the coastline for preventing sea-water intrusion. Note, however, that the downward slope of the line representing the cost of water service for plan 117-11 flattens as the ad valorem tax rate increases. This is due to the negation of the advantageous differential by the increased tax burden on the Coastal

Plain of Los Angeles County. By comparing the cost of water service as indicated by the three groups of curves, the difference in the cost of water service between plans 117-4 and 117-11 lessens as the revenue from taxation is increased. This is due to the fact that the assessed valuation in the Coastal Plain is high and the tax burden is greater than the advantages that can be attributed to differential in imported water prices.

The relationship between present worth of the total cost of water service and the ad valorem tax is shown in six groups of curves on Figures 16 and 17. The assumed energy rate is $12 per acre-foot on Figure 16 and $23 per acre-foot on Figure 17. For each assumed energy rate, price differentials of 0, $15, and $25 were assumed.

Figure 16 shows that the cost of water service is the least for plan 117-11 and that the cost increases as the amount of imported water used increases. Also, a comparison of the two safe-yield plans shows that the cost of water service for plan 318-5 is less than the cost for plan 117-4. For plans 318-5 and 117-4, the cost of water service increases only slightly as the rate of ad valorem tax is increased, while the cost of water service for plan 117-11 shows a marked increase with the increase in the rate of taxation. This difference is due to the assumption made on the delivery of imported water into the District service area under different plans of operation. For plan 117-11, the amount of imported water into the District service area would be smaller than the amount of imported water for plans 117-4 and 318-5. Consequently, the effect of an increase in the taxation is much more strongly felt in plan 117-11 than in the safe-yield plans. It is also noted that the difference in the cost of water service between plan 117-11 and plan 117-4 is significantly greater when the differential in water price is $25 per acre-foot than when the price differential is 0.

The comments made in reference to Figure 16 also apply to all curves shown on Figure 17. However, when no financial obligation is paid by taxes (tax rate = 0), the least cost for the most economical plan (117-11) is less than $900 million on Figure 16, while on Figure 17 it is between $900 and $950 million. This increase reflects the rising cost of imported water under the $23 per acre-foot energy rate assumed for Figure 17 compared with the $12 energy charge assumed for Figure 16.

By using the nomographs (Figures 18, 19, and 20), Figure 21 was prepared. This figure shows the costs of water service in the Coastal Plain from 1963 to 1990 and from 1963 to perpetuity for three different assumed conditions.

In the lower group of curves, representing the present worth of the total cost of water service up to 1990, all of the curves go downward with an increase in accumulated reduction of ground water in storage. However, in the upper group of curves, representing the present worth of the total cost of water service from 1963 to perpetuity, the curve that represents the condition with no price differential and 100 percent revenue from

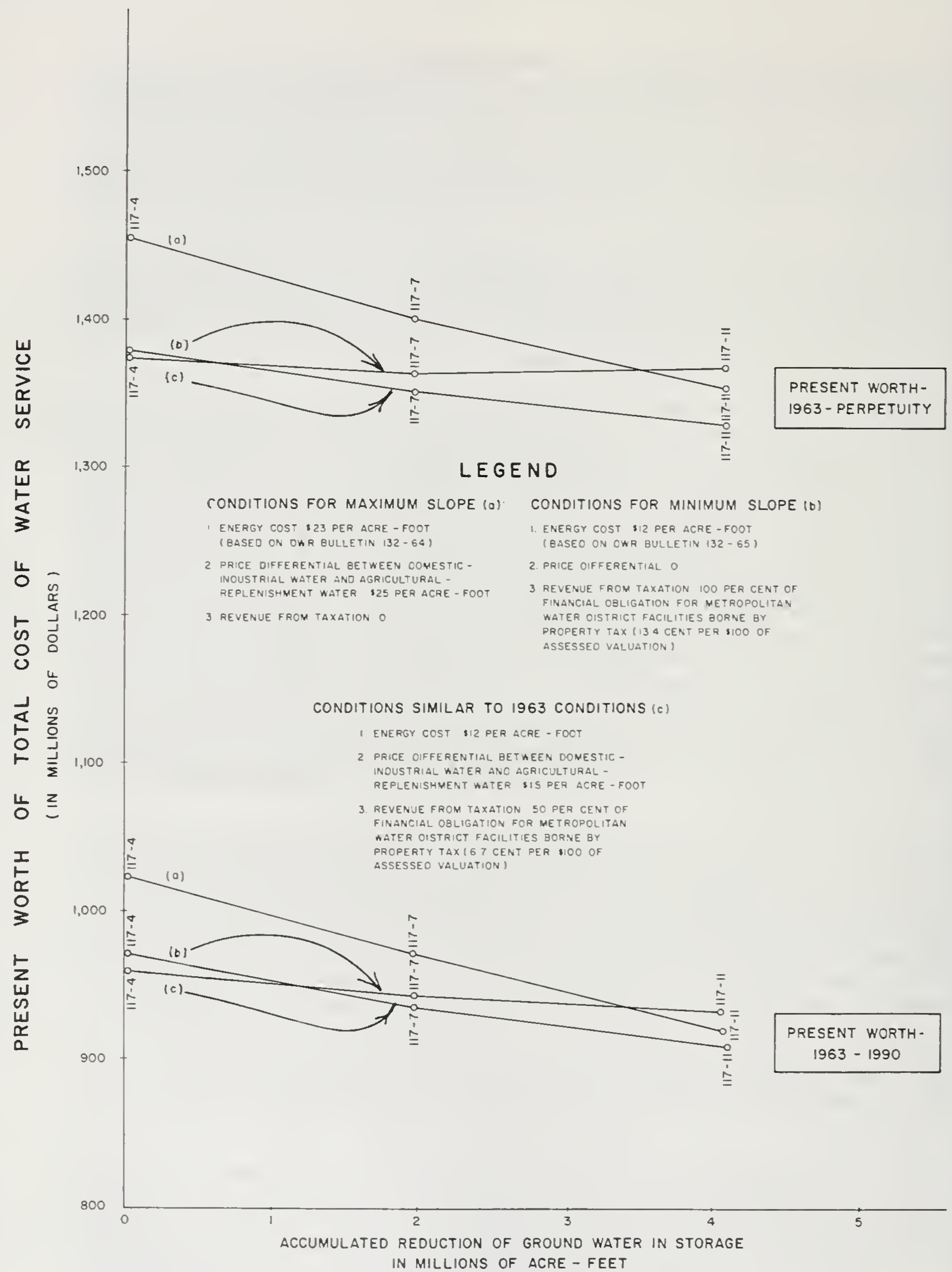

Figure 21. RELATION BETWEEN PRESENT WORTH OF TOTAL COST OF WATER SERVICE AND ACCUMULATED REDUCTION OF GROUND WATER IN STORAGE IN THE COASTAL PLAIN OF LOS ANGELES COUNTY

taxation indicates a slight increase in the cost of water service under plan 117-7. A comparison of Figure 21 with Figure 13 shows that the relationships between the present worth of the total cost of water service and the accumulated reduction of ground water in storage is essentially the same on both figures. The interpretation of operational alternatives shown on Figure 13 is further substantiated by the use of Figures 14, 15, 16, and 17. These analyses indicate that the changes in those factors that affect the price of water imported by The Metropolitan Water District of Southern California will not alter the findings of this investigation.

Interpretation of Results of Economic Analyses

The results as depicted in Figure 13 were interpreted for the Coastal Plain with regard to the four independent operational variables of the ground water basin operation. The following discussion also refers to Figures 7(A) and 7(B) of Chapter III and to Figure 21 of this chapter to assist in understanding the results.

As was stated previously, use of imported water is complementary to the use of ground water: if a selected amount of ground water is decreased, an equal amount of imported water must be increased to meet a given applied water demand schedule. If the plan of operation of the ground water basin is one in which the amount of fresh ground water in storage is not reduced, imported water may be spread to take advantage of the excess capacity of the existing primary distribution facilities during the period of buildup. This would delay the construction of additional imported-water facilities. Under this condition, as long as the present worth of the cost of spreading imported water and extracting it later is less than the present worth of cost of imported water for direct domestic and industrial use, almost any amount of spreading would be economically advantageous. The amount is limited only by waterlogging, which is affected by the hydraulic characteristics of aquifers and operating conditions of ground water basins with respect to amounts and locations of extraction.

It was shown previously by the use of Figure 7(A) that, for the condition assumed for price-of-water study No. I, it is not economical to spread imported water, under the premise that the ground water in storage may be reduced until the limit of economic pumping level is reached. This statement is true for the conditions assumed for all three price-of-water studies.

The above statement is true also for any conditions that may develop in the future. The analyses of Figures 14, 15, 16, and 17 indicate that the present worth of the total cost of water service in the study area will be smaller for a plan of operation in which a large amount of ground water is used without replenishment of imported water than the cost of water service for a plan in which a large amount of imported water is spread and subsequently extracted for use.

In Chapter III, it was shown that use of freshwater barriers is the more economical of the two methods of preventing sea-water intrusion.

The alternative method considered--creation of a seaward gradient of fresh water--would require immediate filling of the storage space with large amounts of imported water. Because only limited amounts of water will be available for recharge before 1972, and because the rate of subsurface flow into this area is low (and would decrease as added water produced a flatter hydraulic gradient), such a plan was considered impractical. Creation of such a hydraulic gradient would also require a large immediate capital outlay.

The freshwater-injection barriers, on the other hand, require relatively small amounts of both immediate capital outlay and annual outlays for operation and maintenance.

Furthermore, under the plan in which a seaward gradient of fresh water is a prerequisite, the possibility of using the ground water presently in storage as a resource would be eliminated because, under such a plan, water levels must be kept high. On the other hand, the range of operational possibility can be kept wide for economical operation of the ground water basins under plans in which freshwater barriers are utilized to prevent saline intrusion.

As to pumping patterns, the observations made in Chapter III also apply to the economic evaluations in price-of-water studies No. II and III. It would be economical to limit the amount of extraction along the coast to the minimum workable amount. However, this comment can be made with certainty only in regard to those points in the Coastal Plain where the existing and proposed surface systems are adequate to meet the imported-water demand for the entire range of operational possibilities investigated in this study.

Under a certain condition affecting the price of imported water the large amount of extraction along the coastline would be advantageous to the study area in the Coastal Plain. This is implied on Figure 15. The graph at the top of the figure indicates that the cost of water service for plan 117-11 becomes lower as the differential increases. On the other hand, the same graph shows that the cost of water service for plan 117-4 rises as the differential increases. This indicates that the cost of water service in the study area could be kept small, even if the amount of extraction along the coastline were to be large and intrusion of sea water into the ground water basin were to be prevented by injection of imported water along the coastline. The cost of water service for plan 117-11 becomes lower with the increase in the amount of differential because, under this plan, the Coastal Plain of Los Angeles County would be receiving a financial advantage through the use of imported water in the injection barrier--water purchased at a relatively low price. This financial advantage would offset the amount of tax paid by property owners in the Coastal Plain.

Interpretation of the economics of the amounts of extraction vary widely for the three different price-of-water studies. Under the condition presumed for price-of-water study No. I, a 6 percent ($51 million) savings could be made by the use of large amounts of ground water and small amounts of imported water to meet applied water demands. On the other hand, the variation in the total cost of operation for the 1963-90 period amounted to less than 1 percent ($7 million) under the conditions presumed for price-of-water study No. II; for price-of-water study No. III, the variation was approximately 1 percent ($10 million). Consequently, any plan within the wide range of possible methods of operating the ground water basins may be chosen without causing significant differences in the cost in water service to meet applied water demands under price-of-water studies No. II and III.

Figure 21, which incorporates more recent information on the determination of the cost of water service, illustrates and confirms the previous findings--that, if the trend in the factors affecting the price of imported water continues in the future, a considerable amount of money could be saved in the study area by adoption of a plan of basin operation whereby the large amount of ground water in storage might be reduced.

CHAPTER V. SUMMARY OF FINDINGS AND CONCLUDING REMARKS

The results of the operational and economic studies of the ground water basins in the Coastal Plain of Los Angeles County are presented in the following summary of physical, operational, and economic findings. The interpretation of the results of these studies is given in the concluding remarks.

Because the primary objective of these studies was to provide local water management agencies with information on a wide range of operational plans with which they can formulate the optimum plan for use in the Coastal Plain, these studies were not limited to those that are possible within the existing legal and organizational framework. For the purposes of this study, the economic analyses were conducted primarily from a local point of view, and, for all plans studied, it was assumed that legal obstacles would be overcome and the necessary management organization would be made available.

The major findings of this phase are:

Physical Findings

1. The water supply available from local and import sources, both existing and committed-for, supplemented by ground water now in storage in the Coastal Plain, would be adequate to meet the increasing total water demand of the Coastal Plain through the year 1990 and beyond.

2. The annual applied water demand of the Coastal Plain is projected to grow from 861,000 acre-feet in 1963 to 1,218,000 acre-feet in 1990. In addition to applied water demand, there will be an imported water requirement in the Coastal Plain.

3. For the alternative plans investigated, the largest annual operation requirement for spreading and injection was 151,000 acre-feet, and the smallest annual amount was 33,000 acre-feet.

4. Flood runoff, rising water, and imported spread water conserved in the streambeds and spreading grounds in the Montebello Forebay Area reach the zone of saturation within a year regardless of the water levels. Cyclic fluctuations of the water levels in Montebello Forebay Area are due primarily to the variation in the amounts of deep percolation of these waters. The average annual amount of flood runoff and rising water conserved in the past was 53,000 acre-feet; the future amount is estimated to be 48,000 acre-feet. The amounts of imported water spread for each plan of operation were varied.

5. With the effective use of spreading grounds in the Montebello Forebay, only a small amount could be spread continuously in the Los Angeles Forebay after the storage space now available in that area is filled.

6. The average amount of annual deep percolation of applied water and precipitation to the zone of saturation is predicted to be approximately 82,000 acre-feet in the Coastal Plain for the period from 1963 through 1990. This deep percolation takes place approximately at a constant rate and due to the apparent attenuating effects of the zone of aeration, is affected little by cyclical variation of precipitation.

7. In many parts of the Coastal Plain, the existing surface storage capacities are large. The total existing surface storage capacity for short-term regulation is 22,380 acre-feet, of which 21,200 acre-feet of surface storage capacity is within the delivery system of the City of Los Angeles.

8. Physical conditions make it impossible to create a seaward gradient of fresh water by filling the basins as rapidly as would be required to prevent further saline intrusion in coastal areas.

9. The quality of ground water in the Coastal Plain will not change significantly enough to affect the comparative economics of alternative plans of operating the ground water basins during the study period.

Operational Findings

1. Satisfactory predictions of regional future water elevations can be made for any plan of operating the ground water basins by using the linear mathematical model of the ground water basins in the Coastal Plain, developed in this investigation. Although the model is believed to be sufficiently reliable for economic evaluation of alternative plans resulting in the lowering of water levels considerably below the historical low, a nonlinear mathematical model of the ground water basins of the Coastal Plain may be needed for accurate determination of water levels when they fall below the top of the Lynwood aquifer. It is estimated that this condition would occur if the ground water in storage were to be decreased 2,000,000 acre-feet below the amount that existed in 1962.

2. For all plans of ground water basin operation, temporary use of ground water in excess of the amount replenished annually may be necessary before 1972 because of the limitation on the delivery capacity of the primary surface water system before that year. However, the surface distribution system proposed for completion in 1972, and in 1983, along with the existing pipeline networks, will provide adequate capacity for delivery of imported water through 1990, even if the amount of ground water use is limited to the amount replenished annually. Under this condition, however, additional laterals would be required to deliver imported water to the easterly portion of the Coastal Plain, where there are presently no existing laterals.

3. Because of the large capacity of existing imported water delivery and storage facilities available to meet peak demands, pumps and boosters in the study area can be economically operated at relatively high use factors. The pump use factors for the Coastal Plain ranged between 48 and 77 percent under all plans of operation studied.

4. The capacity of existing service connectors of the primary distribution system, which is approximately 1,598 cubic feet per second, is adequate to supply the present (1963) need for imported water. For the selected plans investigated, the largest additional capacity required during the study period was 230 cubic feet per second and the smallest was 120 cubic feet per second.

5. The sum of the rated power of existing pumps in the Coastal Plain is approximately 62,600 horsepower, which equals an equivalent system comprised of 626 units of 100 horsepower each. By increasing the use factor through efficient and economic-area-wide coordinated operation of all facilities, the number may be reduced to approximately one-third of the present equivalent number by 1990, under the plan of operation in which safe-yield operation is initiated as soon as physically possible.

Economic Findings

1. The economics of ground water basin operation must be evaluated by considering all items which affect the comparison of the cost and benefits of water service. These items include surface and ground water supply facilities, electrical energy, and imported water supply. In the Coastal Plain, the present worth of the total costs of water service from 1963 to perpetuity ranged from 1,179 to 1,299 million dollars, or a difference of 10 percent for the five selected plans of operation under a selected set of conditions affecting the price of imported water. The present worths between 1963 to 1990 ranged from $844 million to $964 million or a difference of 14 percent. The price of imported water, which comprised 60 to 70 percent of the total cost of operation, was the largest single factor affecting the total cost of water service. However, costs of other items, especially those costs of providing ground water, including cost of facilities and electrical energy, affected the cost comparison of alternative plans appreciably.

2. Under the assumed condition that a safe-yield operation of ground water basins will be initiated in 1990, the present worths of the cost of perpetual water service could differ substantially if additional imported water in later years is considerably more expensive than that now being obtained.

3. The economics of spreading of imported water depends upon the planned future use of presently existing ground water in storage. If it is decided that ground water in storage will not be used, the present worth of all future costs of purchasing, spreading, and extracting a given volume of imported water must be compared with the present worth of the

cost of an equivalent volume of imported water directly used to meet the water demand. If, however, it is decided to partially utilize the ground water in storage, the present worth of the cost for spreading and extracting must also be compared with the present worth of extracting ground water from greater depths without spreading imported water, but with increased requirement for injecting water in fresh water barriers.

4. Constructing freshwater-injection barriers along the coast, where continuity exists between sea water and aquifers containing fresh water, is the most economical method of preventing sea-water intrusion.

5. The economics of ground water basin operation in the Coastal Plain, which includes spreading and injection of imported water, largely depends on the price of imported water, which, in turn, depends on, from local points of view, the amount of water imported by the Metropolitan Water District and its pricing policy.

6. Under conditions similar to those existing in 1963 that affect the price of water imported by the Metropolitan Water District, the cost of water service would be less for a plan which delays safe-yield operation until after 1990 than for a plan which requires immediate safe-yield operation.

7. Under existing price differentials for MWD water, the cost of water service to the Coastal Plain increases as the amount of water extracted near the coastline increases.

Concluding Remarks

The water demand of the Coastal Plain of Los Angeles County can be met, with overall economy, by coordinated operation of the surface water system and the ground water system. With present techniques and knowledge available, the alternative plans of coordinated operation of the ground water system and the surface water system can be economically evaluated and management decisions can be made based on the evaluation.

In this investigation, extensive operational and economic information was developed for a wide range of alternative plans of operating the ground water basins in coordination with surface water supplies and facilities. Plans which would require immediate commencement of safe-yield operation of the ground water basins, as well as a large number of practical plans permitting the deferment of safe-yield operation to 1990, were formulated and analyzed.

The legal, organizational, and financial frameworks existing in the Coastal Plain are consistent with an immediate commencement of safe-yield operation of ground water basins; the existing adjudicated rights to extract ground water in the West Coast Basin, and the stipulated agreement to limit the extraction of ground water in the Central Basin provide steps toward safe-yield operation of the ground water basins. The authority vested in the Central and West Basin Water Replenishment District represents organizational and financial tools which are effective for this kind of operation.

Implementation of any plan of coordinated operation will greatly affect, and in turn be affected by, ground water conditions in the adjacent basins -- the San Gabriel Valley and the Coastal Plain of Orange County. The scheme of ground water basin operation in one basin will affect the water users of the Coastal Plain of Los Angeles County and the Coastal Plain of Orange County; therefore, independent operation of the Coastal Plain of Los Angeles County may be hampered by legal problems arising out of this boundary condition.

Along the coast, where sea-water intrusion might take place, pumping of ground water should be adjusted within the physical limitations of the area so that the cost of water service to the local users is the minimum possible. This may require some legal or organizational changes. The relative costs of extraction in these areas would depend on the price differential between imported water for domestic and industrial purposes and imported water for injection. If the differential is small, the combined cost of injecting and pumping imported water may be more than the cost of direct use of imported water. On the other hand, if the differential in water prices is very large, the cost of injecting a large amount of water in the coastal areas and subsequently pumping it for use may be less than the cost of buying imported water for direct use.

Because decisions regarding the variable factors which affect the future price of future imported water have yet to be made, a single most economical plan of operating the ground water basins in the Coastal Plain of Los Angeles County could not be developed at this time. As these decisions are made and the conditions that were assumed for this phase become established, the economics of water service in this area can be reexamined. The tools and techniques developed and presented in this study provide a means for rapid reevaluation, under changing conditions, of the plans already studied; analyses can also be made of other alternative plans that have been or may be proposed. The most suitable of all the plans can be selected for future implementation by the appropriate local agency.

In prior years, it was necessary for water leaders to proceed cautiously in planning for use of ground water, because of limited supplemental supplies. The State Water Project may be considered as an indispensable safety factor that the people of Southern California must have if the maximum advantage is to be derived from use of local water resources.

Another limitation was the lack of knowledge of basin capacities and of the behavior of water moving through the basins. Through technical advancements in the electronic computer field, as well as in the fields of hydrology and geology, it is now possible to measure the water in storage --

more than 20 million acre-feet in the basins of the Coastal Plain of Los Angeles County -- and to simulate the physical reactions within the ground water basins under various plans of basin operation.

With such information and equipment, and with the State Water Project as well as the aqueducts from the Colorado River and the Mono-Owens Areas as a readily available source of imported water, it is now possible for local water managers to consider planned utilization of the ground water in storage, as well as the use of the storage space in ground water basins, to provide water at the minimum cost to water users.

ATTACHMENT NO. 1

LIST OF REFERENCES

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ATTACHMENT NO. 2

DEFINITION OF TERMS

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Acre-foot. The volume of water required to cover one acre one foot in depth (43,560 cubic feet or 325,829 gallons).

Applied Water. The water delivered to a farmer's headgate in the case of irrigation use, or to an individual's meter in the case of urban use, or the equivalent. It does not include direct precipitation.

Aquifer. A geologic formation, or zone, sufficiently permeable to yield an appreciable supply of water to wells or springs.

Artificial Recharge. For this study, the water that is added to the ground water basin through facilities primarily designed for that purpose, such as spreading basins and injection wells.

Consumptive Use of Water. Water consumed by vegetative growth in transpiration and building plant tissue, and water evaporated from adjacent soil, from water surfaces, and from foliage. It also includes water similarly consumed and evaporated by urban and nonvegetative types of land use.

Delivered Water. The sum of the applied water and any conveyance losses that occur within a study area in the process of delivering this water. For this investigation, delivered water is the sum of the imported water and extractions less the amount of exported water.

Drawdown. The change in water surface elevation in a well as the result of extracting ground water.

Economic Area. A subdivision of a study area, generally delineated along agency boundaries, made for regional economic analysis (See Plate 2).

Forebay Area. An area of unconfined ground water which is, generally, in hydraulic continuity with the ground surface, and so located that it provides a supply of ground water by subsurface flow to a body of confined ground water.

Ground Water. Subsurface water occurring in the zone of saturation and moving under control of the water table slope or piezometric gradient.

Ground Water Overdraft. For this study, the average annual decrease in the amount of fresh ground water in storage that occurs during a long period under a particular set of physical conditions affecting the supply, use, and disposal (including extractions) of water in the ground water basin.

Ground Water Safe Yield. For this study, the average annual amount of ground water that could be extracted from a ground water basin over a long period without effecting a long-time net change in storage of ground water. The extractions must occur under a particular set of physical conditions affecting the supply, use, and disposal of water in the ground water basin.

Ground Water Storage. That stage of the hydrologic cycle during which water occurs as ground water in the zone of saturation, including that part of such stage when water is passing through the zone of aeration and entering or leaving storage.

Ground Water Table. See Water Table.

Hydraulic Gradient. Under confined ground water conditions, it is the slope of the profile of the water table. Under confined ground water conditions, it is the line joining the elevations to which the water would rise in wells if they were perforated in the aquifer.

Index of Wetness. A unitless number showing the ratio of an annual precipitation to an average precipitation for a long period.

Infiltration. The flow, or movement, of water through the soil surface into the ground.

Irrigation Water. For this investigation, it is equal to the total applied water less the domestic and industrial use of applied water.

Master Influence Function. The water level elevation response at each polygon from an action of 100,000 acre-feet per year rate of net inflow to or outflow from the surface to the zone of saturation in a selected polygon or group of polygons.

Operation Area. A subdivision of a study area along geological and water service area boundaries, made for identifying alternative plans of operation with respect to operational variables (See Plate 2).

Overdraft. See Ground Water Overdraft.

Percolation. The movement, or flow, of water through the interstices, or pores, of a soil or other porous media.

Percolation, Deep. The movement of water in the zone of aeration from the belt of soil water into and through the intermediate belt.

Period. A specified division or portion of time.

Mean. A period chosen as representative of conditions of water supply and climate over a long series of years. Because the precipitation during a 23-year base period, 1934-35 through 1956-57, nearly equaled the precipitation that occurred over a longer period of time, this 23-year base period was assumed to represent a long-time mean period for this investigation.

Pervious Area. A ground surface area that is not paved or covered by permanent man-made structures.

Piezometric Surface. An imaginary surface that everywhere coincides with the head of water in the aquifer. It is represented by the elevation to which water will rise in wells drilled into the confined aquifer.

Pressure Area. A ground surface area underlain by an aquifer containing confined ground water.

Rising Water. Ground water from the zone of saturation that rises to the ground surface, usually to a streambed, when the ground surface is at a lower elevation than the ground water table or the piezometric surface of a confined aquifer.

Safe Yield. See Ground Water Safe Yield.

Storage Factor. A measure of the storage characteristics at each polygon of an equivalent aquifer, expressed in acre-feet per foot of depth. This factor is the area of a polygon times the average specific yield of the water-bearing sediments within the area.

Subsurface Water Zones.

Zone of Aeration. The zone above the water table in which the interstices are partly filled with air. This zone lies between the surface and the zone of saturation. Starting from the surface, this zone includes the belt of soil water, the intermediate belt, and the capillary fringe.

Zone of Saturation. The zone below the water table in which all the interstices are filled with ground water, which moves under the control of the water table slope or piezometric gradient. This zone lies between the zone of aeration and bedrock.

Surface Inflow-Outflow Factor. The net amount of deep percolation to and extraction from an equivalent aquifer.

Thiessen Method. A method used to determine the amount of precipitation on an area by constructing polygons or areas of influence about each gaging station. The polygon is formed by the perpendicular bisectors of the straight lines joining adjacent gaging stations. In using this method, the assumption is made that the depth of precipitation within the polygon is equal to the depth of precipitation at the corresponding gaging station.

Total Dissolved Solids. The material left in a vessel after evaporation, at a definite temperature, of a filtered sample of water.

Transmissibility Factor. Transmissibility of the equivalent aquifer at the midpoint of a line connecting the centers of two adjacent polygons multiplied by the length of the common boundary of the two polygons and divided by the length of the line. This term is expressed in acre-feet per year per foot of difference in representative ground water elevations.

Use Factor, Pump. The annual ground water extraction, in cubic feet per second, divided by the peak hourly rate of extraction, in cubic feet per second.

Waste Water. For this study, water that has been put to some use or uses and has been disposed of to a sewer. It may include liquid industrial wastes, sewage, or both, but specifically excludes oil brines.

Water Supply Surplus or Deficiency. For this study, the difference between the inflow to and the outflow from a ground water basin during any given period. The outflow of water includes the consumptive use of water. A water supply surplus exists when the inflow is greater than the outflow, and a water supply deficiency exists when the inflow is less than the outflow.

Water Table. The surface of ground water at atmospheric pressure in an unconfined aquifer. This is revealed by the levels at which water stands in wells penetrating the unconfined aquifer.

ATTACHMENT NO. 3

ESTIMATION OF FUTURE DEEP PERCOLATION
IN THE COASTAL PLAIN
OF LOS ANGELES COUNTY

ATTACHMENT No. 3

ESTIMATION OF FUTURE DEEP PERCOLATION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY

Introduction

To make operational and economic evaluations of future alternative plans for operating the ground water basins in the Coastal Plain of Los Angeles County, future ground water level elevations were estimated. The amounts and locations of deep percolation of surface water supplies, ground water extractions, and subsurface flows were required to predict the future water levels reliably for each alternative plan of operation. In this attachment the procedures are described for the determination of the amounts and locations of the deep percolation of surface water supplies.

For this determination, the total deep percolation was divided into "natural" and "artificial" components. The natural component consisted of percolation from: (1) water applied to the irrigated land to sustain plant life (applied water), (2) that portion of rainfall that did not run off to the streams (precipitation), and (3) storm or rising (local) water that percolated in stream channels or spreading grounds (streamflow). The artificial component included percolation from: (1) water injected along the coast to prevent sea-water intrusion and (2) imported and reclaimed waters recharged in the spreading grounds or stream channels.

Because the artificial component is introduced into the water-bearing aquifers directly in continuous amounts, the assumption is that the amounts that are spread or injected reach the zone of saturation within a short time. For this reason, the artificial recharge component could be varied arbitrarily. Therefore, it was selected as a variable for each alternative plan of operation and is not discussed in this attachment.

For the natural component, deep percolation was estimated from three sources: applied water, precipitation, and streamflow. The estimated amounts of deep percolation at various locations were used to predict ground water level elevations in the future. In this attachment, the steps taken to estimate deep percolation from the three sources are discussed in detail.

Deep Percolation From Applied Water and Precipitation

To estimate deep percolation from applied water and precipitation, criteria of percolation to the zone of aeration were first established and hydraulic relationships between the zones of aeration and saturation were developed. Then estimates were made for future applied water and precipitation. By using the criteria and the relations, amounts and locations of future deep percolation from these two sources were estimated.

Criteria of Percolation to the Zone of Aeration

Criteria of percolation to the zone of aeration were developed for applied water and precipitation for each of the four basins: Hollywood, Santa Monica, West Coast, and Central. For the Central Basin, however, the criteria were developed for two subareas. The criteria were based on the historical (1934-35 through 1956-57) hydrologic data for the items of surface water supply, use, and disposal, which were determined for and published in Appendix B, "Safe Yield Determinations" to Department of Water Resources Bulletin No. 104, "Planned Utilization of the Ground Water Basins of the Coastal Plain of Los Angeles County".

The percolation values published in Tables 8-1 through 8-5 in Appendix B, Bulletin 104, were obtained by subtracting the items of water use and disposal from the items of water supply for each basin within the Coastal Plain according to the following equation:

Total Deep Percolation of Surface Water Supply = (Ground Water Extractions + Water Import + Surface Inflow + Precipitation) - (Water Export + Waste Water + Surface Outflow + Consumptive Use) . . . . (1)

To solve for the three natural components of the total percolation using the above equation, the following modifications were made:

1. Imported water spread or injected was subtracted from the total percolation values. This was done because the "water import" item included water spread in the Montebello Forebay area of Central Basin, as well as water injected at the West Coast Basin Barrier Project.

2. The consumptive use of phreatophytes was subtracted from the consumptive use values and, consequently, values for the total percolation were increased by an equal amount to account for the amount of percolation reduced by the consumptive use of phreatophytes.

The resulting seasonal amounts of total percolation for each basin were then used as a control on values of the annual percolation due to precipitation, applied water, and streamflow. In this analysis, the following equations were used:

Percolation of Precipitation = Precipitation - (Consumptive Use of Precipitation + Runoff Reaching Streams + Storm Infiltration into Sewers) . . . . (2)

Percolation of Applied Water = Applied Water - Waste Water* - Consumptive Use of Applied Water . . . . (3)

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*Includes industrial waste in stream channels and excludes storm infiltration in sewers.

Runoff Reaching Streams = (Surface Outflow + Stream Percolation) - (Surface Inflow + Industrial Wastes in Streams) . . . . (4)

Irrigation Water = Applied Water - Waste Water* - Consumptive Use of Industrial Processes . . . . (5)

For each basin, seasonal deep percolation of precipitation and applied water were computed by applying equations (2) and (3), using water supply and disposal items pertaining to the total basin, i.e. including the water-bearing and nonwater-bearing areas. The computed percolation was then assumed to have occurred in the water-bearing portion of the basin.

When equations (2) and (3) were applied, several values of percolation of precipitation and of applied water were found to be unreasonable because of inexactness in the data. These percolation values were adjusted by modifying consumptive use of precipitation and applied water, and streamflow percolation. However, total consumptive use and percolation, as presented in Appendix B, were not altered.

The assumptions made to develop the percolation criteria were as follows: percolation from precipitation is related to seasonal amounts of precipitation and to the size of pervious areas; percolation from applied water is related to the seasonal amount of irrigation water, which, as expressed in equation (5) above, is equal to the applied water less the waste water and consumptive use of industrial processes, the size of the area irrigated, and to the indexes of wetness (ratios of the annual to a long-time mean precipitation). The index of wetness factor was included because, although the volume of irrigation water applied during wet years tends to be smaller than during dry years, the percentage of percolation may be greater than that for a dry year, due to increased soil moisture.

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*Includes industrial waste in stream channels and excludes storm infiltration in sewers.

For each basin, the seasonal percolation of precipitation that would have occurred had the average size of pervious area prevailed throughout the entire base period was computed and plotted against the seasonal average depth of precipitation over the water-bearing portion of the basin. By trial and error, a straight line was drawn through the points, until the sum of the percolation obtained from the line equaled the sum of the historical percolation represented by the plotted points. A straight line plot was established for each basin. The ordinates of these curves were then converted to percolation in acre-feet per acre of pervious area.

Seasonal historical percolation of applied water, in acre-feet per acre, was plotted against the product of the seasonal average depth of irrigation water per acre of irrigated area (duty) and the index of wetness. Again, a straight line was drawn through the points, by trial and error, until the total percolation obtained from the line equaled the total historical percolation. A straight line plot was established for each basin.

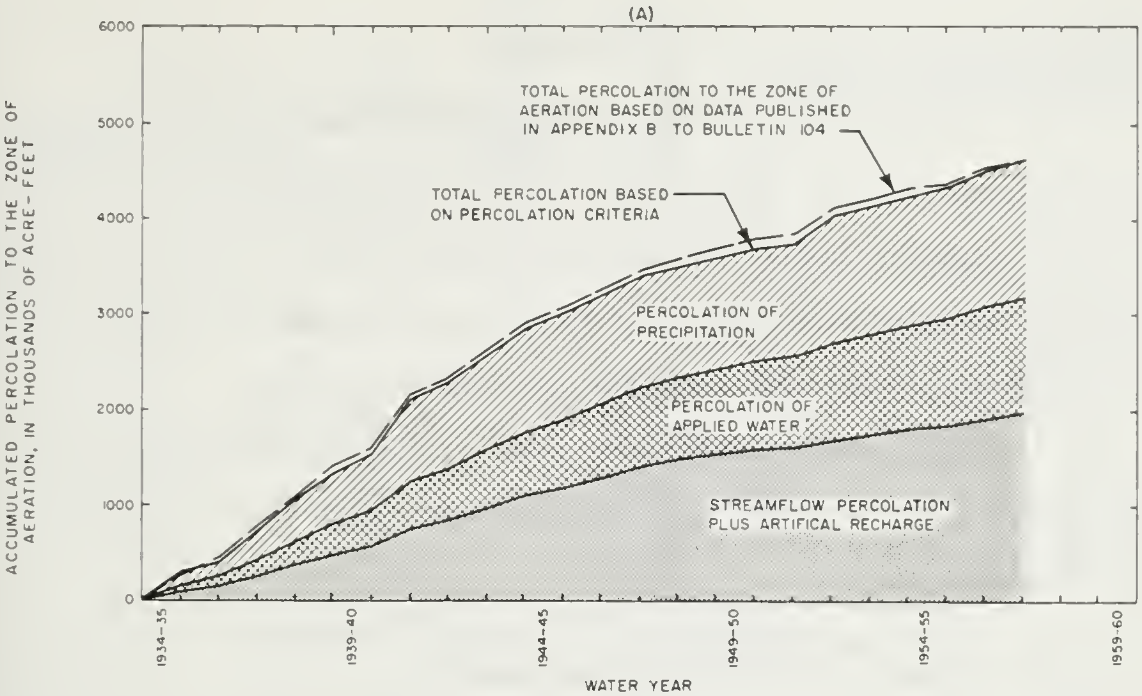
For the Central Basin, curves for the entire basin were first developed. The basin was then divided into two parts: (1) an area where the ground water aquifers are known to be in direct hydraulic continuity with the surface, including the forebay areas as defined by the Department of Water Resources in 1960, plus the Gaspur aquifer; and, (2) an area where the aquifers are not in hydraulic continuity with the surface, consisting of the area outside the forebay, excluding the Gaspur aquifer. For brevity, these areas were called the permeable and semipermeable areas, respectively, and are shown on Plate 16.

The semipermeable area of Central Basin, being geologically similar to West Coast Basin, was considered to have similar percolation characteristics. Therefore, the West Coast Basin percolation curves were utilized to represent percolation criteria for the semipermeable area in the Central Basin. The percolation curves for the permeable area were derived by subtracting the percolation curves of the semipermeable area from those representing the entire basin with due regard to pervious and irrigated acreages.

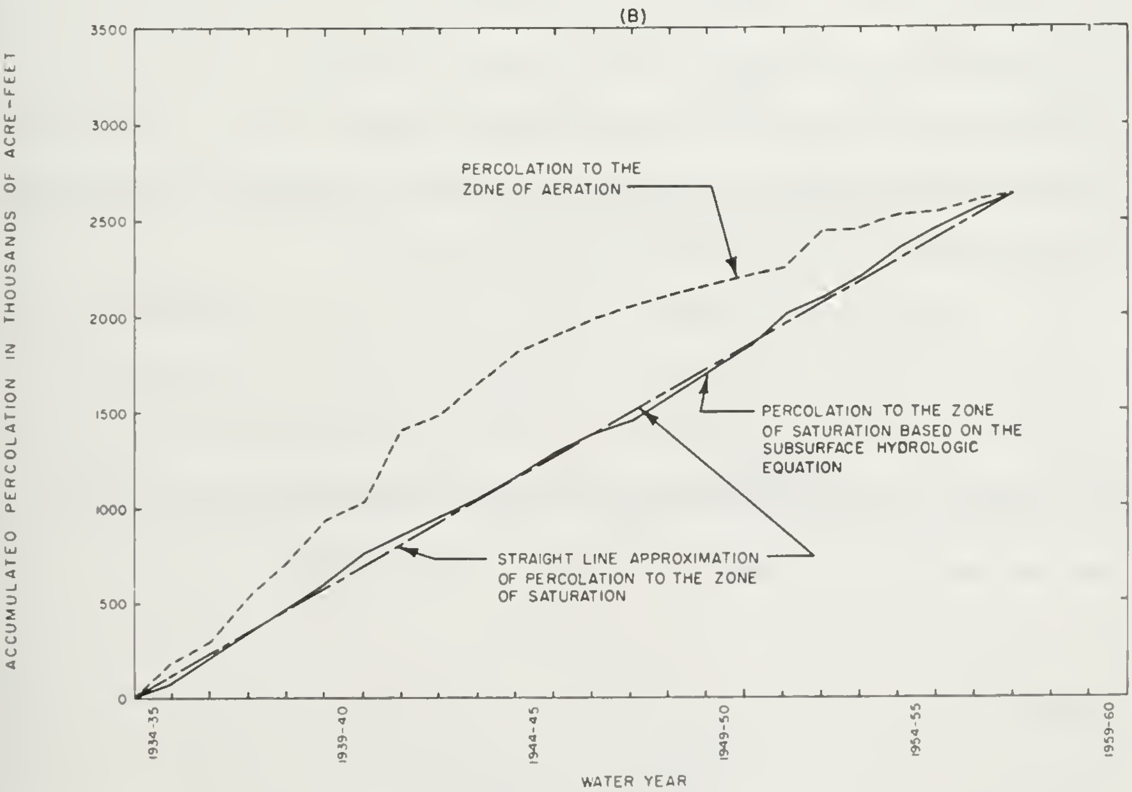
The curves for the percolation due to precipitation are shown on Figure 3A and those for the percolation of applied water are shown on Figure 3B in Chapter 2 of the main body of the text. The curves are both reasonable and compatible with the geologic characteristics of the various basins.

It is believed that the percolation curves are S-shaped, rather than straight lines. However, when the data were plotted, the points were found to lie in the portion where the S-curve could be approximated by a straight line. Because a straight line approximation would fall well within the limits of the accuracy of the data, a straight line relationship was assumed for both percolation of precipitation and applied water.

The accuracy of the data does not justify a more refined analysis than that described above. It is believed that the curves yield dependable mean values but are best suited for application only to the range of values on which they were based. Figure 3-1A shows the result of a comparison between the amounts of percolation estimated using the criteria curve and the amounts established by solving the hydrologic equation for the historic period 1934-35 through 1956-57.



ACCUMULATED HISTORIC PERCOLATION TO THE ZONE OF AERATION USING PRECIPITATION AND APPLIED WATER PERCOLATION CRITERIA IN THE COASTAL PLAIN OF LOS ANGELES COUNTY



ACCUMULATED HISTORIC PERCOLATION TO THE ZONES OF AERATION AND SATURATION DUE TO PRECIPITATION AND APPLIED WATER IN THE COASTAL PLAIN OF LOS ANGELES COUNTY

D[illegible]ARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

Hydraulic Relationships Between Zones of Aeration and Saturation

In establishing a relationship between the quantity of water from precipitation and applied water that reaches the zone of aeration and the quantity of water reaching the saturated zone, it was assumed that water percolating from streamflow, spreading, and injection passed the root zone and reached the saturated zone within one year.

Total seasonal amounts of deep percolation for each basin, for the historic period, were obtained by solving the following equation (see Figure 3-2):

Total Deep Percolation = (±) Change in Storage + Extraction - Net Subsurface Inflow . . . . (6)

The annual streamflow, spreading, and injection amounts were subtracted from the total deep percolation determined utilizing equation (6) for each affected basin, enabling annual amounts of the deep percolation due to precipitation and applied water only to be obtained. These values were accumulated for each basin and graphically compared with the accumulated seasonal percolation due to applied water and precipitation to the zone of aeration used in deriving the criteria curves.

As depicted on Figure 3-1B, the slope of the accumulated percolation to the zone of aeration from applied water and precipitation is generally steeper in the earlier wet period (1934-44) than in the dry period (1945-57); however, the percolation rate to the saturated zone remained relatively constant throughout both periods. This suggests that water percolates from the zone of aeration to the zone of saturation at a constant rate. It is believed that this condition is due to the release capacity of the zone of aeration. It is thought that the zone of aeration

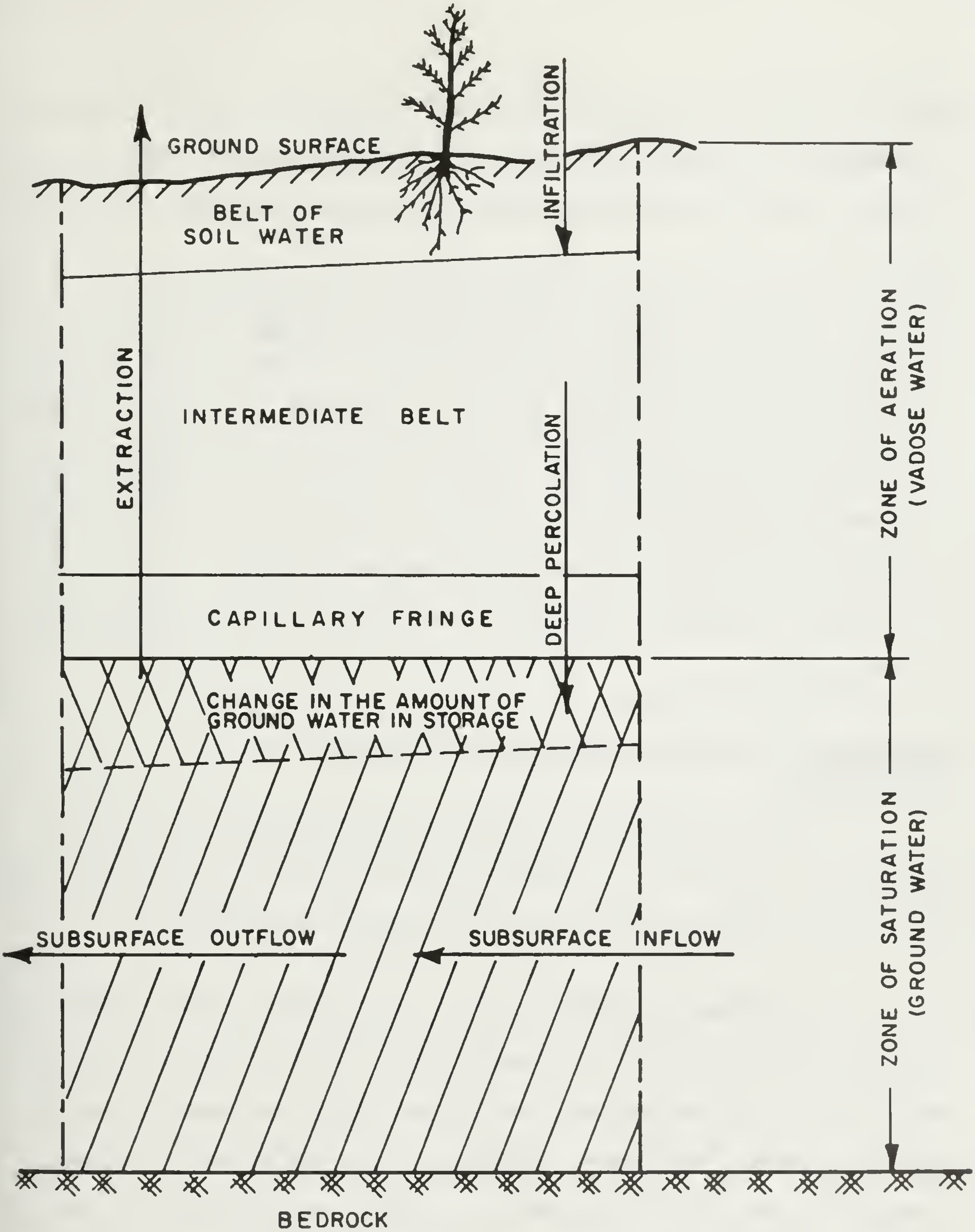


DIAGRAM SHOWING
GENERALIZED HYDROLOGIC ELEMENTS OF SUBSURFACE WATER

DE RTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966 behaves much like a large reservoir with a small pipe. Consequently, the volume of water released from the zone of aeration to the lower zone can be expected to be relatively constant provided that sufficient water is available.

For predicting the total amounts of future percolation from applied water and precipitation to the zone of saturation under a given rainfall cycle, it was assumed that the accumulated quantities of water percolating to the zone of aeration and to the zone of saturation would be equal and, furthermore, that the annual amount entering the saturated zone would be constant. It was further assumed that this relationship would hold, regardless of whether the percolation was from applied water or precipitation.

Estimates of Future Water Supplies to the Ground Water Basins

To estimate amounts of future deep percolation in each basin within the Coastal Plain, irrigated and pervious areas, and the deep percolation due to precipitation and applied water were evaluated.

Irrigated and Pervious Areas. For estimating irrigated and pervious areas in each basin, the basin area was separated into three types of land: native, agricultural, and urban. Native land was any pervious land that was not irrigated. Agricultural land was any area that was irrigated, such as dairies, truck crops, etc. The remaining area was considered to be urban. The areas of the three lands were estimated, based on 1960 land use data. The ratio of the pervious urban land area (primarily lawns, shrubs, and ornamental horticulture) to the total urban area for 1960 was assumed to remain fixed throughout the study period. Agricultural and native lands were considered to be negligible in 1980 and were decreased at a constant rate for the intervening years. After 1980 it was assumed that there would be no change in pervious and irrigated areas.

Deep Percolation of Precipitation. The record of seasonal precipitation at the City of Los Angeles was used as a basis for estimates of future precipitation on the water-bearing portion of the study area. The precipitation at this station was considered to be representative of the precipitation at the Coastal Plain. The records for this station date back to 1872, the longest historic record of any station in the Coastal Plain. The seasonal precipitation at this station varied from a high of 38.18 inches in 1883-84 to a low of 4.93 inches in 1960-61.

The precipitation pattern at this station was separated into three generally discernible cycles consisting of several wet years followed by several relatively dry years. The three cycles were segregated and the accumulated departure from the 88-year mean precipitation for this station (15.0 inches) was plotted for each cycle separately. Based on these three graphs, a general future cyclic precipitation graph for the study area was plotted. Estimates of precipitation were obtained from this graph utilizing the 88-year mean and adding or subtracting values from the general future cyclic precipitation graph. These values were assumed to be the average magnitudes of the future precipitation for the entire water-bearing portion of the Coastal Plain. To estimate the rainfall for each basin, it was assumed that the index of wetness for any future year for each of the basins within the Coastal Plain would be the same as the index for the Coastal Plain.

To check the effect of changing cycles of rainfall on the percolation quantities, three distinct arrangements of the general future cycle were developed by shifting the location of the peak ordinate. The amounts of rainfall for each basin under each of the three cycles and the basic cycle, as well as a mean precipitation condition, were determined, utilizing the historic relationship of the basin's index of wetness to that of the Coastal Plain. Allowing for the change in the pervious area for each basin, the criteria curves were used to determine the quantity of percolation to the zone of aeration for each basin for each year throughout the 27-year study period. The summation of each basin's quantities for each year was accumulated and on the basis of the historic relationship, this amount was assumed to be equal to the amount entering the zone of saturation for the study period. Table 3-1 shows that the effect of the different cycles on the amount of percolation is negligible. Thus, the yearly mean rainfall on the Coastal Plain was used to develop the quantity of percolation to the zone of saturation for this study. The average annual percolation was, as shown in Table 3-1, 29,000 acre-feet.

Deep Percolation of Applied Water. To determine the quantity of future percolation of applied water utilizing Plate 16 for each basin, estimates of applied and waste water, irrigated area, and the index of wetness were required. The assumptions and methods used to estimate these items are discussed below.

Projections of annual applied water demand for the Coastal Plain were made for the study period extending from 1963 to 1990. The projected demands were determined for each basin within the study area. The future annual applied water demand for each basin was estimated by determining the past and present water uses, and adding incremental increases in annual water demand to the present water use. The determination of the historic

TABLE 3-1

COMPARISON OF ESTIMATED PERCOLATION OF PRECIPITATION TO THE ZONE OF SATURATION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FOR FOUR PRECIPITATION CYCLES AND A MEAN ANNUAL RAINFALL FROM 1963 THROUGH 1990

In acre-feet

Basin	General cycle (Base)		Cycle #1 (Peak in 1975)		Cycle #2 (Peak in 1985)		Cycle #3 (Peak in 1968)		Mean annual precipitation	
	Percolation		Percolation		Percolation		Percolation		Percolation	
	Aeration (1) Accumulated total	Saturation (2) =(1)/28 average annual	Aeration (1) Accumulated total	Saturation (2) =(1)/28 average annual	Aeration (1) Accumulated total	Saturation (2) =(1)/28 average annual	Aeration (1) Accumulated total	Saturation (2) =(1)/28 average annual	Aeration (1) Accumulated total	Saturation (2) =(1)/28 average annual
Hollywood	22,000	1,000	22,000	1,000	22,000	1,000	22,000	1,000	22,000	1,000
Santa Monica	120,000	4,000	118,000	4,000	120,000	4,000	112,000	4,000	120,000	4,000
Central										
Pressure	132,000	5,000	115,000	4,000	120,000	4,000	123,000	4,000	128,000	5,000
Forebay	456,000	16,000	431,000	15,000	434,000	16,000	448,000	16,000	456,000	16,000
West Coast	101,000	3,000	90,000	3,000	95,000	3,000	92,000	3,000	95,000	3,000
TOTAL = Coastal Plain		30,000		28,000		28,000		28,000		29,000

rate of increase of annual water demand and the present use of applied water were based on data contained in Tables 8-1 to 8-5 of Appendix B to Bulletin 104. Incremental annual increases in applied water demand for the future study period were estimated by analyzing data for projected applied water demands of this area. The projection of the applied water demand was made by utilizing data on the future population and unit values of urban water use contained in the basic data for Appendix D, "Economic Demand for Imported Water", to Department of Water Resources Bulletin 78, "Investigation of Alternative Aqueduct Systems to Serve Southern California". The estimated rate of increase in applied water compared favorably with the historic rate.

It was assumed that for each basin the future depth of irrigation water, in acre-feet per acre of irrigated area, would not substantially deviate from either the historic average or the average of the latest years.

To check the reasonableness of this assumption, the annual demand for irrigation water for the future was determined for each basin within the Coastal Plain by multiplying the assumed unit depth of irrigation water by the annual amount of irrigated area. Then, the ratio of waste water to applied water was estimated by subtracting the irrigation water from the applied water and dividing this quantity by the applied water. The rate of increase of the resulting ratio for each basin was compared with that for the historic period. This comparison showed that the future rate of increase was consistent with the historic rate and, furthermore, that the maximum ratio of waste water to applied water for each basin was between 70 and 80 percent, which is considered reasonable for an urban area such as the Coastal Plain of Los Angeles County.

Based on the duty of irrigation water and the irrigated area for each basin for each future year, annual values of percolation of applied water were derived, assuming the mean precipitation throughout the study period. The average amount of applied water percolation for the future study period, which was assumed to be equal to the average annual quantity reaching the zone of saturation, was found to be 53,000 acre-feet (see Table 3-2).

TABLE 3-2

ESTIMATED FUTURE DEEP PERCOLATION OF APPLIED WATER IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FOR A MEAN ANNUAL RAINFALL FROM 1960 THROUGH 1990*

In 1,000 acre-feet

Basin	Percolation to the zone of aeration				
	1960	1970	1980	1990	Average (1960-90)
Hollywood	3.0	3.0	3.0	3.0	
Santa Monica	4.0	5.0	5.0	5.0	
Central	32.0	33.0	33.0	33.0	
West Coast	11.0	12.0	14.0	14.0	
TOTAL for Coastal Plain of Los Angeles County	50.0	53.0	55.0	55.0	53.0

*Average for this period is assumed to be equal to the 27-year average for 1963 through 1990; and, in accordance with criteria between the zones of aeration and saturation, the value shown for the average to the zone of aeration is assumed to be equal to the average annual quantity of deep percolation due to applied water.

Streamflow Percolation

In determining the amounts of future streamflow percolation and recharge at the Montebello Forebay, the basic principles of settlement between the Upper and Lower Basin were considered. In essence, the basic principle of settlement states that the Upper Basin (San Gabriel) would guarantee a certain amount of water or its monetary equivalent to the Lower Basin (Coastal Plain) in the future. For this investigation, it was assumed that the amount of the Upper Basin local water that would percolate in the Coastal Plain in the future would be equal to the historic (1934-35 through 1956-57) average annual amount of percolation due to rising and storm waters minus an amount of 5,000 acre-feet per year previously agreed upon to be credited to the Upper Basin.

The average amount was determined utilizing the following equation:

> Historical Local Water Conserved in the Montebello Forebay = Streamflow Percolation in Rio Hondo and San Gabriel Rivers + Local Water Spread in the Rio Hondo and San Gabriel Coastal Spreading Grounds - Imported Water Recharged in the San Gabriel River Streambed.

This amount was found to be 53,000 acre-feet per year.

To check the reasonableness of this value, a rough estimate of the amount of storm water conserved in the Montebello Forebay was made by the Los Angeles County Flood Control District for the 19-year period 1930-31 through 1948-49. The average for this period was found to be about 10,000 acre-feet per year. The average amount of rising water during the period 1934-35 through 1956-57, according to data presented in the Los Angeles County Flood Control District's biennial reports, was about 50,000 acre-feet per year. Assuming that a similar amount of conservation of storm water would have occurred during the period 1934-35 through 1956-57 and that all the rising water could be percolated, an average annual of some 60,000 acre-feet could have been conserved in both the streambed and spreading ground in the Montebello Forebay. However, due to the nature of the spreading operation (i.e. during heavy rainfall, rising water as well as floodwater is released for flood control reasons) a portion of the historic amounts of rising water was lost. Therefore, 53,000 acre-feet per year was adopted for the amount of replenishment in the Montebello Forebay due to percolation of storm and rising waters. In accordance with the aforementioned principle of agreement between Upper and Lower Basins, a deduction of 5,000 acre-feet per year was made. Consequently, the average annual amount of conserved local water presumed in this study was 48,000 acre-feet.

Areal Distribution of Deep Percolation

To predict future water level elevations reliably for the alternative plans of operation, the amounts of deep percolation from the various components were distributed to the nodal polygons of the mathematical model of the Coastal Plain as described in detail in Attachment No. 5, "Formulation and Verification of a Mathematical Model of the Ground Water Basins of the Coastal Plain of Los Angeles County". Estimates of the quantities of deep percolation from applied water and precipitation, which were determined for each basin, were distributed to the polygons based on the amounts of irrigated and pervious area together with their relative soil infiltration rate. Estimates of the streamflow deep percolation were distributed to the polygons in proportion to the area of the spreading grounds and streambed within the polygon.

ATTACHMENT NO. 4

FORMULATION AND UTILIZATION OF MATHEMATICAL MODELS
FOR HYDRAULIC ANALYSES OF THE PRIMARY
SURFACE DISTRIBUTION SYSTEM

ATTACHMENT No. 4

FORMULATION AND UTILIZATION OF MATHEMATICAL MODELS FOR HYDRAULIC ANALYSES OF THE PRIMARY SURFACE DISTRIBUTION SYSTEM

Introduction

The maximum delivery capacity of the primary surface distribution system is an important factor in the economic analyses of conjunctive operation of surface and subsurface water systems. For this study, the distribution system of The Metropolitan Water District of Southern California, which represents the primary surface distribution system within the Coastal Plain, was analyzed. The distribution facilities of the City of Los Angeles, the City of Long Beach, and other municipalities were not analyzed as primary systems because their delivery requirements were considered to be common for all plans of operation.

The distribution system of the Metropolitan Water District is set forth in case VII of the District's Report No. 802, "Comparative Economic Study of the East Branch and West Branch of the California Aqueduct, and of Additional Distribution Facilities Required in the Southern California Coastal Plain by 1990". In case VII, the first major expansion is scheduled in 1972 and water is expected to be available through the West Branch of the State Water Project in that year; an additional expansion of the distribution system is scheduled in 1983. The presumed 1972 and 1983 expansions of the primary distribution system serving the Coastal Plain of Los Angeles County are shown on Plate 5.

In the determination of the maximum delivery capacity of the system, first, the expanding system was represented by three networks of pipeline, the physical characteristics of which were clearly defined. Then, mathematical models were developed to simulate the hydraulic characteristics of the pipeline networks and the maximum delivery capacities of the networks were estimated using these models. In the remaining portion of this attachment, a detailed discussion will be presented on the pipeline networks studied, the formulation of the mathematical models of the pipeline networks, and the utilization of the models, as well as on the results of the study.

Distribution Systems

The expanding distribution systems analyzed were: (1) the network existing in 1963; (2) the network presumed to be in service in 1972; and (3) the network presumed to be in service from 1983 through 1990. The boundaries of the systems analyzed were determined by analyses of control structures. The data on physical characteristics of the system was derived primarily from information available from the Metropolitan Water District. Estimates were used in those cases where firm data was not available.

Future Expansion of Systems

As mentioned before, case VII presented in the Metropolitan Water District's Report No. 802 was used to represent the future expansion of the primary distribution system serving the Coastal Plain of Los Angeles County. Case VII is an alternative design in which both branch aqueducts would be constructed concurrently for service in the year of initial water delivery, with delivery capacity of each branch aqueduct one-half of the total.

At the time of this study, a decision had not been made as to which of the alternate plans was to be incorporated. The Department of Water Resources, in an office report entitled "Study of the Optimum Division and Timing of Water Deliveries Between the East and West Branches of the California Aqueduct", March 1962, recommended plan 3, which follows a similar expansion schedule as case VII. Therefore, case VII was used in this study to represent the primary facilities needed to convey water from the East and West Branches to distribution points within the various constituent agencies.

Boundary Control and Internal Control Structures

By analyzing control structures within the system, a hydraulically independent network of feeders and laterals serving the Coastal Plain was isolated from the Metropolitan Water District's entire distribution system.

The F. E. Weymouth Memorial Softening and Filtration Plant on the Upper Feeder and the newly constructed R. B. Diemer Filtration Plant on the Lower Feeder afforded excellent dividing points in the system; the network west of these plants was the distribution system analyzed. These plants were designed to provide hydraulic grade line elevations that vary only slightly under actual operating conditions and constitute a continuous source of water within physical limitations.

The isolated system was further reduced by analyses of physical and hydraulic characteristics of the system as affected by internal control structures. These controls were located at Garvey Reservoir, the south portal of Ascot Tunnel, the Palos Verdes Reservoir, and the proposed pressure control structures near Ballona Creek. These control structures are shown on Plate 17; their control elevations are shown in Table 4-1.

TABLE 4-1

BOUNDARY CONTROL STRUCTURE AND
CONTROL ELEVATIONS IN FEET

Control structure	Control hydraulic grade line elevation
F. E. Weymouth Memorial Softening and Filtration Plant	1,080
R. B. Diemer Filtration Plant	830
South portal of Ascot Tunnel (weir structure)	632
Garvey Reservoir	570
Palos Verdes Reservoir	280
Proposed Ballona pressure control structures	415

Garvey and Palos Verdes Reservoirs interconnect with the primary distribution system and act as water sources during periods of large demand. In both reservoirs, the differences in hydraulic grade line elevation from high water level to low water level are approximately 50 feet. Garvey Reservoir was designed to have a high water level of 570 feet and a low water level of 520 feet, while Palos Verdes was designed to operate with a high water level of 320 feet and a low of 270 feet. Garvey and Palos Verdes Reservoirs have storage capacities of 1,500 and 1,100 acre-feet, respectively.

The structures at the south portal of Ascot Tunnel maintain hydraulic grade line elevations within a small range of variation. The structure contains a weir that is perpendicular to the direction of flow in the Palos Verdes Feeder. Maximum flow, about 210 cfs, through the Palos Verdes Feeder line north of Ascot Tunnel is available to the system south of this point when the hydraulic grade line elevation is 950 feet at the Eagle Rock control structure.

Pressure control structures were presumed to be located near Ballona Creek in those pipelines that are to be placed in service in 1972 and 1983. The maximum allowable hydraulic grade line elevation at these structures was assumed to be 415 feet, based on the allowable elevations at existing internal control structures in the system. As a result of a network analysis, it appears that during normal operating conditions with peak flows, the upstream hydraulic grade line elevation at these control structures will always exceed 415 feet by a considerable amount. Thus, a constant hydraulic grade line elevation of 415 feet was presumed to be available to the distribution system downstream from these control structures.

Internal manifold and regulator control structures used to control the pressure head downstream of the structure are located throughout the distribution system. The hydraulic grade line elevations at these internal structures are shown in Table 4-2.

Assumptions Concerning Future System

In accordance with case VII, assumptions were made for the distribution system with respect to the location of connectors and alignments of pipelines scheduled to be constructed in the future. These assumptions are:

1. The existing Orange County Feeder will interconnect with the Lower Feeder, and the Middle Cross Feeder will connect to the Palos Verdes Feeder. In 1972, there will be a connection of the West Coast Feeder to the Palos Verdes Feeder.

2. The proposed pipeline facilities will interconnect with existing pipelines in those locations where the two alignments intersect.

TABLE 4-2

HYDRAULIC GRADE LINE ELEVATION LIMITS FOR INTERNAL CONTROL STRUCTURES*

Pressure control structure location	Code number*	Feeder	Hydraulic grade line elevation, in feet	
			Upstream	Downstream
Los Angeles River	58	Palos Verdes	620	415
Rio Hondo River	26	Middle	650	490
San Gabriel River	63	Lower	725	650
Coyote Creek	21	West Orange County	725	658
Coyote Creek	7	Lower	810	725
Compton Creek	43	Palos Verdes	537	415

*The locations of these structures are shown on Plate 17.

Determination of Pipeline Characteristics

Hydraulic analyses of the primary distribution system were required to determine physical dimensions of the pipelines and to define the area in which the takeout connectors serve.

Pipe lengths, diameters, and invert elevations were determined through the use of topographic maps, Metropolitan Water District reports, and specification manuals. Ground surface elevations, taken from topographic maps, were used to represent approximate invert elevations at connectors and junctions. Actual elevations were obtained for internal and boundary control structures because these were the primary boundary controls on the system.

Location of each of the takeout connectors with respect to economic subdivisions of the study area was required to determine the maximum delivery to each area. This was accomplished by: (1) determining the location of service connectors in the distribution system, (2) determining the water agencies served from the connectors, and (3) determining the economic area in which the agencies are located. If any agency was not contained exclusively in one area, the percentage of total service area in each economic area was determined. In several cases, one connector served two or more economic areas.

Equivalent Distribution System. The complex system of pipelines, controls, takeout connectors, and junctions was represented by 80 equivalent takeout connectors, controls, and junctions and 96 equivalent pipelines of varying lengths and diameters to accommodate the data within the capacity of a computer program used for analyses of the system. The numbering code for equivalent connectors and pipelines is shown on Plate 17.

An equivalent connector represented a group of two or more Metropolitan Water District adjacent service connectors on a pipeline. The equivalent connector was hydraulically representative of the actual service connectors. However, the connectors that represented boundary controls and internal control structures were located as if in the actual systems. Pipelines contained between equivalent connectors were called equivalent pipelines. Total lengths of feeders and laterals in the distribution system were maintained in the equivalent system. The equivalent pipeline diameters and lengths are shown in Table 4-3.

TABLE 4-3

EQUIVALENT PIPELINE CHARACTERISTICS OF THE PRIMARY DISTRIBUTION SYSTEM

Line number	Diameter (D), in inches	Length (L), in feet	Hazen-Williams Coefficient (C)	Relative roughness, $F \times 10^{-9.0}$*
1	42	8,000	129	133
2	42	18,000	129	293
3	36	10,000	129	342
4	36	9,000	129	308
5	36	38,500	129	1,319
6	96	21,500	126	6
7	96	8,500	105	3
8	78	13,000	120	11
9	78	13,500	120	12
10	78	13,500	120	12
11	78	11,500	124	10
12	78	7,000	124	5
13	78	2,000	124	1
14	72	10,500	108	16
15	72	11,000	108	18
16	72	8,500	108	13
17	72	9,500	108	15
18	96	19,500	122	6
19	36	21,500	130	722
20	36	17,500	108	826
21	33	11,500	108	826
22	42	7,000	120	125
23	42	19,500	120	362
24	42	13,500	120	246
25	42	14,000	120	260
26	54	15,000	120	80
27	45	4,000	114	61
28	72	6,500	130	9
29	72	9,000	130	10
30	72	9,000	130	10
31	72	13,000	130	14
32	72	5,500	108	8
33	45	13,000	114	191
34	36	15,500	138	467
35	36	3,000	138	90

EQUIVALENT PIPELINE CHARACTERISTICS OF THE PRIMARY DISTRIBUTION SYSTEM (continued)

Line number	Diameter (D), in inches	Length (L), in feet	Hazen-Williams Coefficient (C)	Relative roughness $F \times 10^{-9.0}$*
36	50	6,000	104	63
37	50	11,500	104	116
38	50	6,000	104	61
39	50	7,000	104	73
40	50	4,000	104	40
41	50	3,000	104	29
42	54	14,000	120	77
43	54	4,500	120	23
44	50	16,000	104	165
45	45	12,000	120	157
46	45	17,500	120	229
47	45	2,500	120	32
48	45	1,500	120	18
49	45	3,000	120	36
50	50	4,500	104	47
51	50	2,500	104	28
52	60	42,000	120	136
53	60	9,500	120	31
54	60	23,000	120	74
55	60	2,000	120	7
56	50	6,500	104	69
57	50	8,000	112	71
58	78	5,500	108	5
59	78	6,500	108	7
60	78	5,500	108	6
61	78	10,500	108	11
62	78	8,000	108	8
63	36	6,500	120	262
64	36	6,500	120	254
65	50	14,500	112	128
66	50	2,500	112	20
67	50	3,000	112	28
68	48	29,000	120	280
69	48	10,000	120	95
70	48	4,000	120	40

EQUIVALENT PIPELINE CHARACTERISTICS OF THE
PRIMARY DISTRIBUTION SYSTEM
(continued)

Line number	Diameter (D), in inches	Length (L), in feet	Hazen-Williams Coefficient (C)	Relative roughness $F \times 10^{-9.0}$*
71	48	4,000	120	40
72	48	5,000	120	50
73	48	7,000	120	67
74	48	1,500	120	16
75	50	12,000	112	107
76	72	79,500	103	141
77	50	13,500	103	143
78	51	12,500	103	121
79	60	30,500	120	99
80	51	2,500	103	25
81	75	44,000	120	48
82	84	35,000	120	22
83	84	28,000	120	17
84	48	15,000	120	145
85	48	15,000	120	145
86	48	15,000	120	145
87	84	38,000	120	23
88	84	30,000	120	18
89	84	23,000	120	14
90	54	14,500	120	78
91	81	12,000	120	9
92	81	18,000	120	13
93	81	47,000	120	35
94	45	48,000	120	636
95	84	44,000	120	27

*Relative roughness = $\dfrac{10.43\ L}{C^{1.85} D^{4.87}}$

Determination of Roughness Factor. The Hazen-Williams roughness factors (C) of the pipelines were determined using roughness factors of component equivalent pipelines. Roughness factors of existing pipelines in the primary system were computed on the basis of pipe lengths, diameters, capacities, and normal operating hydraulic grade line elevations obtained from Appendix F, "Conveyance and Distribution of Imported Water Within Service Areas", of Department of Water Resources Bulletin No. 78, "Investigation of Alternative Aqueduct Systems to Serve Southern California". A Hazen-Williams roughness factor of 120, which was found to be the representative roughness factor of existing pipelines, was used for future pipelines. The roughness factors for segments shown on Plate 17 which are used for the equivalent pipelines in the analyzed system are given in Table 4-3.

Mathematical Model of the Primary Distribution System

To estimate the maximum delivery capacity of the primary distribution system, hydraulic grade line elevations had to be determined at various control and takeout structures under numerous rates and patterns of of delivery. For this, mathematical models of the expanding primary distribution system were formulated and utilized in the subsequent phases of this work. In the formulation of these models, a general pipeline network equation was developed.

Derivation of General Pipeline Network Equation

The general pipeline network equation which relates the physical characteristics of a pipeline network to the hydraulic characteristics was used to form an integral portion of the mathematical model. The continuity equation as it is related to flow in pipeline networks and the Hazen-Williams flow relationship were combined to formulate the general pipeline network equation.

The general continuity equation is:

Inflow - Outflow = 0

or

Net Pipeline Flow at a Connector = 0

If the connector of interest is identified by subscript B and all adjacent connectors as subscript i, the continuity equation can be rewritten as:

$$\Sigma_i \; Q_{i,B} + Q_B = 0 \qquad (1)$$

where: $\Sigma_i Q_{i,B}$ refers to the net pipeline flow at a connector and Q_B is the amount of flow entering or leaving the pipeline network at connector B.

The equation used in computing the amount of flow, based on the Hazen-Williams relationship, is:

$$(h_i - h_B) = F_{i,B} \; Q_{i,B}^{1.85} \qquad (2)$$

and

$$F_{i,B} = \frac{10.4 \; L_{i,B}}{C_{i,B}^{1.85} \; D_{i,B}^{4.87}}$$

where: $(h_i - h_B)$ = difference in hydraulic grade line elevation, in feet, in the pipeline linking connector B and adjacent connector i;

$F_{i,B}$ = relative roughness of the pipeline linking connector B and adjacent connector i;

$Q_{i,B}$ = flow, in gallons per minute, in the pipeline linking connector B and adjacent connector i;

$L_{i,B}$ = length of pipeline, in feet, linking connector B and adjacent connector i;

$C_{i,B}$ = Hazen-Williams coefficient of pipeline linking connector B and adjacent connector i;

$D_{i,B}$ = diameter of pipeline, in inches, linking connector B and adjacent connector i.

Equation (2) is rewritten as:

$$Q_{i,B} = \frac{\left(\frac{1}{F_{i,B}}\right)^{1/1.85}}{(h_i - h_B)^{-1/1.85}} \qquad (3)$$

Multiplying the right side of equation (3) by $\frac{(h_i - h_B)}{(h_i - h_B)}$ simplifying, and setting:

$$Y_{i,B} = \frac{\left(\frac{1}{F_{i,B}}\right)^{1/1.85}}{(h_i - h_B)^{0.85/1.85} + E} \qquad (4\text{-}A)$$

the expression becomes:

$$Q_{i,B} = Y_{i,B}\,(h_i - h_B) \qquad (4\text{-}B)$$

where $Y_{i,B}$ is the conductance factor of the pipeline linking connector B and adjacent connector i. The purpose of the constant E in equation (4-A) is to enable the computer to handle the condition in which the difference in hydraulic grade line elevation, $(h_i - h_B)$, becomes very small or zero.

The general pipeline network equation, obtained by the combination of equations (1) and (4-B), is:

$$\Sigma_i \left[(h_i - h_B)\,Y_{i,B}\right] + Q_B = 0 \qquad (5)$$

This equation is directly used in the formulation of the mathematical model of the pipeline network serving the Coastal Plain.

Formulation of Mathematical Model

For each of the equivalent connectors, a specific equation in the form of equation (5) with a proper value of $(Y_{i,B})$ was written in terms of relative roughness ($F_{i,B}$) as shown in equation (4-A). The factor ($Y_{i,B}$) for each equation included the effects of diameters, lengths, and roughness of adjacent equivalent pipelines. A set of these equations, which simulated hydraulic characteristics of the distribution system they represented, constituted the mathematical model of the system. This model was formulated for each of the three pipeline networks considered in the study: the network existing in 1963, the network presumed to be in service in 1972, and the network presumed to be in service from 1983 through 1990.

Development of a Computer Program

As mentioned before, the mathematical model for each network was composed of a large set of equations. To determine a hydraulic grade line elevation for each equivalent connector and resulting flow in each equivalent pipeline under a selected scheme of water delivery, those equations had to be solved simultaneously while satisfying two conditions: (1) the algebraic sum of the pressure drop around any pipeline loop had to equal zero, and (2) the flow entering a connector had to equal the flow leaving it. The laborious and repetitive computation required to solve each set of equations is a formidable task to undertake with manual methods. Therefore, a computer program was developed.

The computer program is shown on Figure 4-1, and its corresponding flow chart on Figure 4-2. The procedure utilized in the program is as follows:

1. Accept input data;
2. Solve for conductance factor ($Y_{i,B}$) for each equivalent pipeline;
3. Compute ($Q_{i,B}$) for each equivalent pipeline;

```
      ITRNO = 0
   10 ITRNO = ITRNO + 1

      Y(1) = XX(1)/((ABSF(H(1) - H(2)))**.4594 + E)
      Y(2) = XX(2)/((ABSF(H(2) - H(3)))**.4594 + E)
      .
      .
      Y(55) = XX(55)/((ABSF(H(71) - H(72)))**.4594 + E)
      .
      .
      Y(95) = XX(95)/((ABSF(H(76) - H(75)))**.4594 + E)

      RELAX(1) = 0.0
      RELAX(2) = COEFF/(Y(2) + Y(1))
      .
      .
      RELAX(52) = COEFF/(Y(67) + Y(68) + Y(75))
      .
      .
      RELAX(80) = COEFF/(Y(89) + Y(90) + Y(91))

      Q(1) = Y(1)*(H(1) - H(2))
      Q(2) = Y(2)*(H(2) - H(3))
      .
      .
      Q(46) = Y(46)*(H(36) - H(37))
      .
      .
      Q(95) = Y(95)*(H(76) - H(75))

      RES(1) = 0.0
      RES(2) = Q(1) - Q(2) + AQ(2)
      .
      .
      RES(35) = Q(50) - Q(44) - Q(45) + AQ(35)
      .
      .
      RES(80) = Q(89) + Q(91) - Q(90) + AQ(80)

      DO 20 K = 1, 80
   20 H(K) = H(K) + RELAX(K)*RES(K)
      SUM = 0.0
      DO 30 K = 1, 80
   30 SUM = SUM + ABSF(RES(K))
      IF(SUM - ERROR) 40, 40, 10

   40 CONTINUE

      PRINT, ITRNO
      DO 50 K = 1, 80
   50 PRINT, K, RELAX(K), RES(K), AQ(K), H(K)
      DO 60 K = 1, 95
   60 PRINT, K, Y(K), Q(K)

      END
```

DEFINITIONS

ITRNO = ITERATION NUMBER
Y(2) = CONDUCTANCE FACTOR OF PIPELINE(2), GALLONS/MINUTE-FEET
XX(2) = RESISTANCE FACTOR OF PIPELINE(2), GALLONS/MINUTE-FEET$^{0.5406}$
H(2) = HYDRAULIC GRADE LINE ELEVATION AT CONNECTOR(2), FEET
E = A CONSTANT USED TO HANDLE IN COMPUTER THE CONDITION OCCURRING WHEN THE DIFFERENCE IN HYDRAULIC GRADE LINE ELEVATION BETWEEN TWO CONNECTORS BECOMES ZERO
RELAX(2) = RELAXATION COEFFICIENT AT CONNECTOR(2), MINUTE-FEET/GALLON
COEFF = RELAXATION FACTOR WHICH SPEEDS CONVERGENCE
Q(2) = FLOW IN PIPELINE(2), GALLONS/MINUTE
RES(2) = RESIDUAL FLOW RATE AT CONNECTOR(2), GALLONS/MINUTE
AQ(2) = TAKEOUT FLOW AT CONNECTOR(2), GALLONS/MINUTE
K = CONNECTOR OR PIPELINE NUMBER
SUM = TOTAL RESIDUAL FLOW RATE IN THE NETWORK, GALLONS/MINUTE
ERROR = MAXIMUM ALLOWABLE TOTAL RESIDUAL FLOW RATE IN THE NETWORK, GALLONS/MINUTE
ABSF = ABSOLUTE SYMBOL
* = MULTIPLICATION SYMBOL
** = EXPONENTIAL SYMBOL
/ = DIVISION SYMBOL
DO = PERFORM COMPUTATION A SPECIFIED NUMBER OF TIMES

FIGURE 4-1

SIMPLIFIED FORTRAN PROGRAM FOR DIGITAL COMPUTER SOLUTION OF A SET OF PRINCIPAL PIPELINE NETWORK EQUATIONS

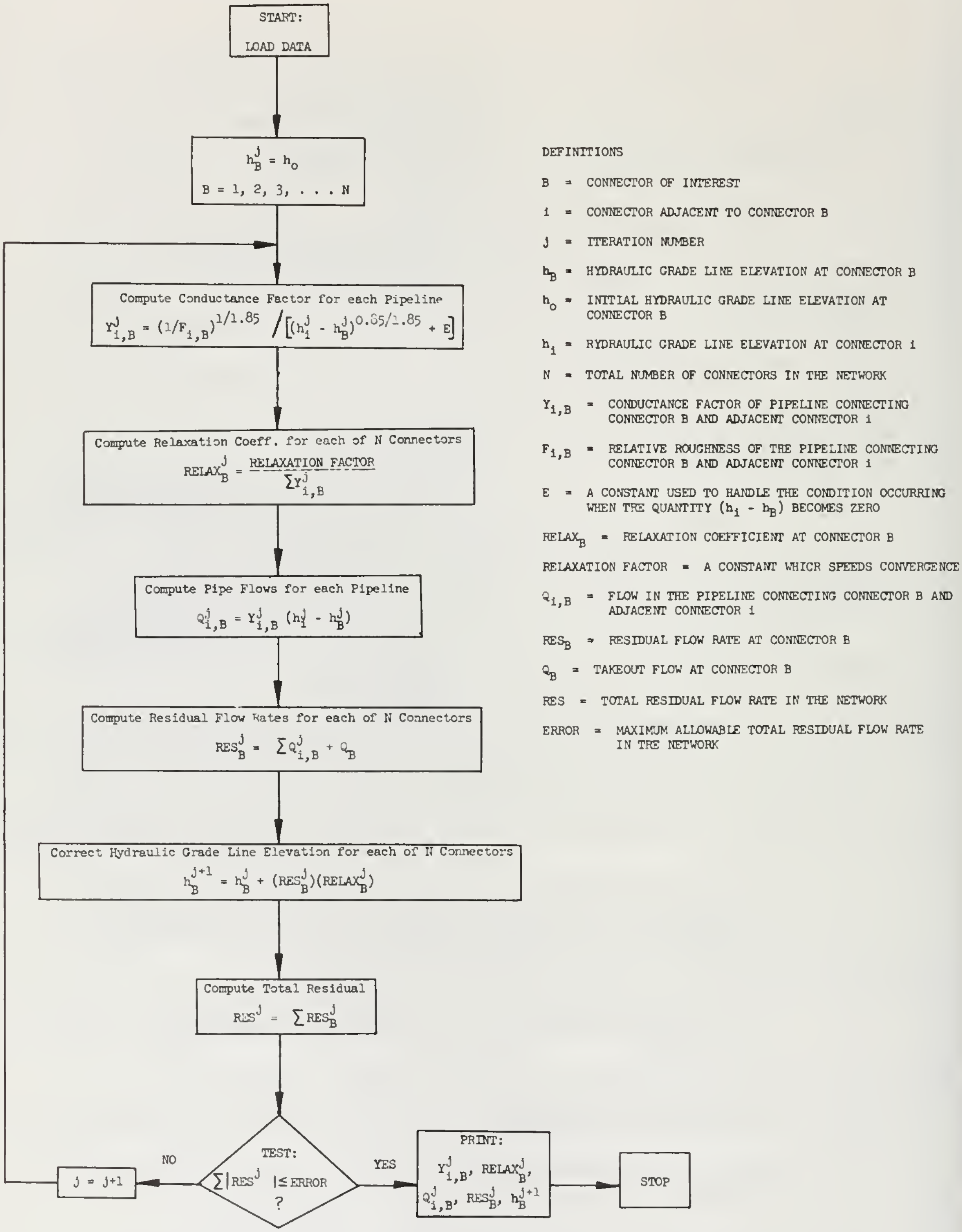
4. By using the continuity equation, determine the amount of deviation from the condition Q = 0, at each connector (residual factor, RES_B);

5. Correct hydraulic grade line elevation at each connector by using $RES_{i,B}$ and a relaxation coefficient ($RELAX_B$);

6. Compare the total residual flow with a preselected tolerance factor (ERROR);

7. Repeat the procedure until the total residual flow becomes less than ERROR;

8. Print out final hydraulic grade line elevations at connectors and flows in pipelines.



SIMPLIFIED FLOW CHART FOR DIGITAL COMPUTER SOLUTION
OF A SET OF PRINCIPAL PIPELINE NETWORK EQUATIONS

The correction mentioned in item 5 above is a product of residual (RES) and a relaxation coefficient (RELAX = $1/Y_{i,B}$).

Input data to the program included an assumed initial hydraulic grade line elevation (HZERO), a takeout flow (AQ) for each connector, and a resistance factor (XK) which is a function of the Hazen-Williams Coefficient (C), a diameter, and length of a pipeline. The resistance factor is equal to $(1/F_{i,B})^{1/1.85}$, as shown in equation (4-A). Additional information included identification numbers for connectors and pipelines and a corresponding sign to each pipeline, showing direction of flow. The equivalent connector and pipeline numbering code is shown on Plate 17. In the system map in Plate 17, the sign of each flow (Q) was determined according to a sign convention in which all westerly and southerly flows were positive, easterly and northerly flows were negative. The direction of flows through slanted pipelines are indicated in Plate 17.

A relaxation factor was applied to the relaxation coefficient ($RELAX_{i,B}$) to shorten the solution time. The relaxation coefficient is represented by the following equation:

$$RELAX_{i,B} = \frac{\text{RELAXATION FACTOR}}{Y_{i,B}} \qquad (6)$$

Computer time was lessened by choosing reasonable initial hydraulic grade line elevations to shorten the solution time.

Approximation of Maximum Delivery Capacity of System

Utilizing the mathematical model and computer program for hydraulic grade line elevation and flow determinations under various schemes of water delivery, the maximum delivery capacity was approximated for each of the three networks studied. Maximum delivery capacity of a distribution system is defined as the maximum amount of water that can be delivered by the distribution system with pressures equal to or higher than specified pressures at connectors and control structures.

To approximate the maximum capacity, operational criteria for maximum delivery were formulated, assumptions were made to ensure a solution consistent with limitations imposed by boundary conditions, and logical procedures were followed to satisfy the criteria and the limitations. The criteria, assumptions, and the procedures will be discussed here.

Criteria for Maximum Delivery

The criteria for maximum delivery consisted of three requirements: (1) pressures at nearly all the takeout connectors must be equal to or above 65 psi without use of booster pumps, (2) pressures at control structures must be consistent with control hydraulic grade line elevations given in Table 4-1, and (3) a selected delivery rate is the largest rate that will satisfy the pressure requirement for any assumed takeout pattern.

Assumptions

To ensure operationally realistic delivery rates, several physical limitations were considered and numerically defined under certain assumptions. The limitations considered were conveyance capacity of feeders leading to the network studied, minimum amount of ground water extraction and water demands for fresh-water barriers and spreading facilities, as well as domestic and municipal needs.

It was assumed that for the period 1963-72 the annual delivery capacity of the system to the Coastal Plain will not be greater than the amount that is needed to meet the imported water need of the area when total extractions in the area are reduced to 40 percent of the annual extraction of 1956-57. Peak required delivery rate was considered to be 130 percent of average annual rate of delivery. During the period of heavy water demand, spreading operations were assumed to be suspended. However, fresh-water injection was considered to be a continuous operation. Consequently, spreading demand for imported water was subtracted from the total water requirements for this analysis.

Procedures for Approximating Maximum Delivery Rate

In approximating the maximum delivery rate of the primary distribution system, amounts of takeout were assigned within the assumed limits of the various connectors. Pressure responses at all takeout connectors and control structures were then computed on a digital computer. When the resulting pressure responses were lower than desired pressure, the pattern of takeout was changed but the total amount of delivery was kept the same to satisfy pressure requirements. A number of takeout patterns were analyzed until the pressure requirements were satisfied, or until it became apparent that with the assumed rate of delivery there was no pattern that could satisfy the pressure requirement. When the computed pressure was higher than the desired pressure, the pattern of takeout was kept the same, but the total amount of delivery was increased to reduce pressure. Total deliveries were varied until the pressure requirements were satisfied, or it became apparent that no pattern would work. Throughout this operation, hydraulic grade line elevations at control structures and rates of flow in the equivalent pipeline coming out of the boundary controls were monitored to avoid physically incompatible situations. Hence, the solution obtained for each of the three pipeline networks was compatible with reasonable operating conditions.

Results

The resulting flows in the equivalent pipelines and the hydraulic grade line elevations at connectors for each of the analyzed networks are shown in Table 4-4.

Estimates of the maximum delivery capacities of the equivalent networks representing the primary distribution system serving the Coastal Plain of Los Angeles County during the period from 1963-1972, from 1972-1983, and from 1983-1990, are shown in Table 7 in Chapter II.

For this study, the pressure requirements were satisfied at all control structures and connectors, except for a small number of connectors where the pressure was slightly below 65 psi. These connectors were generally in the pipelines west of the Palos Verdes Feeder.

TABLE 4-4

CONNECTOR TAKEOUTS, HYDRAULIC GRADE LINE ELEVATIONS AND PIPELINE FLOWS RESULTING FROM MAXIMUM DELIVERY BY THE PRIMARY DISTRIBUTION SYSTEM

Code number[a]	Takeout at connector, in gallons per minute			Hydraulic grade line elevation at connector, in feet			Flow in pipeline[b,c] in gallons per minute		
	1963-72	1972-83	1983-90	1963-72	1972-83	1983-90	1963-72	1972-83	1983-90
1	0	0	0	1,080	1,080	1,080	26,000	31,000	30,000
2	1,000	2,000	2,000	1,050	1,050	1,050	25,000	28,000	28,000
3	1,000	2,000	2,000	1,015	1,000	1,000	25,000	26,000	26,000
4	1,000	1,000	1,000	965	945	945	24,000	25,000	25,000
5	1,000	2,000	2,000	925	905	905	23,000	23,000	23,000
6	6,000	10,000	10,000	770	745	745	237,000	275,000	273,000
7	8,000	17,000	17,000	710	665	670	229,000	258,000	256,000
8	0	0	0	675	630	630	188,000	205,000	203,000
9	8,000	18,000	19,000	605	645	550	180,000	187,000	184,000
10	15,000	14,000	14,000	540	470	475	165,000	173,000	170,000
11	11,000	29,000	29,000	435	385	400	157,000	103,000	95,000
12	0	0	0	415	380	395	146,000	74,000	66,000
13	0	0	0	410	380	390	83,000	37,000	30,000
14	10,000	16,000	16,000	445	415	425	107,000	110,000	105,000
15	5,000	16,000	16,000	490	470	475	117,000	126,000	121,000
16	11,000	5,000	6,000	530	520	520	122,000	142,000	137,000
17	8,000	16,000	16,000	580	465	470	133,000	147,000	143,000
18	20,000	18,000	18,000	550	440	445	246,000	292,000	290,000
19	5,000	8,000	8,000	555	445	445	26,000	30,000	30,000
20	10,000	10,000	10,000	570	465	470	20,000	27,000	27,000
21	12,000	15,000	15,000	650	580	585	12,000	11,000	11,000
22	2,000	10,000	10,000	325	345	350	- 8,000	- 7,000	- 7,000
23	2,000	5,000	5,000	335	345	355	- 13,000	- 15,000	- 15,000
24	12,000	17,000	17,000	350	350	360	23,000	25,000	25,000
25	9,000	13,000	13,000	365	355	365	29,000	38,000	38,000
26	0	0	0	395	370	385	41,000	53,000	53,000
27	29,000	45,000	47,000	270	275	270	37,000	- 6,000	0
28	15,000	20,000	22,000	270	275	275	78,000	34,000	39,000
29	0	0	0	275	285	285	79,000	39,000	44,000
30	20,000	25,000	30,000	270	275	270	91,000	56,000	61,000
31	16,000	20,000	24,000	270	275	270	100,000	69,000	74,000
32	5,000	7,000	8,000	295	330	335	100,000	69,000	74,000
33	0	0	0	300	330	340	30,000	42,000	44,000
34	10,000	12,000	12,000	315	340	345	1,000	- 3,000	- 3,000
35	0	0	0	300	335	345	- 14,000	- 23,000	- 25,000
36	1,000	10,000	10,000	275	325	335	13,000	28,000	31,000
37	1,000	5,000	7,000	240	325	330	- 7,000	3,000	1,000
38	7,000	32,000	33,000	235	315	320	- 23,000	17,000	- 23,000
39	15,000	18,000	18,000	230	310	320	28,000	51,000	56,000
40	2,000	8,000	8,000	315	335	350	28,000	14,000	16,000
41	0	12,000	14,000	320	340	355	33,000	21,000	24,000
42	11,000	7,000	7,000	280	340	350	29,000	18,000	17,000
43	0	0	0	340	340	365	39,000	30,000	29,000
44	6,000	8,000	6,000	355	340	370	4,000	3,000	7,000
45	12,000	20,000	20,000	360	345	370	27,000	13,000	15,000
46	4,000	4,000	3,000	370	350	375	26,000	3,000	5,000
47	3,000	8,000	10,000	380	355	380	25,000	- 1,000	- 2,000
48	2,000	4,000	5,000	395	370	385	22,000	50,000	51,000
49	9,000	12,000	25,000	335	305	355	15,000	18,000	18,000
50	10,000	15,000	12,000	345	340	365	31,000	17,000	22,000
51	37,000	46,000	47,000	345	340	365	33,000	25,000	30,000
52	10,000	12,000	12,000	350	355	380	63,000	37,000	36,000
53	1,000	2,000	3,000	345	385	400	63,000	6,000	14,000
54	1,000	2,000	3,000	345	395	410	53,000	0	7,000
55	2,000	5,000	10,000	345	405	415	47,000	24,000	12,000

CONNECTOR TAKEOUTS, HYDRAULIC GRADE LINE ELEVATIONS
AND PIPELINE FLOWS RESULTING FROM MAXIMUM DELIVERY BY THE
PRIMARY DISTRIBUTION SYSTEM
(continued)

Code number[a]	Takeout at connector, in gallons per minute			Hydraulic grade line elevation at connector, in feet			Flow in pipeline[b,c] in gallons per minute		
	1963-72	1972-83	1983-90	1963-72	1972-83	1983-90	1963-72	1972-83	1983-90
56	5,000	51,000	51,000	345	410	410	33,000	6,000	22,000
57	(...		dummy connection			...)	33,000	6,000	22,000
58	0	0	0	400	400	415	70,000	42,000	23,000
59	24,000	28,000	32,000	470	465	465	82,000	63,000	43,000
60	0	0	0	590	590	590	86,000	67,000	46,000
61	0	0	0	632	632	632	89,000	74,000	56,000
62	0	0	0	570	570	570	90,000	79,000	61,000
63	8,000	72,000	72,000	480	405	415	14,000	20,000	- 19,000
64	0	0	0	830	830	830	9,000	12,000	25,000
65	6,000	10,000	10,000	660	600	600	- 17,000	- 8,000	- 13,000
66	6,000	12,000	12,000	600	500	505	- 7,000	7,000	- 1,000
67	7,000	21,000	21,000	305	345	351	30,000	53,000	46,000
68	0	0	0	285	325	335	8,000	- 20,000	- 18,000
69	0	35,000[d]	33,000[d]	280	280	280	7,000	- 22,000	- 21,000
70	3,000	4,000	5,000	235	325	330	6,000	- 24,000	- 23,000
71	6,000	7,000	7,000	235	340	350	6,000	- 24,000	5,000
72	47,000	47,000[e]	33,000[e]	235	340	350	4,000	- 29,000	- 5,000
73	0	0	0	345	415	415	4,000	16,000	16,000
74	0	0	0	345	415	415	0	- 35,000	- 35,000
75	0	0	0	345	400	415	47,000	45,000	40,000
76	5,000	8,000	18,000	340	315	395	(...	Dummy Pipeline	...)
77		8,000	10,000		420	425	47,000	45,000	40,000
78		8,000	10,000		410	415	71,000	73,000	73,000
79		8,000	10,000		405	415	- 21,000	- 21,000	- 21,000
80		0	0		425	330	93,000	94,000	93,000
81								167,000	166,000
82								161,000	160,000
83								161,000	160,000
84								- 18,000	- 16,000
85								- 10,000	- 6,000
86								- 2,000	4,000
87								136,000	134,000
88								68,000	68,000
89								31,000	28,000
90								52,000	56,000
91								21,000	28,000
92								76,000	86,000
93								107,000	98,000
94								23,000	21,000
95									- 61,000
96							(...	Dummy Pipeline	...)

a. See Plate 17 for system code; code numbers 81 through 96 for pipelines only.

b. Direction of flow is determined through the use of a sign convention in which all westerly and south-erly flows are positive, easterly and northerly flows are negative. The direction of flows througl slanted pipelines are shown in Plate 17. The system map shown on Plate 17 is used in conjunction with the sign convention to determine the direction of flow in all pipelines.

c. The pipeline flows were rounded off to the nearest 1,000 gpm.

d. The net inflow of water from pipelines 38 and 90 into Palos Verdes Reservoir (Connector 69) was used to directly serve the Coastal Plain. The new inflows for the 1972-83 and 1983-90 distribution systems are 35,000 gpm and 33,000 gpm, respectively.

e. The takeout was increased by 18,000 gpm to give an adequate supply of water to the freshwater barri system along the coastal area. The distribution systems can deliver this increase without appreci ably lowering the pressures in adjacent nodes.

ATTACHMENT NO. 5

FORMULATION AND VERIFICATION OF A MATHEMATICAL MODEL OF THE GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY

ATTACHMENT No. 5

FORMULATION AND VERIFICATION OF A MATHEMATICAL MODEL OF THE GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY

Introduction

The successful attainment of an optimum operating plan for the ground water basins of the Coastal Plain of Los Angeles County in coordination with the overlying surface distribution and storage facilities required a "model" that could reliably simulate the complex hydraulic properties of the ground water basins. A cursory study in the early stages of this investigation indicated that a mathematical model properly formulated and verified on a differential analyzer (analog computer) would be an invaluable tool to obtain the information required for subsequent operational studies. Specifically, a reliable model was needed to determine water level responses at various locations in the Coastal Plain for planned replenishments and extractions of varying amounts and locations.

Information on water level responses translated to pumping lifts, changes in the amounts of ground water in storage, and subsurface flow rates between various areas was needed to determine the number of facilities required to execute each alternative plan, and the costs of their construction, operation, and maintenance.

In the fall of 1959, a computation firm in Los Angeles offered the use of its general purpose analog computer system, at no cost to the State, to solve a problem of statewide significance. The purpose of this offer was to demonstrate the capacity and applicability of its computer system. The State accepted the offer, and integrated the role of the computation firm into a program to formulate and verify a mathematical model of the ground water basins in the Coastal Plain of Los Angeles County.

As shown on Plate 18, the Coastal Plain includes Central Basin, West Coast Basin, Santa Monica Basin, and Hollywood Basin. The region is located in the southwest portion of Los Angeles County. It has a total area of about 625 square miles and the portion considered as the ground water reservoir has an area of about 480 square miles.

Procedures to formulate and test a mathematical model of the Coastal Plain or any other ground water basin on the differential analyzer were not available in the early stages of this investigation. Consequently, a program was immediately implemented to develop the procedures concurrently with the conduct of the geologic and hydrologic phases of the investigation. The establishment of the new procedures in obtaining a reliable mathematical model required full utilization of the technical disciplines related to hydrology, geology, hydraulics, mathematics, and electronics.

As anticipated, the formulation and verification of the mathematical model required extensive simplification of the complex elements of the prototype, in order to handle all facets of the program within the framework of the available equipment and time.

The following detailed discussion describes the formulation of a much simplified mathematical model of the complex ground water basins of the Coastal Plain, and the verification of this model on a general purpose analog computer that successfully simulated the historical ground water conditions. The subsequent use of the verified mathematical model as a tool to obtain operational data is presented in Attachment No. 6, "Development and Superpositioning of Master Influence Functions".

General Method

In formulating and verifying the mathematical model, a general method evolved that could be adapted with ease to similar investigations of any size ground water basin, whether situated in other parts of California or other parts of the world. General steps of this method follow:

1. A generalized ground water equation was derived that defines storage, transmissive, and water inflow-outflow characteristics. Also, an electrical circuit equation analogous to the general ground water equation was derived for adaptation on a general purpose analog computer. These equations are applicable to any unit area of any ground water basin.

2. A set of assumptions was made within the framework of the equation, the geologic and hydrologic data, and the analog computer system.

3. The entire Coastal Plain was subdivided into subareas called polygons by using the Thiessen Method of polygon construction. The layers of aquifers underlying the Coastal Plain were converted into one representative "equivalent aquifer".

4. Geologic data were analyzed and the transmissive factor between polygons and storage factor within each polygon were estimated.

5. Historical surface hydrologic data were analyzed and the surface inflow-outflow factors at each polygon were estimated for each year in the period 1946-47 through 1956-57. Also, hydrographs of

representative ground water level fluctuations during the same period were prepared for each polygon, based on historical information of ground water level elevations.

6. A circuit diagram was drawn illustrating the electrical components of the analog computer and their interconnections. Using this diagram, patch panels of the analog computer were wired.

7. The circuitry of the analog computer and the proper initial settings of the transmissive, storage, and surface inflow-outflow factors in the computer were checked, using dynamic and equilibrium check techniques developed in this program. Precalculated water level elevations for each polygon were used in the dynamic check of the analog computer.

8. The output of the analog computer, with initial estimates of transmissibility, storage, and surface inflow-outflow factors, was used to verify the mathematical model. The water level elevations generated by the computer were plotted by using X-Y plotters attached to the analog computer and these responses were compared with the hydrographs of historical water level elevations of the ground water basins. The matching of the historical water levels was effected by making reasonable adjustments to the values of the transmissibility, storage, and surface inflow-outflow factors.

Derivation of Principal Equation

The principal ground water equation and its analogous electrical circuit equation for adaptation to the analog computer were derived in this study. The continuity equation and Darcy's equation were used to derive a differential equation that defines the storage and movement of ground water for any unit area in the zone of saturation of a ground water basin. A set of these differential equations, covering all the subareas of the Coastal Plain, and with the proper coefficients of storage and transmissibility, is referred to as the mathematical model of the Coastal Plain.

The general continuity equation as used in ground water flow is:

$$\text{Inflow} - \text{Outflow} = \pm \text{ Change in Storage} \qquad (1)$$

or

$$\text{Net Subsurface Flow} + \text{Net Surface Flow} = \pm \text{ Change in Storage}$$

The specific equation used in computing the amount of subsurface flow, based on Darcy's law is:

$$Q = PAI \text{ or } TWI \qquad (2)$$

where: Q is the subsurface flow of ground water,

P is the permeability,

A is the gross saturated area,

I is the slope of the water table or piezometric surface, depending upon the type of aquifer, at the desired location,

T is the transmissibility and is equal to P times the depth of saturated sediments, and

W is the width through which the ground water moves.

The combination of equations (1) and (2) for any general unit area within the ground water basin yields:

$$\Sigma_i \left[(h_i - h_B) \frac{T_{i,B} W_{i,B}}{L_{i,B}} \right] + A_B Q_B = A_B S_B \frac{dh_B}{dt} \qquad (3)$$

where: h_B = representative ground water level (head), in feet, of the general unit area B.

h_i = representative ground water level, in feet, of a unit area adjacent to area B.

$L_{i,B}$ = distance, in feet, between the nodal points of areas B and i. Therefore, $(h_i - h_B)/L_{i,B}$ is an average slope of a ground water surface between the unit areas B and i.

$T_{i,B}$ = representative transmissibility between areas B and i, in acre-feet per year per foot of width.

$W_{i,B}$ = width, in feet, through which the subsurface flow occurs between areas B and i.

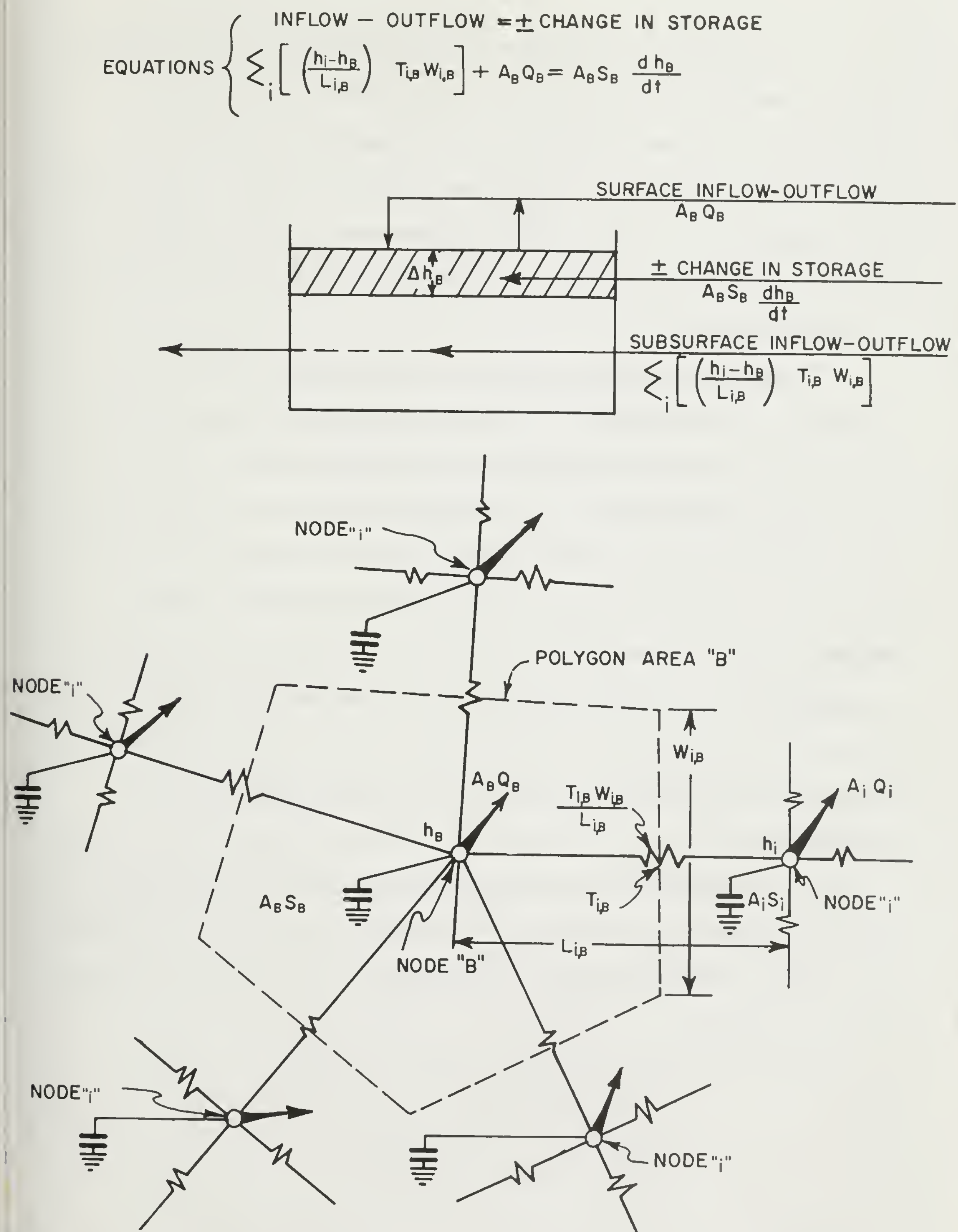
A_B = area, in acres, of general unit area B.

Q_B = rate of net surface inflow and outflow, in acre-feet per year per acre of general unit area B.

S_B = representative specific yield of sediments in general area B.

t = time, in years.

As shown on Figure 5-1, a general unit area is expressed by subscript B and all surrounding unit areas are subscripted i. The first term of the left-hand member of equation (3) is a summation of subsurface flows between area B and its surrounding areas i. The net surface flow into or from area B is given by the second term of the left-hand member and a change in storage is given by the right-hand member of the equation.



SCHEMATIC SHOWING A GENERALIZED GROUND WATER FLOW EQUATION

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

As stated previously, the mathematical model of the Coastal Plain is composed of a set of differential equations (one for each polygon area) with proper storage and transmissibility factors. In equation (3), the TW/L is the transmissibility factor, AS is the storage factor, and AQ is the surface inflow-outflow factor. Determination of the quantitative values of these factors is discussed in later sections of this attachment.

The physical characteristics of a ground water basin can be compared to the characteristics of various electronic components within a computer. These characteristics can be directly related to the electronic components by means of simple equations. In turn, by these equations, the flow of ground water in the basin can be compared to flow of electricity within the computer as it is affected by the components therein. The transmissibility of the aquifer is analogous to electrical conductivity, the specific yield of the basin is analogous to the capacitance, and the difference in head or ground water levels causing water to flow is analogous to the difference in voltage causing electrical current to flow.

The schematic sketch presented on Figure 5-1 illustrates the analogy between the basic ground water equation describing the movement and storage of ground water in an idealized unit area B and an electrical circuit equation.

The electrical equation analogous to equation (3) is:

$$\Sigma_i \left(\frac{e_i - e_B}{R_{i,B}}\right) + I_B = C_B \frac{de_B}{d\theta} \qquad (4)$$

where: e_B = the voltage at node B (general area B) representing the ground water elevation h_B;

e_i = the voltage at node i (adjacent areas to general area B) representing the ground water elevation h_i;

$R_{i,B}$ = the resistance to flow of current between node B and node i; it is the inverse of the transmissibility factor, $T_{i,b}\ W_{i,B}/L_{i,B}$;

I_B = the net current into node B representing the surface inflow-outflow factor, A_BQ_B;

C_B = the capacitance at node B representing the storage factor, A_BS_B;

θ = the electrical time representative of time t.

In this equation, the general area B is replaced by nodal point B, which serves as a connecting point for all electrical circuits in the analog computer.

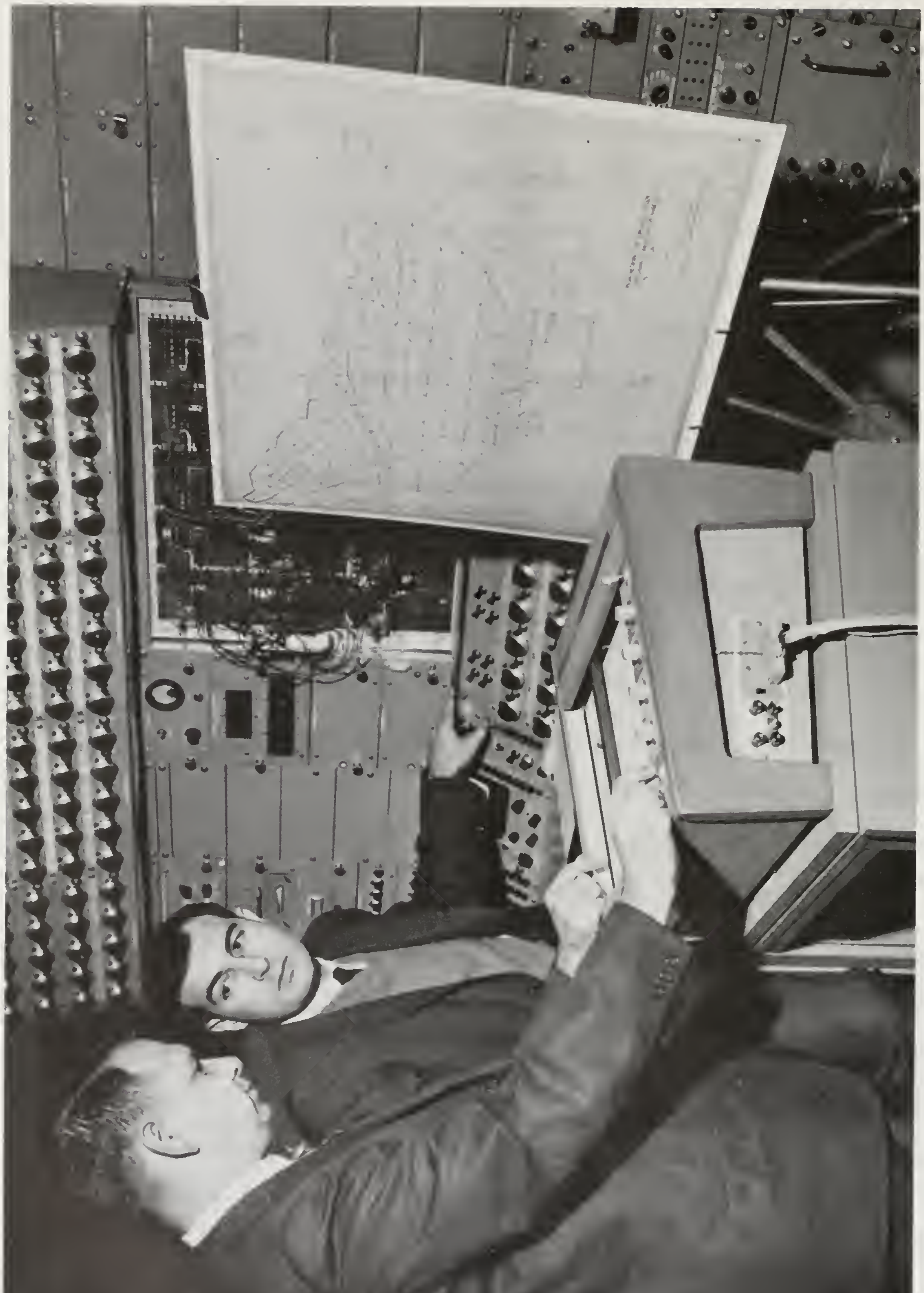
Note again that the values of TW/L, AS, and AQ in the principal equation are directly related to the values of R, C, and I, respectively, by scale factors. The equations showing these relationships are given here:

$$R_{i,B} = \left(\frac{a_2}{a_1}\right) \frac{L_{i,B}}{T_{i,B}\ W_{i,B}} \tag{5}$$

$$C_B = a_3 \left(\frac{a_1}{a_2}\right) A_BS_B \tag{6}$$

$$I_B = (a_1)\ A_BQ_B \tag{7}$$

Figure 5-2



A GENERAL PURPOSE ANALOG COMPUTER USED TO VERIFY THE MATHEMATICAL MODEL OF GROUND WATER BASINS where: a_1 = current scale factor in micro-amperes/acre-feet/year,

a_2 = voltage scale factor in volts/foot,

a_3 = time scale factor in computer seconds/year.

As later described, the electrical equivalents of transmissibility ($R_{i,B}$) and storage (C_B) are set into the analog computer by means of potentiometer dials. The values of surface inflow-outflow (I_B), which vary with time, are introducted by means of diode function generators. The surface inflow-outflow factor at each node consists of 10 straight line segments.

A typical Pace 231-R general purpose analog computer used in this study is shown on Figure 5-2. A discussion of the electronic components and their internal operation is not within the scope of this attachment.

Assumptions Used in Formulation

In the formulation of the mathematical model the following assumptions were made:

1. A single equivalent aquifer can be substituted for the complex system of aquifers in the Coastal Plain. The equivalent aquifer is a composite of the properties of the several actual aquifers. The deeper aquifers of the Pliocene age were not included in the equivalent aquifer because of the relatively small amount of ground water, if any, that has been extracted from these aquifers in the past.

2. The impervious bedrock found in the surrounding hills in the north and northeast parts of the basin does not supply a significant amount of ground water to the equivalent aquifer.

3. Along Santa Monica Bay and adjacent to Los Alamitos Gap, the ocean is in hydraulic continuity with the equivalent aquifer. The ground water level elevation at the seacoast will be held constantly at sea level.

4. Along San Pedro Bay, the ocean is not in hydraulic continuity with the equivalent aquifer. This was assumed even though the Recent aquifer is actually in contact with the ocean. However, ground water extractions from the Recent aquifer are considered to be insignificant and extractions from this aquifer do not affect the water level elevations in the heavily pumped deeper aquifers.

5. The water level elevation at the upper end of the Whittier Narrows is fixed at 190 feet.

6. The major faults in the Coastal Plain act as complete or partial barriers to the movement of ground water as indicated by the geologic investigation.

7. The transmissibility factor (TW/L) and storage factor (AS) do not vary with time or with ground water level elevations.

Determination of Control Nodes and Their Polygons

The equivalent aquifer of the entire Coastal Plain was divided into subareas called polygons. In the analog computer, each polygon was represented by a node. In this study, the number of control nodes and polygons was mainly limited by the number of electrical components available at a computation firm in Los Angeles. At that time, about 250 amplifiers and inverters, 435 potentiometers, and 38 time-dependent diode function generators were available in various computers for use in this program. A system with 82 control nodes was developed with the available equipment. This equipment was housed in three separate, but interconnected, computers of various sizes.

The determination of locations of the 82 nodes was based primarily on water level elevations at various locations in the basin. These levels are affected by the location and amount of replenishment and extraction and by the value of transmissibility and specific yield at various locations. The number of nodes was increased in areas where water level elevations changed rapidly, and nodes were located farther apart in areas where water level elevations changed more slowly. This approach in locating control nodes is believed to have provided better overall results.

The polygon area represented by each node was determined by intersecting the perpendicular bisectors of lines connecting nodes in the same manner that the Thiessen polygon is prepared. The number of sides of the polygon is not important. However, the nodes were located so that no interior angle of a triangle formed by lines connecting nodes was greater than 90 degrees. The locations of the 82 nodes and the polygon areas are shown on Plate 18.

In 9 of the 82 nodes, water level elevations were not varied with time. Eight of these nine nodes were located at Santa Monica Bay and Alamitos Bay, and the elevations of these nodes were fixed at mean sea level to represent the elevation of the ocean. One node at the upper end of Whittier Narrows was held at a constant elevation of 190 feet.

Determination of Transmissibility and Storage Factors

Results from the comprehensive geologic investigation of the Coastal Plain were evaluated to estimate the values of transmissive and storage factors of the aquifers. Some 5,000 drillers' logs of water and oil wells scattered throughout the area were analyzed to delineate 11 major water-producing zones in various portions of the Coastal Plain. These aquifers are separated in certain areas by fine-grained sediments, silts and clays, and they are merged in other areas. Specific yield and transmissibility values were assigned to all water-bearing sediments. These values were used as the first estimates of the coefficients of storage and transmissibility in the set of differential equations that make up the mathematical model of the Coastal Plain.

As mentioned before, the complex aquifer network of the study area was represented by a single equivalent aquifer. The transmissibility factor (TW/L), which affects the subsurface flow between two nodes of the equivalent aquifer, was estimated by the following procedure:

1. Maps showing lines of equal transmissibility (T) were prepared for each aquifer.

2. The average transmissibility value at the northeast corner of each section (an arbitrary starting point) was estimated for each of the aquifers by interpolating between contour lines of equal transmissibility values.

3. Each average transmissibility value at a particular northeast section corner was added to estimate a total transmissibility value for the equivalent aquifer.

4. These total transmissibility values were plotted on a map, and lines of equal average total transmissibility were drawn for the equivalent aquifer.

5. From this map, the values of transmissibility (T) of the equivalent aquifer were estimated at the midpoint of the line connecting any two nodes.

6. The transmissibility value (T) was multiplied by the width (W) of the perpendicular bisector of each line connecting the two nodes, and was divided by the length (L) of the line connecting the two nodes to obtain the transmissibility factor (TW/L). A map showing TW/L values for the equivalent aquifer is shown on Plate 19. The transmissibility factor was assumed constant with time or water level elevations.

The storage factor (AS) is a measure of the storage characteristics of the equivalent aquifer for each polygon. This factor is the product of the area of the polygon times the average specific yield of the water-bearing sediments within that area. The values of specific yield used in this study were principally based on information obtained from previous studies, such as information in Department of Water Resources Bulletin No. 45, and the San Fernando Valley Reference Report of Referee. Also, additional information was obtained during a recent geologic investigation of the Coastal Plain. The storage factor at each control node polygon was estimated by the following procedure:

1. A map showing the areal extent of the dewatering of the aquifers in 1947 and 1957 was prepared. A line was drawn to denote the average areal extent of dewatering from 1947 through 1957. For the area outside this line where no change in storage occurred, the storage factor

was assumed to be zero. The significance of the period 1947 through 1957 is that the mathematical model was verified with historical water level elevations from 1947 through 1957.

2. A map showing lines of equal average specific yield (S) was prepared for that portion of the equivalent aquifer where changes in storage took place. From this map, the average specific yield value was determined for each polygon where storage change occurred.

3. The average area (A) of each polygon in which changes in storage occurred was determined.

4. The average specific yield value (S) of each nodal polygon was multiplied by the area (A) of the corresponding nodal polygon to determine the storage factor (AS). A map showing the storage factor for each polygon for the equivalent aquifer is presented on Plate 18. This storage factor was assumed constant with time and changes in water level.

Preparation of Historical Surface Inflow-Outflow and Water Level Data

Historical data on replenishment to, extraction from, and water level elevations in the aquifers in the area of investigation were prepared for use in verifying the mathematical model. The amount of the annual net surface flow into and out of each polygon was determined for the 11-year period from 1946-47 through 1956-57, this being the period for which most reliable hydrological data were readily available. Most of these data were compiled in the hydrologic studies of the Coastal Plain.

The net amount of the deep percolation to, and the extractions from, the equivalent aquifer makes up the surface inflow-outflow factor (AQ). In addition, the annual subsurface flow into or out of each boundary node along the Los Angeles County-Orange County line was determined and included with the net amount of annual surface inflow-outflow at the corresponding node. The following procedure was used to determine the amounts of annual surface inflow-outflow and the historical water level at each polygon during the 11-year period from 1946-1947 through 1956-1957:

1. A basin-wide inventory was made of the annual amounts of each of the components of water supply, use, and disposal. Then the annual surplus or deficiency in water supply was determined for the entire basin by summing the contributions of all the components. The components of inflow were precipitation, import, stream percolation, artificial recharge, and subsurface inflow across the Los Angeles Narrows and Whittier Narrows. Components of outflow were consumptive use of applied water and precipitation, sewage, surface runoff originating in and flowing out of the area, and subsurface outflow across the Los Angeles-Orange county line.

2. Historical ground water level hydrographs for the period 1947 through 1957 were developed for each nodal polygon. The annual change in the amount of ground water in storage in each polygon was determined by multiplying the annual change in historical water level elevation (dh) with the storage factor (AS) associated with the corresponding nodal polygon. A basin-wide annual change in storage was estimated by summing the changes in storage of all the polygons.

3. The annual water supply surplus or deficiency and the total annual change in storage were compared and balanced by using the basic hydrologic equation. In general, this balance was achieved by making reasonable changes in the values of specific yield and in the amounts of some of the components of water supply, use, and disposal.

4. The total annual amounts of each of the items of water supply inflow or outflow were then distributed to subareas in the manner indicated as follows:

a. Records of measured annual precipitation of selected stations within the basin were obtained, and by the use of the Thiessen Method, polygons were constructed and the annual volume of rainfall within each polygon was determined;

b. The consumptive use of applied water and precipitation was distributed to subdivisions utilized in the land use surveys of the Coastal Plain in 1950 and 1955. These subdivisions were adopted for distribution of several other components of water supply and use;

c. Measured amounts of imports were distributed in the same ratio as the computed percentage of total water delivered to each land use survey subdivision;

d. Measured annual amounts of sewage were distributed in the same ratio as the computed percentage of the total water delivered to (minus the consumptive use of applied water from) the land use survey subdivisions;

e. The annual amounts of stream percolation were determined for each reach between existing stream gaging stations;

f. The records of annual amounts of water spread and injected in each artificial recharge project were utilized; and

g. Extractions for each square mile section were determined.

5. The annual amounts of inflow or outflow of each component were further distributed to or accumulated in each nodal polygon, by utilizing the data mentioned in step 4.

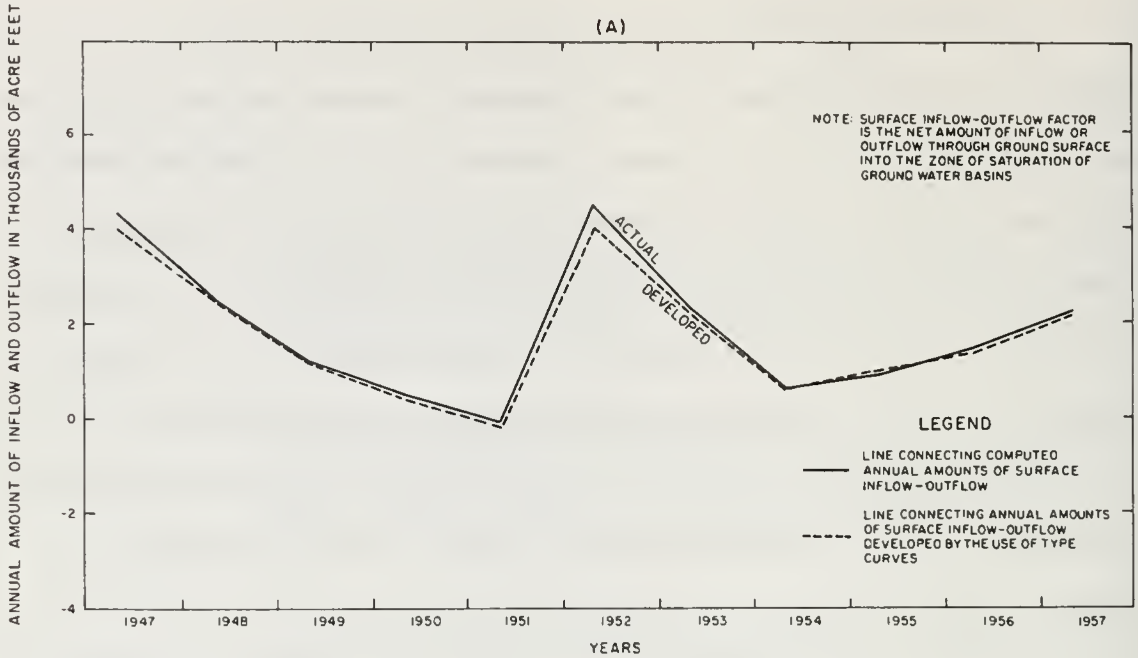
6. The annual net surface inflow-outflow was determined for each nodal polygon by taking an algebraic sum of all the inflow and the outflow. Graphs of the annual net surface inflow-outflow at each nodal polygon were prepared.

7. The surface inflow-outflow curves were compared and similar curves were grouped because of the limited number of function generators and amplifiers available to impose time-varying inflow-outflow functions upon the computer. Thus, type-curves were developed for each group of curves. Eighteen type-curves were utilized in this study to reproduce the surface inflow-outflow characteristics of 73 nodes in which water levels fluctuated. An example of the computed surface inflow-outflow factor for node 11, and that generated by the diode function generator through the use of a type-curve for the same node is presented on Figure 5-3A.

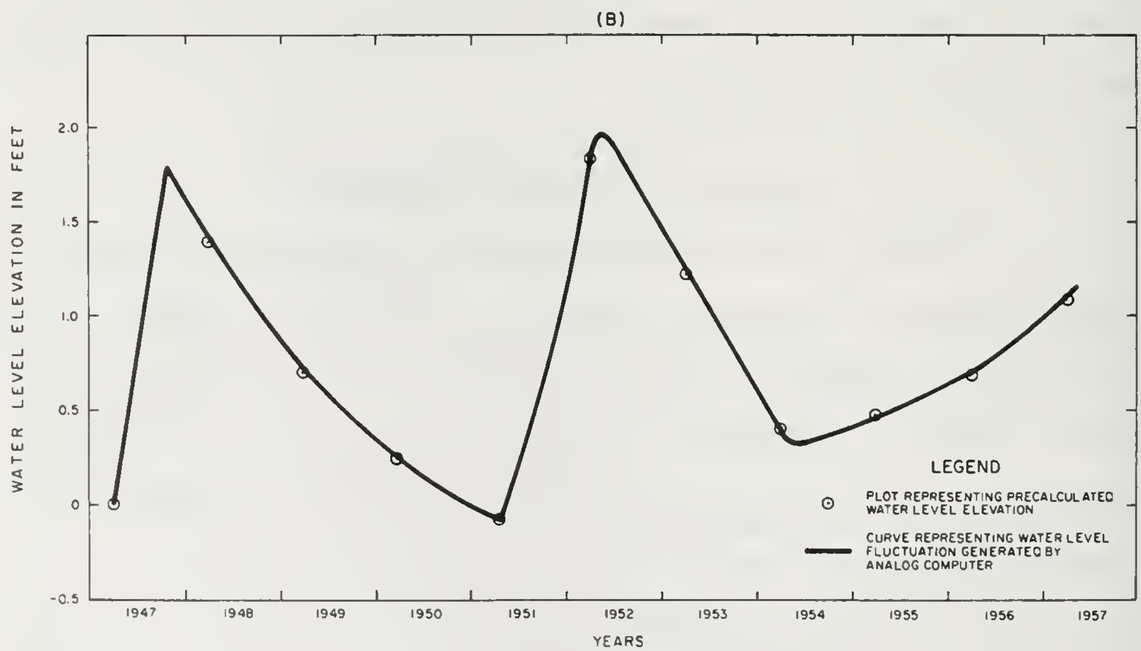
8. By using historical ground water hydrographs developed in step 2, maps showing the estimated lines of equal water level elevations at the beginning (1947) and the end (1957) of the study period were prepared. Also, these historical average water level elevations of the equivalent aquifer at the beginning and the end of the study period were tabulated for each nodal area.

Preparation of Dynamic Check Data

A dynamic check was incorporated in the general procedure to check the wiring of the analog circuitry representing the ground water basins of the Coastal Plain; the setting of the first best values of the surface inflow-outflow factors, storage factor, and transmissibility factors associated with each node in the computer; and the operation of computer components. For this dynamic check, water levels of all nodes were first set at zero elevation; then, a surface inflow-outflow function at a particular node of interest was imposed upon the analog computer



COMPUTED AND SIMULATED SURFACE INFLOW-OUTFLOW FACTORS FOR NODE 11



COMPUTED AND SIMULATED WATER LEVEL ELEVATION AT NODE 11 USED FOR DYNAMIC CHECK

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

through the diode function generator for a ten-year period. The water level of the node of interest was allowed to fluctuate while water level elevations at all remaining nodes were held at zero elevation. Water level responses generated by the computer at each node under this condition had to match a set of water level elevations that were independently precalculated for corresponding nodes.

The equation that was used by engineers of the Department of Water Resources to precalculate water level elevations at each node for this dynamic check follows:

$$h_t = h_o + R\left[(I_t - I_o) + \left(I_o - (I_t - I_o)\frac{RC}{t} - \frac{h_o}{R}\right)(1 - e^{-t/RC})\right] \quad (8)$$

where: h_o and h_t are water level elevations at the beginning and at the end of a time interval of one year;

I_o and I_t are a net surface inflow or outflow at the beginning and end of a time interval of one year;

$R = \frac{1}{\left(\frac{TW}{L}\right)}$ where $\frac{TW}{L}$ is a transmissibility factor;

C = AS, which is a storage factor;

t = a time interval in years (in this case, one year);

e = 2.718 (napierian base).

When the storage factor AS or C is zero, equation (8) is

$$h_t = RI_t \quad (9)$$

By using equations (8) and (9), water level elevation for each of the ten increments of time were precalculated for given values of TW/L, AS, I_o, and I_t. Note that these equations describe the annual water level elevations with the surface inflow-outflow factor varying according to a type-curve associated with a particular node.

As a part of the dynamic check, the water level elevations were also calculated for 1 year and for 10 years of operation, with the net surface inflow-outflow at the beginning of the period (I_o) held constant over the 10 years. In this check the diode function generators were not in operation. Equations (10) and (11), which follow, were used to precalculate the water level elevations that would occur under this condition at 1 year and 10 years, respectively, for each node:

$$h_t = RI_o\ (1 - e^{-t/RC}) \tag{10}$$

$$h_{10t} = RI_o\ (1 - e^{-10t/RC}) \tag{11}$$

Graphs of the precalculated water level elevations, plotted as a function of time, were used to dynamically check the curves generated by the analog computer. An example of the precalculated water level elevations of node 11, and a graph generated by the computer for the same node is presented on Figure 5-3B.

Wiring and Checking the Model on the Computer

The staff of the computation firm had the responsibility of preparing the circuit diagram (programming the problem), wiring the patch panel to connect the proper electronic components, and running on the analog computer a dynamic check of each node and a steady-state check of the entire analog circuitry. Some of the work by the computation firm was done concurrently with the preparation, by this Department, of the geologic and hydrologic data, and close coordination was maintained between the staffs of both agencies. An application engineer of the computation firm was informed of the geology and the hydrology of the Coastal Plain and of the reliability of the basic geologic data incorporated in the mathematical model, and of the historical hydrologic data that were used to verify the model.

The basic geologic, hydrologic, and dynamic check data required by the computer application engineer were provided in the following form:

1. A map showing the area under investigation and locations of geologic structures significantly affecting the storage and movement of ground water;

2. A reproducible map showing the location of the 82 control nodes and the area represented by each node;

3. A reproducible map showing the values of the transmissibility factor (TW/L) at the midpoint of each line connecting the nodes;

4. A tabulation of the values of the storage factor (AS) of each polygon;

5. A reproducible set of type-curves, and a tabulation of type-curve numbers, amounts of inflow or outflow at the start of the study period, and a type-curve ordinate multiplier for each control node point;

6. A reproducible set of historical water level elevation hydrographs of each node and a tabulation showing water level elevations at the beginning, middle, and end of the study period for each node; and

7. A copy of a dynamic check computation and a reproducible set of graphs for the dynamic check of the analog circuit.

Engineers and geologists from the Department of Water Resources aided the engineers of the computation firm in the dynamic check of the analog circuit by rechecking the precalculations whenever the need arose, by operating the X-Y plotter, and by helping to operate the analog computer. The main function of the Department's representatives was to ensure that the dynamic check was being effected to a sufficient degree of accuracy. As expected, the dynamic check was found to indicate all errors in programming, patch-board wiring, computer operation, and parameter scaling.

As a final check of the circuitry, flows of the entire network were balanced after the ground water system was brought to a steady-state condition. In this check, all boundary conditions were set in, and initial surface inflow-outflow values (I_o) were inserted. The computer was then allowed to run until the ground water system reached equilibrium. The change in the amount of ground water in storage became equal to zero when equilibrium was reached. Thus, under this condition the total amount of water entering the system was equal to the total amount of water leaving the system. Moreover, the algebraic sum of the subsurface flow at each node was equal to the value of the initial surface inflow-outflow of water at the corresponding node.

Verification of the Mathematical Model

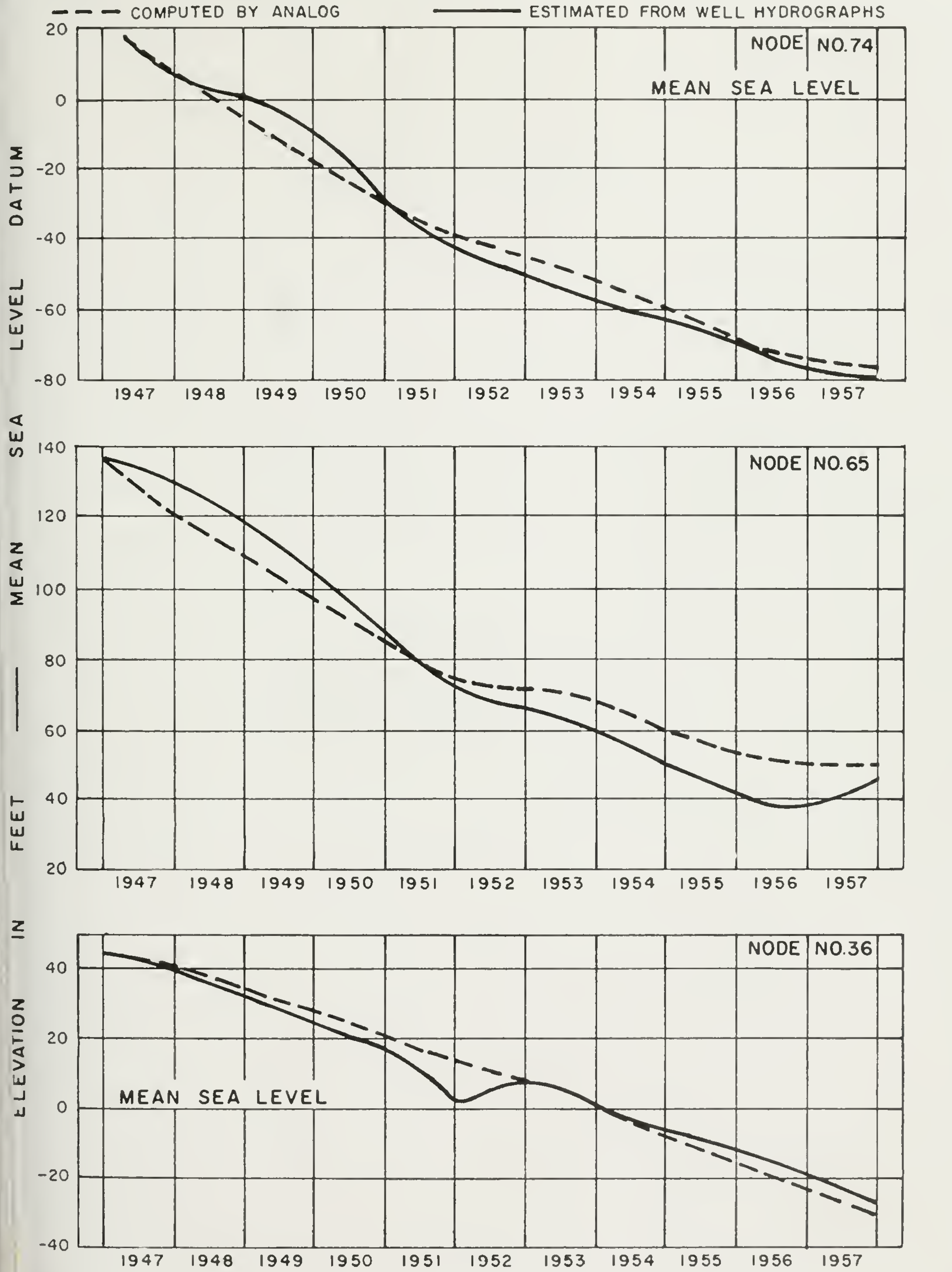
Following an adequate check of the analog computer circuitry, the mathematical model was verified to insure accuracy in the operational phase of the investigation. The test consisted of matching the water level elevations generated by the computer with the corresponding hydrographs of historical water level elevations for each node. When the best overall match commensurate with the available data and equipment was achieved, the mathematical model was accepted as representative of the ground water basins in the Coastal Plain.

In the verification, a complete set of water level elevations generated by the computer were plotted by X-Y plotters. The initial plots reflected the best values of the surface inflow-outflow factor, transmissibility factors, and storage factors that were estimated by the geologists and hydrologists and initially set into the computer. These plots were compared with the hydrographs of historical water level elevations of corresponding nodes. Visual inspection of these plots enabled rapid analysis by the engineers and geologists who were then able to convert the basic information for further use in the analog computer.

Although the initial water level responses from the analog computer matched historical water level elevation reasonably well in most areas, there were significant deviations in some areas. To get a closer match of the generated water levels with the historical hydrographs for each of 73 nodes, some of the values of storage factors, transmissibility factors, and surface inflow-outflow factors were systematically changed within reasonable limits by Department geologists and hydrologists.

Corrections for these factors were rapidly made on the analog computer by adjusting the proper potentiometers. After the new values were placed in the computer and double checked with a digital voltmeter, a new set of plots was obtained on the X-Y plotters. The computer generated a complete solution for a 10-year period in 7 seconds; it required about 15 minutes to prepare a complete set of 73 curves, using three plotters. Thus, the speed and the flexibility of the analog computer were useful in the verification phase because a number of adjustments in the various factors could be rapidly incorporated, the effects of these changes could be graphically plotted in an equally fast time. An example of the historical changes in ground water elevations for three nodes in the basin and of those generated by the analog computer for the same nodes is shown on Figure 5-4.

The information generated by the analog computer during the verification or tailoring phase was especially valuable to both the geologists and hydrologists. The resultant water level responses generated by the changes in the parameters gave the geologists and hydrologists a keener insight into the influences of the various parameters on the dynamic behavior of the water level in the ground water basin. For example, the extent of directional transmissibility became known to the personnel during the tailoring phase. For maximum development of this kind of information, the geologists and hydrologists maintained close coordination during the verification phase.



COMPARISON OF CHANGES IN GROUND WATER ELEVATIONS AT SELECTED NODES IN COASTAL PLAIN OF LOS ANGELES COUNTY

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

ATTACHMENT NO. 6

DEVELOPMENT AND SUPERPOSITIONING OF MASTER INFLUENCE FUNCTIONS

ATTACHMENT No. 6

DEVELOPMENT AND SUPERPOSITIONING OF MASTER INFLUENCE FUNCTIONS

Future water level elevations under varying amounts and locations of planned replenishment and extractions were needed for the operational-economic studies of the ground water basins in the Coastal Plain of Los Angeles County. The required water level data were obtained by utilizing a verified mathematical model, the development and verification of which are described in Attachment No. 5. Because the equation for the mathematical model was considered to be linear, water level elevations could be determined for any specific condition of future replenishment and/or extraction. This was done by superpositioning a set of master influence functions developed for this study.

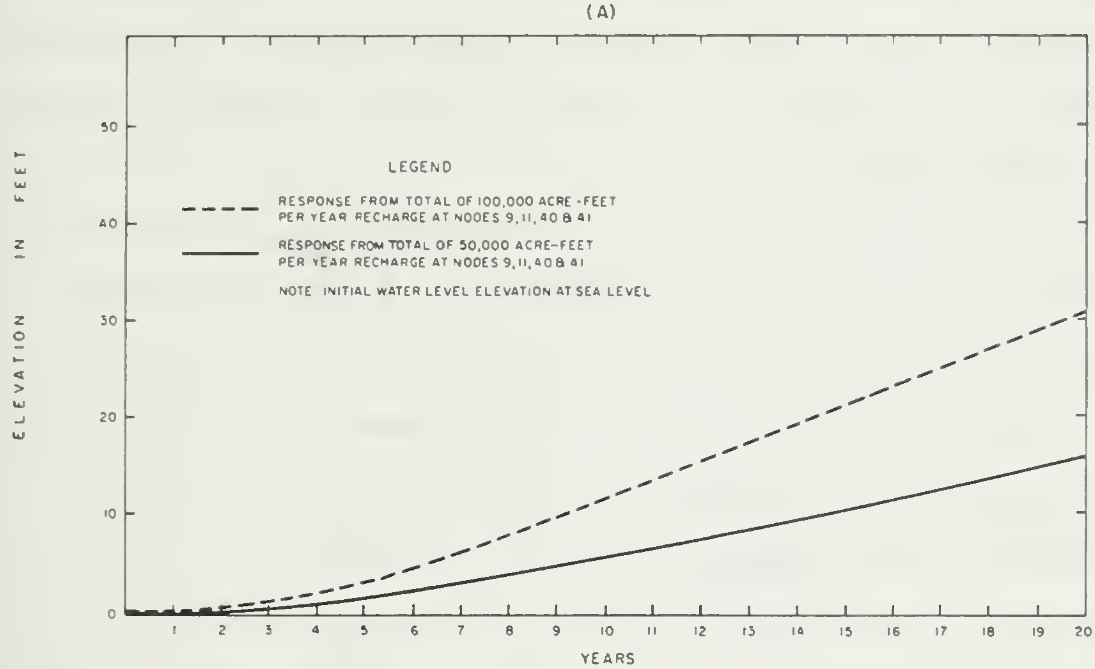
The discussions that follow describe: (1) the linearity of the mathematical model, (2) the master influence functions, (3) a digital computer program to solve the set of equations constituting the mathematical model, and (4) superpositioning techniques.

Linearity of the Mathematical Model

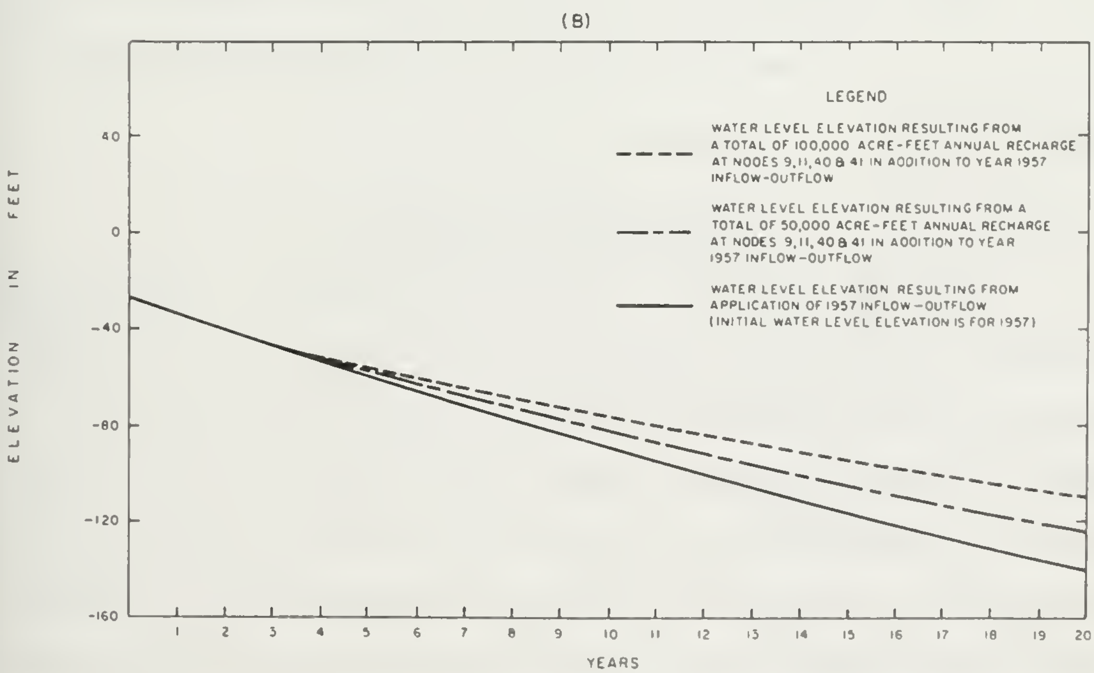
The basic equation used for developing and testing the mathematical model of the study area is linear by definition, because it was assumed that the storage coefficient and the transmissibility coefficient do not vary with changes in water level elevations. Because the system is linear, the dynamic responses (water level elevations with respect to time) in the system are multiplicable, additive, and relocatable with respect to time.

To check the model's linearity, a test was made of multiplicability of its responses. This test was made to establish if the water level response of 100,000 acre-feet per year of recharge at a group of nodes as obtained by the mathematical model was twice that of 50,000 acre-feet per year of recharge at the same group of nodes. For this test, the ground water elevations of the entire system were initially set at a common elevation, which was, in this case, sea level, or zero elevation. Then, unit flows of 100,000 and 50,000 acre-feet per year were separately imposed at nodes 9, 11, 40, and 41, located in the Montebello Forebay. Water level responses at each node under the imposed flows were determined by using a computer and then were compared. The computer response for 50,000 acre-feet of recharge was half that of the 100,000 acre-feet of recharge, thus demonstrating multiplicability. Figure 6-1A shows the responses for node 36, under unit flows of 50,000 and 100,000 acre-feet per year.

A second test was made to establish the additive nature of the water level responses from the model. Responses from the multiplicability test were added to a response from imposing continuous 1957 inflow-outflow on a model whose initial levels were set at 1957 water level elevations; the sum of these two responses was the same as that obtained by directly superimposing the unit flow rates as well as the identical hydrologic conditions on the model. In addition to the 1957 net inflow-outflow functions, the same unit flows were imposed at the same nodes as in the first test. All initial water level elevations were maintained at 1957



WATER LEVEL RESPONSE AT NODE 36 FROM APPLICATION OF 50,000 AND 100,000 ACRE-FEET PER YEAR RECHARGE AT MONTEBELLO FOREBAY



WATER LEVEL RESPONSE AT NODE 36 FROM APPLICATION OF 50,000 AND 100,000 ACRE-FEET PER YEAR AT MONTEBELLO FOREBAY IN ADDITION TO 1957 INFLOW-OUTFLOW levels. The computer was allowed to generate dynamic responses for each node in the system. Shown in Figure 6-1B are water level elevations at node 36 under the imposition of 1957 water level elevations and continuous 1957 inflow-outflow.

By adding the values for the responses from the initial test runs of 50,000 and 100,000 acre-feet per year recharge (with initial water level elevations at zero) to those obtained by an extension of the 1957 inflow-outflow functions (with initial water levels of 1957, shown in Figure 6-1B), new combined water level elevations were determined. The results of this additive process were identical to the results of the computer runs in which 50,000 and 100,000 acre-feet per year of recharge in the Montebello Forebay were superimposed on 1957 inflow-outflow and 1957 initial conditions, thus demonstrating the additive feature of the model.

The success of these two tests demonstrated the model's linearity. Thus, it is axiomatic that the responses are relocatable with respect to time.

Master Influence Functions

With the linearity of the model demonstrated, it was necessary to develop a set of master influenee functions that could be utilized in determining future water level elevations under any assumed plan of ground water basin operation. Master influence functions are defined as water level responses at each node due to 100,000 acre-feet per year surface inflow to, or outflow from, the zone of saturation at a particular node or group of nodes. A unit flow of 100,000 acre-feet distributed to selected nodes is called an action condition in this study.

A complete set of master influence functions for unit flows at all nodes would require a very large number of solutions. A compromise between a complete set of master influence functions and specific operational conditions was achieved by preparing a specific set of master influence functions, under future anticipated operating conditions. Even this compromise required a large number of solutions. The action conditions that were used in the operation-economic studies of the Los Angeles Coastal Plain are listed and briefly described in Table 6-1.

Because the responses from a linear model are additive, multiplicable, and relocatable with time, the technique of superpositioning master influence functions was used to determine future water level elevations under many assumed plans of operation. A very large number of simple computations were required to carry out the superpositioning. To reduce the workload of the engineer, a program to carry out this tedious procedure was developed for the IBM 1620 Data Processing System. This procedure will be discussed in a later section.

Digital Computer Program

In developing master influence functions, an IBM 7074 System was utilized. The digital computer was utilized because it enabled the engineers to obtain the functions as direct data input for the superpositioning technique carried out by an IBM 1620 digital computer. An additional reason for using a digital computer was that small batches of master influence functions, spaced a few months apart for review and study of results, could be developed at different times. This approach on an analog computer would have entailed a costly manual set-up and check-out procedure for each group of runs and would have resulted in a higher cost.

TABLE 6-1

ACTION CONDITIONS USED

All quantities imposed for 30 years

Condition number	Area of action	Node number and quantity, in acre-feet per year	Total amount, in acre-feet per year
1	Operational area 1	1 - - - 30,000	
		32 - - - 15,000	
		33 - - - 55,000	100,000
2	Operational area 2	2 - - - 90,000	
		3 - - - 10,000	100,000
3	Operational area 3	34 - - - 15,000	
		35 - - - 33,000	
		36 - - - 4,000	
		60 - - - 4,000	
		61 - - - 4,000	
		71 - - - 23,000	
		72 - - - 15,000	
		74 - - - 2,000	100,000
4	Operational area 4	7 - - - 12,000	
		8 - - - 2,000	
		9 - - - 2,000	
		37 - - - 14,000	
		38 - - - 9,000	
		39 - - - 10,000	
		40 - - - 1,000	
		61 - - - 4,000	
		62 - - - 18,000	
		63 - - - 6,000	
		64 - - - 4,000	
		72 - - - 5,000	
		75 - - - 13,000	100,000
5	Operational area 5	11 - - - 24,000	
		12 - - - 2,000	
		13 - - - 3,000	
		14 - - - 12,000	
		41 - - - 6,000	
		42 - - - 24,000	
		43 - - - 22,000	
		65 - - - 7,000	100,000

ACTION CONDITIONS USED
(continued)

All quantities imposed for 30 years

Condition number	Area of action	Node number and quantity, in acre-feet per year	Total amount, in acre-feet per year
6	Operational area 6	30 - - - 15,000	
		31 - - - 2,000	
		54 - - - 5,000	
		55 - - - 16,000	
		56 - - - 30,000	
		57 - - - 18,000	
		58 - - - 7,000	
		70 - - - 7,000	100,000
7	Operational area 7	49 - - - 29,000	
		50 - - - 5,000	
		69 - - - 9,000	
		73 - - - 40,000	
		74 - - - 17,000	100,000
8	Operational area 8	15 - - - 6,000	
		17 - - - 3,000	
		44 - - - 6,000	
		45 - - - 10,000	
		46 - - - 14,000	
		48 - - - 3,000	
		63 - - - 3,000	
		64 - - - 4,000	
		66 - - - 15,000	
		67 - - - 20,000	
		68 - - - 13,000	
		73 - - - 3,000	100,000
9	Operational area 9	22 - - - 22,000	
		23 - - - 20,000	
		24 - - - 7,000	
		25 - - - 8,000	
		26 - - - 6,000	
		28 - - - 3,000	
		29 - - - 2,000	
		50 - - - 1,000	
		51 - - - 2,000	
		52 - - - 9,000	
		53 - - - 14,000	
		54 - - - 6,000	100,000

ACTION CONDITIONS USED
(continued)

All quantities imposed for 30 years

Condition number	Area of action	Node number and quantity, in acre-feet per year	Total amount, in acre-feet per year
10	Operational area 10	17 - - - 9,000 18 - - - 10,000 19 - - - 10,000 20 - - - 17,000 21 - - - 7,000 46 - - - 6,000 47 - - - 24,000 48 - - - 16,000 68 - - - 1,000	100,000
22	Montebello Forebay	11 - - - 2,000 40 - - - 33,000 41 - - - 16,000 42 - - - 16,000 65 - - - 33,000	100,000
23	San Gabriel River	11 - - - 28,000 42 - - - 23,000 43 - - - 41,000 44 - - - 8,000	100,000
25	Dominguez Gap Barrier	23 - - - 41,000 24 - - - 8,000 25 - - - 51,000	100,000
30	Entire Coastal Plain	Average deep percolation of applied water to the zone of saturation under mean rainfall conditions was distributed to each of the polygonal areas in proportion to their irrigated areas (see Attachment No. 3)	100,000
37	Entire Coastal Plain	Average deep percolation of precipitation to the zone of saturation under mean rainfall conditions was distributed to each of the polygonal areas in proportion to their pervious areas (see Attachment No. 3)	29,000

ACTION CONDITIONS USED
(continued)

All quantities imposed for 30 years

Condition number	Area of action	Node number and quantity, in acre-feet per year	Total amount, in acre-feet per year
38 (Base condition)*	Boundary nodes	14 - - - 5,500	
		17 - - - 9,600	
		18 - - - 10,700	
		19 - - - 3,200	29,000

*For the development of this function, initial water level elevations, representative of the water level of 1960 and compatible with the mathematical model, were imposed. The water level elevations of several nodes along the coast were held at zero and the elevation of a node at Whittier Narrows was held at 190 feet. Cumulative effects of all other functions were superimposed on this function to determine future water level elevations.

A program was developed in FORTRAN (FORmula TRANslation) language for the IBM 7074 System to solve the principal ground water equation described in Attachment No. 5 by use of a numerical integration technique. The principal ground water equation,

$$\Sigma_i \left[(h_i - h_B) \frac{T_{i,B} W_{i,B}}{L_{i,B}} \right] + A_B Q_B = A_B S_B \frac{dh_B}{dt},$$

is replaced by:

$$\Sigma_i \left[(h_i^{j+1} - h_B^{j+1}) \right] Y_{i,B} + A_B Q_B{}^{j+1} = A_B S_B (h_B^{j+1} - h_B^j)$$

$$Y_{i,B} = \frac{W_{i,B} T_{i,B}}{L_{i,B}}$$

where: $Y_{i,B}$ is the transmissibility factor between nodes i and B, and the superscript j denotes points along the time coordinate.

A portion of the FORTRAN program which was used is shown on Figure 6-2, and a simplified flow chart of the entire program is shown on Figure 6-3.

Referring to the flow chart of the program on Figure 6-3, note that all node-to-node subsurface flows are calculated first. Then, all the storage flow rates are calculated. All the flows are then balanced at each node by setting their sums equal to a residual (RES) term. The water level elevation at the node is then adjusted by the magnitude of the residual, modified by a relaxation coefficient. When all the water level elevations are adjusted, a sum is formed of the nodal residuals. This sum is compared with an error value (E). The error value is a maximum acceptable sum of nodal flow residuals at any time step. If the sum of the residuals is less than or equal to the error value, the calculation of water level elevations is complete for that time step. Otherwise, the calculation is repeated as many times as is required to reduce the sum of residuals to a value less than or equal to the error value. The error value must be properly chosen because the amount of computer time spent on each time step depends on it. In the Los Angeles Coastal Plain the error value was set at 200 acre-feet per year.

The IBM 7074 computer is a fully transistorized computer with a magnetic core storage capacity of 10,000 words. The high speed processor of the computer executes 100,000 10-digit additions per second. The program and data are first placed on magnetic tapes. Through the use of magnetic tape units, the program and data are introduced into the computer core storage unit. The program statements are executed by the high speed processor, sequentially drawing the required instructions and data

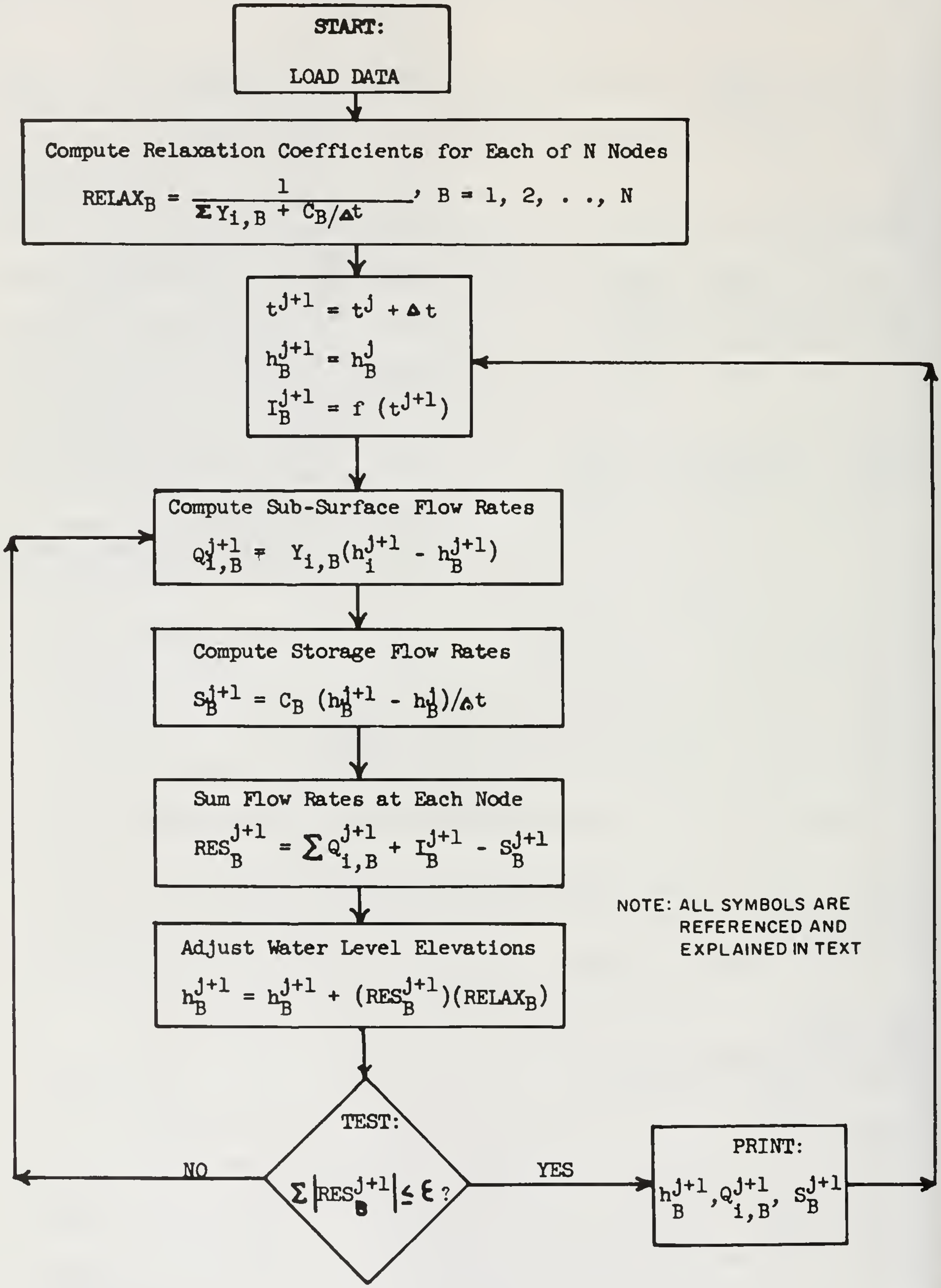
```
      T = 0.0

      DO 80 M=1, MAJOR
      DO 70 J=1, MINOR

      T = T + DELTA

      DO 40 K=1,N
40    HO(K) = H(K)

41    Q(2) = Y(2)*(H(81) - H(1))
      Q(3) = Y(3)*(H(1) - H(2))
      Q(4) = Y(4)*(H(2) - H(3))
      Q(5) = Y(5)*(H(1) - H(32))
      .
      .
      .
      Q(79) = Y(79)*(H(63) - H(64))
      Q(80) = Y(80)*(H(39) - H(64))
      Q(81) = Y(81)*(H(64) - H(65))
      .
      .
      .
      Q(187) = Y(187)*(H(69) - H(50))

      DO 50 K=1,N
50    S(K) = AS(K)*(H(K) - HO(K))/DELTA

      RES(1) = Q(2) - Q(3) - Q(6) - Q(5) - S(1) + AQ(1)
      RES(2) = Q(3) + Q(7) - Q(8) - Q(4) - S(2) + AQ(2)
      .
      .
      RES(64) = Q(79) = Q(80) - Q(81) - Q(82) - Q(89) - S(64) + AQ(64)
      .
      .
      RES(75) = Q(55) = Q(39) - Q(40) - Q(53) - S(75) + AQ(75)

      DO 100 K=1,N
100   H(K) = H(K) + RELAX(K)*RES(K)

      SUM = 0.0
      DO 60 K=1,N
60    SUM = SUM + ABSF(RES(K))
      IF(SUM - ERROR) 70, 70, 41

70    CONTINUE

      PRINT, T
      DO 80 K=1,N
80    PRINT, K, H(K)

      PAUSE
```

Definitions:

DELTA = Time Step (t), Years
ERROR = Max. Acceptable Sum of Nodal Flow Residuals at Any Time Step, Acre-Ft./Yr.
AQ(K) = Source Flow Rate at Node (K) at Time (j+1) t, Acre-Ft./Yr.
AS(K) = Capacitance at Node (K), Acres
H(K) = Water Level Elevation at Node (K) at Time j(t), Ft.
HO(K) = Water Level Elevation at Node (K) at Time j(t), Ft.
S(K) = Storage Flow Rate at Node (K) at Time (j+1) t, Acre-Ft./Yr.
Q(80) = Subsurface Flow Rate Along Node-to-node Branch (80) at Time (j+1) t, Acre-Ft./Yr.
Y(80) = Conductance of Node-to-node Branch (80), Acre-Ft./Yr.-Ft.
T = (j+1) t, Years
RELAX(K) = Relaxation Coefficient at Node (K), Yr.-Ft./Acre-Ft.
RES(K) = Nodal Flow Residual, Acre-Ft. /Yr.

SIMPLIFIED FORTRAN PROGRAM FOR DIGITAL COMPUTER SOLUTION OF A SET OF PRINCIPAL GROUND WATER EQUATIONS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966



SIMPLIFIED FLOW CHART FOR DIGITAL COMPUTER SOLUTION OF A SET OF PRINCIPAL GROUND WATER EQUATIONS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

from storage as programmed. Modification to the program or data can be made through a typewriter on the console control unit. The required results are read out on magnetic tapes. Through the use of peripheral equipment, water level elevations are punched on cards for direct use on an IBM 1620 System. The same peripheral equipment also tabulates the output information for the engineer's use.

In addition to water level elevations, the following information is printed: subsurface flows between nodes and residual flows at a selected time; all input data including the initial values of parameters; and a set of statements, identifying symbols, and the computer program.

The program illustrated on Figure 6-2 is utilized to develop not only master influence functions, but also water level elevations unique to specific plans of operation. The latter data are obtained by introducing a schedule of surface inflow-outflow at each node.

Once the master influence functions for all required action conditions have been developed on the IBM 7074 System, these influence functions can be utilized through superpositioning techniques to predict water level elevations under any assumed plan of operation.

Superpositioning Techniques

Superpositioning is a method of utilizing master influence functions to predict water level changes which result from such functions. To apply this technique to the various plans of operation, a schedule of extraction and/or recharge, in acre-feet per year, was selected for each operational area. Each schedule was matched to its respective action condition, that is, the set of master influence functions associated with the particular operational area involved. Master influence functions were multiplied with weighting factors to adjust the functions to represent the effect of the selected amounts of extraction or replenishment. In this process, the modified functions were arranged so that the beginning and ending periods of all operational actions were properly accounted for.

A superpositioning program was written for the IBM 1620 digital computer, using the IBM punch card system as the input-output medium. Floating point arithmetic and subroutine functions were discarded, to increase program speed and allow program packing. This superpositioning program determined average ground water levels at each node. These levels were then converted to nodal pumping lift requirements in a subsequent computer study.

A simplified flow diagram of the IBM 1620 superpositioning program which is discussed below is shown on Figure 6-4.

Because all master influence functions were computed on the basis of a constant flow of 100,000 acre-feet per year at a group of nodes, a weighting factor is applied to each function to determine the amount of influence effected by each selected flow schedule. The equation used to find the first weighting factor is:

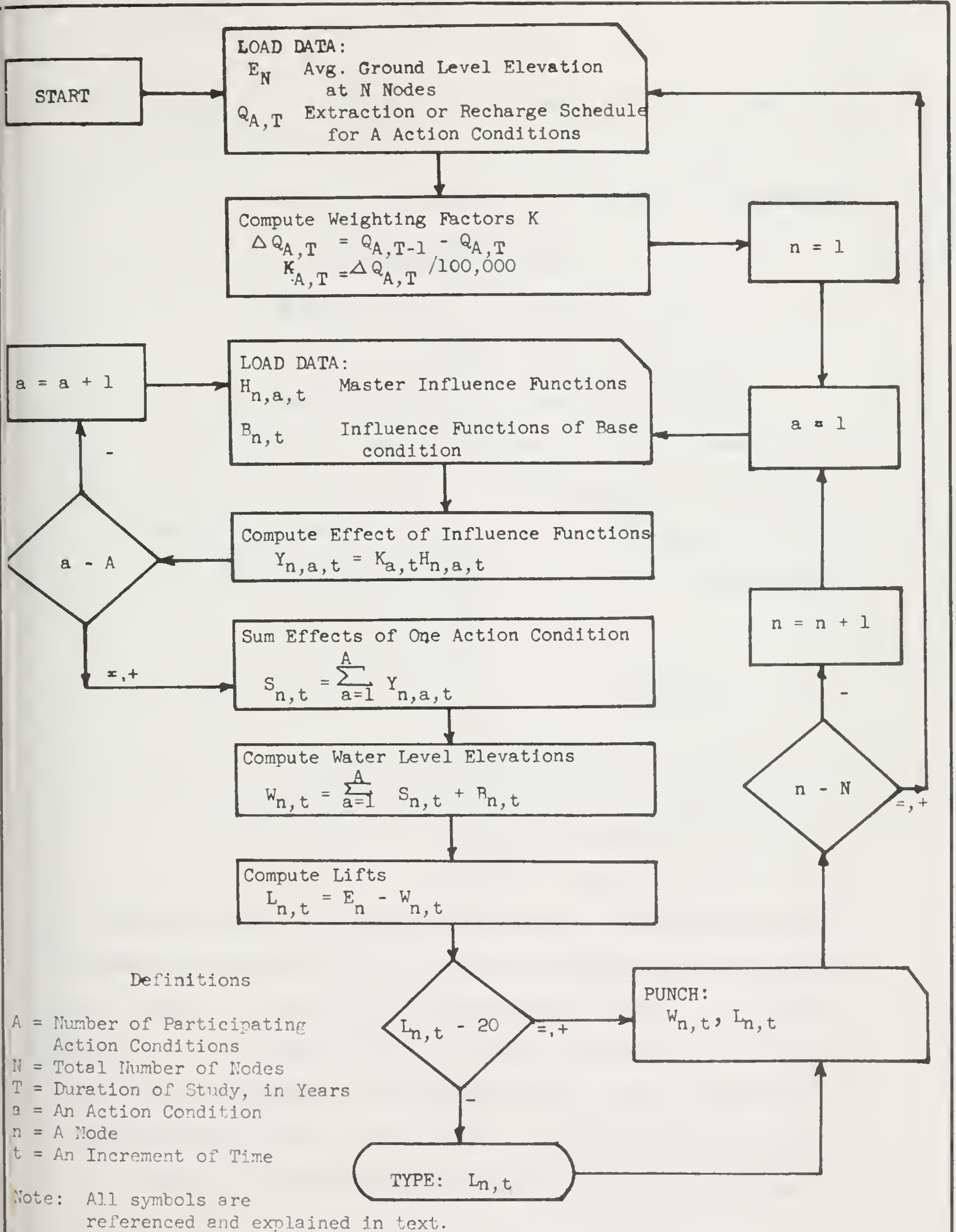
$$K_{a,t} = \frac{Q_{a,t}}{100,000}$$

where: K = weighting factor

Q = first proposed flow in each action condition,

a = action condition's identification number,

t = the first increment of time.



PHASE A

SIMPLIFIED FLOW CHART FOR DIGITAL COMPUTER PROCESSING OF THE SUPERPOSITIONING OF MASTER INFLUENCE FUNCTIONS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

The influence trend initiated by the first proposed flow is reinitiated at all subsequent flow changes; consequently, all subsequent weighting factors are determined by the change in flow using the following equation:

$$K_{A,T} = \frac{(Q_{A,T-1} - Q_{A,T})}{100,000}$$

where: A = number of participating action conditions,

T = duration of study, in years.

Figure 6-5 indicates the water level changes at a node due to the influence of one action condition. Line Y is the influence line determined by multiplying the first weighting factor of the first action condition with a master influence function at each time interval, as given in general terms in the following equation:

$$Y_{n,a,t} = K_{a,t}H_{n,a,t}$$

where: Y = influence imposed on a node by the proposed flow schedule,

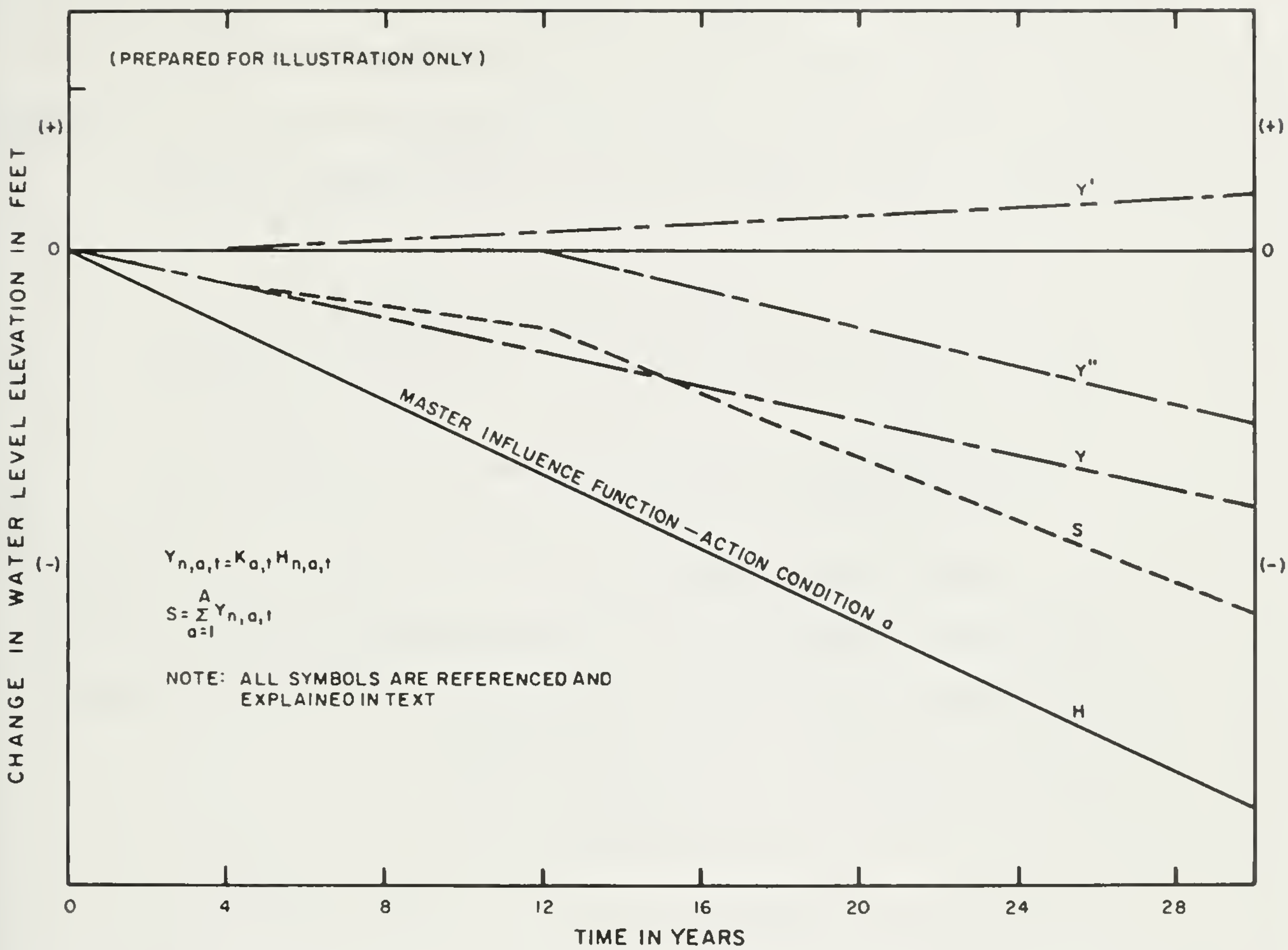
H = master influence function,

a = action condition identification number,

n = node number,

t = time increment, in years.

Each weighting factor, in turn, is multiplied by a schedule of master influence functions beginning again with the first factor. All additional influences are assumed to take effect from the time of each flow change or when $K \neq 0$. Referring to Figure 6-5, lines Y' and Y" are the influences attributable to changes in amounts of planned recharge or in extraction in years 4 and 12, respectively; the algebraic sum of these positioned influences (Y + Y' + Y") is the total effect of an action condition on



A GRAPHIC EXAMPLE OF SUPERPOSITIONING OF MASTER INFLUENCE FUNCTIONS TO DETERMINE FUTURE WATER LEVEL ELEVATIONS OF AN OPERATIONAL PLAN

FIGURE 6-5

the node being considered. This algebraic summation is given in the following equation:

$$S_{n,t} = \sum_{a=1}^{A} Y_{n,a,t}$$

where: S = total influence of an action condition on a node.

The influences of all action conditions on the node under consideration are computed by incrementing the action condition subscript and repeating the above steps. When the effects of all action conditions on the node are found, the values of S's are summed algebraically and added to a given base action condition yielding the water level elevation at the node. This summation is given by the following equation:

$$W_{n,t} = \sum_{a=1}^{A} S_{n,t} + B_{n,t}$$

where: W = water level elevation due to the proposed operation plan,

B = water level elevation referred to as a base action condition.

The technique discussed in this attachment is equally applicable to the study of either individual nodes or operational areas, which are groups of nodes. The application can be effected with little change in the computer program.

ATTACHMENT NO. 7

COST OF FACILITIES
AND IMPORTED WATER

ATTACHMENT No. 7

UNIT COST OF FACILITIES AND IMPORTED WATER

In the investigation of planned utilization of the ground water basins in the Coastal Plain of Los Angeles County, a comparative economic evaluation was made of many alternative plans of coordinated operation of surface and ground water supplies and facilities. This evaluation was made by comparing the total cost of operation for each alternative plan. Information on costs of water service items which will prevail in the area during the study period was necessary for determination of total cost.

Cost information was developed for water supply facilities, electrical energy, and imported water supplies. The facilities considered were storage tanks, pumping plants, booster plants, connectors to Metropolitan Water District's distribution system, laterals and artificial recharge projects. An electrical energy consumption charge as well as a service charge was considered. The following water supplies were considered: water imported by the City of Los Angeles Department of Water and Power from the Owens River and San Fernando Valley; water imported by the City of Whittier and other agencies from San Gabriel Valley; and water imported by The Metropolitan Water District of Southern California from the Colorado River and, in later years, from the State Water Project.

Costs of facilities were developed in two ways. For facilities requiring identical design and components, the costs were developed for unit-sized facilities, representative of the facilities in the study area. Those facilities were storage tanks, pumping plants, booster plants, and connectors to the primary distribution system. Annual cost and cost curves, related to design capacity, were developed for facilities requiring individual design, different components, or different sizes for different locations. These facilities were the additional freshwater barriers, neither existing nor proposed by the Los Angeles County Flood Control District, which would be required for certain plans of operation.

For electrical energy, equations were developed to relate amounts of annual energy consumption with annual costs for a unit-sized pump, or booster that was typical of the sizes used in the study area. In addition, a unit annual service connection cost was determined for these facilities.

For the cost of imported water, a unit cost per acre-foot was developed for waters from different sources. For water imported by the Metropolitan Water District, pricing schedules were determined under three different assumed conditions.

The procedure for the studies and the cost data developed are presented in detail in three sections: cost of facilities, cost of electrical energy, and cost of imported water.

Cost of Facilities

The unit annual costs of facilities were estimated for elevated storage tanks, pumping plants, booster plants, and connectors to the Metropolitan Water District's distribution system. Unit costs of pipes were determined so as to estimate the costs of laterals connected to the primary distribution system and the costs of proposed and assumed freshwater barrier projects. Annual costs were determined for existing, proposed, and assumed recharge facilities at the West Coast Basin, Alamitos, Dominguez Gap Barrier Projects, and also for additional recharge facilities. In addition, graphs were developed relating capacity and cost of the assumed recharge facilities. Unit annual costs of facilities were determined by first obtaining the average unit capacity of each facility, then determining capital costs of fabrication and installation from costs surveys of various manufacturers and local water supply agencies. Capital costs were converted to annual costs by application of uniform capital recovery factors with 4-1/2 percent interest rate and an average life for each facility that had been based on interviews with various water supply agencies. The unit annual costs of surface and ground water facilities were estimated for each of the 10 economic areas in the Coastal Plain. All the costs were adjusted to 1963 cost level by using the March 1963 Engineering News-Record Construction Cost Index for the City of Los Angeles.

Storage Tanks

Reservoirs and surface storage tanks are presently constructed in areas of high elevation. The advantage of the natural heights and the resulting head contribute to economies in supplying water to communities in the Coastal Plain. The future increase in water demand of the Coastal Plain, expected to take place mainly in the lower areas, will continue to require elevated storage tanks or equivalent storage systems to supply water at the desired heads. Cost data developed for elevated surface storage tanks are considered to be representative of both existing and assumed future facilities.

Capacity and cost data on storage facilities were obtained from basic data furnished by 20 water agencies serving the Coastal Plain. Some of the city water departments which contributed data were: Los Angeles, Beverly Hills, Santa Monica, Inglewood, and Long Beach. The private water companies which furnished data include the Southern California Water Company, California Water Service Company, Park Water Company, and Dominguez Water Corporation. The future unit annual cost for elevated storage tanks was based on 500,000-gallon-capacity tanks, the most commonly used tank size in the study area. The total annual cost included costs for engineering erection, piping, normal accessories, foundation and excavation, right-of-way, maintenance, and contingencies. The tank cost also reflected the added cost of construction required to withstand seismic forces in this area. The capital cost data for elevated storage tanks were obtained from a tank manufacturer in the area.

The right-of-way requirements for an elevated storage tank were based on a survey of several water agencies such as the City of Los Angeles Department of Water and Power, City of Inglewood Water Department, City of Long Beach Water Department, and Park Water Company. The average lot size used by these agencies was approximately 55 by 115 feet. The cost of the lot for a storage tank in each economic area was based on the assessed land value for representative incorporated cities. Estimated market values for a typical lot were derived for operational areas 1, 4, 5, 6, 7, 8, 9, and 10. For operational areas 2 and 3, $15,000 per lot was assumed reasonable because of dense urban development.

To determine the annual cost, a tank life of 100 years was assumed. The unit annual costs for elevated storage tanks for each economic area are given in Table 7-1.

TABLE 7-1

ANNUAL AND CAPITAL COSTS FOR
500,000-GALLON ELEVATED STORAGE TANKS

Economic area	Elevated tank costs including accessories	Foundation and excavation	Right-of-way cost	Total capital cost	Annual cost
1	$115,000	$1,000	$12,400	$128,400	$5,800
2	115,000	1,000	15,000	131,000	6,000
3	115,000	1,000	15,000	131,000	6,000
4	115,000	1,000	8,900	124,900	5,700
5	115,000	1,000	4,600	120,600	5,500
6	115,000	1,000	8,800	124,800	5,700
7	115,000	1,000	6,300	122,300	5,600
8	115,000	1,000	5,300	121,300	5,500
9	115,000	1,000	5,600	121,600	5,500
10	115,000	1,000	7,900	123,900	5,600

Pumping Plants

Unit costs for a pumping plant included the following items: well and casing, well development, motor, pump, meter, valves, housing, electrical wiring, right-of-way, and annual operation and maintenance. In estimating the cost of the pumping plant, the average depth and diameter of the wells in each economic area were determined based on 1962 well data. Costs of items considered in determining the average pump cost for a 100-horsepower motor, which was found to be the most common unit, are given below:

Item		Cost
Motor and pump	$ 25.50	per foot depth of pump bowl
Well and casing	1.00	per inch diameter, plus $1.00 per foot depth of well
Meters and controls	1,450.00	per well
Valves	645.00	per well
Housing	500.00	per well
Electrical wiring	880.00	per well
Development of well	2,000.00	per well

The above cost data were obtained from manufacturers, well drillers, and electrical contractors acquainted with this study area. The right-of-way costs are the same as those used in determining the unit annual cost of elevated storage tanks. The annual operation and maintenance cost was approximately $100. The life of the pumping plant was assumed to be 20 years. The annual pumping plant costs are shown in Table 7-2.

Booster Plants

To determine the unit cost of booster plants, a 100-horsepower motor (the average size for 1962 pumps in the area) was assumed. The cost of a booster plant was $4,700 which included the cost of booster installation, pump motor, and appurtenances. Cost data on the booster installation were obtained from a pump manufacturer. Annual cost of the booster plant was $360, assuming a 20-year life. Annual operation and maintenance cost was approximately $100. The total annual cost of the booster plant was $460. The right-of-way cost was not included in annual operation and maintenance cost, because the booster plant was assumed to be located on the same right-of-way as the pumping plant.

TABLE 7-2

TOTAL ANNUAL COSTS OF 100-HP MOTOR PUMPING PLANTS IN EACH ECONOMIC AREA

Economic area	Average pump cost	Right-of-way cost	Annual operation and maintenance cost	Annual pump cost	Annual right-of-way cost[a]	Total annual pumping plant cost[b]
1	$14,570	$12,400	$100	$1,120	$560	$1,780
2	19,380	15,000	100	1,490	680	2,270
3	21,370	15,000	100	1,640	680	2,420
4	17,900	8,900	100	1,370	400	1,870
5	11,180	4,600	100	850	210	1,160
6	13,140	8,800	100	1,010	400	1,510
7	14,950	6,300	100	1,150	290	1,540
8	14,030	5,300	100	1,070	240	1,410
9	13,890	5,600	100	1,060	260	1,420
10	15,550	7,900	100	1,190	360	1,650

a. An infinite life and 4-1/2 percent interest were assumed for annual right-of-way costs.

b. The differences in annual costs of pumping plants in various economic areas arise from differences in cost of right-of-way and average depths and diameters of wells within each area.

Connectors

The cost of connectors to the Metropolitan Water District's distribution system included the cost of excavation, backfill, concrete, reinforcing steel, resurfacing, side outlet, meter, valves, pipe, and other accessories. It was assumed, in determining the cost of connectors, that they would be installed within the District's existing right-of-way. The cost data for connectors were obtained from the Metropolitan Water

District and various private companies. The capital cost, shown below, for a 10-cfs connector, which was found to be an approximate average capacity, was assumed to represent the future cost in this study.

Item	Cost
Excavation	$ 2,200
Backfill	200
Concrete	5,300
Reinforcing steel	200
Resurfacing	200
Side outlet	1,000
Venturi tube and meter instruments	4,800
Valves	4,700
Pipe and fittings	3,500
Electrical connection	500
Miscellaneous items	2,000
Installation	4,800
Contingencies	3,400
Administration and indirect charges	5,600
TOTAL COST	$38,400

In determining the annual cost of the connector, a 100-year life for all items was assumed except for resurfacing, meters, and electrical connections. These items were assigned lives of 20, 30, and 20 years, respectively. The average annual unit cost of a 10-cfs connector was determined to be $1,850.

The annual unit costs of elevated storage tank, booster plant, pumping plant, and connector for each economic study area are shown in Table 10 in Chapter II.

Pipelines

The costs of additional laterals connected to the Metropolitan Water District's distribution system were determined by a cost-diameter relationship: $1.90 per linear foot per inch of diameter. This relationship was based on data for actual construction costs of pipelines in residential areas by the City of Los Angeles Department of Water and Power. The pipe cost included costs for all appurtenances and regulator stations.

Unit pipeline costs for sea-water intrusion barrier projects were developed by the Department of Water Resources. These costs were used to determine the pipe costs of the assumed Dominguez Gap barrier facilities. The pipe costs were for pipe-in-place. Table 7-3 shows costs for pipe of various diameters, assuming a maximum head of 300 feet.

Artificial Recharge Facilities

Artificial recharge facilities consist of the Montebello Forebay spreading grounds and existing or potential freshwater barrier projects in the West Coast Basin, Dominguez Gap, Los Alamitos Gap, and Santa Monica Basin.

TABLE 7-3

UNIT PIPELINE COST USED IN ESTIMATING
THE COST OF FRESHWATER BARRIER PROJECTS

Diameter of pipe, in inches	Cost per linear foot
8	$ 7.17
10	8.44
12	9.41
14	11.08
16	13.38
18	14.31
21	15.70
24	19.70
27	21.44
30	24.80
33	26.65
36	30.65

Additional freshwater barrier projects that were deemed necessary for some of the alternative plans of operation but have not been constructed or proposed by the Los Angeles County Flood Control District were also determined. The procedures for determining the costs of these additional facilities are discussed in detail in Attachment No. 8.

Montebello Forebay. The operation and maintenance cost of the existing spreading grounds was estimated at $1.25 per acre-foot of recharge water. This estimate was presented in a report by the Los Angeles County Flood Control District, "Report on Required Facilities for Replenishing and Protecting Ground Water Reserves in the Central and West Coast Ground Water Basins", Part I, Montebello Forebay Recharge Project, West Coast Basin Barrier Project, February 1961.

West Coast Basin Barrier Project. The annual cost of the West Coast Basin Barrier Project was based on a preliminary cost estimate presented in the above-named report. Estimated capital costs of the facilities required for the existing and proposed project are shown in Table 7-4.

The annual cost of the barrier project facilities was determined by using a 20-year life for observation and recharge wells and a 100-year life for supply and recharge lines. The annual unit cost for 1963-64 is $253,000 and $307,000 for 1964-65 and thereafter. The increase reflects the expansion of the project in the latter year. The Los Angeles County Flood Control District estimated that the ultimate design capacity of the project is 50,000 acre-feet per year, based on the present method of operating the ground water basins. The annual operation and maintenance

TABLE 7-4

WEST COAST BASIN BARRIER PROJECT
COST ESTIMATES AND CONSTRUCTION SCHEDULE

Completion, fiscal year	Item	Estimated cost	Cumulative total
1960-61	Observation wells - Beryl Street to Torrance Boulevard	$ 40,000	
	Recharge well 7B, connecting pipeline and observation wells	58,200	
	Joint pipeline from Aviation Boulevard to pressure regulating station, including meter	330,000	
	Preparation of plans for pressure regulation station supply line to center and south sections, recharge line from Agate Street to Torrance Boulevard, and south section chlorination facilities	95,000	
	TOTALS	$ 523,200	$ 523,200
1961-62	Pressure regulation station for supply line to center and south sections. South supply line including recharge line from Agate Street to Torrance Boulevard. Chlorination facilities, office, and yard for south section, including right-of-way	$1,490,800	
	Observation wells - one-half of the internodal wells for north section and north extension of center section	22,700	
	Single recharge and shallow observation wells to complete south section from Agate Street to Torrance Boulevard (no off-line wells)	$ 387,400	
	TOTALS	$1,900,900	$2,424,100

WEST COAST BASIN BARRIER PROJECT
COST ESTIMATES AND CONSTRUCTION SCHEDULE
(continued)

Completion, fiscal year	Item	Estimated cost	Cumulative total
1962-63	Joint supply line to north recharge line	$ 186,900	
	North supply line, chlorination facilities including right-of-way, meter, and north recharge line including north extension of center section and pressure regulation for north section	448,800	
	Recharge and observation wells to complete north section and north extension of center section	376,100	
	Recharge line south extension of center section and south section from Agate Street to north end	92,700	
	TOTALS	$1,104,500	$3,528,600
1963-64	Observation wells to complete south extension of center section and south section to Torrance Boulevard	$ 414,000	
	Recharge wells to complete south extension of center section and south section to Torrance Boulevard	419,900	
	TOTALS	$ 833,900	$4,362,500
1964-65	Recharge line south section Torrance Boulevard to south end	$ 257,000	
	Recharge wells to complete south section	550,100	
	TOTALS	$ 807,100	$5,169,600

cost for this design capacity is $287,500. The unit cost of operation and maintenance was $5.75 per acre-foot, obtained by dividing the annual operation and maintenance cost by the ultimate capacity of the project. It was assumed that operation and maintenance cost for the Alamitos, Dominguez Gap, and Santa Monica Basin Barrier Projects would also be $5.75 per acre-foot.

Alamitos Barrier Project. A preliminary cost estimate for the Alamitos Barrier Project was made in a report by the Los Angeles County Flood Control District, "Report on Required Facilities for Replenishing and Protecting Ground Water Reserves in the Central and West Coast Ground Water Basins", Part II, Alamitos Barrier Project, January 1962. The estimated capital costs of the proposed facilities in Los Angeles County, shown in Table 7-5, are those presented in that report.

The barrier project's total annual cost was determined by using a 20-year life for wells, pump installation, and office and chlorination facilities and 100-year life for pipelines, well appurtenances, geologic investigation, planning, and construction contingencies. As mentioned previously, the assumed unit cost of operation and maintenance was $5.75 per acre-foot. The annual energy cost for each pumping well was estimated by the Los Angeles County Flood Control District to be $1,500 per year. The total annual energy cost for 16 pumping wells was estimated to be $24,000. The annual costs for the capital facilities from 1961 through 1990 are given below. The annual cost from 1964 through 1990 included the annual energy charge for the pumping wells.

Year	Annual Cost
1961-62	$ 2,300
1962-63	39,500
1963-64	101,600
1964-90	125,600

The Los Angeles County Flood Control District estimated that the ultimate design capacity of the project, which is located in Los Angeles and Orange Counties, would be 20,000 acre-feet per year, based on the present method of operating the ground water basin.

TABLE 7-5

ALAMITOS BARRIER PROJECT
COST ESTIMATES AND CONSTRUCTION SCHEDULE FOR
BARRIER FACILITIES IN LOS ANGELES COUNTY

Fiscal year	Item	Annual cost	Cumulative cost
1961-62	Prepare plans for supply pipeline	$ 37,000	
	Prepare plans for office and chlorination facility	8,000	
	TOTALS	$ 45,000	$ 45,000
1962-63	Acquire right-of-way	$ 20,000	
	Construct supply pipeline	594,000	
	Construct office and chlorination facility	60,000	
	Prepare plans for distribution pipeline	16,000	
	Prepare plans for recharge wells	26,000	
	Prepare plans for pumping wells	9,000	
	Prepare plans for observation wells	15,000	
	TOTALS	$740,000	$ 785,000
1963-64	Construct distribution pipeline	$204,000	
	Construct recharge wells	358,000	
	Construct pumping wells	118,000	
	Construct observation wells	211,000	
	TOTALS	$891,000	$1,676,000

Dominguez Gap Barrier Project. A preliminary cost was estimated for the Dominguez Gap Barrier Project based on data obtained from the Los Angeles County Flood Control District. The operation and maintenance cost was assumed to be $5.75 per acre-foot. The capital cost of the facilities was based on unit cost data developed by the Department of Water Resources. The estimated capital costs of facilities required for the proposed project are shown in Table 7-6.

TABLE 7-6

DOMINGUEZ GAP BARRIER PROJECT
CAPITAL COST ESTIMATES

Item	Capital cost
1. Supply pipeline	$ 471,000
2. Distribution line	296,000
3. a. Recharge wells	261,000
b. Appurtenances	38,000
4. a. Observation wells	163,000
b. Appurtenances	55,000
5. Geologic investigation	37,000
6. Office building and chlorination facilities	95,000
7. Planning, designing, testing, inspecting, etc.	212,000
8. Construction contingencies	212,000
TOTAL	$1,840,000

The estimated life of the facilities was the same as that used in the Alamitos Barrier Project. The annual cost for the facilities is $100,000. It was assumed that this barrier project would be in operation in 1967-68.

Additional Recharge Facilities. For some of the alternative plans of operation, additional freshwater-injection facilities were required from Santa Monica Bay to Los Alamitos Gap. These facilities were required in addition to those presently constructed and proposed along the Santa Monica Basin, West Coast Basin, Dominguez Gap, and Los Alamitos Gap. The estimated present worth of costs of additional injection facilities for various rates of injection are presented in Attachment No. 8.

Cost of Electrical Energy

For the electrical energy cost, equations were developed to relate amounts of annual energy consumption with annual costs for a unit-sized pump or booster, representative of the sizes used in the study area. In addition, a unit annual cost of connection for those facilities was determined. For pumping power costs, a study was made to determine the most economical power-rate schedule of the Southern California Edison Company, which serves most of the ground water extractors in the Coastal Plain. Calculations were made for selected combinations of 30, 60, and 100 horsepower connected loads for pump use factors of 30, 60, 90, and 100 percent, using that company's rate schedules PA-1, A-7, and PA-2. In this analysis, the PA-1 schedule was found to be the most economical; therefore, it was used in this study for any given use factor for a connected load of 100 horsepower. This schedule was applicable to power service for boosters and pumps. A portion of the PA-1 power-rate schedule is shown below.

SOUTHERN CALIFORNIA EDISON COMPANY
SCHEDULE PA-1 FOR BOOSTERS AND PUMPS

		To be added to the service charge Cents per KWHR		
Horsepower of connected load	Service charge per HP per year	First 1,000 KWHR per HP per year	Next 1,000 KWHR per HP per year	All over 2,000 KWHR per HP per year
100 and over	\$6.50	\$1.36	0.82	0.64

The following equations were developed for this investigation based on the Southern California Edison Company coast schedule PA-1 for a 100-horsepower pump motor. The total annual service and electrical energy charge, in dollars per unit, is given by the following equation:

$$T_e = U_c + U_e$$

where: T_e = total annual service and electrical energy charge, in dollars per unit;

U_c = annual service charge on connected load, in dollars per unit;

U_e = annual energy consumption charge, in dollars per unit.

The service connection charge per pump is \$6.50 per horsepower for a pump with a 100-horsepower or larger motor. Because all the pumps and boosters were considered to have 100-horsepower motors, the total service connection charge for all ground water pumping units could be expressed in the following equation:

$$U_c = HP_u \text{ (6.50 Dollars/HP-YR)}$$

where: HP_u = horsepower of pump motor;

HP = horsepower;

YR = year.

The energy consumption charge per pump varies by three rate schedules, depending upon the duration for which a pump is used. Equations were developed from Southern California Edison Company cost schedule PA-1 for three ranges of use factors. They are presented below:

1. For use factors from 0 to 15 percent
   $U_{e_1} = HP_u \left[(.0136 \text{ Dollars/KWHR})(6530 \text{ KWHR/HP-HR})(\text{Use Factor}) \right]$
2. For use factors from 15 to 30 percent
   $U_{e_2} = HP_u \left[(.0082 \text{ Dollars/KWHR})(6530 \text{ KWHR/HP-YR})(\text{Use Factor}) + 5.4 \right]$
3. For use factors from 30 to 100 percent
   $U_{e_3} = HP_u \left[(.0064 \text{ Dollars/KWHR})(6530 \text{ KWHR/HP-YR})(\text{Use Factor}) + 9.0 \right]$

where: KWHR = kilowatt-hour.

The above equations were used to determine the total annual service and electrical energy charge of pumps and boosters in each plan of operation.

Cost of Imported Water

One of the most important factors in the evaluation of alternative schemes of ground water basin operation in the Coastal Plain is the cost of imported water. For economic comparisons of the alternatives, costs were estimated for imported waters from all sources. Water is presently imported into the study area by the following agencies: The Metropolitan Water District of Southern California (hereinafter referred to as the District), the City of Los Angeles Department of Water and Power, and several small agencies which import water from the San Gabriel Valley.

Because the amounts of water imported during the study period from the San Gabriel Valley and by the Los Angeles Department of Water and Power were presumed to be the same for all plans of operation and the costs of these waters did not affect economic comparisons of alternatives, a cursory study was made of unit cost of water from the two sources. The cost of imported water from the San Gabriel Valley was $20 per acre-foot, excluding the cost of the secondary distribution facilities, but including the cost of extraction and conveyance to the Coastal Plain. Extraction cost of ground water in the San Gabriel Valley was based on pumping lift data in that area and also cost of extraction data in other basins. Conveyance cost included the cost of pipelines required to convey the water to the study area. In this determination, all agencies which export water from the San Gabriel Valley were considered as one entity to simplify the study.

The estimated average unit cost of Mono-Owens water and San Fernando Valley water imported into the Coastal Plain by the Los Angeles Department of Water and Power is $20 per acre-foot. The average cost, which does not include distribution cost, was based on unit cost data furnished by the City of Los Angeles for surface and ground water.

A detailed cost study of the District's water was undertaken because the amount of water imported by the District varied for each plan of operation and the District's announced pricing policy was not definite enough to provide a schedule for the entire study period. The remaining portion of this attachment presents the procedure used to estimate the total cost of importing the District's water and the resulting price to the Coastal Plain water users for each alternative plan of operation.

In 1963, the District consisted of 26 member agencies serving a population of 8,825,000 in six counties in Southern California. Nine of the District's member agencies served the Coastal Plain; their service areas contained a total population of 3,940,000. Since June 1941, the District has met its members' water demands with Colorado River water. As of June 30, 1963, the member agencies of the District which serve the Coastal Plain have used approximately 40 percent of this diverted water while paying about 68 percent of the total cost. The total payments include collection from regular annual tax levies, special levies for annexation charges, and payment for water delivered.

To meet the increasing demand of its service area, the District contracted with the State in 1960 to purchase up to 1,500,000 acre-feet of State Water Project water annually. This was amended in 1964 and increased to 2,000,000 acre-feet. The District will begin to distribute a portion of this water supply in 1971. At the time of this study, 1963, the District also had rights to divert 1,212,000 acre-feet annually from the Colorado River.*

In this study, the unit price of water was defined as that amount paid by the member agencies per acre-foot of water. As of 1963, the cost has been more than the price, and the difference has been made up by taxes levied on property owners in the District's service area.

Because the Coastal Plain carries a higher share of the District's financial burden for its facilities, the cost of the district water supply cannot be treated like the costs of waters from the San Gabriel Valley and

*As the result of the Supreme Court decision (1964) apportioning water to Arizona and California, the amount available by each user agency may decrease in future years. This possibility is reflected in the comparative curves shown on Figure 13, Chapter IV.

that distributed by the City of Los Angeles. The cost of water to the water users is composed of the price paid for the purchase of water and the ad valorem tax payment to the District; this sum is equal to the capital cost of water facilities, plus the minimum operation and maintenance cost of water delivery.

The magnitude of the unit price of water and the ad valorem tax levied on property owners has depended on the policy of the District. The District's policy at the time of the study on the future prices was outlined in its Resolution 5821. The following quotation of Resolution 5821 is from the District's Twenty-Third Annual Report, 1961, pages 128-129:

> "On September 27, 1960, the Board of Directors adopted Resolution 5821 containing certain recitals and declarations of water pricing policies which the resolution provided shall become effective beginning January 1, 1964. Those policies are: (1) all payments received for annexation charges shall be applied first to bond obligations to which they are pledged and next to reduce other indebtedness resulting from capital expenditures; (2) at least one-half of all remaining capital charges plus all operation and maintenance costs of the District shall be borne by sales of water at uniform rates to constituent members irrespective of the source or point of delivery of the water, except for equitable surcharges to reflect the cost of special services -- the rate for water shall be at least as large as the total of all such costs in the three prior fiscal years plus the anticipated cost in the next three years divided by the total quantity delivered to constituent members in the three prior years and that quantity projected for the ensuing three years; and (3) the remainder of all capital charges may be met from tax levied on the basis of assessed value of property within the District to the extent permitted by law, with the expectancy that this tax burden will diminish progressively as the use of water approaches the total of the Aqueducts' supplies."

Because this resolution is set forth in broad terms, varying interpretations can be made by the Department. As of 1963, the price of the District's water had been established through 1967. To develop a pricing schedule for water during the study period, 1963 through 1990, studies were made to predict the cost of water from 1967 through 1990.

In order to provide a range of economic data for the alternative plans of operation, three pricing schedules were determined, based on the three different sets of assumptions considered to be likely under existing policies and conditions. These are designated as price-of-water studies Nos. I, II, and III. The major difference among the three price-of-water studies was in the approach used in paying for the District's expenditures after 1967. In price-of-water study No. I, it was assumed that all the District's expenditures will be borne by the revenue from the sale of water after 1969. For price-of-water study No. II, it was assumed that all the deficiency in revenue will be borne by revenue from an ad valorem tax. For price-of-water study No. III, it was assumed that the ad valorem tax was fixed to cover 50 percent of the capital cost of the facilities and the remaining portion of the expenditures will be borne by revenue from the sale of water. Table 7-7 shows a summary of assumptions for the three price-of-water studies.

The basic assumptions on which the three price-of-water studies were based were: all users will be charged an equal unit price for untreated water regardless of the source of water -- Colorado River water or State Water Project water; cost of treating raw water, such as softening and filtering, will be charged as a surcharge only to the users of treated water; the price of water will be as established by the District until 1967 but after that the price will be different under each price-of-water study; and the unit water prices charged for like water used for different purposes will have no differential.

TABLE 7-7[1/]

SUMMARY OF ASSUMPTIONS FOR PRICE-OF-WATER STUDY

Assumptions common to all three price-of-water studies

1. The State Water Project aqueduct system will be constructed according to the schedule outlined in Plan 3 of the Department of Water Resources office report, "A Study of the Optimum Division and Timing of Water Deliveries Between East and West Branches of the California Aqueduct," March 1962.

2. The distribution system will be constructed according to the construction schedule outlined in case No. 7 of The Metropolitan Water District of Southern California Report No. 802.

3. All users will be charged an equal unit rate for untreated water, and cost of treating raw water will be charged only to the users of treated water.

4. The water rates until 1967 will be those already established by the District.

Assumptions for Price-of-Water Study No. I	Assumptions for Price-of-Water Study No. II	Assumptions for Price-of-Water Study No. III
I-1 The amount of water imported by the District to its service area will be as specified in the District's Report No. 802.	II-1 The amount of water imported by the District to its service area will vary in direct proportion to the variation in amount of imported water to the Coastal Plain.	III-1 The amount of water imported by the District to its service area will vary in direct proportion to the variation in amount of imported water to the Coastal Plain.
I-2 The price of water after 1967 will increase at the historical rate until 1969 at which time the price is to be equal to the cost of importing water.	II-2 The prices of water will be as established in Price-of-Water Study No. I. Deficiency in revenue will be borne by ad valorem tax revenue.	III-2 Fifty percent of the capital cost will be borne by ad valorem tax revenue, and the remaining cost of importing water will be borne by sales revenue.

1/ Reproduced from Chapter II.

In conducting the study, the amount of tax revenue originating from the Coastal Plain was not initially included in the cost of water service but was subsequently added to the total cost of operation after the costs of all other items were determined.

The cost of water included the cost of the District's facilities and State Water Project costs that will be allocated to the District. Supporting data were found in the Department of Water Resources office report, "A Study of the Optimum Division and Timing of Water Deliveries Between East and West Branches of the California Aqueduct", March 1962, (hereinafter referred to as DWR Office Report) and the District's Report No. 802.

The components of the three price studies were the following: the unit cost of water, the present worth of monies to pay for water treatment facilities, and the present worth of taxes levied on its member agencies. Cost analyses were made for the period between 1960-2037 on a 4 percent interest rate. The ending year, 2037, which is fifty years after the last construction date, was chosen because it is the date of final payment for the projects involved. The interest rate and the year of the last payment were the same as those used in the reports mentioned earlier.

The unit price of untreated water was determined by dividing the present worth of the cost of delivering the water from 1960 to 2037 by the product of the volume of the scheduled water deliveries for the same period and present worth factors; this was done to make the volume comparable to the present worth of the cost. The product is referred to as the discounted volume of the scheduled water delivery; in succeeding discussions this will be referred to as discounted volume for convenience.

A surcharge for treatment was added to the unit price of untreated water to determine the price of filtered and softened water.

Based on these calculated unit prices, the pricing schedule of the District's water was estimated for its member agencies in the Coastal Plain for untreated, filtered, and filtered and softened water for artificial recharge, agricultural, domestic and other uses from 1963 through 1990. The prices of water to 1967, which have been established by the District, were incorporated in the above-mentioned schedule.

Capital cost, minimum operation and maintenance cost, and variable operation and maintenance cost, included in the determination of the unit price, are defined below:

1. Capital cost includes the cost of construction, surveys, engineering studies, exploratory work, designs, preparation of construction plans and specifications, acquisition of lands, easements and rights-of-way, and relocation work, except for monies spent on treatment plant facilities.

2. Minimum operation and maintenance cost includes the cost of minimum operation and maintenance, power capacity and replacement, except for treatment plant facilities. (This cost is incurred irrespective of the amount of water delivered.)

3. Variable operation and maintenance cost includes the cost of operation, maintenance, power replacement, and treatment. (This cost is incurred in an amount which is dependent upon and varies with the amount of water delivered.)

The present worth of the ad valorem tax assessment was determined for each price-of-water study. This assessment was required in all three studies because the unit price of water did not entirely pay for the cost of importing the water. In this analysis the cost of treatment was levied only on the agencies that were assumed to use treated water. In price-of-water study Nos. II and III the treatment facilities were not fully utilized for the alternative plans of operation; therefore, only the areas for which the facilities were constructed were assessed for them.

A detailed description is presented below for each of the three price-of-water studies to estimate the District's future pricing schedule of water, including the tax assessment on the Coastal Plain.

Price-of-Water Study No. I

In study price-of-water No. I, it was assumed that the member agencies of the District would pay 100 percent of the cost of water directly to the District through unit prices without resorting to tax revenues soon after their present price schedule expires in 1966-67. Additional assumptions for this study are summarized in Table 7-7. In determining the price of water, an analysis was made of the entire cost of the future water service of the District. This included the cost of water service between 1960 and 2037 from the Colorado River and the State Water Project.

Colorado River Water. To estimate the future cost of the Colorado River water sold in the Coastal Plain, the following items were considered:

1. Long-term obligations, which represent the cost of existing facilities and annexation payments to the District as of June 30, 1960, considered as asset;

2. Present worth of capital cost of future expansion of the District's Colorado River Aqueduct system;

3. Present worth of the operation and maintenance cost of the present and future facilities of the District;

4. Present worth of variable cost of Colorado River water, excluding treatment cost; and

5. Unit variable cost of treatment of Colorado River water.

The information on long-term obligations by the District and annexation payments to it as of June 30, 1960, was obtained from the District's Twenty-Second Annual Report dated 1960, except for the estimated bonds that were outstanding on the La Verne Treatment Plant. Part 1 of Resolution 5821 states that the annexation charges will be used initially to reduce the bonded indebtedness. When the annexation charges and the estimated bonds that were outstanding on the La Verne Plant were subtracted from the bond charges, the remaining long-term obligations equaled $89,323,000.

The present worth of capital cost of future expansion of the District's system was based on data obtained from the District's Report No. 802, Table VII-C, Financial Analysis for Case VII. The future system assumed for this study is the alternative system provided for the assumed State Water Project, in which East and West Branch each has a delivery capacity of 750,000 acre-feet per year. The total present worth of the capital cost of the future expansion of the District's system from 1960 to 2037 at 4 percent interest equaled $288,390,000.

The present worth of the minimum operation and maintenance cost of the District's present and future system included the cost of the following items:

1. Pumping water
    a. Operation and maintenance of pumping plant
    b. Operation and maintenance of electrical transmission lines
2. Delivery and distribution
    a. Operation and maintenance of main aqueduct
    b. Operation and maintenance of distribution reservoirs and lines
3. Communication
    a. Operation and maintenance of telephone system
    b. Operation and maintenance of radio communication
4. Administration
5. Depreciation

The minimum operation and maintenance cost was determined by multiplying each prior year's accumulated construction cost by 1.5 percent. This is the same factor used by the District in Report No. 802 in estimating the minimum operation and maintenance cost of its facilities. The present worth of total operation and maintenance cost of the District's facilities from 1960 to 2037, at 4 percent interest, equaled $244,823,000.

The variable cost of Colorado River water included the price of water at Parker Dam and the pumping cost from Parker Dam to Lake Mathews but did not include the cost of treatment. The District pays the U. S. Bureau of Reclamation $0.25 per acre-foot for water diverted from the Colorado River. Pumping cost from Lake Havasu to Lake Mathews is approximately $7.12 per acre-foot. The cost is a weighted average of the pumping costs resulting from three different power sources used by the District to deliver up to 1,180,000 acre-feet of Colorado River water to its member agencies. The total present worth of the variable cost of this water from 1960 to 2037, not including treatment cost, equaled $211,403,000.

The pumping cost will vary to some extent in the future due to varying rates charged by the Southern California Edison Company and the U. S. Bureau of Reclamation for energy generated at Hoover and Parker Dams. However, these energy rates were assumed fixed for this study. A peak capacity standby charge, which varies with the amount of power required by the District, is included in all three energy rates.

The variable unit cost data for the water treatment were for the District's La Verne Treatment Plant, which has a softening and filtering capacity of 400 MGD. The cost of filtering at the R. B. Diemer Plant was assumed to be the same as the filtering cost at the La Verne Treatment Plant. The softening cost is the cost to reduce the hardness of water to approximately 125 ppm. When the plant is operating at capacity, approximately two-thirds of the water is softened to between 0 and 5 ppm hardness and this volume is mixed with the remaining one-third of the water, resulting in a total hardness of 125 ppm. The following chemical cost data pertain to this mode of operation:

Item	Cost per acre-foot
Cost of treatment (softening and filtering including O & M and amortization	$8.40
Cost of treatment (softening and filtering) minus O & M and amortization	4.30
Cost of softening including O & M and amortization	4.80
Cost of softening minus O & M and amortization	3.63
Cost of filtration including O & M and amortization	3.60
Cost of filtration (includes chlorine, coagulants, and power) minus O & M and amortization	0.67

The unit cost of treating the District's water was assumed to be constant during the study period even though Colorado River water and State Water Project water will be mixed. The total hardness due to calcium carbonate of State Water Project water is expected to be lower than that of Colorado River water and any intermingling of the two waters would result in a net decrease in the total hardness of the mixed water under that of Colorado River water. Due to the development of the Upper Colorado River Basin, an increase in the total hardness of Colorado River water is expected. However, it was assumed for this study that any future intermingling with State Water Project water would not increase the total hardness of the mixture over the present total hardness of Colorado River water. It follows from the foregoing assumptions that the unit cost of treatment of Colorado River water would not change due to a change in the total hardness of the water supply.

State Water Project Water. To estimate the State Water Project cost allocated to the District, the following costs were considered:

1. Present worth of capital cost;
2. Present worth of minimum operation and maintenance cost;
3. Present worth of variable operation and maintenance cost; and
4. Unit variable cost of treatment.

The capital cost allocated to the District included the Delta water charge and part of the capital cost of the transportation facilities from the Delta to Perris and Castaic Reservoirs. The capital cost, operation and maintenance cost, and variable cost assumed for this investigation were the same as the costs developed for the DWR Office Report. It was assumed that the power credit derived from the sale of electricity at Oroville Dam would be applied to the variable and minimum operation and maintenance costs of the Delta water charge before being applied to the capital cost. Because the power credit is greater than the variable and minimum operation and maintenance costs and because the variable and minimum operation and maintenance costs of the Delta water charge were considered to be zero, the excess was applied to the total capital cost. The present worth of total capital cost of the State Water Project allocated to the District equaled $566,603,000.

The operation and maintenance cost component of the transportation charges of the State Water Project allocated to the District included a part of the cost of those transportation facilities from the Delta to Perris and Castaic Reservoirs. The total present worth of minimum operation and maintenance cost of the State Water Project allocated to the District was $127,949,000.

The variable operation and maintenance cost component of the transportation charges was comprised of the variable cost of the transportation facilities to be allocated to the District and the cost of treatment, charged only to the users of treated water. The variable operation and maintenance cost component of the transportation charge included the cost of the following items: energy from Pumping Plant No. 1 to Castaic and Perris Reservoirs, power generating facilities, and losses due to evaporation and seepage. The total present worth of variable cost allocated to the District was $379,366,000.

The cost of softening and filtering State Water Project water is based on the cost of treating Colorado River water. (The cost of softening State water mixed with Colorado River water was discussed earlier in the section on treatment of Colorado River water.)

The variable costs of filtering State Water Project water included the cost of coagulants, chlorine, and power. The cost of this treatment was estimated to be $1.50 per acre-foot. This cost is $0.83 per acre-foot higher than the cost of comparable treatment of Colorado River water because of the expected higher suspended matter in State Water Project water which will require continuous coagulation and, therefore, more chemicals. The cost of operation, maintenance, and amortization of the treatment facilities was assumed to be the same as that of the La Verne Treatment Plant. The total cost of treating State Water Project water, which includes the cost of chemicals, rapid sand filtration, operation and maintenance, and amortization, was $4.43 per acre-foot. For this study, the future surcharge for filtering water was assumed to be the same as that required to filter State Water Project water.

In determining the unit cost of various items thus far discussed, the present worth of the total cost of each item during the repayment period was divided by the discounted volume of the imported water delivered by the District during the repayment period. The discounted volume of Colorado River water to be diverted and utilized by the District's member agencies from 1960 to 2037, at 4 percent interest, was estimated to be 18,108,000 acre-feet. The total discounted volume of imported water deliveries (46,792,000 acre-feet) was based upon data in the DWR Office Report.

A summary of the data developed on Metropolitan Water District's capital cost, minimum operation and maintenance cost, unified variable operation and maintenance cost, and treatment cost is presented below.

Capital cost:

1. The District's long-term obligations less treatment facilities and annexation charges, June 30, 1960	= $ 89,323,000
2. The District's present worth of capital cost for future facilities (1960-2037)	= 288,390,000
3. Present worth of capital cost of the State Water Project allocated to the District	= 566,603,000
Total present worth of capital cost of the State Water Project to be paid by the District, plus the cost of its future facilities	= $944,316,000
Discounted volume of imported water deliveries	= 46,792,000 acre-feet
Unit capital cost	= $20.18 per acre-foot

Minimum operation and maintenance cost:

1. Present worth of operation and maintenance cost of present and future District facilities (1960-2037)	= $244,823,000
2. Present worth of operation and maintenance cost of the State Water Project to be allocated to the District	= 127,949,000
Total present worth of minimum operation and maintenance of the State Water Project to be allocated to the District, plus the cost of its present and future facilities	= $372,772,000
Discounted volume of imported water deliveries	= 46,792,000 acre-feet
Unit minimum operation and maintenance cost	= $7.97 per acre-foot

Unified variable operation and maintenance cost:

Total present worth of variable cost of Colorado River water	= $211,403,000
Total present worth of variable cost of State Water Project water	= 379,366,000
Total present worth of variable cost	= $590,769,000
Discounted volume of imported water deliveries	= 46,792,000 acre-feet
Unified variable operation and maintenance cost	= $12.62 per acre-foot

Treatment cost:

Unit treatment cost for filtration chemicals, power, operation, maintenance, and replacement	= $4.43 per acre-foot
Unit treatment cost for softening, filtration, chemicals, power, operation, maintenance, and replacement	= $8.40 per acre-foot

Schedule of Water Prices. Water prices for imported Colorado River water, shown in Table 7-8 have been established in the past and proposed, until June 30, 1967, by the District's Resolutions 5645 and 6129. To determine the water prices that will be paid by the member agencies directly to the District between 1967 and 1990, the present water price schedule had to be analyzed. The District's established and proposed water prices showing continued rises between 1960 and 1967 are plotted on Figure 7-1(A) as solid lines. The rises will be limited by the unit costs of waters when 100 percent of the District's entire expenditure is borne by the revenue from the sale of water. The approximate upper limit of unit prices was governed by the unit cost of water determined under assumptions stated previously. To calculate the unit cost

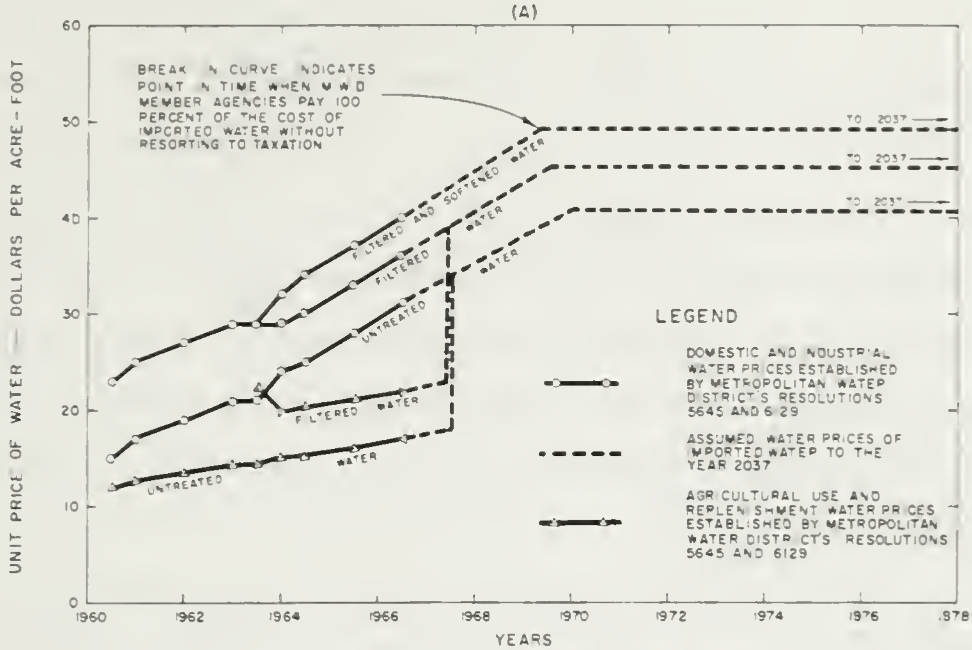
TABLE 7-8

ESTABLISHED AND PROPOSED WATER PRICES
FOR COLORADO RIVER WATER*

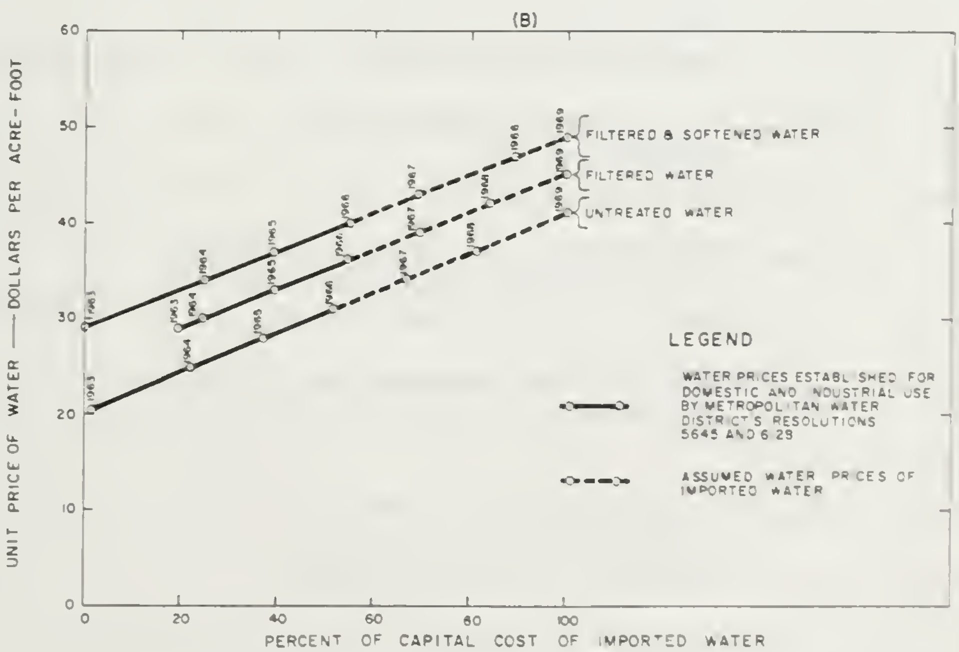
Per acre-foot

		For agriculture and ground water replenishment			For other purposes including domestic use		
From	To	Untreated	Filtered	Filtered and softened	Untreated	Filtered	Filtered and softened
7-1-60	1-1-61	$12.00	--	$20.00	$15.00	--	$23.00
1-1-61	1-1-62	12.75	--	20.75	17.00	--	25.00
1-1-62	1-1-63	13.50	--	21.50	19.00	--	27.00
1-1-63	7-1-63	14.25	--	22.25	21.00	--	29.00
7-1-63	1-1-64	14.25	$22.25	22.25	21.00	$29.00	29.00
1-1-64	7-1-64	15.00	20.00	23.00	24.00	29.00	32.00
1964	1965	15.25	20.25	24.25	25.00	30.00	34.00
1965	1966	16.00	21.00	25.00	28.00	33.00	37.00
1966	1967	17.00	22.00	26.00	31.00	36.00	40.00

*Rates established by Metropolitan Water District Resolutions 5645 and 6129.



UNIT PRICES OF IMPORTED WATER FROM METROPOLITAN WATER DISTRICT



ESTIMATED UNIT PRICES OF IMPORTED WATER FOR VARIOUS PERCENTAGES OF CAPITAL COST PAID BY THE SALE OF WATER

of water, the present worth of the District's expenditures were determined between 1960 and 2037 on facilities constructed from 1960 through 1987 to meet the 1990 water demand. The unit cost of untreated water was obtained by determining the discounted volume of State Water Project water and Colorado River water delivered to the District's service area between 1960 and 2037 and by dividing this quantity into the present worth of the District's expenditures between 1960 and 2037. The surcharge for treated water was obtained by adding the unit cost of treatment to the unit cost of untreated water.

The present worth and unit costs of State Water Project and Colorado River waters imported into the Coastal Plain from 1960 to 2037 are as follows:

1.	(a)	Present worth of capital cost and bond cost	=	$944,316,000
	(b)	Unit capital cost	=	$20.18 per acre-foot
2.	(a)	Present worth of minimum operation and maintenance cost	=	$372,772,000
	(b)	Unit minimum operation and maintenance cost	=	$7.97 per acre-foot
3.	(a)	Present worth of variable operation and maintenance cost less treatment cost	=	$590,769,000
	(b)	Unit variable operation and maintenance cost except for treatment	=	$12.62 per acre-foot
	(c)	Unit treatment cost for filtration, chemicals, power, operation, maintenance, and replacement	=	$4.43 per acre-foot

(d) Unit treatment cost for softening, filtration, chemicals, power, operation, maintenance, and replacement = $8.40 per acre-foot

4. Summation

(a) Present worth of total cost except treatment cost = $1,907,857,000

(b) Unit cost of water

(1) Untreated water = $40.77 per acre-foot

(2) Filtered water = $45.20 per acre-foot

(3) Softened and filtered water = $49.17 per acre-foot

The unit price for untreated, filtered, and filtered and softened water, when the District's member agencies pay 100 percent of the cost of water directly, are plotted on Figure 7-1A as dashed horizontal lines. The established and proposed water prices are also plotted on Figure 7-1A as solid lines and are extrapolated by dashed straight lines at a constant slope. The intersections of these three lines with their upper limits, the horizontal lines, occur in all cases during the year 1969. Each intersection indicates time when the District's member agencies will pay the same unit price as the unit cost of water directly to the District. The District's water prices to its member agencies for water used for agriculture and ground water replenishment are also plotted on Figure 7-1A. The price differential between waters destined for domestic and industrial use and agriculture and ground water replenishment proposed by the District will be $14.00 per acre-foot in 1966-67. Because the District has not made a price schedule for water after 1966-67, it was assumed that the domestic water price schedule would be used as the price schedule for agricultural and recharge waters after 1966-67.

The unit prices for untreated, filtered, and filtered and softened water used for domestic and ground water replenishment purposes between 1967 and 1990 were obtained from Figure 7-1A and the District's established, proposed, and estimated water prices to member agencies in the Coastal Plain are shown in Table 9 in Chapter II.

The lines on Figure 7-1B were plotted to indicate the unit price of water within the Coastal Plain when the District's member agencies pay varying percentages of the capital cost as direct charges for purchase of water (the remaining portion of the total cost was assumed to be paid by tax levies). Also plotted on this graph are the District's water prices established up through 1966, at which time the member agencies will be paying between 55 and 58 percent of the total capital cost of the District's facilities.

Taxes. Because revenue from the established unit prices of water will be insufficient to pay for the entire cost of facilities between 1963 and 1969, taxes will be levied. Regardless of the plan of operation, the annual taxes to be paid by the Coastal Plain were assumed to be the same for all the alternative plans studied under this price-of-water study. The present worth of taxes is the repayment required now for the facilities between 1963 and 1969, less the money obtained from the sale of water. The present worths of taxes which will be paid by the taxpayers of the Coastal Plain were determined by multiplying the ratio of projected assessed valuation of the Coastal Plain to the projected total assessed valuation of the District's total service area for each year by total money to be supplied by taxation. The present worth of the taxes to be paid by the Coastal Plain from 1963 to 1969 equaled $53,348,000.

Price-of-Water Study No. II

The five plans of operation that were selected for detailed discussions in this report were analyzed under the assumptions made for price-of-water study No. II. This analysis was made to ascertain the effect on the total cost of operation from 1963 through 1990 when the unit prices of water are held the same as in price-of-water study No. I and the amount of water imported to the District's service area is reduced in proportion to the reduction of the District's water delivered to the Coastal Plain. The unit prices of water under price-of-water study No. I are shown in Table 9, Chapter II.

Because of the fixed price of water schedule, the reduction in the amount of imported water, and the fixed amount of revenue needed for the facilities, deficiencies in revenue to repay for the facilities occurred for all the plans of operation that were analyzed. These deficiencies were considered to be made up by the ad valorem tax levied upon the assessed valuation of the District's source area.

The amounts of ad valorem tax raised from the Coastal Plain were determined in terms of present worths so that they may be added to the present worths of total cost of operation for comparison. The present worths of the ad valorem tax revenue postulated to be raised from the Coastal Plain were determined by first establishing the present worths needed from the District's entire service area and multiplying this amount with the ratio of the assessed valuation of the Coastal Plain to that of the entire District. The present worths of the District's tax revenue needed were determined by taking the difference between the present worths of revenue needed to repay for the facilities and revenue obtained by the District through the sale of water. The ratio of assessed valuation was based on the District's estimate of the future assessments for their service area. The present worth of the tax determined for each of the five selected plans for the period, 1963 through 1990, is shown in Table 7-9. After 1990, safe yield operations of the ground water basins were assumed for each plan of operation, and the annual amounts of water imported to the Coastal Plain were considered to be the same as the amounts assumed for price-of-water study No. I. Therefore, no ad valorem tax revenue was needed.

TABLE 7-9

PRESENT WORTH OF AD VALOREM TAX TO BE PAID BY THE COASTAL PLAIN OF LOS ANGELES COUNTY FOR SELECTED PLANS OF OPERATION FOR PRICE-OF-WATER STUDY No. II

Selected plans of operation	Present worth of ad valorem tax to be paid by the Coastal Plain of Los Angeles County
117-4	$116,627,000
318-5	119,896,000
117-5	130,058,000
117-7	141,604,000
117-11	168,267,000

Price-of-Water Study No. III

Price-of-Water Study No. III was made for the selected plans of operation to analyze the effects of holding the ad valorem tax at 50 percen of the annual repayment of the capital cost of facilities, while varying the unit price of water for the selected plans of operation.

Because the tax revenue was fixed and the amount of water sold was assumed to be reduced in proportion to the importation of the District's water in the Coastal Plain, unit prices of water had to be varied for each of the five selected plans of operation to raise adequate revenue to cover the entire expenditure of the District. Furthermore, because the price of water prevailing before 1990 was assumed to also prevail after that period, an ad valorem tax revenue was necessary from 1990 to perpetuity for each plan.

To determine the unit rate of water for each plan of operation, the total present worth of money required from the water users directly from 1963 to 2037 was divided by the discounted volume of water imported by the District for each plan of operation. The total present worth of money that is required from all the member agencies of the District directly was determined by multiplying the discounted volume of the imported water delivery assumed in price-of-water study No. I by one-half of the unit capital cost plus the unit minimum operation and maintenance cost. The unit prices of water for the five selected plans of operation are shown in Table 7-10.

The present worths of the ad valorem tax to be raised from the Coastal Plain were determined for the period from 1963 through 1990 and from 1990 to perpetuity. Because the water prices have been established through 1967, the amount of money to be raised from the tax equals the difference in the amount of money required for repayment of the system and the amount of revenue obtained from the sale of water. After 1967, the

TABLE 7-10

PRESUMED WATER RATES OF THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA BETWEEN 1967 AND 1990 IN THE OPERATIONAL-ECONOMIC STUDY OF THE GROUND WATER BASINS IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FOR PRICE-OF-WATER STUDY No. III*

In dollars per acre-foot

Alternative Plans	For domestic, industrial, agricultural, and ground water replenishment uses		
	Untreated	Filtered	Filtered and softened
Plan No. 318-5	$33.25	$37.25	$41.25
Plan No. 117-4	33.14	37.14	41.14
Plan No. 117-5	33.68	37.68	41.68
Plan No. 117-7	34.15	38.15	42.15
Plan No. 117-11	35.42	39.42	43.42

*Established and proposed water rates from 1962 to 1967 used for study No. III are the same as those used in study Nos. I and II which are given in Table 8 in Chapter II.

tax revenue required is equal to the discounted volume of the water deliveries through 1990 or perpetuity multiplied by one-half the unit capital cost of water. The present worths of ad valorem tax to be paid by the Coastal Plain from 1963 through 1990 and from 1963 to perpetuity are shown in Table 7-11.

Additional Costs for Treatment Facilities. Additional costs for treatment facilities were considered to be borne by the users of treated water only. Because the treatment costs used in this study were based on the assumption that a fixed amount of water will be treated in the future

TABLE 7-11

PRESENT WORTH OF AD VALOREM TAX TO BE PAID BY THE COASTAL PLAIN OF LOS ANGELES COUNTY FOR SELECTED PLANS OF OPERATION FOR PRICE-OF-WATER STUDY NO. III

Plan of operation	1963 to 1990	1963 to perpetuity
117-4	$153,716,000	$235,579,000
318-5	154,573,000	236,436,000
117-5	155,625,000	237,488,000
117-7	157,615,000	239,478,000
117-11	160,430,000	242,293,000

and because the amounts treated for each plan of operation varied from 1963 through 1990 for price-of-water study Nos. II and III, the deficiency in revenue to pay for the capital cost of treatment facilities in the District depends upon the alternative plans. This deficiency was considered to be borne by the users of treated water in the Coastal Plain through a tax levy to meet surcharge requirements.

The present worths of the tax revenues required from the Coastal Plain from 1963 through 1990 to meet surcharge requirements were estimated and are shown in Table 7-12.

TABLE 7-12

PRESENT WORTH OF TAX REVENUE REQUIRED FROM THE
COASTAL PLAIN OF LOS ANGELES COUNTY TO MEET SURCHARGE REQUIREMENTS
FOR TREATMENT FACILITIES FOR SELECTED PLANS OF OPERATION
UNDER PRICE-OF-WATER STUDY Nos. II AND III

Plan of operation	Present worth
117-4	$ 481,000
318-5	1,322,000
117-5	1,341,000
117-7	2,521,000
117-11	5,356,000

ATTACHMENT NO. 8

DETERMINATION OF PRESENT WORTHS OF CAPITAL COSTS FOR CONSTRUCTION OF FRESHWATER-INJECTION BARRIERS AND LATERALS; ADJUSTMENT OF PUMPING PLANT COSTS

ATTACHMENT No. 8

DETERMINATION OF PRESENT WORTHS OF CAPITAL COSTS FOR CONSTRUCTION OF FRESHWATER-INJECTION BARRIERS AND LATERALS; ADJUSTMENT OF PUMPING PLANT COSTS

Introduction

In the study of the planned utilization of ground water basins in the Coastal Plain of Los Angeles County, all items affecting the total cost of operation of alternative plans of coordinately utilizing the ground and surface water supplies and facilities were considered. Costs of most items are discussed in Attachment No. 7. Those items that were not considered in Attachment No. 7 are: (1) freshwater barrier facilities that were deemed necessary for some of the alternative plans of operation, but which have been neither constructed nor proposed by the Los Angeles County Flood Control District; (2) laterals connected to the primary distribution system serving the Coastal Plain (Case VII in Metropolitan Water District's Report 802) which were not included in the determination of unit cost of imported water; and (3) adjustment of pumping plant costs due to the lowering of ground water level elevations in the ground water basin. Detailed discussions will be presented in this attachment on the methods utilized to estimate present worths of costs of these three items.

Additional Freshwater Barrier Facilities

The freshwater barrier facilities considered in this section supplement the barriers that have been either constructed or proposed by the Los Angeles County Flood Control District. The present worths of costs of additional barrier facilities were determined for each alternative plan of operation and added to present worths of costs of other items in the economic study.

In this analysis, a survey of the locations and capacities of constructed or proposed barrier projects was made. Then, based on this survey, the location and number of additional facilities were determined and finally, present worths of costs of these facilities were calculated.

Survey of Constructed or Proposed Barrier Projects

Since 1953, the Los Angeles County Flood Control District has injected softened Colorado River water into a line of wells located near Manhattan Beach to create a freshwater barrier against saline intrusion. In 1963, the barrier, known as the West Coast Basin Barrier Project, consisted of 12 injection wells along a reach of about 8,000 feet parallel to the coastline. This barrier is scheduled to be extended to provide protection for approximately 11 miles of the coast by 1968. In addition to the extension of the West Coast Basin Barrier Project, freshwater barrier projects have been authorized at Los Alamitos and Dominguez Gaps. Table 6, in Chapter II, contains the lengths of the injection lines and design injection rates for each of the proposed barrier projects, while Plate 4 shows the location of these barrier projects.

Location of Additional Barrier Facilities

In addition to the barrier projects constructed or proposed by the Flood Control District, other barrier facilities were considered to be required along the coastline from Santa Monica Bay to Los Alamitos Bay under the majority of alternative plans of operation studied in 1963. The locations of additional barrier projects were based on a study of:

(1) geologic data on the depth and location of aquifers along the coastline, (2) present extent of sea-water intrusion, (3) future ground water elevations as determined through the use of a mathematical model of the ground water basins in the Coastal Plain, and (4) location of barrier projects constructed or proposed by the Flood Control District. The locations of the additional required barrier projects determined by this study are shown on Plate 4.

Additional freshwater barrier facilities were necessary along the coastline of the Santa Monica and West Coast Basins, and at Dominguez and Los Alamitos Gaps. The barrier facilities required along the Santa Monica Bay, referred to as Santa Monica Barrier Project in this attachment, followed rights-of-way of existing streets and were located so that they protected the area where sea-water intrusion presently occurs. The additional facilities required for the Alamitos and West Coast Basin Barrier Projects were presumed to follow alignments of barrier projects that have been constructed or proposed. The additional facilities required for the Dominguez Barrier Project were considered to extend west to the Palos Verdes Hills and east to Signal Hill. All of these additional freshwater barrier facilities were deemed necessary to adequately protect the freshwater-bearing aquifers in the Coastal Plain from saline intrusion under plans of operation in which the ground water level along the coastline is below the sea water level.

Additional Facilities Required for Each Barrier Project

The number and size of additional facilities required for each barrier project were determined for assumed injection rates. The facilities of the barrier projects considered for this study were supply pipelines, recharge wells, observation wells, appurtenances, pressure regulators, and connections to the primary distribution system.

The facilities required for Santa Monica, West Coast, and Alamitos Barriers were determined on the basis of three assumed injection rates for each project. The largest of these injection rates was adequate to meet the greatest requirement of the plans of operation investigated. For Dominguez Barrier, however, the injection rates for all plans of operation were assumed to be 17,000 acre-feet per year initially for one year to create a barrier mound, and approximately 4,000 acre-feet per year to maintain the freshwater mound. This assumption was based on the geologic and hydrologic information obtained during the verification of the mathematical model of the basins of the Coastal Plain of Los Angeles County.

For the determination of supply pipeline requirements, head losses in the pipelines were assumed to be the same as head losses in the supply pipelines of existing or proposed barrier projects and the delivery capacities of the pipelines were assumed to satisfy the assumed injection rates. For Dominguez Barrier, the supply pipeline proposed by the Los Angeles County Flood Control District was found to be adequate to deliver the initial injection rate of 17,000 acre-feet per year. For the determination of the number of required injection wells, acceptance rates of 1.0 cfs per well at Santa Monica and Dominguez Barriers and 0.8 cfs per well at Los Alamitos and West Coast Basin Barriers were based on data provided by the Flood Control District. An observation well was also placed between each pair of injection wells.

Present Worths of Costs of Additional Barrier Projects

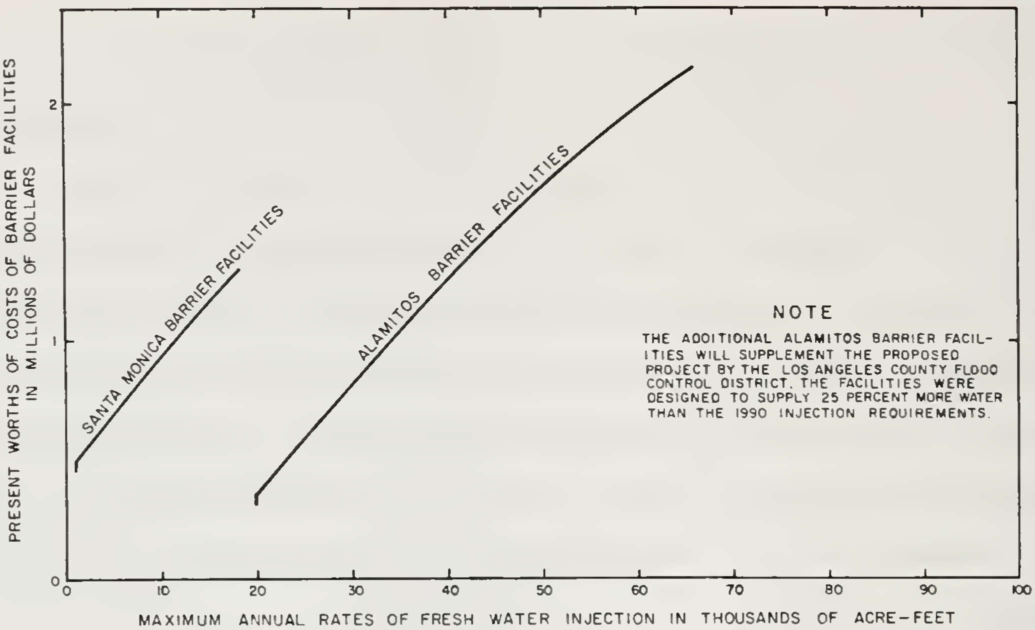
Present worths of costs of additional facilities required for each barrier project were determined. The cost analysis was based on unit cost data obtained from the Los Angeles County Flood Control District. These unit costs are summarized in Attachment No. 7. An interest rate of 4-1/2 percent, an appropriate economic life for each facility of the barriers, and a capital expenditure date of 1968 were assumed for the determination of present worths of costs. For each estimate, 20 percent of the total capital cost was included for engineering services and contingencies.

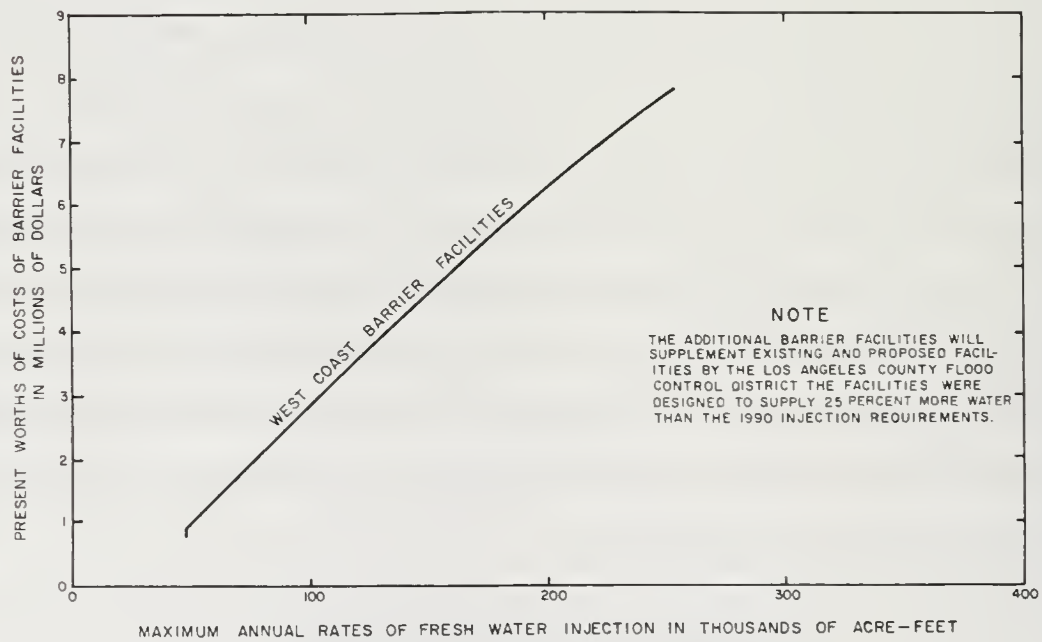
The present worths of costs of additional barrier facilities required for Santa Monica, West Coast Basin, and Alamitos Barriers were plotted against injection rates as are shown on the graphs in Figure 8-1.

To determine the present worths of additional barrier facilities needed for a particular plan of operation, these graphs were used. The maximum rate of injection required during the period from 1963 through 1990 in each plan of operation was determined for each freshwater barrier project and corresponding present worths of costs were obtained from the graphs. These costs, which vary with each plan of operation, were then included in the total cost of operation. The present worth of additional facilities at Dominguez Barrier, $482,000, was considered to remain the same for all plans of operation.

Additional Laterals Connected to the Primary Distribution System

The laterals considered in this section supplement the existing and proposed primary distribution system (Case VII in Metropolitan Water





RELATION BETWEEN COSTS OF ADDITIONAL BARRIER FACILITIES AND INJECTION RATES IN THE COASTAL PLAIN OF LOS ANGELES COUNTY

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

District's Report 802). The cost of additional laterals has not been included in the unit cost and price of imported water. Present worths of costs of additional laterals were determined for each alternative plan of operation and added to present worths of other cost items.

In this analysis, additional laterals were found to be required for economic areas 4, 5, and 8, which are located in the eastern portion of the study area. In economic areas 1, 2, 3, 6, 7, 9, and 10, additional laterals were not considered necessary. This decision was based on the following: (1) the Cities of Los Angeles and Long Beach have ample distribution systems to meet their 1990 requirements; (2) the existing Metropolitan Water District's laterals and connectors are adequate; and (3) the present industrial and domestic complex will change only slightly in the future.

Under the set of assumptions made in this analysis, locations and sizes of the additional laterals were determined. Finally, capital costs were developed and converted into present worths of costs, and for the affected economic areas, graphs were plotted to show the relation between the total present worths and water supply from the primary surface distribution system in 1990.

<u>Assumptions</u>

The assumptions under which the locations and sizes of supplementary laterals were determined are:

1. The applied water demand in 1990 within any economic area was assumed to be uniformly distributed throughout the area;

2. Additional laterals will contain takeout connectors, spaced 2 miles apart, and 1 mile from the existing and proposed primary

distribution system, so that the laterals will supply water to an area 1 mile wide on adjacent sides of the lateral; and

3. The friction losses in the laterals are limited to the change in ground surface elevation of the beginning and end points of the laterals; Manning's roughness factor of the pipelines is assumed to be 0.012.

Determination of Location and Size of Additional Laterals

To determine the location and size of additional laterals, each economic area was classified as having adequate or inadequate lateral facilities or distribution systems. This was accomplished through the use of information obtained from personal interviews with major water agencies in the area, maps of existing secondary distribution systems, and analysis of the primary distribution system. The distribution of population and the degree of industrial and domestic development were also considered.

In those areas where additional laterals were required, they were designed to meet the 1990 peak monthly applied water demand in coordination with water supplied through the ground water facilities. This conforms to criteria developed for the design of other water facilities in this investigation. The design capacities of the additional laterals were based on meeting 100, 75, 50, and 25 percent of the 1990 peak monthly water demands. These percentages were used to determine the cost of laterals for all plans of operation. The diameters of the laterals that were determined by considering reasonable roughness factors and friction losses in those laterals were comparable to the friction losses of the existing laterals.

Method of Determining Present Worths of Capital Costs

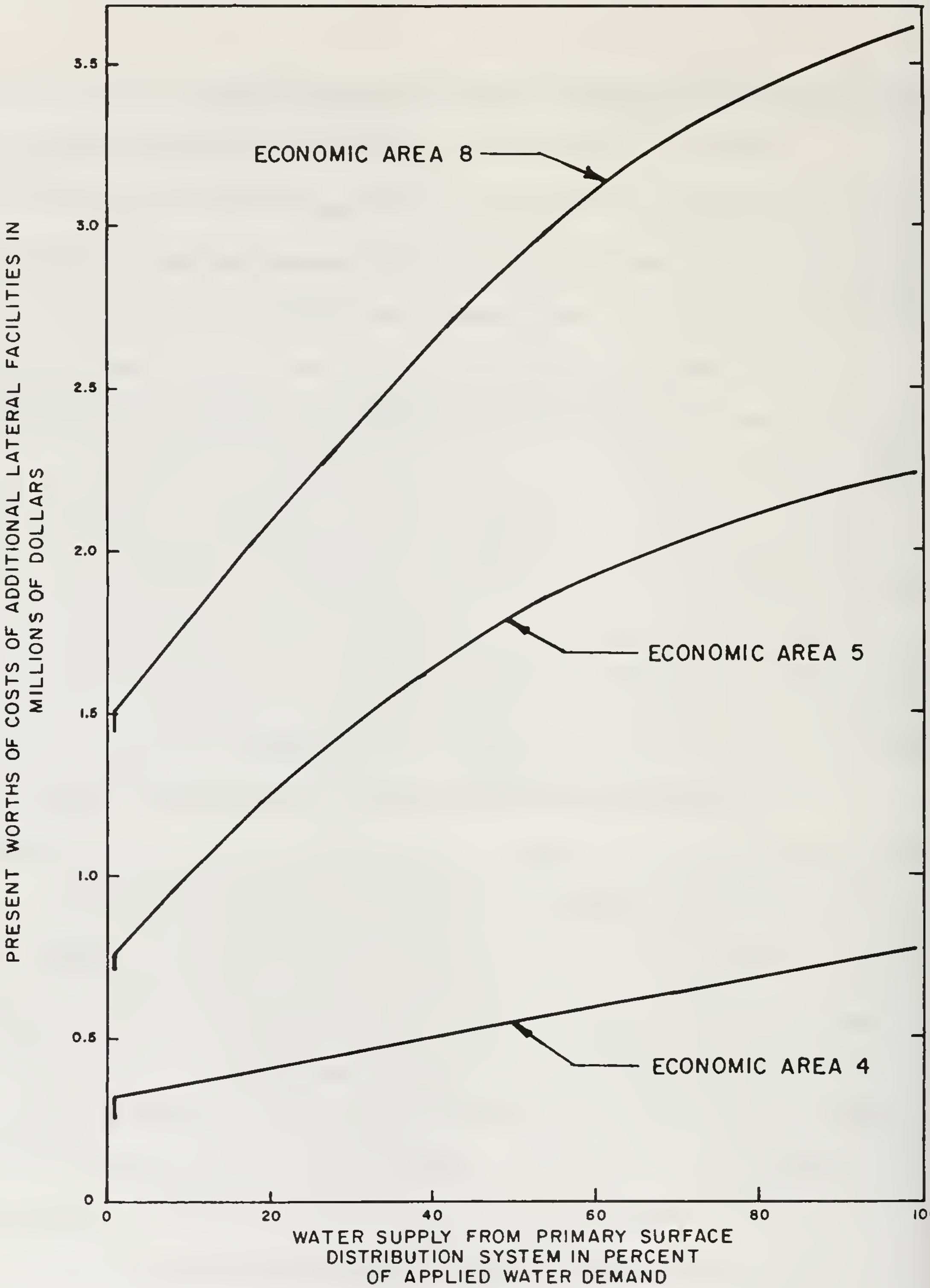
Capital cost estimates of lateral facilities were made for four assumed flow rates. The capital costs were converted to present worths by assuming an interest rate of 4-1/2 percent, an economic life of the facilities of 100 years, and a capital expenditure date of 1963.

The capital cost estimates were based on an average unit cost of $1.90 per foot of pipe per inch of diameter. This unit cost includes the cost of all appurtenances and regulating stations and is based in part on construction projects in residential areas which are comparable to economic areas 4, 5, and 8 in the Coastal Plain as compiled by the City of Los Angeles Department of Water and Power. Because the areas in the Coastal Plain in which additional laterals were required are residential, this unit cost estimate was presumed to be reasonable for this study.

A graph showing the relationship between present worths of costs of additional lateral facilities and the percentage of water supply delivered in 1990 by the primary distribution system to economic areas 4, 5, and 8 was plotted. Then the percentage of water supply delivered by the primary distribution system to these economic areas in 1990 was determined for each plan of operation, and the graph was utilized to estimate the present worth of cost of lateral facilities for each plan of operation. The graph for each of the three areas is shown in Figure 8-2.

Adjustment of Pumping Plant Costs

Table 7-2, Attachment No. 7, presents average pumping plant costs for each economic area, based on average depths of pumping bowls and well casings and average diameters of wells existing in the Coastal Plain in



RELATION BETWEEN COSTS OF ADDITIONAL LATERALS AND WATER SUPPLY FROM PRIMARY SURFACE DISTRIBUTION SYSTEM IN 1990 IN THE COASTAL PLAIN OF LOS ANGELES COUNTY

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

1962. These costs were used to determine the present worths of costs of pumping facilities for each plan of ground water operation.

Though these figures give a good indication of the cost of existing pumping plants in the Coastal Plain, they do not account for the conditions under which the future pumping levels of ground water would exceed the average pumping limits of the 1962 wells. This condition occurs in several of the selected plans of operation. Since this would require deeper wells to penetrate to the lower water levels, adjustment of the cost of wells and pumping facilities was necessary to reflect the cost of the additional labor and parts required.

In this study, a set of assumptions and a general procedure for adjusting the pumping plant costs due to the lowering of ground water levels are presented. The adjusted plant costs were based on unit costs of well and casing, discharge column pipe and driveshaft, and well redevelopment. These unit costs are:

Item	Cost
Well and casing	\$1 per inch diameter plus \$1 per foot depth of well
Discharge column pipe and driveshaft	\$10 per foot
Well redevelopment	\$2,000 per well

The 1963 present worth of these adjusted costs is included in the summary Sheet 1 of each plan of operations, Attachments 11 through 15.

Assumptions for Adjusting Pumping Plant Costs

Assumptions used in the formulation of Table 7-2, Attachment No. 7, were also used in the determination of adjusted pumping plant costs, with the single exception that, for the adjusted costs, the predicted static ground water levels in the future determine the depths of pumping, rather than the average 1962 pumping levels, as previously assumed. Extensions of the assumptions are:

1. The average future economic life of wells existing in 1962 is 10 years; the economic life of a new well is 20 years;

2. The interest rate used in the determination of annual cost and 1963 present worths of costs is 4-1/2 percent;

3. The average diameter of wells in use in 1962 in each economic area is to be the diameter of the new well in the corresponding economic area. These average well diameters ranged from 6 to 14 inches;

4. The average pumping drawdown throughout the Coastal Plain is 70 feet, and the minimum distance from static ground water levels to pumping levels is 75 feet. Well casings extend 5 feet beyond the pumping bowl;

5. The depth of ground water levels estimated for 1990 will be maintained for the years from 1990 to perpetuity;

6. Existing wells will be extended, and new wells will be drilled to the maximum depth of future static ground water levels in the first year in which modification or new development is required.

General Procedure in Determining Annual and 1963 Present Worths of Costs

A general procedure used in determining adjusted pumping plant costs as annual costs and 1963 present worths of costs was translated into a computer program so rapid computation of these costs could be obtained for the selected plans of operation. This general procedure is:

1. Determine the year in which the initial adjustment of pumping plant costs is necessary for each economic area. This was

accomplished by comparing the average depths of existing pumping bowls to the depths of computed future static ground water levels, plus 75 feet. Future static ground water levels were determined by using the mathematical model of the ground water basins.

2. Determine the depth to which the wells must penetrate before they are deemed operable. This was accomplished by searching for the maximum future ground water level for each economic area. All wells will be constructed to penetrate the maximum depths of water levels.

3. Determine the length of well casing, discharge column pipe and driveshaft that, when mulitiplied by the proper unit costs, yield adjusted pumping plant costs. This was done by applying the following equations:

Length of well and casing = (Maximum depth of ground water level) - (average depth of well casing in 1962) + 80 feet

Length of discharge column pipe and driveshaft = (Maximum depth of ground water level) - (average depth of pumping bowl in 1962) + 75 feet

4. Determine the adjustments of annual costs required for each economic area and for each year that follows the initial year to 1990. This is accomplished by first determining the capital costs. The product of the lengths determined under item 3 multiplied by the proper unit costs yields capital costs. These capital costs are then converted to annual costs.

5. Determine the adjustment to 1963 present worths of costs of wells for ground water operation from 1963 through 1990, by applying the proper present worth factors to the annual costs.

6. Determine the adjustments to 1963 present worths of costs of wells for ground water operation from 1990 to perpetuity. This was

done by first determining the annual payments over the period from 1990 to perpetuity. These annual payments were then brought back to 1963 present worths. These figures were used in the preparation of Figure 13, Chapter IV.

This procedure was utilized to yield estimates of adjusted pumping plant costs due to the lowering of ground water levels in the Coastal Plain. These estimates are within the scope of the ground water utilization studies.

ATTACHMENT NO. 9

A METHOD FOR DETERMINING THE MOST ECONOMICAL
COMBINATION OF GROUND AND SURFACE WATER FACILITIES

ATTACHMENT NO. 9

A METHOD FOR DETERMINING THE MOST ECONOMICAL COMBINATION OF GROUND AND SURFACE WATER FACILITIES

Introduction

In the investigation of the planned utilization of the ground water basins of the Coastal Plain of Los Angeles County, costs of many alternative plans of operation were analyzed and compared. In this comparison, costs were developed for all plans of operation, under the assumption that all the water supply facilities would be utilized most economically to meet the growing and fluctuating water demands. To determine the most economical combination of water supply facilities, an equation was written and a method was developed for its utilization.

Prior to designing water supply facilities, future water demand, as well as the peak variations in the water demand for the study area, had to be determined. The projected annual water demand and the estimated monthly and daily variations in demand are discussed in Chapter II and are shown on Figure 2. For this study, the maximum water demand on facilities was taken as the peak hourly demand on the day of maximum water demand plus the fire flow requirement. The maximum period of water demand was taken as five maximum water demand days in succession, added to the fire flow for a specified duration, as recommended by the National Board of Fire Underwriters.

The facilities required to meet the applied water demand during the hour of peak flow were the primary distribution system, ground water pumping facilities, and surface storage facilities. The primary distribution system considered was the primary distribution system of The

Metropolitan Water District of Southern California, the ground water pumping facilities considered were the ground water pumps and booster pumps, and the storage facilities considered were surface storage tanks or reservoirs which included normal accessories.

For the distribution system, a feeder construction schedule was assumed, and the maximum delivery capacity was determined. This determination is discussed in Attachment No. 4. During the hour of peak flow, it is most economical to utilize the primary distribution system to its maximum delivery capacity and to meet the remaining portions of the maximum hourly water demand (hourly peak flow plus fire flow requirement) by a combined flow from surface storage and ground water pumping facilities. The pumping facilities comprise two types: those pumping ground water directly to operating head, and those pumping ground water initially to ground surface for treatment and subsequently boosting to operating head. However, because many different combinations of pumping and storage facilities would satisfy the remaining demand, the most economical combination was determined for each alternative plan of operation each year to insure validity of the economic comparison of alternatives.

In this attachment, detailed discussions will be presented on the major steps of developing and utilizing the equation to determine the most economic combination of pumps and surface facilities. For convenience, a list of definitions of symbols is provided at the end of this attachment.

General Steps of Method

To determine the most economical combination of pump and surface storage facilities, a general cost equation for total annual costs of facilities to meet specific annual water demands was written in terms of one unknown. The equation was solved by differentiating and setting its derivative equal to zero. The solution provided information to determine the most economical combination of primary feeder system, well pumping and booster facilities, and surface storage facilities. Subsequently, costs of these facilities were estimated and were included in a total estimated cost of each alternative plan.

The general steps taken in the development and utilization of this equation to determine the most economical combination of surface and ground water facilities are as follows:

1. A general cost equation was written with the following components to express the total cost of pumping, boosting, and surface storage:

    a. The number and unit cost of booster facilities,

    b. The number and unit cost of ground water pumping facilities,

    c. The number and unit cost of surface storage facilities, and

    d. The electrical energy and service connection charge for pump and booster facilities.

2. Equations were written to express the number of water supply facilities, in terms of booster flow capacity. These facilities are:

    a. Boosters,

    b. Ground water pumps, and

    c. Surface storage reservoirs

3. The unit cost of facilities and the electrical energy cost were determined.

4. An equation was developed to determine the most economical flow capacity of facilities.

5. A method was developed for using the most economical flow capacity equation to determine the most economical combination of boosters, pumps, and storage facilities, considering existing and additional facilities.

Development of a General Cost Equation*

The general cost equation derived to obtain the total annual cost of pumping and surface storage facilities is:

$$C_t = C_p + C_b + C_s \qquad (1)$$

or

$$C_t = N_p\ (U_p + U_e + U_c) + N_b\ (U_b + U_e + U_c) + N_s U_s \qquad (2)$$

where: $C_p = N_p\ (U_p + U_e + U_c)$ = total cost of pumping, including cost of pump and well unit, right-of-way, electrical energy, and electrical energy connection service charge, in dollars,

$C_b = N_b\ (U_b + U_e + U_c)$ = total cost of boosting, including cost of booster units, electrical energy, and electrical energy connection service charge, in dollars,

$C_s = N_s U_s$ = total cost of surface storage, including cost of surface storage tank with normal accessories, right-of-way, foundation, and excavation, in dollars,

N_p = number of well and pump units,

N_b = number of booster units,

N_s = number of surface storage units,

U_p = average annual cost of a well and pump unit, in dollars,

U_e = annual cost of electrical energy consumption per pump or booster unit, in dollars,

U_c = annual cost of electrical energy connection service charge per pump or booster unit, in dollars,

*Symbols used are defined in Table 9-1, at the end of this attachment.

U_s = average annual cost of a surface storage unit, in dollars.

In this study, it was found most convenient to express the number of pumping, boosting, and surface storage facilities in terms of the flow capacity of boosters (Q_b) required to lift water from the ground surface to the operating head of the distribution system. This approach was taken by assuming that a relationship between the existing number of boosters and the number of pumps at wells in the study area will be the same in the future and that all the pumping facilities will have a modular-sized motor, typical of the sizes presently used in the area.

Equations were developed to relate the number of boosters, pumps, and surface storage facilities to the flow capacity of boosters (Q_b). Derivation of these equations is given in detail in subsequent pages. The ultimate equations are presented here for convenience:

$$N_b = \frac{Q_b \; W \; L_o}{550 \; E \; HP_u} \tag{3}$$

$$N_p = N_g + N_o = \frac{2Q_b W \; (L_d + L_g)}{550 \; E \; HP_u} \tag{4}$$

and

$$N_s = \frac{V_s}{V_t} = \frac{13{,}900 \; (D_m - Q_f - FQ_b)^2}{D_d \; V_t} \tag{5}$$

or

$$N_s = \frac{V_s}{V_t} = \frac{423{,}600 \; D_d - 408{,}600 \; (Q_f + FQ_b) + V_f}{V_t} \tag{5a}$$

where: D_d = average water demand on the day of maximum water demand, in cubic feet per second,

D_m = maximum hourly water demand, in cubic feet per second, consisting of the peak hourly water demand on the day of maximum water demand, plus the fire flow demand,

E = efficiency of the pump and booster units, as a decimal,

F = factor that relates the flow capacity of boosters (Q_b) to the total ground water pumping capacity (Q_t),

HP_u = rated horsepower of a modular-sized pumping or boosting facility,

L_d = drawdown of a well, in feet,

L_g = pumping lift from static water level to ground surface, in feet,

L_o = pumping lift to operating head of the distribution system from ground surface, in feet,

N_g = number of ground water pumps, lifting ground water to ground surface elevation,

N_o = number of ground water pumps, lifting ground water directly to distribution system operating head,

Q_f = peak flow rate available from the feeder system, in cubic feet per second,

Q_b = booster flow capacity, in cubic feet per second, lifting ground water from ground surface to operating head,

W = unit weight of water, 62.4 pounds per cubic foot,

V_f = volume of storage required for fire protection, in cubic feet,

V_s = volume of required surface storage, in cubic feet,

V_t = volume of a surface storage tank unit, in cubic feet.

These four equations, expressing the number of facilities in terms of booste flow capacity, are derived in the following sections.

Derivation of Equation to Determine Required Number of Boosters

The number of boosters was determined by first writing an equation for the total horsepower required to lift the booster flow capacity (Q_b) from ground surface to operating head, and by subsequently dividing the total horsepower by the horsepower of a modular-sized booster unit (HP_u). The equation for the power required for lifting the booster flow rate (Q_b) is:

$$HP_b = \frac{Q_b \; W \; L_o}{550 \; E} \qquad (6)$$

where: HP_b is the horsepower required for boosting. An equation representing the number of boosters can be expressed as:

$$N_b = \frac{HP_b}{HP_u} \qquad (7)$$

After combining equations (6) and (7), the equation to determine the number of boosters takes the form:

$$N_b = \frac{Q_b \; W \; L_o}{550 \; E \; HP_u} \qquad (3)$$

Derivation of Equation to Determine Required Number of Pumps

The number of ground water pumps was derived in a manner similar to that for boosters. The difference was that there were two types of ground water pumps: those that lift water to ground surface for subsequent boosting to operating head and those that lift the water directly to operating head.

The number of pumps that lift ground water to ground surface for subsequent boosting was determined by writing the equation for the horsepower required to lift the flow rate of water (Q_g) to ground surface and dividing by the horsepower of a modular unit pump motor. The equation for power required to pump an amount of ground water (Q_g) to ground surface is:

$$HP_g = \frac{Q_g W (L_d + L_g)}{550 E} \qquad (8)$$

where: HP_g = total horsepower of ground water pumps, lifting ground water to ground surface elevation,

Q_g = total capacity of ground water pumps, lifting ground water to ground surface elevation, in cubic feet per second.

The number of pumps required to deliver the flow rate (Q_g) to ground surface is:

$$N_g = \frac{Q_g W (L_d + L_g)}{550 E HP_u} \qquad (9)$$

The number of pumps that lift ground water directly to operating head was determined by writing the equation for the horsepower required to lift ground water directly to operating head and dividing this by the horsepower of a modular unit pump motor. The equation for power required to pump an amount of water (Q_o) directly to operating head is:

$$HP_o = \frac{Q_o W (L_d + L_g + L_o)}{550 E} \qquad (10)$$

where: HP_o = the horsepower required to lift ground water directly to operating head, and

Q_o = the flow capacity of the pumped water, in cubic feet per second.

The number of ground water pumps lifting ground water directly to operating head is:

$$N_o = \frac{Q_o W (L_d + L_g + L_o)}{550 E HP_u} \qquad (11)$$

A survey of existing pumps in the study area revealed that the number of pumps that lift ground water to operating head is approximately equal to the number of pumps that lift ground water to ground level for subsequent boosting to operating head. The survey also showed the sump capacity to be small and, because of this, the flow capacity (Q_g) of pumps supplying sumps was assumed to equal the flow capacity of boosters lifting this water to operating head (Q_b). Thus, it was presumed that the above relationships would hold in the future. They are shown in equation form below:

$$N_o = N_g \tag{12}$$

and

$$N_p = N_g + N_o \tag{13}$$

or

$$N_p = 2\ N_g \tag{14}$$

and

$$Q_b = Q_g \tag{15}$$

By substitution of equations (9) and (15) into equation (14), the total number of pumps (N_p) in terms of booster capacity (Q_b) is:

$$N_p = \frac{2Q_b\ W\ (L_d + L_g)}{550\ E\ HP_u} \tag{4}$$

Derivation of Equations to Determine Required Number of Storage Facilities

As indicated earlier, equations (5) and (5a) were developed to determine the number of storage tanks. Equation (5) is applicable to cases where flow from storage facilities is less than the average flow rate required to meet the water demand on a day of maximum demand.

Equation (5a) is applicable to cases where the flow from storage facilities is more than the average demand flow rate on that same day. These equations were derived by establishing the following: (1) the relation between the volume of storage required and the rate of flow from storage facilities, (2) the relation between flow from surface storage and booster capacity, and (3) the required volume of storage and the volume of a modular storage facility.

Relation Between Release Rate and Volume

To obtain a relation between the required peak release rate from storage and the volume of storage required, a relation was established between water supply and demand; this relation is illustrated on Figure 2(C, Chapter 2. Because the storage is normally used to even fluctuations in water demand, the supply from storage is shown as the top area under this curve. With a typical hourly water demand curve for the Coastal Plain developed, the relation between storage flow and storage volume was determined by plotting the distance down from the peak hourly demand (storage flow) against the volume accumulated under the hourly water demand curve (storage volume). The relation between the surface storage volume required to meet the hourly water demand variation on the day of maximum water demand and the maximum flow release rate required from storage facilities is shown on Figure 5A. The shape of the curve approximates a parabola up to and including 100 percent of the flow rate from surface storage and a straight line above 100 percent of the flow rate from surface storage. The equation that approximates the flow rate volume relationship for the water demand curve is as follows:

$$V_p = \frac{Q_p^2}{25.9} \quad (16)$$

when

$$Q_p \leq 100$$

and

$$V_p = 17.5Q_p - 1{,}333 \quad (16a)$$

when

$$Q_p > 100$$

where V_p is the volume of storage in percent-hours and Q_p is the flow from storage expressed as a percent of the average demand on the day of maximum water demand (D_d). Equation (16) is for the case where the flow required is less than 100 percent of the average flow on a day of maximum water demand, and equation (16a) is for the case where flow is greater than 100 percent. The constants for these equations are related, in terms of units of flow in cubic feet per second and the volume in cubic feet, as follows:

$$Q_p = \left(\frac{Q_s}{D_d}\right) 100 \quad (17)$$

where Q_s is the flow rate from storage in cubic feet per second.

For storage release rates that are less than 100 percent of the average flow on the day of maximum water demand, the required volume of storage is:

$$V_p = \frac{\left[\left(\frac{Q_s}{D_d}\right) 100\right]^2}{25.9} \quad (18)$$

Equation (18), transformed into volume in cubic feet, is:

$$V_r = \frac{\left[\left(\frac{Q_s}{D_d}\right) 100\right]^2 \left(\frac{D_d}{100}\right) 3{,}600}{25.9}$$

or

$$V_r = 13,900\left(\frac{Q_s^2}{D_d}\right) \qquad (19)$$

Because the flow capacities of the water supply facilities are designed to meet the peak flow water demand, the relationship of water supply to water demand is:

$$D_m = Q_f + Q_t + Q_s \qquad (20)$$

where Q_t is the flow, in cubic feet per second, from all pumps pumping ground water. Equation (20), rewritten in terms of surface storage flow capacity (Q_s), is:

$$Q_s = D_m - Q_t - Q_f \qquad (21)$$

By substituting equation (21) for the surface storage flow capacity (Q_s) in equation (19), the volume of storage is:

$$V_r = \frac{13,900\ (D_m - Q_t - Q_f)^2}{D_d} \qquad (22)$$

When the flow release rate from surface storage is more than 100 percent, the volume of storage, in percent-hours, is:

$$V_p = 17.5\ \left(\frac{Q_s}{D_d}\right)\ 100 - 1,333 \qquad (23)$$

Converting this equation to cubic feet results in:

$$V_p = \left[17.5\ \left(\frac{Q_s}{D_d}\right)\ 100 - 1,333\right]\ \left(\frac{D_d}{100}\right)\ 3,600$$

or

$$V_r = 63,000\ Q_s - 48,000\ D_d \qquad (24)$$

In a study of the water demand for the Coastal Plain of Los Angeles County, the relationship between average hourly water demand on a day of maximum water demand and the peak hourly water demand on this day is:

$$D_h = 2D_d \qquad (25)$$

where D_h is the peak hourly water demand on the day of maximum water demand, in cubic feet per second. In areas that have large volumes of existing storage, the fire protection requirement was handled separately. The peak hourly water demand then is the maximum flow demand of the facilities and this relation is expressed as:

$$D_h = D_m = 2D_d \qquad (26)$$

By substituting equation (26) for the maximum hourly water demand (D_m) in equation (21), the following equation is obtained:

$$Q_s = 2D_d - Q_t - Q_f \qquad (27)$$

Incorporating equation (27) into equation (24), the equation to determine the volume of storage required on the maximum water demand day is:

$$V_r = 63{,}000\ (2D_d - Q_f - Q_t) - 48{,}000\ D_d$$

or

$$V_r = 78{,}000\ D_d - 63{,}000\ (Q_f + Q_t) \qquad (28)$$

Relation Between Total Pump Capacity and Booster Flow Capacity

To write an equation expressing the volume of surface storage in terms of booster capacity, a relationship had to be developed between the total ground water pump capacity and the booster capacity. The booster capacity was then substituted into the storage volume equations (22) and (28) to get the equation in terms of booster capacity.

The total pump capacity is equal to the capacity of pumps that lift ground water to ground surface for subsequent boosting, plus the capacity of pumps that lift ground water directly to operating head. The total pump capacity can be expressed as:

$$Q_t = Q_g + Q_o \tag{29}$$

In a previous discussion it was shown that:

$$N_g = N_o \tag{12}$$

$$N_g = \frac{Q_g\ W\ (L_d + L_g)}{550\ E\ HP_u} \tag{9}$$

and

$$N_o = \frac{Q_o\ W\ (L_d + L_g + L_o)}{550\ E\ HP_u} \tag{11}$$

By equating equations (9) and (11) and simplifying, the relation between Q_g and Q_o is:

$$Q_o = \frac{Q_g\ (L_d + L_g)}{L_d + L_g + L_o} \tag{30}$$

Then, by substituting equation (30) into equation (29), the total pump capacity can be expressed as:

$$Q_t = Q_g\ (1 + \frac{L_d + L_g}{L_d + L_g + L_o})$$

or

$$Q_t = FQ_g \tag{31}$$

where:

$$F = 1 + \frac{L_d + L_g}{L_d + L_g + L_o} \tag{32}$$

Then, by substituting equation (15) into equation (31),

$$Q_t = FQ_b \tag{33}$$

The factor F is multiplied by the capacity of boosters lifting water from ground surface to operating head to determine the total capacity of all pumps that extract ground water.

Storage Required During Maximum Water Demand

The demand on the day of maximum water requirement is met, simultaneously, from three sources of supply: the distribution system, the pumping facilities, and the storage facilities. The day of maximum water demand was based on a period of five consecutive days with the maximum water demand. The method of using storage depends upon the use of the distribution system and pumping facilities on this day. Two methods of utilizing storage on the maximum day of water demand are possible: (1) storage can be used just to even out fluctuations in demand on the day of maximum water demand, if the distribution system and pumping facilities can supply the volume of water demand on this day; or (2) in addition to evening out fluctuations in water demand, storage can be used as a supply source of water to meet a portion of the maximum water demand for five maximum days, when the distribution system and pumping facilities cannot meet the quantity of water required.

Storage is required only to even out fluctuations in demand on the day of maximum water demand when the distribution system and ground water pumping facilities can supply 100 percent of the average water demand, but not the peak flow rate demand. The peak hourly water demand on the day of maximum water demand within the Coastal Plain of Los Angeles County is approximately 200 percent of the average demand on this day. Therefore, storage is required only for evening out fluctuations in water demand for storage flows up to 100 percent of the average demand on the day of maximum water demand.

The storage required to even out fluctuation in demand when the capacities of the distribution system and pumping plants are adequate to meet the average water demand on the day of maximum water demand is derived as follows: because the storage is used only for evening out fluctuations in demand, the volume of storage required on the day of maximum water demand equals the volume of storage required for the duration of the maximum five-day demand period. Thus, relationship can be expressed as:

$$V_s = V_r \tag{34}$$

By substituting equation (22) into equation (34), then:

$$V_s = \frac{13{,}900\ (D_m - Q_t - Q_f)^2}{D_d} \tag{35}$$

since,

$$Q_t = FQ_b \tag{33}$$

then,

$$V_s = \frac{13{,}900\ (D_m - Q_f - FQ_b)^2}{D_d} \tag{36}$$

Storage is required for both evening out fluctuations and a source of supply when the storage flow required is more than 100 percent of the average demand flow rate on a day of maximum water demand. This storage is required when the combined capacity of feeders and pumping plants is less than the average rate of water demand on the day of maximum water demand. Then, the remaining demand must be met from the release from surface storage facilities, a part of which is not refilled during the five consecutive days for subsequent release. Equation (22) was derived to determine the volume of storage required under this flow condition during any one maximum water demand day. The equation for the storage volume that cannot be refilled is:

$$V_{ir} = V_{md} - V_x \tag{37}$$

where: V_{ir} = the irreplaceable volume of water, in cubic feet, in storage on the day of maximum water demand,

V_{md} = the total volume of water demand, in cubic feet, on the day of maximum water demand,

V_x = the volume of water, in cubic feet, delivered through feeders and pumping plants.

The total volume of water demand on the day of maximum water demand and the volume of water delivered through feeders and ground water pumping plants in terms of cubic feet are:

$$V_{md} = 86{,}400\ D_d \tag{38}$$

and

$$V_x = 86{,}400\ (Q_t + Q_f) \tag{39}$$

The total storage required for five consecutive days of maximum demand in cubic feet is:

$$V_s = 5V_{ir} + (V_r - V_{ir}) + V_f$$

or

$$V_s = 4V_{ir} + V_r + V_f \tag{40}$$

where V_s is the total storage volume required, and V_f is the recommended fire flow for the duration specified by the National Board of Fire Underwriters, in cubic feet.

By making the following substitutions, equation (36) is transformed in terms of the flow capacity of boosters (Q_b). In this transformation, equations (28) and (33) are first substituted into equation (40), and the total storage volume required is:

$$V_s = 4V_{ir} + 78{,}000\ D_d - 63{,}000\ (Q_f + FQ_b) + V_f$$

After substituting equation (37) into the above equation,

$$V_s = 4\ (V_{md} - V_x) + 78{,}000\ D_d - 63{,}000\ (Q_f + FQ_b) + V_f.$$

Finally, substituting equations (38) and (39)

$$V_s = 4\ (86{,}400\ D_d - 86{,}400\ FQ_b - 86{,}400\ Q_f)$$
$$+ 78{,}000\ D_d - 63{,}000\ (Q_f + FQ_b) + V_f$$

or

$$V_s = 423{,}600\ D_d - 408{,}600\ (Q_f + FQ_b) + V_f \qquad (41)$$

Equation (41) was used in operational and economic analyses of areas that have large existing storage capacities.

Number of Storage Tanks

In the previous equations, the volume of storage was written in terms of booster flow capacity (Q_b) for two ranges of storage flow: for storage flows up to 100 percent of the average annual demand on the day of maximum water demand, and for storage flows greater than 100 percent of the average demand flow rate on this day. Equations for the number of storage tanks required were derived by dividing the terms in equations (36) and (41), by the volume of a modular storage tank which was assumed to be 66,800 cubic feet (500,000 gallons).

The number of storage tanks required for storage flows below 100 percent of the average demand flow rate on the day of maximum water demand is derived as follows:

$$V_s = \frac{13,900\ (D_m - FQ_b - Q_f)^2}{D_d} \qquad (36)$$

and

$$N_s = \frac{V_s}{V_t}$$

or

$$N_s = \frac{13,900\ (D_m - FQ_b - Q_f)^2}{D_d\ V_t} \qquad (5)$$

The number of storage tanks required for storage flows greater than 100 percent of the average demand flow rate on the day of maximum water demand is the volume of storage divided by the volume per tank and is derived as follows:

$$V_s = 423,600\ D_d - 408,600\ (Q_f + FQ_b) + V_f \qquad (41)$$

and

$$N_s = \frac{V_s}{V_t}$$

or

$$N_s = \frac{423,600\ D_d - 408,600\ (Q_f + FQ_b) + V_f}{V_t} \qquad (5a)$$

Determination of Unit Cost of Facilities and Energy Cost

The determinations of unit annual cost of boosting, pumping, and storage facilities (U_p, U_b, and U_s), electrical energy charge (U_e), and the electrical energy connection service charge (U_c) are discussed in detail in Attachment No. 7. The unit costs of facilities are fixed costs, that is, the unit cost of a facility does not vary with the pump capacity because modular-sized units are used. However, the electrical energy cost is given in three rate schedules depending upon the use of the pump. Three equations of energy cost were developed relating the cost of energy to flow capacity of boosters (Q_b).

Determination of Electrical Energy and Service Connection Charges

To determine the cost of electrical energy consumption and the cost of electrical energy service connection, the current cost rate schedule of the Southern California Edison Company, a major supplier of electrical energy in the study area, was used. A portion of the cost rate schedule is shown in Attachment No. 7.

The energy consumption charge per pump varies by three rate schedules, depending upon the duration that a pump is used. Three equations were developed for three ranges of pump use factors from Southern California Edison Company Cost Schedule PA-1 and are presented below:

For pump use factors between 0 and 15 percent,

$$U_{e_1} = \left[(0.0136 \text{ Dollars/KWHR})(6530\text{KWHR/HP-YR})(\text{UF})\right] \text{HP}_u \tag{42}$$

For pump use factors between 15 and 30 percent,

$$U_{e_2} = \left[(0.0082 \text{ Dollars/KWHR})(6530\text{KWHR/HP-YR})(\text{UF}) + 5.4\right] \text{HP}_u \tag{43}$$

For pump use factors of 30 percent and larger,

$$U_{e_3} = \left[(0.0064 \text{ Dollars/KWHR})(6530\text{KWHR/HP-YR})(\text{UF}) + 9.0\right] \text{HP}_u \tag{44}$$

The symbols used in the energy cost equations are:

U_{en} = unit energy consumption charge, with the subscript "n" referring to subscript 1, 2, or 3 in equations (42), (43), and (44),

KWHR = kilowatt-hours,

HP-YR = horsepower-year,

UF = the use factor of pumping is expressed as the annual ground water extraction, in cubic-feet per second, divided by the peak hourly rate of extraction FQ_b, in cubic feet per second.

Because all the ground water facilities were assumed to be utilized with the same set of use factor equations given above, the total energy cost for all units of pumping and boosting can be expressed by the following equation:

$$E_c = (N_g + N_o + N_b)\ U_{en} \qquad (45)$$

where E_c = total energy cost for all units of pumping and boosters.

The equations for the number of pump and booster facilities were previously derived in terms of booster flow capacity (Q_b) and are repeated here for convenience:

$$N_b = \frac{Q_b W\ L_o}{550\ E\ HP_u} \qquad (3)$$

and

$$N_g + N_o = N_p = \frac{2Q_b\ W\ (L_d + L_g)}{550\ E\ HP_u} \qquad (4)$$

Hence, the cost of electrical energy of pumps and boosters is:

$$E_c = \left(\frac{2Q_b\ W\ (L_d + L_g)}{550\ E\ HP_u} + \frac{Q_b\ W\ L_o}{550\ E\ HP_u}\right) U_{en} \qquad (46)$$

Annual service connection charge per pump is $6.50 per horsepower per year for a pump with a 100-horsepower or larger motor. Because all the pumps and boosters were considered to have a 100-horsepower motor, the total annual service connection charge for all ground water pumping units then, is:

$$P_c = (HP_g + HP_o + HP_b)(6.50 \text{ Dollars/HP-YR}) \quad (47)$$

Substituting equations (6), (8), and (10) for horsepower of each pumping facility in terms of flow capacity of boosters (Q_b), the equation for cost of electrical service connection becomes.

$$P_c = \left(\frac{Q_g W (L_d + L_g)}{550 E} + \frac{Q_o W (L_d + L_g + L_o)}{550 E} + \frac{Q_b W L_o}{550 E}\right)(6.50) \quad (48)$$

where P_c is the total cost of electrical service connection, in dollars. However, it was previously shown that:

$$Q_o = \frac{Q_g (L_d + L_g)}{L_d + L_g + L_o} \quad (30)$$

and

$$Q_b = Q_g \quad (15)$$

By substituting the above two equations into equation (48), the following connection service charge equation results:

$$P_c = \left(\frac{Q_b W (2L_d + 2L_g + L_o)}{550 E}\right)(6.50) \quad (49)$$

Development of Cost Equation to Determine
Most Economical Flow Capacity of Facilities

Utilizing the relationship developed heretofore, equation (2) was rewritten in the following form:

$$C_t = N_p U_p + N_b U_b + N_s U_s + E_c + P_c \quad (50)$$

where: E_c = the total annual energy cost,

P_c = the total annual connection service cost of the entire ground water pump and booster facilities.

The number and horsepower of facilities, derived in the previou section in terms of booster flow capacity (Q_b), were substituted into equation (50) resulting in the following cost equation:

$$C_t = \frac{2Q_b W (L_d + L_g)}{550 E HP_u} U_p + \frac{Q_b WL_o}{550 E HP_u} U_b + \frac{13{,}900 (D_m - Q_f - FQ_b)^2}{D_d V_t} U_s$$

$$+ \left(\frac{2Q_b W (L_d + L_g)}{550 E HP_u} + \frac{Q_b WL_o}{550 E HP_u}\right) U_{en} + \left(\frac{Q_b W (2L_d + 2L_g + L_o)}{550 E}\right)(6.50) \quad (51)$$

The term "U_{en}" is applicable to any of the three equations (42), (43), and (44). However, for illustration, equation (42) is used exclusively in the subsequent discussion.

By applying the definition of use factor to equation (42), the unit cost of energy consumption is expressed in terms of booster flow capacity (Q_b) as:

$$U_{e_1} = \frac{1.227 \text{ EXTR}}{FQ_b} \quad (52)$$

where EXTR = annual ground water extraction in acre-feet per year.

Simplifying equation (51) by substituting equation (52), and by substituting the values of 62.4 pounds per cubic foot for the unit weight of water, W; 0.65 for the efficiency of the pump unit, E; 100 for the horsepower of a modular unit, HP_u; and 66,800 cubic feet for the volume per modular tank, V_t; the cost equation is:

$$C_t = 0.00349\, Q_b (L_d + L_g) U_p + \left(\frac{Q_b}{3.82}\right) U_b +$$
$$\left[\frac{0.208 (D_m - Q_f - FQ_b)^2}{D_d}\right] U_s +$$
$$0.00174\, Q_b (2L_d + 2L_g + L_o)\, 1.227 \left(\frac{\text{EXTR}}{FQ_b}\right) +$$
$$0.174\, Q_b (2L_d + 2L_g + L_o)(6.50) =$$
$$0.00349\, Q_b (L_d + L_g) U_p + \left(\frac{Q_b}{3.82}\right) U_b +$$
$$\left[\frac{0.208 (D_m - Q_f - FQ_b)^2}{D_d}\right] U_s +$$
$$0.00213 (2L_d + 2L_g + L_o)\left(\frac{\text{EXTR}}{F}\right) +$$
$$1.134\, Q_b (2L_d + 2L_g + L_o) \quad (53)$$

With the total cost expressed as a function of the booster flow capacity, principles of calculus were applied to determine the booster flow capacity at the minimum cost. The most economical booster flow capacity was determined by first taking the derivative of the total cost with respect to booster flow capacity, and then setting the derivative to zero. The resulting booster flow capacity is the capacity at the minimum cost. The second derivative of the total cost equation, equation (53), is always positive. Accordingly, the solution provides the value of Q_b that results in the least total annual cost in all cases. Differentiating equation (53) with respect to Q_b and using 150 feet for the pumping lift from ground surface to operating head, L_o, results in:

$$\frac{dC_t}{dQ_b} = 0.00349\ (L_d + L_2)\ U_p + \frac{U_b}{3.82}$$

$$+ \left(\frac{0.416\ FU_s}{D_d}\right)(Q_f + FQ_b - D_m)$$

$$+ 0 + 2.269\ (L_d + L_g) + 170.2 \qquad (54)$$

Setting equation (54) equal to zero, and solving for the booster flow capacity (Q_b), at the minimum cost:

$$Q_b = \left(\frac{D_m - Q_f}{F}\right) - \left(\frac{D_d}{0.416F^2\ U_s}\right)\Big[(L_d + L_g)(2.269 + 0.00349\ U_p$$

$$+ 170.2 + \frac{U_b}{3.82})\Big] \qquad (55)$$

The numbers 2.269 and 170.2 in equation (55) are used because equation (42) was used in this illustration; these numbers change when equation (43) or (44) is used in the general equation. For a general solution, symbols X and Y are substituted for these numbers. Then, equation (55) becomes:

$$Q_b = \left(\frac{D_m - Q_f}{F}\right) - \left(\frac{D_d}{0.416F^2\ U_s}\right) \left[(L_d + L_g)(X + 0.00349\ U_p + Y + \frac{U_b}{3.82})\right] \quad (56)$$

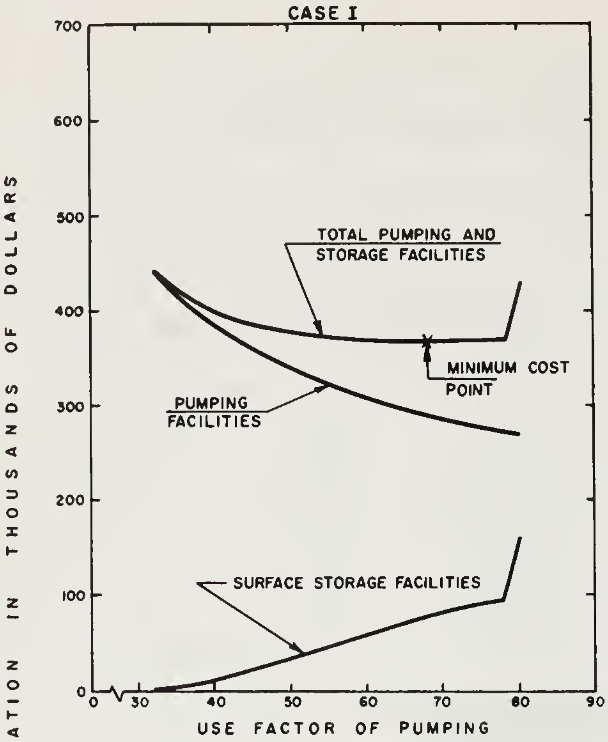
The corresponding values of X and Y for each energy cost equation are listed below:

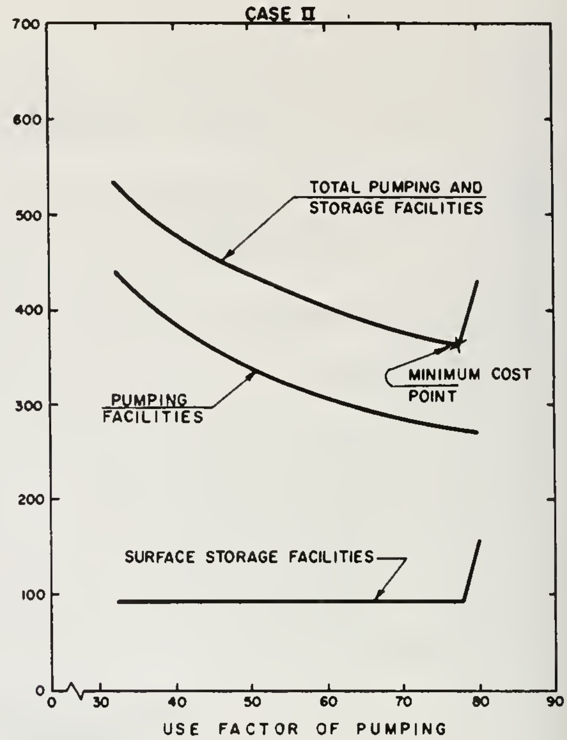
	X	Y
Equation (42)	2.269	170.2
Equation (43)	4.154	311.5
Equation (44)	5.411	405.7

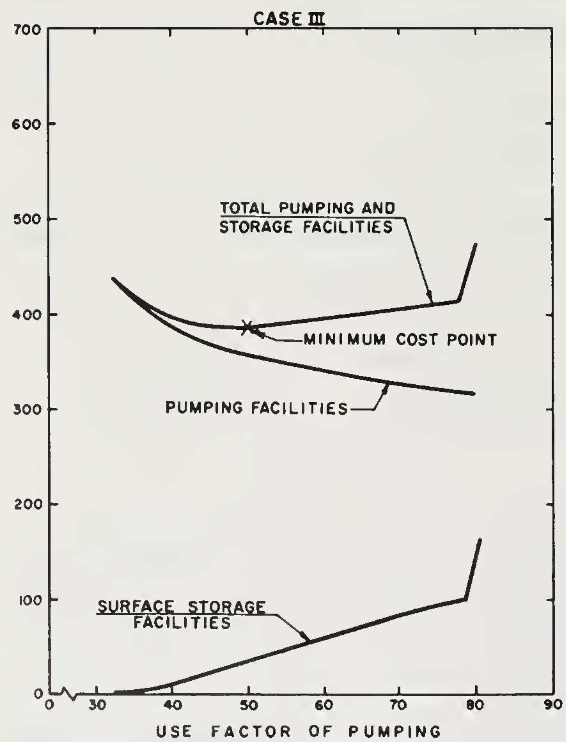
Determination of Most Economical Combination of Facilities

The cost equation to determine the most economical flow capacity of facilities is greatly affected by the capacity of existing ground water pumping, boosting, and surface storage facilities. This effect is shown on Figure 9-1, which was developed for a plan with a large extraction in economic area 5 for 1978. In one case, the result of equation (56) can be used directly, while in two general cases the equation cannot be used directly. The two cases where equation (56) cannot be used directly can be combined to illustrate a fourth case. These four cases can be used to account for all variations in the use of equation (56).

In the development of equation (56), the total number of all modular facilities required was assumed to vary with the capacity of facilities required. However, this is not true in all cases. When the capacity of existing facilities is larger than the capacity of the required facilities, the cost of the facilities in the cost equation becomes







LEGEND

THE RELATIONSHIP OF USE FACTOR OF GROUND WATER PUMPING TO THE COST OF SUPPLYING WATER TO MEET MAXIMUM HOURLY WATER DEMANDS IS REPRESENTED BY THREE CASES:

CASE I THE CAPACITIES OF EXISTING PUMPING AND STORAGE FACILITIES ARE LESS THAN THAT REQUIRED TO IMPLEMENT AN OPERATIONAL PLAN.

CASE II THE CAPACITY OF EXISTING PUMPING FACILITIES IS LESS THAN THAT REQUIRED BUT THE CAPACITY OF EXISTING STORAGE FACILITIES IS GREATER THAN THAT REQUIRED TO IMPLEMENT AN OPERATIONAL PLAN.

CASE III THE CAPACITY OF EXISTING PUMPING FACILITIES IS GREATER THAN THAT REQUIRED, BUT THE CAPACITY OF EXISTING STORAGE IS LESS THAN THAT REQUIRED TO IMPLEMENT AN OPERATIONAL PLAN.

NOTE: THE CURVES WERE BASED ON THE WATER SUPPLY AND DEMAND DATA FOR ECONOMIC AREA 5 FOR THE YEAR 1978 UNDER A PLAN OF OPERATION EXTRACTING THE MAXIMUM AMOUNT OF GROUND WATER ALLOWABLE.

THE SHARP CHANGE IN SLOPE ON THE STORAGE COST CURVE IS CAUSED BY THE ADDITIONAL STORAGE FACILITIES REQUIRED TO CONFORM TO THE CRITERIA THAT THE FACILITIES MUST BE PROVIDED TO MEET THE MAXIMUM DEMAND FOR AT LEAST FIVE CONSECUTIVE DAYS. IN EACH OF THESE CASES, THIS CRITERIA BECOMES A MAJOR FACTOR AT A 78 PERCENT USE FACTOR.

IN THIS PARTICULAR PLAN OF OPERATION, WHEN THE USE FACTOR IS BELOW 78 PERCENT, THE PUMP UNITS AND FEEDERS CAN SUPPLY THE VOLUME OF WATER REQUIRED ON THE MAXIMUM WATER DEMAND DAY AND STORAGE IS REQUIRED ONLY TO REGULATE HOURLY FLUCTUATIONS IN DEMAND. HOWEVER, WHENEVER THE PUMP USE FACTOR EXCEEDS 78 PERCENT, THE PUMP AND FEEDER CANNOT SUPPLY THE VOLUME OF WATER REQUIRED ON THE MAXIMUM WATER DEMAND DAY. THE STORAGE IS THEN REQUIRED FOR TWO PURPOSES: (1) TO EVEN OUT HOURLY FLUCTUATIONS IN DEMAND, AND (2) TO SUPPLY THE DEFICIENCY IN DEMAND FOR FIVE CONSECUTIVE MAXIMUM WATER DEMAND DAYS.

DIAGRAMS SHOWING RELATION BETWEEN USE FACTOR OF PUMPING AND COST OF FACILITIES AND OPERATION FOR MEETING MAXIMUM HOURLY WATER DEMANDS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT 1966 a constant and the resulting derivative of the facilities structures cost becomes zero. Consequently, the equation to determine the most economic facilities capacity is modified. The following discussions will present the four general cases in which equation (56) can be used.

Case I

In case I, shown on Figure 9-1, where the capacities of existing pumping and storage facilities are smaller than the capacities computed by using equation (56), the equation can be utilized without modification to determine the booster capacity (Q_b) and, subsequently, the numbers of pumping and storage facilities for the most economical combination.

In the evaluation of annual costs of unit pumping and storage facilities, it was assumed that interest rates, economic lives, and construction cost would be the same, whether the facilities considered are existing or are to be constructed. For this reason, as long as all facilities are utilized, annual cost of facilities and maintenance and operation of such facilities would be the same, whether the facilities are existing or to be added.

In case I, because the capacities of the existing facilities are less than those computed, new facilities must be added and all must be utilized. Therefore, equation (56) is applicable.

Case II

In case II, on Figure 9-1, where the capacity of existing pumping facilities is less than that computed by equation (56), but the capacity of existing storage facilities is larger than the capacity indirectly determined by using the solution for Q_b, equation (56) cannot be directly utilized.

By using all the existing storage facilities, the capacity of pumping can be made smaller to meet the identical water requirement. This indicates that a smaller number of pumps is required and those pumps can be operated at a higher use factor than determined by the use of equation (56). Because the annual cost of existing storage facilities would be the same whether they are used or not, the annual cost of pumping facilities would be less if a smaller number is used at a higher use factor. The maximum use of the existing storage facilities and minimum use of pumping facilities would result in the most economical cost.

Case III

In case III, as shown on Figure 9-1, where the capacity of existing pumping facilities is larger than that computed by using equation (56), but the capacity of existing storage volume is smaller than the corresponding capacity computed, a modified equation must be utilized to determine the most economical combination.

In equation (53), the terms 0.00349 Q_b $(L_d + L_g)$ U_p and $\frac{Q_b U_b}{3.82}$ represent the total annual cost of the required pumps and boosters, respectively, when the capacities of existing pumping facilities are smaller than those computed by use of equation (53). Whenever the numbers of existing pumps and boosters are larger than computed, the annual cost of those facilities would be constant, thus, they would no longer be a function of Q_b. The derivative of those terms then becomes zero and the resulting equation for Q_b takes the form:

$$Q_b = \left(\frac{D_m - Q_f}{F}\right) - \left(\frac{D_d}{0.416F^2\, U_s}\right)\left[(L_d + L_g)\, 2.269 + 170.2\right] \quad (57)$$

The term Q_b is found by using equation (57) and the capacity of pumping facilities resulting from this solution is compared to the capacity of existing pumping facilities. If the existing pumping capacity is larger than that computed, the computed figure is used as the most economical capacity. However, if the booster and pump capacity computed by use of equation (57) is larger than that existing, the existing capacity is used as the most economical.

Case IV

Case IV is a combination of cases II and III using storage costs of case II with the pump costs of case III. By combining these curves, it can be shown that the most economical combination of facilities will occur when existing storage is utilized at a maximum and pumping supplies are kept at the largest possible use factor to meet the remaining demand.

Because structure costs for certain ranges, where the capacities of existing facilities exceed the capacity of the required facilities, would become constants, the most economical combination of facilities to meet the water demand would satisfy the most economical operating costs of these facilities. This would be accomplished by utilizing existing storage as much as possible and by reducing the amount of peaking from pump facilities. The storage operation and maintenance costs are minor compared with the costs of pump energy.

The variable portion of the total cost equation within the range where pump, booster, and surface storage facilities costs are all constants consists of the cost of electrical energy and service connection. The first derivative of the total cost equation with respect to the booster flow capacity is a constant. The booster flow capacity (Q_b) term drops out, indicating this is a straight line equation. Therefore, within this range the most inexpensive combination of facilities would be that which minimizes the electrical energy cost and service connection charge; this results in using existing storage to a maximum and pumping at the largest use factor.

TABLE 9-1

DEFINITION OF SYMBOLS USED IN EQUATIONS TO DETERMINE THE MOST ECONOMICAL COMBINATION OF PUMP AND SURFACE STORAGE FACILITIES

Equation symbol	Symbol used in computer program	Description
C_b	----	Total annual cost of boosting, including cost of booster units, electrical energy, and electrical energy connection service charge, in dollars.
C_p	----	Total annual ground water pump structures cost including wells, pumps, motors, controls, normal accessories, right-of-way, maintenance, and operation, in dollars.
C_s	----	Total annual cost of surface storage which includes storage tank, foundation, excavation, normal accessories, and right-of-way, in dollars.
C_t	----	Total annual cost of boosting, pumping ground water, and surface storage facilities, in dollars.
D_d	DM	Average water demand flow rate on day of maximum water demand, in cubic feet per second.
D_h	PHD	Peak hourly water demand on the day of maximum water demand, in cubic feet per second.
D_m	DAM	Maximum flow rate of water required under peak conditions with maximum flow equal to the peak hourly water demand on the day of maximum water demand, plus the fire flow, in cubic feet per second.
E_c	----	Energy cost for pumps and boosters, in dollars.

DEFINITION OF SYMBOLS USED IN
EQUATIONS TO DETERMINE THE MOST ECONOMICAL
COMBINATION OF PUMP AND SURFACE STORAGE FACILITIES
(continued)

Equation symbol	Symbol used in computer program	Description
F	A	The head relationship between the total pump capacity and the capacity of pumps pumping to sumps only.
HP_b	----	Total booster pump horsepower.
HP_g	----	Total horsepower of ground water pumps pumping to ground surface.
HP_o	----	Total horsepower of ground water pumps pumping directly to distribution system operating head
HP_u	----	Horsepower per modular unit.
HP-YR	----	Horsepower-year.
KWHR	----	Kilowatt hours.
L_d	----	Well drawdown, in feet.
L_g	H	Distance between the static water level and ground surface, in feet.
L_o	----	Distance between ground surface and operating head of distribution system, in feet.
N_b	XNB	Number of boosters required within the distribution system to boost ground water from ground surface to distribution system operating head.
N_g	----	Number of ground water pumps pumping to ground surface.
N_o	----	Number of ground water pump units pumping directly to operating heads within the distribution system.
N_p	XNP	Total number of ground water pump units within the system.
N_s	XNS	Number of storage units within the system.

DEFINITION OF SYMBOLS USED IN
EQUATIONS TO DETERMINE THE MOST ECONOMICAL
COMBINATION OF PUMP AND SURFACE STORAGE FACILITIES
(continued)

Equation symbol	Symbol used in computer program	Description
P_c	----	Total cost of electrical service connection, in dollars.
Q_b	QS	Rate of pumping booster units, in cubic feet per second.
Q_f	FEDR	Rate of peak flow from feeder supply, in cubic feet per second.
Q_g	QS	Rate of flow of ground water pumps pumping to sumps, in cubic feet per second.
Q_o	----	Rate of flow of ground water pumps pumping directly to system operating head, in cubic feet per second.
Q_p	----	Flow from storage as a percent of average demand on a maximum water demand day.
Q_t	QP	Rate of flow of all ground water pumps, in cubic feet per second.
Q_s	SF	Peak rate of flow from storage facilities, in cubic feet per second.
U_b	UCB	Unit annual cost of booster pump, including structures, pump, motor, right-of-way, normal accessories, maintenance, and operation but not including power, in dollars.
U_c	UCC	Annual cost of electrical energy connection service charge per modular-sized booster or ground water pump unit, in dollars.
U_e	CE	Annual cost of electrical energy per modular-sized motor, in dollars. There are three ranges of energy cost depending upon the use of the motor unit.
U_p	UCP	Average annual cost of ground water pump unit which includes well, pump, motor, controls, normal accessories, right-of-way, maintenance, and operation, in dollars.

DEFINITION OF SYMBOLS USED IN
EQUATIONS TO DETERMINE THE MOST ECONOMICAL
COMBINATION OF PUMP AND SURFACE STORAGE FACILITIES
(continued)

Equation symbol	Symbol used in computer program	Description
U_s	UCS	Average annual cost of a surface storage unit which includes storage tank, foundation, excavation, normal accessories, and right-of-way, in dollars.
UF	UF	Use factor of pumping expressed as a fraction.
V_f	FVOL	Volume of fire requirement storage.
V_{ir}	----	Difference between the volume of water required on the day of maximum water demand and the volume of water available from the pump and feeder supply, in cubic feet.
V_{md}	----	Volume of water demand on the day of maximum water demand, in cubic feet.
V_p	----	Volume of storage flow required on a maximum day of water demand, in percent-hours.
V_r	VR	Volume of storage required to meet demand on maximum day of water demand, in cubic feet.
V_s	VS	Total volume of storage used for duration of maximum demand period, in cubic feet.
V_t	----	Volume per storage tank, in cubic feet.
V_x	----	Volume of water available to the storage facilities from the feeder and pumping supply sources on the day of maximum water demand, in cubic feet.
W	----	Unit weight of water, 62.4 pounds per cubic foot.
X, Y	----	Factors substituted for constants that vary with pump use factors in energy cost equations.

ATTACHMENT NO. 10

OPERATIONAL-ECONOMIC COMPUTER ANALYSES OF
ALTERNATIVE PLANS OF OPERATING THE GROUND WATER BASINS
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY

ATTACHMENT No. 10

OPERATIONAL-ECONOMIC COMPUTER ANALYSES OF ALTERNATIVE PLANS OF OPERATING THE GROUND WATER BASINS IN THE COASTAL PLAIN OF LOS ANGELES COUNTY

Introduction

For the investigation of the planned utilization of the ground water basins in the Coastal Plain of Los Angeles County, a large number of alternative plans of operation were operationally and economically analyzed and compared. For this comparison, numbers and costs of all items of both ground and surface water supplies and facilities that varied according to alternative plans of operation were considered. This involved innumerable simple computations and required a large number of tabulations even for a single plan of operation, which would have been a formidable task to accomplish by the use of desk calculators and typewriters. Therefore, a digital computer and an on-line printer, which are available at the Southern District Office of the Department of Water Resources, were utilized.

The computer used was an IBM-1620 digital computer, with a 20,000-digit memory unit, linked to an IBM-1622 card read-punch unit as an input-output medium. Even though this computer is very versatile, the 20,000-digit memory unit was not adequate to handle all computations in a single phase. Therefore, the analyses for each alternative were divided into six major phases (phases A through F) which are briefly described here:

1. In phase A, future water level elevations and pumping lifts of ground water to ground surface were determined biennially for each plan of operation.

2. In phase B, the information developed in phase A was utilized to determine annual amounts of subsurface flow at selected locations along the coast, annual requirements of fresh water for injection barriers, and adjusted annual pumping amounts and pumping lifts for each of the 10 economic areas.

3. In phase C, a check was made of the sufficiency of imported water for each alternative plan of utilizing ground water basins. If the check showed that under a certain plan of operation, because of the limitation on delivery capacity of feeder lines, an adequate amount of imported water was not available, the amount of ground water use, or pumping of ground water, was increased.

4. In phase D, annual amounts of imported water to meet applied water demand and costs of the water were determined. In addition, annual costs of chlorinating ground water and costs of injection barrier facilitie were determined.

5. In phase E, the capacities and numbers of both surface and ground water facilities required for each plan were computed.

6. In phase F, annual costs of water supplies and facilities were computed and present worths of annual costs were computed and totaled to determine the present worths of total costs of operation between 1963 and 1990 for all plans.

A computer program, which is a set of instructions to the machine to perform various computations, was developed for each phase. The compute program for phase A is discussed in Attachment No. 6. The discussion of th remaining five phases, B through F, is presented in this attachment with th aid of simplified flow charts of the computer programs shown on Figures 10- through 10-5.

Phase B. Injection Requirements and Ground Water Extractions

In phase B, annual amounts of subsurface flow at selected locations along the coast were computed to determine fresh-water injection requirements at sea-water intrusion barriers. In addition, annual pumping amounts and pumping lifts of ground water for each operational area (a study subarea) were adjusted to be applicable to each economic area. A simplified flow chart of the computer program of phase B is shown on Figure 10-1.

The data fed into the computer in this phase were:

1. Annual pumpage at each operational area, in acre-feet;
2. Annual average weighted ground water level elevations at each node and for each operational area, in feet;
3. Annual average pumping lifts to ground surface at each node and for each operational area, in feet;
4. Node to node transmissibility factors, in acre-feet per foot, as derived in Attachment No. 6; and
5. Node numbers of selected boundary nodes where subsurface flow occurred.

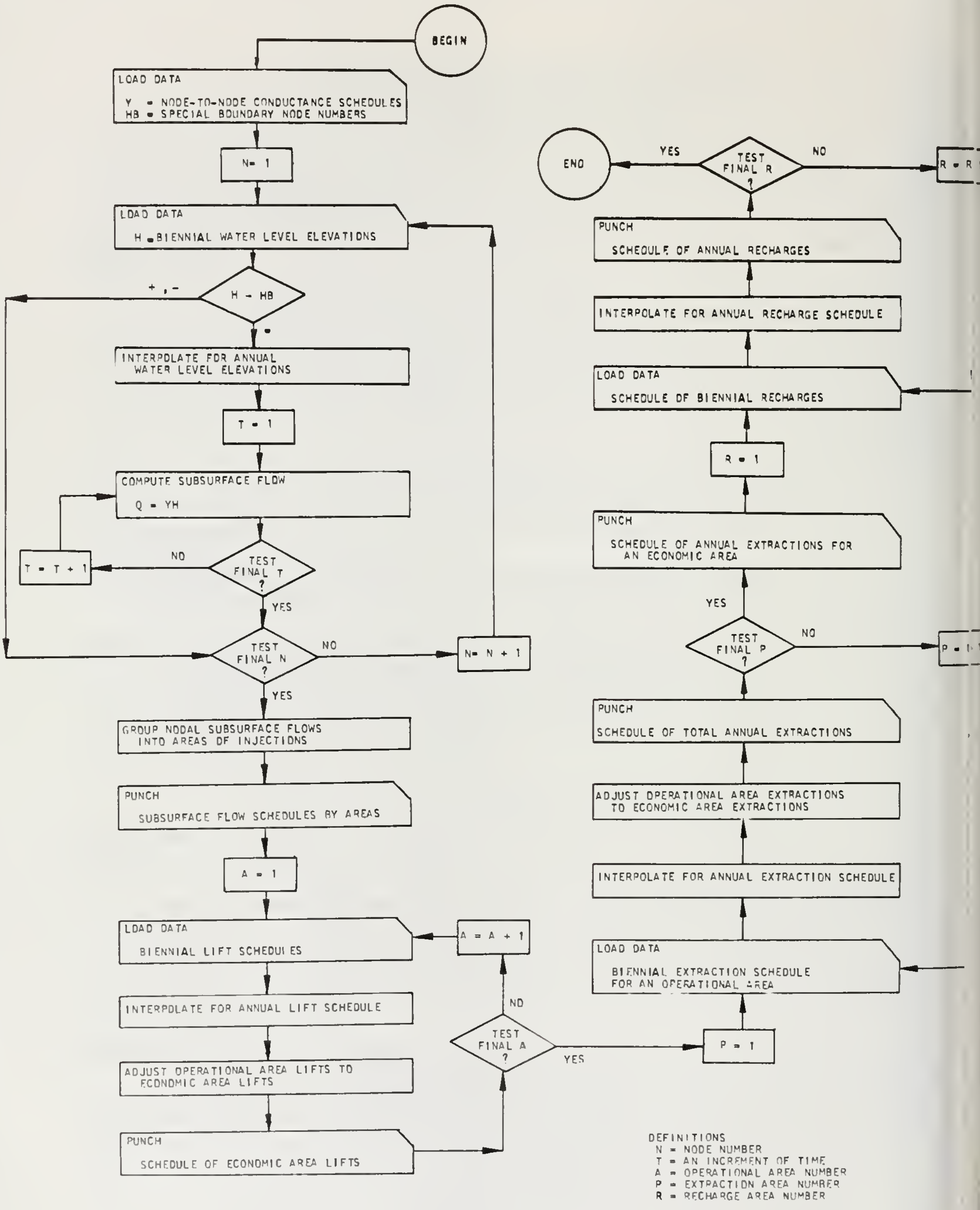
Data under items 1, 2, and 3 above were computed in phase A. All the data, excluding the transmissibility factors, were prepared on a biennial basis.

In determining fresh water requirements for injection, the biennial water level elevation data that were developed in phase A were interpolated to determine annual water level elevations at selected nodes. A nodal breakdown of the study area is shown on Figure 5-4. The amounts of subsurface inflow were computed, based on the equation $Q = Y H$; where:

Q is the subsurface inflow,

Y is the transmissibility factor between nodes, and

H is the difference of water level elevations between nodes.



PHASE B

SIMPLIFIED FLOW CHART FOR A DIGITAL COMPUTER DETERMINATION OF SUBSURFACE FLOW AND ADJUSTMENT OF GROUND WATER EXTRACTION

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

In this computation, nodes 27, 76, 77, 78, 79, 80, 81, and 82 were considered to represent the ocean, and nodes 1, 19, 26, 28, 29, 30, 31, 32, and 53, were considered to represent the land adjacent to the ocean. The computed subsurface flows between the ocean and coastal nodes were considered to be sea water intruding through the fresh-water aquifers until injection barriers were scheduled for construction. After these scheduled dates of construction, the computed subsurface flows were considered to represent landward movement of fresh water injected at the barriers. The transmissibility factors reflecting the construction schedule of the barrier facilities at each node are shown in Table 10-1.

TABLE 10-1

ADJUSTED TRANSMISSIBILITY FACTORS AT
FRESH-WATER BARRIER PROJECTS

In acre-feet per year per foot

Barrier project	Node number	1963	1964	1965	1966	1967	1968
Alamitos	19	0	0	350	350	700	700
Manhattan Beach	31	0	70	70	100	100	100
	30	60	400	400	400	400	400
	29	210	210	210	430	430	430
	28	125	125	125	300	300	300
	53	0	0	0	370	370	370
	26	0	0	0	200	200	200
Santa Monica	1	0	0	0	0	0	100
	32	0	0	0	0	0	60

In addition to the amounts of annual subsurface flow at the coastal area, the annual subsurface flow was computed from node 10, located in the Whittier Narrows, into the study area. The computation was necessary to ascertain that the amount of subsurface flow which appeared in many plans of operation due to the water level elevation at node 10 was consistent with the assumptions made as boundary conditions.

Even though the study area is not completely independent of the adjoining areas hydraulically and operationally, the operational study was conducted by considering the area as an independent unit. Therefore, it was presumed, in the case of node 10, that future water level elevations would not vary significantly from 190 feet. This was the approximate elevation around which the water level fluctuated slightly during the base period 1933 through 1957. However, under some plans of operation that were considered, the use of ground water was much larger than the historical usage. Therefore, water level elevations in the area adjacent to Whittier Narrows would decline significantly and unusually large amounts of subsurface flow would result from San Gabriel Valley into the study area.

Under this condition, an equivalent system was instituted, whereby the computed amount of subsurface flow in excess of the historical average of 28,000 acre-feet was considered to be due to the spreading of imported water. For the determination of the excess amount, amounts of annual subsurface flow from node 10 into nodes 9, 11, and 41 were computed and summed. Then the difference between the sum and the historical average amount of subsurface flow was determined. The difference was then added to the originally assumed amount of spreading of imported water.

The computed annual amounts of subsurface flow, injection requirements, and imported water spread were punched out for use in subsequent phases.

Modifications of annually pumped amounts and pumping lifts developed for each of the 10 operational areas in the study area were made so as to account for the fact that water extracted in one operational area is presently exported to other operational areas and utilized. As shown on Plate 2, the study area was subdivided along geological and operational boundaries into 10 operational areas. This subdivision was made to study the change in water level elevations under various plans of ground water basin operation expressed in terms of extraction in each of the 10 operational areas.

In subdividing the study area, the exportation of pumped ground water from one operational area into other operational areas, in the economic analyses of alternative plans of operation, was not considered. However, operational areas 1, 2, 4, 6, and 7 currently extract and import ground water from operational area 3. This activity was presumed to continue for the duration of the study period. The City of Los Angeles was considered to lie coextensive with operational area 3. Consequently, all areas served by City of Los Angeles, Department of Water and Power, were taken out of other operational areas and added to operational area 3. Some extracted ground water was assumed to be exported out of operational area 9 into operational area 3. After appropriate areal modifications, operational area 3 was referred to as economic area 3. The remaining areas in other operational areas were also referred to as economic areas but the same numbers were retained for identification.

The equations used for modification of annual pumpage and pumping lifts are shown in Table 10-2. In Table 10-2, the letters E, e, H, and h represent annual extraction in an operational area, annual extraction in an economic area, average annual lift in an operational area, and average annual lift in an economic area, respectively. All subscripts represent numbers of either an operational or an economic area. The coefficients of E represent the amount of operational area extractions allocated to each economic area.

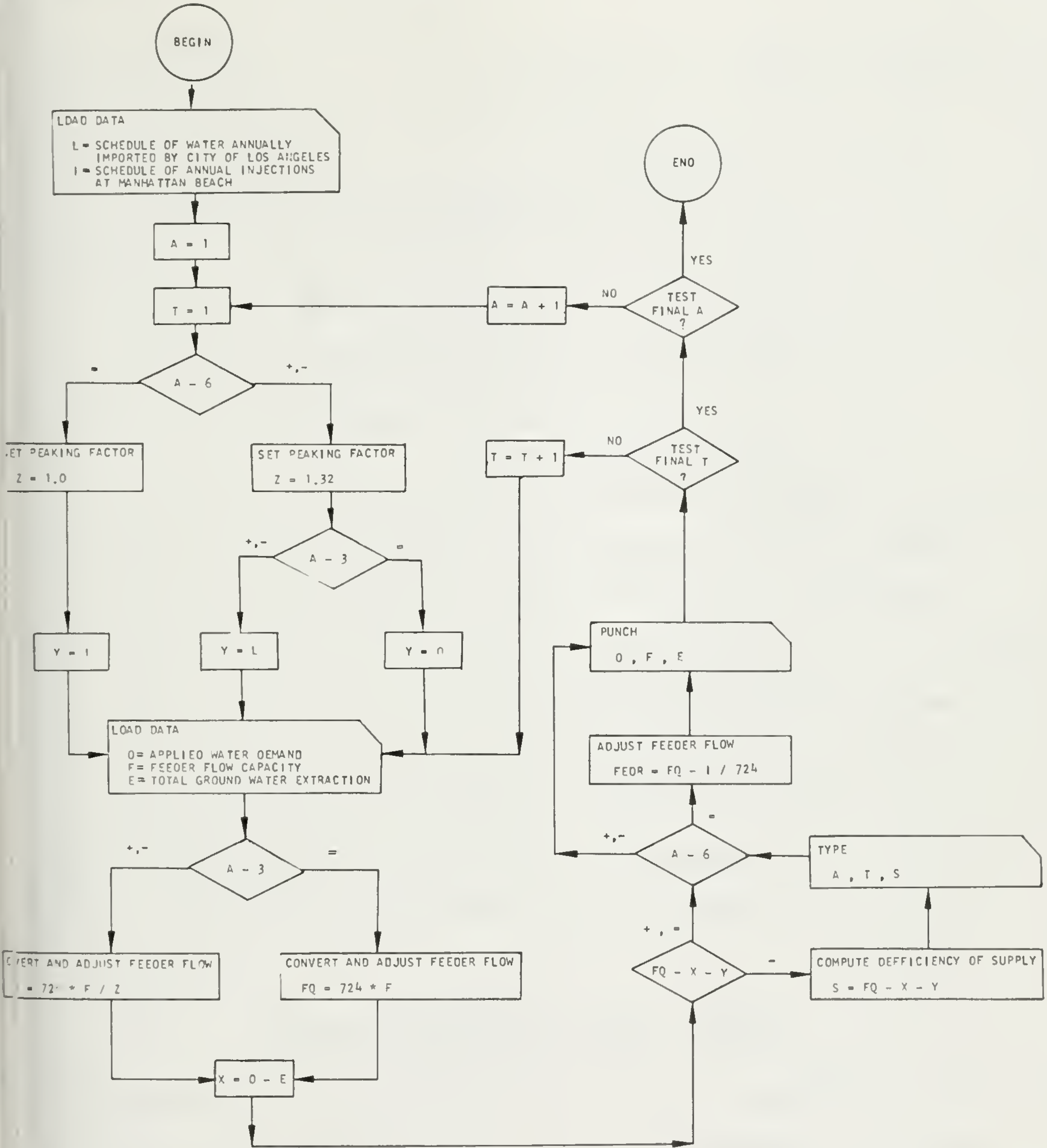
TABLE 10-2

EQUATIONS FOR CONVERSION OF OPERATIONAL AREA, PUMPAGES AND PUMPING LIFTS TO ECONOMIC AREA PUMPAGES AND PUMPING LIFTS

Operational area			Economic area		
No.	Pumpage	Lift	No.	Pumpage	Lift
1	E_1	H_1	1	$e_1 = E_1 + 0.146E_3$	$h_1 = (E_1H_1 + 0.146E_3H_3)/e_1$
2	E_2	H_2	2	$e_2 = E_2 + 0.105E_3$	$h_2 = (E_2H_2 + 0.105E_3H_3)/e_2$
3	E_3	H_3	3	$e_3 = 0.647E_3 + 0.042E_9$	$h_3 = (0.647E_3H_3 + 0.042E_9H_9)/e_3$
4	E_4	H_4	4	$e_4 = E_4 + 0.034E_3$	$h_4 = (E_4H_4 + 0.034E_3H_3)/e_4$
5	E_5	H_5	5	$e_5 = E_5$	$h_5 = H_5$
6	E_6	H_6	6	$e_6 = E_6 + 0.031E_3$	$h_6 = (E_6H_6 + 0.031E_3H_3)/e_6$
7	E_7	H_7	7	$e_7 = E_7 + 0.037E_3$	$h_7 = (E_7H_7 + 0.037E_3H_3)/e_7$
8	E_8	H_8	8	$e_8 = E_8$	$h_8 = H_8$
9	E_9	H_9	9	$e_9 = 0.958E_9$	$h_9 = H_9$
10	E_{10}	H_{10}	10	$e_{10} = E_{10}$	$h_{10} = H_{10}$

Phase C. Adequacy of Imported Water Supply

In phase C, total water supplies were compared with total water demands to assure that the demand for water was satisfied in all economic areas. A simplified flow chart of the computer program of phase C is shown on Figure 10-2.



DEFINITIONS
A = AN ECONOMIC AREA
T = AN INCREMENT OF TIME
* = MULTIPLICATION SYMBOL
/ = DIVISION SYMBOL
Y = ADDITIONAL WATER

PHASE C

SIMPLIFIED FLOW CHART FOR A DIGITAL COMPUTER DETERMINATION OF ADEQUACY OF IMPORTED WATER SUPPLY

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

Data required by this program were:

1. Annual applied water demands in each economic area, in acre-feet;

2. Annual amounts of water, in acre-feet, imported by the City of Los Angeles, as shown in Table 2;

3. Annual amount of water, in acre-feet, injected at the fresh-water barrier projects, as computed in phase B;

4. Feeder capacity in each economic area, in cubic-feet per second, as determined in Attachment No. 4; and

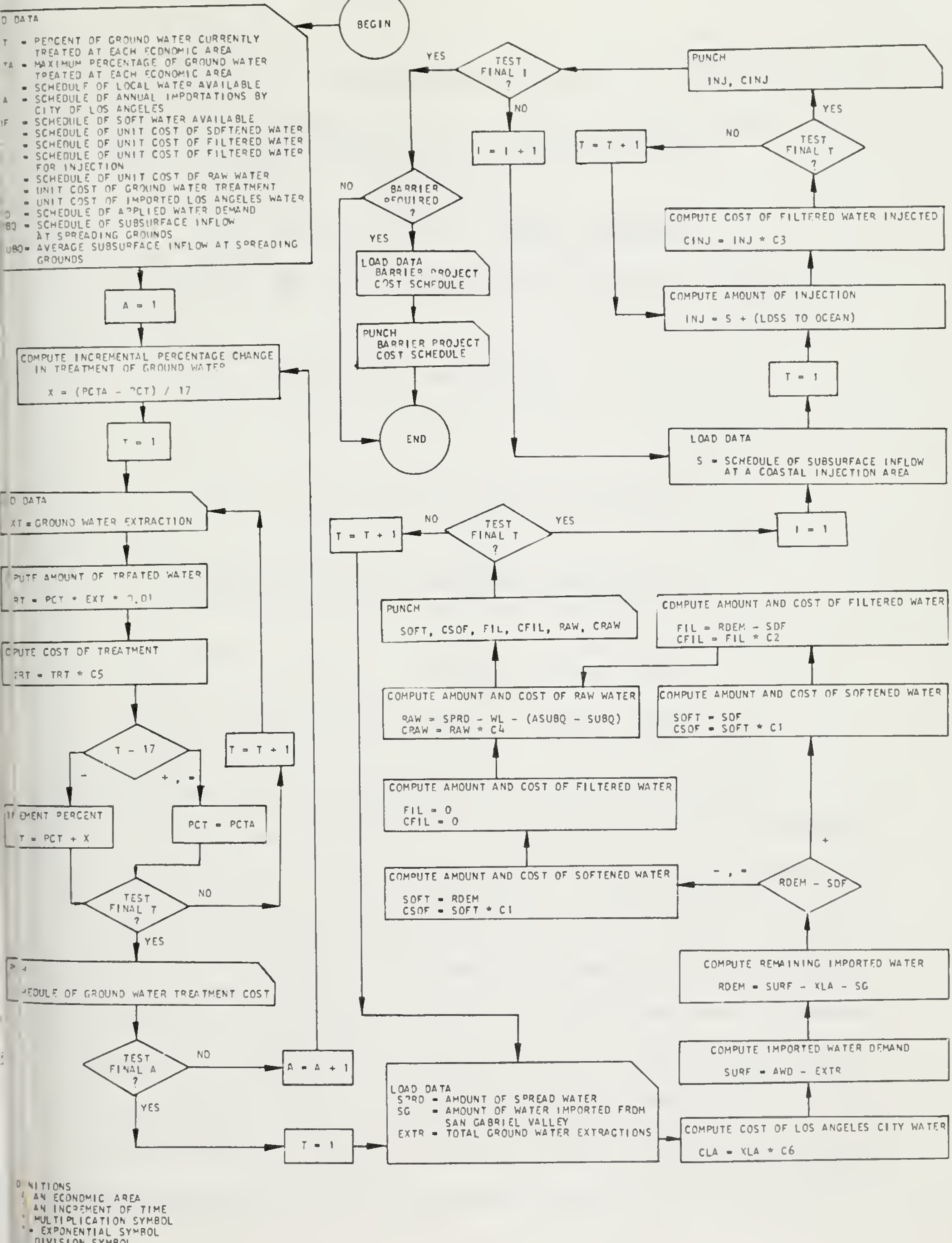
5. Annual extractions at each economic area, in acre-feet, as determined in phase B.

The feeder capacities mentioned above are peak monthly delivery rates. These feeder capacities were divided by a factor of 1.32 to obtain average annual rates and then converted to acre-feet per year.

To check the adequacy of water supplies that were available from the ground water basins and importations, the annual sum of all water supplies was compared to the annual applied water demand in each economic area. When the water supplies were found to be inadequate, the computer printed out the location, time, and amount of shortage. After analysis of this output data, the plan of operation was either discarded or modified.

Phase D. Costs of Ground Water Treatment and Imported Waters

In phase D, the cost of chlorinating ground water extractions, the cost and quantity of water required to meet the need for import, and the cost of facilities to prevent sea-water intrusion were determined. A simplified flow chart of the computer program of phase D is shown on Figure 10-3.



PHASE D

SIMPLIFIED FLOW CHART FOR A DIGITAL COMPUTER DETERMINATION OF COSTS OF GROUND WATER TREATMENT AND IMPORTED WATERS

T OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

The data required for this phase were:

1. Present and anticipated maximum percent of extracted water chlorinated in each economic area, as determined by a survey of local water service agencies;

2. Annual local water available, estimated to be 48,000 acre-feet;

3. Annual importations by the City of Los Angeles, in acre-feet;

4. Unit costs of imported waters, in dollars per acre-foot, as determined in Attachment No. 7;

5. Annual applied water demand of each economic area, in acre-feet.

6. Annual subsurface inflow, in acre-feet, from node 10 as determined in phase B;

7. Annual amount of water, in acre-feet, spread at the Montebello Forebay and the San Gabriel River spreading grounds;

8. Annual ground water extraction in each economic area, in acre-feet; and

9. Annual subsurface inflow in the vicinity of each barrier project, in acre-feet, as computed in phase B.

The present percentage of ground water extractions chlorinated is assumed to increase linearly to an anticipated maximum in the year 1980, and thereafter remain at the maximum percentage. In determining the percentages of treatment, all water used domestically was considered to be chlorinated, and industrial water users were assumed to continue their present chlorination practices. The percentages of ground water chlorinated by operational areas are presented in Table 10-3.

In computing the cost of chlorinating ground water extractions, the amount of water to be treated was determined. This was obtained by multiplying the total amount of pumpage in each operational area by the percentages in Table 10-3. Then the cost of chlorinating this amount was found by simply applying the unit cost of $3.30 per acre-foot.

TABLE 10-3

PERCENT OF EXTRACTED GROUND WATER CHLORINATED

Operational area	1963	1980
1	74	83
2	100	100
3	51	77
4	32	72
5	36	100
6	70	92
7	12	93
8	27	95
9	71	71
10	99	99

The requirement for imported water was assumed to be satisfied from water imported by the City of Los Angeles, pumped water imported from the San Gabriel Valley, and softened and filtered waters from the Metropolitan Water District. The quantity of imported water available from the City of Los Angeles is shown in Table 2, Chapter 2. The annual quantity of San Gabriel Valley pumpage imported and used within the Coastal Plain was assumed to be 10,000 acre-feet, which is approximately the amount presently being received by the study area. This water supply is allocated as follows: 2,500 acre-feet to economic area 4, 2,500 acre-feet to economic area 8, and 5,000 acre-feet to economic area 5. The amount of filtered water available to the study area was considered to be sufficient to meet demands in the Coastal Plain.

Filtered water from the Metropolitan Water District is used in creating a fresh-water barrier to prevent sea-water intrusion. The unit cost of this filtered, injected water is lower than filtered water for domestic use. The annual quantity of water injected at the barrier projects is equal to the annual amount of sea-water intrusion that was computed in phase B, plus a small amount of flow to the ocean. But, during the early study years when the barrier projects are being constructed, the amount of fresh water injected is equal to the existing capacity of the facilities or the computed amount of inflow from the ocean, depending on whichever is less.

The water used for recharge into the ground water basin spreading grounds is untreated, imported (raw) water, plus reclaimed sewage from the Whittier Narrows Reclamation Plant. The capacity of the treatment plant was assumed to be 13,000 acre-feet per year for the duration of the study period.

In the computer analysis of the requirement for imported water, the demand for imported water was considered to be equal to the applied water demand, minus ground water extraction. The amounts of water imported by the City of Los Angeles and from the San Gabriel Valley were first subtracted from the demand for imported water to find the requirement for softened and filtered water for domestic use. Then, the quantity of softened water available was compared to this requirement to determine the amount of filtered water needed. Thus, the quantities of imported waters were determined annually.

The costs of imported waters were found by multiplying the quantity of water from each source by unit cost rates, which are discussed in Attachment No. 7.

The cost of injection facilities required to prevent the intrusion of sea water was derived from the annual cost of required facilities, as reported by the Los Angeles County Flood Control District. When the quantity of water required to prevent sea-water intrusion was greater than the final capacities of facilities required by the Los Angeles County Flood Control District projects, an additional facility was provided for this study. Fresh-water barrier project requirements are discussed in Attachment No. 8.

Phase E. Surface and Ground Water Facility Requirements

Required flow capacities of pumps, storage, and feeders to meet peak flow demands were computed in phase E. The method of finding the most economical combination of pumps and storage is discussed in detail in Attachment No. 9. The equations derived in that attachment were programmed directly into phase E and appear in the simplified flow chart in Figure 10-4.

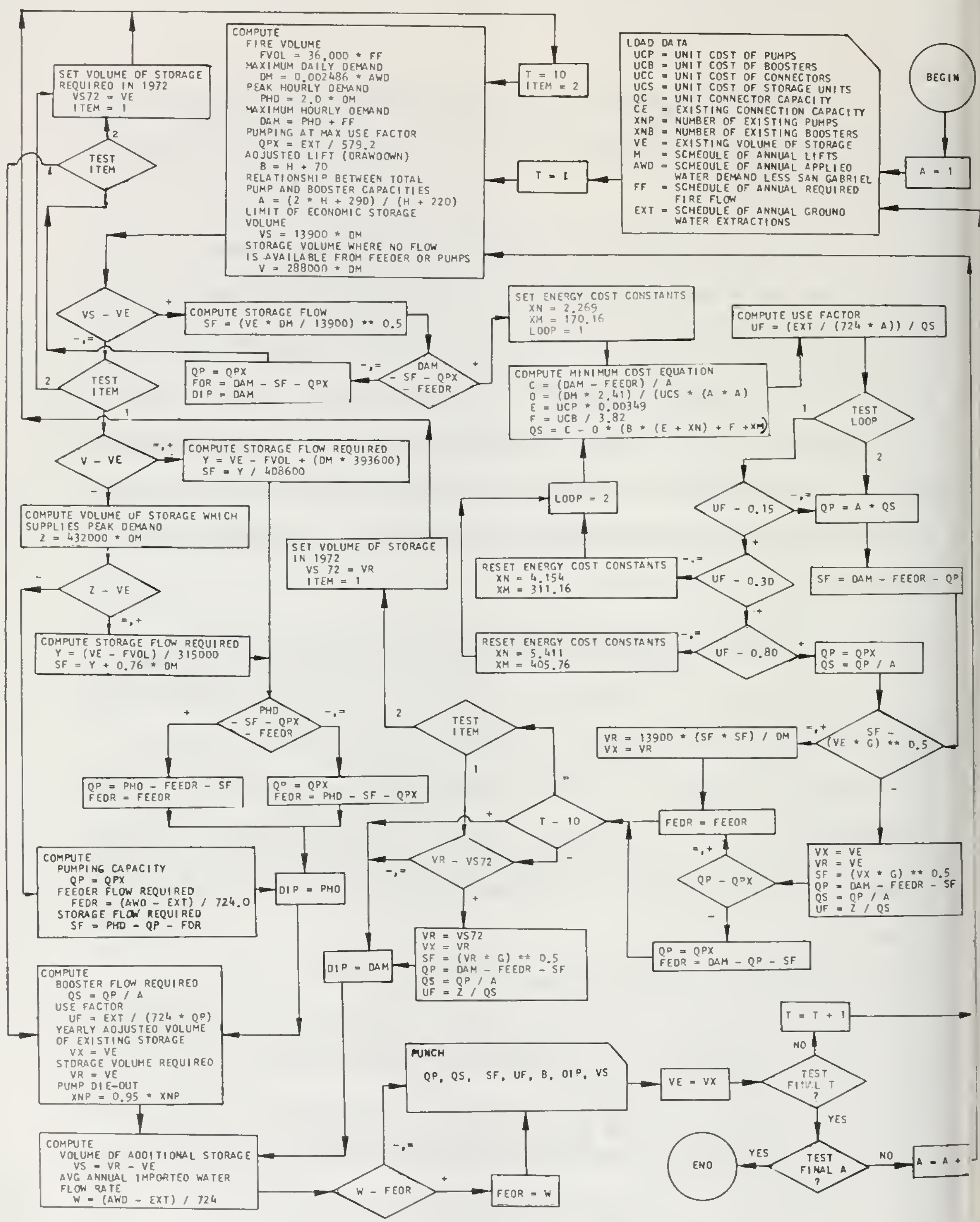
The data required in phase E were:

1. Unit costs of pumps, boosters, storage units, and feeder connectors, in each economic area, discussed in Attachment No. 7;

2. Total existing and unit connector capacities in each economic area, obtained from the Metropolitan Water District;

3. Existing volume of storage in each economic area, determined by a survey of local agencies;

4. Number of existing pumps and boosters in each economic area, determined by a survey of local agencies;



DEFINITIONS
A = AN ECONOMIC AREA
T = AN INCREMENT OF TIME
* = MULTIPLICATION SYMBOL
** = EXPONENTIAL SYMBOL
/ = DIVISION SYMBOL

PHASE E

SIMPLIFIED FLOW CHART FOR A DIGITAL COMPUTER DETERMINATION OF SURFACE AND GROUND WATER FACILITY REQUIREMENTS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

5. Distance from static water level to ground surface (lift) in each economic area, as determined in phase A;

6. Annual applied water demand in each economic area;

7. Annual recommended fire flow in each economic area;

8. Annual ground water extraction in each economic area; and

9. Peak monthly feeder capacity in each economic area, as discussed in Attachment No. 4.

The determination of unit costs of facilities is discussed in Attachment No. 7. Recommended fire flows were calculated with a formula established by the National Board of Fire Underwriters for a high-value district. This equation is:

$$G = 1020 \sqrt{P} \, (1 - 0.01 \sqrt{P})^*$$

where G is required fire flow in gallons per minute and P is population in thousands. The numbers and capacities of existing surface and ground water facilities were based on data determined in a survey of operating agencies.

In the first computer steps for each year, several basic values were determined. These are presented below with their given computer designations (FORTRAN).

Recommended fire volume	FVOL
Maximum daily water demand	DM
Peak hourly water demand	PHD
Maximum hourly demand	DAM
Pumping at maximum use factor	QPX
Economic limit of storage volume	VS

---

*National Board of Fire Underwriters, "Standard Schedule for Grading Cities and Towns of the United States with Reference to their Fire Defenses and Physical Conditions," 1956, p. 15.

Storage volume when no flow is available from feeders or pumps — V

Storage volume that supplies peak demand for a 5-day period — Z

Relationship between total pump and booster capacities — A

The point to which storage volume must be designed to supply a 5-day capacity of water and level daily variations in water -- the economic limit of storage volume (VS) -- was compared with the existing storage volume (VE). When the existing storage volume was greater than the economic limit of storage volume, existing storage volume was utilized in its entirety as the most economical volume of storage. When the existing storage volume was less than the economic limit, the most economical volume of storage was computed with the minimum cost equation, which determines the most economical combination of storage and pumping. The minimum cost equation is derived and discussed in detail in Attachment No. 9.

When the existing volume of storage was greater than the economic limit of storage, the volume of storage (V) when no flow is available from feeders or pumps was compared to the existing volume of storage.

When the volume of existing storage was less than the volume of storage (V) and no other flows are available, the equation used to solve for the required storage flow was:

$$SF = \frac{VE - FVOL + 393{,}600\ DM}{408{,}600} \qquad (1)$$

where SF is required storage flow and VE is existing volume of storage. When this storage flow, plus pumping capacity (QPX) at maximum use factor plus the feeder capacity, exceeded the peak hourly demand, the required pumping capacity was found by the equation

$$QP = PHD - FEEDR - SF, \qquad (2)$$

where QP is required pumping capacity, and FEEDR is capacity of the feeders. When the peak hourly demand was greater than these combined capacities, then the required pumping capacity was equal to the pump flow at maximum use factor, or

$$QP = QPX. \tag{3}$$

When the volume of existing storage was larger than the minimum flow volume (V), the volume of existing storage was compared to the volume of storage which can supply peak demand (Z). When the volume of existing storage was greater, then the required pumping capacity was equal to the pumping capacity at maximum use factor, and the required feeder flow and storage flow were subsequently determined with the following equations:

$$FEEDR = \frac{AWD-EXT}{724} \tag{4}$$

and

$$SF = PHD - QP - FEEDR \tag{5}$$

where FEEDR is required feeder capacity, AWD is applied water demand, and EXT is ground water extractions. When the volume of existing storage was less than the volume of storage which can supply peak demand, required storage capacity was given by the equation

$$SF = \frac{VE-FVOL}{315,000} + 0.38\ DM \tag{6}$$

Required pump capacity was determined for the condition where existing storage volume was less than the storage flow when no flow is available from feeders or pumps.

In the computation of the required capacity of boosters and pump use factor, the following equations were used:

$$QS = \frac{QP}{A} \tag{7}$$

and

$$UF = \frac{EXT}{724\ QP} \tag{8}$$

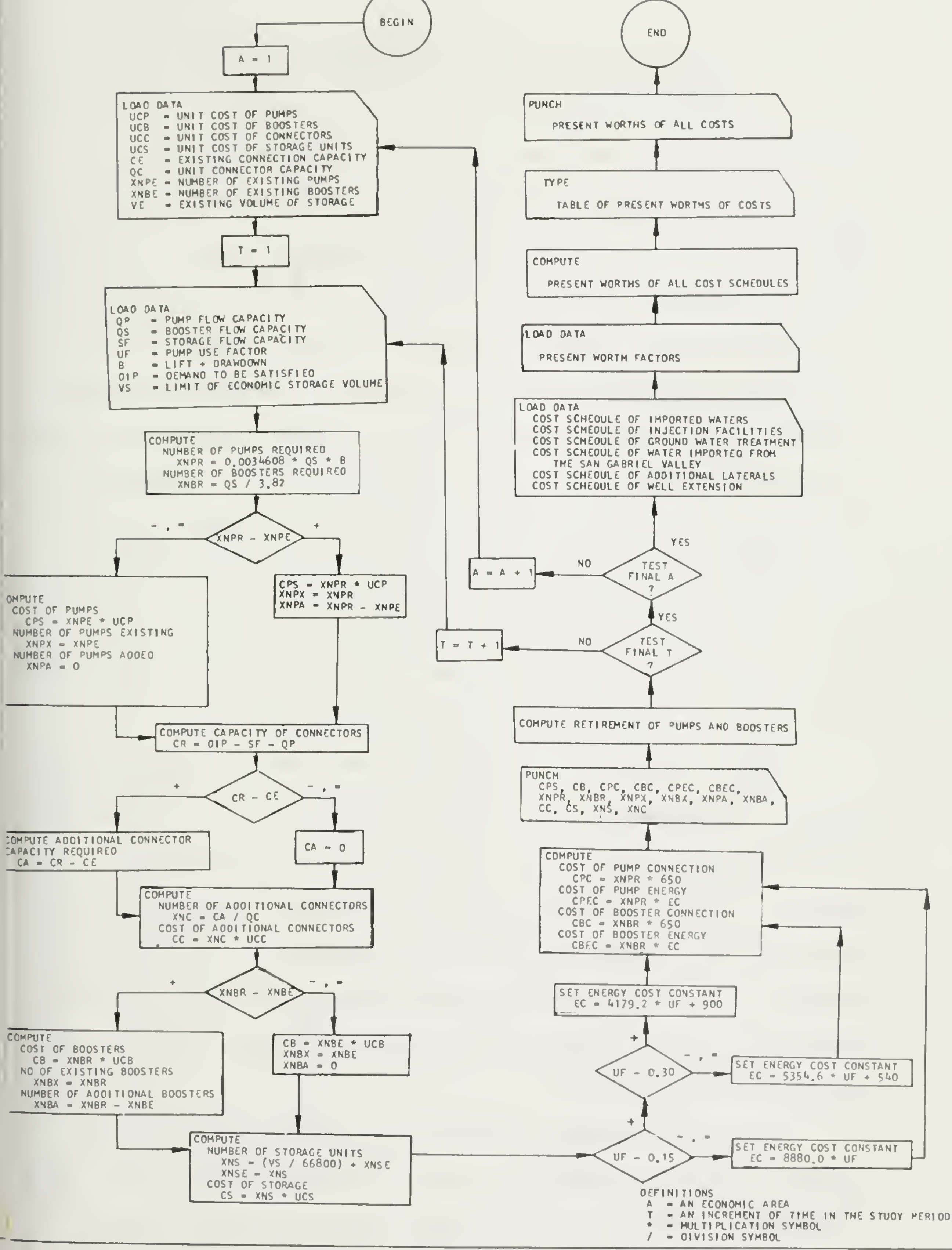
where QS is required booster flow, and UF is use factor.

Phase F. Cost of Surface and Ground Water Facilities and Present Worth of Operational Costs

Phase F concludes the study of surface and ground water supply facilities. In this final phase, the costs of required pumps, boosters, additional storage units, and additional feeder connectors are determined. In addition, phase F computes the present worths of all costs determined in all phases. A simplified flow chart for a digital computer program of this phase is shown on Figure 10-5.

The data required in this phase are the output and input information of phase E. Additional data required in this phase were:

1. Present worth factors at 4.5 percent interest rate;
2. Annual additional pumping cost due to the deepening of wells in each economic area;
3. Annual cost of water imported from the San Gabriel Valley;
4. Capital cost of additional laterals;
5. Capital cost of the spreading facilities at the Montebello Forebay spreading grounds, as obtained from the Los Angeles County Flood Control District;
6. Capital cost of existing storage facilities in each economic area, as determined by a survey of existing agencies;
7. Annual cost of imported waters as determined in phase D;
8. Annual cost of injection facilities for the prevention of sea-water intrusion; and



PHASE F

SIMPLIFIED FLOW CHART FOR A DIGITAL COMPUTER DETERMINATION OF COSTS OF SURFACE AND GROUND WATER FACILITIES, AND PRESENT WORTHS OF OPERATIONAL COSTS

...OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

9. Annual cost of treating ground water extractions in each operation-economic area, as determined in phase D.

Data under items 2, 4, and 8 are discussed in Attachment No. 8.

Present annual cost of the existing injection facilities at Manhattan Beach was found to be $253,000. Additional costs at this barrier project will increase the annual expenditures to $307,000 by 1964, according to the Los Angeles County Flood Control District. The capital cost of the existing spreading facilities at Montebello Forebay was estimated to be $700,000. It has been assumed that the present spreading facilities are adequate and need not be improved during the study. The annual cost of water imported from the San Gabriel Valley was determined to be $200,000 annually -- 10,000 acre-feet at $20 per acre-foot. The costs of well depth extension, additional laterals, and additional injection facilities were determined as described in Attachment No. 8. These values were read into this phase for a present worth analysis only.

Phase F determined the annual required number of pumps, boosters, additional storage units, and connectors in each economic area. The computer then applied a unit cost to each item to determine annual cost schedules. Finally, the annual costs of connection and energy for pumps and boosters were determined according to the annual use factor of these facilities. After adding the cost of well extension to the cost of pumps in each economic area, computations continued on to the determination of the present worth of costs.

The present value of additional laterals, existing spreading facilities, existing storage facilities, and pipeline connectors was found by determining capital cost of each item, applying a capital recovery factor at a 4.5 percent interest rate for an assumed 100-year lifespan, and taking the present worth up to and including the year 1990.

The present worth of all other costs was determined directly from the computed annual cost schedules of the previous phases and tabulated as the final output of the study.

ATTACHMENT NO. 11

TABULATION OF RESULTS

OF OPERATIONAL PLAN NO. 117-4

OPERATIONAL PLAN NO. 117-4

SUMMARY OF PRESENT WORTHS OF FUTURE COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 DOLLARS

WATER SUPPLY			
1. APPLIED WATER		505,806	
2. ARTIFICIAL RECHARGE WATER		39,484	
3. TREATMENT OF GROUND WATER		8,979	
SUBTOTAL			554,269
SURFACE WATER FACILITIES			
1. ADDITIONAL LATERALS		5,611	
2. CONNECTORS		5,320	
3. STORAGE FACILITIES		235,625	
SUBTOTAL			246,556
GROUND WATER FACILITIES			
1. PUMPING FACILITIES		9,812	
2. BOOSTER FACILITIES		909	
3. SPREADING FACILITIES		530	
4. INJECTION FACILITIES		6,693	
SUBTOTAL			17,944
ELECTRICAL ENERGY AND ELECTRICAL SERVICE CONNECTION			
1. PUMPS			
A. ENERGY	13,364		
B. CONNECTION	2,771		
SUBTOTAL		16,135	
2. BOOSTERS			
A. ENERGY	5,413		
B. CONNECTION	1,117		
SUBTOTAL		6,530	
SUBTOTAL			22,665
PRESENT WORTH OF TOTAL COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY			841,434
DISCOUNTED VOLUME OF APPLIED WATER IN 1000 ACRE-FEET			16,993
UNIT COST OF APPLIED WATER IN DOLLARS PER ACRE-FOOT			50

SHEET 2

ESTIMATED ANNUAL AMOUNTS OF REPLENISHMENTS COMMON TO ALL PLANS OF OPERATION TO THE ZONE OF SATURATION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY UNDER WATER SUPPLY CONDITIONS OF MEAN PRECIPITATION FROM 1963 THROUGH 1990

IN ACRE FEET PER YEAR

YEAR	SUBSURFACE GROUND WATER INFLOW			DEEP PERCOLATION OF SURFACE WATER SUPPLIES					REPLENISHMENT COMMON TO ALL PLANS OF OPER.
	ORANGE-L.A. CO.	L.A. FOREBAY	WHITTIER NARROWS	RECLAIMED WATER	RISING WATER	STORM RUNOFF	PRECIP-ITATION	APPLIED WATER	
1963	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1964	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1965	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1966	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1967	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1968	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1969	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1970	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1971	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1972	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1973	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1974	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1975	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1976	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1977	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1978	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1979	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1980	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1981	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1982	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1983	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1984	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1985	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1986	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1987	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1988	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1989	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1990	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500

OPERATIONAL PLAN NO. 117-4

ESTIMATED ANNUAL AMOUNTS OF INFLOW AND OUTFLOW AT ZONE OF SATURATION
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 ACRE-FEET PER YEAR

YEAR	1 COMMON REPLENISH-MENT	2 IMPORT SPREAD AT M.F.	3 FRESH WATER INJECTION BARRIER: WEST COAST	4 FRESH WATER INJECTION BARRIER: WILMING-TON	5 FRESH WATER INJECTION BARRIER: LOS ALAMITOS	6 PROJECTS WATER TO OCEAN	7 GROUND WATER EXTRACTION	8 SURPLUS OR DEFFICIENCY 1 TO 5,-6,-7	9 CUMULATIVE SURPLUS OR DEFFICIENCY
1963	201	44	7	0	0	4	293	-45	-45
1964	201	28	14	0	0	4	264	-25	-70
1965	201	12	13	0	0	4	236	-14	-84
1966	201	13	38	0	0	7	237	8	-76
1967	201	10	39	0	0	8	239	3	-73
1968	201	11	38	17	0	8	245	14	-59
1969	201	11	38	4	0	7	252	-5	-64
1970	201	10	38	4	0	6	255	-8	-72
1971	201	10	38	4	0	6	258	-11	-83
1972	201	10	39	4	0	5	247	2	-81
1973	201	10	38	4	0	5	237	11	-70
1974	201	9	37	4	0	6	232	13	-57
1975	201	9	36	4	0	8	228	14	-43
1976	201	8	35	4	0	10	228	10	-33
1977	201	7	35	4	0	10	228	9	-24
1978	201	7	34	4	0	10	228	8	-16
1979	201	6	34	4	0	10	228	7	-9
1980	201	6	34	4	0	10	228	7	-2
1981	201	6	34	4	0	11	228	6	4
1982	201	5	33	4	0	11	228	4	8
1983	201	5	33	4	0	11	228	4	12
1984	201	5	33	4	0	11	228	4	16
1985	201	4	33	4	0	11	228	3	19
1986	201	4	33	4	0	11	228	3	22
1987	201	4	33	4	0	12	228	2	24
1988	201	4	33	4	0	12	228	2	26
1989	201	4	33	4	0	12	228	2	28
1990	201	3	33	4	0	12	228	1	29
TOTAL	5,628	265	916	105	0	242	6,643	29	

SHEET 4

OPERATIONAL PLAN NO. 117-4

ESTIMATED ANNUAL AMOUNTS OF WATER DEMAND AND WATER SUPPLY
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 ACRE FEET PER YEAR

YEAR	1 APPLIED WATER DEMAND	2 INJEC-TION DEMAND	3 SPREAD-ING DEMAND	4 TOTAL WATER DEMAND 1,2,3	5 IMPORT BY LADWP	6 IMPORT FROM S.G.V.	7 IMPORT BY METRO. WATER DIST. SOFTEN DOMES.	8 FILTER DOMES.	9 FILTER INJECT.	10 RAW SPREAD	11 RECLAIMED WASTE WATER	12 GROUND WATER EXTRACTN	13 TOTAL WATER SUPPLY 5 TO 12
1963	852	7	57	916	197	10	292	60	7	44	13	293	916
1964	872	14	41	927	187	10	308	102	14	28	13	264	926
1965	892	13	25	930	178	10	327	142	13	12	13	236	931
1966	912	38	26	976	168	10	318	179	38	13	13	237	976
1967	932	39	23	994	158	10	308	218	39	10	13	239	995
1968	952	55	24	1,031	148	10	298	251	55	11	13	245	1,031
1969	972	42	24	1,038	138	10	288	285	42	11	13	252	1,039
1970	992	42	23	1,057	128	10	283	317	42	10	13	255	1,058
1971	1,008	42	23	1,073	128	10	270	343	42	10	13	258	1,074
1972	1,024	43	23	1,090	128	10	262	377	43	10	13	247	1,090
1973	1,040	42	23	1,105	127	10	253	413	42	10	13	237	1,105
1974	1,057	41	22	1,120	127	10	244	443	41	9	13	232	1,119
1975	1,073	40	22	1,135	127	10	236	472	40	9	13	228	1,135
1976	1,089	39	21	1,149	127	10	229	495	39	8	13	228	1,149
1977	1,105	39	20	1,164	127	10	222	518	39	7	13	228	1,164
1978	1,121	38	20	1,179	126	10	214	543	38	7	13	228	1,179
1979	1,137	38	19	1,194	126	10	207	566	38	6	13	228	1,194
1980	1,153	38	19	1,210	126	10	201	588	38	6	13	228	1,210
1981	1,158	38	19	1,215	126	10	194	600	38	6	13	228	1,215
1982	1,164	37	18	1,219	126	10	188	612	37	5	13	228	1,219
1983	1,169	37	18	1,224	126	10	182	623	37	5	13	228	1,224
1984	1,174	37	18	1,229	126	10	178	632	37	5	13	228	1,229
1985	1,180	37	17	1,234	127	10	175	641	37	4	13	228	1,235
1986	1,185	37	17	1,239	127	10	168	653	37	4	13	228	1,240
1987	1,191	37	17	1,245	127	10	164	662	37	4	13	228	1,245
1988	1,196	37	17	1,250	127	10	160	672	37	4	13	228	1,251
1989	1,201	37	17	1,255	127	10	157	680	37	4	13	228	1,256
1990	1,207	37	16	1,260	127	10	154	688	37	3	13	228	1,260
TOTAL	30,008	1,021	629	31,658	3,837	280	6,480	12,775	1,021	265	364	6,643	31,665

OPERATIONAL PLAN NO. 117-4

COMPUTED ANNUAL COSTS OF WATER SUPPLY
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 DOLLARS

YEAR	1 IMPORTED BY LADWP	2 IMPORTED FROM S.G.V.	3 IMPORTED BY METROPOLITAN WATER DIST. SOFTENED DOMESTIC	4 FILTERED DOMESTIC	5 FILTERED INJECTED	6 RAW SPREAD	7 RECLAIMED WASTE WATER	8 TOTAL APPLIED WATER 1 TO 4	9 ARTIFICIAL RECHARGE WATER 5,6,7	10 TREATMENT OF GROUND WATER	11 TOTAL COST 8,9,10
1963	3,946	200	8,176	1,197	207	691	203	13,519	1,101	490	15,110
1964	3,748	200	9,394	2,971	377	441	206	16,313	1,024	459	17,796
1965	3,550	200	11,104	4,274	348	196	214	19,128	758	425	20,311
1966	3,352	200	11,766	5,917	1,014	216	224	21,235	1,454	442	23,131
1967	3,154	200	12,320	7,831	1,082	190	237	23,505	1,509	460	25,474
1968	2,956	200	12,814	9,794	2,470	380	458	25,764	3,308	490	29,562
1969	2,758	200	13,536	11,958	2,013	405	497	28,452	2,915	520	31,887
1970	2,560	200	13,867	14,243	2,138	440	549	30,870	3,127	544	34,541
1971	2,556	200	13,230	15,419	2,148	437	549	31,405	3,134	568	35,107
1972	2,552	200	12,838	16,981	2,159	435	549	32,571	3,143	566	36,280
1973	2,548	200	12,397	18,587	2,117	417	549	33,732	3,083	560	37,375
1974	2,544	200	11,956	19,933	2,075	399	549	34,633	3,023	559	38,215
1975	2,540	200	11,554	21,242	2,029	371	549	35,536	2,949	557	39,042
1976	2,536	200	11,221	22,280	1,985	342	549	36,237	2,876	571	39,684
1977	2,532	200	10,878	23,326	1,968	317	549	36,936	2,834	585	40,355
1978	2,528	200	10,486	24,417	1,950	291	549	37,631	2,790	599	41,020
1979	2,524	200	10,143	25,463	1,937	271	549	38,330	2,757	613	41,700
1980	2,520	200	9,864	26,451	1,924	252	549	39,035	2,725	627	42,387
1981	2,522	200	9,506	27,018	1,911	236	549	39,246	2,696	627	42,569
1982	2,524	200	9,212	27,527	1,898	219	549	39,463	2,666	627	42,756
1983	2,526	200	8,918	28,036	1,894	206	549	39,680	2,649	627	42,956
1984	2,528	200	8,722	28,455	1,890	193	549	39,905	2,632	627	43,164
1985	2,530	200	8,560	28,843	1,887	185	549	40,133	2,621	627	43,381
1986	2,532	200	8,232	29,383	1,884	176	549	40,347	2,609	627	43,583
1987	2,534	200	8,036	29,802	1,883	169	549	40,572	2,601	627	43,800
1988	2,536	200	7,840	30,221	1,884	162	549	40,797	2,595	627	44,019
1989	2,538	200	7,693	30,595	1,884	154	549	41,026	2,587	627	44,240
1990	2,540	200	7,566	30,951	1,885	148	549	41,257	2,582	627	44,466
TOTAL	76,714	5,600	291,829	563,115	48,841	8,339	13,568	937,258	70,748	15,905	1,023,911

SHEET 6

OPERATIONAL PLAN NO. 117-4

OPERATIONAL DATA AND COMPUTED FLOW REQUIREMENTS OF FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

YEAR	GROUND WATER EXTRACTION 1000 AF/YR	PUMPING LIFT FT	ANNUAL AND HOURLY WATER DEMAND: AVERAGE ANNUAL 1000 AF/YR	PEAK HOURLY CFS	FIRE FLOW CFS	MAX. HOURLY CFS	FEEDER CAPACITY CFS	FLOW REQUIREMENTS OF FACILITIES: CON-NECTOR CFS	STOR-AGE CFS	BOOST-ER CFS	PUMP CFS	AVERAGE PUMP USE FACTOR PCT
1963	293	138	847	4,183	312	4,500	1,178	874	2,498	371	581	71
1964	264	135	866	4,284	315	4,602	1,178	919	2,549	379	595	64
1965	236	131	887	4,381	318	4,703	1,178	971	2,598	390	614	57
1966	237	126	905	4,481	320	4,806	1,178	955	2,650	443	690	53
1967	239	125	927	4,581	323	4,907	1,178	971	2,702	470	734	51
1968	245	124	946	4,680	325	5,010	1,178	999	2,752	497	774	50
1969	252	124	967	4,778	330	5,111	1,178	1,037	2,802	524	815	50
1970	255	124	988	4,879	330	5,212	1,178	1,045	2,854	551	857	48
1971	258	125	1,002	4,960	330	5,296	1,178	1,054	2,897	567	882	48
1972	247	126	1,017	5,037	332	5,375	2,075	1,444	2,946	337	526	69
1973	237	126	1,034	5,119	333	5,458	2,075	1,476	2,991	341	528	67
1974	232	124	1,051	5,199	335	5,540	2,075	1,514	3,038	340	525	67
1975	228	123	1,068	5,277	336	5,620	2,075	1,549	3,083	337	523	67
1976	228	121	1,084	5,357	338	5,699	2,075	1,580	3,127	343	527	66
1977	228	120	1,101	5,438	339	5,782	2,075	1,610	3,174	347	532	66
1978	228	120	1,115	5,518	341	5,862	2,075	1,637	3,220	349	538	66
1979	228	119	1,131	5,597	343	5,944	2,075	1,661	3,265	357	550	64
1980	228	118	1,149	5,678	345	6,023	2,075	1,683	3,310	366	562	63
1981	228	118	1,153	5,705	345	6,051	2,075	1,689	3,325	368	566	63
1982	228	117	1,157	5,730	345	6,079	2,075	1,699	3,340	370	570	63
1983	228	117	1,166	5,758	345	6,105	2,206	1,745	3,352	349	536	66
1984	228	116	1,170	5,786	345	6,133	2,206	1,755	3,369	351	538	66
1985	228	116	1,175	5,812	345	6,159	2,206	1,765	3,383	352	541	66
1986	228	116	1,181	5,837	345	6,187	2,206	1,774	3,400	354	543	66
1987	228	115	1,184	5,866	346	6,214	2,206	1,783	3,414	355	545	65
1988	228	115	1,191	5,892	346	6,242	2,206	1,793	3,430	358	548	65
1989	228	115	1,196	5,920	346	6,269	2,206	1,802	3,444	359	550	65
1990	228	114	1,202	5,945	346	6,297	2,206	1,845	3,463	361	553	65
AVG	237	121	1,066	5,274	335	5,613	1,824	1,451	3,084	388	601	62

SHEET 7

OPERATIONAL PLAN NO. 117-4

COMPUTED NUMBER OF REQUIRED, AVAILABLE AND ADDITIONAL FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

YEAR	CONNECTORS REQD	CONNECTORS AVAILABLE	CONNECTORS ADDED	STORAGE UNITS REQD	STORAGE UNITS AVAILABLE	STORAGE UNITS ADDED	BOOSTER UNITS REQD	BOOSTER UNITS AVAILABLE	BOOSTER UNITS ADDED	PUMPING UNITS REQD	PUMPING UNITS AVAILABLE	PUMPING UNITS ADDED
1963	88	159	2	815	807	8	97	123	45	264	630	4
1964	93	161	0	815	815	0	100	120	7	266	575	8
1965	97	161	0	815	815	0	103	120	7	270	521	4
1966	96	161	0	815	815	0	117	126	13	296	478	14
1967	98	161	0	815	815	0	124	130	11	312	434	13
1968	100	161	0	815	815	0	131	133	10	327	393	12
1969	104	161	0	815	815	0	138	138	12	344	371	32
1970	105	161	0	815	815	0	145	145	15	362	367	44
1971	105	161	0	815	815	0	149	149	10	373	373	40
1972	145	161	4	815	815	1	89	143	0	220	348	7
1973	148	166	0	815	815	0	90	136	1	219	333	2
1974	152	166	0	815	815	0	90	131	1	217	319	2
1975	155	166	1	815	815	0	89	125	1	215	306	3
1976	158	167	1	815	815	0	90	120	1	215	293	3
1977	161	169	2	815	815	0	91	115	1	216	282	3
1978	164	170	1	815	815	0	92	112	2	218	271	3
1979	166	172	1	815	815	0	94	108	2	223	264	6
1980	169	173	1	815	815	0	96	106	3	227	258	7
1981	169	174	0	815	815	0	97	105	3	228	251	6
1982	171	175	0	815	815	0	98	103	4	230	247	8
1983	175	175	3	815	815	0	92	100	2	215	237	2
1984	175	179	0	815	815	0	92	100	4	215	235	9
1985	176	179	0	815	815	0	93	99	4	216	233	10
1986	178	180	1	815	815	0	93	99	4	217	232	10
1987	179	182	0	815	815	0	94	99	4	217	231	10
1988	179	182	0	815	815	0	94	98	4	218	230	10
1989	180	183	0	815	815	0	95	98	4	219	229	10
1990	185	184	5	815	815	0	95	98	4	219	228	11
TOTAL			22			9			179			293

SHEET 8

OPERATIONAL PLAN NO. 117-4

COMPUTED ANNUAL COSTS OF REQUIRED SURFACE WATER FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

	1	2	3	4	5	6	7
	LATERALS	CONNECTORS		STORAGE FACILITIES		TOTAL SURFACE WATER FACILITIES	
YEAR	ADDITIONAL	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL 1,2,4	TOTAL 1,3,5
1963	342	4	312	45	14,321	391	14,975
1964	342	4	312	45	14,321	391	14,975
1965	342	4	312	45	14,321	391	14,975
1966	342	4	312	45	14,321	391	14,975
1967	342	4	312	45	14,321	391	14,975
1968	342	4	312	45	14,321	391	14,975
1969	342	4	312	45	14,321	391	14,975
1970	342	4	312	45	14,321	391	14,975
1971	342	4	312	45	14,321	391	14,975
1972	342	12	320	49	14,325	403	14,987
1973	342	12	320	49	14,325	403	14,987
1974	342	12	320	49	14,325	403	14,987
1975	342	15	323	49	14,325	406	14,990
1976	342	17	325	49	14,325	408	14,992
1977	342	20	328	49	14,325	411	14,995
1978	342	23	331	49	14,325	414	14,998
1979	342	26	334	49	14,325	417	15,001
1980	342	28	336	49	14,325	419	15,003
1981	342	28	336	49	14,325	419	15,003
1982	342	29	337	49	14,325	420	15,004
1983	342	36	344	49	14,325	427	15,011
1984	342	38	346	49	14,325	429	15,013
1985	342	38	346	49	14,325	429	15,013
1986	342	41	349	49	14,325	432	15,016
1987	342	41	349	49	14,325	432	15,016
1988	342	41	349	49	14,325	432	15,016
1989	342	44	352	49	14,325	435	15,019
1990	342	51	359	49	14,325	442	15,025
TOTAL	9,576	588		1,336		11,500	

OPERATIONAL PLAN NO. 117-4

COMPUTED ANNUAL COSTS OF REQUIRED GROUND WATER FACILITIES IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

	1	2	3	4	5	6	7	8	9	10
	PUMPING FACILITIES		BOOSTER FACILITIES		SPREADING FACILITIES		INJECTION FACILITIES		TOTAL GRND WTR FACILITIES	
YEAR	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL 1,3,5,7	TOTAL 2,4,6,8
1963	6	1,018	20	58	0	33	0	253	26	1,362
1964	13	931	2	56	0	33	54	307	69	1,327
1965	7	843	3	57	0	33	54	307	64	1,240
1966	20	776	5	58	0	33	54	307	79	1,174
1967	19	705	4	60	0	33	54	307	77	1,105
1968	17	640	4	61	0	33	198	451	219	1,185
1969	47	604	5	64	0	33	198	451	250	1,152
1970	69	601	6	66	0	33	198	451	273	1,151
1971	56	611	4	67	0	33	198	451	258	1,162
1972	11	575	0	66	0	33	198	451	209	1,125
1973	3	550	0	62	0	33	198	451	201	1,096
1974	3	526	0	61	0	33	198	451	201	1,071
1975	3	506	0	56	0	33	198	451	201	1,046
1976	3	486	0	56	0	33	198	451	201	1,026
1977	3	467	0	53	0	33	198	451	201	1,004
1978	3	448	0	51	0	33	198	451	201	983
1979	9	439	0	51	0	33	198	451	207	974
1980	10	429	1	49	0	33	198	451	209	962
1981	8	419	1	48	0	33	198	451	207	951
1982	11	413	1	47	0	33	198	451	210	944
1983	2	399	0	46	0	33	198	451	200	929
1984	10	394	1	46	0	33	198	451	209	924
1985	13	391	1	46	0	33	198	451	212	921
1986	13	389	1	46	0	33	198	451	212	919
1987	13	387	1	46	0	33	198	451	212	917
1988	14	386	1	46	0	33	198	451	213	916
1989	14	386	1	45	0	33	198	451	213	915
1990	13	386	1	45	0	33	198	451	212	915
TOTAL	413		63		0		4,770		5,246	

SHEET 10

OPERATIONAL PLAN NO. 117-4

COMPUTED ANNUAL CHARGES OF REQUIRED ELECTRICAL ENERGY AND ELECTRICAL SERVICE CONNECTION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

	1	2	3	4	5	6	7	8	9
	COSTS FOR PUMPS			COSTS FOR BOOSTERS			TOTAL COSTS FOR PUMPS AND BOOSTERS		
YEAR	ENERGY	CONNECTION	SUBTOTAL 1.2	ENERGY	CONNECTION	SUBTOTAL 4.5	ENERGY 1.4	CONNECTION 2.5	TOTAL 3.6
1963	997	173	1.170	371	64	435	1.368	237	1.605
1964	913	174	1.087	345	66	411	1.258	240	1.498
1965	836	175	1.011	322	67	389	1.158	242	1.400
1966	845	191	1.036	336	76	412	1.181	267	1.448
1967	860	203	1.063	344	81	425	1.204	284	1.488
1968	883	213	1.096	355	86	441	1.238	299	1.537
1969	911	223	1.134	368	91	459	1.279	314	1.593
1970	935	236	1.171	376	94	470	1.311	330	1.641
1971	952.	242	1.194	381	96	477	1.333	338	1.671
1972	799	142	941	323	59	382	1.122	201	1.323
1973	765	142	907	314	59	373	1.079	201	1.280
1974	751	141	892	308	58	366	1.059	199	1.258
1975	735	139	874	303	58	361	1.038	197	1.235
1976	731	139	870	304	59	363	1.035	198	1.233
1977	729	141	870	305	59	364	1.034	200	1.234
1978	728	143	871	306	59	365	1.034	202	1.236
1979	730	145	875	307	62	369	1.037	207	1.244
1980	733	147	880	310	63	373	1.043	210	1.253
1981	733	149	882	310	63	373	1.043	212	1.255
1982	732	150	882	311	63	374	1.043	213	1.256
1983	719	139	858	307	60	367	1.026	199	1.225
1984	718	140	858	308	60	368	1.026	200	1.226
1985	718	141	859	308	60	368	1.026	201	1.227
1986	717	141	858	308	61	369	1.025	202	1.227
1987	716	142	858	308	61	369	1.024	203	1.227
1988	717	142	859	308	61	369	1.025	203	1.228
1989	717	142	859	310	62	372	1.027	204	1.231
1990	716	142	858	311	62	373	1.027	204	1.231
TOTAL	22.036	4.537	26.573	9.067	1.870	10.937	31.103	6.407	37.510

OPERATIONAL PLAN NO. 117-4

SUMMARY OF COMPUTED ANNUAL COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

YEAR	1 WATER SUPPLY COL.11.TABLE 5	2 SURFACE WATER FACILITIES COL.7.TABLE 8	3 GROUND WATER FACILITIES COL.10.TABLE 9	4 ENERGY AND SERVICE CONNECTION COL.9.TABLE 10	5 TOTAL 1,2,3,4	6 CUMULATIVE TOTAL
1963	15,110	14,975	1,362	1,605	33,052	33,052
1964	17,796	14,975	1,327	1,498	35,596	68,648
1965	20,311	14,975	1,240	1,400	37,926	106,574
1966	23,131	14,975	1,174	1,448	40,728	147,302
1967	25,474	14,975	1,105	1,488	43,042	190,344
1968	29,562	14,975	1,185	1,537	47,259	237,603
1969	31,887	14,975	1,152	1,593	49,607	287,210
1970	34,541	14,975	1,151	1,641	52,308	339,518
1971	35,107	14,975	1,162	1,671	52,915	392,433
1972	36,280	14,987	1,125	1,323	53,715	446,148
1973	37,375	14,987	1,096	1,280	54,738	500,886
1974	38,215	14,987	1,071	1,258	55,531	556,417
1975	39,042	14,990	1,046	1,235	56,313	612,730
1976	39,684	14,992	1,026	1,233	56,935	669,665
1977	40,355	14,995	1,004	1,234	57,588	727,253
1978	41,020	14,998	983	1,236	58,237	785,490
1979	41,700	15,001	974	1,244	58,919	844,409
1980	42,387	15,003	962	1,253	59,605	904,014
1981	42,569	15,003	951	1,255	59,778	963,792
1982	42,756	15,004	944	1,256	59,960	1,023,752
1983	42,956	15,011	929	1,225	60,121	1,083,873
1984	43,164	15,013	924	1,226	60,327	1,144,200
1985	43,381	15,013	921	1,227	60,542	1,204,742
1986	43,583	15,016	919	1,227	60,745	1,265,487
1987	43,800	15,016	917	1,227	60,960	1,326,447
1988	44,019	15,016	916	1,228	61,179	1,387,626
1989	44,240	15,019	915	1,231	61,405	1,449,031
1990	44,466	15,026	915	1,231	61,638	1,510,669
TOTAL	1,023,911	419,852	29,396	37,510	1,510,669	1,510,669

SHEET 12

OPERATIONAL PLAN NO. 117-4

COMPUTED BIENNIAL AVERAGE GROUND WATER LEVEL ELEVATIONS AT EACH NODE
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1962 THROUGH 1990

IN FEET

NODE NO.	AVG GROUND SURFACE ELEVATION	GROUND WATER LEVEL ELEVATION 1962	1964	1966	1968	1970	1972	974	1976	1978	1980	1982	1984	1986	1988	1990
1	250	11	11	11	11	10	8	9	10	10	10	11	10	10	10	10
2	250	13	5	1	-3	-7	-11	-14	-16	-18	-19	-20	-21	-22	-24	-25
3	300	38	28	22	16	11	7	4	1	0	-1	-2	-3	-4	-5	-6
4	200	-15	-26	-35	-41	-46	-49	-52	-54	-55	-55	-56	-56	-56	-56	-57
5	250	-25	-36	-43	-47	-49	-51	-53	-54	-54	-54	-54	-53	-53	-53	-53
6	250	-45	-51	-51	-51	-50	-51	-52	-51	-50	-49	-48	-48	-47	-46	-46
7	200	-32	-17	-3	3	4	3	6	10	12	15	17	18	20	21	22
8	190	57	65	66	68	68	68	71	74	77	79	80	81	82	83	84
9	260	139	138	131	130	130	130	131	133	135	137	138	139	140	140	141
10	200	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190
11	225	164	152	143	141	142	142	144	146	147	149	150	151	151	151	151
12	200	127	121	115	115	117	118	119	122	124	127	128	130	131	133	134
13	175	63	70	77	83	88	93	96	99	102	105	108	111	113	115	116
14	250	57	66	75	84	90	95	98	102	105	108	111	113	115	117	117
15	100	-2	8	24	36	43	47	50	54	58	61	64	67	69	71	73
16	60	-12	6	27	35	37	37	40	46	49	51	53	55	56	57	58
17	35	-39	-11	17	20	16	13	16	28	29	31	32	33	34	35	36
18	20	-38	-12	13	16	11	8	10	22	23	25	26	27	28	29	29
19	22	-17	-6	4	5	3	1	2	8	8	8	9	9	10	10	10
20	50	-63	-35	-7	-4	-10	-13	-9	2	4	5	6	7	7	8	8
21	50	-71	-44	-18	-15	-20	-23	-18	-7	-5	-4	-2	-1	0	0	1
22	25	-84	-66	-47	-45	-47	-49	-43	-36	-35	-34	-33	-31	-30	-30	-29
23	25	-90	-76	-61	-59	-61	-62	-57	-53	-52	-51	-50	-49	-48	-48	-47
24	10	-87	-74	-60	-58	-60	-61	-57	-52	-51	-50	-49	-49	-48	-48	-48
25	50	-69	-59	-49	-47	-47	-48	-45	-42	-41	-40	-40	-40	-39	-39	-39
26	100	-46	-40	-34	-32	-32	-33	-31	-29	-29	-28	-28	-27	-27	-27	-27
27	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	95	-26	-24	-21	-20	-20	-20	-19	-18	-18	-17	-17	-17	-17	-17	-17
29	140	-14	-13	-11	-11	-11	-11	-10	-10	-10	-10	-9	-10	-9	-10	-10
30	100	-19	-18	-17	-16	-16	-16	-15	-15	-15	-14	-14	-14	-14	-14	-14
31	127	-6	-5	-4	-4	-4	-4	-4	-3	-2	-2	-2	-2	-2	-3	-3
32	15	5	5	7	7	6	6	7	7	8	8	8	8	9	9	9
33	75	-13	-13	-11	-11	-12	-14	-13	-13	-12	-11	-11	-11	-11	-12	-13
34	100	-7	-18	-27	-33	-38	-41	-45	-47	-48	-49	-50	-51	-52	-52	-53
35	132	-40	-50	-57	-62	-65	-67	-69	-70	-71	-71	-71	-71	-70	-70	-70
[illegible]	[illegible]	-77	-74	-67	-64	-64	-66	-64	-62	[illegible]	-58	-57	-57	-56	-55	-55

COMPUTED BIENNIAL AVERAGE GROUND WATER LEVEL ELEVATIONS AT EACH NODE
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1962 THROUGH 1990

IN FEET

NODE NO.	AVG GROUND SURFACE ELEVATION	GROUND WATER LEVEL ELEVATION 1962	1964	1966	1968	1970	1972	1974	1976	1978	1980	1982	1984	1986	1988	1990
39	145	36	47	52	53	54	53	57	61	64	66	67	69	70	71	72
40	175	140	134	121	119	120	120	122	124	127	129	130	131	132	133	134
41	210	154	146	135	134	134	135	136	138	140	141	143	144	145	146	146
42	195	151	138	128	127	128	128	130	132	134	136	138	139	140	141	142
43	145	93	89	88	89	90	91	93	96	99	102	103	105	106	107	108
44	117	35	44	54	58	60	60	63	67	70	73	75	76	78	79	80
45	90	-5	10	27	36	39	41	43	48	52	54	56	58	59	61	62
46	60	-45	-18	8	12	9	7	11	21	23	25	26	27	28	28	28
47	40	-58	-28	1	4	0	-4	0	12	14	15	16	16	17	17	17
48	55	-66	-39	-12	-9	-14	-16	-10	0	1	2	4	5	6	7	8
49	75	-75	-54	-35	-33	-36	-37	-24	-18	-16	-15	-13	-12	-12	-11	-11
50	75	-76	-63	-50	-48	-49	-50	-44	-40	-38	-37	-36	-36	-35	-35	-34
51	17	-65	-55	-45	-43	-44	-45	-42	-38	-37	-37	-36	-36	-35	-35	-35
52	30	-75	-64	-53	-51	-52	-53	-50	-46	-45	-44	-43	-43	-42	-41	-41
53	80	-37	-33	-29	-27	-28	-28	-26	-25	-25	-24	-24	-23	-23	-23	-23
54	45	-53	-48	-41	-40	-40	-41	-38	-36	-35	-34	-34	-33	-32	-32	-32
55	50	-46	-44	-40	-39	-39	-39	-37	-36	-35	-35	-34	-34	-34	-34	-34
56	77	-48	-47	-44	-43	-42	-42	-41	-40	-39	-39	-38	-38	-37	-37	-37
57	120	-52	-53	-52	-51	-49	-50	-49	-48	-47	-46	-45	-44	-43	-43	-42
58	77	-56	-55	-52	-49	-49	-49	-48	-46	-44	-44	-43	-43	-42	-42	-42
59	150	-45	-53	-57	-59	-61	-63	-64	-64	-63	-63	-62	-62	-62	-62	-61
60	150	-62	-65	-62	-60	-60	-62	-61	-60	-58	-57	-56	-55	-54	-53	-52
61	170	-74	-72	-64	-60	-60	-61	-59	-57	-55	-53	-52	-51	-50	-49	-49
62	130	-65	-51	-35	-31	-32	-34	-27	-23	-21	-19	-17	-16	-14	-13	-12
63	115	7	20	30	32	32	31	37	41	44	46	48	49	50	52	53
64	135	51	59	62	64	64	64	67	71	74	76	78	80	81	83	84
65	160	109	107	99	99	99	99	102	105	107	109	111	113	114	115	116
66	105	13	27	39	41	41	41	45	50	53	55	57	58	59	61	61
67	80	-12	7	25	28	28	28	32	38	41	43	45	46	47	48	49
68	65	-51	-28	-6	-3	-5	-7	0	7	9	11	13	14	15	16	17
69	100	-71	-62	-52	-49	-49	-50	-44	-41	-39	-38	-37	-37	-36	-36	-36
70	125	-61	-58	-52	-50	-49	-49	-47	-45	-43	-42	-42	-42	-41	-42	-41
71	150	-88	-79	-68	-64	-65	-66	-60	-56	-53	-52	-50	-49	-48	-46	-45
72	150	-81	-74	-63	-59	-60	-61	-56	-53	-51	-49	-48	-47	-46	-44	-43
73	85	-51	-32	-14	-12	-14	-16	-3	1	4	6	7	8	9	10	11
74	85	-80	-63	-46	-43	-45	-47	-34	-29	-27	-25	-24	-23	-22	-20	-20
75	175	-79	-71	-58	-53	-53	-55	-51	-48	-46	-44	-43	-42	-41	-40	-39

ATTACHMENT NO. 12

TABULATION OF RESULTS

OF OPERATIONAL PLAN NO. 117-5

OPERATIONAL PLAN NO. 117-5

SUMMARY OF PRESENT WORTHS OF FUTURE COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 DOLLARS

WATER SUPPLY				
1. APPLIED WATER			474,348	
2. ARTIFICIAL RECHARGE WATER			45,058	
3. TREATMENT OF GROUND WATER			10,739	
	SUBTOTAL			530,145
SURFACE WATER FACILITIES				
1. ADDITIONAL LATERALS			5,120	
2. CONNECTORS			5,273	
3. STORAGE FACILITIES			235,809	
	SUBTOTAL			246,202
GROUND WATER FACILITIES				
1. PUMPING FACILITIES			11,031	
2. BOOSTER FACILITIES			928	
3. SPREADING FACILITIES			530	
4. INJECTION FACILITIES			8,705	
	SUBTOTAL			21,194
ELECTRICAL ENERGY AND ELECTRICAL SERVICE CONNECTION				
1. PUMPS				
A. ENERGY		17,350		
B. CONNECTION		3,271		
	SUBTOTAL		20,621	
2. BOOSTERS				
A. ENERGY		6,136		
B. CONNECTION		1,166		
	SUBTOTAL		7,302	
	SUBTOTAL			27,923
PRESENT WORTH OF TOTAL COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY				825,464
DISCOUNTED VOLUME OF APPLIED WATER IN 1000 ACRE-FEET				16,993
UNIT COST OF APPLIED WATER IN DOLLARS PER ACRE-FOOT				49

TABLE 2

ESTIMATED ANNUAL AMOUNTS OF REPLENISHMENTS COMMON TO ALL PLANS OF OPERATION
TO THE ZONE OF SATURATION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY
UNDER WATER SUPPLY CONDITIONS OF MEAN PRECIPITATION FROM 1963 THROUGH 1990

IN ACRE FEET PER YEAR

YEAR	SUBSURFACE GROUND WATER INFLOW			DEEP PERCOLATION OF SURFACE WATER SUPPLIES					REPLENISHMENT COMMON TO ALL PLANS OF OPER.
	ORANGE-L.A. CO.	L.A. FOREBAY	WHITTIER NARROWS	RECLAIMED WATER	RISING WATER	STORM RUNOFF	PRECIP-ITATION	APPLIED WATER	
1963	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1964	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1965	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1966	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1967	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1968	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1969	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1970	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1971	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1972	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1973	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1974	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1975	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1976	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1977	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1978	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1979	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1980	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1981	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1982	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1983	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1984	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1985	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1986	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1987	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1988	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1989	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500
1990	29.000	200	28,300	13,000	37,700	10.000	29.400	52,900	200.500

OPERATIONAL PLAN NO. 117-5

ESTIMATED ANNUAL AMOUNTS OF INFLOW AND OUTFLOW AT ZONE OF SATURATION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 ACRE-FEET PER YEAR

YEAR	1 COMMON REPLENISH-MENT	2 IMPORT SPREAD AT M.F.	3 FRESH WATER INJECTION BARRIER WEST COAST	4 WILMING-TON	5 LOS ALAMITOS	6 PROJECTS WATER TO OCEAN	7 GROUND WATER EXTRACTION	8 SURPLUS OR DEFFICIENCY 1 TO 5,-6,-7	9 CUMULATIVE SURPLUS OR DEFFICIENCY
1963	201	45	7	0	0	4	317	-68	-68
1964	201	24	14	0	0	4	301	-66	-134
1965	201	5	14	0	3	4	284	-65	-199
1966	201	9	40	0	2	4	286	-38	-237
1967	201	8	42	0	3	4	287	-37	-274
1968	201	7	42	17	3	5	288	-23	-297
1969	201	6	42	4	4	4	290	-37	-334
1970	201	5	42	4	4	4	291	-39	-373
1971	201	4	42	4	4	4	292	-41	-414
1972	201	4	43	4	5	4	287	-34	-448
1973	201	4	42	4	5	4	282	-30	-478
1974	201	4	42	4	4	4	282	-31	-509
1975	201	4	42	4	4	4	282	-31	-540
1976	201	4	42	4	5	4	282	-30	-570
1977	201	4	42	4	5	4	282	-30	-600
1978	201	4	43	4	5	4	282	-29	-629
1979	201	3	43	4	5	4	282	-30	-659
1980	201	3	43	4	6	4	282	-29	-688
1981	201	3	43	4	6	4	282	-29	-717
1982	201	3	43	4	6	4	282	-29	-746
1983	201	3	44	4	6	4	282	-28	-774
1984	201	3	44	4	6	4	282	-28	-802
1985	201	2	44	4	6	4	282	-29	-831
1986	201	2	44	4	6	4	282	-29	-860
1987	201	2	45	4	6	4	282	-28	-888
1988	201	2	45	4	6	4	282	-28	-916
1989	201	2	45	4	6	4	282	-28	-944
1990	201	4	46	4	7	3	282	-23	-967
TOTAL	5,628	173	1,110	105	128	112	7,999	-967	

SHEET 4

OPERATIONAL PLAN NO. 117-5

ESTIMATED ANNUAL AMOUNTS OF WATER DEMAND AND WATER SUPPLY
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 ACRE FEET PER YEAR

YEAR	1 APPLIED WATER DEMAND	2 INJECTION DEMAND	3 SPREADING DEMAND	4 TOTAL WATER DEMAND 1,2,3	5 IMPORT BY LADWP	6 IMPORT FROM S.G.V.	7 IMPORT BY METRO. WATER DIST. SOFTEN DOMES.	8 FILTER DOMES.	9 FILTER INJECT.	10 RAW SPREAD	11 RECLAIMED WASTE WATER	12 GROUND WATER EXTRACTN	13 TOTAL WATER SUPPLY 5 TO 12
1963	852	7	58	917	197	10	292	36	7	45	13	317	917
1964	872	14	37	923	187	10	308	66	14	24	13	301	923
1965	892	17	18	927	178	10	327	94	17	5	13	284	928
1966	912	42	22	976	168	10	318	131	42	9	13	286	977
1967	932	45	21	998	158	10	308	170	45	8	13	287	999
1968	952	62	20	1,034	148	10	298	208	62	7	13	288	1,034
1969	972	50	19	1,041	138	10	288	247	50	6	13	290	1,042
1970	992	50	18	1,060	128	10	283	280	50	5	13	291	1,060
1971	1,008	50	17	1,075	128	10	270	308	50	4	13	292	1,075
1972	1,024	52	17	1,093	128	10	262	338	52	4	13	287	1,094
1973	1,040	51	17	1,108	127	10	253	368	51	4	13	282	1,108
1974	1,057	50	17	1,124	127	10	244	393	50	4	13	282	1,123
1975	1,073	50	17	1,140	127	10	236	417	50	4	13	282	1,139
1976	1,089	51	17	1,157	127	10	229	440	51	4	13	282	1,156
1977	1,105	51	17	1,173	127	10	222	464	51	4	13	282	1,173
1978	1,121	52	17	1,190	126	10	214	488	52	4	13	282	1,189
1979	1,137	52	16	1,205	126	10	207	511	52	3	13	282	1,204
1980	1,153	53	16	1,222	126	10	201	533	53	3	13	282	1,221
1981	1,158	53	16	1,227	126	10	194	546	53	3	13	282	1,227
1982	1,164	53	16	1,233	126	10	188	557	53	3	13	282	1,232
1983	1,169	54	16	1,239	126	10	182	568	54	3	13	282	1,238
1984	1,174	54	16	1,244	126	10	178	578	54	3	13	282	1,244
1985	1,180	54	15	1,249	127	10	175	586	54	2	13	282	1,249
1986	1,185	54	15	1,254	127	10	168	598	54	2	13	282	1,254
1987	1,191	55	15	1,261	127	10	164	608	55	2	13	282	1,261
1988	1,196	55	15	1,266	127	10	160	617	55	2	13	282	1,266
1989	1,201	55	15	1,271	127	10	157	625	55	2	13	282	1,271
1990	1,207	57	17	1,281	127	10	154	633	57	4	13	282	1,280
TOTAL	30,008	1,343	537	31,888	3,837	280	6,480	11,408	1,343	173	364	7,999	31,884

OPERATIONAL PLAN NO. 117-5

COMPUTED ANNUAL COSTS OF WATER SUPPLY
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 DOLLARS

YEAR	1 IMPORTED BY LADWP	2 IMPORTED FROM S.G.V.	3 IMPORTED BY METROPOLITAN WATER DIST. SOFTENED DOMESTIC	4 FILTERED DOMESTIC	5 FILTERED INJECTED	6 RAW SPREAD	7 RECLAIMED WASTE WATER	8 TOTAL APPLIED WATER 1 TO 4	9 ARTIFICIAL RECHARGE WATER 5,6,7	10 TREATMENT OF GROUND WATER	11 TOTAL COST 8,9,10
1963	3,946	200	8,176	719	209	700	203	13,041	1,112	527	14,680
1964	3,748	200	9,394	1,919	383	379	206	15,261	968	519	16,748
1965	3,550	200	11,104	2,813	443	90	214	17,667	747	508	18,922
1966	3,352	200	11,766	4,326	1,120	148	224	19,644	1,492	528	21,664
1967	3,154	200	12,320	6,114	1,246	147	237	21,788	1,630	548	23,966
1968	2,956	200	12,814	8,119	2,768	264	458	24,089	3,490	570	28,149
1969	2,758	200	13,536	10,353	2,352	248	497	26,847	3,097	591	30,535
1970	2,560	200	13,867	12,614	2,521	232	549	29,241	3,302	614	33,157
1971	2,556	200	13,230	13,880	2,563	190	549	29,866	3,302	636	33,804
1972	2,552	200	12,838	15,190	2,607	190	549	30,780	3,346	645	34,771
1973	2,548	200	12,397	16,544	2,588	173	549	31,689	3,310	654	35,653
1974	2,544	200	11,956	17,681	2,570	178	549	32,381	3,297	672	36,350
1975	2,540	200	11,554	18,781	2,575	172	549	33,075	3,296	690	37,061
1976	2,536	200	11,221	19,818	2,580	166	549	33,775	3,295	709	37,779
1977	2,532	200	10,878	20,864	2,603	159	549	34,474	3,311	727	38,512
1978	2,528	200	10,486	21,956	2,628	152	549	35,170	3,329	746	39,245
1979	2,524	200	10,143	23,002	2,649	145	549	35,869	3,343	764	39,976
1980	2,520	200	9,864	23,990	2,669	139	549	36,574	3,357	782	40,713
1981	2,522	200	9,506	24,557	2,683	131	549	36,785	3,363	782	40,930
1982	2,524	200	9,212	25,066	2,697	123	549	37,002	3,369	782	41,153
1983	2,526	200	8,918	25,575	2,713	116	549	37,219	3,378	782	41,379
1984	2,528	200	8,722	25,994	2,728	108	549	37,444	3,385	782	41,611
1985	2,530	200	8,560	26,381	2,746	102	549	37,671	3,397	782	41,850
1986	2,532	200	8,232	26,922	2,766	98	549	37,886	3,413	782	42,081
1987	2,534	200	8,036	27,341	2,788	92	549	38,111	3,429	782	42,322
1988	2,536	200	7,840	27,760	2,811	85	549	38,336	3,445	782	42,563
1989	2,538	200	7,693	28,134	2,832	78	549	38,565	3,459	782	42,806
1990	2,540	200	7,566	28,490	2,854	154	549	38,796	3,557	782	43,135
TOTAL	76,714	5,600	291,829	504,903	64,692	4,959	13,568	879,046	83,219	19,250	981,515

SHEET 6

OPERATIONAL PLAN NO. 117-5

OPERATIONAL DATA AND COMPUTED FLOW REQUIREMENTS OF FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

YEAR	GROUND WATER EXTRACTION 1000 AF/YR	PUMPING LIFT FT	ANNUAL AND HOURLY WATER DEMAND: AVERAGE ANNUAL 1000 AF/YR	PEAK HOURLY CFS	FIRE FLOW CFS	MAX. HOURLY CFS	FEEDER CAPACITY CFS	FLOW REQUIREMENTS OF FACILITIES: CON-NECTOR CFS	STOR-AGE CFS	BOOST-ER CFS	PUMP CFS	AVERAGE PUMP USE FACTOR PCT
1963	317	140	847	4,183	312	4,500	1,178	840	2,497	392	616	72
1964	301	139	866	4,284	315	4,602	1,178	885	2,547	402	631	68
1965	284	139	887	4,381	318	4,703	1,178	938	2,596	413	649	64
1966	286	138	905	4,481	320	4,806	1,178	928	2,648	457	719	60
1967	287	140	927	4,581	323	4,907	1,178	948	2,700	481	758	58
1968	288	141	946	4,680	325	5,010	1,178	978	2,750	506	796	56
1969	290	143	967	4,778	330	5,111	1,178	999	2,801	531	834	54
1970	291	145	988	4,879	330	5,212	1,178	1,027	2,852	557	877	52
1971	292	146	1,002	4,960	330	5,296	1,178	1,035	2,895	570	902	52
1972	287	149	1,017	5,037	332	5,375	2,075	1,404	2,952	356	560	72
1973	282	150	1,034	5,119	333	5,458	2,075	1,437	2,995	355	560	71
1974	282	151	1,051	5,199	335	5,540	2,075	1,469	3,043	356	563	71
1975	282	152	1,068	5,277	336	5,620	2,075	1,501	3,090	358	566	71
1976	282	154	1,084	5,357	338	5,699	2,075	1,531	3,134	361	570	71
1977	282	155	1,101	5,438	339	5,782	2,075	1,555	3,182	365	578	69
1978	282	156	1,115	5,518	341	5,862	2,075	1,577	3,228	374	590	68
1979	282	158	1,131	5,597	343	5,944	2,075	1,601	3,273	380	602	67
1980	282	159	1,149	5,678	345	6,023	2,075	1,621	3,318	388	616	66
1981	282	160	1,153	5,705	345	6,051	2,075	1,628	3,333	390	620	66
1982	282	162	1,157	5,730	345	6,079	2,075	1,636	3,348	392	623	65
1983	282	163	1,166	5,758	345	6,105	2,206	1,695	3,364	361	574	70
1984	282	164	1,170	5,786	345	6,143	2,206	1,707	3,381	362	575	70
1985	282	165	1,175	5,812	345	6,159	2,206	1,716	3,396	362	577	70
1986	282	166	1,181	5,837	345	6,187	2,206	1,725	3,413	363	580	70
1987	282	168	1,184	5,866	346	6,214	2,206	1,733	3,427	365	581	70
1988	282	169	1,191	5,892	346	6,242	2,206	1,744	3,444	364	583	70
1989	282	170	1,196	5,920	346	6,269	2,206	1,752	3,460	365	584	69
1990	282	171	1,202	5,945	346	6,297	2,206	1,796	3,478	366	587	69
AVG	285	154	1,066	5,274	335	5,614	1,824	1,407	3,090	403	638	66

SHEET 7

OPERATIONAL PLAN NO. 117-5

COMPUTED NUMBER OF REQUIRED, AVAILABLE AND ADDITIONAL FACILITIES IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

YEAR	CONNECTORS REQD	CONNECTORS AVAILABLE	CONNECTORS ADDED	STORAGE UNITS REQD	STORAGE UNITS AVAILABLE	STORAGE UNITS ADDED	BOOSTER UNITS REQD	BOOSTER UNITS AVAILABLE	BOOSTER UNITS ADDED	PUMPING UNITS REQD	PUMPING UNITS AVAILABLE	PUMPING UNITS ADDED
1963	84	159	2	815	807	8	103	128	49	283	634	8
1964	89	161	0	815	815	0	106	123	5	287	582	12
1965	94	161	0	815	815	0	109	122	7	295	531	6
1966	93	161	0	815	815	0	120	128	13	325	493	19
1967	95	161	0	815	815	0	127	130	10	344	451	17
1968	98	161	0	815	815	0	133	135	11	363	415	17
1969	100	161	0	815	815	0	139	139	12	382	401	41
1970	103	161	0	815	815	0	146	146	13	403	403	49
1971	104	161	0	815	815	0	150	150	10	417	417	43
1972	141	161	3	818	815	3	93	144	0	260	401	8
1973	144	165	0	818	818	0	93	137	1	261	384	3
1974	147	165	0	818	818	0	94	132	2	262	370	5
1975	150	165	1	818	818	0	94	127	2	265	356	5
1976	153	166	1	818	818	0	95	123	2	268	344	5
1977	156	168	1	818	818	0	96	119	2	274	333	7
1978	158	169	1	819	818	0	98	115	2	281	327	10
1979	160	169	1	819	819	0	100	113	3	289	323	12
1980	162	170	1	819	819	0	102	111	3	296	318	12
1981	163	171	0	819	819	0	103	109	3	300	314	11
1982	163	171	0	819	819	0	103	107	3	304	312	14
1983	170	171	4	820	819	1	95	104	2	281	304	7
1984	171	176	0	820	820	0	95	102	3	283	302	13
1985	171	177	0	820	820	0	95	101	4	285	302	15
1986	173	177	0	820	820	0	95	101	4	287	303	16
1987	174	178	0	821	820	0	96	101	4	290	303	16
1988	174	178	0	821	821	0	96	100	4	292	304	16
1989	175	179	0	821	821	0	96	100	4	294	305	15
1990	180	179	5	821	821	0	96	100	4	296	305	16
TOTAL			20			12			182			418

SHEET 8

OPERATIONAL PLAN NO. 117-5

COMPUTED ANNUAL COSTS OF REQUIRED SURFACE WATER FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

	1	2	3	4	5	6	7
	LATERALS	CONNECTORS		STORAGE FACILITIES		TOTAL SURFACE WATER FACILITIES	
YEAR	ADDITIONAL	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL 1,2,4	TOTAL 1,3,5
1963	312	4	312	46	14,322	362	14,946
1964	312	4	312	46	14,322	362	14,946
1965	312	4	312	46	14,322	362	14,946
1966	312	4	312	46	14,322	362	14,946
1967	312	4	312	46	14,322	362	14,946
1968	312	4	312	46	14,322	362	14,946
1969	312	4	312	46	14,322	362	14,946
1970	312	4	312	46	14,322	362	14,946
1971	312	4	312	46	14,322	362	14,946
1972	312	9	317	62	14,338	383	14,967
1973	312	10	318	63	14,339	385	14,969
1974	312	10	318	63	14,339	385	14,969
1975	312	12	320	64	14,340	388	14,972
1976	312	15	323	65	14,341	392	14,976
1977	312	17	325	67	14,343	396	14,980
1978	312	18	326	68	14,344	398	14,982
1979	312	19	327	68	14,344	399	14,983
1980	312	21	329	68	14,344	401	14,985
1981	312	21	329	68	14,344	401	14,985
1982	312	22	330	68	14,344	402	14,986
1983	312	30	338	74	14,350	416	15,000
1984	312	32	340	75	14,351	419	15,003
1985	312	32	340	76	14,352	420	15,004
1986	312	34	342	77	14,353	423	15,007
1987	312	35	343	78	14,354	425	15,009
1988	312	35	343	79	14,355	426	15,010
1989	312	37	345	80	14,356	429	15,013
1990	312	44	352	81	14,357	437	15,021
TOTAL	8,736	489		1,758		10,983	

OPERATIONAL PLAN NO. 117-5

COMPUTED ANNUAL COSTS OF REQUIRED GROUND WATER FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

	1	2	3	4	5	6	7	8	9	10
	PUMPING FACILITIES		BOOSTER FACILITIES		SPREADING FACILITIES		INJECTION FACILITIES		TOTAL GRND WTR FACILITIES	
YEAR	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL 1,3,5,7	TOTAL 2,4,6,8
1963	15	1,027	22	60	0	33	0	253	37	1,373
1964	22	947	2	57	0	33	54	307	78	1,344
1965	10	867	3	57	0	33	193	446	206	1,403
1966	28	807	5	60	0	33	193	446	226	1,346
1967	25	741	4	61	0	33	193	446	222	1,281
1968	25	682	4	63	0	33	337	590	366	1,368
1969	65	663	5	65	0	33	337	590	407	1,351
1970	75	668	5	68	0	33	337	590	417	1,359
1971	64	691	4	69	0	33	337	590	405	1,383
1972	13	666	0	68	0	33	337	590	350	1,357
1973	4	638	0	63	0	33	337	590	341	1,324
1974	6	614	0	62	0	33	337	590	343	1,299
1975	7	595	0	59	0	33	337	590	344	1,277
1976	7	573	0	57	0	33	337	590	344	1,253
1977	9	557	0	54	0	33	337	590	346	1,234
1978	16	548	0	53	0	33	337	590	353	1,224
1979	18	543	1	52	0	33	337	590	356	1,218
1980	18	535	1	50	0	33	337	590	356	1,208
1981	16	528	1	50	0	33	337	590	354	1,201
1982	19	524	1	49	0	33	337	590	357	1,196
1983	10	513	0	46	0	33	337	590	347	1,182
1984	17	511	1	46	0	33	337	590	355	1,180
1985	20	511	1	47	0	33	337	590	358	1,181
1986	23	515	1	46	0	33	337	590	361	1,184
1987	22	517	1	46	0	33	337	590	360	1,186
1988	23	518	1	46	0	33	337	590	361	1,187
1989	24	518	1	46	0	33	337	590	362	1,187
1990	22	518	1	45	0	33	337	590	360	1,186
TOTAL	623		65		0		8,384		9,072	

SHEET 10

OPERATIONAL PLAN NO. 117-5

COMPUTED ANNUAL CHARGES OF REQUIRED ELECTRICAL ENERGY AND ELECTRICAL SERVICE CONNECTION
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

	1	2	3	4	5	6	7	8	9
	COSTS FOR PUMPS			COSTS FOR BOOSTERS			TOTAL COSTS FOR PUMPS AND BOOSTERS		
YEAR	ENERGY	CONNECTION	SUBTOTAL 1,2	ENERGY	CONNECTION	SUBTOTAL 4,5	ENERGY 1,4	CONNECTION 2,5	TOTAL 3,6
1963	1,087	186	1,273	399	68	467	1,486	254	1,740
1964	1,044	187	1,231	386	70	456	1,430	257	1,687
1965	1,011	193	1,204	373	72	445	1,384	265	1,649
1966	1,031	211	1,242	383	79	462	1,414	290	1,704
1967	1,054	223	1,277	390	82	472	1,444	305	1,749
1968	1,079	234	1,313	397	87	484	1,476	321	1,797
1969	1,104	248	1,352	403	90	493	1,507	338	1,845
1970	1,130	261	1,391	409	97	506	1,539	358	1,897
1971	1,148	272	1,420	412	98	510	1,560	370	1,930
1972	1,010	168	1,178	360	61	421	1,370	229	1,599
1973	997	169	1,166	354	61	415	1,351	230	1,581
1974	1,002	169	1,171	355	62	417	1,357	231	1,588
1975	1,006	171	1,177	355	62	417	1,361	233	1,594
1976	1,016	174	1,190	355	63	418	1,371	237	1,608
1977	1,026	179	1,205	358	63	421	1,384	242	1,626
1978	1,034	184	1,218	358	64	422	1,392	248	1,640
1979	1,044	188	1,232	359	66	425	1,403	254	1,657
1980	1,056	194	1,250	361	68	429	1,417	262	1,679
1981	1,064	195	1,259	361	68	429	1,425	263	1,688
1982	1,068	198	1,266	362	68	430	1,430	266	1,696
1983	1,052	182	1,234	354	62	416	1,406	244	1,650
1984	1,057	183	1,240	354	63	417	1,411	246	1,657
1985	1,064	185	1,249	354	63	417	1,418	248	1,666
1986	1,068	189	1,257	355	63	418	1,423	252	1,675
1987	1,074	190	1,264	355	63	418	1,429	253	1,682
1988	1,079	190	1,269	355	63	418	1,434	253	1,687
1989	1,085	191	1,276	355	64	419	1,440	255	1,695
1990	1,087	193	1,280	355	64	419	1,442	257	1,699
TOTAL	29,577	5,507	35,084	10,327	1,954	12,281	39,904	7,461	47,365

OPERATIONAL PLAN NO. 117-5

SUMMARY OF COMPUTED ANNUAL COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

YEAR	1 WATER SUPPLY COL.11,TABLE 5	2 SURFACE WATER FACILITIES COL.7,TABLE 8	3 GROUND WATER FACILITIES COL.10,TABLE 9	4 ENERGY AND SERVICE CONNECTION COL.9,TABLE 10	5 TOTAL 1,2,3,4	6 CUMULATIVE TOTAL
1963	14.680	14.946	1.373	1.740	32.739	32.739
1964	16.748	14.946	1.344	1.687	34.725	67.464
1965	18.922	14.946	1.403	1.649	36.920	104.384
1966	21.664	14.946	1.346	1.704	39.660	144.044
1967	23.966	14.946	1.281	1.749	41.942	185.986
1968	28.149	14.946	1.368	1.797	46.260	232.246
1969	30.535	14.946	1.351	1.845	48.677	280.923
1970	33.157	14.946	1.359	1.897	51.359	332.282
1971	33.804	14.946	1.383	1.930	52.063	384.345
1972	34.771	14.967	1.357	1.599	52.694	437.039
1973	35.653	14.969	1.324	1.581	53.527	490.566
1974	36.350	14.969	1.299	1.588	54.206	544.772
1975	37.061	14.972	1.277	1.594	54.904	599.676
1976	37.779	14.976	1.253	1.608	55.616	655.292
1977	38.512	14.980	1.234	1.626	56.352	711.644
1978	39.245	14.982	1.224	1.640	57.091	768.735
1979	39.976	14.983	1.218	1.657	57.834	826.569
1980	40.713	14.985	1.208	1.679	58.585	885.154
1981	40.930	14.985	1.201	1.688	58.804	943.958
1982	41.153	14.986	1.196	1.696	59.031	1.002.989
1983	41.379	15.000	1.182	1.650	59.211	1.062.200
1984	41.611	15.003	1.180	1.657	59.451	1.121.651
1985	41.850	15.004	1.181	1.666	59.701	1.181.352
1986	42.081	15.007	1.184	1.675	59.947	1.241.299
1987	42.322	15.009	1.186	1.682	60.199	1.301.498
1988	42.563	15.010	1.187	1.687	60.447	1.361.945
1989	42.806	15.013	1.187	1.695	60.701	1.422.646
1990	43.135	15.021	1.186	1.699	61.041	1.483.687
TOTAL	981.515	419.335	35.472	47.365	1.483.687	1.483.687

SHEET 12

OPERATIONAL PLAN NO. 117-5

COMPUTED BIENNIAL AVERAGE GROUND WATER LEVEL ELEVATIONS AT EACH NODE
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1962 THROUGH 1990

IN FEET

NODE NO.	AVG GROUND SURFACE ELEVATION	GROUND WATER LEVEL ELEVATION 1962	1964	1966	1968	1970	1972	974	1976	1978	1980	1982	1984	1986	1988	1990
1	250	11	11	11	11	10	9	9	8	7	7	6	5	4	3	2
2	250	13	5	0	-7	-13	-19	-25	-30	-34	-38	-42	-47	-51	-56	-61
3	300	38	28	20	12	4	-2	-8	-14	-19	-23	-27	-32	-36	-41	-46
4	200	-15	-28	-40	-51	-59	-67	-74	-80	-86	-91	-96	-100	-105	-109	-113
5	250	-25	-36	-45	-53	-60	-67	-73	-79	-84	-89	-94	-99	-104	-109	-113
6	250	-45	-52	-57	-61	-66	-71	-77	-82	-87	-91	-96	-100	-105	-109	-113
7	200	-32	-22	-17	-18	-22	-26	-31	-35	-38	-42	-45	-48	-51	-54	-57
8	190	57	62	55	50	45	40	36	33	30	26	23	20	17	14	11
9	260	139	137	123	117	112	108	105	102	100	97	95	93	90	88	86
10	200	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190
11	225	164	150	133	127	123	118	115	112	110	107	105	102	99	96	93
12	200	127	119	106	100	96	91	87	85	82	79	76	74	71	69	67
13	175	63	69	73	75	75	74	73	70	68	66	63	61	59	56	53
14	250	57	65	71	75	76	76	75	73	71	69	66	63	60	57	54
15	100	-2	6	17	23	26	25	24	22	20	18	16	14	12	10	8
16	60	-12	2	15	17	17	14	13	11	8	6	3	1	0	-3	-5
17	35	-39	-19	-1	-2	-4	-7	-6	-8	-10	-12	-13	-15	-16	-17	-19
18	20	-38	-19	-3	-3	-5	-8	-7	-9	-10	-12	-13	-14	-15	-16	-17
19	22	-17	-9	-2	-2	-3	-4	-4	-4	-5	-6	-6	-6	-6	-7	-7
20	50	-63	-43	-25	-26	-28	-32	-30	-32	-33	-35	-37	-38	-40	-41	-43
21	50	-71	-52	-35	-37	-39	-43	-42	-43	-45	-47	-48	-50	-51	-52	-54
22	25	-84	-71	-59	-60	-63	-66	-64	-66	-68	-69	-70	-72	-73	-74	-75
23	25	-90	-79	-69	-70	-72	-74	-73	-74	-75	-76	-77	-78	-79	-79	-80
24	10	-87	-77	-68	-68	-70	-72	-71	-71	-72	-73	-74	-75	-76	-77	-79
25	50	-69	-61	-54	-54	-55	-56	-55	-56	-57	-57	-58	-59	-60	-61	-62
26	100	-46	-41	-37	-36	-37	-37	-37	-37	-38	-38	-39	-39	-39	-39	-40
27	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	95	-26	-24	-22	-22	-22	-23	-23	-23	-23	-23	-23	-23	-24	-24	-25
29	140	-14	-13	-12	-12	-12	-12	-12	-12	-12	-12	-12	-13	-13	-13	-13
30	100	-19	-18	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-18	-18	-18
31	127	-6	-6	-5	-4	-4	-5	-5	-5	-4	-5	-5	-5	-6	-6	-7
32	15	5	5	7	7	7	6	6	6	6	6	6	6	6	5	5
33	75	-13	-13	-12	-11	-12	-14	-14	-15	-15	-16	-17	-19	-21	-23	-26
34	100	-7	-20	-33	-43	-51	-58	-65	-71	-76	-81	-86	-91	-95	-100	-104
35	132	-40	-53	-67	-77	-85	-92	-99	-104	-110	-114	-119	-123	-127	-131	-135
36	200	-51	-59	-66	-71	-77	-83	-89	-94	-98	-103	-107	-111	-115	-119	-123
[illegible]	165	-35	-27	-24	-26	-30	-35	-39	-43	-47	-50	-53	-57	-60	-63	-66

COMPUTED BIENNIAL AVERAGE GROUND WATER LEVEL ELEVATIONS AT EACH NODE
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1962 THROUGH 1990

IN FEET

NODE NO.	AVG GROUND SURFACE ELEVATION	GROUND WATER LEVEL ELEVATION 1962	1964	1966	1968	1970	1972	1974	1976	1978	1980	1982	1984	1986	1988	1990
39	145	36	43	38	33	28	23	20	17	14	11	8	5	2	0	-3
40	175	140	132	109	102	97	91	87	84	81	78	75	72	69	66	63
41	210	154	144	125	119	114	109	106	103	100	97	95	92	90	87	85
42	195	151	136	117	110	105	99	96	93	89	87	84	81	78	75	72
43	145	93	86	77	71	66	61	57	53	50	47	44	41	38	35	32
44	117	35	41	43	40	36	32	29	26	23	20	17	15	12	9	6
45	90	-5	6	17	19	18	15	13	11	8	6	3	0	-1	-4	-6
46	60	-45	-26	-10	-11	-14	-18	-18	-20	-22	-24	-27	-29	-32	-34	-37
47	40	-58	-36	-17	-18	-21	-24	-23	-25	-26	-29	-31	-32	-34	-36	-38
48	55	-66	-46	-31	-33	-36	-40	-38	-40	-43	-45	-47	-48	-50	-52	-54
49	75	-75	-60	-50	-54	-59	-63	-59	-62	-64	-67	-69	-72	-74	-77	-79
50	75	-76	-66	-57	-58	-60	-62	-60	-60	-62	-63	-64	-65	-66	-67	-68
51	17	-65	-57	-51	-51	-52	-54	-53	-53	-54	-55	-56	-57	-57	-58	-59
52	30	-75	-67	-59	-59	-61	-63	-62	-62	-63	-64	-64	-65	-66	-66	-67
53	80	-37	-34	-31	-31	-31	-32	-31	-31	-32	-32	-32	-33	-33	-34	-34
54	45	-53	-49	-45	-44	-45	-47	-46	-46	-46	-47	-47	-48	-48	-48	-49
55	50	-46	-44	-42	-41	-42	-42	-42	-42	-42	-43	-43	-44	-44	-45	-45
56	77	-48	-47	-46	-45	-45	-46	-46	-46	-46	-46	-47	-47	-47	-48	-48
57	120	-52	-53	-53	-52	-52	-52	-52	-52	-53	-53	-54	-54	-54	-54	-54
58	77	-56	-56	-53	-53	-53	-54	-54	-54	-54	-55	-55	-56	-57	-57	-58
59	150	-45	-55	-64	-72	-79	-86	-92	-97	-101	-106	-110	-114	-118	-122	-126
60	150	-62	-68	-73	-78	-83	-89	-94	-98	-102	-106	-110	-114	-117	-121	-124
61	170	-74	-77	-77	-80	-85	-90	-95	-99	-103	-107	-111	-114	-118	-122	-125
62	130	-65	-57	-53	-57	-61	-66	-68	-72	-75	-79	-82	-85	-87	-90	-93
63	115	7	16	16	11	6	1	0	-3	-6	-9	-12	-15	-18	-20	-23
64	135	51	55	49	44	39	34	31	28	25	22	19	16	14	11	9
65	160	109	104	87	80	75	69	65	62	59	56	53	50	47	44	41
66	105	13	22	24	20	16	11	9	6	4	1	-1	-4	-7	-9	-12
67	80	-12	1	9	6	3	0	-2	-4	-7	-10	-12	-15	-18	-20	-23
68	65	-51	-35	-23	-26	-30	-34	-33	-36	-38	-40	-43	-45	-47	-49	-51
69	100	-71	-64	-57	-57	-58	-60	-58	-58	-59	-60	-61	-62	-63	-64	-65
70	125	-61	-59	-55	-54	-55	-56	-55	-55	-56	-57	-57	-58	-59	-60	-61
71	150	-88	-86	-85	-88	-93	-98	-99	-102	-105	-108	-111	-114	-116	-118	-121
72	150	-81	-80	-80	-83	-88	-93	-96	-99	-103	-107	-110	-113	-116	-119	-122
73	85	-51	-38	-29	-34	-40	-44	-42	-44	-47	-50	-53	-55	-58	-61	-63
74	85	-80	-69	-61	-65	-70	-75	-72	-74	-77	-80	-83	-85	-88	-90	-92
75	175	-79	-76	-73	-76	-80	-85	-89	-93	-97	-101	-105	-109	-112	-116	-119

ATTACHMENT NO. 13

TABULATION OF RESULTS

OF OPERATIONAL PLAN NO. 117-7

OPERATIONAL PLAN NO. 117-7

SUMMARY OF PRESENT WORTHS OF FUTURE COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 DOLLARS

WATER SUPPLY				
1. APPLIED WATER			441,404	
2. ARTIFICIAL RECHARGE WATER			55,486	
3. TREATMENT OF GROUND WATER			12,594	
	SUBTOTAL			509,484
SURFACE WATER FACILITIES				
1. ADDITIONAL LATERALS			4,562	
2. CONNECTORS			5,241	
3. STORAGE FACILITIES			236,079	
	SUBTOTAL			245,882
GROUND WATER FACILITIES				
1. PUMPING FACILITIES			12,569	
2. BOOSTER FACILITIES			967	
3. SPREADING FACILITIES			530	
4. INJECTION FACILITIES			10,009	
	SUBTOTAL			24,075
ELECTRICAL ENERGY AND ELECTRICAL SERVICE CONNECTION				
1. PUMPS				
A. ENERGY		22,028		
B. CONNECTION		3,886		
	SUBTOTAL		25,914	
2. BOOSTERS				
A. ENERGY		6,904		
B. CONNECTION		1,230		
	SUBTOTAL		8,134	
	SUBTOTAL			34,048
PRESENT WORTH OF TOTAL COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY				813,489
DISCOUNTED VOLUME OF APPLIED WATER IN 1000 ACRE-FEET				16,993
UNIT COST OF APPLIED WATER IN DOLLARS PER ACRE-FOOT				48

SHEET 2

ESTIMATED ANNUAL AMOUNTS OF REPLENISHMENTS COMMON TO ALL PLANS OF OPERATION TO THE ZONE OF SATURATION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY UNDER WATER SUPPLY CONDITIONS OF MEAN PRECIPITATION FROM 1963 THROUGH 1990

IN ACRE FEET PER YEAR

YEAR	SUBSURFACE GROUND WATER INFLOW ORANGE-L.A. CO.	L.A. FOREBAY	WHITTIER NARROWS	DEEP PERCOLATION OF SURFACE WATER SUPPLIES RECLAIMED WATER	RISING WATER	STORM RUNOFF	PRECIP-ITATION	APPLIED WATER	REPLENISHMENT COMMON TO ALL PLANS OF OPER.
1963	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1964	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1965	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1966	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1967	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1968	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1969	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1970	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1971	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1972	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1973	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1974	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1975	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1976	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1977	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1978	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1979	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1980	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1981	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1982	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1983	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1984	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1985	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1986	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1987	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1988	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1989	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1990	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500

OPERATIONAL PLAN NO. 117-7

ESTIMATED ANNUAL AMOUNTS OF INFLOW AND OUTFLOW AT ZONE OF SATURATION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 ACRE-FEET PER YEAR

YEAR	1 COMMON REPLENISH-MENT	2 IMPORT SPREAD AT M.F.	3 FRESH WATER INJECTION BARRIER PROJECTS WEST COAST	4 WILMING-TON	5 LOS ALAMITOS	6 WATER TO OCEAN	7 GROUND WATER EXTRACTION	8 SURPLUS OR DEFFICIENCY 1 TO 5,-6,-7	9 CUMULATIVE SURPLUS OR DEFFICIENCY
1963	201	45	8	0	0	4	344	-94	-94
1964	201	21	14	0	0	4	340	-108	-202
1965	201	1	14	0	5	4	336	-119	-321
1966	201	4	43	0	5	4	336	-87	-408
1967	201	4	45	0	9	4	336	-81	-489
1968	201	6	45	17	9	4	336	-62	-551
1969	201	7	46	4	10	4	336	-72	-623
1970	201	9	46	4	10	4	337	-71	-694
1971	201	10	47	4	11	4	338	-69	-763
1972	201	8	48	4	12	4	337	-68	-831
1973	201	7	48	4	12	4	336	-68	-899
1974	201	7	49	4	12	4	336	-67	-966
1975	201	6	49	4	13	4	336	-67	-1,033
1976	201	6	50	4	13	4	336	-66	-1,099
1977	201	6	50	4	14	4	336	-65	-1,164
1978	201	5	51	4	14	4	336	-65	-1,229
1979	201	4	51	4	15	4	336	-65	-1,294
1980	201	4	52	4	15	3	336	-63	-1,357
1981	201	4	52	4	16	3	336	-62	-1,419
1982	201	4	53	4	16	3	336	-61	-1,480
1983	201	3	53	4	16	3	336	-62	-1,542
1984	201	3	54	4	17	3	336	-60	-1,602
1985	201	2	55	4	17	3	336	-60	-1,662
1986	201	2	55	4	17	3	336	-60	-1,722
1987	201	1	56	4	18	3	336	-59	-1,781
1988	201	1	56	4	18	3	336	-59	-1,840
1989	201	1	57	4	18	3	336	-58	-1,898
1990	201	1	58	4	19	3	336	-56	-1,954
TOTAL	5,628	182	1,305	105	351	101	9,424	-1,954	

SHEET 4

OPERATIONAL PLAN NO. 117-7

ESTIMATED ANNUAL AMOUNTS OF WATER DEMAND AND WATER SUPPLY
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 ACRE FEET PER YEAR

YEAR	1 APPLIED WATER DEMAND	2 INJEC-TION DEMAND	3 SPREAD-ING DEMAND	4 TOTAL WATER DEMAND 1,2,3	5 IMPORT BY LADWP	6 IMPORT FROM S.G.V.	7 IMPORT SOFTEN DOMES.	8 BY METRO. FILTER DOMES.	9 WATER FILTER INJECT.	10 DIST. RAW SPREAD	11 RECLAIMED WASTE WATER	12 GROUND WATER EXTRACTN	13 TOTAL WATER SUPPLY 5 TO 12
1963	852	8	58	918	197	10	292	9	8	45	13	344	918
1964	872	14	34	920	187	10	308	27	14	21	13	340	920
1965	892	19	14	925	178	10	327	43	19	1	13	336	927
1966	912	48	17	977	168	10	318	81	48	4	13	336	978
1967	932	54	17	1,003	158	10	308	121	54	4	13	336	1,004
1968	952	71	19	1,042	148	10	298	161	71	6	13	336	1,043
1969	972	60	20	1,052	138	10	288	201	60	7	13	336	1,053
1970	992	60	22	1,074	128	10	283	235	60	9	13	337	1,075
1971	1,008	62	23	1,093	128	10	270	263	62	10	13	338	1,094
1972	1,024	64	21	1,109	128	10	262	288	64	8	13	337	1,110
1973	1,040	64	20	1,124	127	10	253	314	64	7	13	336	1,124
1974	1,057	65	20	1,142	127	10	244	340	65	7	13	336	1,142
1975	1,073	66	19	1,158	127	10	236	364	66	6	13	336	1,158
1976	1,089	67	19	1,175	127	10	229	387	67	6	13	336	1,175
1977	1,105	68	19	1,192	127	10	222	410	68	6	13	336	1,192
1978	1,121	69	18	1,208	126	10	214	435	69	5	13	336	1,208
1979	1,137	70	17	1,224	126	10	207	458	70	4	13	336	1,224
1980	1,153	71	17	1,241	126	10	201	480	71	4	13	336	1,241
1981	1,158	72	17	1,247	126	10	194	493	72	4	13	336	1,248
1982	1,164	73	17	1,254	126	10	188	504	73	4	13	336	1,254
1983	1,169	73	16	1,258	126	10	182	515	73	3	13	336	1,258
1984	1,174	75	16	1,265	126	10	178	524	75	3	13	336	1,265
1985	1,180	76	15	1,271	127	10	175	533	76	2	13	336	1,272
1986	1,185	76	15	1,276	127	10	168	545	76	2	13	336	1,277
1987	1,191	78	14	1,283	127	10	164	554	78	1	13	336	1,283
1988	1,196	78	14	1,288	127	10	160	564	78	1	13	336	1,289
1989	1,201	79	14	1,294	127	10	157	572	79	1	13	336	1,295
1990	1,207	81	14	1,302	127	10	154	580	81	1	13	336	1,302
TOTAL	30,008	1,761	546	32,315	3,837	280	6,480	10,001	1,761	182	364	9,424	32,329

OPERATIONAL PLAN NO. 117-7

COMPUTED ANNUAL COSTS OF WATER SUPPLY
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 DOLLARS

YEAR	1 IMPORTED BY LADWP	2 IMPORTED FROM S.G.V.	3 IMPORTED BY METROPOLITAN WATER DIST. SOFTENED DOMESTIC	4 FILTERED DOMESTIC	5 FILTERED INJECTED	6 RAW SPREAD	7 RECLAIMED WASTE WATER	8 TOTAL APPLIED WATER 1 TO 4	9 ARTIFICIAL RECHARGE WATER 5,6,7	10 TREATMENT OF GROUND WATER	11 TOTAL COST 8,9,10
1963	3,946	200	8,176	175	211	710	203	12,497	1,124	568	14,189
1964	3,748	200	9,394	783	388	335	206	14,125	929	581	15,635
1965	3,550	200	11,104	1,280	501	14	214	16,134	729	593	17,456
1966	3,352	200	11,766	2,678	1,258	74	224	17,996	1,556	615	20,167
1967	3,154	200	12,320	4,357	1,488	69	237	20,031	1,794	638	22,463
1968	2,956	200	12,814	6,276	3,198	220	458	22,246	3,876	661	26,783
1969	2,758	200	13,536	8,434	2,839	276	497	24,928	3,612	684	29,224
1970	2,560	200	13,867	10,559	3,069	368	549	27,186	3,986	710	31,882
1971	2,556	200	13,230	11,828	3,150	409	549	27,814	4,108	736	32,658
1972	2,552	200	12,838	12,967	3,232	345	549	28,557	4,126	755	33,438
1973	2,548	200	12,397	14,150	3,261	295	549	29,295	4,105	774	34,174
1974	2,544	200	11,956	15,287	3,291	287	549	29,987	4,127	797	34,911
1975	2,540	200	11,554	16,387	3,339	272	549	30,681	4,160	820	35,661
1976	2,536	200	11,221	17,424	3,388	257	549	31,381	4,194	843	36,418
1977	2,532	200	10,878	18,470	3,445	239	549	32,080	4,233	865	37,178
1978	2,528	200	10,486	19,562	3,504	200	549	32,776	4,253	888	37,917
1979	2,524	200	10,143	20,608	3,556	168	549	33,475	4,273	911	38,659
1980	2,520	200	9,864	21,596	3,609	178	549	34,180	4,336	934	39,450
1981	2,522	200	9,506	22,163	3,652	176	549	34,391	4,377	934	39,702
1982	2,524	200	9,212	22,672	3,697	154	549	34,608	4,400	934	39,942
1983	2,526	200	8,918	23,181	3,745	134	549	34,825	4,428	934	40,187
1984	2,528	200	8,722	23,600	3,794	113	549	35,050	4,456	934	40,440
1985	2,530	200	8,560	23,987	3,836	94	549	35,277	4,479	934	40,690
1986	2,532	200	8,232	24,528	3,878	74	549	35,492	4,501	934	40,927
1987	2,534	200	8,036	24,947	3,926	54	549	35,717	4,529	934	41,180
1988	2,536	200	7,840	25,366	3,974	56	549	35,942	4,579	934	41,455
1989	2,538	200	7,693	25,740	4,023	50	549	36,171	4,622	934	41,727
1990	2,540	200	7,566	26,096	4,072	44	549	36,402	4,665	934	42,001
TOTAL	76,714	5,600	291,829	445,101	85,324	5,665	13,568	819,244	104,557	22,713	946,514

SHEET 6

OPERATIONAL PLAN NO. 117-7

OPERATIONAL DATA AND COMPUTED FLOW REQUIREMENTS OF FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

YEAR	GROUND WATER EXTRACTION	PUMPING LIFT	ANNUAL AND HOURLY WATER DEMAND				FEEDER CAPACITY	FLOW REQUIREMENTS OF FACILITIES				AVERAGE PUMP USE FACTOR
			AVERAGE ANNUAL	PEAK HOURLY	FIRE FLOW	MAX. HOURLY		CON-NECTOR	STOR-AGE	BOOST-ER	PUMP	
	1000 AF/YR	FT	1000 AF/YR	CFS	CFS	CFS	CFS	CFS	CFS	CFS	CFS	PCT
1963	344	143	847	4,183	312	4,500	1,178	800	2,496	413	654	73
1964	340	144	866	4,284	315	4,602	1,178	831	2,547	434	685	70
1965	336	148	887	4,381	318	4,703	1,178	881	2,595	446	707	67
1966	336	151	905	4,481	320	4,806	1,178	875	2,647	485	771	65
1967	336	155	927	4,581	323	4,907	1,178	901	2,699	506	804	62
1968	336	159	946	4,680	325	5,010	1,178	938	2,749	526	838	60
1969	336	162	967	4,778	330	5,111	1,178	963	2,800	547	872	59
1970	337	166	988	4,879	330	5,212	1,178	996	2,852	569	908	57
1971	338	169	1,002	4,960	330	5,296	1,178	1,005	2,895	583	932	56
1972	337	173	1,017	5,037	332	5,375	2,075	1,332	2,957	388	625	74
1973	336	176	1,034	5,119	333	5,458	2,075	1,365	3,002	387	625	74
1974	336	179	1,051	5,199	335	5,540	2,075	1,397	3,050	388	626	74
1975	336	182	1,068	5,277	336	5,620	2,075	1,430	3,097	387	627	74
1976	336	185	1,084	5,357	338	5,699	2,075	1,455	3,143	392	635	72
1977	336	188	1,101	5,438	339	5,782	2,075	1,480	3,191	397	644	71
1978	336	191	1,115	5,518	341	5,862	2,075	1,505	3,238	402	653	70
1979	336	194	1,131	5,597	343	5,944	2,075	1,527	3,284	407	662	70
1980	336	197	1,149	5,678	345	6,023	2,075	1,552	3,331	411	671	69
1981	336	200	1,153	5,705	345	6,051	2,075	1,560	3,346	413	674	69
1982	336	203	1,157	5,730	345	6,079	2,075	1,567	3,363	415	676	69
1983	336	205	1,166	5,758	345	6,105	2,206	1,634	3,377	379	620	74
1984	336	208	1,170	5,786	345	6,133	2,206	1,645	3,394	379	620	74
1985	336	210	1,175	5,812	345	6,159	2,206	1,658	3,410	380	621	74
1986	336	213	1,181	5,837	345	6,187	2,206	1,668	3,428	379	620	74
1987	336	216	1,184	5,866	346	6,214	2,206	1,679	3,442	377	620	74
1988	336	218	1,191	5,892	346	6,242	2,206	1,689	3,460	376	621	74
1989	336	221	1,196	5,920	346	6,269	2,206	1,698	3,476	376	621	74
1990	336	224	1,202	5,945	346	6,297	2,206	1,738	3,495	376	625	74
AVG	336	185	1,066	5,274	335	5,613	1,824	1,348	3,098	425	687	69

SHEET 7

OPERATIONAL PLAN NO. 117-7

COMPUTED NUMBER OF REQUIRED, AVAILABLE AND ADDITIONAL FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

YEAR	CONNECTORS			STORAGE UNITS			BOOSTER UNITS			PUMPING UNITS		
	REQD	AVAILABLE	ADDED	REQD	AVAILABLE	ADDED	REQD	AVAILABLE	ADDED	REQD	AVAILABLE	ADDED
1963	81	159	2	815	807	8	109	132	54	306	639	14
1964	83	161	0	815	815	0	114	128	6	319	591	14
1965	88	161	0	815	815	0	117	126	6	333	543	9
1966	88	161	0	815	815	0	128	132	13	365	510	23
1967	91	161	0	815	815	0	133	136	11	385	470	19
1968	94	161	0	815	815	0	138	140	9	407	438	22
1969	97	161	0	815	815	0	144	144	10	428	434	52
1970	100	161	0	815	815	0	149	149	12	451	451	66
1971	101	161	0	816	815	0	153	153	11	468	468	49
1972	134	161	1	820	816	5	103	147	1	321	453	5
1973	136	162	0	821	820	0	102	141	1	324	438	7
1974	140	163	0	821	821	0	102	137	2	328	425	9
1975	143	163	1	822	821	0	102	132	2	332	418	13
1976	146	164	1	822	822	0	103	129	3	339	411	14
1977	148	165	1	823	822	0	105	126	3	347	405	14
1978	151	166	1	823	823	0	106	123	3	355	400	15
1979	153	167	1	824	823	0	107	120	3	363	395	15
1980	156	168	1	824	824	0	109	118	3	371	392	15
1981	156	169	0	825	824	0	109	116	3	375	388	15
1982	157	169	0	825	825	0	109	113	3	380	385	17
1983	164	170	5	826	825	0	100	111	3	355	381	15
1984	165	175	0	826	826	0	100	109	3	358	380	17
1985	166	176	0	826	826	0	99	108	4	361	379	18
1986	167	176	0	827	826	0	99	106	4	364	380	20
1987	168	177	0	827	827	0	99	105	4	367	381	20
1988	169	177	0	828	827	0	99	104	4	370	383	20
1989	170	178	0	828	828	0	99	103	4	373	384	20
1990	175	178	2	828	828	0	99	103	4	377	385	20
TOTAL			16			13			189			557

SHEET 8

OPERATIONAL PLAN NO. 117-7

COMPUTED ANNUAL COSTS OF REQUIRED SURFACE WATER FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

YEAR	1 LATERALS ADDITIONAL	2 CONNECTORS ADDITIONAL	3 CONNECTORS TOTAL	4 STORAGE FACILITIES ADDITIONAL	5 STORAGE FACILITIES TOTAL	6 TOTAL SURFACE WATER FACILITIES ADDITIONAL 1,2,4	7 TOTAL SURFACE WATER FACILITIES TOTAL 1,3,5
1963	278	4	312	48	14,324	330	14,914
1964	278	4	312	49	14,325	331	14,915
1965	278	4	312	49	14,325	331	14,915
1966	278	4	312	49	14,325	331	14,915
1967	278	4	312	49	14,325	331	14,915
1968	278	4	312	49	14,325	331	14,915
1969	278	4	312	49	14,325	331	14,915
1970	278	4	312	49	14,325	331	14,915
1971	278	4	312	51	14,327	333	14,917
1972	278	5	313	78	14,354	361	14,945
1973	278	6	314	80	14,356	364	14,948
1974	278	6	314	83	14,359	367	14,951
1975	278	8	316	85	14,361	371	14,955
1976	278	10	318	88	14,364	376	14,960
1977	278	12	320	90	14,366	380	14,964
1978	278	13	321	93	14,369	384	14,968
1979	278	15	323	96	14,372	389	14,973
1980	278	17	325	99	14,375	394	14,978
1981	278	17	325	101	14,377	396	14,980
1982	278	19	327	103	14,379	400	14,984
1983	278	28	336	106	14,382	412	14,996
1984	278	30	338	108	14,384	416	15,000
1985	278	30	338	111	14,387	419	15,003
1986	278	31	339	113	14,389	422	15,006
1987	278	33	341	115	14,391	426	15,010
1988	278	33	341	118	14,394	429	15,013
1989	278	34	342	120	14,396	432	15,016
1990	278	38	346	122	14,398	438	15,022
TOTAL	7,784	421		2,351		10,556	

OPERATIONAL PLAN NO. 117-7

COMPUTED ANNUAL COSTS OF REQUIRED GROUND WATER FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

YEAR	1 PUMPING FACILITIES ADDITIONAL	2 PUMPING FACILITIES TOTAL	3 BOOSTER FACILITIES ADDITIONAL	4 BOOSTER FACILITIES TOTAL	5 SPREADING FACILITIES ADDITIONAL	6 SPREADING FACILITIES TOTAL	7 INJECTION FACILITIES ADDITIONAL	8 INJECTION FACILITIES TOTAL	9 TOTAL GRND WTR ADDITIONAL 1.3.5.7	10 FACILITIES TOTAL 2.4.6.8
1963	27	1.040	24	59	0	33	0	253	51	1.385
1964	27	967	2	59	0	33	54	307	83	1.366
1965	18	894	2	59	0	33	193	446	213	1.432
1966	36	842	5	62	0	33	193	446	234	1.383
1967	28	780	4	64	0	33	193	446	225	1.323
1968	34	729	3	63	0	33	447	700	484	1.525
1969	83	725	4	67	0	33	447	700	534	1.525
1970	102	756	5	70	0	33	447	700	554	1.559
1971	74	781	4	71	0	33	447	700	525	1.585
1972	8	759	0	68	0	33	447	700	455	1.560
1973	15	739	0	66	0	33	447	700	462	1.538
1974	18	719	0	64	0	33	447	700	465	1.516
1975	25	707	0	62	0	33	447	700	472	1.502
1976	26	698	1	60	0	33	447	700	474	1.491
1977	26	689	1	59	0	33	447	700	474	1.481
1978	27	683	1	58	0	33	447	700	475	1.474
1979	27	677	1	55	0	33	447	700	475	1.465
1980	28	670	1	55	0	33	447	700	476	1.458
1981	27	663	1	54	0	33	447	700	475	1.450
1982	56	689	1	52	0	33	447	700	504	1.474
1983	53	685	1	52	0	33	447	700	501	1.470
1984	52	675	1	51	0	33	447	700	500	1.459
1985	50	674	1	50	0	33	447	700	498	1.457
1986	55	677	1	50	0	33	447	700	503	1.460
1987	54	679	1	48	0	33	447	700	502	1.460
1988	56	683	1	48	0	33	447	700	504	1.464
1989	56	686	1	47	0	33	447	700	504	1.466
1990	56	686	1	47	0	33	447	700	504	1.466
TOTAL	1.144		68		0		10.914		12.126	

SHEET 10

OPERATIONAL PLAN NO. 117-7

COMPUTED ANNUAL CHARGES OF REQUIRED ELECTRICAL ENERGY AND ELECTRICAL SERVICE CONNECTION
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

	1	2	3	4	5	6	7	8	9
	COSTS FOR PUMPS			COSTS FOR BOOSTERS			TOTAL COSTS FOR PUMPS AND BOOSTERS		
YEAR	ENERGY	CONNECTION	SUBTOTAL 1.2	ENERGY	CONNECTION	SUBTOTAL 4.5	ENERGY 1.4	CONNECTION 2.5	TOTAL 3.6
1963	1.191	199	1.390	429	72	501	1.620	271	1,891
1964	1.196	208	1,404	429	74	503	1,625	282	1,907
1965	1.214	215	1,429	426	78	504	1.640	293	1,933
1966	1.248	237	1.485	434	84	518	1.682	321	2.003
1967	1.279	251	1.530	439	88	527	1,718	339	2.057
1968	1.309	264	1.573	443	90	533	1,752	354	2.106
1969	1.340	279	1.619	446	94	540	1.786	373	2.159
1970	1.373	293	1.666	450	98	548	1.823	391	2,214
1971	1.402	306	1.708	453	100	553	1.855	406	2,261
1972	1.290	211	1.501	408	67	475	1.698	278	1,976
1973	1.300	213	1.513	407	67	474	1,707	280	1.987
1974	1.314	214	1.528	407	67	474	1,721	281	2.002
1975	1.330	218	1.548	406	66	472	1.736	284	2.020
1976	1.347	221	1.568	407	67	474	1.754	288	2.042
1977	1.366	225	1.591	408	68	476	1.774	293	2.067
1978	1.382	230	1.612	409	68	477	1,791	298	2.089
1979	1,401	236	1.637	410	69	479	1.811	305	2.116
1980	1.418	241	1.659	410	70	480	1.828	311	2.139
1981	1.433	244	1.677	410	70	480	1.843	314	2.157
1982	1.446	247	1.693	410	71	481	1.856	318	2.174
1983	1.432	230	1.662	401	66	467	1.833	296	2.129
1984	1.445	233	1.678	401	66	467	1.846	299	2.145
1985	1.455	234	1.689	400	65	465	1.855	299	2.154
1986	1.468	236	1,704	400	64	464	1.868	300	2.168
1987	1.481	239	1,720	399	64	463	1.880	303	2.183
1988	1.494	239	1,733	399	64	463	1.893	303	2.196
1989	1.503	242	1.745	399	64	463	1.902	306	2.208
1990	1.516	245	1.761	399	64	463	1.915	309	2.224
TOTAL	38.373	6.650	45.023	11.639	2.045	13.684	50.012	8.695	58.707

OPERATIONAL PLAN NO. 117-7

SUMMARY OF COMPUTED ANNUAL COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

YEAR	1 WATER SUPPLY COL.11,TABLE 5	2 SURFACE WATER FACILITIES COL.7,TABLE 8	3 GROUND WATER FACILITIES COL.10,TABLE 9	4 ENERGY AND SERVICE CONNECTION COL.9,TABLE 10	5 TOTAL 1,2,3,4	6 CUMULATIVE TOTAL
1963	14,189	14,914	1,385	1,891	32,379	32,379
1964	15,635	14,915	1,366	1,907	33,823	66,202
1965	17,456	14,915	1,432	1,933	35,736	101,938
1966	20,167	14,915	1,383	2,003	38,468	140,406
1967	22,463	14,915	1,323	2,057	40,758	181,164
1968	26,783	14,915	1,525	2,106	45,329	226,493
1969	29,224	14,915	1,525	2,159	47,823	274,316
1970	31,882	14,915	1,559	2,214	50,570	324,886
1971	32,658	14,917	1,585	2,261	51,421	376,307
1972	33,438	14,945	1,560	1,976	51,919	428,226
1973	34,174	14,948	1,538	1,987	52,647	480,873
1974	34,911	14,951	1,516	2,002	53,380	534,253
1975	35,661	14,955	1,502	2,020	54,138	588,391
1976	36,418	14,960	1,491	2,042	54,911	643,302
1977	37,178	14,964	1,481	2,067	55,690	698,992
1978	37,917	14,968	1,474	2,089	56,448	755,440
1979	38,659	14,973	1,465	2,116	57,213	812,653
1980	39,450	14,978	1,458	2,139	58,025	870,678
1981	39,702	14,980	1,450	2,157	58,289	928,967
1982	39,942	14,984	1,474	2,174	58,574	987,541
1983	40,187	14,996	1,470	2,129	58,782	1,046,323
1984	40,440	15,000	1,459	2,145	59,044	1,105,367
1985	40,690	15,003	1,457	2,154	59,304	1,164,671
1986	40,927	15,006	1,460	2,168	59,561	1,224,232
1987	41,180	15,010	1,460	2,183	59,833	1,284,065
1988	41,455	15,013	1,464	2,196	60,128	1,344,193
1989	41,727	15,016	1,466	2,208	60,417	1,404,610
1990	42,001	15,022	1,466	2,224	60,713	1,465,323
TOTAL	946,514	418,908	41,194	58,707	1,465,323	1,465,323

SHEET 12

OPERATIONAL PLAN NO. 117-7

COMPUTED BIENNIAL AVERAGE GROUND WATER LEVEL ELEVATIONS AT EACH NODE
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1962 THROUGH 1990

IN FEET

NODE NO.	AVG GROUND SURFACE ELEVATION	GROUND WATER LEVEL ELEVATION 1962	1964	1966	1968	1970	1972	974	1976	1978	1980	1982	1984	1986	1988	1990
1	250	11	11	10	10	9	8	7	5	4	2	1	0	-2	-4	-6
2	250	13	4	-2	-11	-20	-29	-37	-44	-52	-59	-66	-73	-80	-88	-96
3	300	38	28	18	8	-2	-11	-21	-30	-38	-46	-53	-61	-69	-77	-85
4	200	-15	-29	-45	-60	-74	-86	-97	-107	-117	-126	-135	-144	-152	-160	-169
5	250	-25	-37	-48	-60	-72	-83	-94	-105	-115	-125	-135	-144	-153	-162	-171
6	250	-45	-53	-62	-71	-82	-93	-103	-114	-123	-133	-142	-151	-160	-168	-177
7	200	-32	-26	-30	-40	-50	-60	-69	-78	-86	-94	-102	-110	-117	-124	-131
8	190	57	59	43	31	21	12	4	-3	-10	-18	-26	-33	-41	-48	-55
9	260	139	135	115	103	95	89	83	76	70	64	58	53	47	41	36
10	200	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190
11	225	164	149	124	112	105	99	92	86	79	72	66	60	54	47	41
12	200	127	117	97	84	76	69	61	54	46	38	32	25	18	12	6
13	175	63	68	69	66	62	56	50	44	37	30	23	17	10	3	-2
14	250	57	63	66	66	62	57	52	45	39	32	25	18	11	4	-2
15	100	-2	4	9	11	7	2	-2	-9	-15	-22	-28	-34	-39	-45	-50
16	60	-12	-2	2	0	-5	-12	-17	-23	-29	-36	-41	-47	-53	-58	-64
17	35	-39	-27	-20	-25	-29	-36	-38	-43	-48	-52	-56	-60	-64	-67	-71
18	20	-38	-27	-20	-24	-28	-34	-35	-39	-43	-46	-49	-52	-55	-58	-61
19	22	-17	-12	-9	-11	-12	-15	-15	-16	-18	-19	-21	-22	-22	-23	-24
20	50	-63	-51	-44	-48	-53	-59	-61	-65	-69	-73	-77	-81	-84	-88	-91
21	50	-71	-60	-54	-59	-64	-71	-74	-78	-83	-87	-91	-95	-98	-102	-105
22	25	-84	-76	-73	-77	-82	-87	-90	-94	-98	-102	-106	-109	-112	-115	-118
23	25	-90	-83	-79	-82	-85	-89	-91	-94	-97	-100	-102	-105	-107	-109	-111
24	10	-87	-80	-76	-79	-82	-85	-88	-90	-93	-95	-98	-100	-103	-105	-107
25	50	-69	-63	-60	-61	-64	-66	-68	-70	-72	-73	-75	-77	-79	-81	-83
26	100	-46	-42	-40	-40	-42	-43	-44	-45	-46	-48	-49	-50	-50	-51	-52
27	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	95	-26	-25	-24	-24	-25	-26	-26	-27	-28	-28	-29	-30	-30	-31	-32
29	140	-14	-13	-13	-13	-13	-14	-14	-14	-15	-15	-15	-16	-16	-17	-17
30	100	-19	-18	-18	-18	-18	-19	-19	-20	-20	-20	-21	-21	-21	-22	-22
31	127	-6	-6	-5	-5	-5	-6	-6	-6	-7	-7	-8	-9	-9	-10	-11
32	15	5	5	6	6	6	6	5	5	4	3	3	2	2	1	0
33	75	-13	-13	-13	-13	-14	-15	-17	-19	-21	-24	-27	-30	-33	-37	-42
34	100	-7	-23	-39	-53	-65	-76	-86	-96	-105	-113	-122	-130	-138	-146	-154
35	132	-40	-58	-78	-93	-106	-117	-128	-139	-148	-157	-166	-174	-182	-190	-197
36	200	-51	-62	-74	-85	-97	-108	-119	-129	-138	-147	-156	-164	-172	-180	-188

COMPUTED BIENNIAL AVERAGE GROUND WATER LEVEL ELEVATIONS AT EACH NODE
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1962 THROUGH 1990

IN FEET

NODE NO.	AVG GROUND SURFACE ELEVATION	GROUND WATER LEVEL ELEVATION 1962	1964	1966	1968	1970	1972	1974	1976	1978	1980	1982	1984	1986	1988	1990
39	145	36	39	25	12	3	-5	-13	-21	-29	-37	-44	-51	-59	-66	-72
40	175	140	130	99	84	75	67	59	51	44	35	28	20	13	6	0
41	210	154	142	116	103	95	89	82	74	68	61	54	48	42	35	30
42	195	151	134	106	93	83	77	68	61	53	45	38	31	24	17	10
43	145	93	84	65	51	42	34	25	17	9	0	-6	-14	-22	-29	-36
44	117	35	38	31	21	13	5	-2	-10	-18	-25	-32	-40	-47	-53	-60
45	90	-5	3	5	1	-4	-11	-18	-24	-31	-38	-45	-51	-58	-64	-70
46	60	-45	-34	-30	-36	-42	-50	-53	-59	-65	-70	-76	-82	-87	-92	-98
47	40	-58	-45	-37	-42	-47	-54	-56	-61	-65	-70	-74	-78	-82	-87	-91
48	55	-66	-55	-50	-57	-63	-70	-74	-79	-84	-89	-94	-99	-103	-107	-112
49	75	-75	-68	-68	-76	-83	-91	-97	-103	-109	-115	-121	-126	-132	-137	-143
50	75	-76	-70	-66	-69	-72	-76	-78	-81	-84	-87	-89	-92	-94	-97	-99
51	17	-65	-60	-57	-59	-61	-64	-66	-68	-70	-72	-74	-76	-78	-80	-82
52	30	-75	-70	-66	-68	-71	-74	-76	-78	-80	-82	-84	-86	-88	-89	-91
53	80	-37	-35	-33	-34	-35	-36	-37	-38	-39	-40	-40	-41	-42	-43	-44
54	45	-53	-51	-49	-50	-51	-53	-55	-56	-58	-59	-60	-62	-63	-64	-65
55	50	-46	-45	-44	-44	-45	-46	-47	-49	-49	-51	-52	-53	-54	-55	-56
56	77	-48	-48	-47	-48	-48	-50	-51	-52	-53	-54	-55	-56	-57	-58	-58
57	120	-52	-54	-54	-54	-54	-56	-57	-58	-60	-61	-63	-64	-65	-66	-67
58	77	-56	-57	-56	-56	-58	-59	-61	-63	-64	-66	-67	-69	-71	-72	-74
59	150	-45	-58	-73	-87	-99	-110	-120	-130	-139	-148	-156	-164	-172	-180	-187
60	150	-62	-72	-84	-96	-107	-117	-128	-137	-146	-154	-162	-170	-178	-185	-191
61	170	-74	-81	-91	-101	-112	-122	-132	-141	-150	-158	-167	-175	-182	-190	-197
62	130	-65	-65	-72	-83	-92	-102	-110	-118	-126	-134	-142	-149	-155	-162	-168
63	115	7	10	0	-11	-20	-28	-36	-44	-52	-59	-67	-73	-80	-87	-93
64	135	51	51	36	23	14	5	-2	-10	-17	-25	-32	-39	-46	-52	-58
65	160	109	101	75	60	51	43	34	26	18	10	2	-4	-12	-19	-26
66	105	13	17	9	-1	-10	-18	-25	-33	-40	-47	-54	-61	-68	-74	-81
67	80	-12	-5	-7	-16	-23	-31	-38	-44	-51	-58	-65	-71	-78	-84	-90
68	65	-51	-43	-43	-50	-57	-65	-70	-77	-83	-89	-94	-100	-105	-110	-115
69	100	-71	-66	-64	-65	-68	-71	-73	-76	-79	-81	-83	-86	-88	-90	-93
70	125	-61	-60	-59	-59	-61	-63	-65	-67	-68	-70	-72	-74	-76	-78	-80
71	150	-88	-94	-105	-114	-123	-132	-139	-147	-154	-161	-168	-174	-180	-186	-191
72	150	-81	-87	-98	-108	-118	-128	-137	-145	-153	-161	-169	-176	-183	-189	-196
73	85	-51	-46	-49	-58	-66	-74	-81	-88	-95	-102	-108	-115	-121	-127	-133
74	85	-80	-77	-80	-88	-97	-105	-111	-118	-125	-131	-137	-143	-149	-154	-159
75	175	-79	-82	-89	-99	-109	-119	-129	-138	-147	-156	-164	-172	-180	-187	-194

ATTACHMENT NO. 14

TABULATION OF RESULTS

OF OPERATIONAL PLAN NO. 117-11

OPERATIONAL PLAN NO. 117-11

OPERATIONAL PLAN NO. 117-11

SUMMARY OF PRESENT WORTHS OF FUTURE COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 DOLLARS

WATER SUPPLY			
1. APPLIED WATER		369,609	
2. ARTIFICIAL RECHARGE WATER		76,779	
3. TREATMENT OF GROUND WATER		16,580	
SUBTOTAL			462,968
SURFACE WATER FACILITIES			
1. ADDITIONAL LATERALS		2,781	
2. CONNECTORS		5,190	
3. STORAGE FACILITIES		236,468	
SUBTOTAL			244,439
GROUND WATER FACILITIES			
1. PUMPING FACILITIES		17,796	
2. BOOSTER FACILITIES		1,085	
3. SPREADING FACILITIES		530	
4. INJECTION FACILITIES		13,033	
SUBTOTAL			32,444
ELECTRICAL ENERGY AND ELECTRICAL SERVICE CONNECTION			
1. PUMPS			
A. ENERGY	34,346		
B. CONNECTION	5,682		
SUBTOTAL		40,028	
2. BOOSTERS			
A. ENERGY	8,594		
B. CONNECTION	1,442		
SUBTOTAL		10,036	
SUBTOTAL			50,064
PRESENT WORTH OF TOTAL COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY			789,915
DISCOUNTED VOLUME OF APPLIED WATER IN 1000 ACRE-FEET			16,993
UNIT COST OF APPLIED WATER IN DOLLARS PER ACRE-FOOT			46

SHEET 2

ESTIMATED ANNUAL AMOUNTS OF REPLENISHMENTS COMMON TO ALL PLANS OF OPERATION
TO THE ZONE OF SATURATION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY
UNDER WATER SUPPLY CONDITIONS OF MEAN PRECIPITATION FROM 1963 THROUGH 1990

IN ACRE FEET PER YEAR

YEAR	SUBSURFACE GROUND WATER INFLOW			DEEP PERCOLATION OF SURFACE WATER SUPPLIES					REPLENISHMENT COMMON TO ALL PLANS OF OPER.
	ORANGE-L.A. CO.	L.A. FOREBAY	WHITTIER NARROWS	RECLAIMED WATER	RISING WATER	STORM RUNOFF	PRECIP-ITATION	APPLIED WATER	
1963	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1964	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1965	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1966	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1967	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1968	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1969	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1970	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1971	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1972	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1973	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1974	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1975	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1976	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1977	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1978	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1979	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1980	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1981	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1982	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1983	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1984	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1985	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1986	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1987	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1988	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1989	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1990	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500

OPERATIONAL PLAN NO. 117-11

ESTIMATED ANNUAL AMOUNTS OF INFLOW AND OUTFLOW AT ZONE OF SATURATION
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 ACRE-FEET PER YEAR

YEAR	1 COMMON REPLENISH-MENT	2 IMPORT SPREAD AT M.F.	3 FRESH WATER INJECTION BARRIER WEST COAST	4 WILMING-TON	5 LOS ALAMITOS	6 PROJECTS WATER TO OCEAN	7 GROUND WATER EXTRACTION	8 SURPLUS OR DEFFICIENCY 1 TO 5,-6,-7	9 CUMULATIVE SURPLUS OR DEFFICIENCY
1963	201	46	8	0	0	4	368	-117	-117
1964	201	23	15	0	0	4	388	-153	-270
1965	201	5	15	0	7	4	408	-184	-454
1966	201	7	46	0	8	4	416	-158	-612
1967	201	6	50	0	16	4	424	-155	-767
1968	201	5	51	17	18	4	432	-144	-911
1969	201	4	53	4	20	4	439	-161	-1,072
1970	201	3	55	4	22	4	447	-166	-1,238
1971	201	2	57	4	24	4	455	-171	-1,409
1972	201	4	59	4	26	4	457	-167	-1,576
1973	201	5	61	4	28	3	459	-163	-1,739
1974	201	6	62	4	29	3	459	-160	-1,899
1975	201	6	64	4	31	3	459	-156	-2,055
1976	201	7	66	4	32	3	459	-152	-2,207
1977	201	7	67	4	33	3	459	-150	-2,357
1978	201	7	69	4	34	3	459	-147	-2,504
1979	201	7	71	4	36	3	459	-143	-2,647
1980	201	6	72	4	37	3	459	-142	-2,789
1981	201	6	74	4	38	3	459	-139	-2,928
1982	201	6	75	4	39	3	459	-137	-3,065
1983	201	6	77	4	40	3	459	-134	-3,199
1984	201	5	78	4	41	3	459	-133	-3,332
1985	201	5	80	4	42	3	459	-130	-3,462
1986	201	4	81	4	43	3	459	-129	-3,591
1987	201	3	83	4	43	3	459	-128	-3,719
1988	201	3	84	4	44	3	459	-126	-3,845
1989	201	2	86	4	45	3	459	-124	-3,969
1990	201	1	87	4	46	3	459	-123	-4,092
TOTAL	5,628	197	1,746	105	822	94	12,496	-4,092	

SHEET 4

OPERATIONAL PLAN NO. 117-11

ESTIMATED ANNUAL AMOUNTS OF WATER DEMAND AND WATER SUPPLY
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 ACRE FEET PER YEAR

YEAR	1 APPLIED WATER DEMAND	2 INJEC-TION DEMAND	3 SPREAD-ING DEMAND	4 TOTAL WATER DEMAND 1,2,3	5 IMPORT BY LADWP	6 IMPORT FROM S.G.V.	7 IMPORT BY METRO. WATER DIST. SOFTEN DOMES.	8 FILTER DOMES.	9 FILTER INJECT.	10 RAW SPREAD	11 RECLAIMED WASTE WATER	12 GROUND WATER EXTRACTN	13 TOTAL WATER SUPPLY 5 TO 12
1963	852	8	59	919	197	10	277	0	8	46	13	368	919
1964	872	15	36	923	187	10	287	0	15	23	13	388	923
1965	892	22	18	932	178	10	297	0	22	5	13	408	933
1966	912	54	20	986	168	10	318	1	54	7	13	416	987
1967	932	66	19	1,017	158	10	308	33	66	6	13	424	1,018
1968	952	86	18	1,056	148	10	298	65	86	5	13	432	1,057
1969	972	77	17	1,066	138	10	288	97	77	4	13	439	1,066
1970	992	81	16	1,089	128	10	283	124	81	3	13	447	1,089
1971	1,008	85	15	1,108	128	10	270	145	85	2	13	455	1,108
1972	1,024	89	17	1,130	128	10	262	168	89	4	13	457	1,131
1973	1,040	93	18	1,151	127	10	253	191	93	5	13	459	1,151
1974	1,057	95	19	1,171	127	10	244	216	95	6	13	459	1,170
1975	1,073	99	19	1,191	127	10	236	241	99	6	13	459	1,191
1976	1,089	102	20	1,211	127	10	229	264	102	7	13	459	1,211
1977	1,105	104	20	1,229	127	10	222	287	104	7	13	459	1,229
1978	1,121	107	20	1,248	126	10	214	311	107	7	13	459	1,247
1979	1,137	111	20	1,268	126	10	207	335	111	7	13	459	1,268
1980	1,153	113	19	1,285	126	10	201	357	113	6	13	459	1,285
1981	1,158	116	19	1,293	126	10	194	369	116	6	13	459	1,293
1982	1,164	118	19	1,301	126	10	188	381	118	6	13	459	1,301
1983	1,169	121	19	1,309	126	10	182	392	121	6	13	459	1,309
1984	1,174	123	18	1,315	126	10	178	401	123	5	13	459	1,315
1985	1,180	126	18	1,324	127	10	175	410	126	5	13	459	1,325
1986	1,185	128	17	1,330	127	10	168	422	128	4	13	459	1,331
1987	1,191	130	16	1,337	127	10	164	431	130	3	13	459	1,337
1988	1,196	132	16	1,344	127	10	160	440	132	3	13	459	1,344
1989	1,201	135	15	1,351	127	10	157	449	135	2	13	459	1,352
1990	1,207	137	14	1,358	127	10	154	457	137	1	13	459	1,358
TOTAL	30,008	2,673	561	33,242	3,837	280	6,414	6,987	2,673	197	364	12,496	33,248

OPERATIONAL PLAN NO. 117-11

COMPUTED ANNUAL COSTS OF WATER SUPPLY
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 DOLLARS

YEAR	1 IMPORTED BY LADWP	2 IMPORTED FROM S.G.V.	3 IMPORTED BY METROPOLITAN WATER DIST. SOFTENED DOMESTIC	4 FILTERED DOMESTIC	5 FILTERED INJECTED	6 RAW SPREAD	7 RECLAIMED WASTE WATER	8 TOTAL APPLIED WATER 1 TO 4	9 ARTIFICIAL RECHARGE WATER 5,6,7	10 TREATMENT OF GROUND WATER	11 TOTAL COST 8,9,10
1963	3,946	200	7,766	0	212	714	203	11,912	1,129	603	13,644
1964	3,748	200	8,761	0	392	368	206	12,709	966	657	14,332
1965	3,550	200	10,103	0	561	89	214	13,853	864	714	15,431
1966	3,352	200	11,766	36	1,425	117	224	15,354	1,766	755	17,875
1967	3,154	200	12,320	1,189	1,822	106	237	16,863	2,165	797	19,825
1968	2,956	200	12,814	2,534	3,851	171	458	18,504	4,480	840	23,824
1969	2,758	200	13,536	4,070	3,666	148	497	20,564	4,311	885	25,760
1970	2,560	200	13,867	5,573	4,085	121	549	22,200	4,755	932	27,887
1971	2,556	200	13,230	6,532	4,294	90	549	22,518	4,933	980	28,431
1972	2,552	200	12,838	7,544	4,504	165	549	23,134	5,218	1,017	29,369
1973	2,548	200	12,397	8,602	4,679	203	549	23,747	5,431	1,054	30,232
1974	2,544	200	11,956	9,738	4,856	241	549	24,438	5,646	1,087	31,171
1975	2,540	200	11,554	10,838	5,000	260	549	25,132	5,809	1,120	32,061
1976	2,536	200	11,221	11,876	5,152	278	549	25,833	5,979	1,153	32,965
1977	2,532	200	10,878	12,922	5,303	283	549	26,532	6,135	1,186	33,853
1978	2,528	200	10,486	14,013	5,455	288	549	27,227	6,292	1,219	34,738
1979	2,524	200	10,143	15,059	5,597	283	549	27,926	6,429	1,252	35,607
1980	2,520	200	9,864	16,047	5,738	236	549	28,631	6,523	1,285	36,439
1981	2,522	200	9,506	16,614	5,864	265	549	28,842	6,678	1,285	36,805
1982	2,524	200	9,212	17,123	5,990	252	549	29,059	6,791	1,285	37,135
1983	2,526	200	8,918	17,632	6,117	233	549	29,276	6,899	1,285	37,460
1984	2,528	200	8,722	18,051	6,244	214	549	29,501	7,007	1,285	37,793
1985	2,530	200	8,560	18,439	6,362	192	549	29,729	7,103	1,285	38,117
1986	2,532	200	8,232	18,979	6,481	169	549	29,943	7,199	1,285	38,427
1987	2,534	200	8,036	19,398	6,602	142	549	30,168	7,293	1,285	38,746
1988	2,536	200	7,840	19,817	6,724	115	549	30,393	7,388	1,285	39,066
1989	2,538	200	7,693	20,191	6,845	83	549	30,622	7,477	1,285	39,384
1990	2,540	200	7,566	20,547	6,967	52	549	30,853	7,568	1,285	39,706
TOTAL	76,714	5,600	289,785	313,364	130,788	5,878	13,568	685,463	150,234	30,386	866,083

SHEET 6

OPERATIONAL PLAN NO. 117-11

OPERATIONAL DATA AND COMPUTED FLOW REQUIREMENTS OF FACILITIES IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

YEAR	GROUND WATER EXTRACTION 1000 AF/YR	PUMPING LIFT FT	ANNUAL AND HOURLY WATER DEMAND: AVERAGE ANNUAL 1000 AF/YR	PEAK HOURLY CFS	FIRE FLOW CFS	MAX. HOURLY CFS	FEEDER CAPACITY CFS	FLOW REQUIREMENTS OF FACILITIES: CON-NECTOR CFS	STOR-AGE CFS	BOOST-ER CFS	PUMP CFS	AVERAGE PUMP USE FACTOR PCT
1963	368	145	847	4,183	312	4,500	1,178	767	2,495	436	692	74
1964	388	149	866	4,284	315	4,602	1,178	766	2,544	474	755	71
1965	408	158	887	4,381	318	4,703	1,178	783	2,595	505	805	70
1966	416	167	905	4,481	320	4,806	1,178	764	2,651	548	879	67
1967	424	175	927	4,581	323	4,907	1,178	783	2,707	566	915	66
1968	432	184	946	4,680	325	5,010	1,178	816	2,761	583	948	66
1969	439	193	967	4,778	330	5,111	1,178	838	2,815	601	979	65
1970	447	202	988	4,879	330	5,212	1,178	877	2,872	619	1,012	65
1971	455	211	1,002	4,960	330	5,296	1,178	887	2,919	634	1,041	64
1972	457	220	1,017	5,037	332	5,375	2,075	1,150	2,965	481	800	78
1973	459	229	1,034	5,119	333	5,458	2,075	1,179	3,010	483	804	78
1974	459	237	1,051	5,199	335	5,540	2,075	1,205	3,057	486	812	76
1975	459	245	1,068	5,277	336	5,620	2,075	1,229	3,102	490	823	75
1976	459	252	1,084	5,357	338	5,699	2,075	1,253	3,147	497	834	74
1977	459	260	1,101	5,438	339	5,782	2,075	1,276	3,193	502	844	74
1978	459	267	1,115	5,518	341	5,862	2,075	1,301	3,241	504	854	73
1979	459	274	1,131	5,597	343	5,944	2,075	1,325	3,288	507	862	73
1980	459	280	1,149	5,678	345	6,023	2,075	1,349	3,333	512	870	73
1981	459	287	1,153	5,705	345	6,051	2,075	1,357	3,351	513	873	73
1982	459	293	1,157	5,730	345	6,079	2,075	1,366	3,368	514	875	73
1983	459	300	1,166	5,758	345	6,105	2,206	1,440	3,381	473	809	76
1984	459	306	1,170	5,786	345	6,133	2,206	1,450	3,400	474	812	76
1985	459	312	1,175	5,812	345	6,159	2,206	1,457	3,416	476	815	76
1986	459	318	1,181	5,837	345	6,187	2,206	1,464	3,432	474	818	76
1987	459	324	1,184	5,866	346	6,214	2,206	1,473	3,448	475	820	75
1988	459	330	1,191	5,892	346	6,242	2,206	1,480	3,465	476	823	75
1989	459	335	1,196	5,920	346	6,269	2,206	1,489	3,481	476	826	75
1990	459	341	1,202	5,945	346	6,297	2,206	1,528	3,502	478	829	75
AVG	446	249	1,066	5,274	335	5,613	1,824	1,180	3,104	509	851	72

SHEET 7

OPERATIONAL PLAN NO. 117-11

COMPUTED NUMBER OF REQUIRED, AVAILABLE AND ADDITIONAL FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

YEAR	CONNECTORS			STORAGE UNITS			BOOSTER UNITS			PUMPING UNITS		
	REQD	AVAILABLE	ADDED	REQD	AVAILABLE	ADDED	REQD	AVAILABLE	ADDED	REQD	AVAILABLE	ADDED
1963	77	159	2	815	807	9	115	135	57	328	649	23
1964	77	161	0	816	815	1	125	134	9	361	607	22
1965	79	161	0	817	816	1	133	138	12	399	567	17
1966	77	161	0	819	817	1	144	147	16	446	539	30
1967	78	161	0	820	819	1	149	151	11	477	506	27
1968	82	161	0	821	820	1	154	154	10	507	511	61
1969	84	161	0	823	821	2	159	159	10	538	538	69
1970	87	161	0	825	823	2	163	163	12	570	570	55
1971	87	161	0	826	825	1	167	167	11	601	601	53
1972	115	161	1	826	826	0	127	162	4	491	600	26
1973	118	162	0	826	826	0	127	159	4	506	600	30
1974	121	162	0	826	826	0	128	155	4	524	601	31
1975	123	162	0	826	826	0	129	152	4	542	602	30
1976	126	162	1	826	826	0	130	149	4	559	604	32
1977	128	163	1	826	826	0	132	146	4	576	608	35
1978	131	164	1	826	826	0	133	143	4	593	613	35
1979	133	164	1	827	826	1	134	140	4	608	617	34
1980	136	165	1	828	827	1	135	138	5	623	623	37
1981	136	166	0	828	828	1	135	136	5	635	635	42
1982	137	166	0	829	828	1	135	136	6	647	647	43
1983	144	166	4	829	829	1	124	133	4	618	649	35
1984	145	171	0	830	829	1	124	132	5	629	654	37
1985	146	171	0	830	830	1	125	131	5	640	660	38
1986	146	171	0	831	830	1	125	129	5	650	665	38
1987	148	171	0	831	831	1	125	128	5	661	670	38
1988	148	172	0	832	831	1	126	127	5	671	675	38
1989	149	172	0	832	832	1	126	126	5	680	680	39
1990	153	172	0	833	832	1	126	126	5	691	691	44
TOTAL			12			31			235			1,039

SHEET 8

OPERATIONAL PLAN NO. 117-11

COMPUTED ANNUAL COSTS OF REQUIRED SURFACE WATER FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

	1	2	3	4	5	6	7
	LATERALS	CONNECTORS		STORAGE FACILITIES		TOTAL SURFACE WATER FACILITIES	
YEAR	ADDITIONAL	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL 1,2,4	TOTAL 1,3,5
1963	170	4	312	49	14,325	223	14,807
1964	170	4	312	52	14,328	226	14,810
1965	170	4	312	59	14,335	233	14,817
1966	170	4	312	67	14,343	241	14,825
1967	170	4	312	74	14,350	248	14,832
1968	170	4	312	83	14,359	257	14,841
1969	170	4	312	92	14,368	266	14,850
1970	170	4	312	101	14,377	275	14,859
1971	170	4	312	109	14,385	283	14,867
1972	170	5	313	109	14,385	284	14,868
1973	170	5	313	109	14,385	284	14,868
1974	170	5	313	109	14,385	284	14,868
1975	170	5	313	109	14,385	284	14,868
1976	170	6	314	109	14,385	285	14,869
1977	170	8	316	109	14,385	287	14,871
1978	170	9	317	111	14,387	290	14,874
1979	170	10	318	114	14,390	294	14,878
1980	170	12	320	117	14,393	299	14,883
1981	170	12	320	120	14,396	302	14,886
1982	170	13	321	123	14,399	306	14,890
1983	170	21	329	126	14,402	317	14,901
1984	170	21	329	129	14,405	320	14,904
1985	170	21	329	132	14,408	323	14,907
1986	170	22	330	135	14,411	327	14,911
1987	170	21	329	137	14,413	328	14,912
1988	170	21	329	140	14,416	331	14,915
1989	170	21	329	143	14,419	334	14,918
1990	170	22	330	146	14,422	338	14,922
TOTAL	4,760	296		3,013		8,069	

COMPUTED ANNUAL COSTS OF REQUIRED GROUND WATER FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

	1	2	3	4	5	6	7	8	9	10
	PUMPING FACILITIES		BOOSTER FACILITIES		SPREADING FACILITIES		INJECTION FACILITIES		TOTAL GRND WTR FACILITIES	
YEAR	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL 1.3.5.7	TOTAL 2.4.6.8
1963	50	1.063	25	62	0	33	0	253	129	1.411
1964	45	1.005	3	63	0	33	54	307	241	1.408
1965	37	950	4	64	0	33	193	446	234	1.493
1966	50	908	7	67	0	33	193	446	250	1.454
1967	43	861	4	71	0	33	193	446	240	1.411
1968	110	881	4	71	0	33	702	955	816	1.940
1969	113	928	4	74	0	33	702	955	819	1.990
1970	90	980	4	74	0	33	702	955	796	2.042
1971	149	1.086	4	78	0	33	702	955	855	2.152
1972	111	1.091	1	75	0	33	702	955	814	2.154
1973	120	1.096	1	74	0	33	702	955	823	2.158
1974	123	1.103	1	71	0	33	702	955	826	2.162
1975	126	1.109	1	71	0	33	702	955	829	2.168
1976	147	1.131	1	69	0	33	702	955	850	2.188
1977	156	1.146	1	67	0	33	702	955	859	2.201
1978	151	1.152	1	65	0	33	702	955	854	2.205
1979	152	1.162	1	64	0	33	702	955	855	2.214
1980	158	1.179	1	63	0	33	702	955	861	2.230
1981	113	1.146	1	63	0	33	702	955	816	2.197
1982	139	1.188	2	62	0	33	702	955	843	2.238
1983	192	1.261	1	62	0	33	702	955	895	2.311
1984	197	1.273	1	61	0	33	702	955	900	2.322
1985	205	1.288	1	60	0	33	702	955	908	2.336
1986	189	1.285	1	60	0	33	702	955	892	2.333
1987	193	1.298	1	59	0	33	702	955	896	2.345
1988	198	1.313	1	59	0	33	702	955	901	2.360
1989	201	1.330	1	59	0	33	702	955	904	2.377
1990	212	1.342	2	59	0	33	702	955	916	2.389
TOTAL	3.770		80		0		16.972		20.822	

SHEET 10

OPERATIONAL PLAN NO. 117-11

COMPUTED ANNUAL CHARGES OF REQUIRED ELECTRICAL ENERGY AND ELECTRICAL SERVICE CONNECTION
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

	1	2	3	4	5	6	7	8	9
	COSTS FOR PUMPS			COSTS FOR BOOSTERS			TOTAL COSTS FOR PUMPS AND BOOSTERS		
YEAR	ENERGY	CONNECTION	SUBTOTAL 1,2	ENERGY	CONNECTION	SUBTOTAL 4,5	ENERGY 1,4	CONNECTION 2,5	TOTAL 3,6
1963	1,295	215	1,510	455	74	529	1,750	289	2,039
1964	1,393	237	1,630	484	82	566	1,877	319	2,196
1965	1,527	260	1,787	506	87	593	2,033	347	2,380
1966	1,626	289	1,915	521	95	616	2,147	384	2,531
1967	1,715	310	2,025	528	97	625	2,243	407	2,650
1968	1,804	330	2,134	540	99	639	2,344	429	2,773
1969	1,900	348	2,248	548	104	652	2,448	452	2,900
1970	1,994	371	2,365	558	106	664	2,552	477	3,029
1971	2,096	392	2,488	566	108	674	2,662	500	3,162
1972	2,062	319	2,381	532	82	614	2,594	401	2,995
1973	2,128	330	2,458	533	83	616	2,661	413	3,074
1974	2,186	341	2,527	532	84	616	2,718	425	3,143
1975	2,240	352	2,592	532	85	617	2,772	437	3,209
1976	2,294	363	2,657	532	86	618	2,826	449	3,275
1977	2,345	374	2,719	531	87	618	2,876	461	3,337
1978	2,395	385	2,780	531	87	618	2,926	472	3,398
1979	2,444	396	2,840	532	88	620	2,976	484	3,460
1980	2,493	404	2,897	532	88	620	3,025	492	3,517
1981	2,533	414	2,947	530	87	617	3,063	501	3,564
1982	2,579	420	2,999	530	88	618	3,109	508	3,617
1983	2,584	401	2,985	519	80	599	3,103	481	3,584
1984	2,624	411	3,035	519	81	600	3,143	492	3,635
1985	2,664	417	3,081	517	81	598	3,181	498	3,679
1986	2,701	425	3,126	517	82	599	3,218	507	3,725
1987	2,739	429	3,168	517	82	599	3,256	511	3,767
1988	2,778	437	3,215	516	82	598	3,294	519	3,813
1989	2,814	443	3,257	514	82	596	3,328	525	3,853
1990	2,850	450	3,300	515	82	597	3,365	532	3,897
TOTAL	62,803	10,263	73,066	14,687	2,449	17,136	77,490	12,712	90,202

OPERATIONAL PLAN NO. 117-11

SUMMARY OF COMPUTED ANNUAL COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

YEAR	1 WATER SUPPLY COL.11,TABLE 5	2 SURFACE WATER FACILITIES COL.7,TABLE 8	3 GROUND WATER FACILITIES COL.10,TABLE 9	4 ENERGY AND SERVICE CONNECTION COL.9,TABLE 10	5 TOTAL 1,2,3,4	6 CUMULATIVE TOTAL
1963	13,644	14,807	1,411	2,039	31,901	31,901
1964	14,332	14,810	1,408	2,196	32,746	64,647
1965	15,431	14,817	1,493	2,380	34,121	98,768
1966	17,875	14,825	1,454	2,531	36,685	135,453
1967	19,825	14,832	1,411	2,650	38,718	174,171
1968	23,824	14,841	1,940	2,773	43,378	217,549
1969	25,760	14,850	1,990	2,900	45,500	263,049
1970	27,887	14,859	2,042	3,029	47,817	310,866
1971	28,431	14,867	2,152	3,162	48,612	359,478
1972	29,369	14,868	2,154	2,995	49,386	408,864
1973	30,232	14,868	2,158	3,074	50,332	459,196
1974	31,171	14,868	2,162	3,143	51,344	510,540
1975	32,061	14,868	2,168	3,209	52,306	562,846
1976	32,965	14,869	2,188	3,275	53,297	616,143
1977	33,853	14,871	2,201	3,337	54,262	670,405
1978	34,738	14,874	2,205	3,398	55,215	725,620
1979	35,607	14,878	2,214	3,460	56,159	781,779
1980	36,439	14,883	2,230	3,517	57,069	838,848
1981	36,805	14,886	2,197	3,564	57,452	896,300
1982	37,135	14,890	2,238	3,617	57,880	954,180
1983	37,460	14,901	2,311	3,584	58,256	1,012,436
1984	37,793	14,904	2,322	3,635	58,654	1,071,090
1985	38,117	14,907	2,336	3,679	59,039	1,130,129
1986	38,427	14,911	2,333	3,725	59,396	1,189,525
1987	38,746	14,912	2,345	3,767	59,770	1,249,295
1988	39,066	14,915	2,360	3,813	60,154	1,309,449
1989	39,384	14,918	2,377	3,853	60,532	1,369,981
1990	39,706	14,922	2,389	3,897	60,914	1,430,895
TOTAL	866,083	416,421	58,189	90,202	1,430,895	1,430,895

SHEET 12

OPERATIONAL PLAN NO.117-11

COMPUTED BIENNIAL AVERAGE GROUND WATER LEVEL ELEVATIONS AT EACH NODE
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1962 THROUGH 1990

IN FEET

NODE NO.	AVG GROUND SURFACE ELEVATION	GROUND WATER LEVEL ELEVATION 1962	1964	1966	1968	1970	1972	974	1976	1978	1980	1982	1984	1986	1988	1990
1	250	11	10	9	8	6	4	1	-1	-3	-6	-10	-13	-16	-20	-24
2	250	13	3	-6	-19	-33	-47	-61	-74	-88	-101	-115	-128	-142	-157	-171
3	300	38	27	15	0	-15	-31	-47	-62	-78	-93	-108	-123	-138	-153	-169
4	200	-15	-32	-55	-78	-100	-121	-142	-162	-181	-200	-219	-236	-254	-271	-288
5	250	-25	-38	-52	-70	-90	-111	-133	-155	-177	-198	-219	-239	-259	-278	-296
6	250	-45	-55	-68	-85	-106	-129	-152	-175	-198	-219	-240	-260	-279	-298	-316
7	200	-32	-31	-44	-66	-92	-120	-145	-168	-189	-209	-228	-246	-263	-279	-295
8	190	57	56	34	11	-12	-38	-61	-82	-101	-119	-137	-154	-170	-186	-202
9	260	139	134	111	92	73	53	36	20	5	-9	-22	-35	-48	-60	-72
10	200	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190
11	225	164	148	121	101	81	61	43	27	11	-3	-17	-31	-45	-59	-72
12	200	127	116	92	71	50	27	6	-13	-31	-49	-66	-82	-97	-112	-126
13	175	63	68	67	59	47	31	13	-6	-25	-43	-61	-79	-95	-112	-127
14	250	57	63	64	58	46	30	13	-5	-24	-43	-61	-78	-96	-112	-129
15	100	-2	3	4	-2	-15	-32	-51	-70	-89	-107	-123	-139	-154	-168	-182
16	60	-12	-4	-10	-23	-39	-59	-78	-95	-111	-127	-142	-156	-169	-182	-194
17	35	-39	-31	-42	-57	-74	-92	-107	-119	-131	-142	-152	-161	-170	-179	-187
18	20	-38	-30	-40	-53	-67	-83	-95	-105	-115	-123	-132	-139	-146	-153	-159
19	22	-17	-14	-18	-23	-29	-35	-39	-43	-47	-50	-53	-56	-58	-61	-63
20	50	-63	-55	-66	-81	-97	-114	-127	-138	-149	-158	-167	-176	-184	-192	-200
21	50	-71	-64	-77	-93	-109	-128	-142	-155	-166	-177	-187	-196	-205	-213	-221
22	25	-84	-80	-90	-103	-118	-133	-146	-156	-167	-176	-184	-192	-200	-207	-214
23	25	-90	-85	-91	-100	-111	-121	-131	-139	-146	-153	-159	-165	-170	-175	-180
24	10	-87	-82	-87	-96	-106	-115	-124	-131	-138	-144	-150	-156	-162	-167	-172
25	50	-69	-65	-67	-73	-80	-88	-94	-100	-105	-109	-114	-118	-123	-127	-131
26	100	-46	-43	-44	-47	-51	-55	-59	-63	-66	-69	-71	-74	-76	-78	-80
27	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	95	-26	-25	-26	-28	-30	-32	-35	-37	-38	-40	-41	-43	-45	-46	-48
29	140	-14	-13	-14	-15	-16	-17	-18	-19	-20	-21	-21	-22	-23	-24	-25
30	100	-19	-18	-19	-20	-21	-22	-23	-25	-26	-27	-27	-28	-29	-30	-31
31	127	-6	-6	-6	-7	-8	-9	-10	-11	-12	-13	-14	-15	-17	-19	-20
32	15	5	5	5	5	4	3	2	1	0	-1	-3	-5	-6	-7	-9
33	75	-13	-14	-15	-16	-19	-22	-26	-31	-35	-41	-46	-53	-60	-67	-75
34	100	-7	-27	-52	-72	-92	-110	-128	-146	-163	-180	-197	-214	-230	-246	-262
35	132	-40	-65	-98	-123	-146	-167	-189	-209	-229	-248	-266	-284	-301	-317	-333
36	200	-51	-65	-86	-108	[illegible]	[illegible]	[illegible]	-226	-248	-269	-288	[illegible]	-297	-314	-330

COMPUTED BIENNIAL AVERAGE GROUND WATER LEVEL ELEVATIONS AT EACH NODE
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1962 THROUGH 1990

IN FEET

NODE NO.	AVG GROUND SURFACE ELEVATION	GROUND WATER LEVEL ELEVATION 1962	1964	1966	1968	1970	1972	1974	1976	1978	1980	1982	1984	1986	1988	1990
39	145	36	35	13	-10	-35	-61	-84	-106	-125	-144	-161	-178	-194	-210	-225
40	175	140	128	93	69	45	20	-1	-21	-40	-58	-76	-92	-108	-124	-139
41	210	154	141	112	91	70	48	29	12	-4	-20	-35	-49	-63	-77	-90
42	195	151	133	102	79	55	31	9	-9	-28	-46	-63	-79	-95	-110	-126
43	145	93	82	58	34	9	-16	-40	-62	-82	-101	-120	-137	-154	-171	-187
44	117	35	36	22	2	-20	-44	-67	-88	-108	-126	-144	-161	-177	-193	-208
45	90	-5	1	-4	-18	-37	-58	-79	-98	-117	-134	-151	-166	-181	-196	-210
46	60	-45	-38	-52	-70	-90	-111	-129	-145	-159	-173	-185	-198	-210	-222	-234
47	40	-58	-49	-61	-77	-94	-112	-127	-139	-150	-161	-172	-182	-191	-200	-210
48	55	-66	-59	-74	-92	-111	-132	-149	-163	-176	-189	-200	-211	-222	-232	-242
49	75	-75	-74	-94	-114	-136	-158	-177	-193	-208	-223	-236	-249	-262	-274	-286
50	75	-76	-72	-78	-88	-98	-109	-118	-126	-134	-141	-147	-153	-159	-165	-170
51	17	-65	-62	-65	-72	-79	-87	-94	-100	-105	-110	-115	-120	-124	-129	-133
52	30	-75	-71	-75	-83	-91	-99	-106	-113	-119	-124	-129	-133	-137	-141	-145
53	80	-37	-35	-37	-39	-43	-46	-49	-52	-54	-57	-58	-60	-63	-65	-66
54	45	-53	-52	-54	-59	-64	-70	-74	-79	-83	-86	-90	-93	-96	-99	-101
55	50	-46	-46	-47	-49	-53	-56	-59	-63	-65	-68	-70	-73	-75	-78	-80
56	77	-48	-48	-50	-52	-55	-58	-62	-65	-68	-71	-73	-76	-78	-80	-82
57	120	-52	-54	-55	-57	-60	-63	-67	-71	-75	-79	-83	-86	-89	-92	-95
58	77	-56	-57	-59	-63	-67	-72	-77	-82	-86	-90	-94	-98	-102	-105	-109
59	150	-45	-62	-87	-112	-135	-157	-178	-199	-219	-238	-256	-273	-290	-306	-322
60	150	-62	-78	-102	-126	-149	-173	-196	-217	-238	-257	-275	-293	-310	-325	-341
61	170	-74	-87	-109	-133	-157	-183	-206	-229	-250	-269	-288	-306	-323	-340	-356
62	130	-65	-73	-96	-121	-147	-174	-197	-218	-238	-256	-274	-290	-306	-321	-335
63	115	7	6	-14	-39	-63	-89	-113	-133	-152	-170	-187	-203	-219	-234	-249
64	135	51	49	25	1	-23	-48	-72	-93	-112	-131	-148	-164	-180	-195	-209
65	160	109	100	68	43	18	-7	-31	-52	-72	-91	-108	-126	-142	-158	-174
66	105	13	14	-5	-28	-51	-76	-99	-119	-137	-155	-171	-187	-203	-218	-232
67	80	-12	-8	-24	-45	-67	-91	-112	-131	-149	-165	-181	-196	-210	-224	-238
68	65	-51	-47	-65	-86	-107	-130	-150	-166	-182	-196	-210	-223	-235	-247	-259
69	100	-71	-68	-74	-81	-90	-100	-108	-115	-122	-128	-134	-139	-145	-150	-155
70	125	-61	-61	-63	-68	-74	-80	-86	-91	-96	-101	-106	-110	-114	-119	-123
71	150	-88	-105	-137	-160	-182	-205	-226	-245	-262	-279	-294	-309	-323	-336	-349
72	150	-81	-97	-125	-149	-174	-198	-221	-242	-262	-280	-298	-314	-330	-345	-359
73	85	-51	-51	-72	-96	-120	-144	-166	-184	-201	-217	-233	-247	-261	-275	-288
74	85	-80	-84	-108	-130	-152	-175	-195	-213	-229	-245	-260	-273	-286	-299	-311
75	175	-79	-88	-108	-131	-157	-184	-209	-231	-252	-272	-292	-309	-327	-343	-359

ATTACHMENT NO. 15

TABULATION OF RESULTS

OF OPERATIONAL PLAN NO. 318-5

SHEET 1

OPERATIONAL PLAN NO. 318-5

SUMMARY OF PRESENT WORTHS OF FUTURE COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 DOLLARS

WATER SUPPLY				
1. APPLIED WATER			478,014	
2. ARTIFICIAL RECHARGE WATER			59,760	
3. TREATMENT OF GROUND WATER			10,629	
	SUBTOTAL			548,403
SURFACE WATER FACILITIES				
1. ADDITIONAL LATERALS			5,136	
2. CONNECTORS			5,291	
3. STORAGE FACILITIES			235,477	
	SUBTOTAL			245,904
GROUND WATER FACILITIES				
1. PUMPING FACILITIES			10,044	
2. BOOSTER FACILITIES			941	
3. SPREADING FACILITIES			530	
4. INJECTION FACILITIES			6,693	
	SUBTOTAL			18,208
ELECTRICAL ENERGY AND ELECTRICAL SERVICE CONNECTION				
1. PUMPS				
A. ENERGY		15,222		
B. CONNECTION		2,905		
	SUBTOTAL		18,127	
2. BOOSTERS				
A. ENERGY		6,146		
B. CONNECTION		1,172		
	SUBTOTAL		7,318	
	SUBTOTAL			25,445
PRESENT WORTH OF TOTAL COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY				837,960
DISCOUNTED VOLUME OF APPLIED WATER IN 1000 ACRE-FEET				16,993
UNIT COST OF APPLIED WATER IN DOLLARS PER ACRE-FOOT				49

SHEET 2

ESTIMATED ANNUAL AMOUNTS OF REPLENISHMENTS COMMON TO ALL PLANS OF OPERATION
TO THE ZONE OF SATURATION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY
UNDER WATER SUPPLY CONDITIONS OF MEAN PRECIPITATION FROM 1963 THROUGH 1990

IN ACRE FEET PER YEAR

YEAR	SUBSURFACE GROUND WATER INFLOW ORANGE-L.A. CO.	L.A. FOREBAY	WHITTIER NARROWS	DEEP PERCOLATION OF SURFACE WATER SUPPLIES RECLAIMED WATER	RISING WATER	STORM RUNOFF	PRECIP-ITATION	APPLIED WATER	REPLENISHMENT COMMON TO ALL PLANS OF OPER.
1963	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1964	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1965	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1966	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1967	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1968	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1969	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1970	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1971	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1972	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1973	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1974	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1975	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1976	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1977	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1978	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1979	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1980	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1981	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1982	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1983	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1984	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1985	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1986	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1987	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1988	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1989	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500
1990	29,000	200	28,300	13,000	37,700	10,000	29,400	52,900	200,500

SHEET 3

OPERATIONAL PLAN NO. 318-5

ESTIMATED ANNUAL AMOUNTS OF INFLOW AND OUTFLOW AT ZONE OF SATURATION IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 ACRE-FEET PER YEAR

YEAR	1 COMMON REPLENISH-MENT	2 IMPORT SPREAD AT M.F.	3 FRESH WATER INJECTION BARRIER WEST COAST	4 WILMING-TON	5 LOS ALAMITOS	6 PROJECTS WATER TO OCEAN	7 GROUND WATER EXTRACTION	8 SURPLUS OR DEFFICIENCY 1 TO 5,-6,-7	9 CUMULATIVE SURPLUS OR DEFFICIENCY
1963	201	45	7	0	0	4	304	-55	-55
1964	201	51	14	0	0	4	291	-29	-84
1965	201	53	13	0	0	4	278	-15	-99
1966	201	51	39	0	0	4	280	7	-92
1967	201	49	40	0	0	4	281	5	-87
1968	201	48	39	17	0	4	282	19	-68
1969	201	47	39	4	0	4	283	4	-64
1970	201	46	39	4	0	4	283	3	-61
1971	201	45	39	4	0	5	284	0	-61
1972	201	44	39	4	0	5	281	2	-59
1973	201	43	38	4	0	5	278	3	-56
1974	201	43	38	4	0	5	278	3	-53
1975	201	42	37	4	0	5	278	1	-52
1976	201	41	37	4	0	6	278	-1	-53
1977	201	41	37	4	0	6	278	-1	-54
1978	201	40	37	4	0	6	278	-2	-56
1979	201	40	37	4	0	6	278	-2	-58
1980	201	40	37	4	0	6	278	-2	-60
1981	201	39	37	4	0	6	278	-3	-63
1982	201	39	37	4	0	6	278	-3	-66
1983	201	39	37	4	0	6	278	-3	-69
1984	201	39	37	4	0	6	278	-3	-72
1985	201	39	37	4	0	6	278	-3	-75
1986	201	38	37	4	0	7	278	-5	-80
1987	201	38	37	4	0	7	278	-5	-85
1988	201	38	37	4	0	7	278	-5	-90
1989	201	38	37	4	0	7	278	-5	-95
1990	201	38	37	4	0	7	278	-5	-100
TOTAL	5,628	1,194	976	105	0	152	7,851	-100	

SHEET 4

OPERATIONAL PLAN NO. 318-5

ESTIMATED ANNUAL AMOUNTS OF WATER DEMAND AND WATER SUPPLY
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 ACRE FEET PER YEAR

YEAR	1 APPLIED WATER DEMAND	2 INJECTION DEMAND	3 SPREADING DEMAND	4 TOTAL WATER DEMAND 1,2,3	5 IMPORT BY LADWP	6 IMPORT FROM S.G.V.	7 IMPORT BY METRO. SOFTEN DOMES.	8 IMPORT BY METRO. FILTER DOMES.	9 WATER DIST. FILTER INJECT.	10 WATER DIST. RAW SPREAD	11 RECLAIMED WASTE WATER	12 GROUND WATER EXTRACTN	13 TOTAL WATER SUPPLY 5 TO 12
1963	852	7	58	917	197	10	292	49	7	45	13	304	917
1964	872	14	64	950	187	10	308	76	14	51	13	291	950
1965	892	13	66	971	178	10	327	100	13	53	13	278	972
1966	912	39	64	1,015	168	10	318	137	39	51	13	280	1,016
1967	932	40	62	1,034	158	10	308	176	40	49	13	281	1,035
1968	952	56	61	1,069	148	10	298	215	56	48	13	282	1,070
1969	972	43	60	1,075	138	10	288	253	43	47	13	283	1,075
1970	992	43	59	1,094	128	10	283	288	43	46	13	283	1,094
1971	1,008	43	58	1,109	128	10	270	317	43	45	13	284	1,110
1972	1,024	43	57	1,124	128	10	262	344	43	44	13	281	1,125
1973	1,040	42	56	1,138	127	10	253	372	42	43	13	278	1,138
1974	1,057	42	56	1,155	127	10	244	397	42	43	13	278	1,154
1975	1,073	41	55	1,169	127	10	236	421	41	42	13	278	1,168
1976	1,089	41	54	1,184	127	10	229	444	41	41	13	278	1,183
1977	1,105	41	54	1,200	127	10	222	468	41	41	13	278	1,200
1978	1,121	41	53	1,215	126	10	214	492	41	40	13	278	1,214
1979	1,137	41	53	1,231	126	10	207	515	41	40	13	278	1,230
1980	1,153	41	53	1,247	126	10	201	537	41	40	13	278	1,246
1981	1,158	41	52	1,251	126	10	194	550	41	39	13	278	1,251
1982	1,164	41	52	1,257	126	10	188	561	41	39	13	278	1,256
1983	1,169	41	52	1,262	126	10	182	572	41	39	13	278	1,261
1984	1,174	41	52	1,267	126	10	178	582	41	39	13	278	1,267
1985	1,180	41	52	1,273	127	10	175	590	41	39	13	278	1,273
1986	1,185	41	51	1,277	127	10	168	602	41	38	13	278	1,277
1987	1,191	41	51	1,283	127	10	164	612	41	38	13	278	1,283
1988	1,196	41	51	1,288	127	10	160	621	41	38	13	278	1,288
1989	1,201	41	51	1,293	127	10	157	629	41	38	13	278	1,293
1990	1,207	41	51	1,299	127	10	154	637	41	38	13	278	1,298
TOTAL	30,008	1,081	1,558	32,647	3,837	280	6,480	11,557	1,081	1,194	364	7,851	32,644

SHEET 5

OPERATIONAL PLAN NO. 318-5

COMPUTED ANNUAL COSTS OF WATER SUPPLY
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

IN 1000 DOLLARS

YEAR	1 IMPORTED BY LADWP	2 IMPORTED FROM S.G.V.	3 IMPORTED BY METROPOLITAN WATER DIST. SOFTENED DOMESTIC	4 FILTERED DOMESTIC	5 FILTERED INJECTED	6 RAW SPREAD	7 RECLAIMED WASTE WATER	8 TOTAL APPLIED WATER 1 TO 4	9 ARTIFICIAL RECHARGE WATER 5,6,7	10 TREATMENT OF GROUND WATER	11 TOTAL COST 8,9,10
1963	3,946	200	8,176	981	206	698	203	13,303	1,107	508	14,918
1964	3,748	200	9,394	2,197	373	812	206	15,539	1,391	509	17,439
1965	3,550	200	11,104	2,996	349	871	214	17,850	1,434	507	19,791
1966	3,352	200	11,766	4,527	1,035	879	224	19,845	2,138	526	22,509
1967	3,154	200	12,320	6,333	1,112	903	237	22,007	2,252	545	24,804
1968	2,956	200	12,814	8,372	2,527	1,691	458	24,342	4,676	565	29,583
1969	2,758	200	13,536	10,643	2,062	1,792	497	27,137	4,351	585	32,073
1970	2,560	200	13,867	12,960	2,176	1,931	549	29,587	4,656	604	34,847
1971	2,556	200	13,230	14,263	2,173	1,897	549	30,249	4,619	623	35,491
1972	2,552	200	12,838	15,471	2,170	1,863	549	31,061	4,582	637	36,280
1973	2,548	200	12,397	16,724	2,145	1,833	549	31,869	4,527	650	37,046
1974	2,544	200	11,956	17,861	2,120	1,802	549	32,561	4,471	668	37,700
1975	2,540	200	11,554	18,961	2,106	1,774	549	33,255	4,429	686	38,370
1976	2,536	200	11,221	19,998	2,093	1,747	549	33,955	4,389	704	39,048
1977	2,532	200	10,878	21,044	2,087	1,727	549	34,654	4,363	722	39,739
1978	2,528	200	10,486	22,136	2,082	1,708	549	35,350	4,339	740	40,429
1979	2,524	200	10,143	23,182	2,074	1,693	549	36,049	4,316	758	41,123
1980	2,520	200	9,864	24,170	2,067	1,679	549	36,754	4,295	776	41,825
1981	2,522	200	9,506	24,737	2,061	1,667	549	36,965	4,277	776	42,018
1982	2,524	200	9,212	25,246	2,055	1,654	549	37,182	4,258	776	42,216
1983	2,526	200	8,918	25,755	2,057	1,644	549	37,399	4,250	776	42,425
1984	2,528	200	8,722	26,174	2,058	1,635	549	37,624	4,242	776	42,642
1985	2,530	200	8,560	26,561	2,057	1,630	549	37,851	4,236	776	42,863
1986	2,532	200	8,232	27,102	2,056	1,625	549	38,066	4,230	776	43,072
1987	2,534	200	8,036	27,521	2,061	1,620	549	38,291	4,230	776	43,297
1988	2,536	200	7,840	27,940	2,066	1,614	549	38,516	4,229	776	43,521
1989	2,538	200	7,693	28,314	2,071	1,611	549	38,745	4,231	776	43,752
1990	2,540	200	7,566	28,670	2,077	1,608	549	38,976	4,234	776	43,986
TOTAL	76,714	5,600	291,829	510,839	51,576	43,608	13,568	884,982	108,752	19,073	1,012,807

SHEET 6

OPERATIONAL PLAN NO. 318-5

OPERATIONAL DATA AND COMPUTED FLOW REQUIREMENTS OF FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

YEAR	GROUND WATER EXTRACTION 1000 AF/YR	PUMPING LIFT FT	ANNUAL AND HOURLY WATER DEMAND: AVERAGE ANNUAL 1000 AF/YR	PEAK HOURLY CFS	FIRE FLOW CFS	MAX. HOURLY CFS	FEEDER CAPACITY CFS	FLOW REQUIREMENTS OF FACILITIES: CON-NECTOR CFS	STOR-AGE CFS	BOOST-ER CFS	PUMP CFS	AVERAGE PUMP USE FACTOR PCT
1963	304	138	847	4,183	312	4,500	1,178	858	2,488	384	606	72
1964	291	135	866	4,284	315	4,602	1,178	901	2,539	397	624	68
1965	278	132	887	4,381	318	4,703	1,178	954	2,589	409	640	65
1966	280	129	905	4,481	320	4,806	1,178	940	2,641	458	714	61
1967	281	128	927	4,581	323	4,907	1,178	958	2,692	484	754	59
1968	282	127	946	4,680	325	5,010	1,178	989	2,741	509	792	56
1969	283	127	967	4,778	330	5,111	1,178	1,012	2,793	536	830	54
1970	283	126	988	4,879	330	5,212	1,178	1,041	2,845	560	870	52
1971	284	126	1,002	4,960	330	5,296	1,178	1,030	2,888	577	894	51
1972	281	126	1,017	5,037	332	5,375	2,075	1,416	2,946	357	553	72
1973	278	125	1,034	5,119	333	5,458	2,075	1,448	2,990	359	555	72
1974	278	124	1,051	5,199	335	5,540	2,075	1,480	3,037	361	558	71
1975	278	124	1,068	5,277	336	5,620	2,075	1,511	3,083	364	560	71
1976	278	123	1,084	5,357	338	5,699	2,075	1,545	3,127	365	562	71
1977	278	123	1,101	5,438	339	5,782	2,075	1,574	3,173	368	566	71
1978	278	123	1,115	5,518	341	5,862	2,075	1,601	3,220	376	575	69
1979	278	123	1,131	5,597	343	5,944	2,075	1,624	3,264	384	587	68
1980	278	122	1,149	5,678	345	6,023	2,075	1,645	3,309	391	600	67
1981	278	122	1,153	5,705	345	6,051	2,075	1,652	3,323	394	604	67
1982	278	122	1,157	5,730	345	6,079	2,075	1,661	3,340	397	607	67
1983	278	122	1,166	5,758	345	6,105	2,206	1,710	3,352	373	569	71
1984	278	122	1,170	5,786	345	6,133	2,206	1,721	3,368	375	571	70
1985	278	122	1,175	5,812	345	6,159	2,206	1,731	3,383	376	574	70
1986	278	122	1,181	5,837	345	6,187	2,206	1,740	3,399	377	577	70
1987	278	122	1,184	5,866	346	6,214	2,206	1,749	3,412	379	579	70
1988	278	122	1,191	5,892	346	6,242	2,206	1,759	3,430	381	581	70
1989	278	122	1,196	5,920	346	6,269	2,206	1,769	3,444	382	583	70
1990	278	122	1,202	5,945	346	6,297	2,206	1,811	3,462	384	586	70
AVG	280	125	1,066	5,274	335	5,613	1,824	1,422	3,081	409	631	66

SHEET 7

OPERATIONAL PLAN NO. 318-5

COMPUTED NUMBER OF REQUIRED, AVAILABLE AND ADDITIONAL FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

	CONNECTORS			STORAGE UNITS			BOOSTER UNITS			PUMPING UNITS		
YEAR	REQD	AVAILABLE	ADDED	REQD	AVAILABLE	ADDED	REQD	AVAILABLE	ADDED	REQD	AVAILABLE	ADDED
1963	87	159	2	812	807	5	101	126	48	278	636	11
1964	91	161	0	812	812	0	105	122	6	279	581	7
1965	96	161	0	812	812	0	108	121	6	281	527	2
1966	94	161	0	812	812	0	121	129	15	308	486	15
1967	96	161	0	812	812	0	128	133	12	323	442	14
1968	99	161	0	812	812	0	134	137	10	337	402	13
1969	101	161	0	812	812	0	141	141	11	351	380	32
1970	104	161	0	812	812	0	148	148	15	366	371	40
1971	105	161	0	812	812	0	152	152	10	375	375	37
1972	142	161	3	815	812	3	94	145	0	228	352	8
1973	145	164	0	815	815	0	95	139	1	227	337	3
1974	148	164	0	815	815	0	96	134	2	227	323	3
1975	152	165	1	815	815	0	96	129	2	227	311	4
1976	155	166	2	815	815	0	97	124	2	227	299	4
1977	158	168	2	815	815	0	97	119	2	228	288	4
1978	160	170	1	815	815	0	99	116	2	232	278	4
1979	162	171	1	815	815	0	101	114	3	237	272	8
1980	164	172	1	815	815	0	103	111	3	242	267	8
1981	166	172	0	815	815	0	104	110	4	243	261	7
1982	167	173	0	815	815	0	105	109	4	244	257	9
1983	171	173	4	815	815	0	98	106	2	228	248	4
1984	172	177	0	815	815	0	99	105	4	228	247	10
1985	174	178	1	815	815	0	99	105	5	230	246	11
1986	174	179	0	815	815	0	99	105	5	230	245	11
1987	175	180	0	815	815	0	100	105	5	231	244	11
1988	176	180	0	815	815	0	100	105	5	232	244	11
1989	177	181	1	815	815	0	101	105	5	233	243	11
1990	181	182	4	815	815	0	101	104	5	234	243	11
TOTAL			23			8			194			313

SHEET 8

OPERATIONAL PLAN NO. 318-5

COMPUTED ANNUAL COSTS OF REQUIRED SURFACE WATER FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

	1	2	3	4	5	6	7
	LATERALS	CONNECTORS		STORAGE FACILITIES		TOTAL SURFACE WATER FACILITIES	
YEAR	ADDITIONAL	ADDITIONAL	TOTAL	ADDITIONAL	TOTAL	ADDITIONAL 1,2,4	TOTAL 1,3,5
1963	313	4	312	28	14,304	345	14,929
1964	313	4	312	28	14,304	345	14,929
1965	313	4	312	28	14,304	345	14,929
1966	313	4	312	28	14,304	345	14,929
1967	313	4	312	28	14,304	345	14,929
1968	313	4	312	28	14,304	345	14,929
1969	313	4	312	28	14,304	345	14,929
1970	313	4	312	29	14,305	346	14,930
1971	313	4	312	29	14,305	346	14,930
1972	313	9	317	47	14,323	369	14,953
1973	313	9	317	47	14,323	369	14,953
1974	313	9	317	47	14,323	369	14,953
1975	313	12	320	47	14,323	372	14,956
1976	313	14	322	47	14,323	374	14,958
1977	313	19	327	47	14,323	379	14,963
1978	313	21	329	47	14,323	381	14,965
1979	313	22	330	47	14,323	382	14,966
1980	313	24	332	47	14,323	384	14,968
1981	313	24	332	47	14,323	384	14,968
1982	313	26	334	47	14,323	386	14,970
1983	313	33	341	47	14,323	393	14,977
1984	313	34	342	47	14,323	394	14,978
1985	313	35	343	47	14,323	395	14,979
1986	313	37	345	47	14,323	397	14,981
1987	313	37	345	47	14,323	397	14,981
1988	313	38	346	47	14,323	398	14,982
1989	313	41	349	47	14,323	401	14,985
1990	313	47	355	47	14,323	407	14,991
TOTAL	8,764	527		1,147		10,438	

OPERATIONAL PLAN NO. 318-5

COMPUTED ANNUAL COSTS OF REQUIRED GROUND WATER FACILITIES
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

YEAR	1 PUMPING FACILITIES ADDITIONAL	2 PUMPING FACILITIES TOTAL	3 BOOSTER FACILITIES ADDITIONAL	4 BOOSTER FACILITIES TOTAL	5 SPREADING FACILITIES ADDITIONAL	6 SPREADING FACILITIES TOTAL	7 INJECTION FACILITIES ADDITIONAL	8 INJECTION FACILITIES TOTAL	9 TOTAL GRND WTR FACILITIES ADDITIONAL 1,3,5,7	10 TOTAL GRND WTR FACILITIES TOTAL 2,4,6,8
1963	17	1,029	21	57	0	33	0	253	38	1,372
1964	10	941	2	56	0	33	54	307	66	1,337
1965	2	853	2	57	0	33	54	307	58	1,250
1966	23	789	6	60	0	33	54	307	83	1,189
1967	20	720	5	62	0	33	54	307	79	1,122
1968	17	655	4	65	0	33	198	451	219	1,204
1969	48	620	4	66	0	33	198	451	250	1,170
1970	64	610	6	68	0	33	198	451	268	1,162
1971	52	617	4	69	0	33	198	451	254	1,170
1972	13	582	0	68	0	33	198	451	211	1,134
1973	2	558	0	64	0	33	198	451	200	1,106
1974	2	535	0	63	0	33	198	451	200	1,082
1975	5	515	0	59	0	33	198	451	203	1,058
1976	4	496	0	59	0	33	198	451	202	1,039
1977	5	479	0	55	0	33	198	451	203	1,018
1978	5	463	0	54	0	33	198	451	203	1,001
1979	12	454	1	54	0	33	198	451	211	992
1980	12	446	1	52	0	33	198	451	211	982
1981	11	437	1	52	0	33	198	451	210	973
1982	13	432	1	50	0	33	198	451	212	966
1983	4	418	0	49	0	33	198	451	202	951
1984	14	417	1	49	0	33	198	451	213	950
1985	16	415	1	50	0	33	198	451	215	949
1986	15	414	1	49	0	33	198	451	214	947
1987	16	413	1	49	0	33	198	451	215	946
1988	16	414	1	49	0	33	198	451	215	947
1989	16	412	1	49	0	33	198	451	215	945
1990	16	411	1	48	0	33	198	451	215	943
TOTAL	450		65		0		4,770		5,285	

SHEET 10

OPERATIONAL PLAN NO. 318-5

COMPUTED ANNUAL CHARGES OF REQUIRED ELECTRICAL ENERGY AND ELECTRICAL SERVICE CONNECTION
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

	COSTS FOR PUMPS			COSTS FOR BOOSTERS			TOTAL COSTS FOR PUMPS AND BOOSTERS		
	1	2	3	4	5	6	7	8	9
YEAR	ENERGY	CONNECTION	SUBTOTAL 1,2	ENERGY	CONNECTION	SUBTOTAL 4,5	ENERGY 1,4	CONNECTION 2,5	TOTAL 3,6
1963	1,049	183	1,232	384	65	449	1,433	248	1,681
1964	998	184	1,182	377	69	446	1,375	253	1,628
1965	953	182	1,135	365	71	436	1,318	253	1,571
1966	967	202	1,169	379	79	458	1,346	281	1,627
1967	977	213	1,190	386	83	469	1,363	296	1,659
1968	985	218	1,203	393	89	482	1,378	307	1,685
1969	999	229	1,228	401	92	493	1,400	321	1,721
1970	1,006	239	1,245	405	95	500	1,411	334	1,745
1971	1,013	244	1,257	411	97	508	1,424	341	1,765
1972	884	149	1,033	360	62	422	1,244	211	1,455
1973	874	148	1,022	358	62	420	1,232	210	1,442
1974	869	148	1,017	358	63	421	1,227	211	1,438
1975	866	148	1,014	359	63	422	1,225	211	1,436
1976	864	148	1,012	361	63	424	1,225	211	1,436
1977	864	148	1,012	361	63	424	1,225	211	1,436
1978	868	151	1,019	363	63	426	1,231	214	1,445
1979	870	154	1,024	366	66	432	1,236	220	1,456
1980	874	157	1,031	367	67	434	1,241	224	1,465
1981	876	158	1,034	369	67	436	1,245	225	1,470
1982	873	160	1,033	370	67	437	1,243	227	1,470
1983	859	149	1,008	363	64	427	1,222	213	1,435
1984	858	149	1,007	363	64	427	1,221	213	1,434
1985	858	151	1,009	364	65	429	1,222	216	1,438
1986	857	151	1,008	364	65	429	1,221	216	1,437
1987	860	151	1,011	365	65	430	1,225	216	1,441
1988	861	152	1,013	365	65	430	1,226	217	1,443
1989	861	152	1,013	365	66	431	1,226	218	1,444
1990	861	154	1,015	365	66	431	1,226	220	1,446
TOTAL	25,404	4,772	30,176	10,407	1,966	12,373	35,811	6,738	42,549

OPERATIONAL PLAN NO. 318-5

SUMMARY OF COMPUTED ANNUAL COSTS OF WATER SUPPLY, FACILITIES AND ELECTRICAL ENERGY IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1963 THROUGH 1990

TOTAL COASTAL PLAIN

IN 1000 DOLLARS

YEAR	1 WATER SUPPLY COL.11,TABLE 5	2 SURFACE WATER FACILITIES COL.7,TABLE 8	3 GROUND WATER FACILITIES COL.10,TABLE 9	4 ENERGY AND SERVICE CONNECTION COL.9,TABLE 10	5 TOTAL 1.2.3.4	6 CUMULATIVE TOTAL
1963	14,918	14,929	1,372	1,681	32,900	32,900
1964	17,439	14,929	1,337	1,628	35,333	68,233
1965	19,791	14,929	1,250	1,571	37,541	105,774
1966	22,509	14,929	1,189	1,627	40,254	146,028
1967	24,804	14,929	1,122	1,659	42,514	188,542
1968	29,583	14,929	1,204	1,685	47,401	235,943
1969	32,073	14,929	1,170	1,721	49,893	285,836
1970	34,847	14,930	1,162	1,745	52,684	338,520
1971	35,491	14,930	1,170	1,765	53,356	391,876
1972	36,280	14,953	1,134	1,455	53,822	445,698
1973	37,046	14,953	1,106	1,442	54,547	500,245
1974	37,700	14,953	1,082	1,438	55,173	555,418
1975	38,370	14,956	1,058	1,436	55,820	611,238
1976	39,048	14,958	1,039	1,436	56,481	667,719
1977	39,739	14,963	1,018	1,436	57,156	724,875
1978	40,429	14,965	1,001	1,445	57,840	782,715
1979	41,123	14,966	992	1,456	58,537	841,252
1980	41,825	14,968	982	1,465	59,240	900,492
1981	42,018	14,968	973	1,470	59,429	959,921
1982	42,216	14,970	966	1,470	59,622	1,019,543
1983	42,425	14,977	951	1,435	59,788	1,079,331
1984	42,642	14,978	950	1,434	60,004	1,139,335
1985	42,863	14,979	949	1,438	60,229	1,199,564
1986	43,072	14,981	947	1,437	60,437	1,260,001
1987	43,297	14,981	946	1,441	60,665	1,320,666
1988	43,521	14,982	947	1,443	60,893	1,381,559
1989	43,752	14,985	945	1,444	61,126	1,442,685
1990	43,986	14,991	943	1,446	61,366	1,504,051
TOTAL	1,012,807	418,790	29,905	42,549	1,504,051	1,504,051

SHEET 12

OPERATIONAL PLAN NO. 318-5

COMPUTED BIENNIAL AVERAGE GROUND WATER LEVEL ELEVATIONS AT EACH NODE
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1962 THROUGH 1990

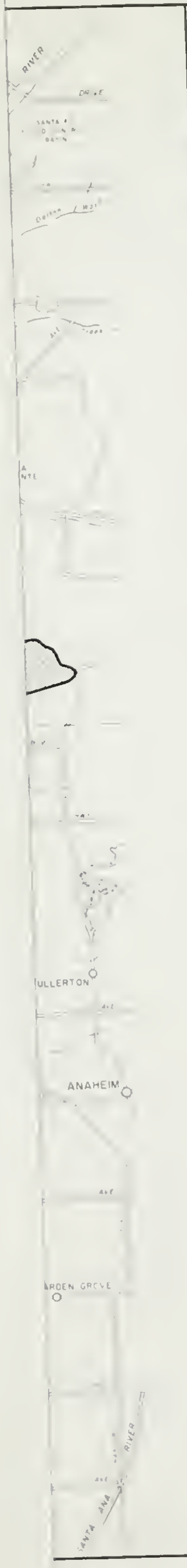
IN FEET

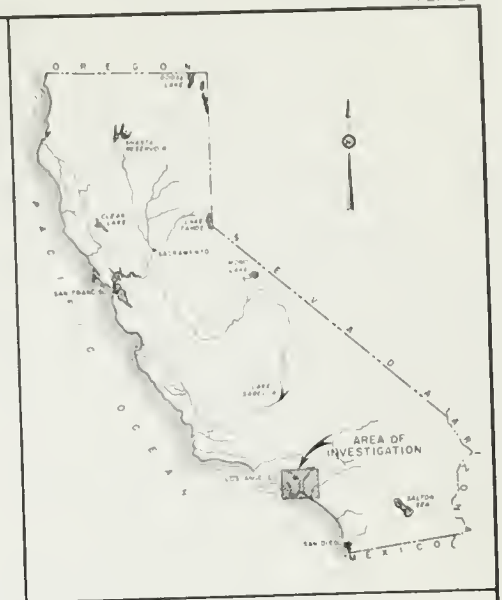
NODE NO.	AVG GROUND SURFACE ELEVATION	GROUND WATER LEVEL ELEVATION 1962	1964	1966	1968	1970	1972	974	1976	1978	1980	1982	1984	1986	1988	1990
1	250	11	10	8	6	5	3	2	1	0	0	0	-1	-2	-2	-3
2	250	13	2	-6	-13	-20	-25	-30	-34	-37	-39	-42	-44	-47	-49	-53
3	300	38	26	15	6	0	-6	-11	-15	-18	-20	-22	-25	-27	-29	-32
4	200	-15	-27	-36	-44	-49	-53	-57	-60	-62	-64	-66	-67	-68	-70	-71
5	250	-25	-36	-45	-51	-55	-58	-60	-62	-63	-64	-64	-65	-66	-67	-68
6	250	-45	-53	-57	-59	-60	-61	-62	-62	-62	-62	-62	-63	-63	-63	-63
7	200	-32	-23	-14	-7	-3	0	3	5	7	8	9	10	11	12	13
8	190	57	63	69	75	80	83	86	88	90	91	92	93	94	94	94
9	260	139	137	140	145	148	151	152	154	156	157	158	159	159	159	160
10	200	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190
11	225	164	150	157	162	165	168	170	172	173	174	175	176	176	176	176
12	200	127	120	127	133	138	142	145	148	150	152	153	154	156	157	158
13	175	63	70	77	85	93	100	106	110	115	118	121	123	125	127	128
14	250	57	65	73	83	91	98	104	109	113	117	120	122	123	125	125
15	100	-2	9	22	33	42	49	54	59	62	65	68	71	73	75	76
16	60	-12	9	22	30	36	40	45	47	50	51	53	54	55	56	57
17	35	-39	-7	5	10	13	15	18	20	21	22	23	24	25	26	26
18	20	-38	-8	2	6	8	9	12	14	15	16	16	17	18	19	20
19	22	-17	-5	0	0	1	2	3	4	4	4	4	5	5	6	6
20	50	-63	-31	-18	-15	-13	-11	-8	-7	-5	-5	-4	-3	-3	-3	-3
21	50	-71	-40	-28	-24	-22	-20	-16	-15	-14	-13	-12	-11	-10	-9	-9
22	25	-84	-63	-52	-50	-48	-47	-43	-42	-41	-41	-40	-39	-38	-38	-37
23	25	-90	-73	-65	-63	-62	-61	-58	-57	-56	-56	-55	-55	-54	-54	-53
24	10	-87	-71	-63	-61	-60	-59	-57	-56	-55	-55	-54	-54	-54	-53	-53
25	50	-69	-57	-51	-49	-48	-48	-46	-45	-44	-44	-44	-44	-44	-43	-44
26	100	-46	-39	-35	-34	-33	-33	-32	-31	-31	-30	-30	-30	-30	-29	-29
27	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	95	-26	-23	-21	-21	-20	-20	-20	-19	-19	-19	-19	-19	-19	-19	-19
29	140	-14	-12	-12	-11	-11	-11	-11	-11	-10	-10	-10	-11	-11	-11	-11
30	100	-19	-18	-17	-17	-16	-16	-16	-16	-16	-16	-16	-16	-16	-16	-16
31	127	-6	-6	-5	-5	-5	-5	-5	-5	-5	-5	-6	-6	-6	-7	-7
32	15	5	5	4	4	3	2	2	1	1	1	0	0	0	0	0
33	75	-13	-14	-17	-19	-22	-24	-26	-28	-30	-32	-33	-35	-37	-40	-42
34	100	-7	-19	-29	-36	-43	-48	-52	-56	-59	-61	-63	-65	-67	-69	-71
35	132	-40	-51	-57	-63	-67	-70	-73	-75	-77	-78	-79	-80	-80	-81	-82
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-68	-68	-69	-69	-69	-70	-70

COMPUTED BIENNIAL AVERAGE GROUND WATER LEVEL ELEVATIONS AT EACH NODE
IN THE COASTAL PLAIN OF LOS ANGELES COUNTY FROM 1962 THROUGH 1990

IN FEET

NODE NO.	AVG GROUND SURFACE ELEVATION	GROUND WATER LEVEL ELEVATION 1962	1964	1966	1968	1970	1972	1974	1976	1978	1980	1982	1984	1986	1988	1990
39	145	36	45	53	59	64	67	71	73	75	77	78	79	80	80	81
40	175	140	133	137	142	146	149	152	154	156	157	158	159	160	161	162
41	210	154	145	150	154	158	161	163	165	166	168	168	169	170	171	171
42	195	151	137	145	150	154	157	160	163	164	166	167	168	169	169	170
43	145	93	89	99	106	112	115	119	122	124	125	127	128	129	130	130
44	117	35	45	57	65	71	75	80	83	85	87	89	90	91	92	93
45	90	-5	12	26	35	42	47	51	55	57	59	61	62	64	65	65
46	60	-45	-14	0	5	8	11	15	17	19	20	21	21	22	22	22
47	40	-58	-24	-10	-6	-4	-2	1	2	4	4	5	5	6	6	6
48	55	-66	-35	-21	-17	-15	-12	-8	-7	-5	-4	-3	-2	-2	-1	0
49	75	-75	-52	-39	-36	-35	-33	-27	-25	-23	-23	-22	-22	-21	-21	-21
50	75	-76	-61	-53	-51	-50	-49	-46	-45	-44	-44	-43	-43	-42	-42	-42
51	17	-65	-54	-48	-46	-45	-45	-43	-42	-41	-41	-41	-41	-40	-40	-40
52	30	-75	-62	-56	-54	-53	-52	-50	-49	-49	-48	-48	-47	-47	-46	-46
53	80	-37	-32	-29	-28	-28	-28	-27	-27	-26	-26	-26	-26	-26	-26	-26
54	45	-53	-47	-43	-41	-41	-40	-39	-38	-38	-38	-37	-37	-37	-36	-36
55	50	-46	-43	-41	-40	-39	-39	-39	-38	-38	-38	-38	-38	-38	-38	-38
56	77	-48	-47	-45	-44	-44	-43	-43	-42	-42	-42	-42	-42	-42	-42	-42
57	120	-52	-53	-53	-53	-52	-53	-53	-53	-53	-54	-54	-54	-53	-53	-53
58	77	-56	-55	-52	-51	-50	-50	-49	-49	-48	-48	-48	-48	-48	-48	-49
59	150	-45	-54	-58	-61	-63	-65	-67	-68	-69	-69	-70	-71	-72	-72	-73
60	150	-62	-66	-66	-65	-66	-66	-66	-66	-66	-66	-66	-66	-66	-66	-66
61	170	-74	-76	-72	-70	-69	-69	-68	-67	-66	-66	-66	-66	-65	-65	-65
62	130	-65	-56	-46	-41	-38	-37	-34	-32	-30	-29	-28	-28	-27	-26	-25
63	115	7	19	29	35	39	42	46	48	50	52	53	54	55	56	57
64	135	51	58	67	73	78	81	85	88	89	91	93	94	95	96	97
65	160	109	106	112	118	123	126	129	132	133	135	136	137	138	139	140
66	105	13	28	39	46	50	54	58	60	62	64	65	66	67	68	68
67	80	-12	9	22	29	33	37	41	44	46	47	48	49	50	50	51
68	65	-51	-25	-11	-7	-4	-2	2	4	6	7	8	9	10	11	11
69	100	-71	-60	-53	-51	-51	-50	-47	-46	-45	-45	-44	-44	-44	-44	-44
70	125	-61	-57	-53	-51	-50	-50	-49	-48	-47	-47	-47	-47	-47	-48	-48
71	150	-88	-80	-70	-67	-66	-65	-62	-60	-59	-59	-58	-58	-57	-56	-56
72	150	-81	-77	-69	-66	-65	-64	-62	-61	-60	-59	-59	-59	-58	-57	-57
73	85	-51	-30	-17	-14	-12	-10	-3	-1	0	1	2	2	3	3	4
74	85	-80	-61	-49	-46	-45	-44	-38	-36	-35	-34	-33	-32	-32	-31	-31
75	175	-79	-77	-71	-67	-65	-64	-62	-61	-60	-60	-59	-59	-59	-59	-58





LOCATION MAP

LEGEND

- BOUNDARY OF INVESTIGATIONAL AREA
- BOUNDARY OF WATER-BEARING MATERIAL
- BASIN BOUNDARY
- HILL AND MOUNTAIN AREAS
- BOUNDARY OF FOREBAY AND WHITTIER AREA*

* BOUNDARY OF FOREBAY AND PRESSURE AREA FROM BULLETIN 45 (CALIF. DWR 1934)

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

LOCATION OF COASTAL PLAIN OF LOS ANGELES COUNTY AND GROUND WATER BASINS

PLATE I


SANTA MONICA MTNS.
HOLLYWOOD BASIN
ELYSIAN HILLS
LOS ANGELES NARROWS
REPETTO HILLS
MERCED HILLS
WHITTIER NARROWS
PUENTE HILLS
SANTA MONICA BASIN
Los Angeles Forebay
Montebello Forebay
Whittier Area
CENTRAL BASIN
Central Basin Pressure Area
WEST COAST BASIN
BALDWIN HILLS
PALOS VERDES HILLS
SANTA MONICA BAY
PACIFIC OCEAN
SAN PEDRO BAY
LOS ANGELES COUNTY
ORANGE COUNTY
PASADENA
GLENDALE
HOLLYWOOD
BEVERLY HILLS
LOS ANGELES
SANTA MONICA
INGLEWOOD
EL SEGUNDO
HAWTHORNE
MANHATTAN BEACH
GARDENA
TORRANCE
REDONDO BEACH
SAN PEDRO
LONG BEACH
COMPTON
SOUTH GATE
DOWNEY
BELLFLOWER
LAKEWOOD
HUNTINGTON PARK
MONTEBELLO
WHITTIER
LA HABRA
BUENA PARK
FULLERTON
ANAHEIM
GARDEN GROVE
SOUTH PASADENA
ALHAMBRA
SAN GABRIEL
ROSEMEAD
MONTEREY PARK
EL MONTE
TEMPLE CITY
ARCADIA
MONROVIA
BALDWIN PARK
LA PUENTE
SHERMAN OAKS
LOS ANGELES RIVER
RIO HONDO
SAN GABRIEL RIVER
LEGEND
BOUNDARY OF INVESTIGATIONAL AREA
BOUNDARY OF WATER-BEARING MATERIAL
BASIN BOUNDARY
HILL AND MOUNTAIN AREAS
BOUNDARY OF FOREBAY AND WHITTIER AREA*
* BOUNDARY OF FOREBAY AND PRESSURE AREA FROM BULLETIN 45 (CALIF DWR 1934)
LOCATION MAP
AREA OF INVESTIGATION
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY
LOCATION OF COASTAL PLAIN OF
LOS ANGELES COUNTY AND
GROUND WATER BASINS
SCALE OF MILES
1966

LEGEND

BOUNDARY OF INVESTIGATIONAL AREA

BOUNDARY OF WATER-BEARING MATERIAL

BOUNDARY OF OPERATIONAL AREA

(5) OPERATIONAL AREA NUMBER

CITY OF LOS ANGELES DEPARTMENT OF WATER AND POWER SERVICE AREA

CITY OF WHITTIER SERVICE AREA

DESCRIPTION OF ECONOMIC AREA

TO FORM ECONOMIC AREAS THE AREA SERVED BY THE CITY OF WHITTIER WAS REMOVED FROM OPERATIONAL AREA 5 AND THE REMAINING AREA WAS REFERRED TO AS ECONOMIC AREA 5. ALSO, THE AREA SERVED BY THE DEPARTMENT OF WATER AND POWER (CITY OF LOS ANGELES), WHICH IS CONTAINED IN MANY OPERATIONAL AREAS, WAS ISOLATED AND WAS INCLUDED WITH OPERATIONAL AREA 3 TO FORM ECONOMIC AREA 3. THE REMAINING AREAS WERE REFERRED TO AS ECONOMIC AREAS AND THE SAME NUMBERS WERE RETAINED FOR IDENTIFICATION.

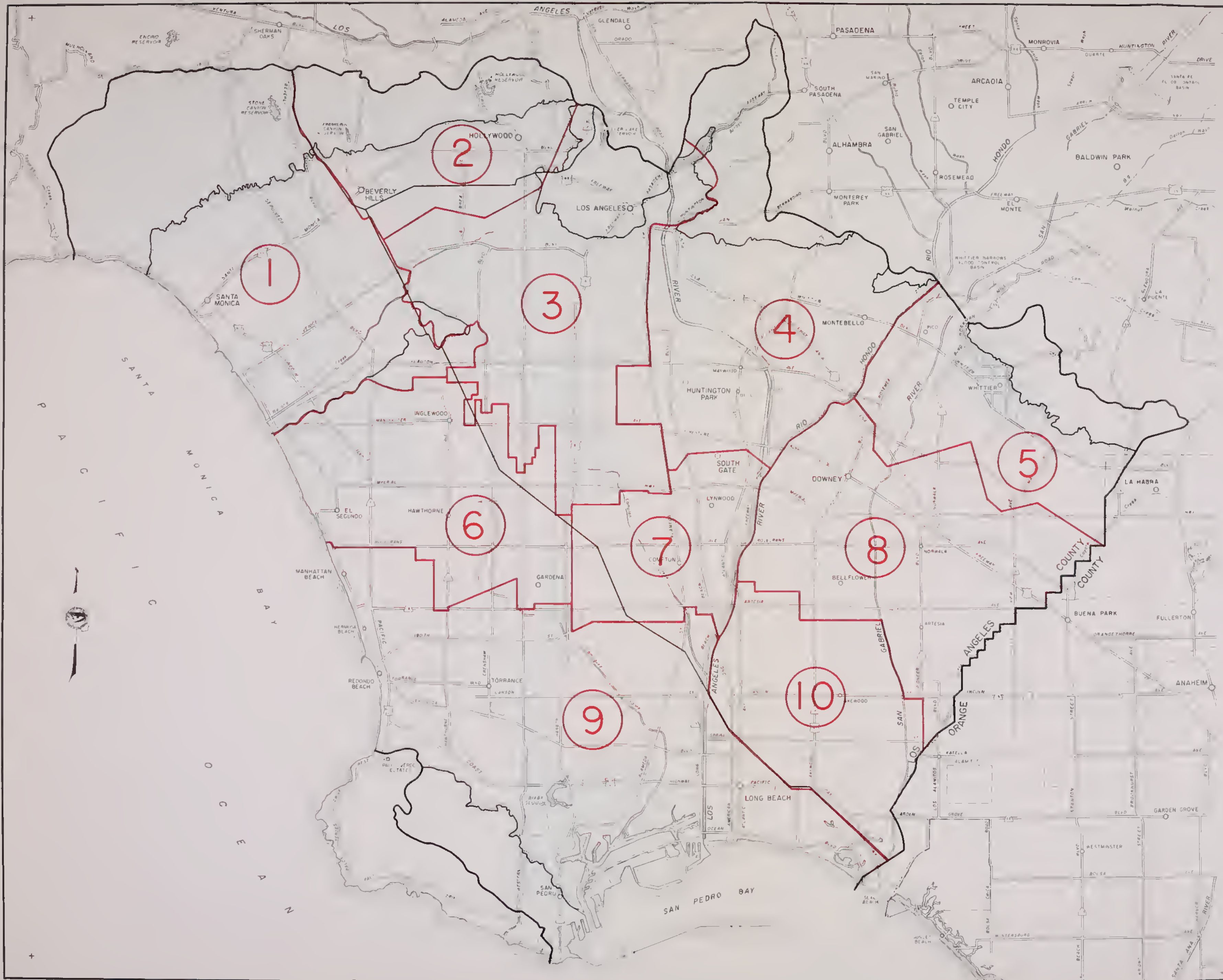
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

OPERATIONAL AND ECONOMIC AREAS

SCALE OF MILES

2 4



LEGEND

- BOUNDARY OF INVESTIGATIONAL AREA
- BOUNDARY OF WATER-BEARING MATERIAL
- BOUNDARY OF OPERATIONAL AREA
- (5) OPERATIONAL AREA NUMBER
- CITY OF LOS ANGELES DEPARTMENT OF WATER AND POWER SERVICE AREA
- CITY OF WHITTIER SERVICE AREA

DESCRIPTION OF ECONOMIC AREA

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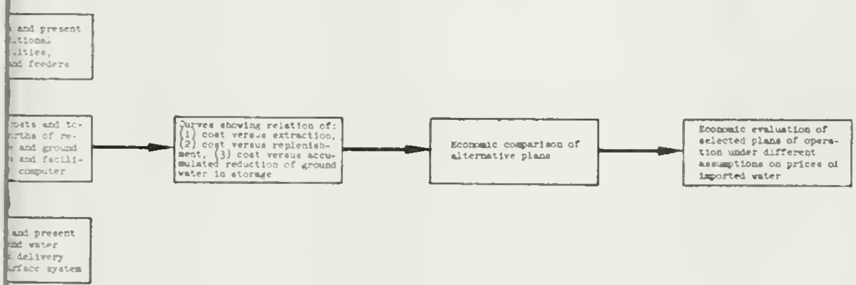
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

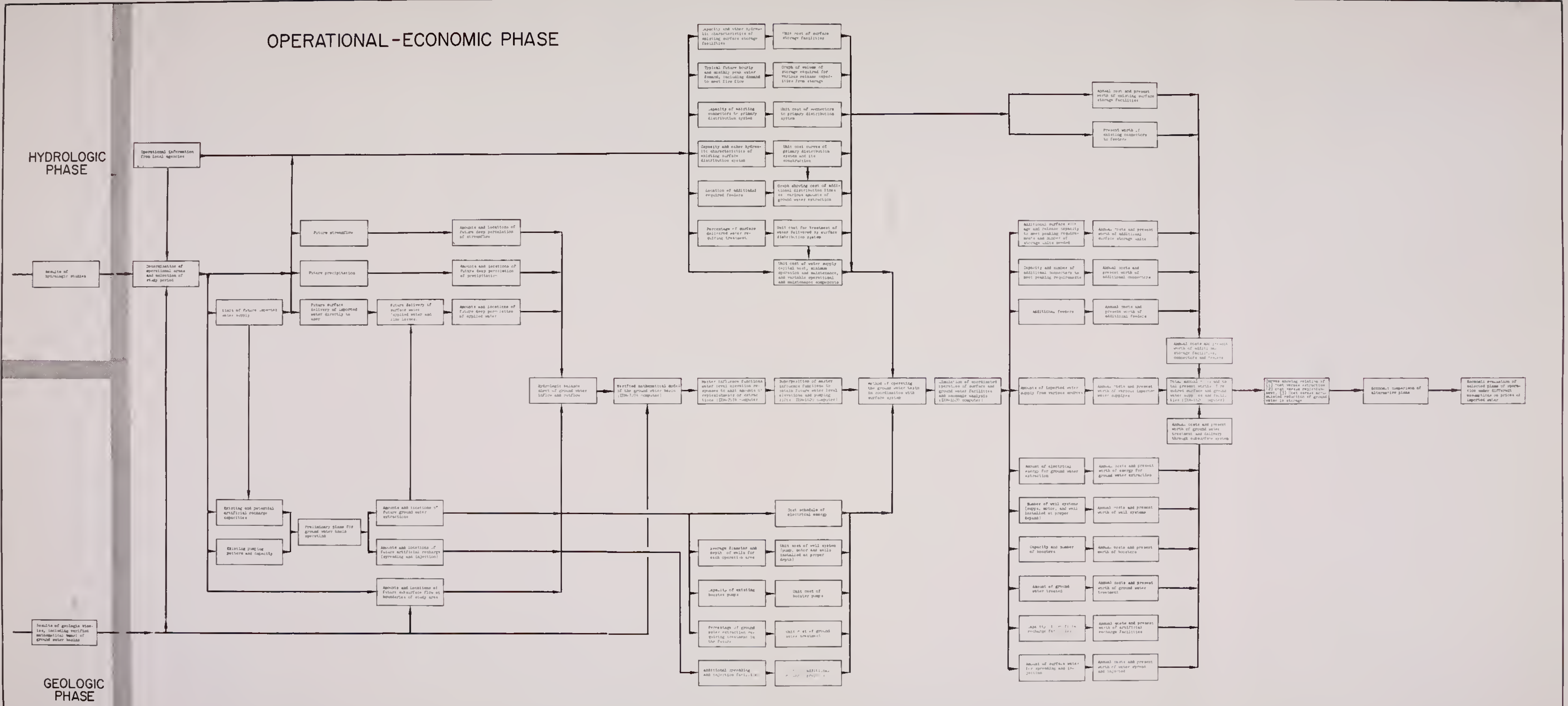
OPERATIONAL AND ECONOMIC AREAS

SCALE OF MILES

1966

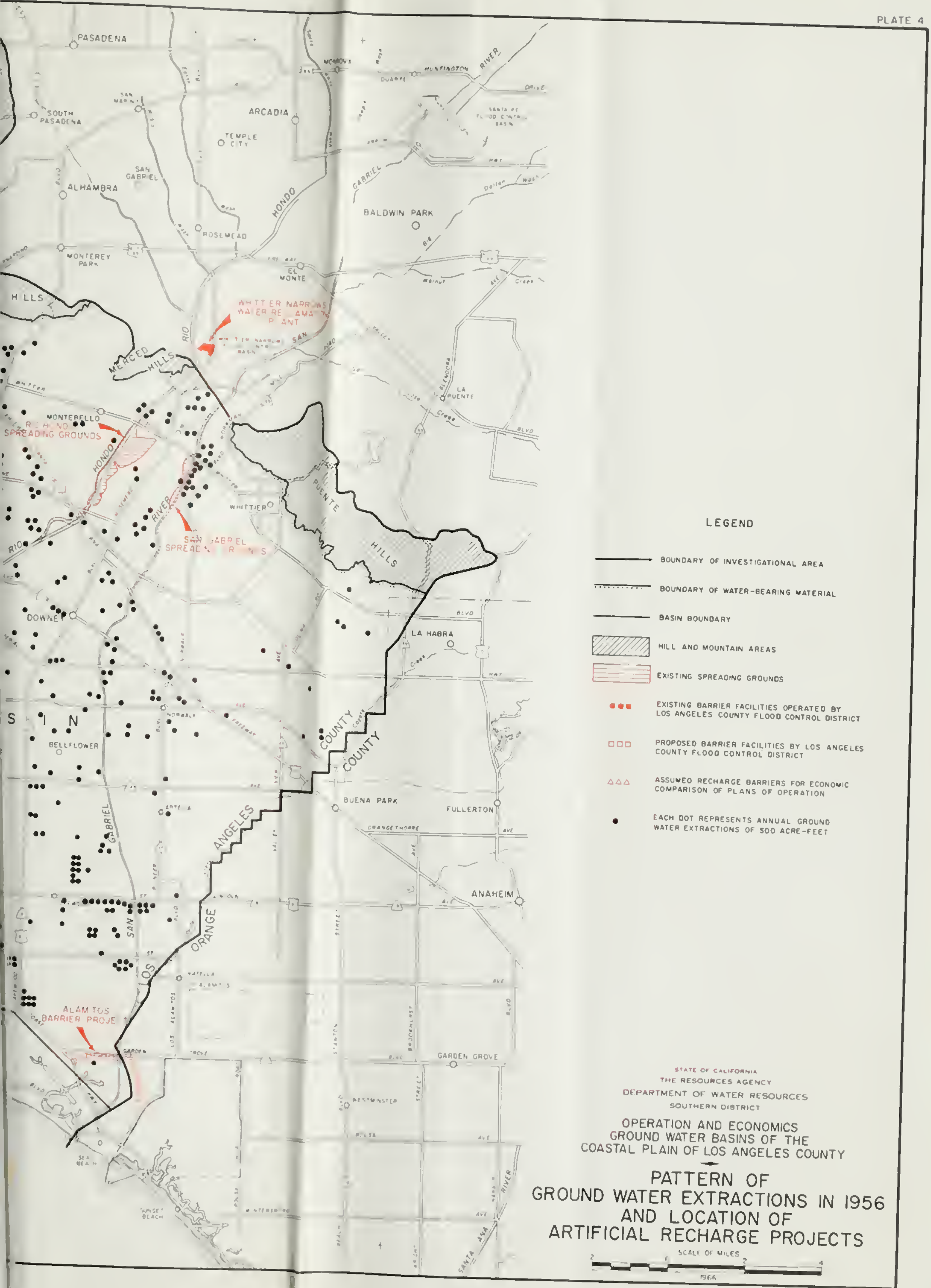


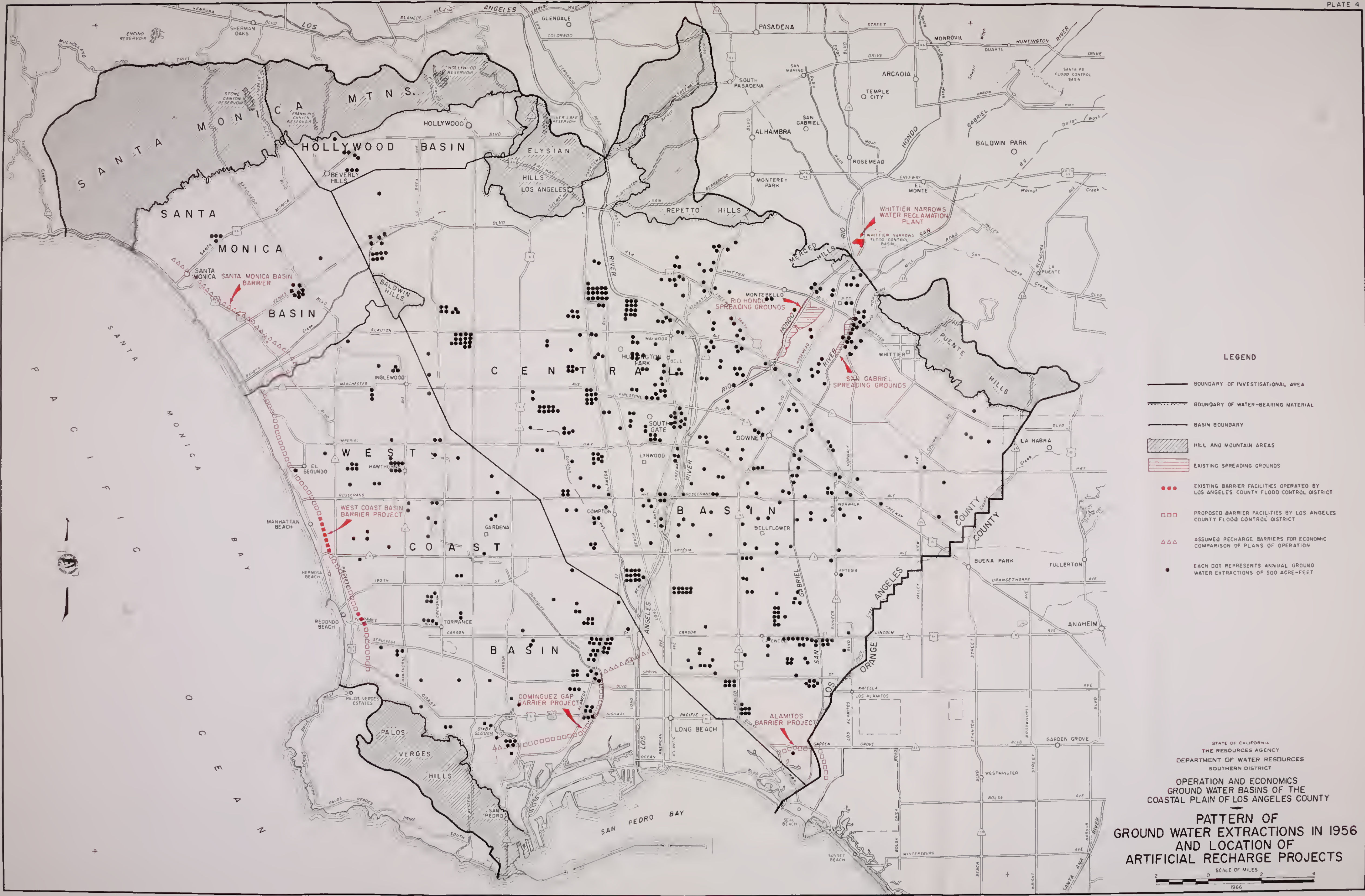
OUND WATER BASINS



FLOW CHART OF OPERATIONAL-ECONOMIC PHASE OF THE INVESTIGATION OF PLANNED UTILIZATION OF GROUND WATER BASINS

PLATE 4


LEGEND
BOUNDARY OF INVESTIGATIONAL AREA
BOUNDARY OF WATER-BEARING MATERIAL
BASIN BOUNDARY
HILL AND MOUNTAIN AREAS
EXISTING SPREADING GROUNDS
EXISTING BARRIER FACILITIES OPERATED BY LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
PROPOSED BARRIER FACILITIES BY LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
ASSUMED RECHARGE BARRIERS FOR ECONOMIC COMPARISON OF PLANS OF OPERATION
EACH DOT REPRESENTS ANNUAL GROUND WATER EXTRACTIONS OF 500 ACRE-FEET
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY
PATTERN OF
GROUND WATER EXTRACTIONS IN 1956
AND LOCATION OF
ARTIFICIAL RECHARGE PROJECTS
SCALE OF MILES
1966
PASADENA
SOUTH PASADENA
ARCADIA
TEMPLE CITY
SAN GABRIEL
ALHAMBRA
ROSEMEAD
MONTEREY PARK
EL MONTE
BALDWIN PARK
MONROVIA
DUARTE
HUNTINGTON
RIVER
DRIVE
GABRIEL
HONDO
RIO
SAN
MERCED
HILLS
LA PUENTE
MONTEBELLO
SPREADING GROUNDS
WHITTIER
PUENTE
DOWNEY
LA HABRA
BELLFLOWER
COUNTY
BUENA PARK
FULLERTON
ANGELES
ORANGE
LOS
ANAHEIM
GARDEN GROVE
WESTMINSTER
SUNSET BEACH
SEAL BEACH
SANTA ANA


SANTA MONICA MTNS.
HOLLYWOOD BASIN
SANTA MONICA BASIN
CENTRAL BASIN
WEST COAST BASIN
ELYSIAN HILLS
REPETTO HILLS
MERCED HILLS
PUENTE HILLS
BALDWIN HILLS
PALOS VERDES HILLS
PACIFIC OCEAN
SANTA MONICA BAY
SAN PEDRO BAY
SANTA MONICA BASIN BARRIER
WEST COAST BASIN BARRIER PROJECT
DOMINGUEZ GAP BARRIER PROJECT
ALAMITOS BARRIER PROJECT
RIO HONDO SPREADING GROUNDS
SAN GABRIEL SPREADING GROUNDS
WHITTIER NARROWS WATER RECLAMATION PLANT
LOS ANGELES COUNTY
ORANGE COUNTY
PASADENA
GLENDALE
HOLLYWOOD
BEVERLY HILLS
LOS ANGELES
SANTA MONICA
INGLEWOOD
HAWTHORNE
EL SEGUNDO
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
TORRANCE
GARDENA
COMPTON
LYNWOOD
SOUTH GATE
HUNTINGTON PARK
BELL
MAYWOOD
DOWNEY
BELLFLOWER
NORWALK
ARTESIA
LAKEWOOD
LONG BEACH
SAN PEDRO
PALOS VERDES ESTATES
SEAL BEACH
SUNSET BEACH
WHITTIER
MONTEBELLO
MONTEREY PARK
ALHAMBRA
SOUTH PASADENA
SAN MARINO
SAN GABRIEL
ROSEMEAD
EL MONTE
TEMPLE CITY
ARCADIA
MONROVIA
DUARTE
BALDWIN PARK
LA PUENTE
LA HABRA
FULLERTON
BUENA PARK
ANAHEIM
GARDEN GROVE
WESTMINSTER
SHERMAN OAKS
LEGEND
BOUNDARY OF INVESTIGATIONAL AREA
BOUNDARY OF WATER-BEARING MATERIAL
BASIN BOUNDARY
HILL AND MOUNTAIN AREAS
EXISTING SPREADING GROUNDS
EXISTING BARRIER FACILITIES OPERATED BY LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
PROPOSED BARRIER FACILITIES BY LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
ASSUMED RECHARGE BARRIERS FOR ECONOMIC COMPARISON OF PLANS OF OPERATION
EACH DOT REPRESENTS ANNUAL GROUND WATER EXTRACTIONS OF 500 ACRE-FEET
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY
PATTERN OF
GROUND WATER EXTRACTIONS IN 1956
AND LOCATION OF
ARTIFICIAL RECHARGE PROJECTS
SCALE OF MILES
2 0 2 4
1966

LEGEND

BOUNDARY OF INVESTIGATIONAL AREA

EXISTING FACILITIES

ASSUMED FACILITIES PROJECTED FOR SERVICE IN 1972 *

ASSUMED FACILITIES PROJECTED FOR SERVICE IN 1983 *

EXISTING WATER SUPPLY

WATER SUPPLY PROJECTED FOR DELIVERY IN 1972

WATER SUPPLY PROJECTED FOR DELIVERY IN 1983

* ASSUMED FACILITIES PROJECTED FOR SERVICE IN 1972 AND 1983 BASED ON CASE NO VII OF THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA REPORT NO 802 ENTITLED "COMPARATIVE ECONOMIC STUDY OF THE EAST BRANCH AND WEST BRANCH OF THE CALIFORNIA AQUEDUCT, AND OF ADDITIONAL DISTRIBUTION FACILITIES REQUIRED IN THE SOUTHERN CALIFORNIA COASTAL PLAIN BY 1990", MARCH, 1962

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

...STING AND ASSUMED FUTURE DISTRIBUTION FACILITIES OF THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

SCALE OF MILES
2 0 2 4 6

1966

PLATE 5

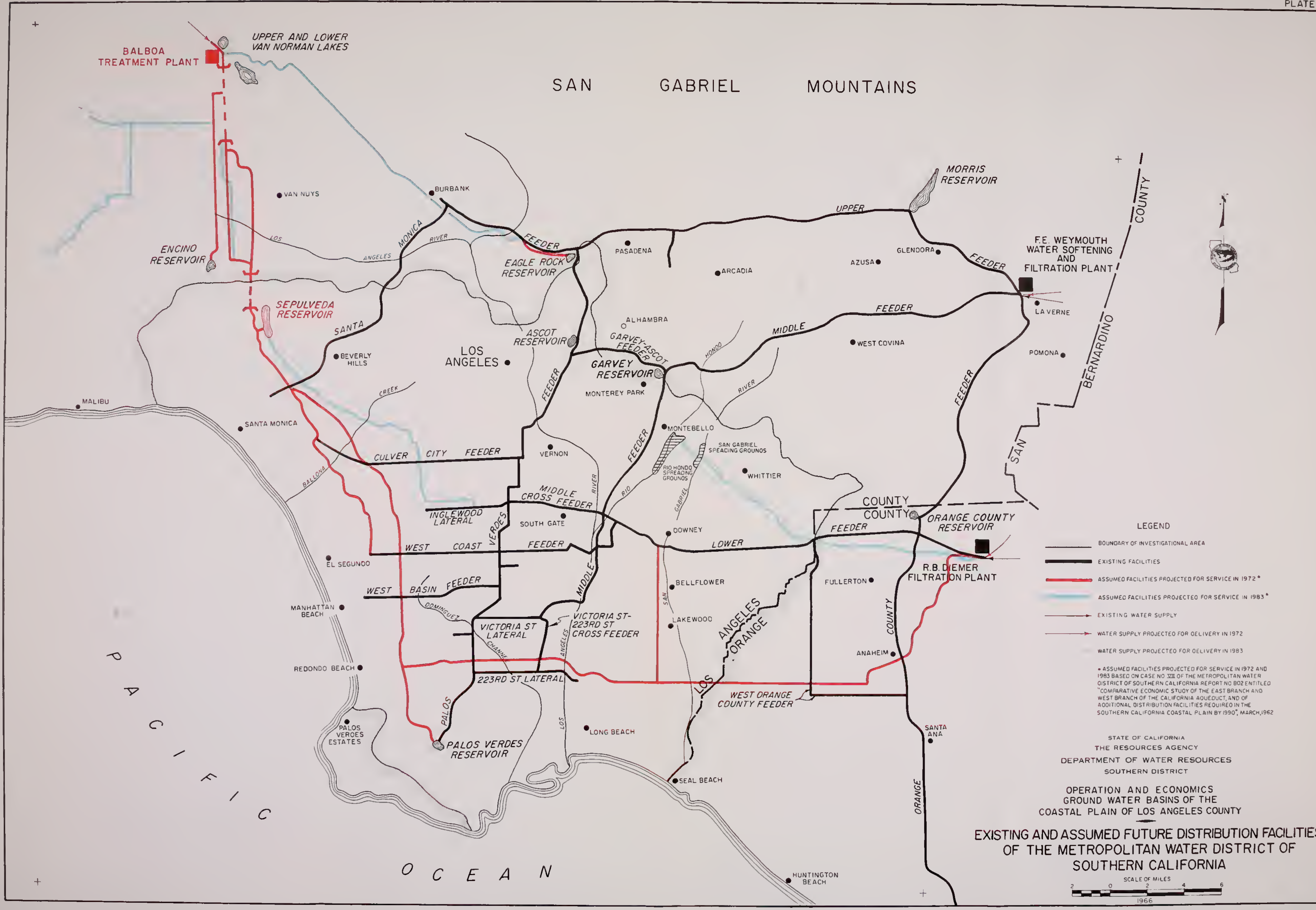
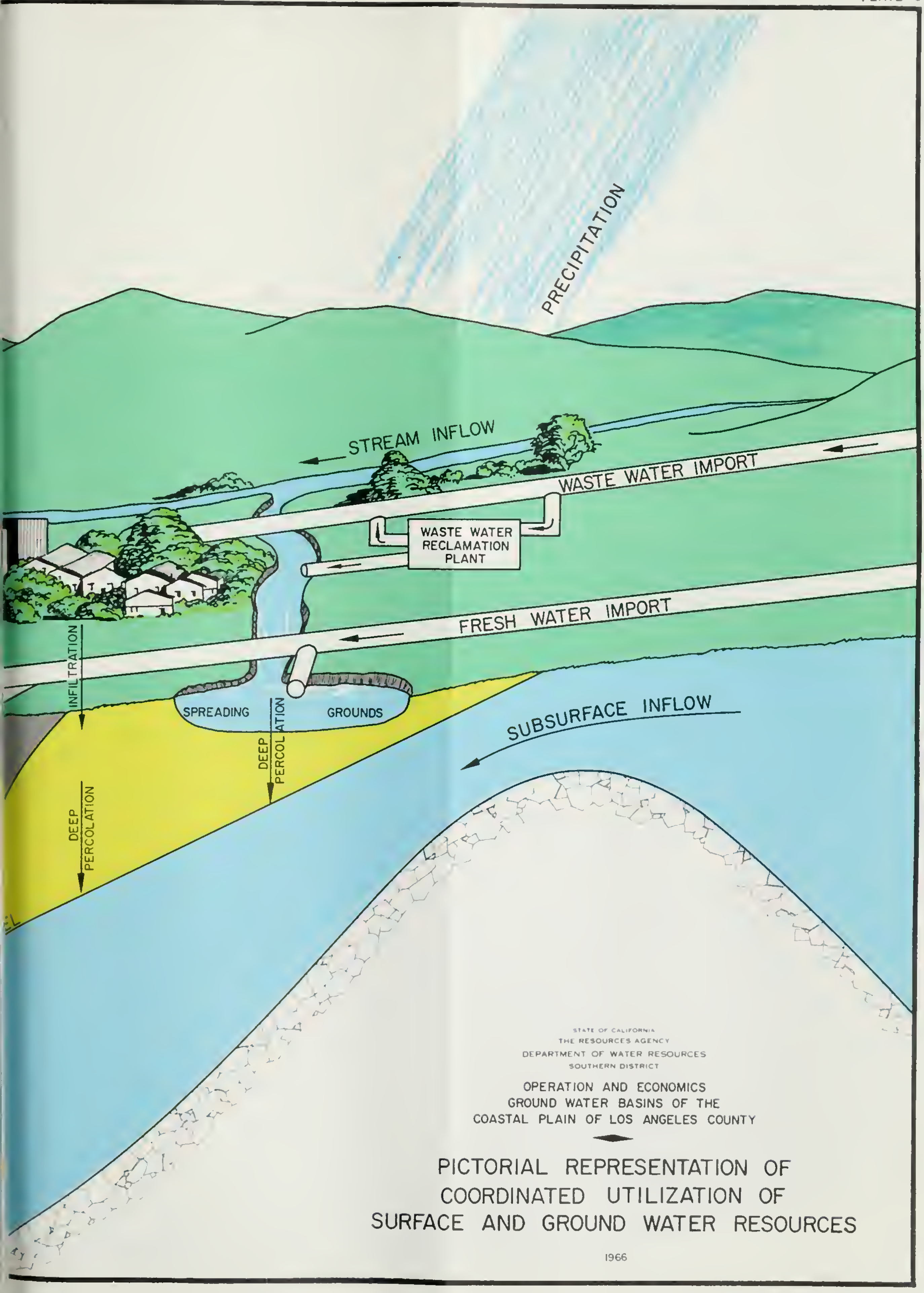

SAN GABRIEL MOUNTAINS
BALBOA TREATMENT PLANT
UPPER AND LOWER VAN NORMAN LAKES
ENCINO RESERVOIR
SEPULVEDA RESERVOIR
VAN NUYS
BURBANK
PASADENA
ARCADIA
AZUSA
GLENDORA
MORRIS RESERVOIR
UPPER FEEDER
F.E. WEYMOUTH WATER SOFTENING AND FILTRATION PLANT
LA VERNE
POMONA
MIDDLE FEEDER
WEST COVINA
ALHAMBRA
GARVEY-ASCOT FEEDER
GARVEY RESERVOIR
MONTEREY PARK
EAGLE ROCK RESERVOIR
ASCOT RESERVOIR
LOS ANGELES
BEVERLY HILLS
SANTA MONICA FEEDER
LOS ANGELES RIVER
MALIBU
SANTA MONICA
CULVER CITY FEEDER
BALLONA CREEK
VERNON
MONTEBELLO
SAN GABRIEL SPREADING GROUNDS
RIO HONDO SPREADING GROUNDS
WHITTIER
RIO HONDO
SAN GABRIEL RIVER
MIDDLE CROSS FEEDER
INGLEWOOD LATERAL
SOUTH GATE
DOWNEY
WEST COAST FEEDER
VERDES
EL SEGUNDO
LOWER FEEDER
WEST BASIN FEEDER
DOMINGUEZ CHANNEL
MANHATTAN BEACH
MIDDLE FEEDER
VICTORIA ST LATERAL
VICTORIA ST-223RD ST CROSS FEEDER
223RD ST LATERAL
BELLFLOWER
LAKEWOOD
LOS ANGELES COUNTY
ORANGE COUNTY
SAN BERNARDINO COUNTY
ORANGE COUNTY RESERVOIR
R.B. DIEMER FILTRATION PLANT
FULLERTON
ANAHEIM
WEST ORANGE COUNTY FEEDER
REDONDO BEACH
PALOS VERDES ESTATES
PALOS VERDES RESERVOIR
LONG BEACH
SEAL BEACH
SANTA ANA
HUNTINGTON BEACH
PACIFIC OCEAN
LEGEND
BOUNDARY OF INVESTIGATIONAL AREA
EXISTING FACILITIES
ASSUMED FACILITIES PROJECTED FOR SERVICE IN 1972 *
ASSUMED FACILITIES PROJECTED FOR SERVICE IN 1983 *
EXISTING WATER SUPPLY
WATER SUPPLY PROJECTED FOR DELIVERY IN 1972
WATER SUPPLY PROJECTED FOR DELIVERY IN 1983
* ASSUMED FACILITIES PROJECTED FOR SERVICE IN 1972 AND 1983 BASED ON CASE NO VII OF THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA REPORT NO 802 ENTITLED "COMPARATIVE ECONOMIC STUDY OF THE EAST BRANCH AND WEST BRANCH OF THE CALIFORNIA AQUEDUCT, AND OF ADDITIONAL DISTRIBUTION FACILITIES REQUIRED IN THE SOUTHERN CALIFORNIA COASTAL PLAIN BY 1990", MARCH, 1962
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY
EXISTING AND ASSUMED FUTURE DISTRIBUTION FACILITIES OF THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA
SCALE OF MILES
2 0 2 4 6
1966

PLATE 6

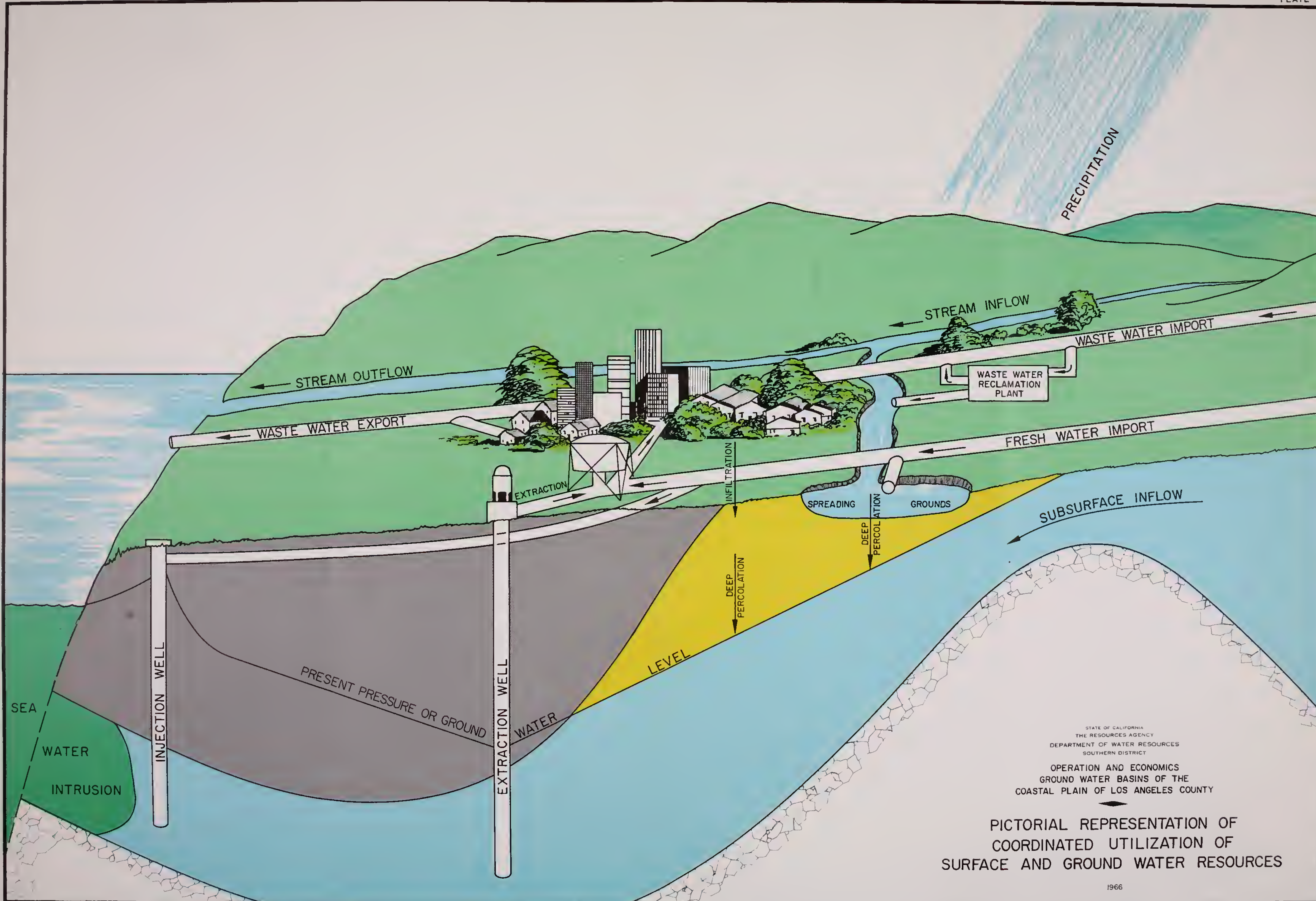


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

PICTORIAL REPRESENTATION OF COORDINATED UTILIZATION OF SURFACE AND GROUND WATER RESOURCES

1966

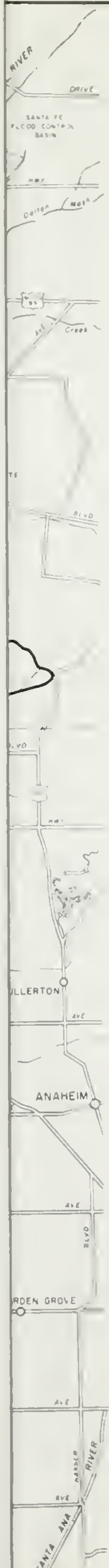


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

PICTORIAL REPRESENTATION OF
COORDINATED UTILIZATION OF
SURFACE AND GROUND WATER RESOURCES

1966



LEGEND

BOUNDARY OF INVESTIGATIONAL AREA

BOUNDARY OF WATER-BEARING MATERIAL

HILL AND MOUNTAIN AREAS

BOUNDARY OF OPERATIONAL AREA

(1) OPERATIONAL AREA NUMBER

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

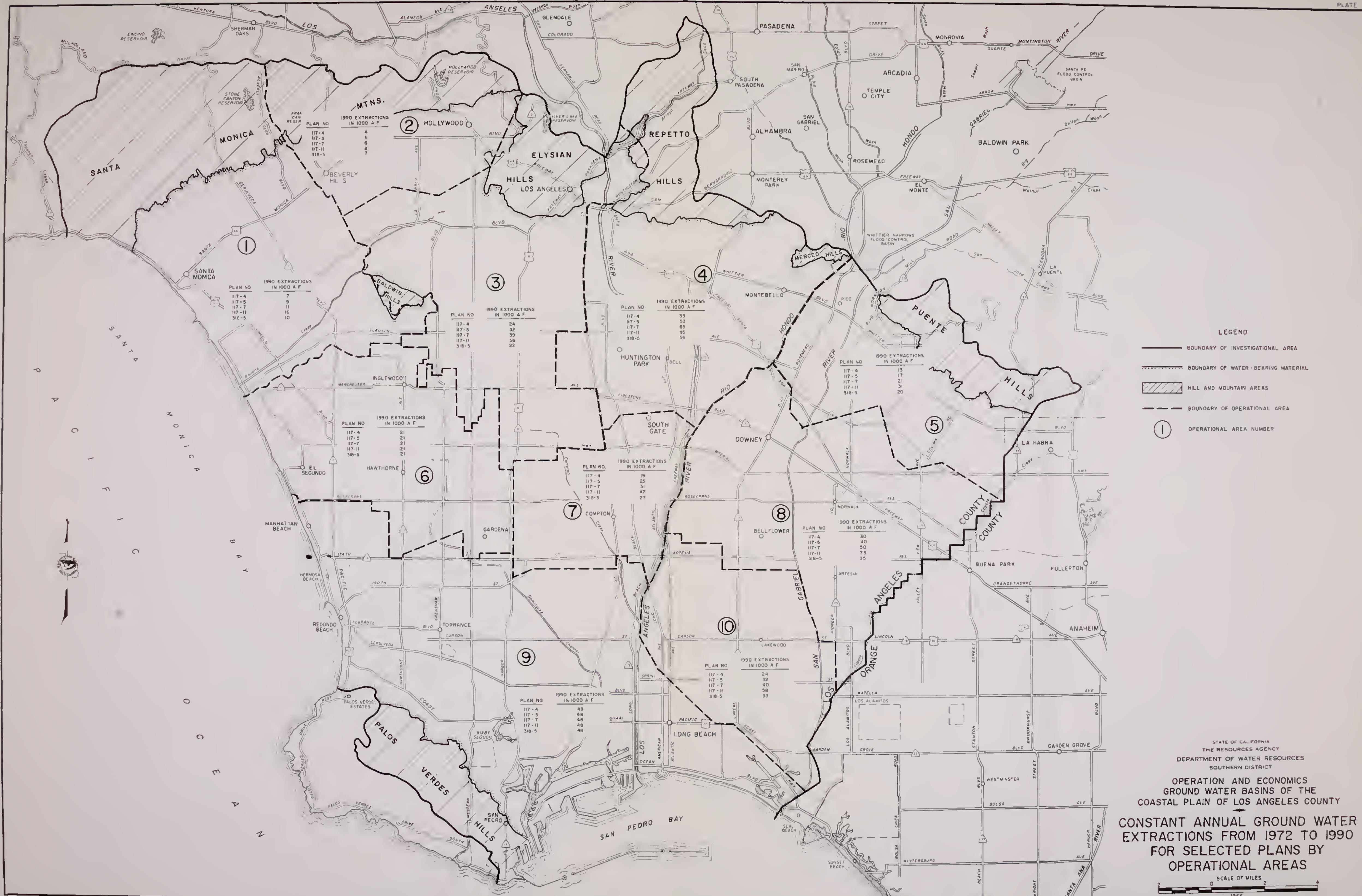
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

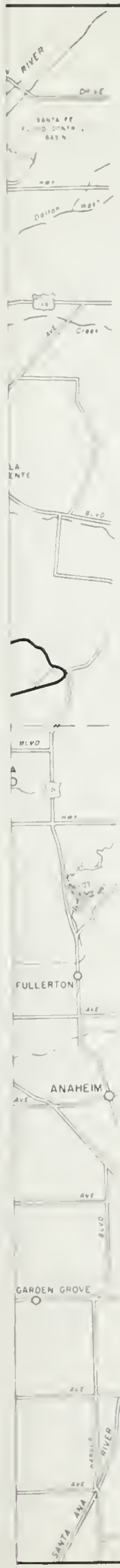
CONSTANT ANNUAL GROUND WATER EXTRACTIONS FROM 1972 TO 1990 FOR SELECTED PLANS BY OPERATIONAL AREAS

SCALE OF MILES

2 0 2 4

1966


LEGEND
BOUNDARY OF INVESTIGATIONAL AREA
BOUNDARY OF WATER-BEARING MATERIAL
HILL AND MOUNTAIN AREAS
BOUNDARY OF OPERATIONAL AREA
OPERATIONAL AREA NUMBER
1 — PLAN NO / 1990 EXTRACTIONS IN 1000 A F: 117-4 7; 117-5 9; 117-7 11; 117-11 16; 318-5 10
2 — PLAN NO / 1990 EXTRACTIONS IN 1000 A F: 117-4 4; 117-5 5; 117-7 6; 117-11 8; 318-5 7
3 — PLAN NO / 1990 EXTRACTIONS IN 1000 A F: 117-4 24; 117-5 32; 117-7 39; 117-11 56; 318-5 22
4 — PLAN NO / 1990 EXTRACTIONS IN 1000 A F: 117-4 39; 117-5 53; 117-7 65; 117-11 95; 318-5 56
5 — PLAN NO / 1990 EXTRACTIONS IN 1000 A F: 117-4 13; 117-5 17; 117-7 21; 117-11 31; 318-5 20
6 — PLAN NO / 1990 EXTRACTIONS IN 1000 A F: 117-4 21; 117-5 21; 117-7 21; 117-11 21; 318-5 21
7 — PLAN NO / 1990 EXTRACTIONS IN 1000 A F: 117-4 19; 117-5 25; 117-7 31; 117-11 47; 318-5 27
8 — PLAN NO / 1990 EXTRACTIONS IN 1000 A F: 117-4 30; 117-5 40; 117-7 50; 117-11 73; 318-5 35
9 — PLAN NO / 1990 EXTRACTIONS IN 1000 A F: 117-4 48; 117-5 48; 117-7 48; 117-11 48; 318-5 48
10 — PLAN NO / 1990 EXTRACTIONS IN 1000 A F: 117-4 24; 117-5 32; 117-7 40; 117-11 58; 318-5 33
PACIFIC OCEAN
SANTA MONICA BAY
SAN PEDRO BAY
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY
CONSTANT ANNUAL GROUND WATER EXTRACTIONS FROM 1972 TO 1990 FOR SELECTED PLANS BY OPERATIONAL AREAS
SCALE OF MILES
1966



LEGEND

BOUNDARY OF INVESTIGATIONAL AREA

BOUNDARY OF WATER-BEARING MATERIAL

HILL AND MOUNTAIN AREAS

BOUNDARY OF OPERATIONAL AREA

(1) OPERATIONAL AREA NUMBER

NOTE:

a PUMPING AMOUNT IN THE WEST COAST BASIN, WHICH IS ROUGHLY REPRESENTED BY OPERATIONAL AREAS 6 AND 9 IS HELD AT THE 1956 - 57 AMOUNT (APPROXIMATELY 69,700 ACRE - FEET) THROUGHOUT THE STUDY PERIOD AND THE PERCENT OF PUMPING IN OPERATIONAL AREAS 6 AND 9 WITH RESPECT TO THE TOTAL AMOUNT PUMPED IN THE WEST COAST BASIN IS 30 AND 70 PERCENT, RESPECTIVELY

b PUMPING AMOUNT IN THE WEST COAST BASIN IS HELD AT A CONSTANT AMOUNT THROUGHOUT THE STUDY PERIOD BUT VARIES WITH EACH OPERATIONAL PLAN THE PERCENT OF PUMPING IS APPROXIMATELY EQUALLY DIVIDED BETWEEN OPERATIONAL AREAS 6 AND 9

c THIS REPRESENTS THE PATTERN THAT EXISTED IN 1956 - 57, THE LAST YEAR FOR WHICH DETAILED INFORMATION WAS AVAILABLE

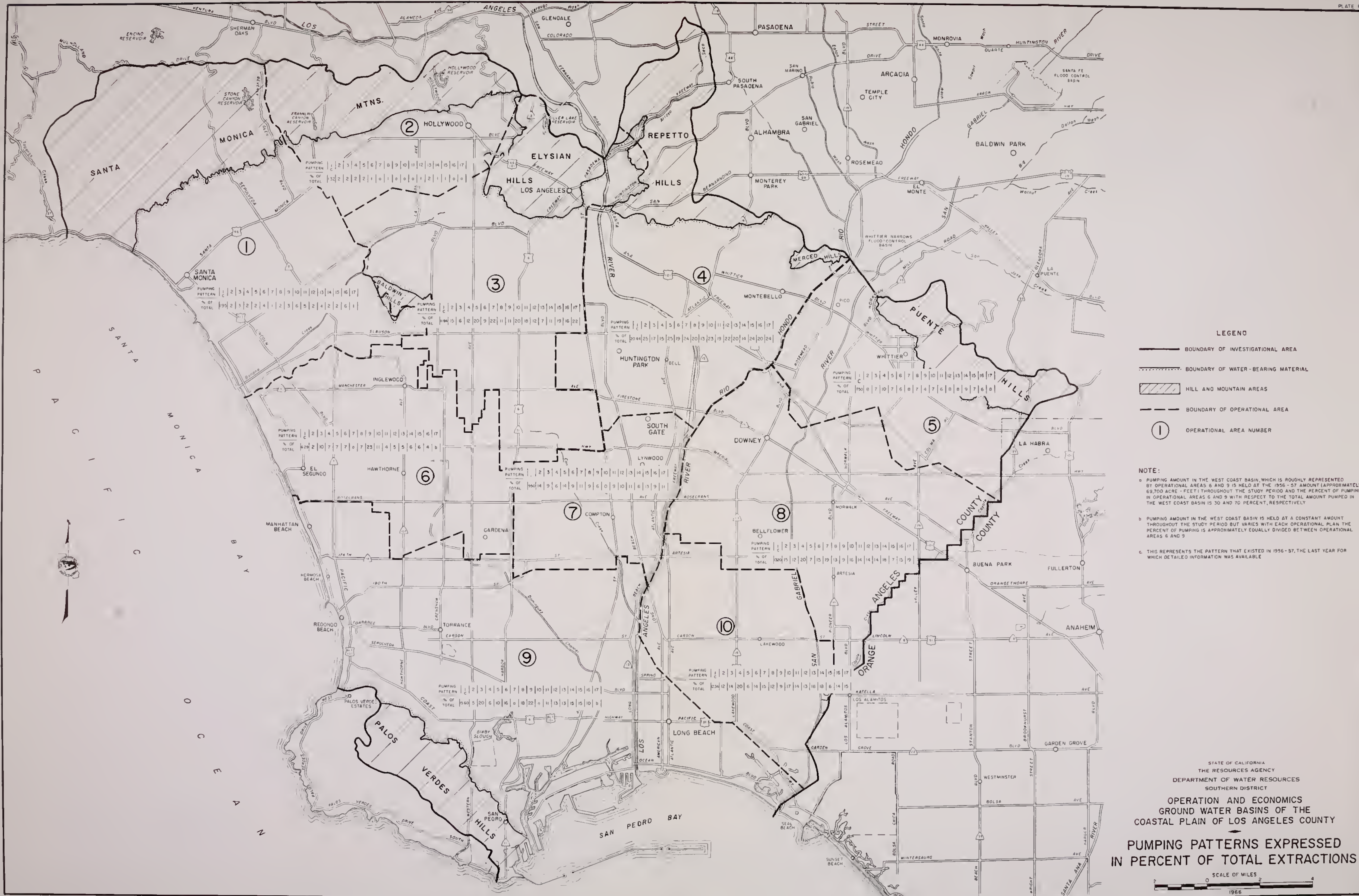
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

PUMPING PATTERNS EXPRESSED IN PERCENT OF TOTAL EXTRACTIONS

SCALE OF MILES
2 0 2 4

1966


SANTA MONICA MTNS.
HOLLYWOOD
ELYSIAN HILLS
LOS ANGELES
REPETTO HILLS
PASADENA
SOUTH PASADENA
GLENDALE
SHERMAN OAKS
ALHAMBRA
ARCADIA
MONROVIA
TEMPLE CITY
SAN GABRIEL
SAN MARINO
ROSEMEAD
MONTEREY PARK
EL MONTE
BALDWIN PARK
SANTA MONICA
BALDWIN HILLS
MONTEBELLO
MERCED HILLS
PUENTE HILLS
LA PUENTE
WHITTIER
HUNTINGTON PARK
SOUTH GATE
LYNWOOD
DOWNEY
LA HABRA
INGLEWOOD
HAWTHORNE
EL SEGUNDO
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
TORRANCE
GARDENA
COMPTON
BELLFLOWER
BUENA PARK
FULLERTON
ANAHEIM
LAKEWOOD
LONG BEACH
LOS ALAMITOS
GARDEN GROVE
WESTMINSTER
SEAL BEACH
SUNSET BEACH
PALOS VERDES HILLS
PALOS VERDES ESTATES
SAN PEDRO
SAN PEDRO BAY
SANTA MONICA BAY
PACIFIC OCEAN
LOS ANGELES COUNTY
ORANGE COUNTY
1
2
3
4
5
6
7
8
9
10
PUMPING PATTERN
% OF TOTAL
LEGEND
BOUNDARY OF INVESTIGATIONAL AREA
BOUNDARY OF WATER-BEARING MATERIAL
HILL AND MOUNTAIN AREAS
BOUNDARY OF OPERATIONAL AREA
OPERATIONAL AREA NUMBER
NOTE:
a PUMPING AMOUNT IN THE WEST COAST BASIN, WHICH IS ROUGHLY REPRESENTED BY OPERATIONAL AREAS 6 AND 9 IS HELD AT THE 1956-57 AMOUNT (APPROXIMATELY 69,700 ACRE-FEET) THROUGHOUT THE STUDY PERIOD AND THE PERCENT OF PUMPING IN OPERATIONAL AREAS 6 AND 9 WITH RESPECT TO THE TOTAL AMOUNT PUMPED IN THE WEST COAST BASIN IS 30 AND 70 PERCENT, RESPECTIVELY
b PUMPING AMOUNT IN THE WEST COAST BASIN IS HELD AT A CONSTANT AMOUNT THROUGHOUT THE STUDY PERIOD BUT VARIES WITH EACH OPERATIONAL PLAN THE PERCENT OF PUMPING IS APPROXIMATELY EQUALLY DIVIDED BETWEEN OPERATIONAL AREAS 6 AND 9
c THIS REPRESENTS THE PATTERN THAT EXISTED IN 1956-57, THE LAST YEAR FOR WHICH DETAILED INFORMATION WAS AVAILABLE
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY
PUMPING PATTERNS EXPRESSED
IN PERCENT OF TOTAL EXTRACTIONS
SCALE OF MILES
2 0 2 4
1966

LEGEND

BOUNDARY OF INVESTIGATIONAL AREA

BASIN BOUNDARY

BOUNDARY OF WATER BEARING MATERIAL

-+20— GENERALIZED LINE OF EQUAL GROUND WATER ELEVATION IN FEET COMPUTED BY THE MATHEMATICAL MODEL FOR 1962

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

LINES OF EQUAL GROUND WATER ELEVATIONS AS COMPUTED BY THE MATHEMATICAL MODEL OF THE GROUND WATER BASINS FOR 1962

SCALE OF MILES
2 0 2 4

Pumping pattern — % of total, by operational area

Operational area	1 (c)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	95	2	3	2	2	4	1	2	3	6	5	2	4	2	2	6	1
2	132	2	2	2	2	1	0	1	0	0	0	1	2	1	1	0	0
3	104	15	6	12	20	9	22	11	11	20	18	12	7	11	19	16	22
4	20.44	25	17	15	25	19	24	20	13	23	19	22	20	14	24	20	24
5	750	8	7	10	7	6	8	7	4	7	6	8	8	9	7	6	8
6	629	2	10	7	7	7	0	7	23	11	4	5	5	6	6	4	6
7	950	14	9	6	14	9	11	9	6	0	9	10	11	6	13	9	11
8	320	15	12	20	7	15	19	13	9	16	14	14	14	18	7	15	19
9	560	5	20	6	10	16	0	18	22	0	11	13	13	15	15	10	6
10	236	12	14	20	6	14	15	12	9	17	14	13	16	18	6	14	15

LEGEND

- BOUNDARY OF INVESTIGATIONAL AREA
- BOUNDARY OF WATER-BEARING MATERIAL
- HILL AND MOUNTAIN AREAS
- BOUNDARY OF OPERATIONAL AREA
- (1) OPERATIONAL AREA NUMBER

NOTE:

a. PUMPING AMOUNT IN THE WEST COAST BASIN, WHICH IS ROUGHLY REPRESENTED BY OPERATIONAL AREAS 6 AND 9 IS HELD AT THE 1956 - 57 AMOUNT (APPROXIMATELY 69,700 ACRE - FEET) THROUGHOUT THE STUDY PERIOD AND THE PERCENT OF PUMPING IN OPERATIONAL AREAS 6 AND 9 WITH RESPECT TO THE TOTAL AMOUNT PUMPED IN THE WEST COAST BASIN IS 30 AND 70 PERCENT, RESPECTIVELY

b. PUMPING AMOUNT IN THE WEST COAST BASIN IS HELD AT A CONSTANT AMOUNT THROUGHOUT THE STUDY PERIOD BUT VARIES WITH EACH OPERATIONAL PLAN THE PERCENT OF PUMPING IS APPROXIMATELY EQUALLY DIVIDED BETWEEN OPERATIONAL AREAS 6 AND 9

c. THIS REPRESENTS THE PATTERN THAT EXISTED IN 1956 - 57, THE LAST YEAR FOR WHICH DETAILED INFORMATION WAS AVAILABLE

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

PUMPING PATTERNS EXPRESSED IN PERCENT OF TOTAL EXTRACTIONS

SCALE OF MILES
2 0 2 4

1966

LEGEND

BOUNDARY OF INVESTIGATIONAL AREA

BASIN BOUNDARY

BOUNDARY OF WATER BEARING MATERIAL

-+20— GENERALIZED LINE OF EQUAL CHANGE [illegible] WATER ELEVATION [illegible] FEET BETWEEN [illegible] AND DASHED WHERE INFERRED

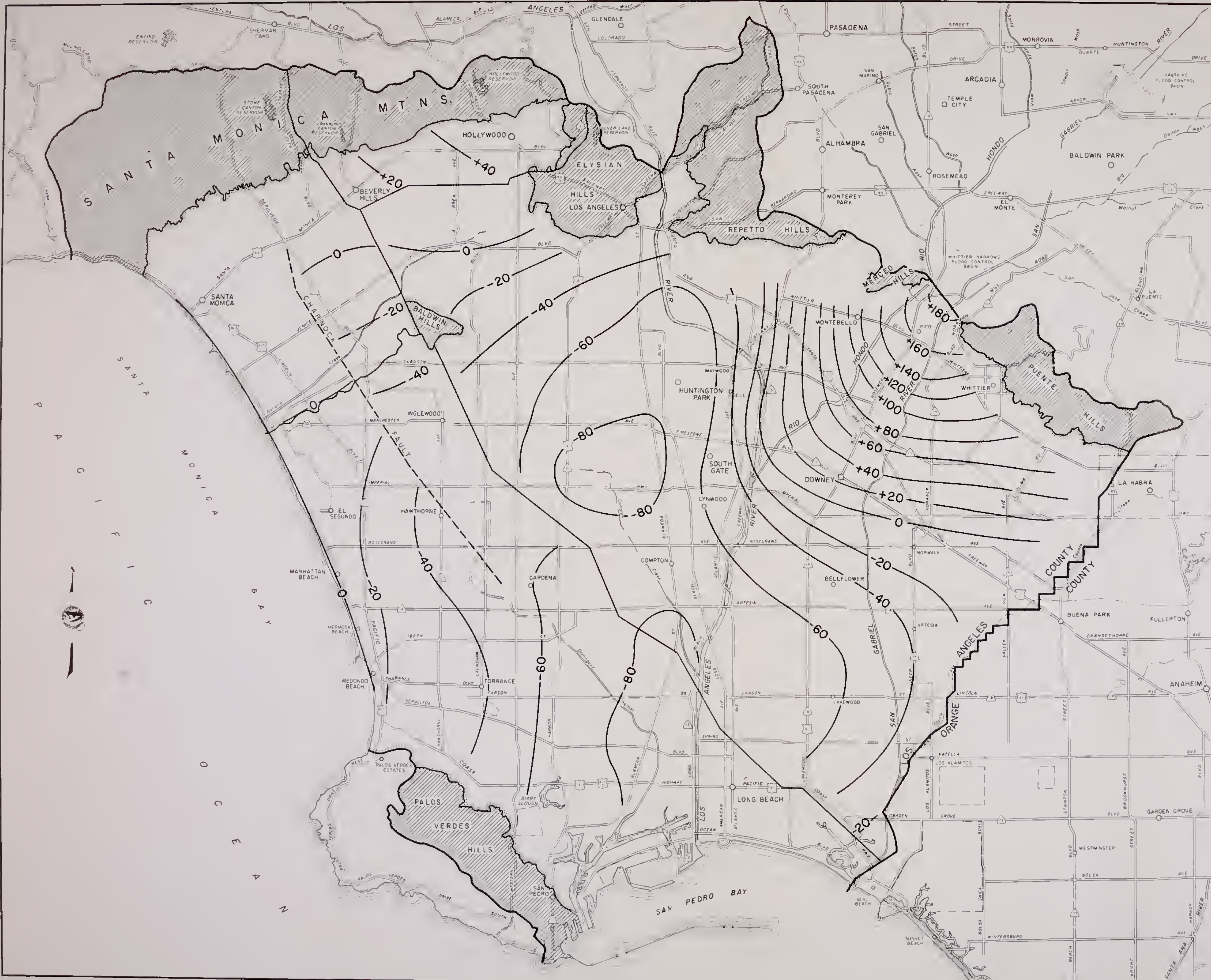
NOTE: [illegible] WATER LEVEL ELEVATIONS FOR [illegible] AND [illegible] WERE DETERMINED BY THE SUPERPOSITIONING OF THE MASTER INFLUENCE [illegible] WHICH WERE DEVELOPED BY THE MATHEMATICAL MODEL [illegible] THE GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES [illegible]

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1962 AND 1990 FOR STUDY PLAN NUMBER 117-4

SCALE OF MILES
2 0 2 4



LEGEND

BOUNDARY OF INVESTIGATIONAL AREA

BASIN BOUNDARY

BOUNDARY OF WATER-BEARING MATERIAL

-+20— GENERALIZED LINE OF EQUAL GROUND WATER ELEVATION IN FEET COMPUTED BY THE MATHEMATICAL MODEL FOR 1962

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

LINES OF EQUAL GROUND WATER ELEVATIONS AS COMPUTED BY THE MATHEMATICAL MODEL OF THE GROUND WATER BASINS FOR 1962

SCALE OF MILES

2 0 2 4

1966

LEGEND

——— BOUNDARY OF INVESTIGATIONAL AREA

——— BASIN BOUNDARY

BOUNDARY OF WATER BEARING MATERIAL

-+20—— GENERALIZED LINE OF EQUAL CHANGE IN GROUND WATER ELEVATION IN FEET BETWEEN 1962 AND 1990 DASHED WHERE INFERRED

NOTE GROUND WATER LEVEL ELEVATIONS FOR 1962 AND 1990 WERE DETERMINED BY THE SUPERPOSITIONING OF THE MASTER INFLUENCE FUNCTIONS WHICH WERE DEVELOPED BY THE MATHEMATICAL MODEL OF THE GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1962 AND 1990 FOR STUDY PLAN NUMBER 117-5

SCALE OF MILES
2 0 2 4


SANTA MONICA MTNS
ELYSIAN HILLS
REPETTO HILLS
MERCED HILLS
PUENTE HILLS
BALDWIN HILLS
PALOS VERDES HILLS
CHARNOCK FAULT
SANTA MONICA BAY
PACIFIC OCEAN
SAN PEDRO BAY
LOS ANGELES RIVER
SAN GABRIEL RIVER
RIO HONDO
LOS ANGELES COUNTY
ORANGE COUNTY
PASADENA
GLENDALE
HOLLYWOOD
BEVERLY HILLS
LOS ANGELES
SANTA MONICA
INGLEWOOD
HAWTHORNE
EL SEGUNDO
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
TORRANCE
GARDENA
COMPTON
LYNWOOD
SOUTH GATE
HUNTINGTON PARK
DOWNEY
BELLFLOWER
MONTEBELLO
WHITTIER
LONG BEACH
SAN PEDRO
ALHAMBRA
MONTEREY PARK
ROSEMEAD
EL MONTE
ARCADIA
MONROVIA
TEMPLE CITY
BALDWIN PARK
LA HABRA
BUENA PARK
FULLERTON
ANAHEIM
GARDEN GROVE
WESTMINSTER
LEGEND
BOUNDARY OF INVESTIGATIONAL AREA
BASIN BOUNDARY
BOUNDARY OF WATER BEARING MATERIAL
-+20— GENERALIZED LINE OF EQUAL CHANGE IN GROUND WATER ELEVATION IN FEET BETWEEN 1962 AND 1990 (DASHED WHERE INFERRED)
NOTE GROUND WATER LEVEL ELEVATIONS FOR 1962 AND 1990 WERE DETERMINED BY THE SUPERPOSITIONING OF THE MASTER INFLUENCE FUNCTIONS WHICH WERE DEVELOPED BY THE MATHEMATICAL MODEL OF THE GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY
LINES OF EQUAL CHANGE IN GROUND
WATER ELEVATIONS BETWEEN
1962 AND 1990 FOR STUDY PLAN
NUMBER 117-4
SCALE OF MILES
1966

LEGEND

BOUNDARY OF INVESTIGATIONAL AREA

BASIN BOUNDARY

BOUNDARY OF WATER-BEARING MATERIAL

-+20— GENERALIZED LINE OF EQUAL CHANGE IN GROUND WATER ELEVATION IN FEET BETWEEN 1962 AND 1990 (DASHED WHERE INFERRED)

NOTE: GROUND WATER LEVEL ELEVATIONS FOR 1962 AND 1990 WERE DETERMINED BY THE SUPERPOSITIONING OF THE MASTER INFLUENCE FUNCTIONS WHICH WERE DEVELOPED BY THE MATHEMATICAL MODEL OF THE GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1962 AND 1990 FOR STUDY PLAN NUMBER 117-7

SCALE OF MILES
2 0 2 4
1966

LEGEND

BOUNDARY OF INVESTIGATIONAL AREA

BASIN BOUNDARY

BOUNDARY OF WATER-BEARING MATERIAL

-+20— GENERALIZED LINE OF EQUAL CHANGE IN GROUND WATER ELEVATION IN FEET BETWEEN 1962 AND 1990 (DASHED WHERE INFERRED)

NOTE- GROUND WATER LEVEL ELEVATIONS FOR 1962 AND 1990 WERE DETERMINED BY THE SUPERPOSITIONING OF THE MASTER INFLUENCE FUNCTIONS WHICH WERE DEVELOPED BY THE MATHEMATICAL MODEL OF THE GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY

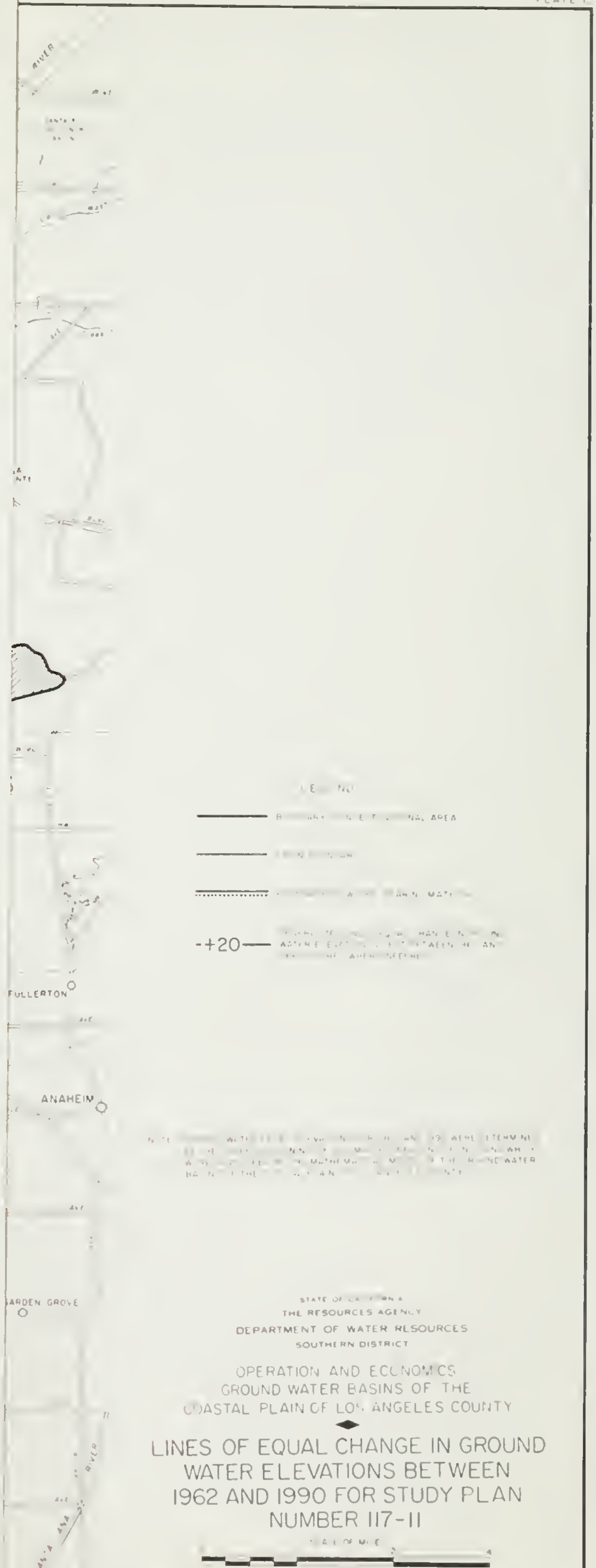
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1962 AND 1990 FOR STUDY PLAN NUMBER 117-5

SCALE OF MILES
2 0 2 4

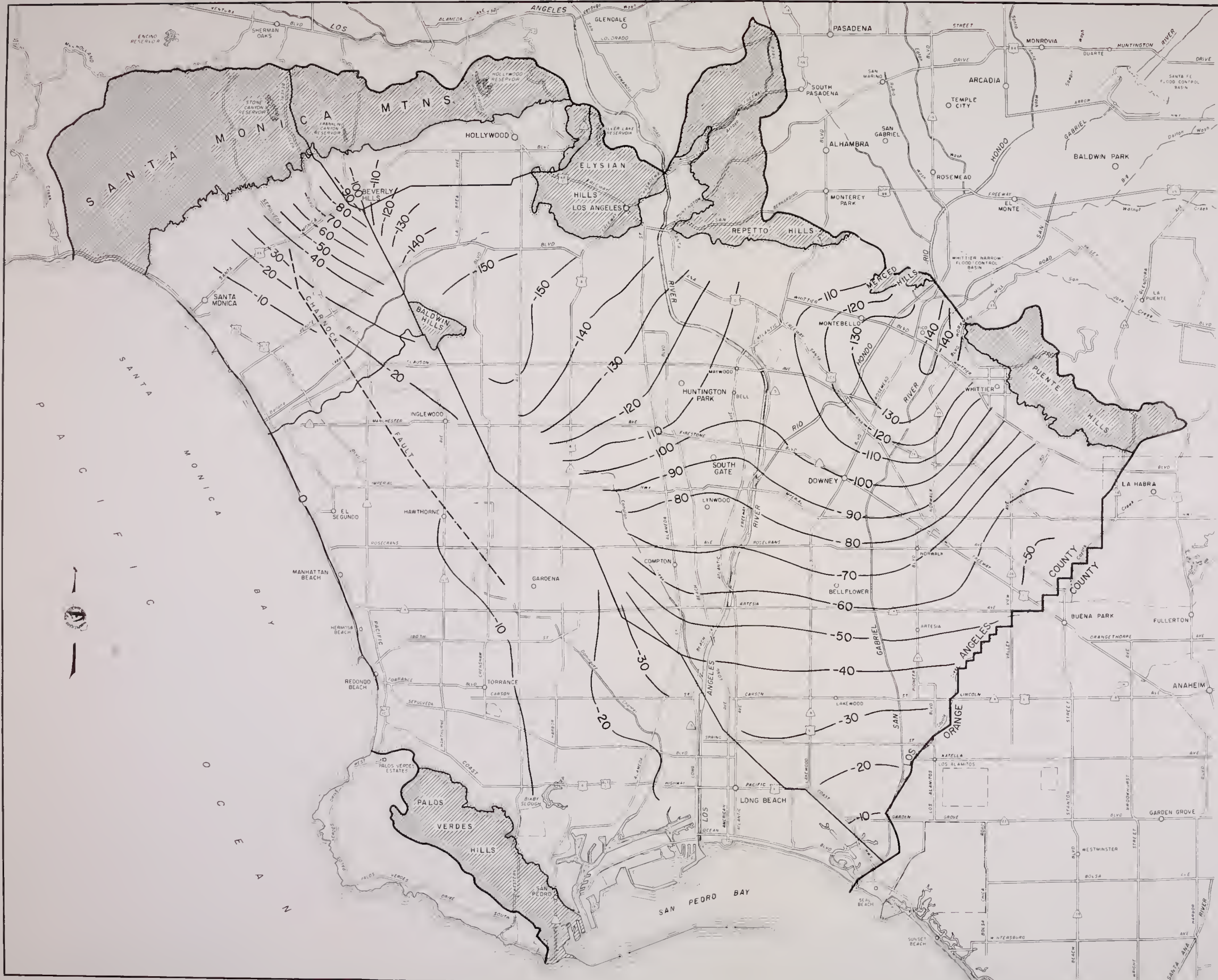
1966



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

LINES OF EQUAL CHANGE IN GROUND
WATER ELEVATIONS BETWEEN
1962 AND 1990 FOR STUDY PLAN
NUMBER 117-11



LEGEND

BOUNDARY OF INVESTIGATIONAL AREA

BASIN BOUNDARY

BOUNDARY OF WATER-BEARING MATERIAL

-+20— GENERALIZED LINE OF EQUAL CHANGE IN GROUND WATER ELEVATION IN FEET BETWEEN 1962 AND 1990 (DASHED WHERE INFERRED)

NOTE GROUND WATER LEVEL ELEVATIONS FOR 1962 AND 1990 WERE DETERMINED BY THE SUPERPOSITIONING OF THE MASTER INFLUENCE FUNCTIONS WHICH WERE DEVELOPED BY THE MATHEMATICAL MODEL OF THE GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1962 AND 1990 FOR STUDY PLAN NUMBER 117-7

SCALE OF MILES

2 0 2 4

1966

LEGEND

BOUNDARY OF INVESTIGATIONAL AREA

BASIN BOUNDARY

BOUNDARY OF WATER BEARING MATERIAL

-+20— GENERALIZED LINE OF EQUAL CHANGE IN GROUND WATER ELEVATION IN FEET BETWEEN 1962 AND 1990 (DASHED WHERE INFERRED)

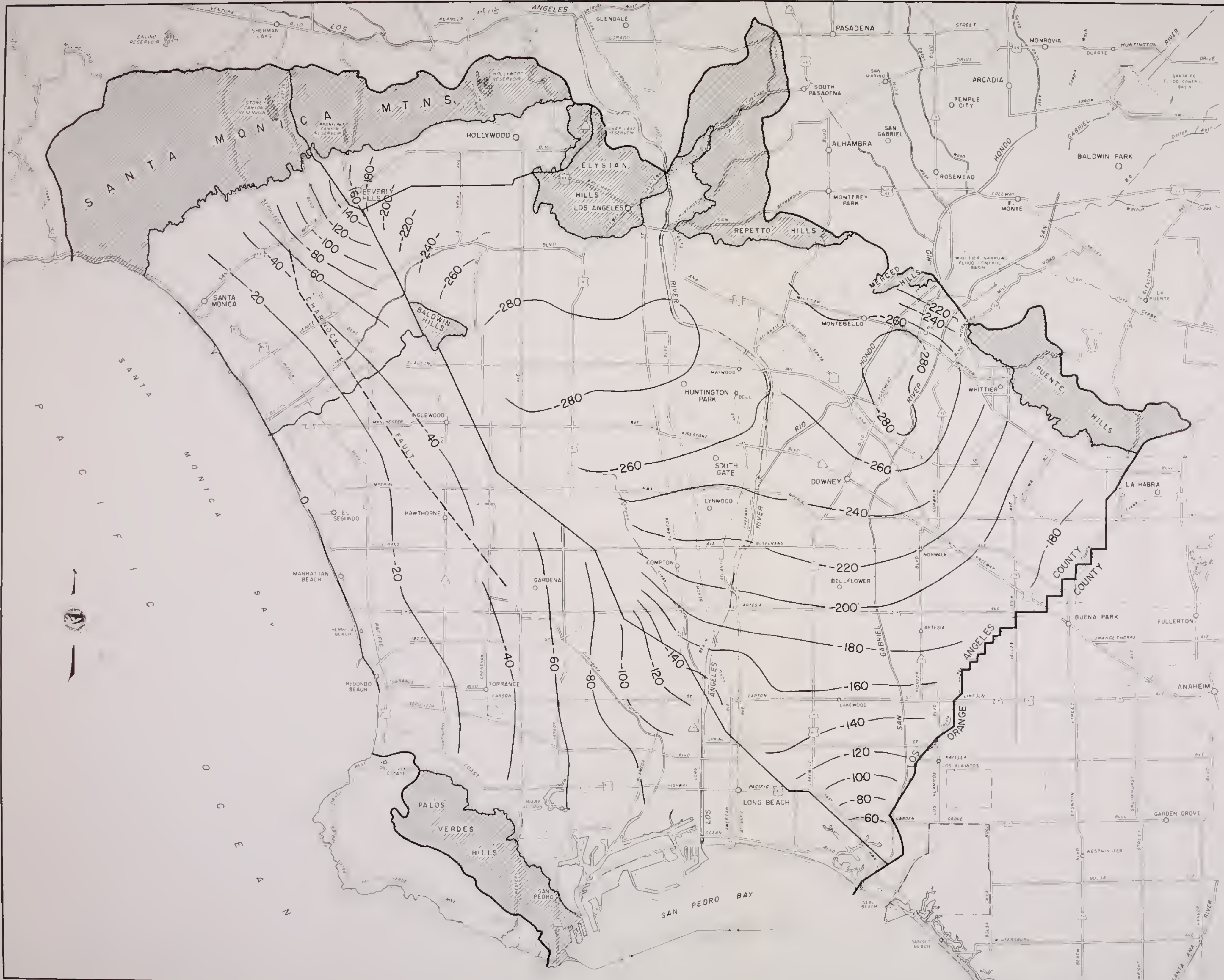
NOTE GROUND WATER LEVEL ELEVATIONS FOR 1962 AND 1990 WERE DETERMINED BY THE SUPERPOSITIONING OF THE MASTER INFLUENCE FUNCTIONS WHICH WERE DEVELOPED BY THE MATHEMATICAL MODEL OF THE GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1962 AND 1990 FOR STUDY PLAN NUMBER 318-5

SCALE OF MILES
2 0 2 4



LEGEND

[illegible] AREA

[illegible]

[illegible] OF WATER BEARING MATERIAL

-+20— GENERALIZED LINE OF EQUAL CHANGE IN GROUND WATER ELEVATION IN FEET BETWEEN 1962 AND 1990 (DASHED WHERE INFERRED)

NOTE: [illegible] WATER LEVEL ELEVATION FOR 1962 AND 1990 WERE DETERMINED BY THE SUPERPOSITIONING OF THE MASTER INFLUENCE FUNCTIONS WHICH WERE DEVELOPED BY THE MATHEMATICAL MODEL OF THE GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY

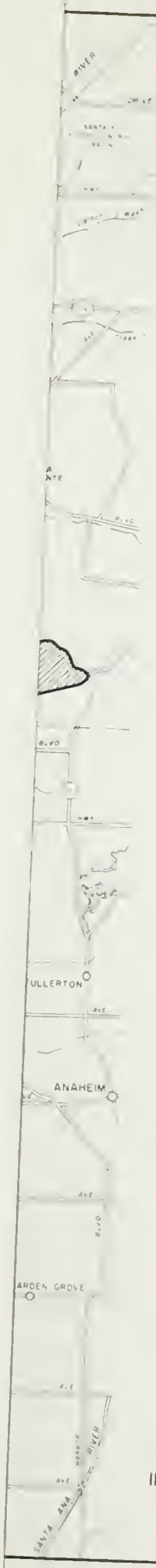
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1962 AND 1990 FOR STUDY PLAN NUMBER 117-11

SCALE OF MILES
2 0 2 4

1966



-+20——

AND END OF ... CYCLE ... YEARS

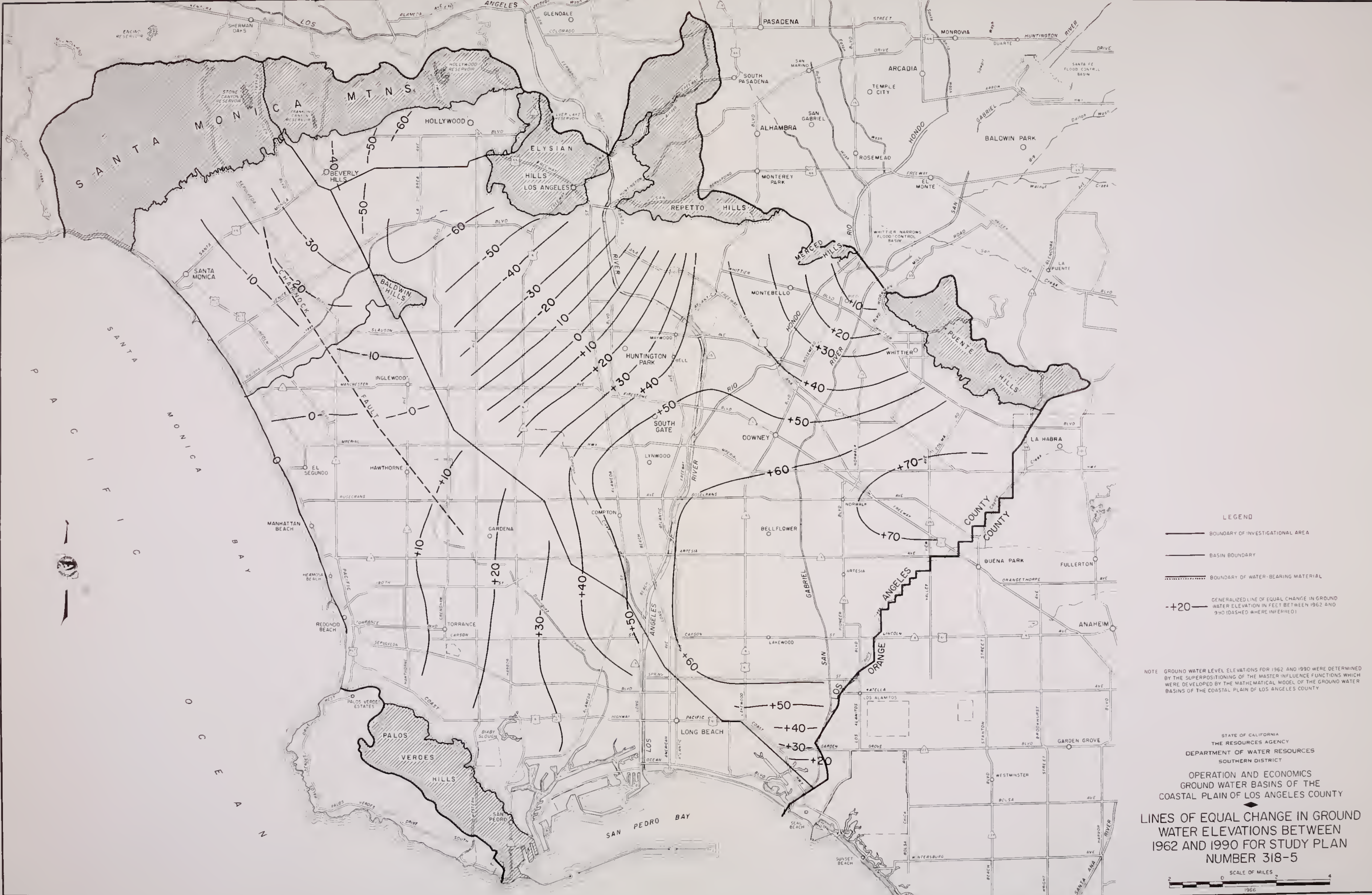
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

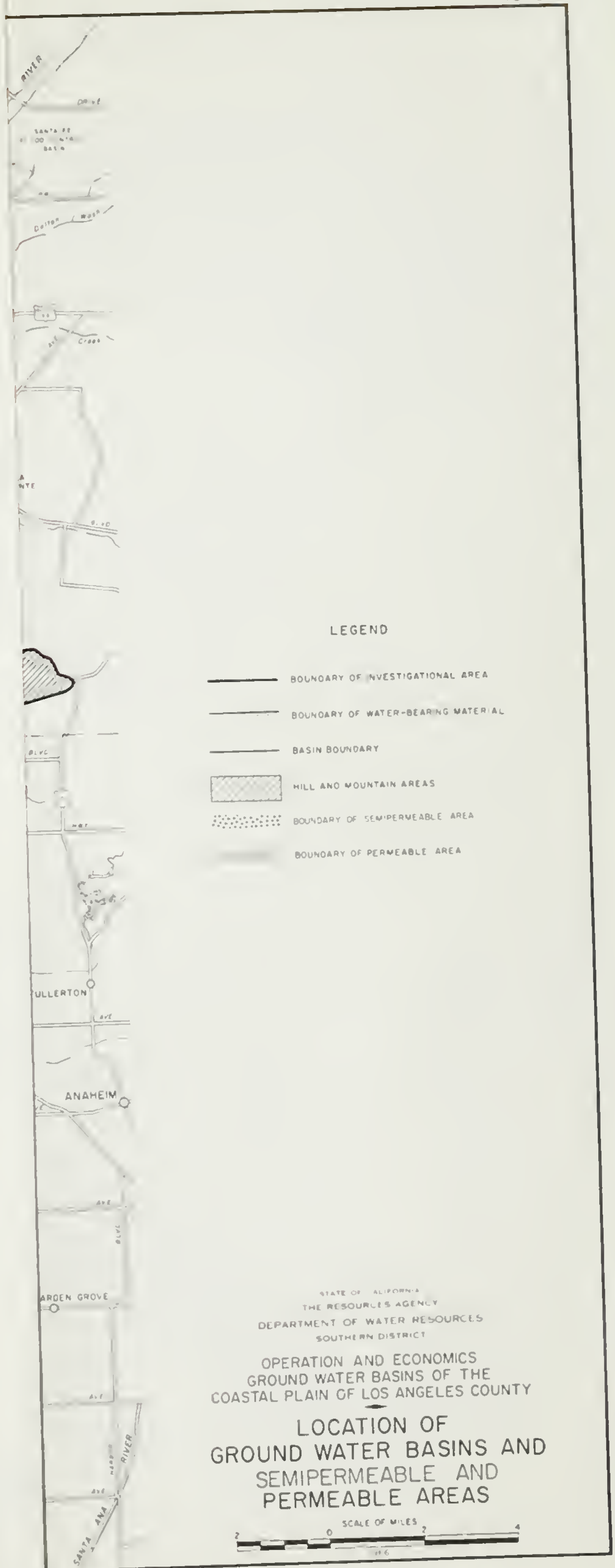
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

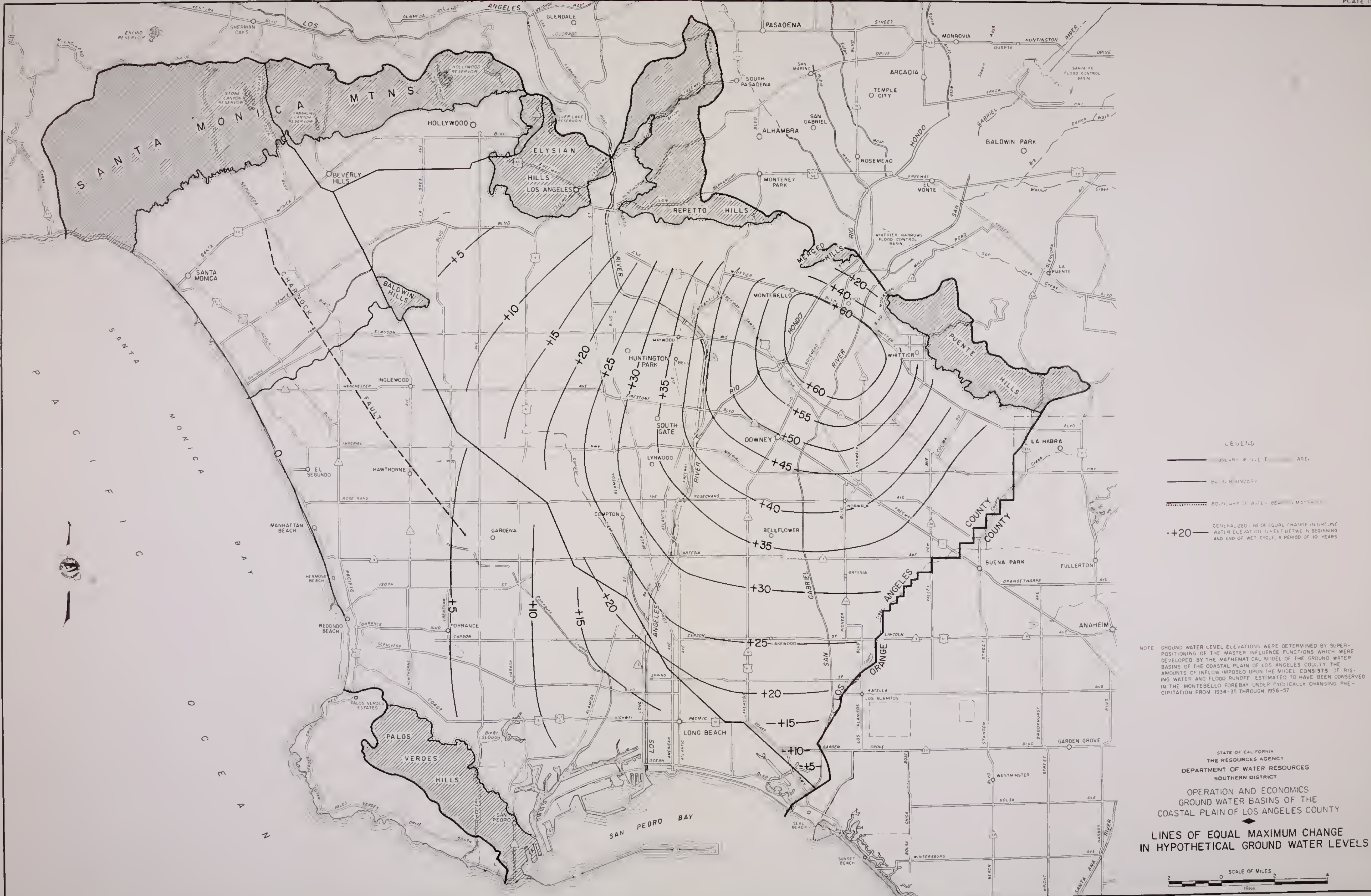
LINES OF EQUAL MAXIMUM CHANGE IN HYPOTHETICAL GROUND WATER LEVELS

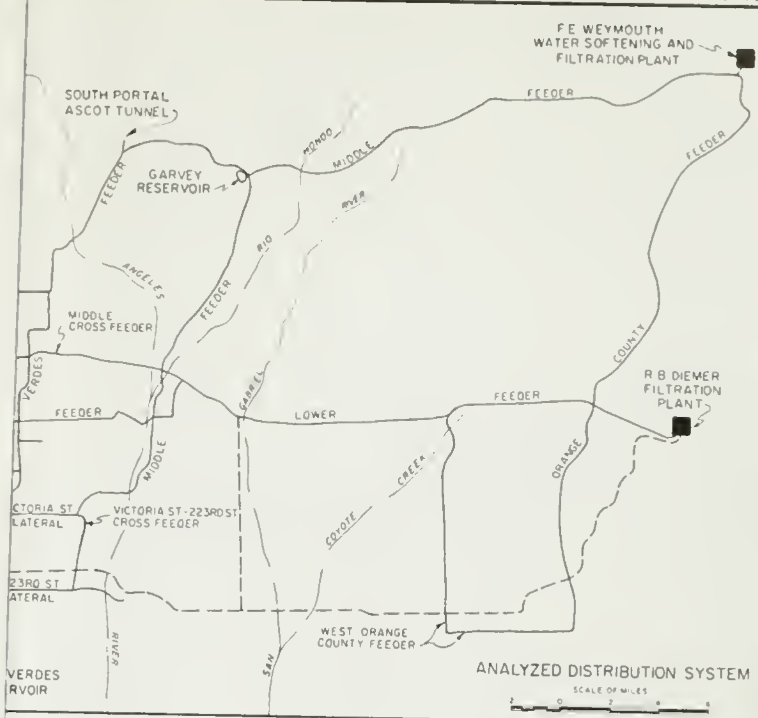
SCALE OF MILES
2 0 2 4

84684


LEGEND
BOUNDARY OF INVESTIGATIONAL AREA
BASIN BOUNDARY
BOUNDARY OF WATER-BEARING MATERIAL
+20 GENERALIZED LINE OF EQUAL CHANGE IN GROUND WATER ELEVATION IN FEET BETWEEN 1962 AND 1990 (DASHED WHERE INFERRED)
NOTE: GROUND WATER LEVEL ELEVATIONS FOR 1962 AND 1990 WERE DETERMINED BY THE SUPERPOSITIONING OF THE MASTER INFLUENCE FUNCTIONS WHICH WERE DEVELOPED BY THE MATHEMATICAL MODEL OF THE GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY
LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1962 AND 1990 FOR STUDY PLAN NUMBER 318-5
SCALE OF MILES
1966
SANTA MONICA MTNS
SANTA MONICA BAY
PACIFIC OCEAN
SAN PEDRO BAY
PALOS VERDES HILLS
BALDWIN HILLS
ELYSIAN HILLS
REPETTO HILLS
MERCED HILLS
PUENTE HILLS
CHARNOCK FAULT
LOS ANGELES COUNTY
ORANGE COUNTY
PASADENA
GLENDALE
HOLLYWOOD
BEVERLY HILLS
LOS ANGELES
SANTA MONICA
INGLEWOOD
HAWTHORNE
EL SEGUNDO
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
TORRANCE
GARDENA
COMPTON
LYNWOOD
SOUTH GATE
HUNTINGTON PARK
BELL
MAYWOOD
DOWNEY
MONTEBELLO
WHITTIER
NORWALK
BELLFLOWER
ARTESIA
LAKEWOOD
LONG BEACH
SAN PEDRO
SEAL BEACH
SUNSET BEACH
LOS ALAMITOS
GARDEN GROVE
WESTMINSTER
BUENA PARK
FULLERTON
ANAHEIM
LA HABRA
ALHAMBRA
SOUTH PASADENA
SAN MARINO
SAN GABRIEL
ROSEMEAD
MONTEREY PARK
EL MONTE
TEMPLE CITY
ARCADIA
MONROVIA
BALDWIN PARK
LA PUENTE
SHERMAN OAKS
PALOS VERDES ESTATES
WHITTIER NARROWS FLOOD CONTROL BASIN


RIVER
SANTA FE FLOOD CONTROL BASIN
Dalton Wash
Creek
FULLERTON
ANAHEIM
GARDEN GROVE
SANTA ANA RIVER
LEGEND
BOUNDARY OF INVESTIGATIONAL AREA
BOUNDARY OF WATER-BEARING MATERIAL
BASIN BOUNDARY
HILL AND MOUNTAIN AREAS
BOUNDARY OF SEMIPERMEABLE AREA
BOUNDARY OF PERMEABLE AREA
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY
LOCATION OF
GROUND WATER BASINS AND
SEMIPERMEABLE AND
PERMEABLE AREAS
SCALE OF MILES
2 0 2 4


SANTA MONICA MTNS
ELYSIAN HILLS
REPETTO HILLS
MERCED HILLS
PUENTE HILLS
BALDWIN HILLS
PALOS VERDES HILLS
CHARNOCK FAULT
SANTA MONICA BAY
PACIFIC OCEAN
SAN PEDRO BAY
LOS ANGELES COUNTY
ORANGE COUNTY
LOS ANGELES RIVER
SAN GABRIEL RIVER
RIO HONDO
PASADENA
GLENDALE
HOLLYWOOD
BEVERLY HILLS
LOS ANGELES
SANTA MONICA
INGLEWOOD
HAWTHORNE
EL SEGUNDO
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
TORRANCE
GARDENA
COMPTON
LYNWOOD
SOUTH GATE
HUNTINGTON PARK
MAYWOOD
MONTEBELLO
WHITTIER
DOWNEY
NORWALK
BELLFLOWER
LAKEWOOD
LONG BEACH
SAN PEDRO
PALOS VERDES ESTATES
ALHAMBRA
SOUTH PASADENA
SAN MARINO
SAN GABRIEL
ROSEMEAD
MONTEREY PARK
EL MONTE
TEMPLE CITY
ARCADIA
MONROVIA
BALDWIN PARK
LA PUENTE
LA HABRA
FULLERTON
BUENA PARK
ANAHEIM
GARDEN GROVE
WESTMINSTER
LOS ALAMITOS
SEAL BEACH
SUNSET BEACH
ARTESIA
+5
+10
+15
+20
+25
+30
+35
+40
+45
+50
+55
+60
LEGEND
BASIN BOUNDARY
-+20— GENERALIZED LINE OF EQUAL CHANGE IN GROUND WATER ELEVATION IN FEET BETWEEN BEGINNING AND END OF WET CYCLE, A PERIOD OF 10 YEARS
NOTE GROUND WATER LEVEL ELEVATIONS WERE DETERMINED BY SUPER-POSITIONING OF THE MASTER INFLUENCE FUNCTIONS WHICH WERE DEVELOPED BY THE MATHEMATICAL MODEL OF THE GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY THE AMOUNTS OF INFLOW IMPOSED UPON THE MODEL CONSISTS OF RISING WATER AND FLOOD RUNOFF ESTIMATED TO HAVE BEEN CONSERVED IN THE MONTEBELLO FOREBAY UNDER CYCLICALLY CHANGING PRECIPITATION FROM 1934-35 THROUGH 1956-57
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY
LINES OF EQUAL MAXIMUM CHANGE
IN HYPOTHETICAL GROUND WATER LEVELS
SCALE OF MILES
1966



ANALYZED DISTRIBUTION SYSTEM

SCALE OF MILES

LEGEND

9	EQUIVALENT PIPELINE OF EXISTING SYSTEM AND CODE NUMBER
94	EQUIVALENT PIPELINE PROJECTED FOR SERVICE IN 1972 AND CODE NUMBER
95	EQUIVALENT PIPELINE PROJECTED FOR SERVICE IN 1983 AND CODE NUMBER
33	EQUIVALENT CONNECTOR AND CODE NUMBER
26	INTERNAL PRESSURE CONTROL STRUCTURE AND CODE NUMBER
62	BOUNDARY PRESSURE CONTROL STRUCTURE AND CODE NUMBER
FLOWS)	SIGN CONVENTION SHOWING THE DIRECTION OF FLOW IN THE PIPELINES

NOTE THE NUMBERING CODE APPLIES TO ASSUMED FACILITIES PROJECTED FOR SERVICE IN 1972 AND 1983 BASED ON CASE VII OF THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA REPORT NO 802, "COMPARATIVE ECONOMIC STUDY OF THE EAST BRANCH AND WEST BRANCH OF THE CALIFORNIA AQUEDUCT, AND OF ADDITIONAL DISTRIBUTION FACILITIES REQUIRED IN THE SOUTHERN CALIFORNIA COASTAL PLAIN BY 1990." MARCH, 1962

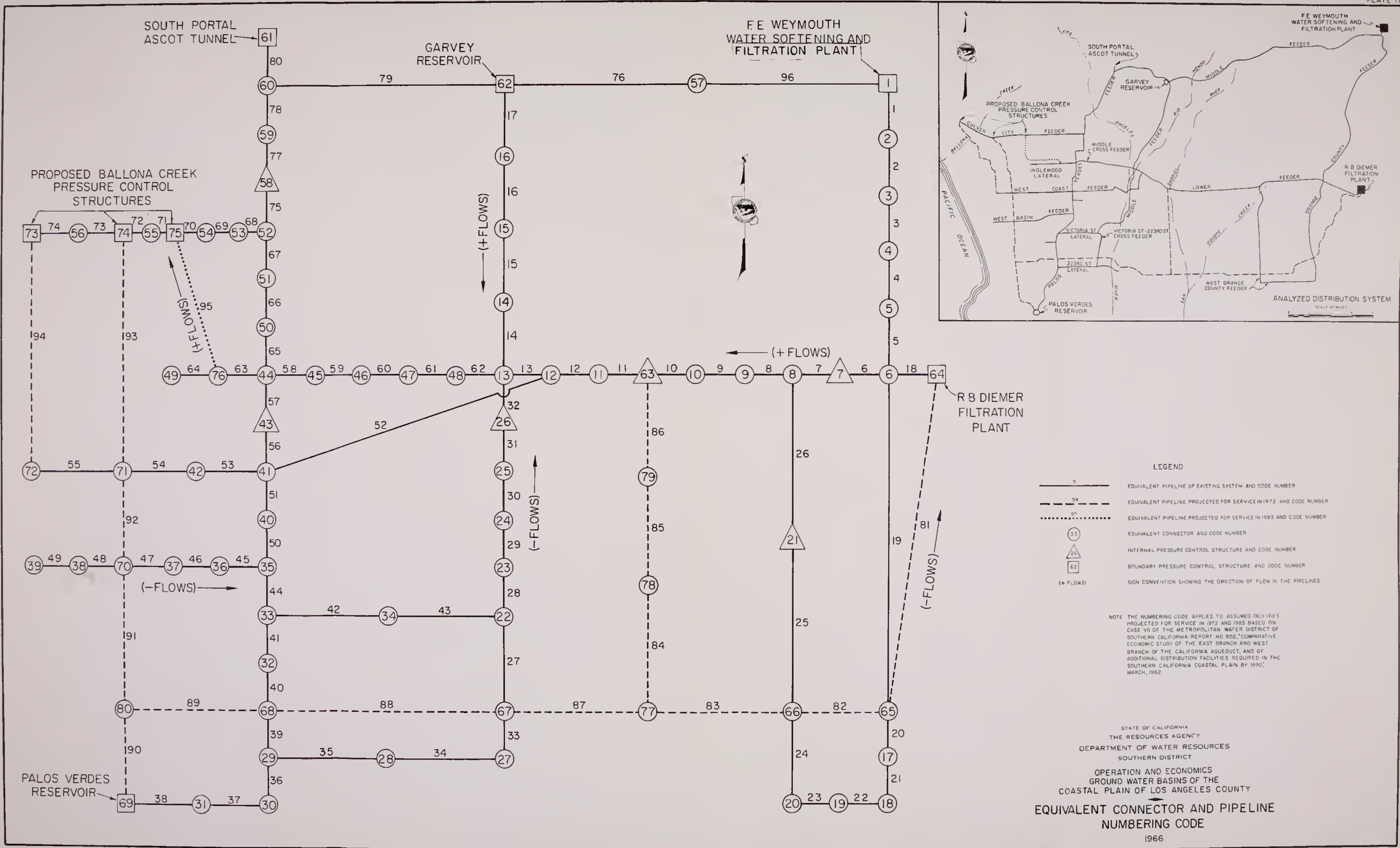
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
OASTAL PLAIN OF LOS ANGELES COUNTY

VALENT CONNECTOR AND PIPELINE
NUMBERING CODE

1966

SANTA MONICA MTNS.
HOLLYWOOD BASIN
ELYSIAN HILLS
REPETTO HILLS
MERCED HILLS
PUENTE HILLS
BALDWIN HILLS
PALOS VERDES HILLS
SANTA MONICA BASIN
CENTRAL BASIN
WEST COAST BASIN
Permeable Area
Semipermeable Area
LOS ANGELES NARROWS
WHITTIER NARROWS
PACIFIC OCEAN
SANTA MONICA BAY
SAN PEDRO BAY
LOS ANGELES COUNTY
ORANGE COUNTY
LOS ANGELES RIVER
SAN GABRIEL RIVER
RIO HONDO
GLENDALE
PASADENA
SOUTH PASADENA
HOLLYWOOD
BEVERLY HILLS
LOS ANGELES
ALHAMBRA
MONTEREY PARK
SAN MARINO
SAN GABRIEL
ARCADIA
TEMPLE CITY
MONROVIA
DUARTE
ROSEMEAD
EL MONTE
BALDWIN PARK
LA PUENTE
MONTEBELLO
PICO
WHITTIER
SANTA MONICA
MAYWOOD
BELL
HUNTINGTON PARK
SOUTH GATE
DOWNEY
LYNWOOD
COMPTON
BELLFLOWER
NORWALK
ARTESIA
LAKEWOOD
LONG BEACH
INGLEWOOD
EL SEGUNDO
HAWTHORNE
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
GARDENA
TORRANCE
PALOS VERDES ESTATES
SAN PEDRO
SEAL BEACH
SUNSET BEACH
LOS ALAMITOS
GARDEN GROVE
WESTMINSTER
BUENA PARK
FULLERTON
ANAHEIM
LA HABRA
SHERMAN OAKS
ENCINO RESERVOIR
HOLLYWOOD RESERVOIR
STONE CANYON RESERVOIR
FRANKLIN CANYON RESERVOIR
SILVER LAKE RESERVOIR
SANTA FE FLOOD CONTROL BASIN
WHITTIER NARROWS FLOOD CONTROL BASIN
LEGEND
BOUNDARY OF INVESTIGATIONAL AREA
BOUNDARY OF WATER-BEARING MATERIAL
BASIN BOUNDARY
HILL AND MOUNTAIN AREAS
BOUNDARY OF SEMIPERMEABLE AREA
BOUNDARY OF PERMEABLE AREA
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY
LOCATION OF
GROUND WATER BASINS AND
SEMIPERMEABLE AND
PERMEABLE AREAS
SCALE OF MILES
2 0 2 4
1966



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

EQUIVALENT CONNECTOR AND PIPELINE NUMBERING CODE

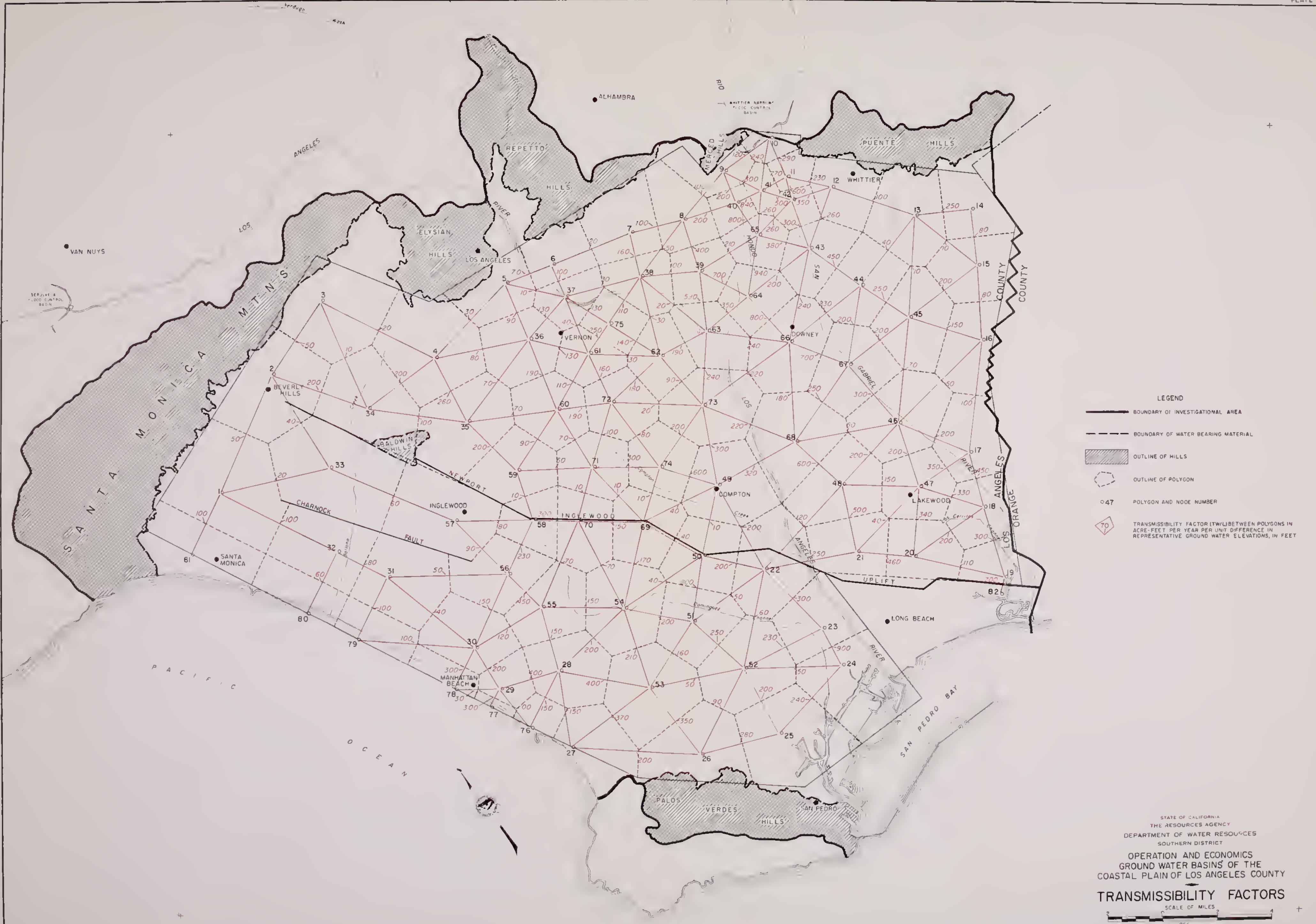
1966

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS GROUND WATER BASINS OF THE COASTAL PLAIN OF LOS ANGELES COUNTY

STORAGE FACTORS

1965



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

OPERATION AND ECONOMICS
GROUND WATER BASINS OF THE
COASTAL PLAIN OF LOS ANGELES COUNTY

TRANSMISSIBILITY FACTORS

1966