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**WATER AND SEWERAGE AUTHORITY GOVERNMENT OF
TRINIDAD AND TOBAGO**

ON

WATER STUDY TRINIDAD AND TOBAGO

SEPTEMBER 23, 1970

REPORT TO

WATER AND SEWERAGE AUTHORITY

GOVERNMENT OF TRINIDAD AND TOBAGO

ON

WATER STUDY

TRINIDAD AND TOBAGO

September 23, 1970



METCALF & EDDY INTERNATIONAL, INC.

ENGINEERS

BOSTON • NEW YORK • PALO ALTO

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Port Authority
Meteorological Service

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Crown Lands Division
Lands and Survey Department

Mapping and Control Section
Central Experimental Station

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Permanent Secretary
Geological Section

MINISTRY OF HOME AFFAIRS

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ABBREVIATIONS

cfs	cubic feet per second
deg	degrees
El	elevation
F	Fahrenheit
gal	gallons (Imperial unless otherwise noted)
gcd	gallons per capita per day
gpd	gallons per day
gpm	gallons per minute
JTU	Jackson turbidity units
MSL	mean sea level
mg/L	milligrams per liter
ml	milliliters
mm	millimeters
mil gal	million gallons
mgd	million gallons per day
MPN	most probable number
ppm	parts per million
psi	pounds per square inch

MONETARY UNIT

All costs are in Trinidad and Tobago dollars unless otherwise noted. In this report two TT\$ are considered equivalent to one US\$.

REPORT

CHAPTER 1

INTRODUCTION

History

Previous to 1853 there were no organized water supply systems in Trinidad and Tobago. However, with the construction and commissioning of the Maraval waterworks in that year as a source of supply for the City of Port of Spain, the history of organization began. During the 1920s there was considerable activity in the development of supplies for the three main communities in Trinidad, Port of Spain, San Fernando, and Arima, and for Scarborough in Tobago. By the end of the 1930s, the Hollis waterworks had been developed and water from this source was piped to remote areas to the east, west, and south.

There was much activity in the development of groundwater supplies during the early forties to provide the wartime requirements of the military and naval personnel of the British and American governments stationed in Trinidad at the time. The U.S. forces provided for their own requirements and handed over all facilities to the local government at the end of the war. At the end of the forties, total production was approximately 15 mgd (million gallons per day) for a population of about 620,000.

In 1950 Government issued a council paper setting out its policy for the provision of an adequate supply of wholesome water for domestic and other uses for every inhabitant of the country at rates as low as

possible. This council paper marked the beginning of a comprehensive program of development of the water resources of Trinidad and Tobago.

Implementation of the physical program commenced in 1953. By the middle of 1965, significant gains had been made. The development of new borehole fields, including in particular the El Socorro waterworks, together with the installation of a number of small intakes throughout the country had been completed, and the construction of the Navet waterworks was nearing completion. The new facilities increased daily production from 16 million gallons at the end of 1953 to 47 million gallons by mid-1965. Unfortunately, however, this increase in supply did not keep pace with the increasing demand, and Government took steps to expedite establishment of a single agency for the development and management of the country's water resources.

The Water and Sewerage Authority

In the Second Five-Year Plan, 1963-1968, the Government of Trinidad and Tobago declared its intention to establish a national Water and Sewerage Authority to take the place of the six agencies which at the time were individually responsible for the production and/or distribution of water, each within its own corporate or geographical boundaries.

With technical guidance provided by the Pan American Health Organization (PAHO), a Bill for the establishment of the new Authority was completed by the middle of 1965 and presented to Parliament. On September 1, 1965, Act No. 16 of 1965 establishing the Water and Sewerage Authority (WASA) as a statutory body was proclaimed.

The new Authority was added to the portfolio of the Minister of Public Utilities and became the sole agency responsible for the development of the water resources of Trinidad and Tobago, the conservation and proper use of water, and the collection, treatment, and disposal of sewage.

Purpose and Scope of the Study

Over the past decade the annual increase in water demand for domestic and industrial uses has consistently exceeded the annual increment to the supply. Consequently, a large deficit has developed and will continue to grow unless a significant addition to the supply is made in the shortest possible time.

Shortly after the Navet waterworks was placed in operation during 1966, it became apparent that this supply was insufficient to do more than reduce the then deficit and that water demand was developing faster than supply and transmission facilities were being increased.

Recognizing, therefore, that a major source was necessary and a comprehensive plan of development desirable, the Government of Trinidad and Tobago negotiated an Inter-American Development

Bank (IDB) loan late in 1967 for part-financing of the needed study, and WASA, the executing agency for Government, selected Metcalf & Eddy International, Inc., to conduct the study.

The "Description of the Project" setting forth the scope of the study calls for a far-reaching investigation of the production and distribution of water throughout Trinidad and Tobago as a basis for recommendations for the development of a system to meet the requirements of the Act which established the Authority. It also calls for an examination of WASA's organizational structure and for proposals for strengthening it to provide for greater efficiency in the management of a growing complex.

Purpose and Scope of Present Report

Present water needs in Trinidad and Tobago are estimated at about 68 mgd, or about 8 mgd in excess of the present production of 60 mgd.

Water requirements for all purposes except irrigation are expected to be about 115 mgd by 1985, and 170 mgd by the year 2000. Short and long-term plans are therefore necessary prerequisites to the construction of the facilities required for the production and transport of water in sufficient quantities to meet these requirements.

This report covers the following:

1. Appraisal of existing facilities and systems.
2. Existing and future requirements.

3. Identification of new sources of supply for development.
4. Establishment of priorities.
5. Proposals for a program of immediate improvements.
6. A long-term development program.
7. Cost estimates.

It is designed to serve two purposes. First, it sets out a comprehensive program of construction scheduled for parallel implementation of improvement works and the development of new sources, as a means of providing the population with an adequate supply of wholesome water for all purposes other than irrigation. Secondly, it provides the required support to an application for a bank loan for part-financing of one or a set of projects contained in the program of construction deemed necessary to improve the situation.

Previous Reports

Numerous reports, old and new, directly and indirectly related to the development of the country's water resources have been obtained and perused. In general, the data collected dealt with such subjects as the geology of specific geographical areas throughout the country, rainfall, land use, population, and other related subjects.

Useful background information was provided in the "Outline Report on Water Supply in Trinidad and Tobago - 1964" prepared by Ian G. de Verteuil, who at the time was Chief Technical Officer (Water) in the Ministry of Public Utilities, and who in 1965 became Superintendent Engineer (Water) in the newly established Water and Sewerage Authority. This report projected the country's requirements to 1980, and identified areas for development to meet those requirements.

Additional useful information was provided in two reports prepared by Howard Humphreys & Sons, Consulting Engineers, of London, England. The two reports, "Notes on the Investigation into the Water Supply of Port of Spain, 1959-1960" and "Brief Notes on Impounding Potentialities in the Central Range of Trinidad", were published in 1962 and 1965, respectively.

By an agreement concluded between the Canadian Government and the Government of Trinidad and Tobago, M.M. Dillon Ltd., Consulting Engineers of London, Ontario, were engaged by the Canadian Government to conduct a water resources survey in Trinidad between 1966 and 1969. Dillon's third report, dated December 1968, presented geological data on the Sum Sum sand aquifers and updated the previous two reports, which covered stream-gauging, rainfall, and other aspects of the hydrological cycle. Their fourth report, dated August 1969, covered the northern gravel aquifers and updated previous reports.

CHAPTER 2

DESCRIPTION OF THE STUDY AREA

Geography

The area to which the study applies covers the islands of Trinidad and Tobago. The island of Trinidad lies approximately 8 miles off the northeastern corner of Venezuela on the South American continent. It is located about 10 degrees north of the equator between 61 and 62 degrees west longitude and is the southernmost island in the Caribbean Archipelago.

The sister island of Tobago lies northeast of Trinidad and is separated therefrom by a channel about 18 miles wide. It is situated about 11 degrees north of the equator at about 60 degrees west longitude.

Topography

Trinidad is approximately 65 miles long by 48 miles wide with an area of about 1,863 square miles (see Figure 1). The physical features include three mountain ranges: the Northern Range, which runs the full length of the northern coast; the Central Range, which runs diagonally across the island in a northeasterly direction from California, a little more than halfway down the west coast, to Caigual in the east; and, finally, the Southern Range, which follows the southern coast in a broken line. The area between the Northern and Central Ranges is flat and comprises about 400 square miles. In the rest of the island, that is, between the Central and the Southern Ranges, the

topography is broken and represents an irregular pattern of partly flat, partly rugged, and mildly undulating terrain.

Tobago is some 32 miles long by 11 miles wide with an area of about 116 square miles. The topography of Tobago is broken with a chain of peaks running along the center of the island. The highest point in the main ridge is about 1,880 feet above sea level (see Figure 2).

Climate

The climate of the two islands is tropical, with two clearly defined seasons — the dry season and the wet season. The dry season begins in January and ends between mid-May and June 1 with March usually the driest month. The wet season begins in May or June and runs into December with July and August usually the wettest months. A dry period of about three weeks' duration occurs in September-October. This season is known as the "petit careme."

Precipitation in Trinidad is greater in the eastern half of the island than in the western half with the greatest intensity occurring in the eastern end of the Northern Range and the northeast end of the Central Range. In Tobago, precipitation is greatest in the higher elevations and near the center of the island.

On both islands, mean temperatures range between a mean low of 71.4 deg F

and a mean high of 87.5 deg F. March and September are the hottest months of the year. During these months peak temperatures of 93 deg F are often experienced.

Relative humidity ranges between 87 percent at 8:00 a.m. and 65 percent at 2:00 p.m.

Annual mean wind speed is approximately 6 miles per hour. Highest velocities up to about 10 miles per hour occur during the months of March to May, inclusive, and the wind direction shifts from southeasterly in April-May to northeasterly in November-December.

Land Use

Indications are that population densities will increase most significantly in the presently developed areas. Any dispersion will be the result of expansion of agricultural and industrial activity, and the location of housing estates.

Insofar as agriculture is concerned, activities under the Crown Lands Program are at present confined to the completion of developments at Waller Field and Carlsen Field while future plans will include large acreages distributed throughout Trinidad and Tobago.

In industry, as in agriculture, Government's efforts are being directed to the consolidation of existing estates throughout the country. The same approach is being taken by private developers who have established large industrial estates in north and south Trinidad.

In the field of housing development, Government is spending large sums of money on the construction of low-cost housing throughout Trinidad and Tobago. Private developers are also active in the development of sites for housing for the higher income brackets.

The provision of tourist facilities presents a slightly different picture in that they are planned for the coastline away from the centers of population. The development of hotels, marinas and bathing beaches brings into focus such places as Maracas Bay, Tyrico Bay, Blanchisseuse, Toco, Chaguaramas, Carenage, Scotland Bay, Manzanilla, and Mayaro in Trinidad, and the southwestern corner of Tobago.

The Economy

Up to the beginning of the twentieth century, the economy of Trinidad and Tobago was essentially an agricultural economy in which the production of cane sugar played the dominant role with the cultivation of cocoa, coconuts, and coffee playing lesser parts. However, with the discovery of oil early in the twentieth century and the stupendous growth in the drilling and refining operations that followed, the economy was quickly transformed into an oil economy with the production of cane sugar occupying second place in spite of a considerable increase in output during the same period.

Government derives 30 percent of its recurrent revenues from the oil industry. Petroleum products constitute 83 percent of the country's gross exports and 26 percent of the Gross Domestic Product.

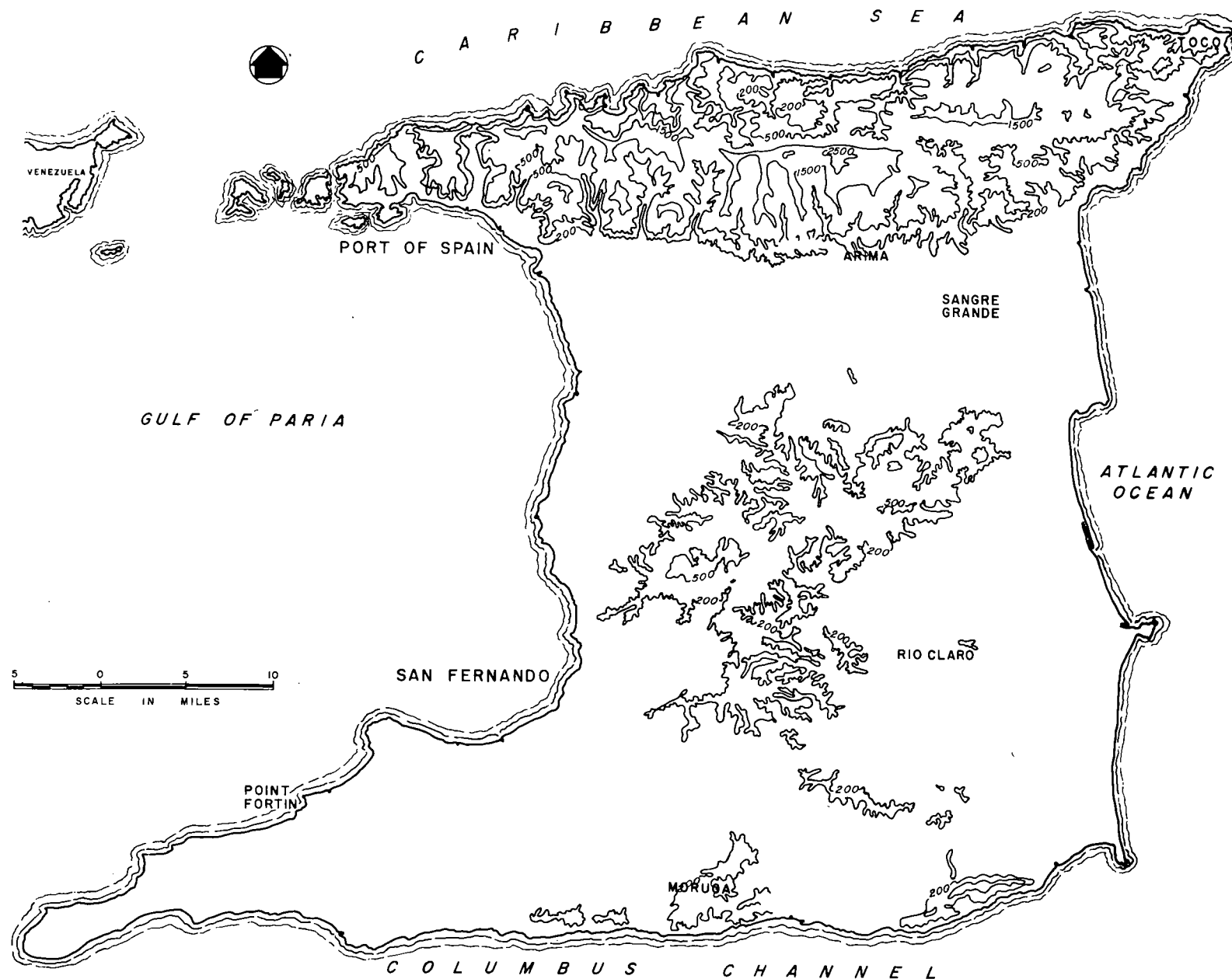


FIG. 1 RELIEF MAP OF TRINIDAD

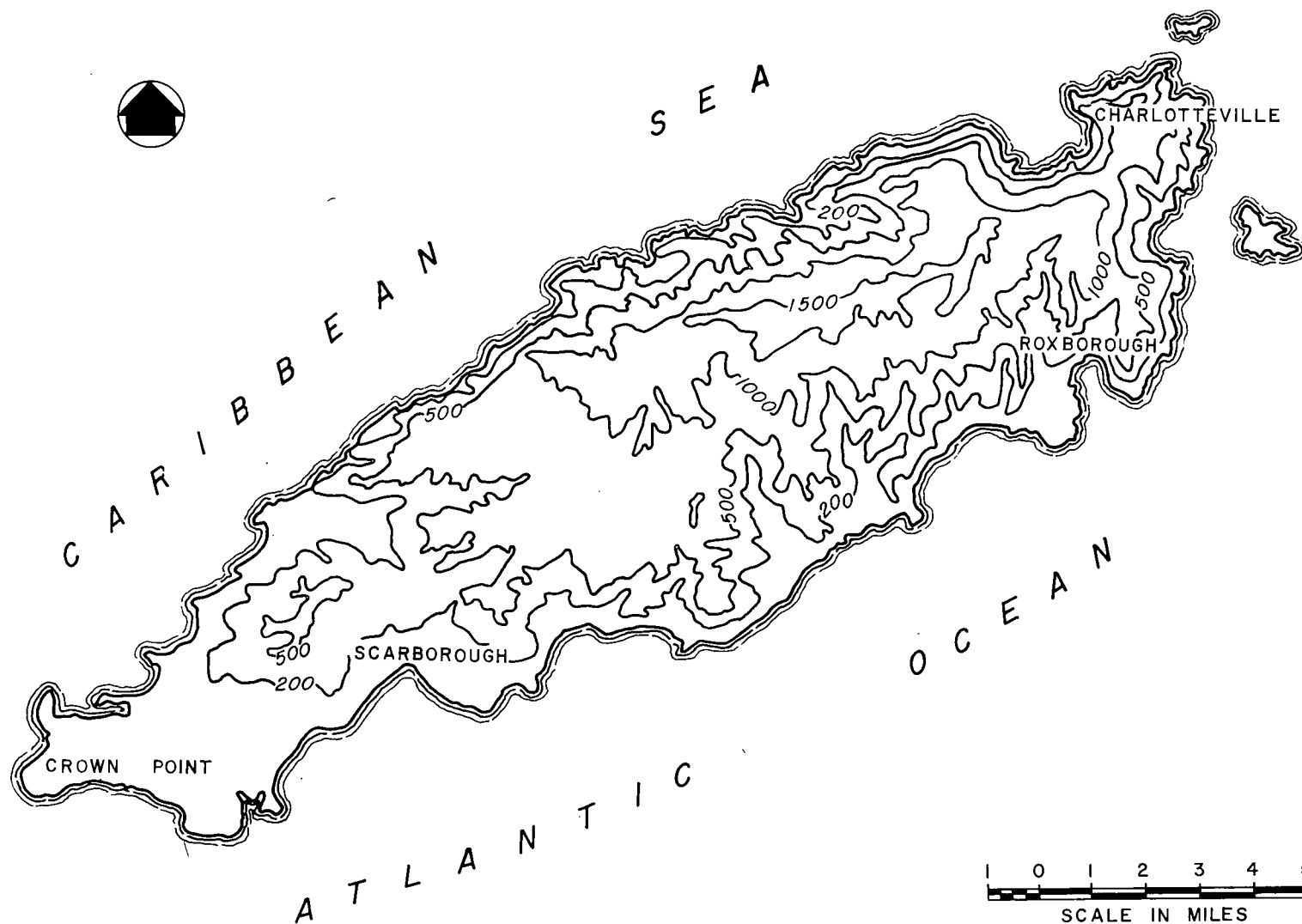


FIG. 2 RELIEF MAP OF TOBAGO

In the early sixties, however, a decline in the daily production of crude oil started and there was fear or suspicion of a significant depletion of reserves. There followed a reduction in drilling and refining activity and a consequent retrenchment in employment in the industry.

Economic Diversification. Fortunately, this turn of events did not immediately affect the industry's contribution to economic development, but it served to expedite implementation of Government's long-considered plans for economic diversification.

The main aim of the policy of diversification was to reduce the degree of dependence upon the oil industry by intensive development of the other sectors of the economy while still encouraging continued development of the oil industry as evidenced in the intensification of offshore drilling. Accordingly, in the Second and Third Five-Year Plans, 1963-1968 and 1969-1973, respectively, substantial sums were allocated for the development of agriculture, industry, and tourism, mainly. The new strategy of economic development, as outlined in the Third Plan, included:

1. Greater exploitation of the mineral and agricultural resources of the country.
2. Increased manufacturing output.
3. Expansion of service industries, with particular reference to tourism.

The Place of Water in the Economy. Development of the necessary climate for industrial expansion was an important objective of both the Second and the Third Five-Year Plans. Accordingly, large provisions were made for the construction of highways, the expansion of electricity generating capacity, and the expansion and modernization of telephone and telecommunication facilities.

Comparably large provisions were included for increasing the production of water primarily to meet increasing domestic requirements, but it was recognized that the provision of an adequate supply of water for all purposes was necessary for stimulating economic development.

CHAPTER 3

EXISTING SYSTEMS

General

A clear understanding of the existing systems is essential for an appreciation of the nature of the problems involved and the reasons for the solutions proposed. This chapter presents a description of the existing facilities as well as those under construction.

Water Service Areas

For purposes of describing the existing water system, projecting future demands, and recommending improvements, Trinidad and Tobago have been subdivided into the water service areas and subareas shown on Figure 3. The boundaries of the subareas were so selected that subareas could be grouped in combinations to coincide with either WASA's administrative districts and areas or the 15 water service areas established by Mr. Ian de Verteuil in his reports of 1964 and 1968. Therefore, data for one or more subareas can be combined to describe those areas also.

In establishing the boundaries for the subareas, the following guidelines were used:

1. Topography.
2. Number of interconnections to adjoining areas.
3. Proposed future improvements.

4. Boundaries of existing administrative areas.

If desired, each subarea may be operated as a separate distribution system; and, with the installation of a few meters, records of area consumption could be maintained. The boundaries of the regional or main water service areas were selected on the basis of the availability of historical water use data. It is not intended that the limits of these areas should represent possible boundaries for operational areas.

Sources of Supply

Total production capacity at the beginning of 1970 was 60 mgd. Approximately 22 mgd came from surface water sources, and the remainder from groundwater sources. The earliest public water supplies in Trinidad and Tobago came exclusively from surface water sources. The use of groundwater was initiated shortly after World War II as a result of successful development of groundwater aquifers by the U.S. forces then based in Trinidad.

Surface Water Sources. Large-scale development of surface water has been limited to three rivers in Trinidad and Tobago. These are the Quare River in the Northern Range and the Navet River in the Central Range in Trinidad, and the Hillsborough River in Tobago. The largest

river systems in the country still remain undeveloped, except for limited withdrawals for irrigation, industrial use, and gravel-washing.

The Quare River is a tributary of the North Oropouche River, which drains to the east. Hollis Dam on the upper reaches of the Quare in the Northern Range forms an impoundment with a catchment area of 6.6 square miles, and provides a dependable yield of 7 mgd. The Quare River is also used as a source of supply downstream of the dam at a point where the flow is approximately 1.5 mgd.

The Navet River has been developed in its upper reaches by an earth-fill dam and reservoir with a catchment area of 7.2 square miles. It was chosen for development on the basis of its location in relation to the demand in south Trinidad and suitability of the dam site.

Only a very small portion of the Hillsborough catchment area in Tobago has been developed. Here, where the demand was small, emphasis was placed on developing a supply at a high enough level to serve most of the distribution system by gravity.

Intakes have been constructed on many other small rivers and streams. Most of these intakes are located in catchment areas in the Northern Range of Trinidad where seepage from groundwater aquifers maintains substantial dry-season base flows. The principal rivers serving as sources for direct intakes, as well as those with impoundments, are listed in Table 1.

Table 1. Rivers Serving as Sources of Water Supply in Trinidad and Tobago

<i>River</i>	<i>Catchment area, sq mi</i>	<i>Dependable yield, mgd</i>	<i>Storage, mil gal</i>
Trinidad			
Quare at Hollis Dam	6.6	7.0	1,050
Quare at Intake	8.9	1.5	None
Navet at Dam	7.2	7.0	4,200
Maraval at Intake	3.2	0.6	None
St. Ann's at Intake	0.7	0.2	None
Cascade at Intake	0.4	0.1	None
Tompson at Intake	11.3	1.5	None
Tyrico at Intake	0.6	0.2	None
Tobago			
Hillsborough at Dam	0.8	1.5	200
Courland at Intake	10.7	0.8	None

Except following heavy rains, water from practically all the Northern Range sources is low in turbidity. It tends to be higher in dissolved solids than other Trinidad waters and is moderately hard. For example, water from the Quare River has an average hardness of 130 mg/L (milligrams per liter) and total dissolved solids average 150 mg/L. Navet and Hillsborough waters tend to be high in turbidity and color all year round.

Groundwater Sources. The total groundwater potential of Trinidad is estimated at 72 mgd. The Authority is presently pumping 39 mgd from existing boreholes. Private groundwater supplies account for another 5 mgd. The Authority's groundwater supply has been developed from the seven aquifers listed in Table 2. The most extensive development has taken place in the Northern Valley and Alluvial Fan Aquifers in the north, and the Sum Sum and Durham Aquifers in central Trinidad. A more complete description of these aquifers is given in Chapter 7.

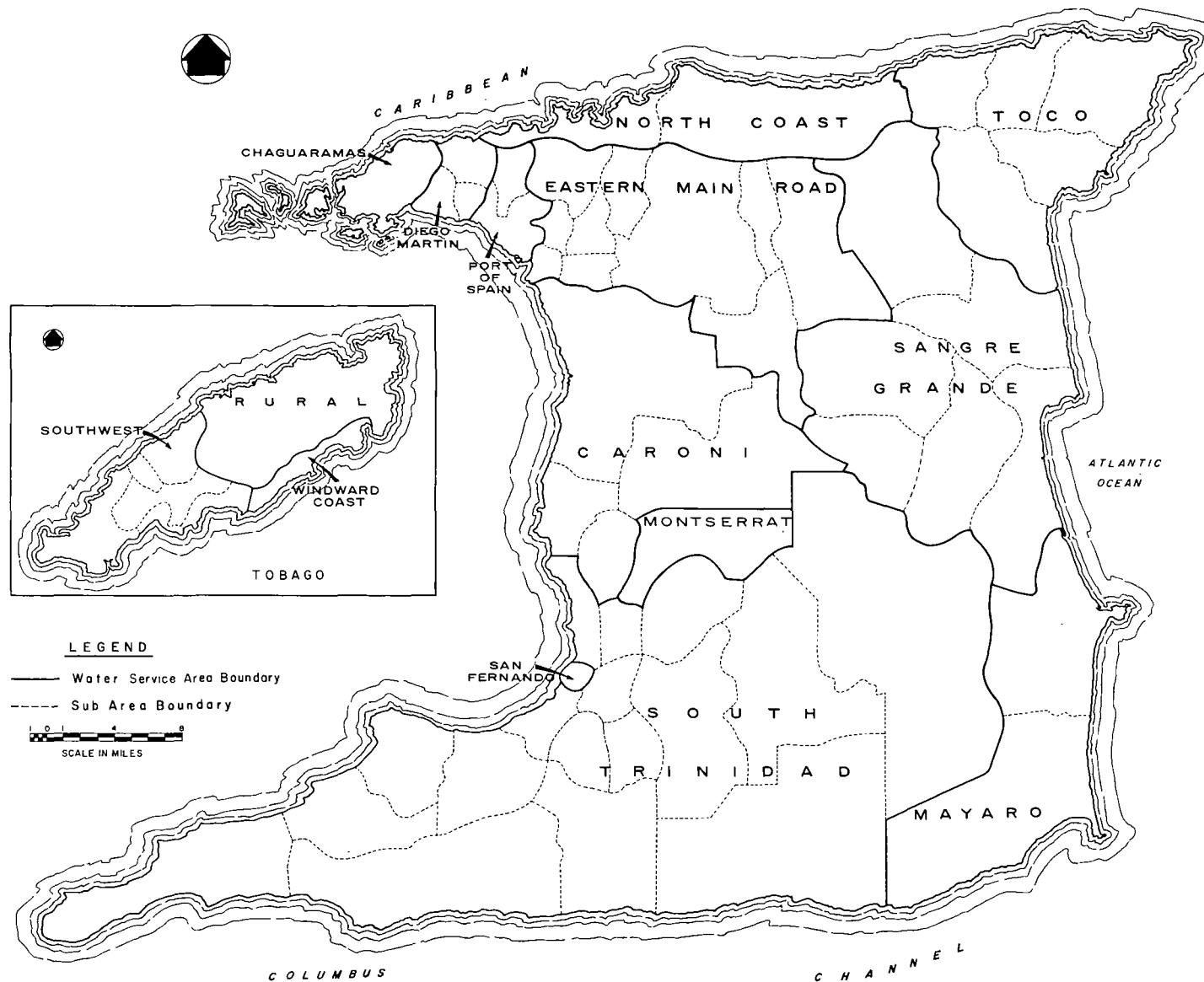


FIG. 3 WATER SERVICE AREAS

Table 2. Groundwater Aquifers in Trinidad

<i>Aquifer</i>	<i>Estimated potential yield, mgd</i>	<i>Existing borehole pumping rate, mgd</i>
Northern Valleys	16	13.3
Alluvial Fan	17	17.1
Sum Sum	11	3.5
Durham	4	0.6
Limestone	2	0.3
Erin-Morne L'Enfer	18	3.7
Mayaro Sandstone	<u>4</u>	<u>0.2</u>
Total	72	38.7

Water from the northern gravels is free of iron but high in carbon dioxide. In some areas it is used without treatment other than disinfection. Iron in excessive quantities is found in water from all the other groundwater aquifers.

Supply, Treatment, and Transmission Facilities

There are 66 separate water supply systems in Trinidad and Tobago. These systems range from the isolated rural intakes supplying less than 100,000 gpd (gallons per day) to the Navet waterworks and transmission system, which can produce and deliver up to 11 mgd at maximum output. Tables 3 and 4 list the supply systems. Data for the rural intakes are summarized in Table 3 as a single item and listed for the individual intakes in Table 5. The major supply and transmission systems are shown on Figure 4 (at the back of the report).

Major Surface Water Facilities. There are three surface supply systems which are considered as major systems. They are the Navet and the Hollis systems in Trinidad, and the Hillsborough system in Tobago. Each of these systems consists of a dam and impounding reservoir, treatment facilities, and an extensive transmission system.

The Navet system is the principal source of supply for San Fernando and south Trinidad. The impoundment is created by a 100-foot high earth-fill dam. A raw-water pumping station delivers water from an intake tower to a conventional water treatment plant rated at 12.0 mgd. Upflow clarifiers provide flocculation and sedimentation. Activated carbon is used for taste and odor control. Treated water flows by gravity from the treatment plant clearwell through a 20-mile trunk main to San Fernando. Production in 1969 was 3 mgd greater than the estimated dependable yield of 7 mgd.

The Hollis supply stream is the second largest in Trinidad. This system was completed and brought into service in 1936. It consists of the Hollis Dam and Reservoir in the Quare River, a pressure-filter plant, and a transmission network which originally carried water by gravity as far south as Penal. At present the Hollis system serves Port of Spain, the Eastern Main Road communities, Caroni and, on occasions, Sangre Grande. A booster pumping station has been added at Tunapuna to permit full use of supply capacity. The station is used exclusively to pump to Port of Spain. What remains of the original transmission system

Table 3. Existing Surface Water Supply Systems

System	Source	Treatment(1)	Capacity, mgd		Installed production
			Potential	Dependable yield Developed	
Trinidad					
Navet Reservoir	Navet River	Sed, Fil, Car, Chl	7.0	7.0	11.0
Hollis Reservoir	Quare River	Fil, Chl	7.0	6.5	6.5
Maraval Intake	Maraval River	Chl	0.6	0.6	2.5
St. Ann's Intake	St. Ann's River	Fil, Chl	0.2	0.2	1.0
Cascade Intake	Cascade River	Fil, Chl	0.1	0.1	0.3
Valencia Intake	Quare River	RFil, Chl	1.5	1.5	1.5
Tompson Water Works	Tompson River	RFil, Chl	1.5	0.2	0.2
Biche Water Works	Local catchment	Sed, Fil, Chl	0.1	0.1	0.1
Dibe Intake	Dibe River	Chl	0.1	0.1	0.1
Tyrico Bay Intake	Tyrico River	Chl	0.2	0.2	0.2
Rural Intakes	Local catchment	—	0.2	0.2	0.3
Trinidad Total			18.5	16.7	23.7
Tobago					
Hillsborough Reservoir	Hillsborough River	Sed, Fil, Chl	1.5	1.5	1.5
Courland Intake	Courland River	RFil, Chl	0.8	0.5	0.5
Charlotteville Intake	Local catchment	RFil, Chl	0.1	0.1	0.1
Tobago Total			2.4	2.1	2.1
Total			20.9	18.8	25.8

1. Fil = Filtration; Chl = Chlorination; RFil = Filtration by roughing filter; Car = Carbon addition.

south of Caroni has been incorporated into other supply systems.

The third major surface supply is the Hillsborough system in Tobago. This system is the principal source of supply for Scarborough and southwest Tobago. It consists of the Hillsborough impounding reservoir, a conventional water treatment plant, and a high-lift pumping station which pumps to a 16- and 12-inch transmission

main. The existing facilities are designed for an output of 1.5 mgd.

Major Groundwater Facilities. As of January 1, 1970, there were 113 producing boreholes in Trinidad. Fifty of these operate as independent sources of supply, water being pumped directly to distribution. The remainder operate as sources for larger supply systems. A typical groundwater supply system consists of two or more wells

Table 4. Existing Groundwater Supply Systems

System	Aquifer	Treatment(1)	Capacity, mgd		Installed production
			Dependable yield		
			Potential	Developed	
Trinidad					
Morichal Spring	Limestone	Chl	0.2	0.2	0.2
Guaracara Spring	Limestone	Chl	0.1	0.1	0.3
Chaguaramas	Northern Valley	Chl, Cal	1.8	0.5	0.5
Tucker Valley	Northern Valley	Aer, Chl	6.0	1.5	1.5
Carenage	Northern Valley	—	0.1	0.1	0.1
River Estate	Northern Valley	Chl			2.0
Four Roads	Northern Valley	Chl	4.5	4.5(2)(3)	2.9
Cocorite	Northern Valley	Chl			2.2
Brieves Road	Northern Valley	Chl			0.1
Wharf	Northern Valley	Chl			1.6
Dockside	Northern Valley	Chl			1.0
St. Clair	Northern Valley	Chl	4.0	4.0(2)(3)	0.3
Savannah	Northern Valley	Chl			0.8
George V Park	Northern Valley	Chl			1.5
Haleland Park	Northern Valley	—			0.5
El Socorro	Alluvial Fan	Aer, Chl			9.0
Santa Cruz	Northern Valley	Chl	4.5	4.5(2)	0.1
Valsayn	Alluvial Fan	Aer, Chl	5.0	5.0(2)	5.6
Tacarigua	Alluvial Fan	—	5.0	2.6(2)	3.2
Arouca	Alluvial Fan	—			0.3
Arima	Alluvial Fan	Chl	2.0	0.8	0.5
Waller Field	Sum Sum	Cal, Chl	3.0	1.0	1.0
Maracas Bay	Alluvial Fan	Chl	0.1	0.1	0.1
Carlsen Field	Sum Sum	Aer, Sed, Fil, Chl	2.0	1.0	1.2
Freeport	Sum Sum/Durham	Aer, Sed, Fil, Chl	2.5	1.6	2.0
Penal	Erin-Morne L'Enfer	Aer, Sed, Fil, Chl	2.0	0.8	0.8
Point Fortin	Erin-Morne L'Enfer	Aer, Sed, Fil, Chl, Car	1.0	0.3	0.3
Cap-de-Ville	Erin-Morne L'Enfer	Aer, Chl	1.0	0.2	0.2

Table 4 (Continued). Existing Groundwater Supply Systems

System	Aquifer	Treatment(1)	Capacity, mgd		Installed production
			Potential	Dependable yield Developed	
Granville	Erin-Morne L'Enfer	Aer, Sed, Fil, Chl	0.5	0.5	0.5
Clarke Road	Erin-Morne L'Enfer	—	1.0	0.3	0.3
Mayaro	Mayaro Sandstone	Aer, Chl	<u>1.5</u>	<u>0.2</u>	<u>0.2</u>
Trinidad Total			47.8	29.8	40.8
Tobago					
Richmond Water Works	Valley	Aer, Fil, Chl	<u>0.6(4)</u>	<u>0.2</u>	<u>0.2</u>
Total			48.4	30.0	41.0

1. Aer = Aeration; Sed = Sedimentation; Fil = Filtration; Chl = Chlorination; Car = Carbon addition; Cal = Calgon addition.

2. Does not include private capacity.

3. Draft may be greater than dependable yield due to recirculated water.

4. Flow of stream.

from which water is pumped to a central treatment plant, a clearwell, and a high-lift pumping station which takes suction from the clearwell and pumps through a transmission system to distribution. Minimum treatment provided is chlorination, although at some independent boreholes there are no treatment facilities. The Valsayn and El Socorro treatment facilities include forced-draft aeration to reduce carbon dioxide. Where iron is present in excessive quantities, treatment facilities consist of aeration and sedimentation followed by rapid sand filtration. Four groundwater systems are considered major because of their capacities and the extent of their transmission systems. These are the Valsayn, El Socorro, Freeport, and Cocorite groundwater systems.

The Valsayn system consists of eight boreholes in the northern gravels. Water

from the boreholes is aerated by forced-draft aerators for carbon dioxide removal and stored in a 0.5-million gallon clearwell. High-lift pumps deliver treated water from the clearwell to the Eastern Main Road communities as far as Success Village to the west and Tunapuna to the east. The transmission system consists of a 30-, 24-, and 18-inch main to the west from the high-lift pumping station and a 30-inch connection to the 3.7-million gallon St. Augustine Reservoir. A 15-inch main from the 30-inch St. Augustine Reservoir connecting main supplies water to Tunapuna. The existing system was brought into full service in 1955. The high-lift pumping station has an existing installed capacity of 7.5 mgd and provision for increasing the future capacity to 9.0 mgd.

The El Socorro waterworks comprises seven boreholes in the northern gravels at

**Table 5. Existing Rural Water Intakes
in Trinidad**

<i>Name</i>	<i>Service area</i>	<i>Capacity, gpd</i>
Tamana	Sangre Grande	10,000
La Pastora No. 1	Eastern Main Road	50,000
La Pastora No. 2	Eastern Main Road	40,000
Los Armadillos	Sangre Grande	8,000
Matelot	Toco	8,000
Sans Souci	Toco	8,000
Grande Riviere	Toco	10,000
Montevideo	Toco	10,000
Salybia	Toco	10,000
Matura	Toco	10,000
Cumana	Sangre Grande	12,000
Lopinot Spring	Eastern Main Road	3,000
Surrey Village	Eastern Main Road	10,000
La Canoa	Eastern Main Road	6,000
St. John's Road	Eastern Main Road	10,000
Blanchisseuse	North Coast	10,000
Lloango	Eastern Main Road	15,000
Maracas Valley	Eastern Main Road	10,000
Brasso Seco	Eastern Main Road	5,000
Aripo Spring	Eastern Main Road	12,000
La Cuevas	North Coast	5,000

the mouth of the Santa Cruz Valley. Water is pumped from the boreholes to the El Socorro Water Treatment Plant, where it is aerated and chlorinated. A high-lift pumping station delivers the treated water from a 0.5-million gallon clearwell reservoir to two 2.5-million gallon reservoirs on Picton Hill in Port of Spain via a 30-inch steel transmission main. The estimated dependable yield of the El Socorro borehole field is 4.5 mgd. The high-lift pumping station and 30-inch

transmission main, however, have a capacity of 12 mgd.

The Freeport system consists of seven boreholes, an extensive raw-water transmission system, an iron-removal plant, a 0.5-million gallon clearwell, and a high-lift pumping station. Treated water is pumped through a 16-, 21-, and 20-inch transmission main to San Fernando. A separate pumping system delivers water to the Montserrat service area through a 10-inch main. A separate small pumping station next to the high-lift pumping station delivers untreated water to the Trinidad Cement Company at Claxton Bay. This system is owned and operated by the Company. The present pumpage from the boreholes is 1.8 mgd. The treatment plant is being expanded to a capacity of 3.0 mgd by the addition of another sedimentation basin.

The Cocorite system obtains water from shallow wells and two boreholes at the southern end of the Diego Martin Valley. Water from the wells and boreholes is collected in two separate pumping sumps at the Farrell Pumping Station. Water from one sump is pumped to the Knaggs Hill Reservoir through a 21-inch transmission main laid in 1903 as part of an original supply system from the River Estate wells at the north end of the valley. A 16-inch cast-iron main laid in 1922 takes water pumped from the other sump directly to distribution in Port of Spain. Two boreholes at King George V Park, drilled in 1957, are considered part of the Cocorite system because water from them is pumped to Knaggs Hill through the same 21-inch main which conveys the supply from the Farrell Pumping Station. The combined output

from both sources is 4.0 mgd. The supply from the Cocorite boreholes is supplemented by approximately 0.5 mgd from two boreholes at Four Roads. The supply from these two boreholes is delivered through a 6-inch main to one of the sumps at the Farrell Pumping Station.

Minor Groundwater Facilities.

Individual boreholes from which water is pumped directly to distribution with little or no transmission have been classified as minor groundwater supplies. These facilities are best described by the areas they serve. Areas with minor groundwater supplies are: Chaguaramas, Diego Martin, Port of Spain, Eastern Main Road, Caroni, Mayaro, and south Trinidad.

The Chaguaramas area is served by a water system constructed by the U. S. forces during World War II. This system is supplied entirely by groundwater from over 43 boreholes, only 11 of which are now in production. Two of the producing boreholes located in the Chaguaramas area are used exclusively to serve the Diego Martin area. Water from the boreholes in the Tucker Valley Aquifer is pumped to a service reservoir from which it flows through a 10-inch main by gravity to a booster station at Carenage, where it is pumped to the Point Cumana Reservoir through another 10-inch main.

Two borehole fields serve the Diego Martin area. One is located at River Estate at the north end of the valley and the other at Four Roads at the southern end of the valley. At River Estate there are four boreholes and two dug wells, the borehole pumps discharging directly through a 21-inch

main to reservoirs at Covigne. A high-lift pumping station rated at 2.5 mgd is now under construction at River Estate. At Four Roads water is pumped from five boreholes to a small contact tank from which a high-lift pumping station with a rated capacity of 4.0 mgd pumps water to the system. The pumping head at Four Roads is controlled by the level in the Covigne Reservoir.

There are 14 boreholes within the Port of Spain area which together produce over 4.2 mgd. These boreholes were constructed between 1942 and 1969. The King George V Park boreholes have already been mentioned as part of the Cocorite supply system. There are five boreholes in the port area. From two of these boreholes, called the Docksite boreholes, water is pumped directly to supply in the wharf area. The remaining three, called the Wharf boreholes, deliver water to a central booster station where it is pumped to a reservoir on Laventille Hill. Three boreholes in the Queen's Park Savannah, together with a borehole at St. Clair, supply water to the Knaggs Hill Reservoir. The least productive of the boreholes is located at Brieves Road and supplements the supply to the Dibe area northwest of Port of Spain. Two wells were recently drilled at Haleland Park in the Maraval Valley to supply local demands.

There are three areas of borehole development along the Eastern Main Road. The largest is at Tacarigua where the pumps at nine boreholes, each operating independently, pump water into the system. Average production at Tacarigua is 2.6 mgd. Approximately 1.2 mgd is used to supply the industrial area along the

Churchill-Roosevelt Highway, the University of the West Indies, and domestic demands in Curepe; the remainder is used locally. Three boreholes at Arouca are connected to the same system. The remaining groundwater development in the Eastern Main Road area consists of three boreholes at Arima from which water is pumped to a small sump. It is then repumped through a 12-inch main to the new Arima Reservoir, from which it flows by gravity to the Arima distribution system.

Two boreholes at Waller Field supply water directly to a reservoir at Malabar through a 15-inch main. These boreholes are the principal source of supply to the Piarco service area.

In Caroni three boreholes at Carlsen Field produce about 1.0 mgd which is treated at an iron-removal plant and repumped by a high-lift pumping station direct to distribution and to the Freeport Reservoir, which was originally part of the Hollis system. Treatment consists of aeration, settling, and rapid sand filtration. Lime is used for coagulation and pH control.

Four minor supplies in south Trinidad are located at Penal, Point Fortin, Cap-de-Ville, and Granville. These four supplies are similar treatment facilities for iron removal. The treatment facilities at Point Fortin and Granville are permanent installations. The treatment works at Penal is a temporary plant; however, it is well maintained and has many years of useful service left. The boreholes at Cap-de-Ville are a relatively new source. The temporary treatment plant here is soon to be replaced by a permanent treatment plant with

pressure filters. Each system has a high-lift pumping station and some form of transmission. Water from the Point Fortin source is pumped through a 7-inch main to a reservoir at Guapo and then distributed to La Brea. Water from the Cap-de-Ville boreholes is pumped to the Cap-de-Ville Reservoir from which it flows by gravity through a 10-inch main to Point Fortin. A small booster pumping station at the reservoir pumps a limited amount of water south to Buenos Aires through a 4-inch main. Water from the Granville plant is pumped to a reservoir at Granville for supply to Cedros and Icacos. A limited supply is pumped through a reservoir at Cap-de-Ville for use in Point Fortin. The Penal waterworks is the principal source of supply for Siparia and Palo Seco. A small supply is also pumped to Penal via a separate high-lift pumping station and transmission main. Water for Siparia and Palo Seco is first pumped to a reservoir in Siparia from which it is distributed by gravity to the areas of demand.

The Mayaro borehole supply consists of five boreholes connected directly to storage in Mayaro through a single transmission main. Water for Guayaguayare is pumped by a small booster station to a tank at Maloney Road. Treatment consists of chlorination.

Surface Water Intakes. There are over 12 river and stream intakes supplying the systems. Most of these serve small rural systems which supply untreated water through 2-, 3-, and 4-inch pipes. Six of these intakes, listed in Table 3, produce substantial quantities of water and are worthy of note. These are: the Maraval, St. Ann's, and Cascade intakes in Port of Spain,

the Tompire River intake serving the Toco area, the Valencia intake serving Sangre Grande, and the Courland River intake which serves the southwest part of Tobago.

The most productive intake is located on the Maraval River. This intake has been supplying Port of Spain off and on since 1853. Water is taken directly from the river into an open storage tank, chlorinated, then supplied to Port of Spain by gravity through a 27-inch main constructed in 1853 as part of the original supply. Water used to supply the upper Maraval Valley is first pumped to a tank on a hill above the intake.

The Cascade and St. Ann's intakes were also part of the original supply system for Port of Spain. Water from each source is chlorinated and stored in a reservoir before being released to the distribution system.

The Valencia intake on the Quare River was first constructed in 1922, to serve Sangre Grande. It was taken out of service in 1936 with the completion of the Hollis supply system, but reactivated in 1968 to conserve Hollis water for other areas. Supply is obtained from the intake through a roughing filter and then pumped to a tank from which it is distributed by gravity to Sangre Grande. Water can also be drawn from the Hollis system either to supplement the supply from the intake or to replace it when the intake is out of service.

The Tompire River intake is the principal source of supply for Toco. Supply from the intake is supplemented by water from three shallow wells which draw water directly from the river through a natural gravel formation. Water from both the wells

and the intake flows by gravity to a sump from which it is pumped through an 8-inch main to storage in Toco. Chlorination is the only form of treatment.

In Tobago a major intake supply has recently been constructed on the Courland River. Water is withdrawn through a roughing filter consisting of cylindrical pipe screens, buried in the stream bed, which are connected to a concrete sump. Water is pumped from the sump directly to a distribution system through a new 15-inch asbestos-cement main. The existing intake and roughing filter is a temporary arrangement. Plans and specifications have already been prepared for the construction of distribution storage near the intake. Long-term plans call for the construction of a conventional water treatment plant. When completed this system will have a capacity of 0.8 mgd.

Rural Intakes. Scattered throughout the Northern Range and central Trinidad are 21 rural intakes operated by the Authority. These are untreated gravity supplies with limited distribution. None of these supplies produces more than 50,000 gpd and the majority are rated at 10,000 gpd or less (see Table 5). In addition, there are a few smaller intakes that were constructed and are operated by the County Councils.

Distribution

The distribution system is comprised of those mains which deliver water from the principal transmission mains or distribution storage reservoirs to the customers' service connections. In general, these mains are

smaller than 12 inches except in the rural areas where transmission and distribution mains are one and the same. The total length of mains smaller than 12 inches in Trinidad and Tobago is 1,375 miles. These mains account for 87 percent of the length of mains of all sizes. It is only in the well-developed urban areas that a true distinction can be made between transmission and distribution. These areas are: Port of Spain, Diego Martin, San Fernando, Arima and the Eastern Main Road communities. Since most of the recommended improvements deal primarily with supply and transmission, a detailed knowledge of the individual distribution systems is not necessary for an understanding of the recommended improvements.

Distribution Storage

There are over 106 distribution storage facilities throughout the system. These range in size from the 5,000-gallon, horizontal, cylindrical, steel tanks serving small high-service areas to the 3.09-million gallon reinforced-concrete storage reservoir at Knaggs Hill in Port of Spain. Most of the distribution storage is located in areas with well-developed distribution systems. There are 11 storage reservoirs of reinforced-concrete or prestressed-concrete construction with a capacity exceeding 1.0 million gallons. Reinforced concrete is also used in the construction of many of the smaller reservoirs including those serving as clearwell storage at the various treatment plants. Many of the older reservoirs, 1.0 million gallons and smaller, are of prefabricated bolted steel construction. The last reservoir of this type was constructed in

1958; since then the Authority has been using cylindrical welded-steel reservoirs similar to those used in the oil industry. At one time, there were two elevated storage tanks in service in Trinidad and Tobago. At present only one, with a capacity of 20,000 gallons, is in use. The use of elevated storage tanks has proved unnecessary in Trinidad because of the many hills near the areas of major demand. Table 6 lists the total distribution storage reservoirs by area and individual reservoirs of 1.0-million gallon capacity and larger.

Service Connections and Standpipes

Approximately 48 percent of the population is served by direct connections on the premises. The remainder gets its supply from standpipes, from private sources, or by truck. Table 7 lists the estimated number of direct connections and standpipes as supplied by the Authority, and the number of persons served in each category. For most direct connections, the charge is a flat fee based on the Annual Rateable Value of the property; however, some domestic connections in Port of Spain are metered. Outside of Port of Spain only large industrial users are metered. The total number of meters in service is about 8,900.

Table 7. Type and Number of Water Services

Type	Services	Population served
Direct connections	115,000	500,000
Standpipes	5,200	470,000
Truck (County Council)		30,000
Total	120,200	1,000,000

Table 6. Existing Distribution Storage by Water Service Area

<i>Service area</i>	<i>Reservoir</i>	<i>Area capacity, mil gal</i>	<i>Unit capacity, mil gal</i>	<i>Elevation, ft(1)</i>
Trinidad				
Caguaramas	13 Reservoirs	3.14	—	—
Diego Martin		2.72	—	—
	Covigne Reservoir 3 Reservoirs		2.00 .72	315 —
Port of Spain		13.69	—	—
	Picton No. 1 Reservoir		3.00	355
	Picton No. 2 Reservoir		5.00	229
	Knaggs Hill Reservoir		3.09	229
	Laventille Reservoir		1.30	189
	9 Reservoirs		1.30	—
Eastern Main Road		10.96	—	—
	St. Augustine Reservoir		3.70	363
	St. Joseph Reservoir		3.00	258
	Fort Read Reservoir		1.70	333
	13 Reservoirs		2.56	—
Sangre Grande	6 Reservoirs	0.81	0.81	—
Toco	3 Reservoirs	0.22	0.22	—
North Coast	1 Reservoir	0.22	0.22	—
Caroni		2.42	—	—
	Freeport Reservoir		1.00	283
	5 Reservoirs		1.42	—
Montserrat	2 Reservoirs	0.45	0.45	—
San Fernando		6.55	—	—
	Marryat Street Reservoir		2.95	260
	Naparima Reservoir		2.00	243
	Chacon Street Reservoir		1.60	158
South Trinidad		7.09	—	—
	Navet WTP		3.00	485
	23 Reservoirs		4.09	—
Mayaro	4 Reservoirs	0.34	0.34	—
Tobago				
Southwest	9 Reservoirs	0.68	0.68	—
Windward Coast	2 Reservoirs	0.42	0.42	—

1. Above mean sea level.

Existing Plans for System Improvements

The basis for the Authority's present capital improvement program is a report prepared for the Authority at its request in 1968 by Mr. Ian de Verteuil. The purpose of the report was to outline the capital requirements of WASA for the Third Five-Year Plan 1969-1973. The report recommended improvements to alleviate the present shortage of supply and to maintain an adequate supply until 1973 or until the anticipated impact of the improvements recommended in this study could be realized. The report defined over 24 separate projects. Incorporating these proposals with its own, the Authority has scheduled a total of 74 projects, which include additional sources of supply and numerous extensions to the distribution system. Of these 74 projects, five had been completed by the end of December 1969, and another 19 were in progress.

The completed projects have increased production capacity by an estimated 3 mgd. Of the 50 projects that have not yet been started or completed, 40 have been incorporated, generally with modifications, in the recommended development program described in Chapter 11. These modifications have been made on the basis of additional data now available on groundwater and surface sources and long-term projections of water requirements. Of the remaining 10 projects, four are not recommended, two have been replaced by alternative projects, and four are maintenance items which have not been investigated.

Included in the above projects is the secondary distribution extension program, at

present proceeding at the rate of about 20 miles per year.

Sewerage System

The first underground sewerage system in Trinidad was constructed in Port of Spain in 1861. It was extended in 1902 and again in 1937. The largest single sewerage project was undertaken in 1962, when the Port of Spain system was improved and extended to areas outside the city, and new systems were constructed in San Fernando and Arima. In Port of Spain, an east-west trunk main collects sewage from as far as Diego Martin in the west and San Juan in the east, and conveys it to a pumping station on the eastern outskirts of Port of Spain. The raw sewage is pumped from this location to oxidation ponds located in the Caroni Swamp about three-quarters of a mile from the pumping station.

In San Fernando, a gravity system conveys sewage to a high-rate, trickling-filter type plant. The treated effluent is discharged to the Cipro River. A similar plant of this type is used to treat sewage collected by the sewer system in Arima. Effluent from the Arima plant flows into the Mausica River, which eventually reaches the Caroni.

The San Fernando sewage treatment plant currently serves as a source of industrial water supply for the Texaco Refinery at Pointe-a-Pierre. A pumping station, owned and operated by Texaco, pumps the treated effluent from the final settling tank through a reconditioned portion of the original Hollis trunk main to storage reservoirs at the Texaco Refinery. This water is used to supplement Texaco's

supply from the Guaracara River, which in recent years has been found to be

insufficient to meet Texaco's industrial requirements during the dry season.

CHAPTER 4

WATER REQUIREMENTS

General

Estimates of future water requirements are based on population projections, trends in past water use, and economic forecasts of industrial development. These estimates are made according to use classification. Based on availability of data, we have identified the following classifications of water use in Trinidad and Tobago:

Domestic
Industrial
Irrigation

These classifications are subdivided into WASA supplied water and water supplied by private or other government agencies. Requirements met outside the WASA system are considered because requirements supplied from private sources lower the demand upon WASA's system. Also, other interests are in most cases in competition with WASA for the same sources of supply.

Locations of future demands are as important as magnitude because a major portion of the cost of developing new supplies will be for transmission and distribution. For estimating area demands, the water areas identified in Chapter 3 have been used (see Figure 3).

Variations in demand are also important. Projections of future

requirements are based on annual average quantities. In practice, demand rates can vary to as much as three to four times the average. For purposes of design, these variations must be considered along with average requirements.

This chapter reviews past trends in water use, presents estimates of future population, projects future water requirements to be supplied by WASA, and defines criteria for estimating variations in demand.

Population

The population of Trinidad and Tobago has increased steadily since 1900 as indicated by the census figures listed in Table 8.

Table 8. Population of Trinidad and Tobago

<i>Year</i>	<i>Population</i>
1901	255,148
1911	333,552
1921	365,913
1931	412,783
1946	557,970
1950	646,000
1960	827,957
1965	974,000

Projection of future population growth is based on recent trends in the birth rate, death rate, and migration. Recently, the birth rate has dropped from a high of 39 per 1,000 in 1960 to 30 per 1,000 in 1968. Taken as the difference between births and deaths, the natural increase in population fell from 31 per 1,000 in 1960 to 23 per 1,000 in 1968. A Family Planning Program which was started in 1965 is expected to reduce the natural increase in the years ahead. For purposes of population projection, it is assumed that the natural rate of increase will remain at 23 persons per 1,000 until 1983, after which it is expected to fall even further to 20 persons per 1,000.

Migration can be closely related to employment opportunities. For the 10-year period ended in 1963, migration produced a net annual gain of about 2,000. Since 1964 the trend has reversed, and migration has resulted in a net loss of about 30,000 between 1964 and 1968. This shift can be attributed to high unemployment, which in 1968 was 14 percent. The Third Five-Year Plan, 1969-1973, estimates that full employment will be reached in 1983 and that during the Plan period 60,000 persons will have gone abroad permanently. For purposes of projection, this pattern of outward movement has been taken into consideration and a net migration of zero following 1983 has been assumed.

The population estimate for the year 2000 based on the above assumptions is 2.0 million.

Trinidad's existing population of about one million is concentrated in and around its two largest cities, Port of Spain and San Fernando. Around Port of Spain in County St. George the direction of growth has been both east and west of the city such that an urban strip exists between Chaguaramas to the west and Arima to the east. In the south, growth has been in a radial direction from San Fernando. Strip development has also occurred along the Gulf Coast extending northward from San Fernando to Chaguanas and southward to Point Fortin. The Gulf Coast development is not as dense as the strip development in County St. George and tends to cluster in towns and villages.

Except for a few urban areas, the largest of which are Sangre Grande, Toco, Princes Town, Rio Claro, and Siparia, the rest of Trinidad can be described as rural.

Future population growth is expected to occur in the established urban areas where employment opportunities, educational and other facilities are located.

In Tobago the population is located largely in scattered settlements in the southwestern half of the island. Scarborough has the only large concentration of population. In the future Scarborough and the coastal areas in the southwest and southeast windward coast are expected to experience the greatest growth due mainly to resort development.

Figure 5 shows projections of future population growth by counties and for

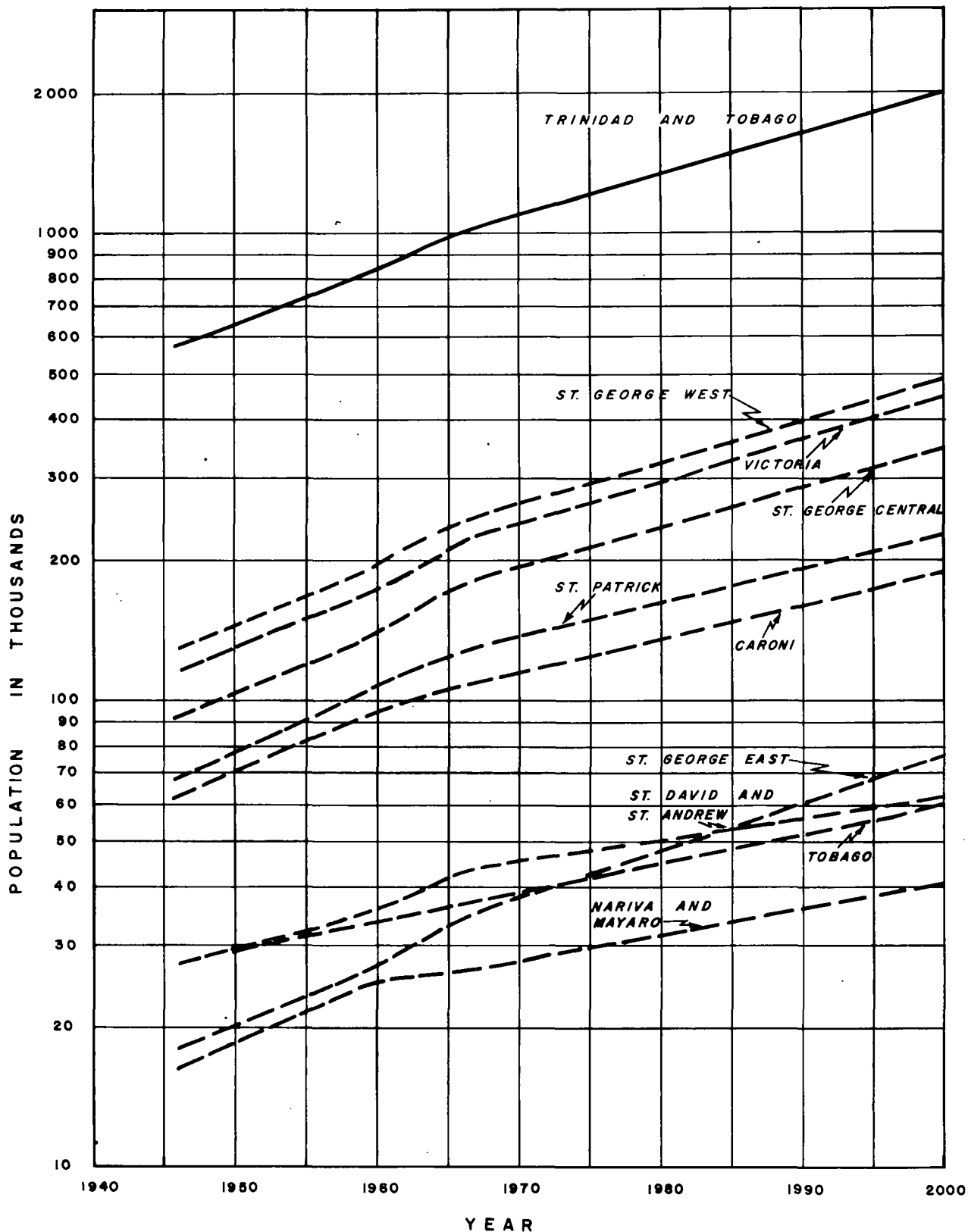


FIG. 5 POPULATION TRENDS AND PROJECTIONS 1940-2000

Trinidad and Tobago as a whole. Future population distribution by water service area is given in Table 9.

breakdown by percentage from this survey is as follows:

Population Served

A housing survey made in 1964 by the Central Statistical Office placed the number of persons served by piped water systems at 93 percent of the population. The

<u>Type of service</u>	<u>Percent</u>
Direct connections	48
Standpipes	45
Springs, streams, ponds, or truck	7
Total	100

Table 9. Future Population by Water Service Area

<u>Service area</u>	<u>1970</u>	<u>1975</u>	<u>1980</u>	<u>1985</u>	<u>2000</u>
Trinidad					
Chaguaramas	—	5,400	11,300	18,200	39,000
Port of Spain	179,000	198,000	215,000	232,000	280,000
Eastern Main Rd.	280,000	315,000	350,000	392,000	522,000
Caroni	120,000	138,000	155,000	173,000	222,000
Sangre Grande	44,000	48,000	51,000	54,000	54,000
Diego Martin	43,000	51,000	59,000	67,000	88,000
Montserrat	6,200	7,100	7,900	9,000	12,200
San Fernando	72,000	78,000	82,000	86,200	100,000
South Trinidad	328,000	365,000	400,000	440,000	600,000
Mayaro	9,100	9,600	10,500	11,300	14,800
Toco	7,700	8,600	9,600	10,500	12,300
North Coast	<u>3,700</u>	<u>4,400</u>	<u>5,300</u>	<u>6,000</u>	<u>7,000</u>
Trinidad Total	1,092,700	1,228,100	1,356,600	1,499,200	1,961,300
Tobago					
Southwest	26,000	28,000	30,900	33,600	44,000
Windward Coast	7,400	7,800	8,200	8,600	10,000
Rural	<u>4,200</u>	<u>4,400</u>	<u>4,600</u>	<u>4,700</u>	<u>5,000</u>
Tobago Total	37,600	40,200	43,700	46,900	59,000
Total	1,130,300	1,268,300	1,400,300	1,546,100	2,020,300

WASA is estimated to serve 90 percent of the population directly from its system. The remaining three percent with piped water are supplied by the three major oil companies: Texaco Trinidad Inc.; Shell Trinidad Ltd.; and Tesoro Trinidad Ltd.; and by other private concerns, which together produce approximately 1.8 mgd for domestic use. The County Councils as agents of WASA serve another three percent by truck, leaving only four percent, or 40,000 persons, so isolated as not to be supplied either directly or indirectly by WASA. The fact that more than 90 percent of the population is served in some way by WASA is a remarkable accomplishment for a developing country.

Past and Present Water Use

Historical data on total water production by WASA and its predecessor agencies from 1950 are listed in Table 10.

Table 10. Past Water Production for Trinidad and Tobago

Year	Production, mgd	Year	Production, mgd
1950	14.5	1960	29.3
1951	14.9	1961	32.0
1952	15.5	1962	34.9
1953	16.2	1963	39.2
1954	17.2	1964	42.3
1955	18.1	1965	48.1
1956	18.5	1966	48.1
1957	20.1	1967	50.7
1958	22.9	1968	54.1
1959	26.8	1969	59.9

Records which indicate production by source are available only from 1962 onward. Except for Port of Spain, no records are available which reflect use by area; however, in view of the isolation of the regional service areas, estimates of area use can be made from production records, and are presented in Table 11. No historical data are available which give a breakdown of WASA's production by use or which list production from private sources. Accordingly, estimates have been made from the limited information available for 1968.

Domestic Water Use. In the analysis of present use, domestic use, small commercial use, and waste and loss have been considered together under domestic use. In order to separate domestic, small commercial use and waste from total use, WASA's meter records were reviewed and the figures for industrial and large commercial metered water use were subtracted from total production. The remainder was assumed to be domestic use, and the 1968 estimates of such are given in Table 12.

As mentioned earlier, domestic water supplied by the major oil companies and other private concerns is estimated at 1.8 mgd.

Industrial Water Use. Present industrial use is estimated at 20.4 mgd. Approximately 6 mgd of this total is supplied by WASA; the remainder comes from private supplies and includes 1 mgd of sewage effluent which WASA sells to Texaco. Texaco is the island's largest industrial user with a demand of approximately 7.8 mgd, of which all but 0.2

Table 11. Annual Average Daily Water Use by Service Area(1)

Service area	Million gallons per day						
	1962	1963	1964	1965	1966	1967	1968
Trinidad							
San Fernando	3.2	3.3	3.4	3.5	3.6	3.7	3.8
Port of Spain	11.8	11.5	12.0	14.8	13.6	14.6	14.9
Diego Martin	3.1	3.7	3.8	4.0	3.6	3.5	3.9
Chaguaramas	-	-	-	-	-	0.5	1.3
Eastern Main Road	10.6	10.7	12.3	14.3	14.6	15.0	15.6
Sangre Grande	0.7	0.6	0.8	0.9	0.9	1.0	1.0
Caroni	1.6	2.7	3.0	2.8	2.8	2.8	3.4
Montserrat	0.1	0.1	0.1	0.1	0.2	0.4	0.5
South Trinidad	2.6	4.9	5.2	5.9	7.1	7.5	7.7
Mayaro	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Toco	<u>0.1</u>	<u>0.2</u>	<u>0.2</u>	<u>0.2</u>	<u>0.2</u>	<u>0.2</u>	<u>0.2</u>
Trinidad Total	33.9	37.8	40.9	46.7	46.8	49.4	52.5 ²
Tobago							
Southwest	1.0	1.2	1.4	1.4	1.3	1.3	1.4
Southeast	<u>-</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>0.2</u>
Tobago Total	1.0	1.2	1.4	1.4	1.3	1.3	1.6
Total	34.9	39.0	42.3	48.1	48.1	50.7	54.1

1. Exclusive of unmetered rural intakes.

mgd, purchased from WASA at Barrackpore, is supplied from Texaco's own sources. The areal distribution of the industrial demand supplied by WASA is given in Table 13.

Federation Chemicals Limited is the largest single user depending entirely on WASA. Their demand is approximately 1 mgd. The Port Authority and Trinidad Cement Ltd. are, respectively, the second and third largest users of WASA water. WASA's remaining industrial customers, numbering about 150, use relatively small quantities.

Besides Texaco, other large users with private supply sources are Shell Trinidad Ltd., Tesoro Trinidad Ltd., Caroni Estates Ltd., The Trinidad Sugar Estates Ltd., and the Trinidad and Tobago Electricity Commission. Together these companies produce and use approximately 5.2 mgd. The remaining 1.6 mgd produced privately comes from groundwater and is divided among about 30 different concerns.

Water for gravel-washing is withdrawn from the Arima, North Oropouche, and Caroni rivers in Trinidad, and the Courland

Table 12. 1968 Domestic Water Use by Area Supplied by WASA(1)

Service area	Population(2)	Domestic water use	
		Total, mgd	Per capita, gpd
Trinidad			
Port of Spain	172,800	12.7	74
Diego Martin	43,900	3.8	87
Eastern Main Road	259,100	14.4	56
Sangre Grande	36,600	1.0	27
Caroni	116,400	3.4	29
Montserrat	9,000	0.5	55
South Trinidad	301,600	6.3	21
San Fernando	48,500	3.3	66
Mayaro	6,800	0.2	29
Toco	6,200	0.2	32
Tobago			
Southwest	25,000	1.4	55
Windward Coast	7,400	0.2	27
Total	1,033,300	47.4	46 (Avg)

1. Does not include Chaguaramas, or areas served by minor intakes.

2. Includes total population within area served.

River in Tobago. However, gravel-washing is a nonconsumptive use since the water is returned to its source immediately after use downstream of the point of withdrawal. Although gravel-washing is of major concern as a source of pollution, it does not affect the quantity delivered by the source from which the water is withdrawn. Pollution caused by gravel-washing is not a threat to health. Its worst effects are that it increases the cost of treatment and would increase silting if practiced upstream from a reservoir.

Irrigation. Irrigation is practiced widely in Trinidad, and consists primarily of small diversions from creeks and streams at works built by private individuals. Some irrigation

is also practiced in floodplains where part or all of the stream flow can be diverted by gravity flow. This type of irrigation takes place on a small scale on the Guanapo, Aripo, and San Juan rivers, and on a large scale on the Caroni and South Oropouche rivers. The largest engineered irrigation system is the Caroni system, constructed in 1949 to serve the surrounding rice fields. This system diverts up to 12 mgd from the Caroni River at the Kelly Headworks via a feeder canal to the Guayamare River from which feeder canals distribute the water over an area of about 3,000 acres. Similar projects are planned for the Oropouche Lagoon and the Nariva Swamp. Maximum irrigation use at present is estimated at 20 mgd during the dry season.

**Table 13. 1968 Industrial Water Use by
Area Supplied by WASA**

<i>Service area</i>	<i>Million gallons per day</i>
Trinidad	
Port of Spain	2.2
Diego Martin	0.1
Eastern Main Road	1.2
Sangre Grande	-
Caroni	-
Montserrat	-
South Trinidad	1.4
San Fernando	0.5
Mayaro	-
Toco	-
Chaguaramas	<u>0.6</u>
Trinidad Total	6.0
Tobago	
Southwest	-
Windward Coast	-
Tobago Total	0
Total	<u>6.0</u>

WASA does not furnish irrigation water, nor do any of the proposed projects include irrigation as a benefit. However, as the principal water resource agency in Trinidad and Tobago, WASA is responsible for approving the withdrawal of water from any stream or groundwater aquifer. This procedure is designed to prevent indiscriminate development from interfering with the existing and proposed supplies of the Authority. To date the Authority has not been faced with the problem of irrigation as a competitive use for any of the proposed sources. Nevertheless, irrigation may be a consideration when the available

groundwater resources become fully exploited and the Authority must turn to additional surface supplies to meet increasing demands.

Waste and Loss. In systems that are fully metered, there is usually a difference between metered production and water use as measured by customers' meters. This difference is usually referred to as "unaccounted-for" water and includes leakage, fire-fighting, and flushing water, and under-registration of meters. Unaccounted-for water may range from 5 to 50 percent of total production. In well managed systems it should not exceed 20 percent.

In unmetered systems leakage is the primary concern. In a tight transmission and distribution system, 10 percent leakage is considered a reasonable figure. This figure does not include leakage in the customers' systems, which can be excessive when billing is not based on the amount used. Leaks that do not cause much inconvenience to the customer, such as a leaking water closet or a broken float valve on a storage tank, are not promptly repaired. Even when the customer has the best of intentions, many leaks go unnoticed, but in a metered system the existence of leaks would be recognized by a large water bill.

Complete information on waste and loss in the present system is not available. Therefore, as mentioned earlier, estimates of waste and loss have been included with domestic use in the analysis of present water use. Some idea of the amount of waste can be determined by studying the per capita consumption figures listed in Table 12.

Where all homes have baths and flush toilets, studies of recent meter records in Port of Spain indicated that 57 gpd (gallons per capita per day) is an average use. In Diego Martin where daily per capita use in 1968 was estimated at 87 gallons, a waste and loss survey conducted for this study identified 161 leaks representing an estimated loss of 1 mgd. After most of these leaks had been repaired, the required production dropped by about 28 percent. The reduction in overall demand that could be achieved by an effective program of leak detection and repair and metering of all direct connections is estimated to be at least 20 percent.

Future Water Requirements

Future water requirements are projected for domestic and industrial demands. It is assumed that private supplies will continue to operate at about the present level. Most of the areas served by private systems are now served by WASA also. Projections assume that all future water requirements over and above existing production from both WASA and private sources will be provided by WASA through its pipe-borne water system.

Projections for irrigation water are outside the scope of this report. A preliminary report on the irrigation requirements and potential within the Caroni River watershed by Mr. S. Hirai (Japan Technical Co-operation Plan for Latin America) indicates that for a rice culture program with a 7-month per year growing season, the maximum demand for irrigation water would be 175 cfs (cubic feet per second) or 94 mgd. This would provide irrigation of 10,400 acres of land, 6,200 of

which are presently part of the Caroni swamp and may not be reclaimed for agricultural purposes. The Caroni River flow at Kelly Village averages about 200 mgd for the average year, as indicated by stream flow records at this point. Therefore, even if the maximum irrigation demand were taken as an average daily irrigation requirement, about 106 mgd of the Caroni gross average runoff would be available for other uses.

Domestic Water Requirements. Estimates of future domestic water requirements are based on population projections and estimates of per capita demand in each subarea. The total future domestic demands for each water service area are given in Table 14. Where the percentage of unserved population is high and the majority of users are on standpipes or served by truck, these conditions are reflected in the per capita use value selected for the area.

Estimated per capita production in 1968 for domestic use was 46 gallons per day. Although this value should have been adequate, demands were not satisfied in all the areas served. It is estimated that the present per capita demand, including waste and loss, is 57 gallons per day. Universal metering and a metered water rate schedule adequate to cover all capital and operating costs should reduce demand by 20 percent, resulting in a per capita demand of 46 gallons per day including a 20 percent waste and loss allowance. This value is excessive, and the reasons for such a high per capita demand are: excessive system leakage due partly to high pressures in some areas of the system, leakage in private plumbing systems, and wasteful water use practices. The Authority can

Table 14. Future Average Annual Domestic Water Demand

Service area	1975		1980		1985		2000	
	Per capita, gpd	Total, mgd	Per capita, gpd	Total, mgd	Per capita, gpd	Total, mgd	Per capita, gpd	Total, mgd
Trinidad								
Chaguaramas	63	0.3	65	0.7	68	1.2	75	2.9
Port of Spain	63	12.4	66	14.1	69	16.0	75	21.0
Eastern Main Road	50	15.8	54	19.0	57	22.3	65	33.9
Caroni	37	5.1	43	6.7	49	8.4	60	13.3
Sangre Grande	37	1.7	43	2.2	49	2.6	60	3.8
Diego Martin	63	3.2	66	3.9	69	4.6	75	6.6
Montserrat	48	0.3	51	0.4	55	0.5	68	0.8
San Fernando	63	4.9	66	5.4	69	5.9	75	7.5
South Trinidad	41	15.0	45	18.0	50	22.0	62	37.2
Mayaro	49	0.5	52	0.6	56	0.6	66	1.0
Toco	39	0.3	40	0.4	42	0.4	50	0.6
North Coast	49	0.2	53	0.3	56	0.3	66	0.5
Trinidad Total		59.7		71.7		84.8		129.1
Tobago								
Southwest	39	1.1	40	1.2	42	1.4	50	2.2
Windward Coast	31	0.2	32	0.3	33	0.3	36	0.4
Rural	30	0.1	30	0.1	30	0.1	30	0.2
Tobago Total		1.4		1.6		1.8		2.8
Total		61.1		73.3		86.6		131.9

control pressures and system leakage, but can do very little about the customers' plumbing or water use habits except by charging realistic water rates based on metered use. In assigning per capita demands it has been assumed that new water rates will be implemented on the basis of metered use, and that the meter rates charged will be high enough to encourage water conservation and thereby reduce per capita demand. Establishment of future per capita demand on an average value of 57 gpd would result in

expenditure that the Authority could not readily pass on to users. It is also a fact that most lending institutions make the adoption of adequate rates based on metered water sales a prerequisite to granting loans for water system improvements. Therefore, it can be assumed that metering and an increase in rates will occur out of economic necessity.

Per capita demand values selected for design by subarea result in the weighted averages for each water service area and for

Trinidad and Tobago as listed in Table 14. Per capita use is expected to increase in all areas from the initial values and to be greatest in areas now having a higher percentage of standpipes. Such areas have the largest potential for increases in the percentage of direct connections and the number of houses with plumbing. Figure 6 shows the projected increase in the maximum, minimum, and average per capita demand values selected for design.

Industrial Requirements. Industrial water consumption can be expected to increase at a greater rate than the growth in population. Industrial use is now about 20 mgd. It is estimated that per capita industrial use will increase by the year 2000 to 29 gpd, equivalent to 58 mgd, of which 38 mgd must be supplied by WASA.

Studies and investigations indicate that the greater proportion of the industrial growth, and consequently the demand for industrial water, will occur along the Eastern Main Road near Port of Spain and southward between Port of Spain and San Fernando. Table 15 shows the allowances made for future industrial water demands on the WASA system.

The projections shown in Table 15 are called allowances rather than demands in view of the uncertainties of future industrial development. It is felt that they will allow for a reasonable rate of growth in the manufacturing and industrial capability in Trinidad. However, it should be remembered that one large industry could easily change these requirements. The recent offshore oil and gas find by AMOCO (formerly Pan American Oil) represents such a situation.

AMOCO is currently considering the feasibility of constructing a gas liquefaction plant or petrochemical plants in Trinidad to utilize the gas from their find. The water requirements for such plants are estimated at 2 mgd initially, increasing to 5 mgd within a three-year period and later reaching 10 mgd or more. Since the need for this water is a definite possibility, ample allowance for a large petrochemical industry has been made in the projections. The precise location of the industry or industries is not yet fixed. However, both Point Fortin and Point Lisas are under consideration and, for purposes of sizing future transmission mains, capacity has been provided for making this quantity of water available at San Fernando, that is, midway between the two areas under consideration.

Included in the estimates of industrial use are institutional water, government use, farm use and hotel use, which were all included with industrial use primarily because of their unpredictability and the amount involved. Industrial demands in Tobago and along the north and east coasts of Trinidad are hotel demands. Agricultural demands, which include water for livestock but not for irrigation, are located in Waller Field, Carlsen Field, and Tobago. Industrial demand in the Eastern Main Road area, Port of Spain, San Fernando, and Point Fortin includes manufacturing, institutional, and hotel requirements.

Total Requirements. Total annual average water requirements for Trinidad and Tobago are shown graphically on Figure 7 and listed by service area in Table 16. The quantities shown are the sum total of projections for domestic and industrial

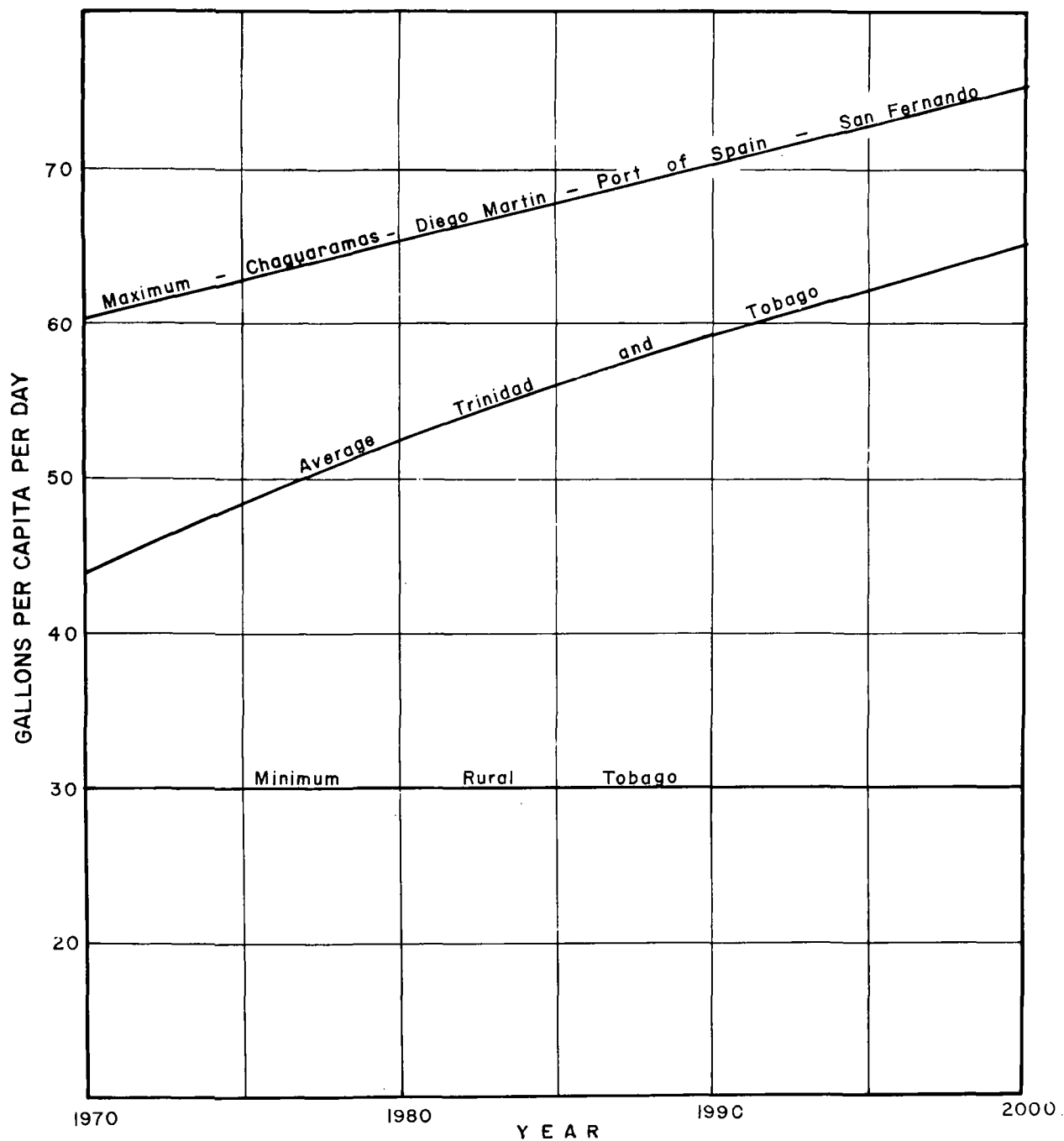


FIG. 6 PROJECTED PER CAPITA DOMESTIC WATER DAMAND

Table 15. Allowances for Future Industrial Water to be Supplied by WASA

Service area	Million gallons per day				
	1970-74	1975	1980	1985	2000
Trinidad					
Chaguaramas	0.7	0.7	0.9	1.0	1.0
Port of Spain	2.8	2.8	3.3	3.7	5.0
Eastern Main Road	1.4	2.3	2.9	3.5	5.3
Caroni	0.1	0.2	0.2	0.2	0.2
Sangre Grande	—	0.1	0.1	0.2	0.4
Diego Martin	0.1	0.1	0.1	0.2	0.3
Montserrat	—	—	—	—	—
San Fernando	0.9	0.9	1.4	1.8	3.0
South Trinidad	2.7	3.2	4.6	6.0	9.5
Mayaro	—	0.1	0.1	0.2	0.4
Toco	0.1	0.2	0.2	0.3	0.4
North Coast	0.1	0.2	0.2	0.3	0.5
Petrochemical demand	<u>2.0</u>	<u>5.0</u>	<u>6.5</u>	<u>7.5</u>	<u>10.0</u>
Trinidad Total	10.9	15.8	20.5	24.9	36.0
Tobago					
Southwest	0.4	0.5	0.6	0.8	1.5
Windward Coast	—	—	—	0.1	0.2
Rural	<u>—</u>	<u>—</u>	<u>—</u>	<u>0.1</u>	<u>0.1</u>
Tobago Total	0.4	0.5	0.6	1.0	1.8
Total	11.3	16.3	21.1	25.9	37.8

requirements to be supplied by WASA. WASA's past production is also shown on Figure 7.

Variations in Demand

So far, only annual average water requirements have been discussed. In actual practice, the demand for water does not remain constant but varies from season to season, from day to day, and even from hour

to hour. To meet daily fluctuations, water treatment plants and certain distribution facilities are commonly designed for the maximum one-day demand, that is to say, the total demand during the 24-hour period of greatest water use. Secondary distribution facilities are designed for the maximum one-hour rate of demand that is likely to occur, expressed as a daily rate.

Maximum one-day and maximum one-hour demands are generally expressed as a

Table 16. Future Average and Maximum Day Total Water Requirements

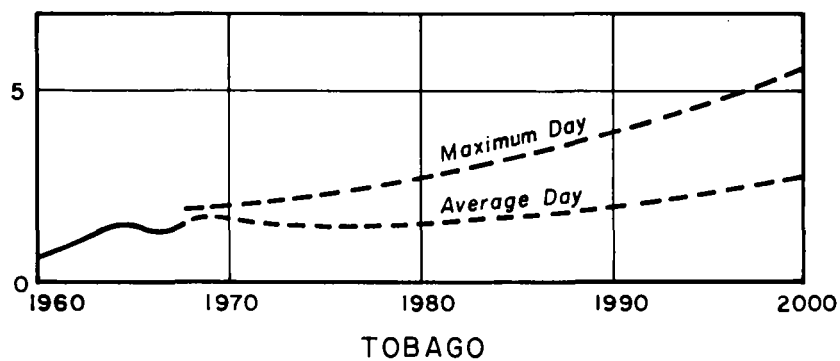
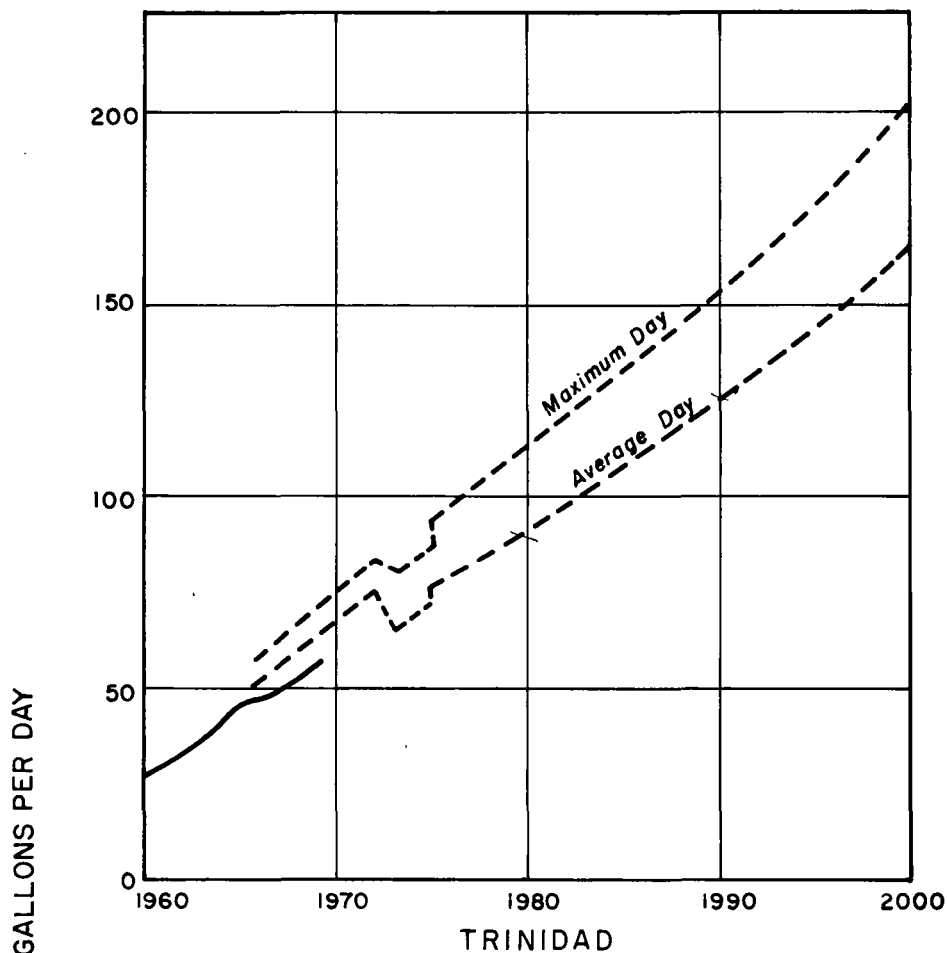
Service area	Million gallons per day							
	1975		1980		1985		2000	
	Avg	Max	Avg	Max	Avg	Max	Avg	Max
Trinidad								
Chaguaramas	1.0	1.2	1.6	1.9	2.2	2.6	3.9	4.7
Port of Spain	15.2	18.6	17.4	21.2	19.7	24.1	26.0	31.8
Eastern Main Road	18.1	22.3	21.9	26.9	25.8	31.7	39.2	48.2
Caroni	5.3	6.6	6.9	8.6	8.6	10.7	13.5	16.8
Sangre Grande	1.8	2.2	2.3	2.9	2.8	3.5	4.2	5.2
Diego Martin	3.3	4.1	4.0	5.0	4.8	6.0	6.9	8.6
Montserrat	0.3	0.4	0.4	0.5	0.5	0.6	0.8	1.0
San Fernando	5.8	7.1	6.8	8.3	7.7	9.4	10.5	12.7
South Trinidad	18.2	22.3	22.6	27.6	28.0	34.1	46.7	57.0
Mayaro	0.6	0.7	0.7	0.9	0.8	1.0	1.4	1.7
Toco	0.5	0.6	0.6	0.7	0.7	0.8	1.0	1.2
North Coast	0.4	0.5	0.5	0.6	0.6	0.7	1.0	1.2
Petrochemical demand	<u>5.0</u>	<u>5.5</u>	<u>6.5</u>	<u>7.2</u>	<u>7.5</u>	<u>8.3</u>	<u>10.0</u>	<u>11.0</u>
Trinidad Total	75.5	92.1	92.2	112.3	109.7	133.5	165.1	201.1
Tobago								
Southwest	1.6	1.9	1.8	2.2	2.2	2.6	3.7	4.4
Windward Coast	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.7
Rural	<u>0.1</u>	<u>0.1</u>	<u>0.1</u>	<u>0.1</u>	<u>0.2</u>	<u>0.2</u>	<u>0.3</u>	<u>0.4</u>
Tobago Total	1.9	2.2	2.2	2.7	2.8	3.3	4.6	5.5
Total	77.4	94.3	94.4	115.0	112.5	136.8	169.7	206.6

percentage of the annual average daily demand. Estimates of future maximum one-day demands have been taken as 125 percent of annual average daily demand for domestic service. Industrial maximum one-day demands have been assumed to be 110 percent of the annual average daily demand. The total estimated maximum day water requirements for Trinidad and Tobago

are also shown on Figure 7 and listed by service area in Table 16.

Fire-Flow Requirements

Where water is to be provided for fire protection, good design practice requires that a distribution system be capable of providing the maximum daily demand plus the required



LEGEND

- Past Production
- - - - - Future Demand

**FIG. 7 PAST WATER PRODUCTION AND
FUTURE DEMAND TRINIDAD AND TOBAGO**

fire flow. In small distribution systems, fire flows are the controlling factor in the design. However, since fire flows are generally

supplied from distribution storage, they are not considered as a factor in the design of major transmission or supply systems.

CHAPTER 5

ADEQUACY OF THE EXISTING WATER SYSTEM

General

The existing water system was evaluated primarily on its ability to supply present and estimated future demands within the existing service area. Other factors considered were the quality of the water produced and the physical condition of the existing facilities. The evaluation procedure consisted of interviews with WASA's engineers and operating personnel, pressure surveys, pipe condition tests, visual inspection of existing facilities, and analysis of operating records. In order to get the customers' point of view, questionnaires were sent out to the heads of Village Councils throughout Trinidad and Tobago requesting comments on the adequacy of the water supply in their respective areas. Response to the questionnaires was 51 percent. Of the replies received, 75 percent indicated dissatisfaction with the present service. These complaints were cross-checked with known problem areas to ensure that each problem would be eliminated by the recommended improvements where correction was economically feasible.

Supply

The demand curve for Trinidad and Tobago shown on Figure 7 indicates a 1970 maximum day demand of 78 mgd. Present production capacity, both maximum and average, is only 60 mgd. Demands will continue to increase until 1973 when a 20

percent reduction is expected to result from metering. Before metering becomes effective in 1973, however, average and maximum day demands are expected to reach 75 and 85 mgd, respectively. These are the critical demands that must be met before any major supply project can be completed. Table 17 lists the available supply to the major water service areas and the additional supply required to meet average and maximum day demands in the years immediately prior to the construction of a major source of supply, and for the long term. Water deficient districts within the existing service areas are shown on Figure 8 (at the back of the report).

The 1975 increase in demand indicated on Figure 7 is industrial demand which cannot be supplied until sufficient water is made available.

Treatment

Except for the untreated supplies from rural intakes, which are all small, there are only two large supplies that do not receive some form of treatment other than disinfection. These are the boreholes at Tacarigua and Arouca. While bacterial tests show that the water is safe, chlorination should be practiced as a safeguard, and aeration facilities should be provided for stabilization.

Table 17. Supply Deficiencies by Water Service Area

Service area	Developed supply, ⁽¹⁾ mgd		Supply deficiency, mgd							
	Aver- age day	Maxi- mum day	1970		1973		1974		2000	
			Aver- age day	Maxi- mum day	Aver- age day	Maxi- mum day	Aver- age day	Maxi- mum day	Aver- age day	Maxi- mum day
Trinidad										
Chaguaramas	1.5	1.5	-	-	0.1	0.2	-	-	2.4	3.2
Diego Martin	3.9	4.7	-	-	0.5	0.6	-	-	3.0	3.9
Port of Spain	10.4	17.0	8.1	2.9	9.4	4.4	4.8	1.6	15.6	14.8
Eastern Main Rd.	15.0	17.7	1.8	2.6	4.2	5.2	1.7	2.9	24.2	30.5
Sangre Grande	1.6	1.6	-	-	-	0.2	0.1	0.5	2.6	3.6
Toco	0.3	0.3	-	0.1	0.1	0.2	0.1	0.2	0.7	0.9
North Coast	0.3	0.3	-	-	-	-	-	-	0.7	0.9
South Trinidad	3.0	6.4	8.5	7.7	10.4	10.4	12.6	12.7	43.7	50.6
Caroni	3.3	3.9	1.5	1.9	2.1	2.6	2.2	3.0	10.2	12.9
Montserrat	0.6	0.6	-	-	-	0.1	-	-	0.2	0.4
San Fernando	6.4	7.0	-	-	0.5	0.6	-	-	4.1	5.7
Mayaro	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.2	1.2	1.4
Petrochemical demand	-	-	-	-	-	-	2.0	2.2	10.0	11.0
Trinidad Total	46.5	61.3	20.1	15.4	27.6	24.8	23.7	23.3	118.6	139.8
Tobago										
Southwest	2.0	2.0	-	-	-	0.7	-	-	1.7	2.4
Windward Coast	0.2	0.2	0.1	0.2	0.1	0.2	-	-	0.4	0.5
Rural	0.1	0.1	-	-	-	-	-	-	0.2	0.3
Tobago Total	2.3	2.3	0.1	0.2	0.1	0.9	-	-	2.3	3.2
Total	48.8	63.6	20.2	15.6	27.7	25.7	23.7	23.3	120.9	143.0

1. Based on allocations of dependable yields and production capacities listed in Tables 3 and 4. Maximum day capacities of surface water intakes assumed equal to dependable yield. Maximum day capacities of other sources assumed equal to installed production capacity. Average day capacities are based on developed dependable yield.

Treatment methods employed for iron removal, turbidity, and stabilization are in general adequate and should be continued. Equipment at the temporary plants at Carlsen Field and Penal is antiquated or inoperative and should be replaced.

Treatment problems exist at the surface water intakes, particularly at Maraval, Tompire, and Courland. At Courland, turbidity is a constant problem caused by gravel-washing operations upstream of the intake. The existing roughing filter can

partly cope with this turbidity with constant maintenance. It is completely inadequate for handling the increased turbidity that occurs after heavy rainfalls. This same problem of turbidity after rains exists at all the other intakes. A water treatment plant is currently under construction at the Maraval intake in order to allow continuous withdrawals from this source. Similar plants are required at Tompire and at Courland. A treatment plant for Valencia is not recommended because the Hollis Reservoir can be used as an alternate supply during periods of high turbidity with very little effect in the flow rate to other areas of the system.

Transmission and Primary Distribution

Areas shown on Figure 8 as having the greatest supply deficiency are generally the same areas with inadequate transmission and distribution systems. An increase in supply in these areas is not expected to solve the water shortage problem. Deficient pressures in general result from long lengths of undersize mains and inadequate storage capacity. In areas such as Diego Martin, excessively high pressures are a problem. High pressures result from inadequate segregation of the system into low- and high-pressure service areas.

Storage

Supply and treatment facilities are usually sized to meet maximum one-day demands. The additional water to meet peak demands of short duration normally comes from distribution storage. Existing operational storage facilities in Trinidad and Tobago have a total capacity of 51 million gallons, which is 65 percent of the estimated

1970 maximum day demand. At least 25 percent of the maximum day demand is required to meet normal peak demands. Storage must also be provided to meet fire-fighting requirements and to provide an emergency supply in case of a breakdown in supply or treatment facilities. Storage provided for these purposes is, in effect, insurance against the unexpected, and thus the criterion "as much as you can afford" is sometimes used. We recommend that, in the future, storage required for fire-fighting and emergencies together with dead storage be at least 25 percent of the maximum day demand in areas served by two or more sources. Total storage requirements in these areas would thus be about 50 percent of the maximum one-day demand. In areas where the demand is small and the supply is from a single source, emergency storage equal to 75 percent of the maximum one-day demand is not unreasonable.

The existing storage appears to be sufficient when comparing total storage with total demand. To be adequate, however, storage must be properly located. Table 18 lists the deficiencies in existing storage capacity by service area.

Secondary Distribution System

Within the corporate limits of Port of Spain and San Fernando, the secondary distribution system is generally adequate. In these areas there are very few mains smaller than 4 inches. However, in other areas 1-1/2- and 2-inch pipes are common and are the primary cause of low pressure.

The adequacy of the secondary distribution system depends to a great

Table 18. Storage Deficiencies by Water Service Area

<i>Service area</i>	<i>Deficiency, million gallons</i>	
	<i>1974</i>	<i>2000</i>
Trinidad		
Chaguaramas	-	-
Diego Martin	0.4	1.6
Port of Spain	1.0	2.1
North Coast	0.1	0.3
Eastern Main Road	3.5	15.2
Toco	0.2	0.4
Sangre Grande	0.3	1.9
Mayaro	0.1	0.9
San Fernando	-	-
South Trinidad	9.7	22.0
Montserrat	-	0.2
Caroni	2.0	5.4
Tobago		
Southwest	0.3	1.3
Windward Coast	-	-
Rural	<u>0.1</u>	<u>0.2</u>
Total	17.7	51.5

extent on whether or not it must meet fire-fighting requirements. The inclusion of fire-fighting capacity in the distribution system can be economically justified only in urban areas. Generally, standards for sizing secondary distribution mains for fire-fighting require a minimum main size of 6 inches. In rural areas smaller mains can be used.

Condition of Mains

The condition of a distribution main refers both to its hydraulic carrying capacity and its physical condition. The hydraulic

condition of a main is determined by flow and pressure measurements; the evaluation of the physical condition is based on inspection and review of maintenance records.

Hydraulic Flow Tests. As part of the waste and loss study, pipe condition tests were made on the Hollis trunk main, the 21-inch Cocorite main from the Farrell Pumping Station, and a 12-inch main in Tacarigua. The hydraulic condition of the 36-inch section of the Navet trunk main was also determined from available data. The condition of these mains is indicated by the Hazen-Williams C values listed in Table 19. The Hazen-Williams C value is an indication of pipe capacity. The C value of a new pipe approximates 140. The capacity of the main varies directly with the C value; therefore, the Hollis trunk main, which has a C value of 88, has approximately only 88/140th, or 73 percent, of its original carrying capacity. The reduction in carrying capacity measured in the mains tested is considered normal for their type and age. Measures to restore the original carrying capacity of these or other mains are not recommended.

Physical Condition of Mains and Valves. Main breaks are common throughout the system; however, only in a few areas are they considered excessive. Diego Martin is one area where breaks are common due to excessive pressures. Some of the pipes in this system are thin-walled steel pipes which are unsuitable for the service pressures being experienced. Breaks on steel mains have occurred. Valve maintenance appears to be ineffective. The waste and loss study in Diego Martin indicated that many of the leaks were occurring through valve stuffing

Table 19. Pipe Condition Test Results

<i>Main</i>	<i>Diameter, inches</i>	<i>Test length, feet</i>	<i>Material</i>	<i>Age, years</i>	<i>C value</i>
Hollis Trunk Main — Valencia to Tunapuna	24	75,000	Steel	33	88
Navet Trunk Main — Navet Dam to Arch Trace	36	39,999	Steel	7	120
Cocorite Main — Cocorite to Port of Spain	21	11,000	Cast- iron	66	70
Tacarigua South Main — Tacarigua Boreholes to Trincity Industrial Park	12	3,000	Steel	7	150

boxes. A continued program of valve maintenance which includes an effective and up-to-date system of record-keeping is required.

Local Supply Problems

Many of the areas and subareas presently suffering from water shortages have potential groundwater supplies which, if developed, would ease, if not completely eliminate, present problems. Other areas

suffer shortages because supply mains are too small to carry the water now required or pumping stations are unable to meet increasing demands. Still others suffer from a combination of these problems.

Area and subarea problems have been studied in detail and the major causes of shortages in each identified. The local supply projects and major supply projects presented later in this report are designed to correct these inadequacies.

CHAPTER 6

POTENTIAL ADDITIONAL SURFACE SOURCES

General

Potential surface water sources in Trinidad and Tobago are more than adequate to meet projected demands beyond the year 2000. However, most sources investigated will require development of an impounding reservoir for any significant yield, and all should be provided with treatment (coagulation, sedimentation, filtration, and disinfection) to ensure a safe, palatable water supply.

Rainfall

Rainfall patterns in Trinidad and Tobago are largely determined by the seasonal movement of the trade wind belt and the equatorial trough. During the wet season, the equatorial trough advances northward toward Trinidad, reaching its northernmost position around September or October. As the trough shifts northward and again southward (after September or October), the track of vortical type disturbances crosses and recrosses Trinidad and Tobago. During the wet season, shower type precipitation is caused by regional vortical type disturbances and by moisture-laden unstable air masses crossing the islands, lifted or raised by topography or convection currents.

During the dry season, January to May inclusive, the northeasterly trade winds bring dry air to the islands, resulting in a virtual

absence of rainfall. Such rainfall as does occur in this period is primarily due to convection or orographic lifting, whereas during the wet season regional vortical disturbances contribute mainly to the rainfall. Consequently, during the dry season, precipitation follows the relief of the island quite closely. However, nowhere is rainfall during the dry season greater than about 8 percent of the annual precipitation.

Runoff

Trinidad's most productive watersheds lie in the eastern portion of the Northern Range. In this area total runoff ranges from 40 to about 70 percent of rainfall, and dry-season runoff is around 20 to 30 percent of the annual total. Generally, the annual runoff from watersheds in other areas of Trinidad is between 20 and 40 percent of annual rainfall and the dry-season runoff ranges from 1 to about 14 percent of total runoff. Table 20 is a summary of runoff distribution for those rivers for which limited stream gauging data and fairly long-term rainfall records are available.

While the percentage of rainfall which runs off is dependent upon soil types, topography, land use and rainfall patterns, there is sufficient similarity between the streams listed in Table 20 (and their catchment areas), with the exception of the St. Joseph River, to allow a comparison of

Table 20. Runoff Distribution by Season(1)

Stream	Year	Total rainfall, inches	Runoff			
			Total	Percent of rainfall	Percent during dry season	Percent during wet season
			Inches			
Northern Range						
St. Joseph River	1968	64.02	14.01	21.9	30.5	69.5
Caura River	1968	68.52	-	-	25.0(2)	75.0(2)
North Oropouche River	1968	126.00	86.33	68.5	27.5	72.5
North Oropouche River	1967	119.34	63.68	53.0	22.4	77.6
El Mamo River(3)	1968	94.54	38.64	41.0	10.6	89.4
Central Region						
Pure River	1968	83.70	23.51	28.0	1.4	98.6
Navet River	1963	94.60	26.88	28.4	9.2	90.8
“ “	1964	112.47	49.02	43.5	1.7	98.3
“ “	1965	97.65	31.71	32.5	9.5	90.5
“ “	1966	103.95	38.37	36.9	1.5	98.5
“ “	1967	95.82	36.20	37.7	4.0	96.0
“ “	1968	93.61	42.09	45.0	5.7	94.3
Cunapo River(3)	1968	97.68	44.29	45.3	14.7	85.3
Couva (Chickland)	1968	75.19	15.11	20.0	2.5	97.5
Southern Area						
Ortoire River	1968	91.41	28.22	31.0	12.0	88.0
Northern Range/ Central Region						
Caroni River (Kelly)	1968	90.24	34.24	37.0	10.5	89.5

1. Based on reports by M. M. Dillon.

2. Partial record (estimated).

3. Catchment differs from others in zone.

runoff. St. Joseph River Valley contains a thick valley fill of sands and gravels. Consequently, a considerable portion of the annual rainfall infiltrates and travels seaward as groundwater. This groundwater has been developed by the Valsayn well field.

Canvass of Potential Sources

Figures 9 and 10 are isohyetal maps of mean annual rainfall for Trinidad and Tobago, respectively. The pattern of rainfall indicated by these maps was used together with

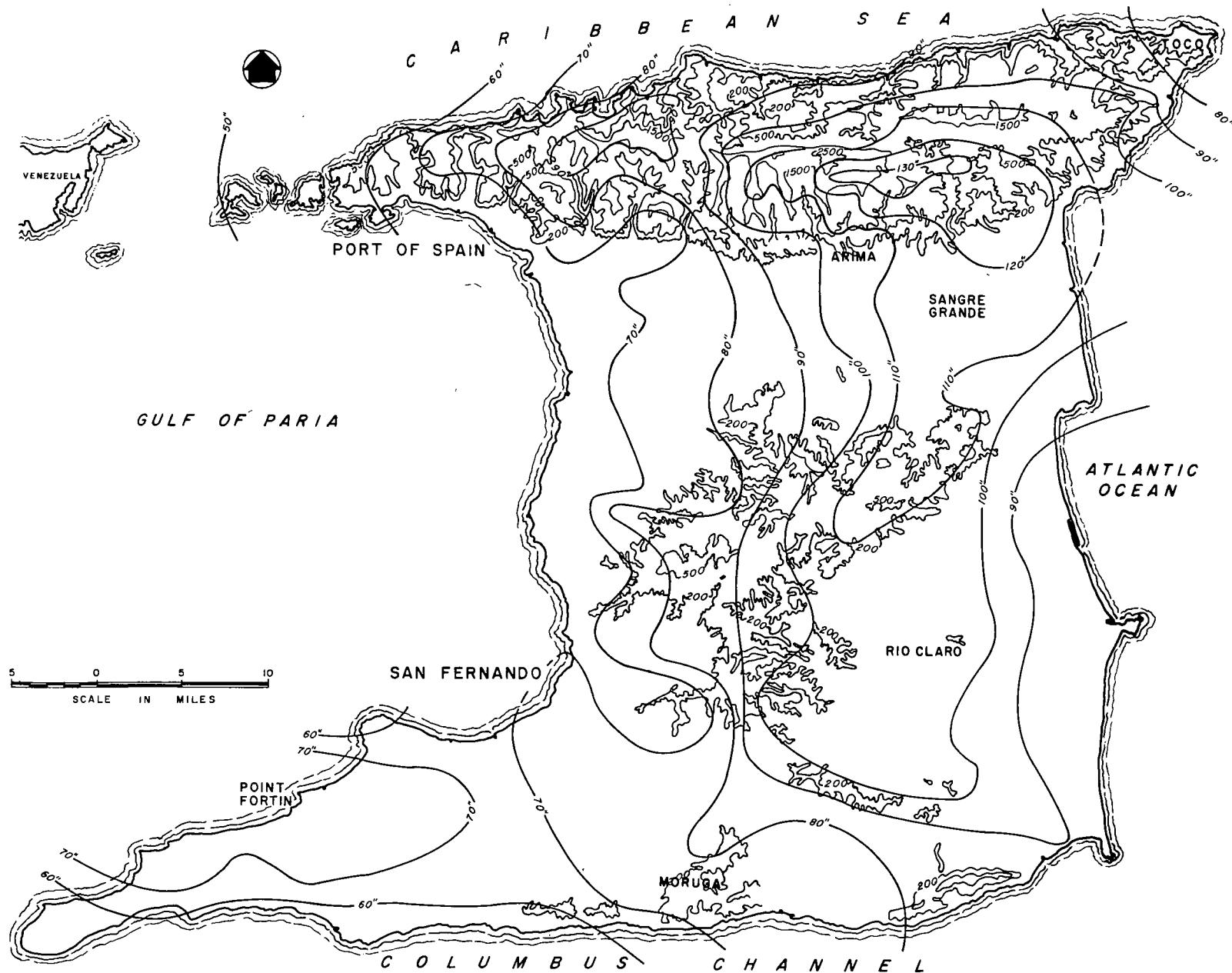


FIG. 9 TRINIDAD MEAN ANNUAL RAINFALL

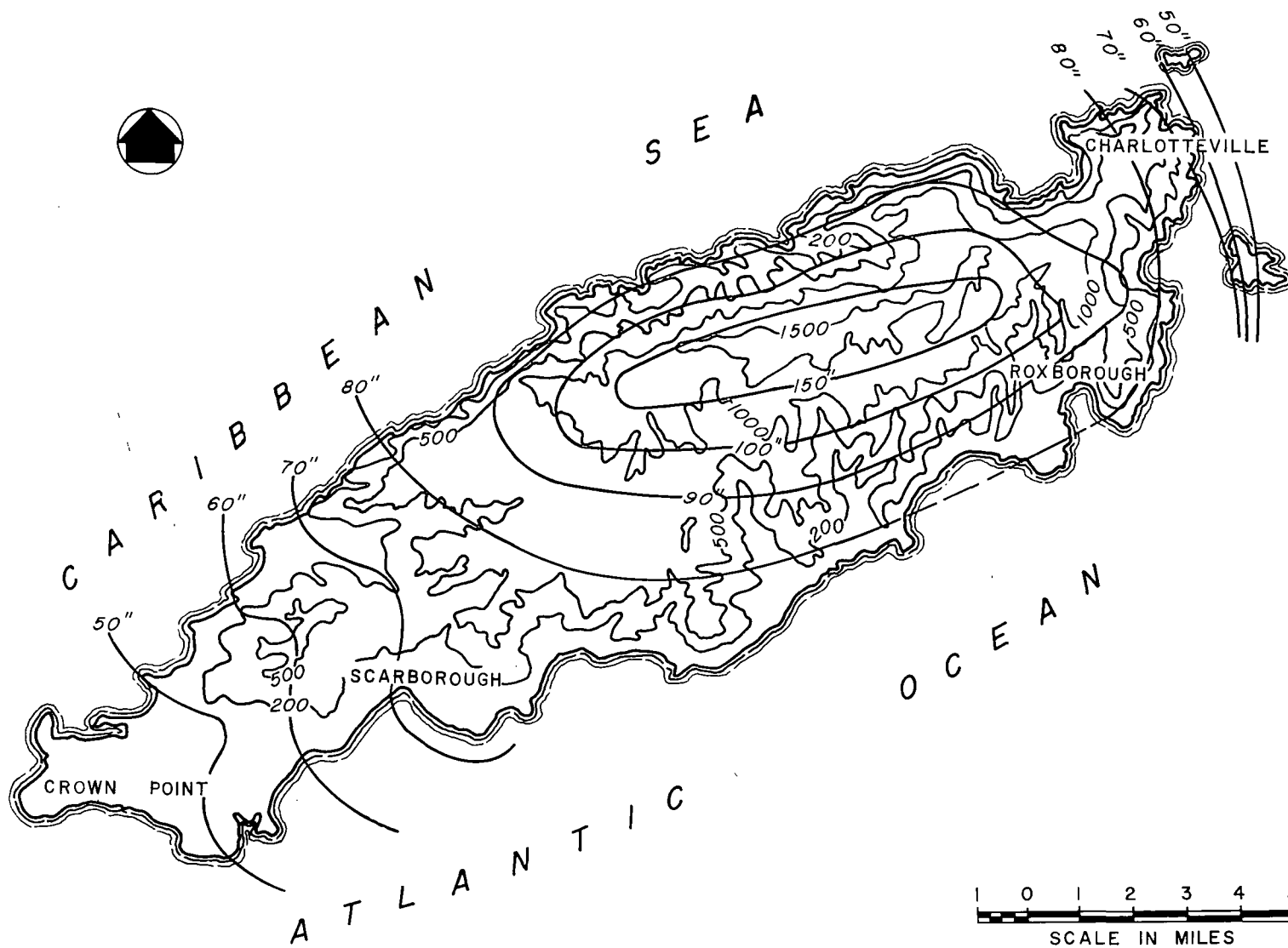


FIG. 10 TOBAGO MEAN ANNUAL RAINFALL

topographic maps to make a preliminary selection of potential surface water sources for additional investigation.

First, the topography of the watersheds within the high precipitation zones was studied and tentative damsites selected. Next, working with Lands and Surveys instrument plots and topographic maps at 1:10,000 scale, the watershed area and possible storage capacities were determined.

The third step in the selection process involved a study of known geologic features at the selected sites followed by a field trip to each site which appeared geologically satisfactory and was so situated geographically as to be considered for first-stage development.

As previously indicated, Trinidad's present water requirements and projected future demand are geographically concentrated in a T-shaped area with the stem extending from Curepe southward to the San Fernando area, and the top extending in an east/west direction along the base of the Northern Range from Arima to Chaguaramas.

The zones of highest precipitation contiguous with this area are along the eastern end of the Northern Range from about the Arouca River to the Matura River, and in the central portion of the Central Range. For ease of reference, these areas are referred to in this report as Zones 1 and 2, respectively. Since Zone 1 (the Northern Range area) is closest to the area in which the existing and projected future water demand is highest, the first sites canvassed were in this zone.

Examination of the topography, active land development, and basin geology narrowed the number of potential reservoir sites as indicated in Table 21.

Dependable Yield

The reservoir sites not eliminated in the preliminary canvass were considered to be satisfactory for development. Accordingly, prior to field investigations, studies were made to determine probable yield and cost of development including pipelines for transmission.

Because the dry season is about five and one-half to six months long with eight percent or less of the annual rainfall occurring in that period, water for use then must be stored. In addition, because of lawn and shrub irrigation, more frequent bathing, and other forms of use, water demands reach their peak in the dry season. Accordingly, wherever possible, storage has been sized to allow a dry-season draft of 1.25 to 1.5 times the dependable yield of the source, after allowance for evaporation losses from the reservoirs. The dependable yield is taken as the yield to be expected in a 95 percent dry year (a year with a five percent chance of occurrence or which may be expected to occur with a frequency of 1 in 20). Rainfall data for Trinidad and Tobago have been recorded for a long enough period of time to allow for most areas a reasonably good determination of the amount of rainfall to be expected in a 95 percent dry year. The limited runoff data available, up to six years at the Navet Reservoir, are sufficient to indicate probable runoff patterns for specific

Table 21. Summary of Preliminary Watershed Canvass

<i>Watershed</i>	<i>Zone</i>	<i>Action</i>
Trinidad		
Arima River	1	Eliminate — basin developed and no suitable damsite.
Aripo River	1	Eliminate — catchment too small and poor damsites.
Guanapo River	1	Consider for first stage.
North Oropouche River	1	Consider for first stage.
Matura River	1	Consider for first stage.
Salybia River	1	Eliminate — catchment too small, no suitable damsites.
Tompson River	1	Eliminate — fault down center of valley.
Grande Riviere	1	Eliminate — fault down center of valley.
Shark River	1	Eliminate — too steep and small.
Matelot River	1	Eliminate — too small, no suitable damsite.
Madamas River	1	Consider for future supply.
Paria River	1	Eliminate — too small, no suitable damsite.
Marianne River	1	Consider for future supply.
Yarra River	1	Consider for future supply.
Caroni-Arena River	1 & 2	Consider for first stage.
Caura River	West of 1	Eliminate — poor damsite, low yield.
Tumpuna River	2	Consider for first stage.
Talparo River	2	Consider for first stage.
Cunapo River	2	Consider for future or local development.
Couva-Chickland River	2	Eliminate — low yield.
Pure River	2	Eliminate — no satisfactory reservoir site.
Ortoire River	2	Eliminate — no satisfactory reservoir site.
Navet River	2	Consider for pumped storage project first stage.
Moruga River	South coast	Consider for future supply.
Tobago		
Courland River		Consider for future supply.
Richmond Great Dog River		Consider for future supply.

catchment areas in each rainfall zone, provided some runoff data are available for a catchment area with similar geology,

topography, and land use or ground cover. The runoff data available in Trinidad cover years with precipitation approximately equal

to the mean. Therefore, seasonal runoff distribution and total runoff should be representative of normal or average conditions, and should allow a fairly accurate estimate of average yield for the watersheds measured and for similar watersheds in the same rainfall zone.

In Table 20 the watersheds listed are grouped according to location and similar catchment conditions. The location of each catchment is shown on Figure 11.

The variations in percent runoff for the Navet watershed over the six-year period of record demonstrate that, with the shower-type storms which prevail in Trinidad, antecedent moisture conditions and storm frequency during the wet season have a strong influence on annual and seasonal runoff. However, on the basis of rainfall data available for the general area, the 95 percent dry-year rainfall should be about 78 inches and total dry-year runoff should be 20 to 25 percent of rainfall, or 16 to 20 inches. Gross runoff at the Navet Reservoir for the 95 percent dry year would range from 1,615 to 2,020 million gallons, equivalent to between 4.5 and 5.4 mgd. After reducing the yield by the amount of evaporation from the free reservoir surface, the dry-year watershed yield was estimated at around 4.0 mgd.

Navet Reservoir storage capacity is 4,100 million gallons, or about 315 million gallons more than the average annual runoff for the six years of record. With this reservoir capacity, water stored during years of excess runoff can be used during a two- to three-year dry period, thereby increasing the 95 percent dry-year yield to about 7 mgd. Generally, provision of storage capacity in excess of, or

even equal to, average annual runoff cannot be justified economically. However, the desirable effective storage for optimum watershed development in hydrographic areas like Trinidad and Tobago may approach three-quarters of the average annual runoff, especially where 90 percent or more of the runoff occurs in the wet season. Desirable storage capacity for optimum development of watersheds where the wet season runoff is around 75 percent of annual runoff may range from about 40 to 50 percent of average annual runoff.

Table 22 lists the potential reservoirs (shown on Figure 12), their catchment areas, effective storage, mean annual rainfall, estimated dependable yield, and the dam height. Storage capacity for the northern area reservoirs is, where possible, around 50 percent of estimated average annual runoff. For the central area and Tobago it is about 75 percent of estimated annual runoff.

Required Treatment

The raw water quality for the watersheds listed in Table 22 is strongly influenced by land use. Generally, those watersheds utilized for forests or forest-type crops such as cocoa, citrus fruit, etc., will produce a less turbid water than will those used for other forms of agriculture such as truck farming, sugarcane cultivation, or dairy farming.

Lands used extensively for sugarcane cultivation may produce water rather heavily contaminated by insecticides and herbicides. Since most of these chemicals are quite stable, they are not naturally removed while the water is in storage. In addition, they are not easily detected in the water supply.

Table 22. Potential Reservoirs

	<i>Potential reservoir</i>	<i>Catchment, sq mi</i>	<i>Flowage, acres</i>	<i>Storage, mil gal</i>		<i>Mean annual rainfall, inches</i>	<i>Esti- mated yield, mgd</i>	<i>Type dam</i>	<i>Dam height, ft</i>	<i>Land ownership</i>
				<i>Total effective</i>	<i>Per square mile</i>					
NORTHERN RANGE AREA	Trinidad									
	North Oropouche River	20.5	1,140	10,000	500-	120 to 130	45	Rock-fill	258±	All required is Crown lands
	Matura River	13.9	490	5,500	400±	120+	20	“ “	180±	Same
	Guanapo River	10.0	160	2,200	220±	110+	10	“ “	138	Estate and Crown lands
	Yarra River	13.4	520	4,000	300	85+	9+	Earth	86±	Mostly estates
	Marianne River (site “A”)	13.2	400	4,000	300+	90+	10	Rock-fill	98+	“ “
CENTRAL AREA	Madamas River	18.3	300	4,000	220	95+	18	“ “	175	“ “
	Caroni-Arena River ⁽¹⁾	150.0	861	3,500	23+	90+	33	Earth	63	Most required is Crown lands
	Talparo River ⁽²⁾	2.9	260	1,400	480	85+	2	“	99	Crown lands
	Tumpuna River ⁽²⁾	4.5	350	1,300	290±	90+	3+	“	52	Crown lands
	Cunapo River	4.4	305	1,300	300-	100+	3+	“	41±	90 percent Crown lands
	Moruga River	31.5	2,000	10,000	290±	80+	25	“	56	Oil reserve lands
Tobago										
	Courland River	10.8	804	4,000	370	65+	6	“	43	Estate lands
	Richmond River	4.4	74	1,350	300+	80+	3	“	43	Estate lands

1. Includes all watershed above Kelly headworks at Caroni with pumped storage at Arena.

2. With the Caroni-Arena project, Talparo and Tumpuna reservoirs increase the yield by 9 mgd, or 4± mgd more than if developed separately.

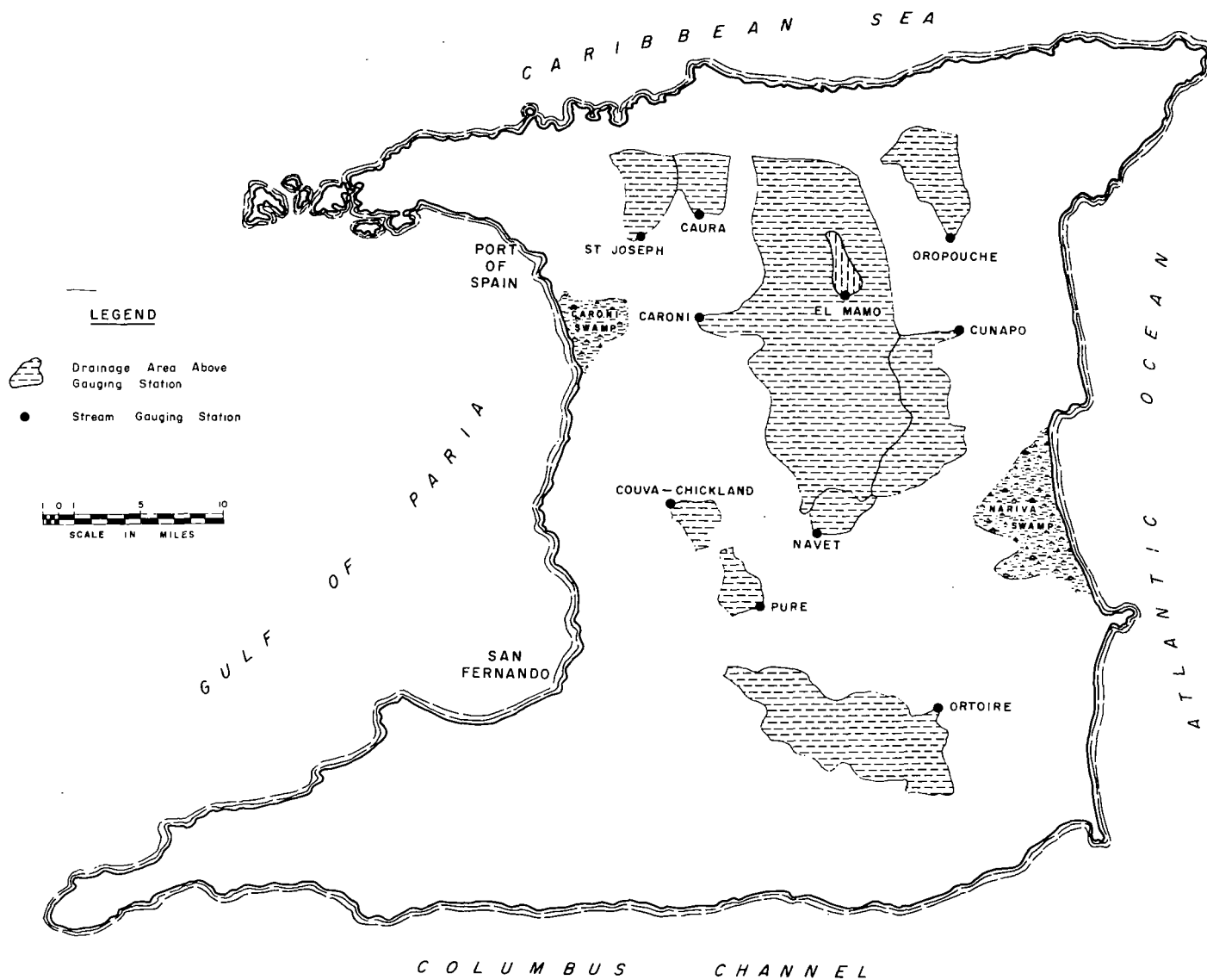


FIG. 11 KEY WATERSHEDS

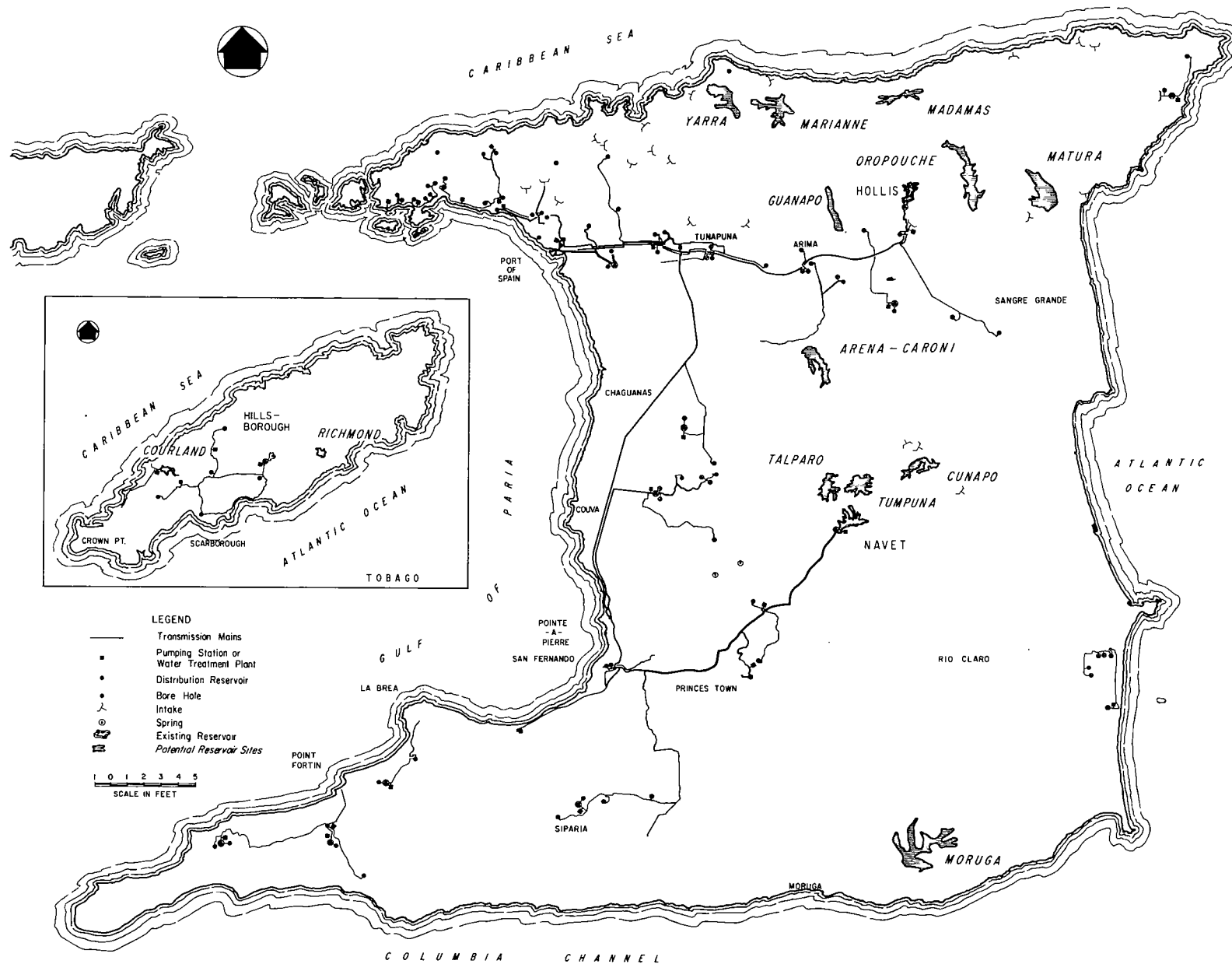


FIG. 12 POTENTIAL RESERVOIRS

Accordingly, catchment areas used extensively for a type of agriculture with heavy dependence upon chemical means of pest and weed control are less attractive for initial watershed development than are those without this potential source of water contamination.

In Trinidad and Tobago the crop most heavily dependent upon chemicals for weed and pest control is sugarcane, although increasing use is being made of chemicals in the citrus industry and on the truck farms.

Treatment for turbidity removal and disinfection would be required for water produced from any of the watersheds investigated. Table 23 indicates the probable raw water quality and the type of treatment required for the potential reservoirs investigated.

The values shown in Table 23 for the potential sources in Trinidad are based on the results of laboratory tests conducted by WASA upon samples of water collected by the Consultant. The values shown for the

Table 23. Raw-Water Quality and Required Treatment

<i>Potential reservoir</i>	<i>Turbidity, JTU(1)</i>	<i>Hardness, ppm CaCO₃</i>	<i>B. coil, MPN(2)</i>	<i>Color</i>	<i>Required treatment(3)</i>
Trinidad					
North Oropouche River	0.5 to 5.0	160±	1,800+	15±	c,s,f,d
Matura River	0.5 to 5.0	150±	1,800+	20±	c,s,f,d
Guanapo River	0.5 to 5.0	100±	1,800+	25±	c,s,f,d
Yarra River	0.5 to 5.0	90±	1,800+	20±	c,s,f,d
Marianne River	0.5 to 5.0	200±	1,800+	25±	c,s,f,d
Madamas River	0.5 to 5.0	200±	1,800+	20	c,s,f,d
Caroni-Arena	10 to 200+	70±	1,800+	100±	c,s,f,d
Talparo River	0.5 to 5.0	130±	1,800+	70+	c,s,f,d
Tompire River	0.5 to 5.0	130±	1,800+	70+	c,s,f,d
Cunapo River	0.5 to 5.0	130±	1,800+	70+	c,s,f,d
Moruga River	5 to 10	40±	1,800+	70+	c,s,f,d
Tobago					
Courland River	5 to 10	-	1,800+	25±	c,s,f,d
Richmond	5 to 10	150±	1,800+	25±	c,s,f,d

1. Jackson turbidity units.

2. Most probable number per milliliter.

3. c = coagulation; s = sedimentation; f = filtration; d = disinfection.

Tobago sources are based on tests of samples collected by WASA from the present water supply schemes utilizing these sources.

The value of 1,800+ for the most probable number of coliform of the B. coli type represents the maximum number reported, that is, beyond 1,800 no attempt was made to determine the probable number of organisms per ml (milliliter). However, the plate counts for the confirmation tests indicated a higher number of organisms for the Caroni by a considerable margin over the other sources checked (30± times as many colonies). This is attributed mainly to the fact that the Caroni watershed is extensive and that raw, domestic, farm, and industrial

wastes are discharged directly into the river and its tributaries.

Potable Water Standards

The degree of treatment recommended in Table 23 is that considered necessary to approach the goals adopted by the American Water Works Association (AWWA) and meet the recommended standards of the United States Public Health Service (USPHS).

It is recommended that WASA adopt the potable water quality goals of the AWWA as long-range objectives and immediately strive to conform as closely as is possible to the quality limits of the USPHS. These goals and the USPHS limits are summarized in Table 24.

Table 24. Potable Water Quality Goals and Limits

<i>Characteristic</i>	<i>AWWA Goal</i>	<i>USPHS limits(1)</i>
Physical		
Turbidity	Less than 0.1 unit(2)	Less than 5 units
Nonfilterable residue	Less than 0.1 unit	-
Macroscopic and nuisance organisms	None	-
Color	Less than 3 units	Less than 15 units
Odor	None	Threshold odor No. 3
Taste	No objectionable	
Chemical in mg/L		
Chloride	-	Less than 250
Aluminum (Al)	Less than 0.05	-
Iron (Fe)	Less than 0.05	Less than 0.30
Manganese (Mn)	Less than 0.01	Less than 0.05
Copper (Cu)	Less than 0.20	Less than 1.00
Zinc (Zn)	Less than 1.00	Less than 5.00
Filterable residue	Less than 200.0	-
Carbon-chloroform extract (CCE)	Less than 0.04	Less than 0.20
Methylene-blue-active substances (MBAS)	Less than 0.20	-
Bacteriologic Factors		
Coliform organisms by (mtf)(3)	None	(Allowed in a percentage of samples.
Coliform organisms by (mf)(4)	None	(See "standard methods".
Radiologic Factors		
Gross beta activity	Less than 100 pc/l	1,000 pc/l

1. United States Public Health Service.

2. Standard units (see Standard Methods for Examination of Water and Waste Water, AWWA).

3. Multiple-fermentation techniques.

4. Membrane filter techniques.

CHAPTER 7

GROUNDWATER SOURCES

General

This chapter describes the groundwater resources of the islands of Trinidad and Tobago. Particular emphasis is placed on the ability of known groundwater sources to sustain current withdrawals and the determination of additional quantities of water that might be available. Limitations as to groundwater development are discussed for those aquifers where overdrafts are evident. Additional sources are described, although the lack of more complete data precludes really significant evaluation of their potential for development. Recommendations are also made for conserving groundwater supplies by means of artificial recharge, reducing withdrawal rates, and relocating well fields to maximize the use of the available groundwater.

The study is limited largely to the island of Trinidad. Available geologic data indicates that Tobago's groundwater resources are meager. They are briefly described in this chapter. A fuller evaluation of Tobago's groundwater resources will require the collection of additional hydrologic data including rainfall intensity and distribution, stream flow data, and geologic mapping. Water resources survey work in Tobago and on the north coast of Trinidad was not included in M. M. Dillon's terms of reference, and no data on these districts were available.

Most of this evaluation is based on hydrologic studies made by M. M. Dillon, Consulting Engineers, in cooperation with the Government of Trinidad and Tobago. Among other available studies is the report by de Verteuil (1968) which describes the major aquifers in Trinidad and makes estimates of the quantities of groundwater available from them. These aquifers have been delineated in unpublished maps prepared by K. M. W. Marshall, former geologist in the Ministry of Petroleum and Mines. Additional information on groundwater supplies and related hydrologic data have also been made available by the Trinidad Water Resources Survey, the WASA, the Ministry of Petroleum and Mines, the Ministry of Agriculture, the University of the West Indies, and a number of petroleum companies. In addition, numerous individuals from the above-mentioned agencies have generously contributed information for this study.

Groundwater Resources of Trinidad

Groundwater is found throughout most of Trinidad. Its availability is dependent on a number of geologic and hydrologic parameters which will be discussed subsequently. The importance of groundwater supplies is evidenced by the fact that about two-thirds of Trinidad's current water supply is taken from groundwater aquifers. There are excessive withdrawals from some of these

aquifers. Reduction in pumpage will be required to maintain their usefulness as sources of fresh water supply. It is expected that these reductions can be made by a redistribution of pumping centers or from groundwater sources as yet not fully developed. However, future development, especially in the northern part of Trinidad, will require greater reliance on surface water sources. Transmission and development costs would preclude the use of potential surpluses from central and southern aquifers. A complete realization of Trinidad's groundwater potential cannot be attained without more detailed hydrologic studies.

Geology

The island of Trinidad is made up of five physiographic provinces, all of which roughly parallel each other along an east-west direction. These, in the order of their location, are the Northern Range, Northern Plain, Central Range, Southern Basin, and the Southern Range.

The Northern Range is made up of the oldest known rocks on the island. They are of Jurassic and Cretaceous age and include principally metamorphic and sedimentary rocks of schist, phyllite, limestone, and shale. The rocks are not believed to be an important source of groundwater and no major well supplies are expected to be developed from them. Of greater importance are the sand and gravel aquifers in alluvial valley fill, especially in the southwestern part of the Range where they are relatively thick and widely distributed in the larger valleys. Their importance as groundwater sources in the rest of the Range, however, diminishes with their less widespread occurrence and suspected

shallower depth in narrow valleys. Other major sand and gravel aquifers are found in alluvial fans which flank the southern edge of the Range. The fans consist mostly of sediments deposited by streams at the foot of southerly draining valleys in the Northern Range. They attain a maximum thickness of over 500 feet near El Socorro and become progressively thinner toward the east. Generally, the fan deposits are coarsest near the mouth of valleys and become increasingly finer radially outward.

The fans form the northern limits of the Northern Plain, where in places they have been modified into a series of marine terraces formed by the progressive lowering of the sea level since Pleistocene times. To the south, the Plain is underlain at varying depths by sediments (mostly clays) which are older in age than the fan deposits. Some extensive artesian aquifers are found in the clays and are an important source of industrial and municipal supplies in west-central Trinidad. These aquifers comprise two distinct sandy horizons, the Sum Sum and the Durham sands, in the Talparo Formation which consists mostly of clay and silt. The sands outcrop within a narrow band in the south-central part of the Northern Plain. They become progressively deeper toward the west and north and are overlain by thick sequences of clay and silt which confine water within them. The sands have been segmented by a series of northwesterly trending faults whose principal effect has been to limit groundwater interflow between adjoining sand bodies. Thus, where sands have been significantly offset by faulting, they form distinct aquifers which are not connected hydraulically. Extensive sandstone deposits also occur in formations older than Talparo along the

southern limits of the Northern Plain. These deposits may have some potential for groundwater development but at present are not a source of major supplies. Information on their water-bearing character is presently lacking, and detailed investigation is needed before valid estimates can be made.

The Central Range is primarily made up of clay, shale, and marl and has little or no potential for large-scale groundwater development. Scattered areas of permeable reef limestone are reported which may yield moderate supplies. The lack of exposure to recharge from rainfall and the limited area of these deposits probably limit significant withdrawal of groundwater.

A thick sequence of sediments underlies the area just south of the Central Range where it forms the Southern Basin. The sediments are predominantly clayey in the northern half of the Basin, but become progressively sandier to the south. The principal water-bearing materials are sand layers in the Morne L'Enfer, Erin, and Mayaro formations. Other sandy aquifers may occur in the Moruga Formation along the southwestern edge of the Basin and in parts of the Southern Range. Groundwater is developed from the Morne L'Enfer and Erin formations at the western end of the Basin. The central part is predominantly underlain by nonwater-bearing clay and silt deposits, although toward the east and southeast the Basin sediments include sandy aquifers in the Mayaro Formation and also in the Moruga Formation whose potential for development is presently unknown. The Authority is currently drawing water from the Mayaro Formation at the extreme eastern end of the Basin.

Hydrology

The principal source of groundwater is rainfall which percolates through the soil mantle to the water table. Most rainfall, however, is lost by evaporation, plant transpiration, and direct surface runoff. Under natural conditions, that part of the rainfall which reaches the water table sustains an essentially hydrologically balanced groundwater system in which, on the average, recharge equals discharge out of the system. In major aquifers, the effect of seasonal variations in recharge becomes negligible in relation to the total volume of water stored within them.

Hydrologic imbalances have been created in some aquifers where groundwater withdrawals exceed recharge. Water levels, as a result, are steadily declining. In some coastal areas, pumping is also diverting groundwater flow required to maintain a stabilized fresh-saltwater front. The lowering of water levels or reversal of groundwater flow toward inland pumping centers has caused salt water to intrude into some coastal aquifers. This condition is evident at the El Socorro well field, where average chloride levels have steadily risen from 50 ppm (parts per million) in 1966 to 205 ppm in 1969.

Other imbalances are the result of impermeable man-made structures such as buildings and pavements, which are limiting recharge opportunity to aquifers in urban areas. The magnitudes of such imbalances are unknown, and they may be somewhat offset by infiltration of sewage effluent from on-lot sewage disposal and from leaking water mains.

Sizable reductions in annual recharge, especially in the Diego Martin and Port of Spain areas, will severely limit groundwater development from the existing coastal well fields.

In inland areas of formerly high water table, some beneficial effects can result from lowering water levels by pumping thereby making additional aquifer storage capacity available for recharge from rainfall and stream flow infiltration. Lowering water levels can also cause an increase in the available groundwater supply through a reduction in losses from evapotranspiration.

Direct recharge from rainfall is the most important source of groundwater in the major aquifers. The average yearly rainfall in Trinidad ranges from 60 to 130 inches of which about 92 percent falls during the wet season, which begins in June and ends in December. Because of a potentially high evapotranspiration rate that reaches as high as 64 inches annually (Smith, 1965), little if any of the dry-season rainfall during January to May becomes available for recharge. On the basis of studies by Smith (1965 and 1968), evapotranspiration during the wet season is estimated at about 30 inches. Available stream-flow data in areas with less than 100 inches of annual rainfall, in which most major aquifers are located, similarly indicate that about 30 to 40 inches of the wet-season rainfall is lost, mostly by evapotranspiration.

In determining potential groundwater supplies, a value of 30 inches for wet-season evapotranspiration was used. Wet-season rainfall island-wide is estimated to be about 80 percent of the mean annual rainfall. The effective rainfall during the wet season which

contributes to both aquifer recharge and direct surface runoff is equal to the wet-season rainfall less evapotranspiration. Although little information is available for determining direct runoff, studies by Smith (1965) suggest that it totals about 10 percent of the wet-season rainfall in most lowlying aquifer areas but that it can be 20 percent or more in mountainous and developed urban areas. Estimates of recharge using these values for evapotranspiration and direct runoff are more or less in agreement with those determined by a more detailed analysis of pumping and water-level relations.

Principal Groundwater Areas

The known major groundwater areas include the Northern Valley Aquifers in alluvial deposits at Chaguaramas, Tucker Valley, Diego Martin and Port of Spain; the Alluvial Fan Deposits at El Socorro, Valsayn, Tacarigua and Arima; the Artesian Aquifers in the Sum Sum and Durham sands; the reef limestones of the Central Range; and sands in the Erin, Morne L'Enfer, and Mayaro formations of southern Trinidad (see Figure 13). Detailed information on their subsurface distribution and thickness is available in reports prepared by Dillon (1968). Other potential areas for groundwater development are also shown and include predominantly sandy facies of the Manzanilla and Moruga formations located, respectively, in central and southeastern Trinidad.

Their area of outcrop as shown is based on a geologic map by Kugler (1959). Smaller supplies may be available from alluvial sediments along numerous streams throughout Trinidad and possibly from limestone deposits in the Northern Range.

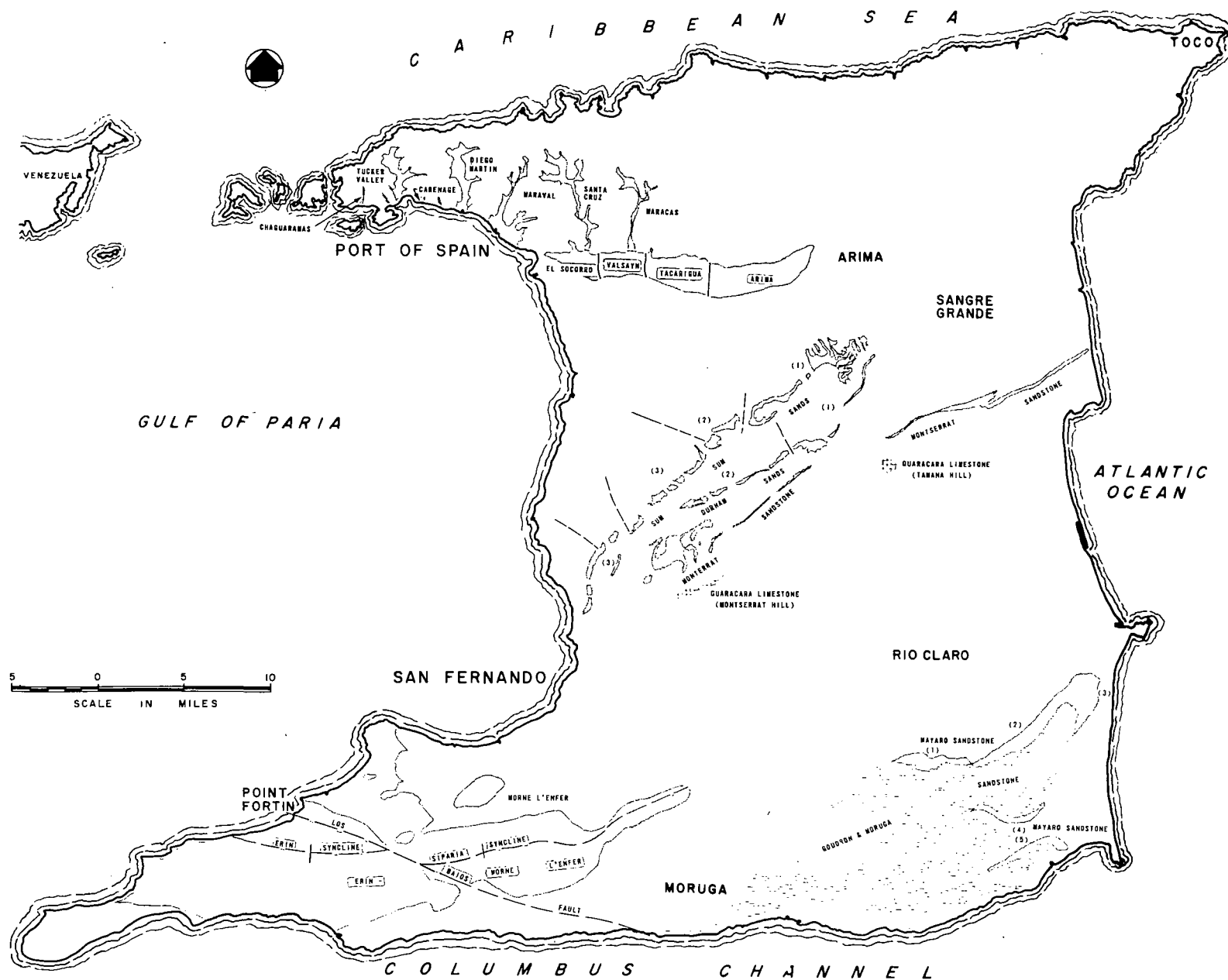


FIG. 13 GROUNDWATER AQIFERS IN TRINIDAD

The most promising areas for development are in the alluvial fill of the southerly draining Santa Cruz and Maracas valleys in the central part of the Northern Range. The upper part of the Santa Cruz Valley is underlain by as much as 100 feet of fill, which, if sufficiently permeable, should be capable of yielding 50,000 gpd or more to a well.

Northern Valley Aquifers. The deposits of alluvium lying in bedrock valleys along the southern coastal areas of northwestern Trinidad are referred to collectively as the Northern Valley Aquifers. The principal aquifers are the Chaguaramas, Tucker Valley, Diego Martin and Port of Spain.

Typically, the aquifers thicken and widen rather abruptly within 2,000 to 4,000 feet of the coast. The thickening is caused by a sharp increase in bedrock depth associated with fault zones paralleling the coast.

Numerous wells, both public and private, are at present withdrawing a total of about 14 mgd. A large number of these wells is near the coast. The lowering of water levels by pumping has produced a landward migration of the fresh-saltwater interface. The resultant rise in chloride levels has forced some reduction in pumping rates for the purpose of maintaining a stable fresh-saltwater front.

Estimated available groundwater supplies which can be developed from each aquifer without causing a serious inland migration of salt water are as follows:

<u>Aquifer</u>	<u>Mgd</u>
Chaguaramas	1.8
Tucker Valley	6.0
Diego Martin	4.5
Port of Spain	4.0

These quantities are already being exceeded in the Diego Martin and Port of Spain aquifers. Groundwater withdrawals from them average 6 mgd for each source. The difference between pumpage and the available groundwater may be made up by secondary recharge probably originating as leakage from pipelines and seepage from sewage disposal systems. A reduction of this leakage may be expected to significantly lessen the amount available for pumping. Additional groundwater amounting to 2 mgd is estimated to originate in the inland portions of the Port of Spain aquifer as base flow in the Maraval River. A part of this water is currently diverted by an intake on the river. Any development of well supplies upstream from the intake would therefore decrease the flow component of the river, thereby limiting surface water diversions especially during the dry season when stream flow is at a minimum.

Available groundwater in Chaguaramas and Tucker Valley exceeds present pumpage, which totals about 0.5 and 1.4 mgd, respectively. Additional development is possible although some relocation of coastal wells to inland areas may be required to prevent contamination by salt water.

Alluvial Fan Aquifers. The fans adjoin the southern edge of the Northern Range where they extend from Port of Spain to a point east of Arima. Their southern limit

roughly parallels the Churchill-Roosevelt Highway.

Groundwater withdrawals from these totaled nearly 17 mgd in 1968, all developed from wells tapping sand and gravel in alluvial fan deposits.

Four major groundwater systems are recognized within these deposits. They are the El Socorro, Valsayn, Tacarigua and Arima aquifers (see Figure 13). Very little hydraulic connection is believed to exist between them since the fan deposits tend to become finer and less permeable away from the mouths of streams which formed them.

Groundwater in the fan aquifers is found under water-table and artesian conditions where it is confined by extensive clay and silt layers. It is estimated that recharge to these aquifers annually averages 17 mgd, most of which is from rain falling directly on the fans. However, significant amounts of water, estimated at a minimum of 15 percent of the total recharge in the El Socorro and Valsayn aquifers, enter the aquifer by stream flow infiltration (Dillon, 1968). Recharge also takes place as underflow from the adjoining bedrock and the contiguous alluvial fill in the Northern Range. In the deeper artesian aquifers, recharge is by leakage through the overlying clay and silt layers.

Pumping from wells develops the greater portion of the present groundwater discharge out of these aquifers. Prior to major development, discharge probably occurred principally along seepage facies and from springs in low-lying swampy areas along the southern extremities of the fans, and to streams crossing them.

(1) *El Socorro Aquifer.*
Groundwater development from the El Socorro Aquifer started in 1959. Since that time withdrawals have increased from 0.4 to 6.8 mgd by 1968. These increases have been accompanied by a steady decline in water levels to a total of about 30 feet. Current water levels are over 20 feet below sea level and are expected to continue to decline at a rate of up to 5 feet per year if pumping continues at the present rates of 6 to 7 mgd. The extraction of such quantities has effectively intercepted all of the natural groundwater outflow and, starting as early as 1965, has been causing salt-water intrusion into the aquifer.

Estimates of recharge indicate that groundwater storage during the past several years is being depleted at a rate of about 2 mgd, with total recharge estimated at 4.5 mgd. A consequence of overpumping has been a continued rise in the salinity of groundwater, which is of primary concern as it limits development at existing rates of withdrawals. It is expected that the salinity will increase as long as water levels in the aquifer remain substantially below sea level.

Available information indicates that saline waters are entering the upper part of the aquifer from tidal bodies in the Caroni Swamp. Chloride levels of up to 1,200 ppm are reported in a well located near the swamp toward the southwestern edge of the aquifer. The rate and distribution of the intruding salt water, however, remains unknown. More detailed information will be required to determine means to limit further encroachment by artificial recharge or by establishing withdrawal rates which can be maintained without causing additional salt-water contamination.

(2) *Valsayn Aquifer.* Excessive groundwater withdrawals since 1952 from the Valsayn Aquifer have caused water levels to decline up to 40 feet, or to 25 feet below sea level. Pumpage reached an average of 6.5 mgd during the period 1957 to 1961, and has since been reduced to about 6 mgd. It is expected that, at present pumping rates, water levels will continue to decline about 2 to 3 feet per year.

Recharge from rainfall and infiltration from the St. Joseph River is estimated at 5 mgd. The additional 1 mgd is therefore being mined from the aquifer.

Despite water levels that are well below sea level, there is no evidence of salt water entering the aquifer. This is attributed in part to the aquifer's greater separation from salt-water sources than the El Socorro Aquifer, and also because of a high proportion of less permeable sediments toward the edge of the fan deposits which are acting as a partial barrier against salt-water movement from coastal areas. There is no assurance, however, that such movement is not taking place, since it cannot be detected without monitoring water level and quality changes along the seaward margins of the aquifer.

(3) *Tacarigua Aquifer.* The boundaries of the Tacarigua Aquifer are not as well defined as those of the other alluvial fan aquifers, and estimates on recharge are less certain. On the basis of pumping and water-level comparisons with those of the Valsayn Aquifer, it is estimated that a total recharge of about 5 mgd is reaching the aquifer. An additional potential for

development is evident from present withdrawals of about 2.6 mgd, which have not significantly lowered the water table from its predevelopment position.

It is expected that the aquifer will be the least affected by salt-water intrusion because of its inland location, and that water levels could be drawn down below sea level for optimum development. It is not recommended that such development should exceed the average recharge for any prolonged period of pumping. However, temporary mining of groundwater might be feasible to meet critical water demands on a short-term basis.

(4) *Arima Aquifer.* Groundwater production to date in the Arima Aquifer has been limited principally by the lack of suitable sites for high-capacity wells. Predominantly sand and gravel layers are nevertheless reported in the upper part of the aquifer. The aquifer, which is more fully described by Dillon (1968), reaches a maximum depth of 300 feet below sea level and rapidly thins out to the south and east. The deeper deposits adjoin a major east-west trending fault along which sediments have been displaced downward relative to those north of the fault.

A tentative estimate of recharge to the Arima Aquifer indicates that at least 2 mgd could be developed from it. Production in 1968 totaled 0.8 mgd, of which 0.5 mgd was obtained from WASA's Arima well field, the remainder from their Arouca field. Poor aquifer productivity in the latter field is indicated by a water-level decline of over 100 feet since 1965, while those of the Arima

field have remained essentially the same at 120 to 150 feet above sea level since the start of operations in 1966.

The optimum utilization of this aquifer should be systematically investigated by test drilling for more productive well sites since information does indicate a relatively high sand and gravel content in the fan deposits, even where they thin out to the south and east.

Central Artesian Aquifers. These aquifers are a part of two extensive sand units, the Sum Sum and Durham sands of the Talparo Formation. The sands are generally permeable and capable of yielding 400 gpm (gallons per minute) or more to a well. They dip relatively uniformly in a west-northwest direction and range from less than 100 to 300 feet in thickness.

Groundwater withdrawals, which totaled 4.5 mgd in 1968, are mostly developed from aquifers in the Sum Sum Sands with major well fields located at Waller Field, Carlsen Field, Freeport, and Pointe-a-Pierre.

Total recharge to them is estimated at nearly 15 mgd, of which 11 mgd enters the Sum Sum Sands. Recharge is principally derived from rain falling on outcrop areas to the east. Some recharge might be gained by pumping to induce leakage through the overlying clay and silt deposits. A pumping test at Carlsen Field, however, indicated that these deposits are relatively tight and very little recharge by leakage can be expected from them. The aquifers are also believed to pinch out seaward where they are essentially closed off to salt-water bodies. Evidence of

this is the lack of any salt-water contamination in the Pointe-a-Pierre area where water levels have consistently been below sea level since 1945. Because of the relative lack of danger from salt-water intrusion, it should be possible to develop the aquifers at rates equaling recharge to them.

(1) *Sum Sum Sands.* The Sum Sum Sands have been divided into five major aquifer units (see Figure 13). This division is based in part on faulting where the sands have been displaced by 150 feet or more. It is also suspected that additional separation by faulting, as yet unrecognized, occurs in the sands to the north. As a result of major faulting, each aquifer unit is essentially hydrologically discontinuous and groundwater interflow between units is considered to be small.

Recharge to these aquifer units totals nearly 11 mgd, and is tabulated below:

<u>Aquifer unit</u>	<u>Recharge, mgd</u>
1	6.4
2	1.1
3	2.0
4	0.6
5	<u>0.6</u>
Total	10.9

It should be recognized that the recharge originating in one unit is mostly unavailable to adjoining units, and withdrawal from each aquifer should not exceed the rate of recharge.

A total of 4 mgd is being pumped from the Sum Sum aquifers. The Waller Field,

Carlsen Field, and Freeport well fields account for over 80 percent of the total pumpage.

(2) *Durham Sands.* The Durham Sands outcrop east of the Sum Sum Sands and underlie the latter sands to the west and northwest. Limited data from wells indicate that the Durham Sands have hydraulic characteristics similar to those of the Sum Sum Sands. Comparable well yields should therefore be available. Although geologic data are lacking, it is probable that the Durham Sands are segmented by faulting into distinct aquifer units. For purposes of this study the sands have been arbitrarily divided into three units which are shown on Figure 13. It is not known to what degree these units are hydrologically connected. More detailed studies are therefore required to establish the quantities of water that can be withdrawn without causing local overdevelopment.

Estimated recharge, derived from rainfall on outcrop areas, totals nearly 4 mgd. Of this quantity, 2 mgd originates in Area 1, 1.5 mgd in Area 2, and 0.2 mgd in Area 3, Figure 13. Present withdrawals of 0.6 mgd are developed from the southern end of Area 2 by WASA's Freeport-Todds Road well field.

Central Range Aquifers. In the Central Range, groundwater development is limited to the Guaracara limestone. Supplies totaling 0.3 mgd are obtained from several limestone springs in the Montserrat Hills area. The limestones of this area and at Tamana Hill are estimated to receive 1 and 0.8 mgd, respectively, from rain falling on their outcrop areas. Groundwater withdrawals approximating recharge might be feasible.

However, locating of such supplies will necessitate finding suitable well sites by test drilling since information on the hydraulic character of the limestones is lacking. Any major development of wells in the Montserrat Hills area may be expected to affect spring flow and reduce the amount of water now available from these sources.

Southern Aquifers. The southern aquifers include sands in the Erin, Morne L'Enfer, Mayaro and Moruga formations. These formations consist of clay, silt, and sand layers, the latter making up about 30 percent of the Erin Formation and 50 percent of the Morne L'Enfer. The sands, which are mostly fine-grained, are low to moderately permeable and capable of yielding up to 150 gpm or more to a well.

Groundwater withdrawals from the southern aquifers total 3.5 mgd of which over 90 percent is obtained from the Erin and Morne L'Enfer formations with the remainder from Mayaro. These supplies are developed from aquifers which contain groundwater under both water-table and artesian conditions.

Little information is available on the distribution of these aquifers and groundwater movement within them, but it is believed that the sandy aquifers in each of the formations in close proximity are to some degree hydraulically interconnected, and that at depth they confine groundwater less effectively than in the central artesian aquifers. Recharge originating at the land surface, therefore, is believed to reach the deeper aquifers through interconnected sand layers and as leakage through the confining

clay and silt deposits. The amount of such recharge is estimated to total 46 mgd and does not include quantities originating in the Moruga Formation. Of this amount about one-half, or 23 mgd, is estimated to be available for development without causing excessive salt-water intrusion.

The possibility of such intrusion is indicated by the proximity of salt-water bodies which both underlie and, in coastal areas, adjoin fresh groundwater in sandy aquifers. It is therefore essential to achieve a balanced program of groundwater development in which sufficient quantities of groundwater are allowed to discharge seaward in order to maintain a relatively stable fresh-saltwater interface. Excessive development is likely to cause both an upward and inland migration of salt water.

(1) *Erin and Morne L'Enfer Formations.* The Erin and Morne L'Enfer formations are widely distributed in southwestern Trinidad, where they are a major source of water supply. They occupy an easterly trending syncline which has been offset by the Los Bajos fault. The Morne L'Enfer, which underlies the Erin Formation, reaches a maximum depth of over 8,000 feet along the axis of the Erin syncline to the east. The groundwater body occupies mostly the overlying Erin Formation in the western half of the area, while occupying principally the Morne L'Enfer in the eastern half. Hydrologically, it is considered part of a single system in which groundwater flow is controlled mostly by less permeable layers of clay and silt. In inland areas, the groundwater body reaches a maximum depth of about 2,000 feet while toward the coast it generally

occurs at depths above 600 feet. Salt water underlies this body throughout the area.

Groundwater flow is believed to be predominantly seaward and a large part of it probably discharges directly to the sea as underflow. This flow is sustained by an estimated 36 mgd of recharge, of which 18 mgd or more is probably recoverable by properly located wells without causing serious salt-water encroachment. Present groundwater withdrawals of 3.3 mgd are developed from relatively widespread pumping centers.

(2) *Mayaro Aquifers.* Groundwater development is limited to sands which make up a high percentage of the Mayaro Formation. The principal aquifer is the Mayaro Sandstone which is found in southeastern Trinidad. Closely associated with it is the Coudron Sandstone, also of the Mayaro Formation, whose potential for groundwater development is unknown.

In this study, the Mayaro Sandstone has been divided into five subaquifers on the basis of outcropping areas and faulting (see Figure 13). The estimated recharge, which totals 10 mgd, is given below for each subaquifer:

<u>Subaquifers</u>	<u>Recharge, mgd</u>
1	2
2	3.5
3	2.5
4	1
5	<u>1</u>
Total	10.0

A potential development amounting to one-quarter of the recharge which originates

in each subaquifer is estimated to be available without causing serious salt-water contamination. Salt water is known to underlie the subaquifer area 3 at depths below 500 feet and presumably is found at similar depths in the other aquifer areas.

Current withdrawals from the Mayaro Sandstone total 0.2 mgd, all of which is from wells in the northern half of the subaquifer area 3.

Other Groundwater Areas

Moderate well supplies might be available from sandstones as yet undeveloped. These include the Montserrat glauconitic sandstone of the Manzanilla Formation in central Trinidad, the Coudron Sandstone of the Mayaro Formation, and a number of sandstone units in the Moruga Formation in the southeastern part of the island. Although presently not a source of groundwater supplies, their potential for development should be investigated.

The Montserrat Sandstone outcrops within a narrow easterly trending belt along the southern edge of the Northern Plain (see Figure 13). It has a general northerly dip which is modified to some extent by folding and faulting. The water-bearing character of these sandstones is not known. Consequently, test drilling will be required to determine ability to transmit water and to define aquifer units which may be segmented by faulting as are those in the Sum Sum Sands.

The Coudron Sandstones of the Mayaro Formation and sandstone units of the Moruga Formation outcrop extensively in southeastern Trinidad (see Figure 13). Their

large outcrop area indicates a high potential for recharge opportunity. For lack of other information, it is assumed that at best these sandstones are about as permeable as the Mayaro Sandstone and are probably as extensively underlain by salt water. The occurrence of salt water at depth is also indicated by two wells about 2 miles from the coast near the village of Moruga which encountered saline water in sands at depths less than 200 feet.

Water Quality

The major portion of the groundwater found in Trinidad is suitable for use as a public supply. Exceptions occur in areas where overpumping is causing contamination by salt water, along coastal areas and in some of the deeper aquifers in which saline water is found naturally. Restrictions on groundwater development because of a high salt content are presently limited to the coastal extremities of the Northern Valley Aquifers at Port of Spain, along the southeastern end of the El Socorro Aquifer, and in the deeper and coastal parts of the southern aquifers. Occasionally, chloride contents exceeding recommended limits of 250 mg/L are found in public supplies developed from some wells in Port of Spain and El Socorro. A high iron content is common in groundwater from the central artesian and southern aquifers, and treatment is usually required for its removal. Ranges in the iron content of untreated public groundwater supplies, based on analyses made in 1967, are listed in Table 25.

The groundwater has an overall range of pH of about 6 to 8. Total hardness is commonly less than 180 ppm. Hardness in excess of 180 ppm is found in groundwater

Table 25. Range in Iron Content of Untreated Public Groundwater Supplies

<i>Aquifer and well field</i>	<i>Iron, ppm</i>
Northern Valley Aquifers	0.0 – 0.2
Alluvial Fans	
a. El Socorro, Valsayn, Tacarigua and Arouca	0.0 – 0.3
b. Arima	0.0 – 2.9
Central Artesian Aquifers	
a. Freeport	5.5 – 10.9
b. Carlsen Field	1.0 – 2.4
c. Waller Field	0.0 – 0.1
Central Range Aquifers (Guaracara limestone)	
Morichal Spring	10.9 – 19.0
Southern Aquifers	
a. Erin-Morne L'Enfer	
1. Granville	0.5 – 1.7
2. Cap-de-Ville	0.1 – 0.5
3. Point Fortin	0.3 – 5.9
4. Penal	0.0 – 6.1
b. Mayaro	0.0 – 1.1

contaminated by salt water and water originating from limestone materials.

Groundwater Potential

Groundwater available from the principal aquifers in Trinidad is estimated to total 72 mgd of which about 39 mgd is being developed by public and large private supplies. Additional groundwater might also be available from sandstone aquifers, as yet undeveloped, in central and southeastern Trinidad. Table A-1 in Appendix A is a summary of available groundwater from the principal aquifers, the 1968 pumpage from each, and the proposed future development for each.

In Northern Valley Aquifers, additional groundwater totaling nearly 6 mgd is available from Chaguaramas and Tucker Valley. The

development of such supplies is based on existing land-use patterns. A reduction in groundwater recharge can be expected as a result of future urbanization. In anticipation of such reductions, plans should be made to balance such eventual losses by artificial means. The full development of Chaguaramas and Tucker Valley will also require wells to be located away from coastal areas to prevent contamination by salt water.

The Diego Martin and Port of Spain aquifers are fully developed at existing rates of withdrawal. Any increase in pumpage is expected to cause an inland migration of salt water which may result in the eventual abandonment of coastal wells. The apparent balance in these aquifers between the fresh and salt water is presumably maintained by secondary recharge from pipeline losses and the infiltration of wastewaters. The

curtailment of such recharge without reduction in pumpage might result in a substantial overdraft. Some additional groundwater in the Port of Spain Aquifer could be developed by a number of small to moderate capacity wells along the Maraval River. Such development, potentially as much as 2 mgd, would, however, limit surface diversions from the river, which now total 0.7 mgd.

The evident mining of groundwater from the El Socorro and Valsayn aquifers will require a reduction in pumpage to stabilize water levels and prevent further salt-water intrusion.

Pumpage from the El Socorro Aquifer should initially be cut back to 4.5 mgd to equal its recharge rate. There is no certainty, however, that even at such rates salt-water encroachment can be curtailed. On the basis of past pumping records, it may become necessary to maintain pumpage at an average rate of 2 mgd before adequate groundwater flow can be established to prevent further salt-water intrusion.

Although contamination by salt water is not apparent in the Valsayn Aquifer, the mining of groundwater at the present rate of 1 mgd should be stopped. The continued lowering of water levels may ultimately cause saline water to enter the aquifer. A reduction in pumping to 5 mgd, or the rate at which the aquifer is being recharged, will be required to stabilize water levels. Should salt water eventually enter the aquifer, it may become necessary to reduce pumping further, possibly to as little as 3 mgd.

Further increases in pumping are believed possible from the Tacarigua Aquifer. Since the aquifer is some distance from salt-water sources, it should be possible to develop it at a rate equaling recharge. This is estimated to total 5 mgd, of which 2.6 mgd are at present being developed.

Additional groundwater totaling at least 1 mgd is available from the Arima Aquifer. Such development should be preceded by a test drilling program to locate wells for optimum yield. Present production is limited by low-yielding wells.

Means to supplement existing groundwater deficits and to increase productivity should be investigated for the Alluvial Fan Aquifers. Some possibility for surface water spreading, or the use of recharge pits, is suggested by the relatively high infiltration rates from streams crossing the fans. Additional infiltration might be made available by increasing infiltration areas along streams for water-spreading purposes, or by river diversions to recharge pits. The suitability of such procedures is dependent principally on land availability and the physical quality and quantity of stream flow divertible.

Similar means to increase recharge might also be used at suitable sites in the Northern Valley Aquifers, where large quantities of storm runoff are currently wasted to the sea.

A large potential for development from the Sum Sum Sands exists north of Carlsen Field. Additional groundwater that can be developed here (Areas 1 and 2) total over 6 mgd. An additional 0.5 mgd is also available from aquifer Area 4 to the south. The

remaining areas are estimated to be fully developed. Groundwater production in the Freeport and Carlsen Field well fields is already exceeding the estimated available groundwater supplies in aquifer Area 3 by 0.5 mgd. Such excessive withdrawals will cause a gradual and continued decline in water levels. It is not believed that salt-water intrusion will become an immediate problem, but lowering of water levels will cause increased pumping costs.

Other supplies totaling nearly 4 mgd are available from the Durham Sands. Current withdrawals total only 0.5 mgd. Additional geologic data are required to determine hydraulic boundaries which might limit groundwater movement within the sands. This information will facilitate preparation of plans for proper development.

The feasibility of developing well supplies from the Guaracara limestone depends largely on its capacity to transmit water to wells.

Available supplies from the limestones are estimated at nearly 2 mgd, of which about half is available at each of two major outcrop areas. Any major development at the Montserrat Hills area, however, is expected to reduce the flow from limestone springs, of which 0.3 mgd is being used for public supplies.

Major additional supplies can be developed from aquifers in the Erin and Morne L'Enfer formations. Present production from these sources totals 3.3 mgd out of a total potential estimated at 18 mgd. Any additional development should be limited to inland areas to minimize any

contamination by saline waters. Pumping centers should be spaced widely apart to avoid serious interference by pumping. Depths of wells should be carefully regulated to prevent contamination by the upward migration of brines which underlie the Erin and Morne L'Enfer aquifers. Similar precautions are recommended for development of groundwater from the Mayaro Sandstone.

It is estimated that a total of about 5 mgd can be developed from the Mayaro Formation in five separate aquifer areas. The feasibility of such development should first be proven by test drilling in aquifer areas as yet undeveloped. This is needed to determine the location and water-yielding character of sand aquifers and the quality and quantity of groundwater that can be expected from them.

Tobago

The northern two-thirds of Tobago is underlain by either metasediments or igneous intrusive rocks. Both rock types are hard and impervious, and offer no potential for significant groundwater development. The bedrock is overlain by a mantle of residual solids too thin to serve as an aquifer.

The southern third of the island is composed of volcanics and metavolcanics, principally tuffs and tuff breccias. These rocks are highly fractured, and deeply weathered. In areas where sufficient above-sea-level depth can be obtained, the volcanics may produce quantities of water sufficient for domestic use.

On the southwestern tip of Tobago, the volcanics are overlain by deposits of sand, silt,

and clay. Near the coast, thicknesses of 400 feet have been recorded, with some thin sand and gravel zones. However, the bulk of the material is clay, and offers little potential for water supplies. In addition, the material was deposited in sea water, and presently lies predominantly below sea level. Thus, chloride levels would be high, and sea-water intrusion likely.

Most of the clastic sediments are overlain by coral limestone. It occurs in a thin layer up to 40 feet thick, at elevations below 100 feet. The coral is highly fractured and quite "rotten." Where it overlies impermeable clays,

water entrapment can occur, providing some groundwater potential. Available information indicates that yields are likely to be less than 50,000 gpd.

Deposits of sand and gravel are found in several of the river valleys near the coast. They are remnants of material deposited in salt or brackish water when the sea level was higher. Wells in the deposits can induce recharge from the nearby streams. When good hydraulic connection with the streams does not exist, the water from this source is likely to be high in chlorides.

CHAPTER 8

DEVELOPMENT OF POTENTIAL SOURCES

General

This chapter deals with the development problems and costs for each source identified as feasible in Chapters 6 and 7.

Groundwater development will require less lead time than will surface water development since no major structures are required. However, incremental units of groundwater development are limited to about 1.0 mgd per field. Therefore, the number of facilities required to meet existing average day needs and to provide adequate peaking capacity completely from groundwater are not readily developed. In addition, 20 mgd from groundwater at some 1.0 mgd per field would require many more operators than 20 mgd from a single surface water source. Accordingly, a combination of groundwater and surface water sources will best meet the needs of Trinidad and Tobago.

Groundwater

The largest undeveloped groundwater supplies are located in the southern area of Trinidad (see Figure 13), generally outside the area of heaviest water demand. However, some unexploited groundwater does exist in the area of heavy demand.

Within the southern area, not only is there a deficiency in developed supply, but many of the distribution mains are inadequate. Development of strategically

located groundwater supplies will reduce the amount of main reinforcement necessary and delay the need for some major work of a similar nature.

The same distribution and transmission deficiencies exist to a lesser extent in the area of major demand. Development of well fields here will also reduce the supply deficit and delay the need for major distribution reinforcement.

Table 26 lists the well fields proposed for development in Chapter 7, together with the estimated costs. These costs do not include allowances for engineering and contingencies, nor do they cover the transmission and distribution mains necessary to convey developed water to the users.

Development costs for groundwater supplies are estimated to range from a low of \$362,000 per mgd, in the case of the Tacarigua well field, to a high of \$1,464,000 per mgd for the Palo Seco well field. Most of the supplies of over 1.0 mgd are within a cost range of \$500,000 to \$900,000 per mgd.

Surface Water Sources

Table 27 lists the surface sources considered for development and the estimated full development construction cost of each, exclusive of the cost of transmission and distribution mains.

Table 26. Cost of Groundwater Development

Well field	Number of wells	Estimated yield, mgd	Estimated cost in \$1,000 TT			Per mgd
			Local	Foreign	Total	
Chaguaramas	16	1.3	493	383	876	674
Tucker Valley	29	4.6	1,092	986	2,078	542
Tacarigua	7	2.3	485	348	833	362
Arima	7	1.1	381	239	620	564
Waller Field	9	2.1	928	724	1,652	787
Las Lomas	13	3.0	1,333	1,103	2,436	811
Carlsen Field(1)	4	1.0	690	666	1,356	1,356
California	3	0.6	369	286	655	1,090
Freeport(2)	6	0.9	565	443	1,008	1,120
Los Armadillos	2	0.5	141	99	240	480
Penal(3)	8	1.3	816	689	1,605	1,235
Point Fortin	4	0.7	468	369	837	1,196
Cap-de-Ville(3)	5	0.8	549	418	967	1,209
Fyzabad	6	1.0	659	507	1,166	1,166
Clarke Road	6	1.0	659	507	1,166	1,166
La Brea	6	1.0	659	507	1,166	1,166
Palo Seco	3	0.5	412	320	732	1,464
Mayaro	12	1.0	597	375	972	972

1. Sum Sum Sand 2.

2. Durham Sand 2.

3. Includes water treatment plant expansion.

The estimated cost of development for the surface water sources requiring a dam and reservoir ranges from \$417,000 per mgd for the Moruga to \$1,657,000 per mgd for the Cunapo. The high-yield reservoirs in the Northern Range would cost around \$750,000 per mgd to develop, while the lower yield reservoirs in the same area would cost from \$800,000 to \$900,000 per mgd.

Comparison of Alternative Sources

Comparison of development costs in Tables 26 and 27 show that:

1. The cost of increasing Navet dependable yield from 7 to 17 mgd is the lowest supply development cost at \$240,000 per mgd;
2. The development cost of most groundwater from the northern aquifers is less than the development cost of most surface sources; and
3. The development cost of groundwater from the central and southern aquifers is greater than the

Table 27. Cost of Surface Water Development

Source	Estimated yield, mgd	Estimated cost in \$1,000 TT(1)			Per mgd
		Local	Foreign	Total	
North Oropouche	45	17,636	15,942	33,578	745
Matura	20	7,366	6,930	14,290	715
Guanapo	10	4,677	5,232	9,909	991
Yarra	9+	2,900	4,300	7,200	800
Marianne (Site A)	10	2,750	4,400	7,150	715
Madamas	18	7,140	6,490	13,630	756
Caroni-Arena)	42	12,055	11,437	23,492	560
Talparo(2))					
Tumpuna(2))					
Cunapo	3	2,172	2,800	4,972	1,657
Moruga	25	5,611	4,795	10,406	417
Navet Pumped Storage(3)	10	953	1,450	2,403	240
Courland	6	1,620	3,460	5,080	850
Richmond	3	910	2,140	3,050	1,017

1. Costs do not include engineering or contingencies.

2. Costs not computed separately as these are too small to be economic by themselves.

3. No reservoir storage provided; utilizes Navet excess storage.

cost of development of most
surface water sources.

The cost of source development and the cost of transmission and distribution facilities necessary to convey the developed water to users must be considered for the purpose of determining the most economical sources for development. Therefore, a transmission cost allowance for supplying each water service area from each source listed in Tables 26 and 27 was developed. This allowance was based on full utilization of all mains and took into consideration contiguous service areas being supplied from the same source. These allowances were added to the cost of source development shown in the two above-mentioned tables, and the results

compared. Table 28 is a summary of the results of this comparison, showing for each service area the relative economic advantage of supply from each source. The most advantageous source is indicated by the numeral 1, the next by the numeral 2, etc.

Where projected water demand in the area in which the source is located equals or exceeds the yield of the fully developed source, that source has not been considered for supplying other areas.

Inspection of Table 28 reveals that:

1. Generally, groundwater sources within a service area are the most economically advantageous sources of supply for that area.

Table 28. Summary Comparison of Water Sources

Source	Service area												
	Chaguaramas	Diego Martin	Port of Spain	Eastern Main Road	Caroni	Montserrat	San Fernando	South Trinidad	North Coast	Toco	Sangre Grande	Mayaro	P.O.S.-S.F. Urban Tee
Surface sources													
North Oropouche	4	4	5	6	5	—	4	11	—	3	3	—	2
Matura	5	5	6	7	8	—	5	12	—	1	2	—	3
Guanapo	6	6	7	8	8	—	6	13	—	—	—	—	5
Yarra	8	8	9	10	10	—	8	15	2	5	—	—	—
Marianne	7	7	8	9	9	—	7	14	1	4	—	—	—
Madamas	9	9	10	11	11	—	9	16	3	2	—	—	—
Caroni-Arena	3	3	3	5	2	—	3	9	—	—	—	—	1
Moruga	—	—	11	12	6	—	2	6	—	—	—	3	4
Navet	—	—	—	—	—	—	1	1	—	—	—	2	1
Oropouche Intake(1)	—	—	—	—	—	—	—	—	—	—	1	4	—
Hollis(2)	—	—	1	1	—	—	—	—	—	—	—	—	—
Groundwater sources													
Chaguaramas Well Field	2	2	—	—	—	—	—	—	—	—	—	—	—
Tucker Valley Well Field	1	1	—	—	—	—	—	—	—	—	—	—	—
Tacarigua Well Field	—	—	2	3	1	—	—	—	—	—	—	—	—
Arima Well Field	—	—	—	4	—	—	—	—	—	—	—	—	—
Waller Field Well Field	—	—	—	2	—	—	—	—	—	—	5	—	—
Las Lomas	—	—	4	—	—	—	—	—	—	—	—	—	—
Carlsen Field	—	—	—	—	7	—	—	—	—	—	—	—	—
California	—	—	—	—	4	—	—	—	—	—	—	—	—
Freeport	—	—	—	—	3	1	—	—	—	—	—	—	—
Los Armadillos	—	—	—	—	—	—	—	—	—	—	4	—	—
Penal	—	—	—	—	—	—	—	8	—	—	—	—	—
Point Fortin	—	—	—	—	—	—	—	4	—	—	—	—	—
Cap-de-Ville	—	—	—	—	—	—	—	5	—	—	—	—	—
Fyzabad	—	—	—	—	—	—	—	3	—	—	—	—	—
Clarke Road	—	—	—	—	—	—	—	7	—	—	—	—	—
Pluck	—	—	—	—	—	—	—	10	—	—	—	—	—

Table 28 (Continued). Summary Comparison of Water Sources

Source	Service area										
	Chaguaramas	Diego Martin	Port of Spain	Eastern Main Road	Caroni	Montserrat	San Fernando	South Trinidad	North Coast	Toco	Sangre Grande
La Brea	-	-	-	-	-	-	-	3	-	-	-
Palo Seco	-	-	-	-	-	-	-	8	-	-	-
Mayaro	-	-	-	-	-	-	-	-	-	-	1

1. Intake at Sangre Grande utilizing flow from Quare and Oropouche rivers below Hollis Dam and the proposed Oropouche Dam.
2. Increase in yield made possible by pumping to increase flow capacity of main.

2. Where there is no groundwater available within a service area, surface water sources within the area are generally the most economical sources of supply for the area.
3. The Caroni-Arena is the most advantageous major source of supply, and the North Oropouche the next.
4. The Moruga is the most advantageous major source of supply for south Trinidad.

Development of groundwater and local surface supplies in small increments requires less time than does development of major surface supplies. WASA is experienced in the design and construction of small surface water intakes, wells, and small treatment works for turbidity or iron removal. In addition, WASA has completed preliminary planning for many strategically located groundwater sources.

The readily developable groundwater resources are estimated to total about 22 mgd. Of this total about 14 mgd is so located

as to be desirable for first-stage construction. Development by 1974 of this amount of water in conjunction with metering should, in most areas, eliminate the average day but not the maximum day deficit.

Although 8 mgd of readily developable groundwater would remain after development of the above-mentioned 14 mgd, this potential supply is well removed from the areas of deficit, and transmission mains would be required to convey it to these areas. The cost of development of this groundwater at the source is generally greater than the cost of developing the northern surface sources, and the required transmission mains are about the same length. In addition, this water will be needed near the source in the future.

Because surface water is more susceptible to chance pollution than is groundwater and the quality of surface water varies greatly with changes in the stream flow, groundwater, where available, should be developed first. When groundwater resources are insufficient to meet service area needs and the deficits are small, or the area is far from the major urban zones which must be serviced from major waterworks projects, development

of small surface sources to meet water needs is the most economical means of serving the areas. Such sources should be equipped with slow sand filter plants with presettling basins of sufficient size to provide at least 24 hours of detention time during peak use periods.

The projected water demand for the year 2000 is about 170 mgd. Existing developed dependable yield is 46.5 mgd in Trinidad and

2.3 mgd in Tobago, leaving a total additional water requirement of about 121 mgd, of which 2.8 mgd are required in Tobago.

The full development of groundwater, together with the development of three or more of the surface sources indicated in Table 28 as the most economically advantageous to supply Trinidad and Tobago, will meet this requirement as indicated in Table 29.

Table 29. Alternative Development Programs for Providing Additional Water Supply Needed by Year 2000

<i>Source</i>	<i>Estimated dependable yield, mgd</i>
Trinidad	
Navet Pumped Storage	10
Caroni-Arena	42
Groundwater and Miscellaneous Intakes	22
Moruga Reservoir	25
Oropouche Reservoir	19 (Partial development)
	118
Navet Pumped Storage	10
Oropouche Reservoir	45
Moruga Reservoir	25
Groundwater and Miscellaneous Intakes	22
Caroni-Arena	16 (Partial development)
	118
Navet Pumped Storage	10
Oropouche Reservoir	45
Groundwater and Miscellaneous Intakes	22
Caroni-Arena	42
	119
Navet Pumped Storage	10
Caroni-Arena	42
Oropouche Reservoir	45
Groundwater and Miscellaneous Intakes	22
	119
Tobago	
Courland Reservoir	1.3 (Partial development)
Richmond Reservoir	1.5 (Partial development)
	2.8
Courland Reservoir	2.8 (Partial development)
Richmond Intake	0.5
Courland Reservoir	2.3 (Partial development)
	2.8

Development of the Caroni River

General. The Caroni River catchment is one of the largest in Trinidad. However, there are no suitable reservoir sites on the main river. The Arena River, which is one of the streams in the Caroni catchment, has a good reservoir site with potential storage capacity greater than can be filled annually from the contributing drainage area.

The dam and reservoir site are about 3-1/2 miles from the Caroni River at the nearest possible river intake site, located in San Rafael. The proposed Caroni-Arena project comprises:

1. A reservoir on the Arena to store runoff from the Arena watershed and provide off-stream storage capacity for Caroni water;
2. An intake and pumping station on the Caroni at San Rafael to pump water to the Arena reservoir;
3. A raw-water main from the pumping station at San Rafael to the Arena reservoir;
4. An intake, low-lift pumping station, water treatment plant, and high-lift pumping station at Kelly Village on the Caroni River;
5. Transmission mains from the high-lift pumping station to the water-short northwest and southwest urban areas; and
6. As a final development step, two additional reservoirs, the Talparo

and Tumpuna, both on the headwaters of the Tumpuna River, a tributary of the Caroni.

No raw-water main would be provided between the Arena dam and the water treatment plant. Water would be drawn from the Caroni River at the treatment plant, treated, and pumped into the system. Water stored in the Arena, Talparo, and Tumpuna reservoirs would be released in the dry season to supplement the natural flow of the Caroni.

Caroni-Arena Yield. The Caroni River catchment upstream from the proposed intake and treatment works at Kelly Headworks in Kelly Village is about 150 square miles in area (see Figure 14). Flow gauging at Kelly Headworks has been carried on for about two years. Fortunately, total rainfall for the full year of record available approaches the mean annual for the period of record (15 to 30 years for the area gauging station), and the seasonal distribution is normal. Study of the rainfall records for the drainage area indicates that the 95 percent dry-year rainfall on this catchment would be about 20 percent lower than the mean annual rainfall of 89.3 inches, or about 71 inches. Table 20 in Chapter 6 shows that in 1968 the total runoff was about 37 percent of the mean areal rainfall with 10.5 percent occurring in the dry season. It is estimated that the 95 percent dry-year runoff would be about 20 percent less than the mean annual runoff, or about 27 inches. Seasonal distribution should be about the same.

Yield determination for the Caroni-Arena system has been based upon a flow-duration curve derived from the 1967-1968 flow records for the Kelly gauging

station. A flow-duration curve for the pumped-storage intake at San Rafael, where there are no gauging records, was developed by reducing the Kelly flow in proportion to the respective catchment areas. Since the proposed storage reservoirs are located within the Caroni catchment, the portion of the area they control was deducted in obtaining the average year and the 95 percent dry-year curves. The estimated 95 percent dry-year flow duration curve was taken at 20 percent lower than the average-year runoff. The deficit of runoff in relation to storage capacity for the Arena reservoir was estimated to be about 1,650 million gallons for the 95 percent dry year, and 400 million gallons for the average year. Therefore, the estimated maximum annual pumpage required is 1,650 million gallons during the 95 percent dry year.

Available stored water at the end of the wet season in an average year and in a 95 percent dry year is estimated to be as shown in Table 30.

Table 30. Caroni-Arena Available Stored Water

Reservoir	Reservoir capacity, million gallons	Water in storage at end of wet season, million gallons ⁽¹⁾	
		Avg year	95 percent dry year
Tumpuna	1,300	1,300	1,300
Talparo	1,400	1,380	850
Arena	3,500	3,500	3,500
Total	6,200	6,180	5,650

1. In excess of evaporation.

The proposed Tumpuna reservoir would fill during the 95 percent dry year but the inflow to the Talparo, which would fill during

an average year, would be 530 million gallons less than the reservoir capacity. However, unless two drought years of this intensity occur in succession, the 95 percent dry-year yield of the system would be about 42 mgd. If two drought years occur in succession, the yield would be about 41 mgd in the second year.

Figure 15 shows the required flow supplementation, maximum pumpage to Arena reservoir, and the yield for both the 95 percent dry year (42 mgd) and the average year (54 mgd). Since these estimates are based on only one year's runoff data, it is recommended that provision be made for pumping at 20 mgd in lieu of the 15 mgd indicated as necessary to fill the Arena reservoir.

Study of the Caroni River as a source of water included two other means of supplementing dry-weather flow.

The first was to provide a tertiary treatment plant at the Port of Spain sewage ponds for filtering pond effluent to remove algae and other suspended matter. The chlorinated filter effluent would be pumped to the irrigation canal via a steel main. This system would allow use of the total flow of the river at Kelly Headworks for potable water supply. The net dependable yield from the plan would be about 15 mgd.

The second means investigated included construction of an off-stream reservoir to store water pumped from the Caroni at Kelly Headworks in the wet months for release to supplement dry-weather yield. The site investigated for the reservoir is southwest of the El Socorro waterworks. It appears to be

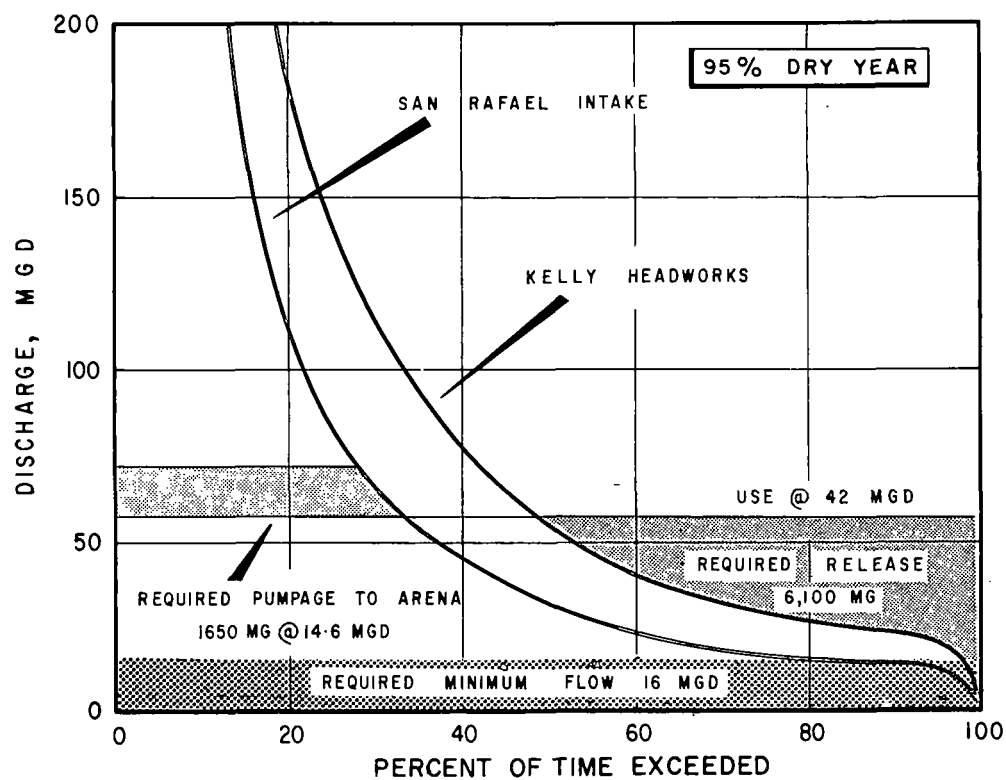
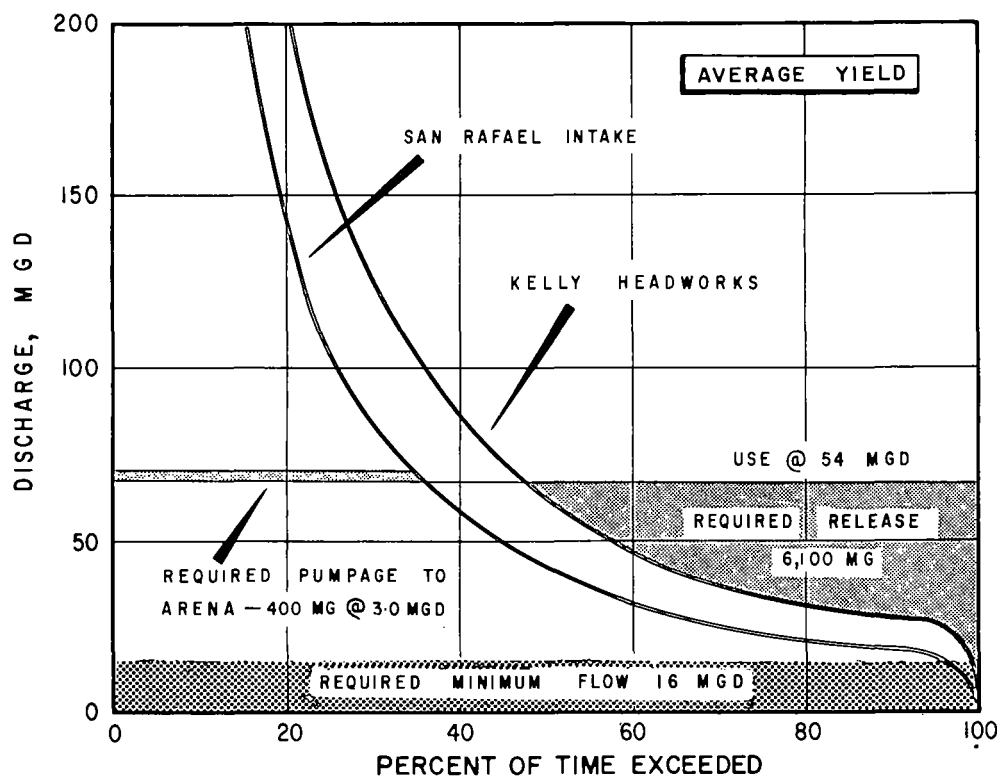


FIG. 15 CARONI - ARENA YIELD

too low and wet for agricultural purposes and is presently idle. The reservoir, to store 3,500 million gallons, would be diked and would measure about 3,800 feet square by 40 feet deep. The dependable yield would be about 33 mgd.

While facilities necessary for the first plan could be constructed in the areas indicated, the cost of development is too high to be competitive with the Oropouche project or the Caroni-Arena system as a first stage.

A soil boring at the proposed dike location for the second plan indicated that foundation conditions were not satisfactory for construction of the proposed reservoir.

Treatment and Pumping Facilities. The water treatment plant would be located at the Kelly Headworks and would require acquisition of about 19 acres of land, 6 houses, and 5 small frame warehouses. Although no borings have been made at the proposed treatment plant site, borings taken for the sewerage system at nearby Piarco Airport, and observation of excavations at the airport, indicate that subsurface conditions are satisfactory for plant construction. The proposed treatment works area is flooded periodically to a depth of 2 to 4 feet. Accordingly, the selected layout of the works is such as to minimize uplift; and the plant site would be filled to a height above anticipated flood levels.

The San Rafael intake site is located on the south bank of the Caroni River just downstream from the Tumpuna Road bridge over the Caroni River (see Figure 16). The area of the land required at this site is about 1.5 acres.

The pipeline from the Caroni intake to the Arena reservoir would (see Figure 16) follow the roadway through San Rafael, up the Talparo Road to a point opposite the reservoir site, then along a trace to the reservoir. The diameter of the pipeline would be 36 inches and the length about 18,700 feet.

Geology of the Arena, Talparo and Tumpuna Basins

Arena. The proposed Arena reservoir site lies in the northern drainage of the Central Range southeast of the village of San Rafael. The area has moderate relief and consists of rolling hills formed by an erosional drainage pattern impressed on fine-grained soils. Geologically it occupies about the center of the Caroni Syncline, although a slight upbow in sediments makes the particular area of the damsite an anticline (the Mahaica anticline). The site lies in the Talparo and Springvale formations of Pliocene and Oligocene age, respectively. They are both unconsolidated formations consisting in this particular area of silts and clays interbedded with thin sand layers (see Figure 17). The ridges near the damsite and along the northeast side of the reservoir area are reported to be outcrops of the Mahaica sands. In the upper reaches of the reservoir area, the Caparo sands are reported to crop out.* These sands are medium to fine-grained and dip beneath the overlying silts and clays in the lower half of the reservoir site. The base of the Caparo sands is more than 300 feet deep at the damsite. The head of the reservoir site is underlain by sands and silts of the Manzanilla Formation, of Oligocene age. The drainageways on both

*Dominion Oil Company.

sides of the Arena have gulleys working headward.

Talparo. The Talparo reservoir site also lies in the northern drainage of the Central Range, about 12 miles south of Arima. It is underlain primarily by northward dipping sands and clays of Miocene age. The proposed damsite lies within the clays of the Springvale and Manzanilla formations. The head of the reservoir site overlies cavernous reef limestones of the Tamana Formation. All of the formations are unconsolidated except the Tamana limestone. The limestone is moderately weathered. No major structural features are reported within the reservoir area.

Tumpuna. The Tumpuna reservoir area is underlain by steeply dipping vertical sands and clays of Oligocene and Miocene age. The geology of the proposed damsite is quite complex. It lies near the crest of an anticlinal structure in the Nariva Formation. The Nariva is folded and faulted into contact with the calcareous sands and marls of the Cipero Formation. At least one major fault is reported near the proposed damsite. The remainder of the strata in the reservoir area belong to the Nariva and Cipero formations. These two formations are in fault contact near the head of the reservoir.

Evaluation of the Arena Basin as a Reservoir

Tightness. Borings taken during this study, as well as test pits dug during the time the area was mapped by Dominion Oil Company, indicate that the reservoir is underlain with relatively impermeable silts and clays with minor sand lenses. Only the northeastern ridges and the head of the basin appear to contain granular material. Provided

the flow line remains below the bottom of the granular material, no appreciable leakage through the reservoir floor or walls is anticipated. Some additional protection may be required to prevent leakage through the sand ridges to the north.

Slope Stability after Impoundment. Slopes in the area of the Arena impoundment are much less steep than slopes in the Northern Range and, although much of the terrain is composed of silt and clay, there are fewer land slips here.

After impoundment it is expected that there will be small slips from time to time into the reservoir and that consideration should be given to clearing but not grubbing the area below the flow line. It is anticipated that leakage through some of the thinner ridges separating headward working gulleys and adjacent drainages will be minimal. However, the stability of the thin ridges and gully sides requires thorough investigation during final design. Stability analyses made for preliminary design from a limited number of borings indicate that slopes are stable.

Dam Location. The proposed dam location is between two ridges which enclose the drainage of the Arena River about 3 miles upstream from the confluence of the Arena and Caroni. The abutment ridges are composed of about 17 feet of coarse brown sand that overlies the softer silty sand and clay which also make up the foundation of the dam. The proposed dam location gives the greatest impoundment consistent with the topography.

Two problems are apparent with the type of subsurface conditions present at this

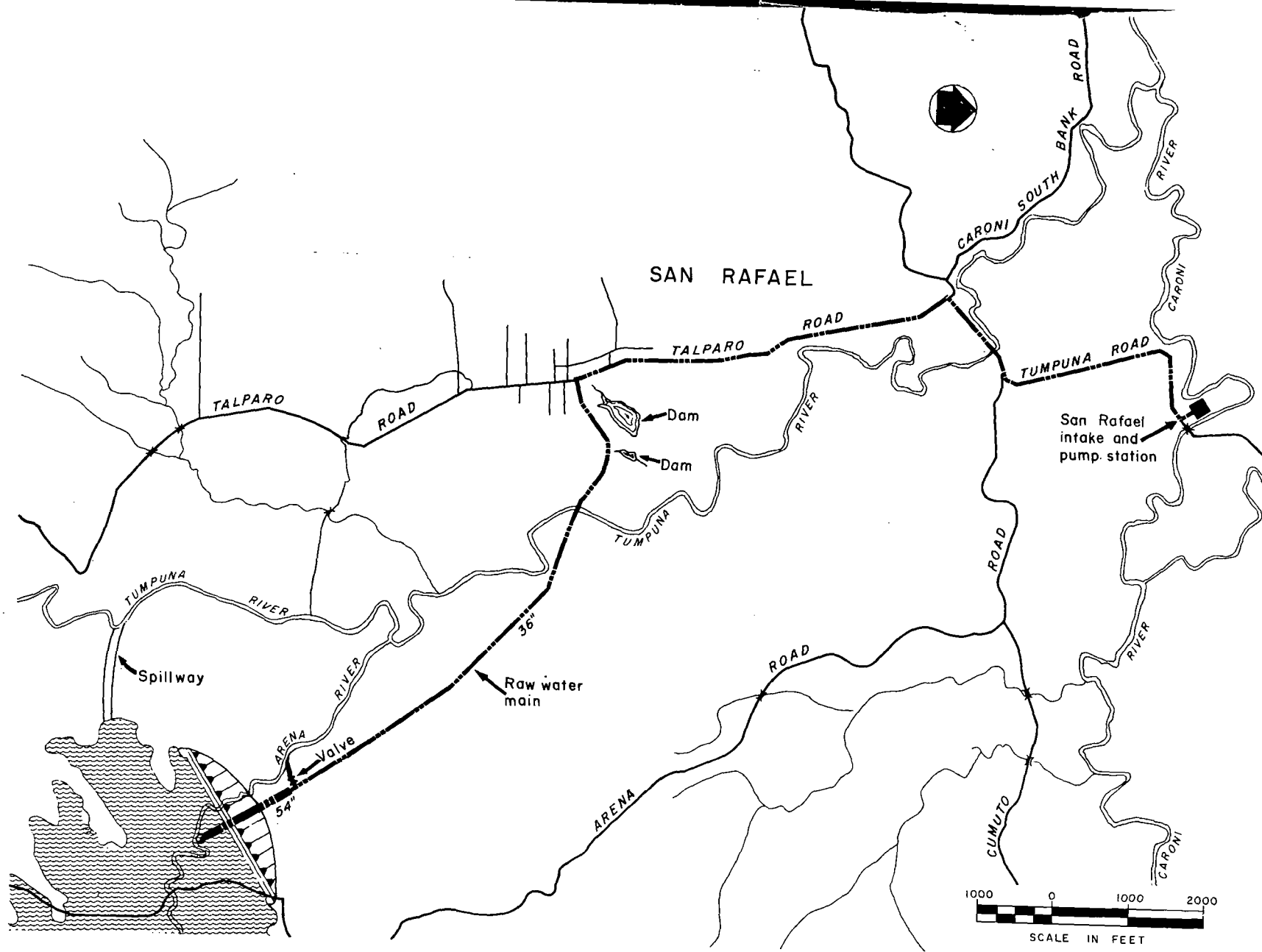


FIG. 16 PIPELINE ROUTE FROM SAN RAFAEL INTAKE TO ARENA RESERVOIR

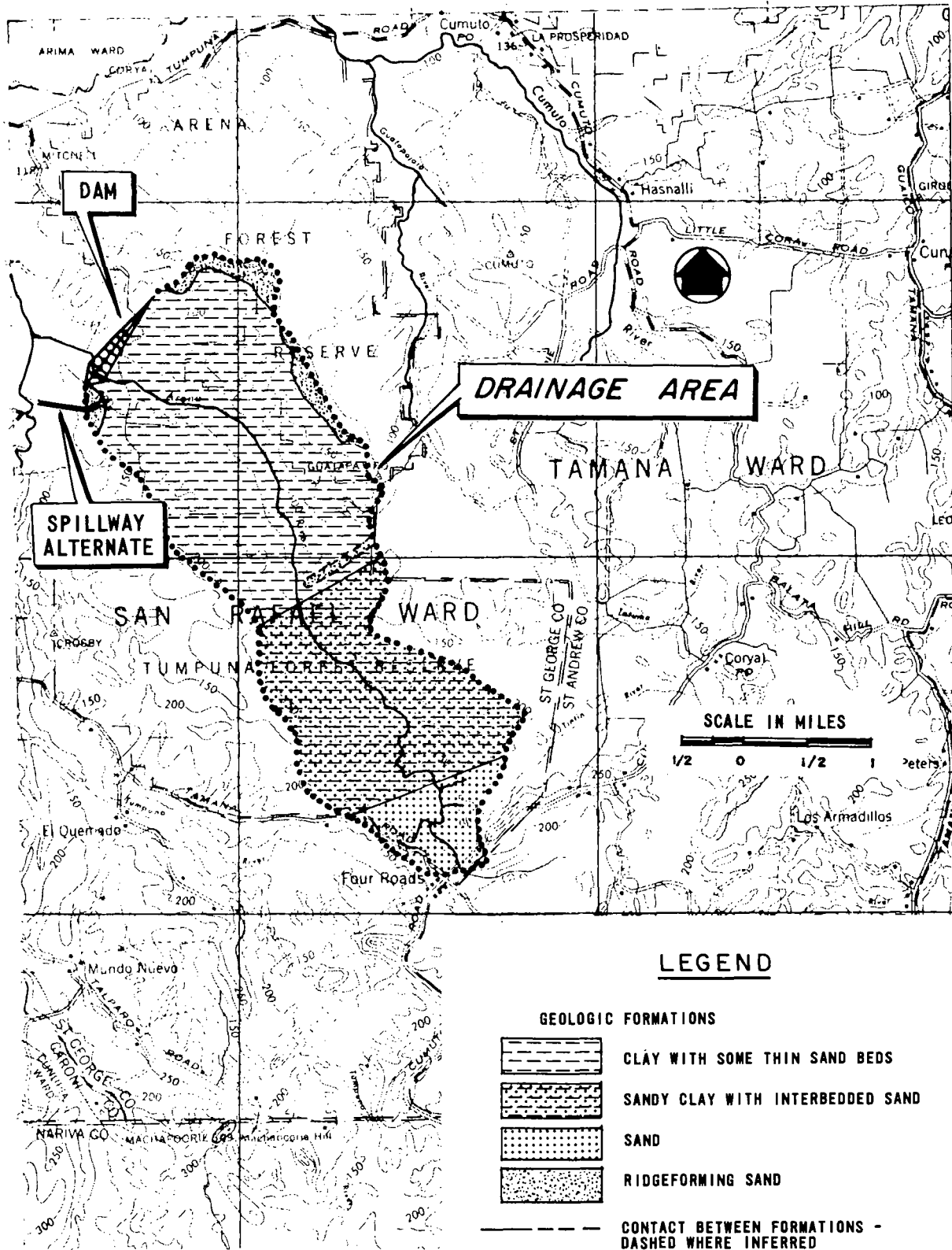


FIG. 17 ARENA RESERVOIR – TOPOGRAPHY AND GEOLOGY

location. One is the stability of the foundation with a dam on it under static conditions and the second is the performance of dam and foundation under the dynamic conditions produced by seismic shock during an earthquake. The stability of the foundation under these two situations has been analyzed and the design concept of the proposed dam evolved (see Figure 18).

In the investigation conducted for the preliminary design, a more suitable site for a dam could not be located. Foundation problems would be similar anywhere along the Arena, gradually getting worse as one approaches the Caroni River.

Spillway Locations. There are two satisfactory locations for spillways. One location is through the ridge to the west of the main dam and the other is in the crest of the main dam directly above the present channel of the Arena River.

Both spillway locations will route water back into the Arena drainage. Some slope protection will be required in the thin sandy ridge area west of the main dam to combat headward erosion from the adjacent drainageway. A spillway in this location can incorporate the necessary protection for the thin ridge.

Construction Materials. Sand is available within the catchment area near the upstream end of the reservoir and at other selected locations within 1-1/2 miles of the damsite.

Gravel is not available within the reservoir area. The nearest location is La Horquette, where there are privately owned pits and a ready-mix plant. The

shortest distance by road to this area is 5.6 miles via San Rafael. Additional gravel sources are to be found along the Arima River in the Waller Field area, where both private and government pits exist. The distance by road to this source is 8 miles.

Riprap will be a problem since the nearest source of sound rock comes from the quarry on the Arima-Blanchisseuse Road about 14 miles from the damsite. Studies of other means of slope protection should be made during final design.

Design Considerations. Design considerations requiring special attention include:

1. Stability of the dam under static and dynamic conditions.
2. Loss via leakage into the Caparo sands, i.e., continuous recharge of aquifers.
3. Stability of thin ridges after impoundment.
4. Consideration of the requirements for construction during the various seasons of the year as they affect the design of the main dam and spillway.
5. Instrumentation required for observing settlement and dissipation of pore water pressure to ensure stability during construction.

Recommended Dam Type. Recommendations as to the type of dam are as follows:

1. It is recommended that a rolled earth-fill dam composed of materials naturally occurring within the reservoir area be constructed at the location shown on Figure 19 with a maximum pool elevation of 125.

Because of subsurface conditions, counterweight berms are required and it is recommended that they be composed of locally excavated silt and clay, buttressed on the downstream side by sand and gravel which will form the toe of the downstream berm. The upstream face of the dam should be protected by dumped riprap over gravel filters which also extend to the downstream face for protection against erosion.

All of the material except the sandy gravel and riprap can be obtained from within the reservoir area. This plan will require a minimum of quarried rock and gravel which must be imported from distances of 14 and 5-1/2 miles, respectively.

The homogeneous rolled earth-fill will be sufficiently flexible to withstand the maximum horizontal acceleration from seismic shock.

2. It is recommended that diversion of the Arena River during construction be through a conduit laid in the floodplain of the Arena River.
3. It is recommended that either a chute-type spillway be constructed

through the thin ridge immediately west of the main dam or that the spillway be constructed on the crest of the main dam above the channel of the Arena River. Further study during the design state is required to fix the optimum position for the spillway.

If the chute-type spillway is not selected, a small dyke composed of rolled earth with riprap protection is recommended to protect the thin ridge.

Development of North Oropouche River

General. The North Oropouche River catchment is located within the highest precipitation zone on Trinidad. The basin is relatively narrow and steep; however, a good damsite is available and a reservoir providing up to 15,000 million gallons of storage capacity could be developed. The North Oropouche project comprises:

1. A dam on the river about a mile upstream from Valencia Road creating a reservoir of 10,000 million gallons capacity;
2. A low-lift pumping station just downstream from the dam;
3. A water treatment plant on a ridge west of the plant and about 100 feet above the spillway crest;
4. A raw-water transfer main from the low-lift pumping station to the treatment works; and

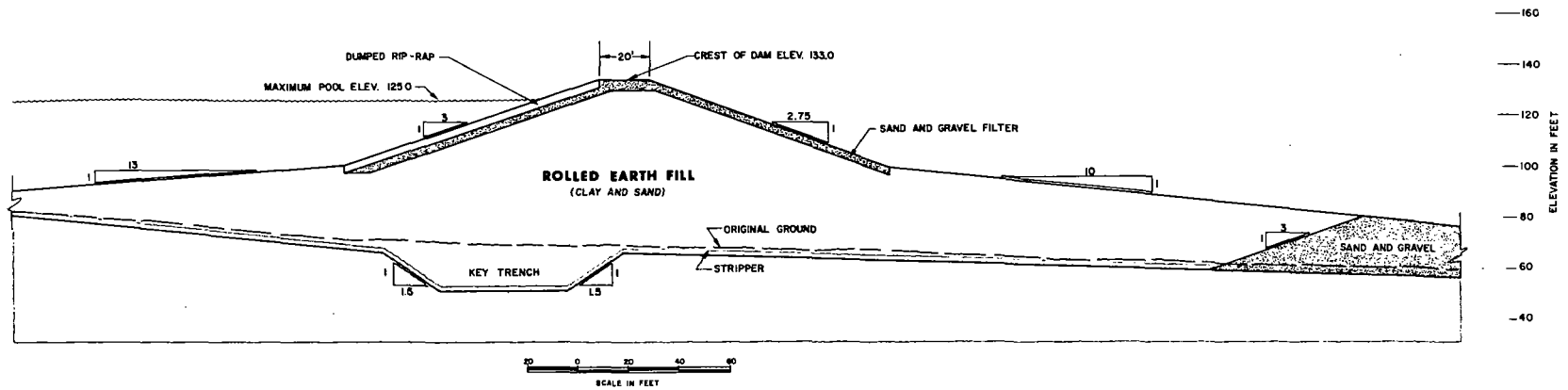


FIG. 18 ARENA DAM TYPICAL PROPOSED SECTION

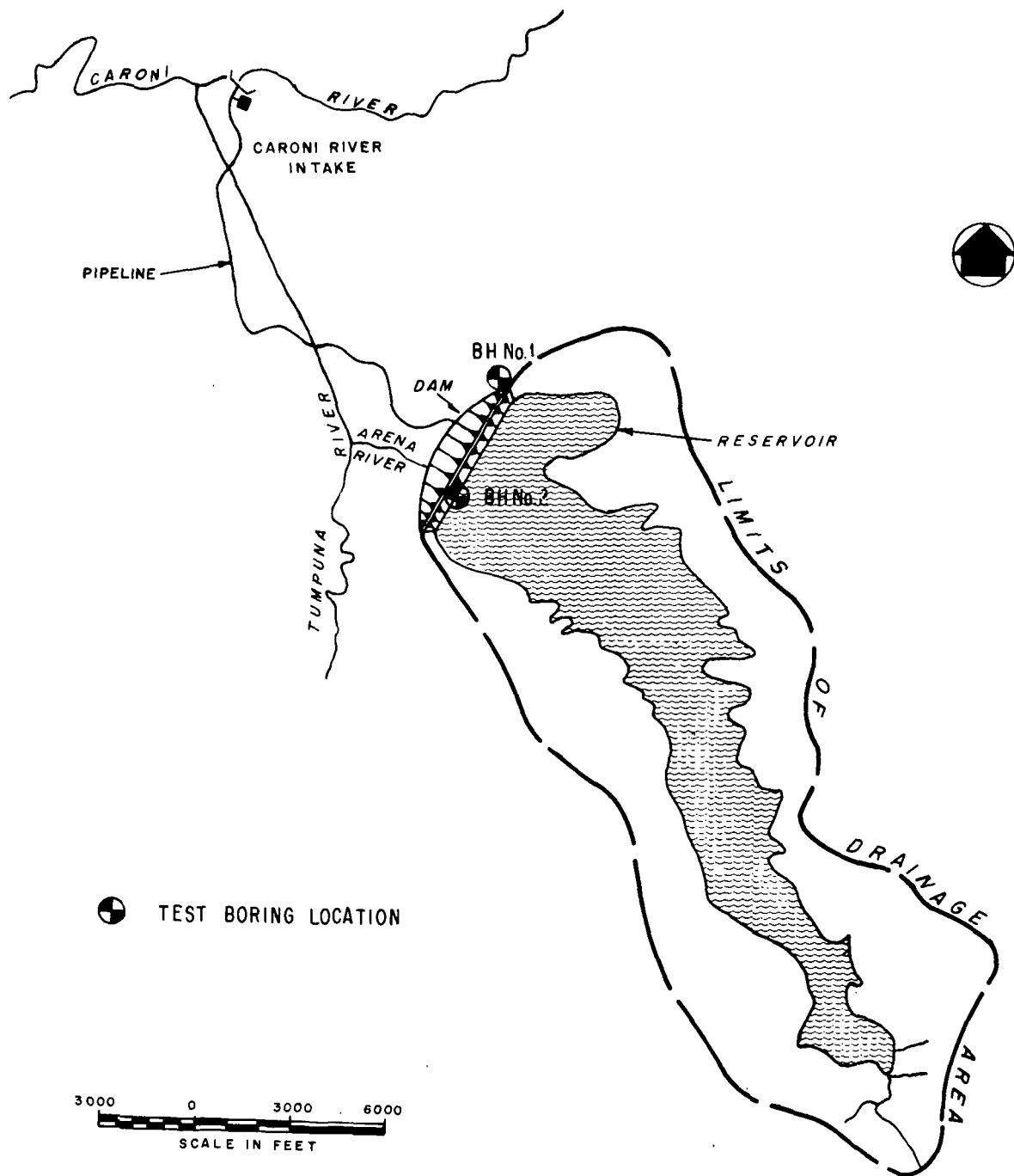


FIG. 19 ARENA RESERVOIR AND DRAINAGE AREA

5. A transmission main from the water treatment plant to the northwest urban area with a branch from Tunapuna to the southwest urban areas.

North Oropouche Yield. The proposed Oropouche reservoir catchment is about 20.5 square miles in area and occupies the southern slope of the Northern Range west of Valencia (see Figure 20). Stream gauging records are available for 1966 to 1968. Rainfall records of about 35 years' duration are available for the Hollis reservoir catchment west of the Oropouche.

A mass diagram of runoff was plotted for 1967 and 1968. Rainfall in this period (based on records at nearby Hollis reservoir) was approximately equal to the mean annual rainfall. Consequently, runoff and yield estimates based upon this mass diagram should approximate mean values. For a gross draft at a uniform rate of 52 mgd, the diagram indicates a minimum storage requirement of 4,750 million gallons. After allowances for losses by evaporation from the reservoir free water surface and leakage from the reservoir, the net mean annual yield would be about 49 mgd. A reservoir storage capacity of about 3,000 million gallons would allow a net draft of 42 mgd at a uniform rate of use.

Since water use or demand does not occur at uniform rates and the maximum rates of use occur in the dry season, sufficient storage capacity must be provided to allow a dry-weather use of 1.25 to 1.5 times as great as the mean annual rate of use. On years with rainfall about equal to the mean, and with a reservoir capacity of about 6,000 million

gallons, the dry-season average rate of use could be as much as 56 mgd and the wet-season use about 43 mgd, or about 49 mgd average for the year.

With a reservoir capacity of about 10,000 million gallons and a use of around 49 mgd, about 4,000 million gallons of stored water would be carried over to the next year. Thus, about 4,000 million gallons of stored water would be available to supplement dry-year runoff. It is estimated that the 95 percent dry-year runoff would total about 13,000 million gallons for the Oropouche catchment. This estimate is based upon 90 inches of rainfall with about 50 percent runoff. At an average use rate of 45 mgd, the annual draft would be about 16,400 million gallons, or 3,400 million gallons more than the runoff. The carryover storage of 4,000 million gallons should therefore be ample to permit about 45 mgd draft on the 95 percent dry year.

With a 10,000-million gallon reservoir, the dry-season draft during the 95 percent dry year could be as much as 12,000 million gallons, or an average rate of use of 65.5 mgd for the 6-month season. The corresponding wet-season draft would then be 4,900 million gallons, or about 27 mgd average. Together the dry- and wet-season draft would average about 45 mgd for the year, the estimated dependable yield.

It is recommended that the North Oropouche reservoir and dam be built with the flow line at an elevation 350 feet above mean sea level, thereby providing a useful storage capacity of 10,000 million gallons and a dependable yield of 45 mgd.

Geology of the North Oropouche Basin

The Oropouche Basin is composed of steeply dipping metamorphic rocks of Upper Jurassic and Lower Cretaceous age. The trend of these beds is roughly east-west and the dominantly southward dip generally averages more than 45 degrees. The rocks consist of low-grade metamorphic noncalcareous phyllites interbedded with calcareous phyllites, thin to moderately thick beds of crystalline limestone and a few grits.

In sequence from south to north and as shown on Figure 21, the younger beds are the first encountered as one enters the Oropouche Basin from the south (Valencia Road).

The basin is broken into roughly five formations from south to north, as follows:

1. Noncalcareous phyllites — thin-bedded; dark gray; interbedded with light gray quartzite grits and a few thin beds of limestone. The damsite occupies most of this section, which is similar in lithology to the shaley phyllite member of the Laventille Formation as described by Brown.
2. Calcareous phyllites — thin bedded; interbedded with thin to massive beds of limestone; and occasional noncalcareous shaley phyllites. The section is characterized by thick sequences of thin beds of the same rock type. It is similar in lithology to the Belvedere Formation as described by Brown. Several potential quarries for dam construction material are located in this section.

3. Massive bedded limestones, occasionally cavernous, make up the central portion of the basin. The massive beds are occasionally interlayered with calcareous phyllites and thin-bedded limestone. This section is similar in lithology to the Aripo limestone member of the Rio Seco Formation described by Brown.
4. Thin calcareous phyllites, interbedded with thin limestones and noncalcareous phyllites occupy most of the upper reaches of the basin. The three rock types are distributed uniformly through the sequence. This section is similar to the phyllite member of the Rio Seco described by Brown.
5. Thin-bedded quartzites interbedded with calcareous phyllites occupy the head of the basin. These rocks are similar in lithology to the Tucuche Formation which forms much of the main crest of the Northern Range.

Structurally, the rocks occupying the Oropouche River drainage basin have been intensely folded over most of the southern part of the basin, resulting in the steep southward dips. Only minor faulting has been noted in the field, however. Several major faults, interpreted from the regional structure, are anticipated to cut the basin in several places. These inferred faults are shown on Figure 21.

A major fault, shown locally as the Arima fault, is part of the great fault system

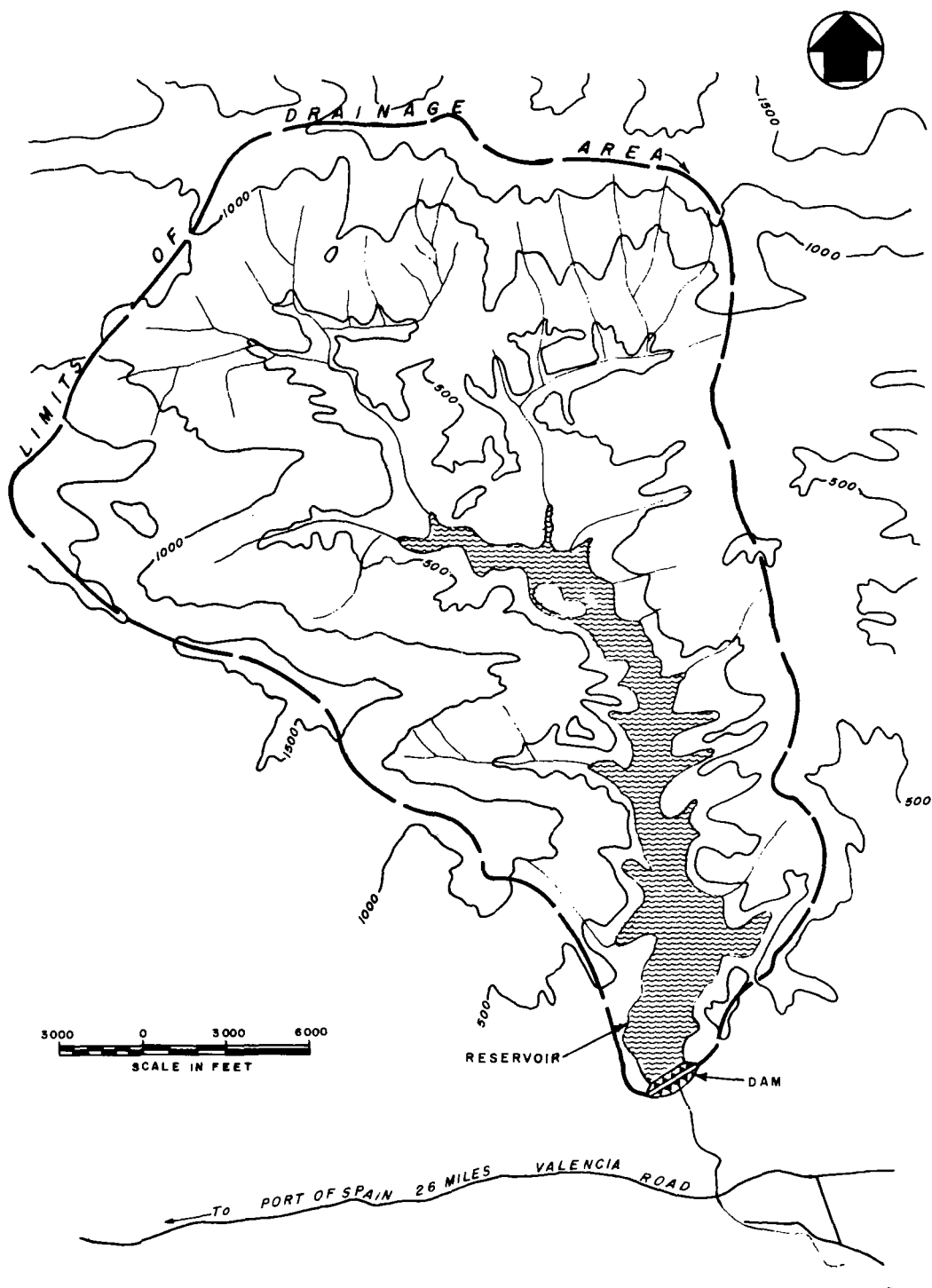
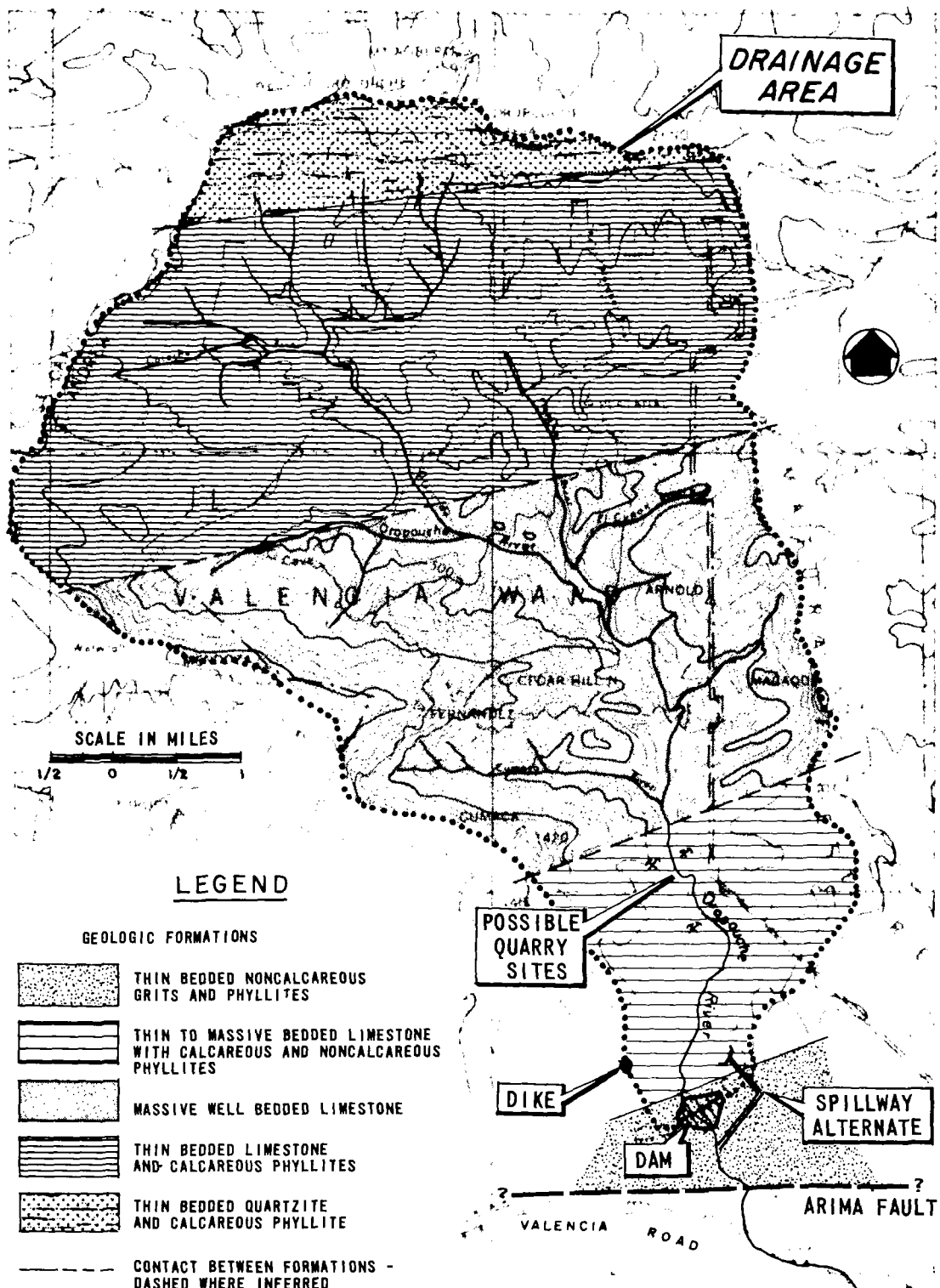


FIG. 20 NORTH OROPOUCHE RESERVOIR AND DRAINAGE AREA



**FIG. 21 NORTH OROPOUCHE RESERVOIR
TOPOGRAPHY AND GEOLOGY**

known as El Pilar which runs east-west along the southern margin of the Northern Range in Trinidad and the Coast Range of Venezuela at least as far as the Caracas Valley. The fault is inferred as falling downstream of the damsite approximately two-thirds of a mile. Little activity has been noted along the Trinidad portion of this fault system for many years. Most rock in the basin is deeply weathered. The phyllites and grits weather the deepest and the limestone least of all. In places where exploration has been carried out, the phyllites are known to weather differently to depths of 100 feet. The stream bottom is the only area, with the exception of road cuts, where fresh rock can be observed. A residual soil has developed on top of the weathered rock and consists of a clayey silt or silty clay. Ridge tops in the southern foothills are covered with a thin cap of terrace gravels unconformably overlying the residual soil.

Evaluation of the North Oropouche Basin as a Reservoir

Tightness. The only threat to tightness in the reservoir impounding area is the massive limestone of the upper basin in the vicinity of Cumaca. This limestone tends to form solution openings and becomes locally cavernous. However, the impounding level (flow line) is low enough in the limestone section to be below the spring line for this rock in neighboring valleys. In addition, the steep dip of the hundreds of thousands of thin beds of limestones, phyllites, and grits downstream prevent major leakage. Further protection against leakage is provided in the cover of residual soil and the deeply weathered grit and phyllite beds which form an impermeable blanket.

Slope Stability after Impoundment. Saturation of the clay and silt soils covering the exceptionally steep valley walls, coupled with the great length of the shore line, provide maximum exposure to sliding. Study of laboratory test results indicates that fluctuation of the reservoir level will probably create landslips.

Dam Location. The proposed damsite is located in a bedrock valley at the southernmost position in the Oropouche Basin. South of the damsite the hills drop sharply away to the Arima flats. The dam location is entirely within the Laventille Formation of noncalcareous phyllites and thin-bedded limestones all dipping steeply south 50 to 70 degrees and trending perpendicular to the valley. The abutments would be in decomposed grits and phyllites and the dam founded on the fresher rock cleaned by the river.

One problem with the site is the abutment or spillway ridge to the east. This ridge is thin, steep-sided, and capped with granular material. It has a high permeability in the granular material at the top and insufficient section to withstand a high level of impoundment.

Spillway Location. The proposed spillway location is through this thin ridge and would be cut down through the granular materials and probably deeply into the weathered rock. Use of a spillway in this location would route water back into the Oropouche River below the proposed dam location. Additional spillway sites were examined, particularly the alternate site at the dike location shown on Figure 21. This site would require extensive protection

downstream as well as protection around the spillway itself. In addition, it would divert all the spillway water into another drainage, therefore requiring new bridges, channel improvements, and drainage structures on the running stream. This particular site would require a dike with cutoff if a high flow line were used.

Construction Materials. Rock suitable for rock fill is available within the Oropouche Basin at approximately the locations shown on Figure 21. Crusher-run rock should be suitable for filter gravels and sand or concrete aggregate.

Impermeable soil suitable for an earth core is available in the vicinity of the proposed damsite. There does not appear to be sufficient material for a rolled-earth dam without extensive stripping of the valley walls and ridge tops. Natural sand is not available within the basin but Melajo sand and gravel can be found south of the Valencia Road in several privately operated pits.

Design Considerations. Reservoir design considerations are:

1. Keep the flow line at a maximum elevation of 350 feet above mean sea level to avoid the necessity of excessive protection for thin ridges in the vicinity of the dam and within the reservoir area.
2. Design a dam to make use of materials naturally occurring in the basin and with due regard to the length of dry and wet seasons as well as their effect on the construction.

3. Consider clearing trees and brush only up to the normal flow line and not above. In an effort to keep landslips on the steep valley walls to a minimum, do not permit grubbing except at the damsite.
4. Locate the dam wholly within the Laventille series of phyllites and grits to take advantage of the favorable geology of the formation.
5. Locate the spillway in the thin ridge to the east of the dam to make use of spillway construction to protect the ridge and turn water back into the lower Oropouche.
6. Design for magnitude 7.5 (Richter scale) seismic loading from earthquakes along the northern coast or from adjustments along the nearby Arima fault.

Recommended Dam Type.

Recommendations as to type of dam are as follows:

1. It is recommended that a rock-fill dam with a maximum pool level at El 350 and a rolled-earth core as shown on Figure 22 be constructed at the location shown on Figure 23. This type dam can be constructed from natural materials located within the basin. The stable rock-fill portion can be placed during the wet season leaving the dry season for placing the relatively small yardage of the rolled core or blanket and its protection.

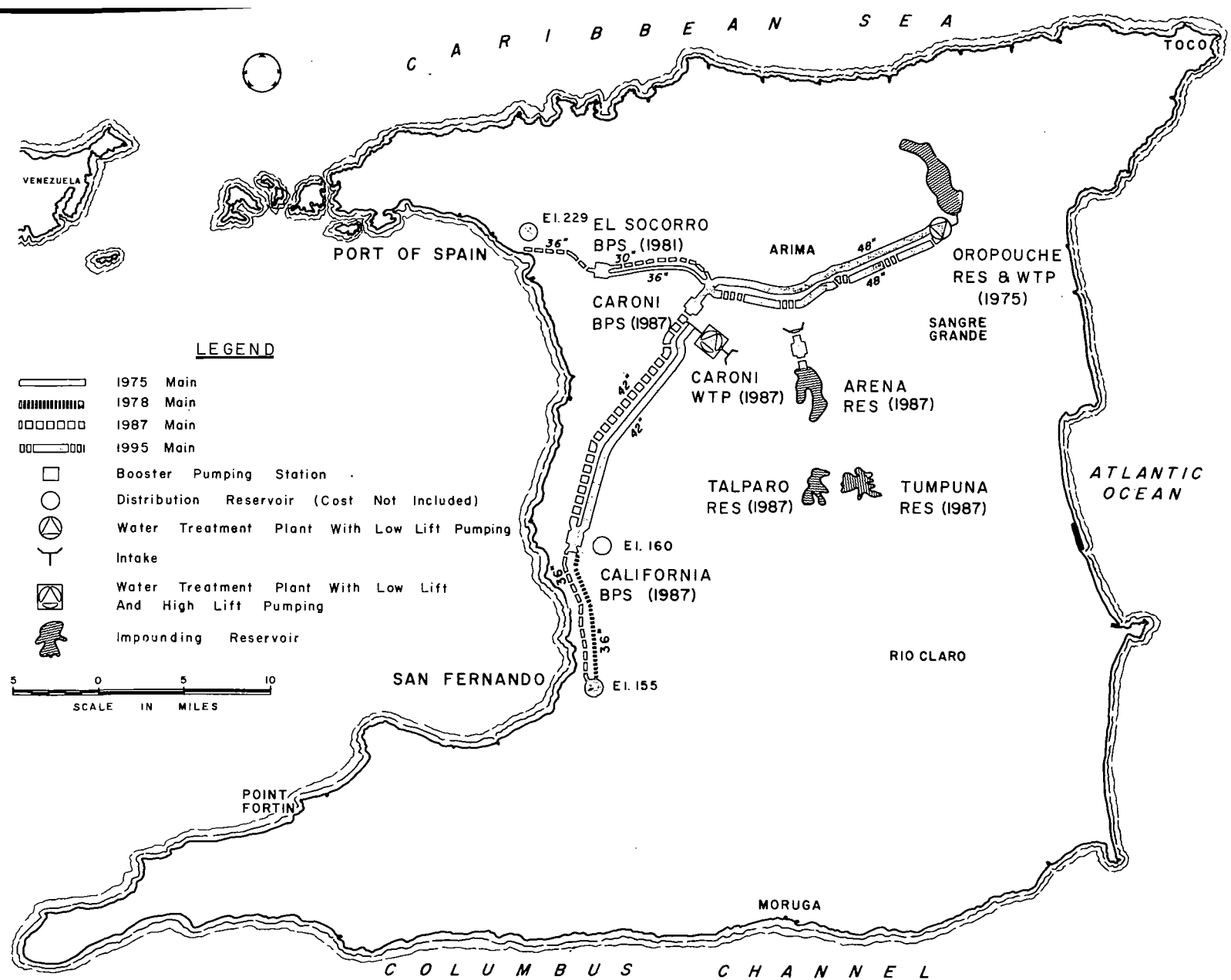


FIG. 25 MAP SHOWING ALTERNATIVE PROGRAM A

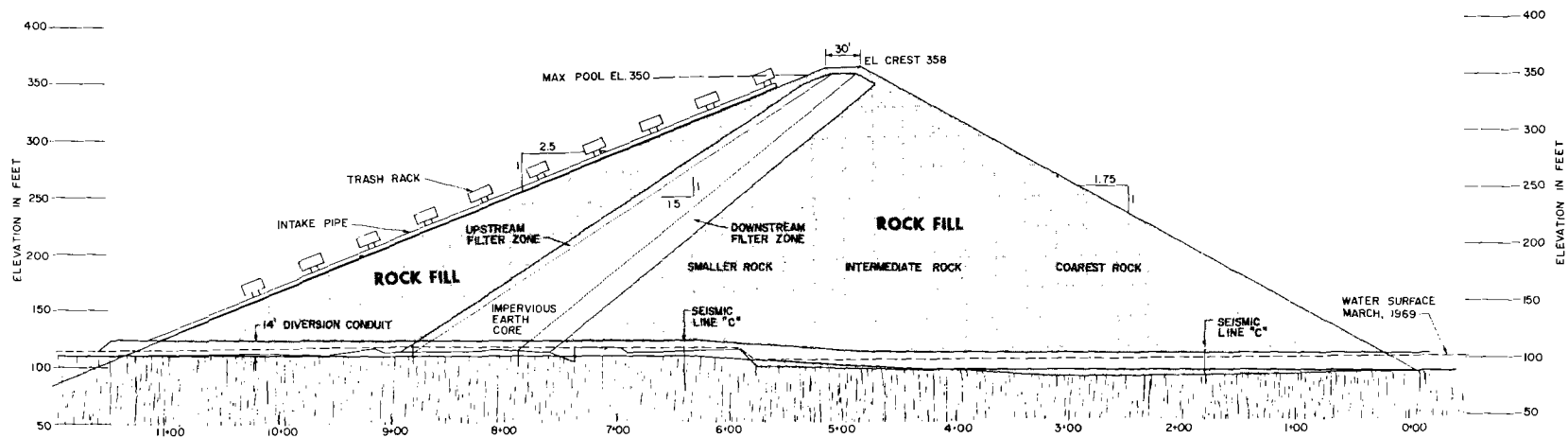


FIG. 22 NORTH OROPOUCHE DAM TYPICAL PROPOSED SECTION

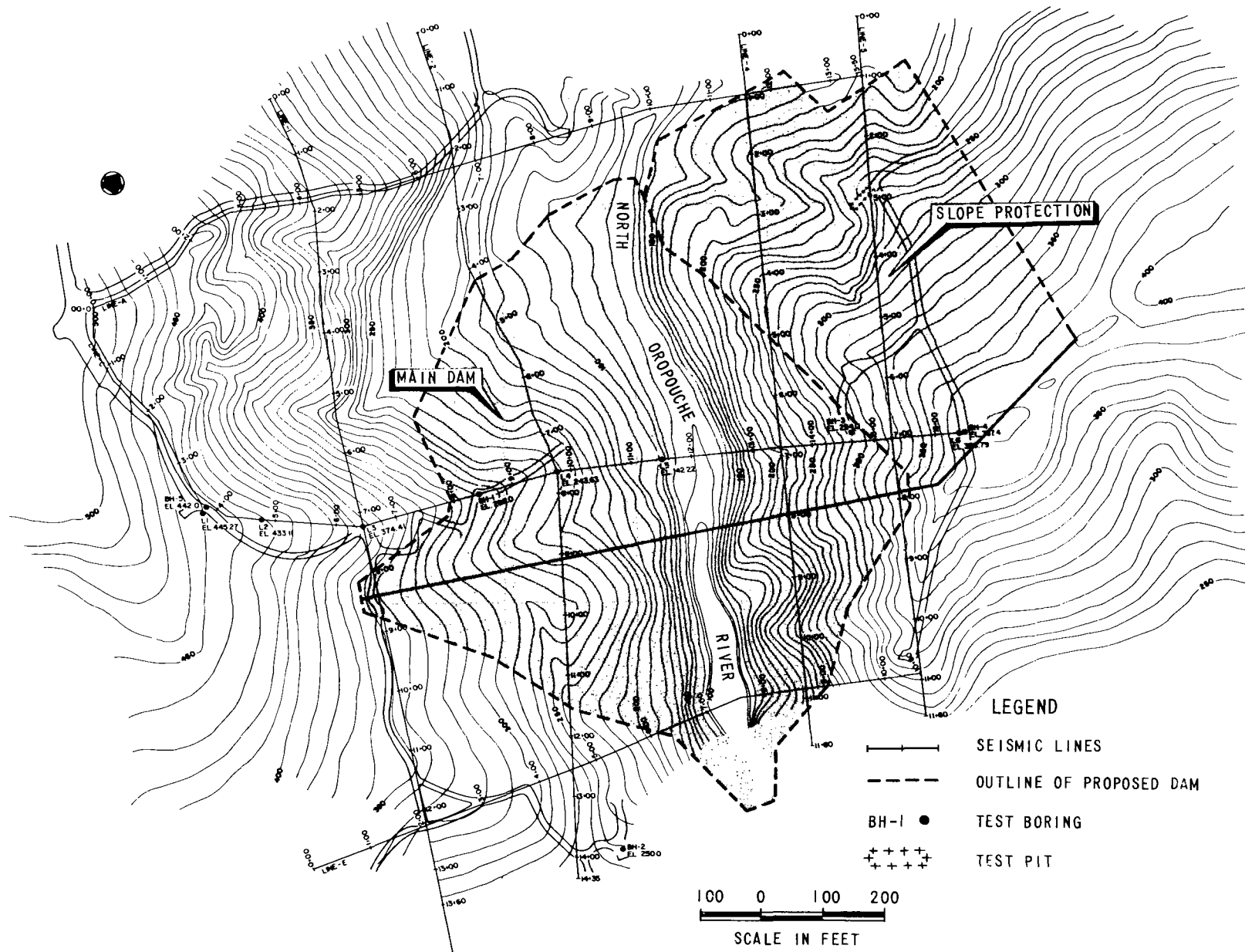


FIG. 23 NORTH OROPOUCHE DAM – PLAN OF SUBSURFACE EXPLORATION

The rock-fill dam will be flexible enough to withstand high seismic loading.

2. It is recommended that diversion of the river during construction be by means of a cut-and-cover tunnel parallel to the river and passing through the base of the dam.
3. A chute-type spillway on the thin ridge immediately east of the main dam is recommended.
4. The recommended intake structure is of the type which lies inclined on the upstream face of the dam and draws water at required elevations through a series of valved openings protected by trash racks. Water would be dropped into the diversion tunnel on the upstream toe so that the intake structure would not penetrate the core. Such a structure eliminates the need for a free-standing intake protected against seismic shock wave actions and with the necessary access appurtenances.

Evaluation of Oropouche First Phase

It has been proposed that initial utilization of the Oropouche be accomplished through construction of an intake to harvest run-of-the-stream yield. Dependable yield of such an intake would be no more than 8 mgd, the recorded minimum flow.

Because of construction operations at the proposed damsite and clearing operations in the reservoir area, regardless of intake

location, water treatment works would be required to assure that this flow could be harvested.

Such a first-phase Oropouche project would not be economically feasible because the investment in temporary facilities of \$420,000 to \$1,135,000, depending on intake location, would be an excessive, nonrecoverable capital cost.

Development of Moruga River

General. The Moruga River drains a catchment located east of the Village of Moruga on the south coast of Trinidad (see Figure 24). The proposed reservoir and dam would be located mostly on oil-reserve lands. This project comprises:

1. A dam and reservoir on the river;
2. A low-lift pumping station at the reservoir;
3. A water treatment plant and high-lift pumping station at the reservoir; and
4. A transmission main from the reservoir to San Fernando, the hub of the southern urban area.

Moruga Yield. The proposed Moruga River reservoir catchment is about 31 square miles in area and is gently rolling. Mean annual rainfall within the catchment is about 80 inches and it is estimated that runoff is between 35 and 45 percent of rainfall. The estimated mean annual and the 95 percent dry-year runoffs are listed below:

	Runoff					
	Annual		Wet season		Dry season	
	Inches	Mil gal	Inches	Mil gal	Inches	Mil gal
Mean annual	33	14,800	29	13,000	4	1,800
95 percent dry year	23	10,300	21	9,400	2	900

With an available storage capacity of 7,500 to 10,000 million gallons, the yields from the proposed reservoir are estimated as follows:

	Yield, mgd	
	Gross	Net
Mean annual	40	36
95 percent dry year	28	25

No stream gauging of the Moruga has been carried out. Therefore estimates of runoff and, consequently, yield are based upon the limited information available on streams in the general area.

It is recommended that the Water Resources Survey establish a stream-gauging station downstream from the proposed damsite at the earliest possible date to determine more exactly the probable yield of the proposed reservoir.

Geology of Moruga Reservoir Area

The Moruga reservoir site lies within the southern drainage of the Southern Range, about 5 miles east of Moruga. It is underlain by deltaic sands, silts, and clays of Miocene age. The proposed damsite is underlain by sands of the Cruse Formation, and abuts

sandstones of the Moruga and Mayaro formations on the north and south, respectively. The reservoir area is underlain primarily by the Cruse and Moruga formations, of which the latter is deeply weathered.

The reservoir lies within a block delineated on three sides by fault systems. However, no major faults are reported within the reservoir area. Prior to construction of a reservoir at this site, a comprehensive survey (surface and subsurface) of the basin to determine tightness, and of the damsite to ascertain foundation conditions, is essential.

Navet Pumped-Storage Project

General. The existing Navet reservoir is located near the headwaters of the Navet River and controls about 7 square miles of the Navet catchment. The reservoir storage capacity is about 4,100 million gallons, equivalent to 590 million gallons per square mile of contributing catchment. For optimum development in this part of Trinidad no more than 340 million gallons per square mile (75 percent of average runoff) is required. Therefore, Navet reservoir has excess capacity of about 1,750 million gallons which could be used to increase the dependable yield of the reservoir if the contributing catchment could be enlarged.

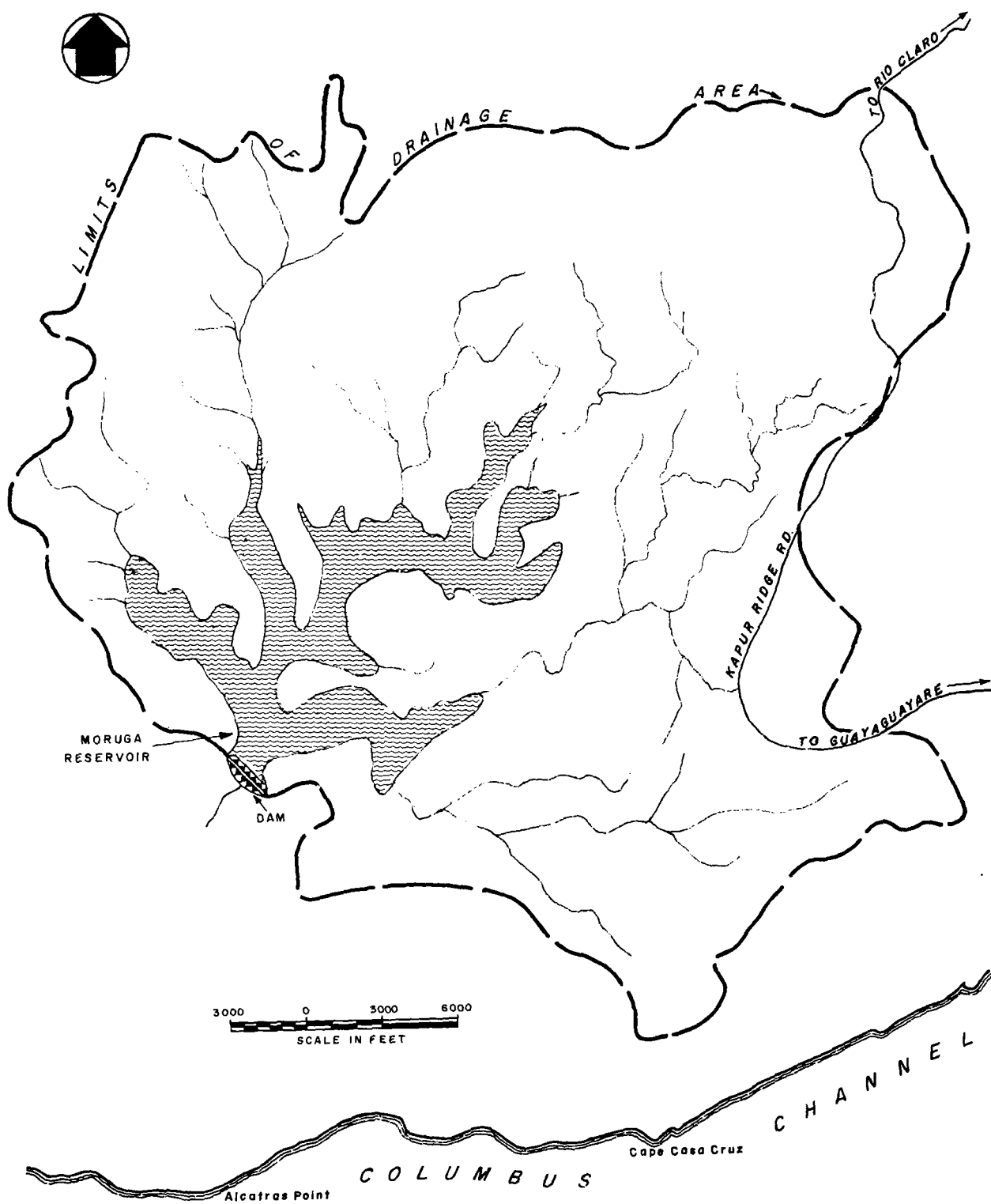


FIG. 24 MORUGA RESERVOIR AND DRAINAGE AREA

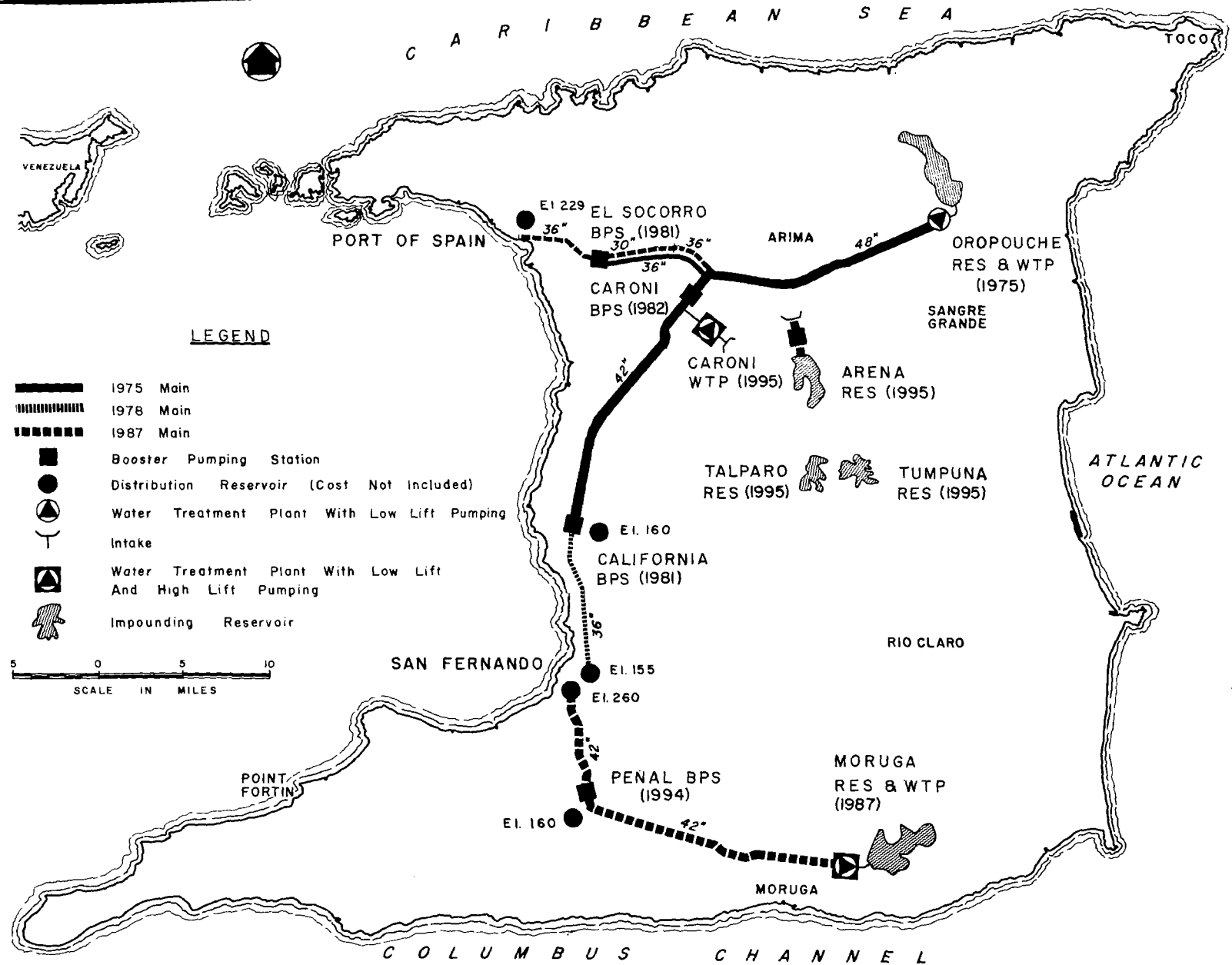


FIG. 26 MAP SHOWING ALTERNATIVE PROGRAM B

The proposed Navet pumped-storage project would enlarge the contributing catchment by collecting runoff from part of the uncontrolled Navet watershed and pumping it to the existing reservoir. The project comprises:

1. A low dam about 1-3/4 miles downstream from the existing reservoir;
2. An intake and raw-water pumping station about 800 feet below the existing dam;
3. Additional settling capacity at the Navet treatment plant to increase plant capacity to 17 mgd;
4. Additional low-lift pumping capacity at the Navet low-lift pump station to increase capacity to 17 mgd; and
5. A booster pumping station on the Navet main at Malgretoute to increase transmission capacity to 17 mgd.

Navet Yield. The estimated dependable yield for the existing reservoir is about 7 mgd. In 1968 the runoff was about 3,557 million gallons and the use was about 3,522 million gallons, including a net reduction of water in storage amounting to 850 million gallons for the year. In other words, leakage and evaporation losses amounted to about 885 million gallons, and the total draft on the reservoir plus leakage and evaporation losses exceeded inflow to the reservoir by about 850 million gallons.

Before the existing reservoir was built, three alternative sites were investigated: the site of the present reservoir and two downstream sites. The elevation of the present site was such that no high-lift pumping would be necessary to deliver water to San Fernando. In addition, the then estimated average yield (12 mgd) was considered to be sufficient to meet the needs of the area for many years.

The alternative Navet damsite nearest the existing dam has a catchment area 11 square miles greater than does the existing reservoir. The third site on Cunapo Southern Road has a drainage area of 25 square miles, 18 square miles greater than the existing reservoir catchment.

Investigation of the two downstream sites revealed that:

1. A low dam at the first site downstream from Navet dam would back water up to just below the Navet dam so that wet-season runoff could be pumped via a short pipeline to the existing reservoir;
2. The lower site would require a much higher dam or a long raw-water main and would therefore be much more expensive.

The yield of the pumped-storage project with the low dam at the first site downstream from the existing reservoir was determined in much the same manner as was the yield of the Caroni-Arena project. From stream-gauging records for the gauging station at the third damsite, adjusted to the second site, flow-duration curves were plotted for the

second damsite and the yield and raw-water pumping capacity determined from these curves.

The dependable yield of the reservoir with the additional inflow from the pumped-storage project was estimated to be about 17 mgd with a raw-water transfer capacity of about 40 mgd. With a somewhat higher raw-water transfer capacity and additional storage capacity, the yield might be raised to around 20 mgd. However, the additional 3 mgd of dependable yield would require a disproportionate additional expenditure in transmission mains, storage and treatment.

Evaluation of the Navet Damsite

General. The site is in the Central Range Forest Reserve, surrounded by teak trees with only light underbrush. The stream at the damsite is sharply incised (5 to 10 feet) into a narrow floodplain, and the stream is choked with trash consisting of bamboo and a few teak trees. There is evidence of rapid erosion and flooding during periods of rainfall. A review of hydrographs from the downstream gauging station indicates that the stream is indeed characterized by flash flooding.

Subsurface Conditions. The site is crossed from east to west by a ridge of conglomerate, and the stream itself in the vicinity of the ridge is underlain by the same bedrock. The bedrock crops out on the western ridge 100 yards from the stream and

appears poorly cemented. Sand and gravel have weathered out and form residual soil cover for the ridge.

Design Considerations. Impoundment works may be expected to cause the following changes in stream regimen:

1. Aggradation and silting upstream caused by a lower velocity above the dam due to a change in gradient;
2. Stripping of the vegetation will expose silty soil which will erode easily and carry sediment into the impoundment; and
3. Down cutting below the dam, due to change in gradient, may occur and endanger the structure.

Recommendations. The foregoing considerations lead to the following recommendations:

1. Keep the dam as low as possible;
2. Remove vegetation from the edge of the reservoir;
3. Provide rock or gravel protection for reservoir cut slopes; and
4. Provide a stilling basin to protect the downstream side of the dam from erosion or undercutting.

CHAPTER 9

EVALUATION OF ALTERNATIVE PROGRAMS

General

In Chapter 8, potential supplies were selected for development to meet projected system demands through the year 2000. Construction of the Navet pumped-storage project for an additional 10 mgd dependable yield and development of groundwater for an additional 14 mgd of dependable yield are obvious projects of any first-stage development plan. Local conditions in the more remote low-demand areas, where a major transmission main from a large source of supply cannot be justified, will govern the sequence of development of the remaining groundwater.

This chapter is primarily concerned with determining the sequence of development of the major supplies (Oropouche, Caroni-Arena, and Moruga). It appears from the comparison of unit capital costs in Table 27 that the Caroni-Arena supply is a logical first-stage project. Unit capital costs are useful when comparing similar types of development. However, operating costs for both the Caroni-Arena and the Moruga supplies would be substantially higher than for the Oropouche, which would be essentially a gravity supply. Therefore, a valid economic comparison requires consideration of annual operating costs as well as capital costs. Also, a project which may appear as a poor choice for first-stage construction may, in later stages of development, prove economical because of a change in conditions.

In this chapter, four alternative programs for staged development are described, and a comparison is made to determine the most economic program. This comparison provides a basis for the recommended development program described in succeeding chapters.

Description of Programs

Of the three major supplies selected for future development, the Oropouche, the Caroni-Arena, and the Moruga, only two appear suitable as first-stage projects. These are the Oropouche and the Caroni-Arena. The Oropouche has long been considered as the next logical source to be developed. However, since it is relatively remote from the principal areas of demand, development will require an extensive transmission system. In comparison, the Caroni-Arena system is relatively close to the areas of demand and will require a much less extensive transmission system. This source, however, is at a lower elevation so that pumping costs will be higher than for the Oropouche supply.

As a first-stage project, the Moruga would have to supply both the north and the south. Because of its remoteness from the centers of demand, the transmission system costs for first-stage development would be prohibitively high. However, after the construction of one of the northern sources, it would become desirable as a second-stage project to supply increasing demands in the south, thereby freeing the northern supplies to meet demands in the north.

If the Caroni-Arena and the Oropouche are the only feasible first-stage projects, the possible development programs involving the Oropouche, the Caroni-Arena, and the Moruga are limited to the four alternatives shown in Figures 25, 26, 27, and 28. Figures 29 and 30 show how each of these programs, together with existing supplies and additional local supplies, both groundwater and rural surface supplies, would meet projected future demands.

Program A – Oropouche/Caroni-Arena. Initial construction in this program would comprise full development of the Oropouche supply and treatment facilities for a dependable yield of 45 mgd and a maximum day capacity of 55 mgd; a 48-inch diameter transmission main from the treatment works to Tacarigua; a 36-inch main from Tacarigua to Tunapuna; a 30-inch main from Tunapuna to the existing El Socorro Pumping Station; and a 42-inch main from Tacarigua to a proposed 4-million gallon distribution storage reservoir at California. Water would be conveyed from El Socorro to Port of Spain via the existing 30-inch El Socorro main.

About 1978, a 36-inch diameter main from California to San Fernando would be required to meet projected demands in the San Fernando area and south Trinidad. The system would operate by gravity until about 1981 when it would be necessary to construct booster pumping stations at California and El Socorro. Around 1982, a third booster pumping station would be required at Caroni to pump water to the California Reservoir.

In 1987, an additional supply and more transmission capacity would be required. The Caroni-Arena system, designed for a

dependable yield and maximum day capacity of 42 mgd; a water treatment plant at Kelly Headworks; a 42-inch diameter main from the water treatment plant to California; a 36-inch main from California to San Fernando; a 36-inch main from Caroni to El Socorro; and a 30-inch main from El Socorro to Port of Spain, would meet the increased needs of Trinidad until 1995. Then a second 48-inch pipeline from the Oropouche water treatment plant to Tacarigua, together with development of local supplies in remote areas, would provide the added capacity required to meet projected demands to the year 2000.

Program B – Oropouche/Moruga. This program is similar to the Oropouche/Caroni program in all respects until the year 1987. At that time, instead of constructing the Caroni-Arena system as a second-stage supply, the Moruga supply and treatment works would be constructed for a dependable yield of 25 mgd and a maximum day capacity of 33 mgd with a 42-inch pipeline from the reservoir to San Fernando. Initially the 42-inch pipeline would be adequate to convey water to San Fernando with a single lift at the reservoir. By 1992, a booster pumping station would be required at Penal. Construction of the Moruga supply would eliminate the need for a second pipeline south from Tacarigua.

Additional supply would again be needed in 1995, at which time the Caroni-Arena system would be constructed. The next improvement would not be required until after the year 2000.

Program C – Caroni/Moruga. Initial construction in this program would include the Caroni-Arena system designed for a dependable yield and maximum day capacity

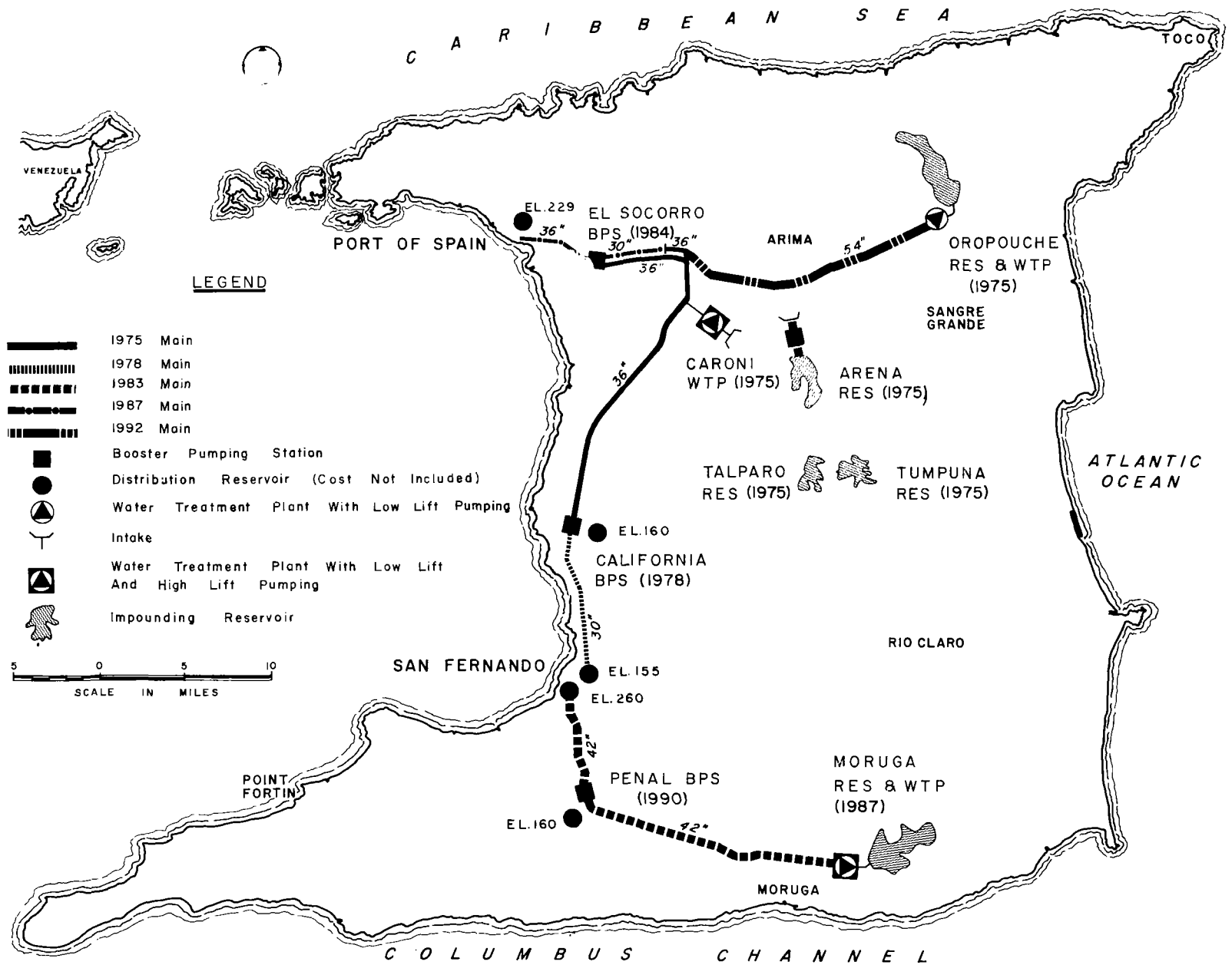
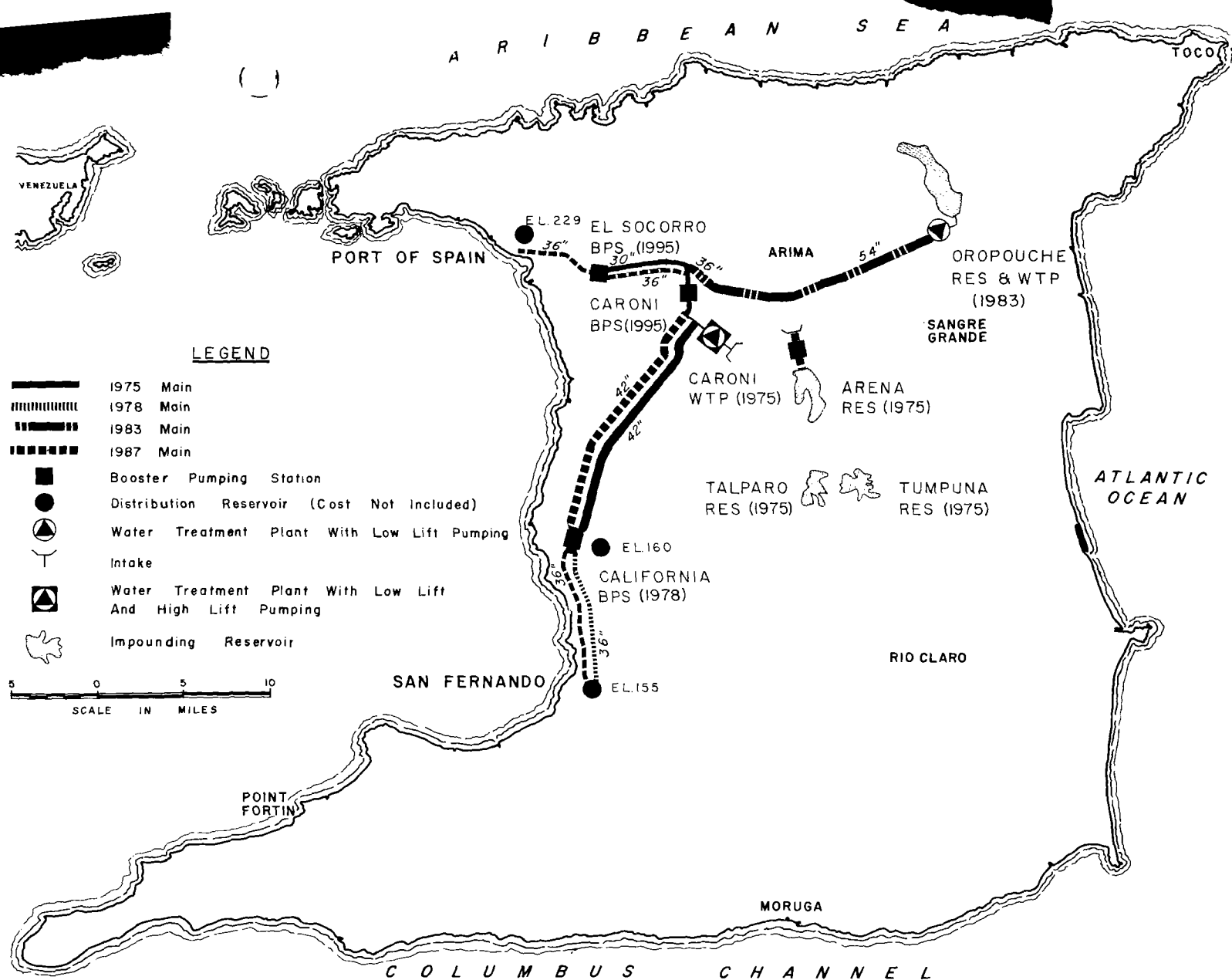


FIG. 27 MAP SHOWING ALTERNATIVE PROGRAM C



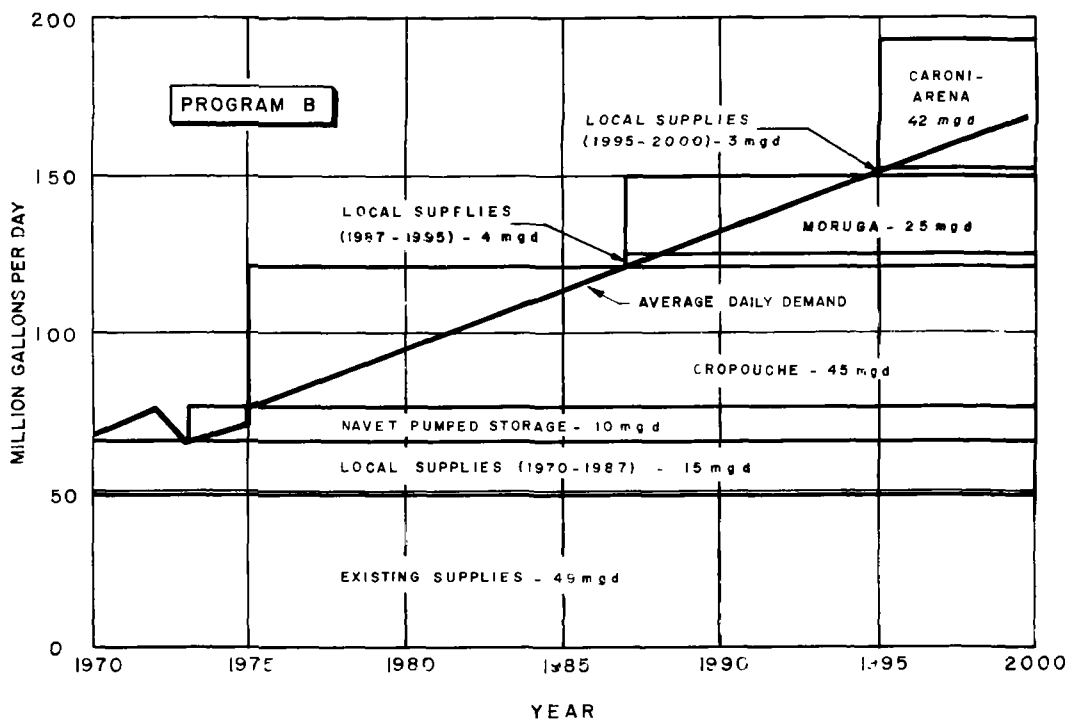
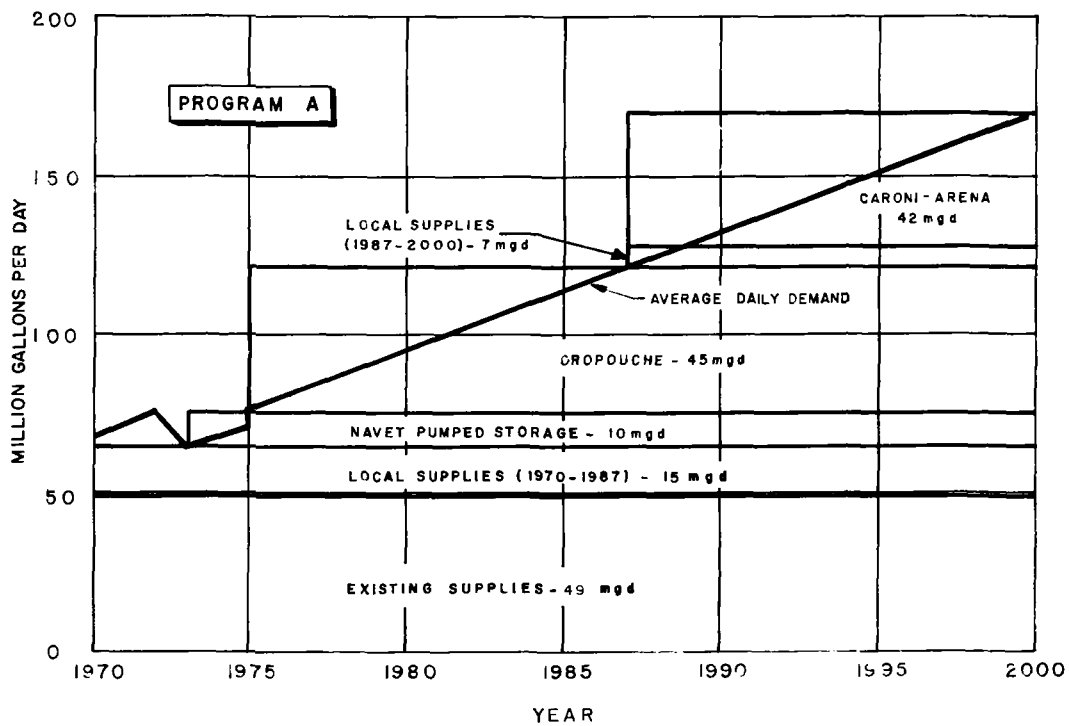


FIG. 29 ALTERNATIVE PROGRAMS A AND B

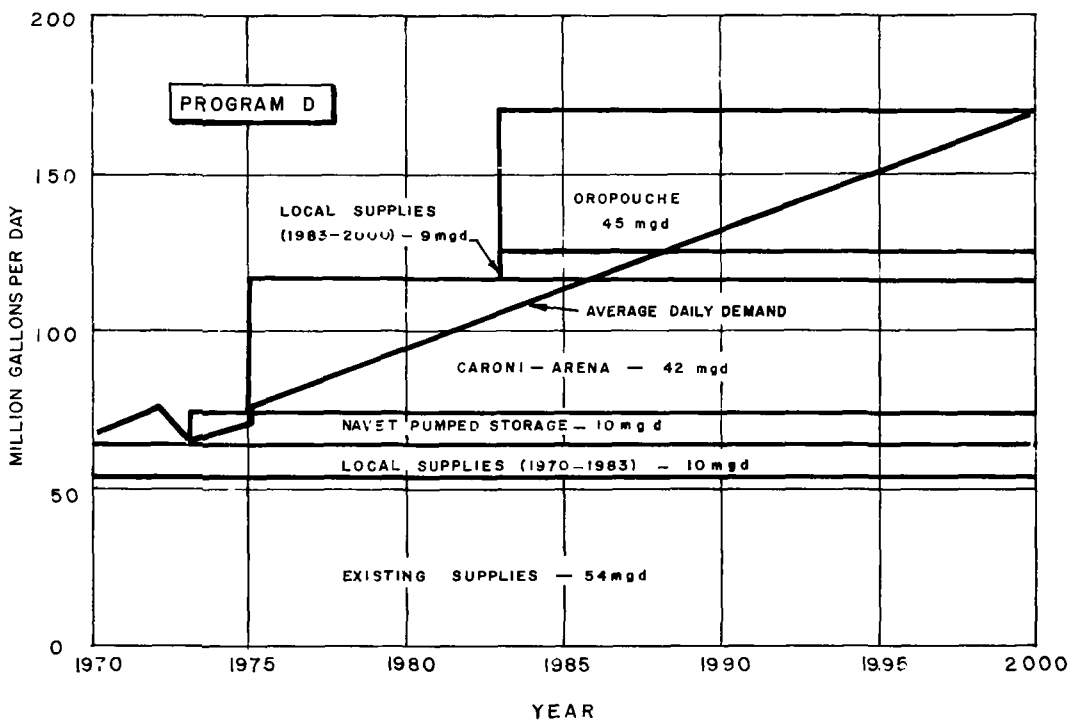
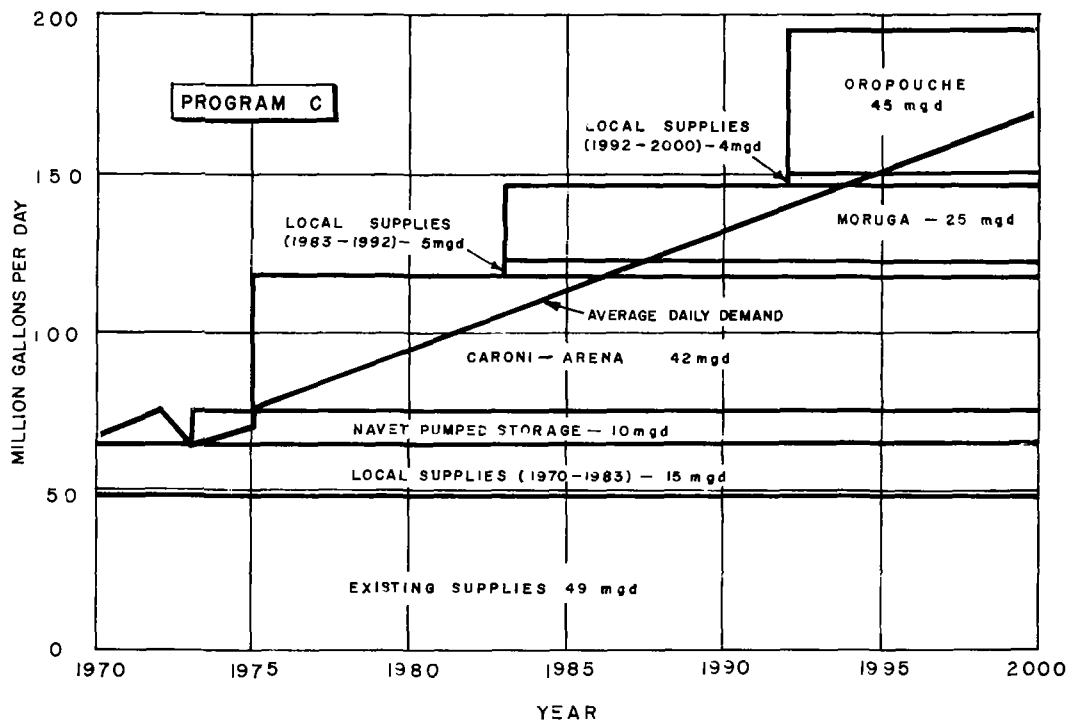


FIG. 30 ALTERNATIVE PROGRAMS C AND D

of 42 mgd; a 36-inch transmission main to the proposed California reservoir; a 36-inch main to Tunapuna; and a 30-inch main from Tacarigua to El Socorro. Two sets of high-lift pumps would be provided at the Caroni water treatment plant, one to pump to the El Socorro pumping station sump and the other to pump to the California reservoir.

By 1978, increasing demands in San Fernando and the south would require laying of a 30-inch main from California to San Fernando and the construction of a booster pumping station at California.

Additional supply would be required in 1983. This would be provided by the construction of the Moruga supply for a dependable yield of 25 mgd and a maximum day capacity of 33 mgd with a 42-inch pipeline from Moruga to San Fernando. An additional 36-inch pipeline from Caroni to Port of Spain would be required in 1987. Around 1989, a booster pumping station would be required at Penal. The capacity of the Moruga and other then-existing supplies would be taxed about 1992. The Oropouche supply would then be constructed with a 54-inch main from the reservoir to Tacarigua. Because Oropouche operating costs would be lower, the Oropouche supply would be operated at near design capacity and production from the Caroni-Arena system would be reduced accordingly.

Program D – Caroni/Oropouche. This program is similar to the Caroni/Moruga program until 1983, except that the transmission main to California from the Caroni water treatment plant would be 42 inches in diameter and that from California to San Fernando would be 36 inches in

diameter. In 1983, instead of constructing the Moruga as the second source as in Program C, the Oropouche supply and treatment works, designed for a dependable yield of 45 mgd and a maximum day capacity of 67 mgd, would be constructed along with a 54-inch transmission main from the reservoir to Tacarigua. To take advantage of lower power and chemical costs, the Oropouche system would be operated at design capacity, and production at Caroni would be reduced accordingly. In 1987, smaller pipelines would be constructed from Tacarigua to Port of Spain and from Caroni to San Fernando. Booster pumping stations at El Socorro and Caroni would be required by about 1995. No additional supplies would be required to meet projected demands for the year 2000.

Basis of Comparison

Each year's capital charges and operating expenses for the four alternative development programs were estimated and then multiplied by the appropriate present worth* factor to find their present worth as of 1971, the year of initial construction.

A comparison of the total 1971 values of these annual expenses for a period of 29 years to the year 2000 indicates the program with the most favorable long-term cost.

Capital Charges. The construction cost of each program was based on 1969 prices. The project cost was determined by adding to the estimated construction cost an allowance

**Present worth is the value at the present time of a sum of money that would repay a future series of payments at a given interest rate.*

of 40 percent to cover the cost of engineering, contingencies, administration, and other overhead expenses. To determine the annual capital charges, the project cost was multiplied by the appropriate capital recovery factor presented in Table 31. These factors are based on the estimated useful life of the facility and an interest rate of 8 percent.

Table 31. Capital Recovery Factors

<u>Type of facility</u>	<u>Estimated useful life, years</u>	<u>Capital recovery factor</u>
Dams and reservoirs	50	0.0817
Transmission mains	50	0.0817
Water treatment plants	25	0.0937
Pumping stations	25	0.0937

Annual capital charges are equated to the annual level debt service payment on a serial bond issue having a term of repayment corresponding with the useful life of the project. They are also equivalent to the interest plus depreciation (computed by the sinking-fund method).

Operating and Maintenance Expenses. Operating and maintenance expenses were developed for each year beginning at the first year that the facility is anticipated to be in service, and include the cost of power, chemicals, maintenance, and salaries.

Power costs were based on the present schedule of rates published by the Trinidad and Tobago Electricity Commission, and, assuming efficient operation, are estimated at \$14 per million gallons per 100 feet of lift.

Chemical costs for each supply were estimated as follows:

<u>Supply</u>	<u>Cost per mil gal</u>
Oropouche	\$40
Caroni-Arena	\$60
Moruga	\$40

Percentages of construction costs were used as approximations of annual maintenance and repair costs, as follows:

<u>Type of facility</u>	<u>Percentage</u>
Dams and reservoirs	0.5
Water treatment plants	2.0
Transmission mains	0.5
Pumping stations	2.0

Salaries used, including benefits, were as follows:

<u>Position</u>	<u>Annual salary</u>
Operator	\$4,000
Supervisor	\$6,000

Staffing of the various facilities assumed heavy reliance on manual operation of all facilities. Pumping stations were assumed to require four operators and a supervisor. Major supply facilities like the Oropouche were assumed to require staffs ranging from 40 to 80.

Economic Comparison

Annual operating and maintenance expenses were added to the annual capital charges for each year. This sum was multiplied by the appropriate present worth factor (interest rate of 8 percent) to

determine the 1971 value of all future expenses.

The year by year present values as of 1971 were added together and cumulative totals developed for each program. These cumulative totals are the sums of the present values of all expenses for the preceding years.

Figure 31 is a plot of present values for the four programs from 1971 to the year 2000. Cumulative capital costs are plotted on Figure 32. Table 32 is a comparison of the cumulative costs at the year 2000. The present worth figures indicate the relative economic merits of the alternative programs. A comparison of the figures in Table 32 shows that Program C, with the Caroni-Arena as the first-stage project followed by Moruga as the second-stage project, has the best overall economic advantage.

Table 32. Comparative Costs of Alternative Programs

<i>Program</i>	<i>Cumulative capital cost at year 2000</i>	<i>Present worth in 1971 of annual capital and operating costs to the year 2000</i>
A	\$150,900,000	\$94,600,000
B	\$154,800,000	\$94,000,000
C	\$156,900,000	\$78,400,000
D	\$138,100,000	\$85,800,000

The most economic program has the highest capital cost by the year 2000. Both Programs B and C have greater capital costs than A and D because they include development of all three recommended major sources and, as a result, would have excess capacity at the year 2000, whereas programs A and D include only two major sources and would have no excess capacity at the year 2000.

The higher capital cost of Program C over Program B is caused by the larger size of the Oropouche transmission main. For Program B with the Oropouche constructed as the initial project and a low initial demand, a 48-inch main was determined to be the economic size. The larger 54-inch main in Program C is economically justified to permit full utilization of the Oropouche supply initially in order to reduce production from the Caroni-Arena system, which has a much higher operating cost.

The higher capital cost of the most economic program is not surprising since it obtains its economic advantage by more advantageous staging of the construction of large capital items, thereby increasing total capital expenditure in order to obtain a more evenly distributed cash flow. This advantage is shown on Figure 32, which compares the capital expenditures for the four programs. Although the total capital cost of Program C is the greatest of the four alternatives up to the year 2000, it is the least up to 1990.

Recommended Program

It is recommended that WASA adopt Program C, providing for the Caroni-Arena as the first-stage project and the Moruga and the Oropouche as the second and third-stage projects, respectively, as the long-term development program. This program is the best from the standpoint of long-term economic and initial capital requirements.

Sanitary Recommendations for Caroni Drainage Area

Economic and hydrologic studies indicate that a water supply project

developing the Caroni-Arena at Kelly headworks will produce water at substantially lower costs than will any alternative project.

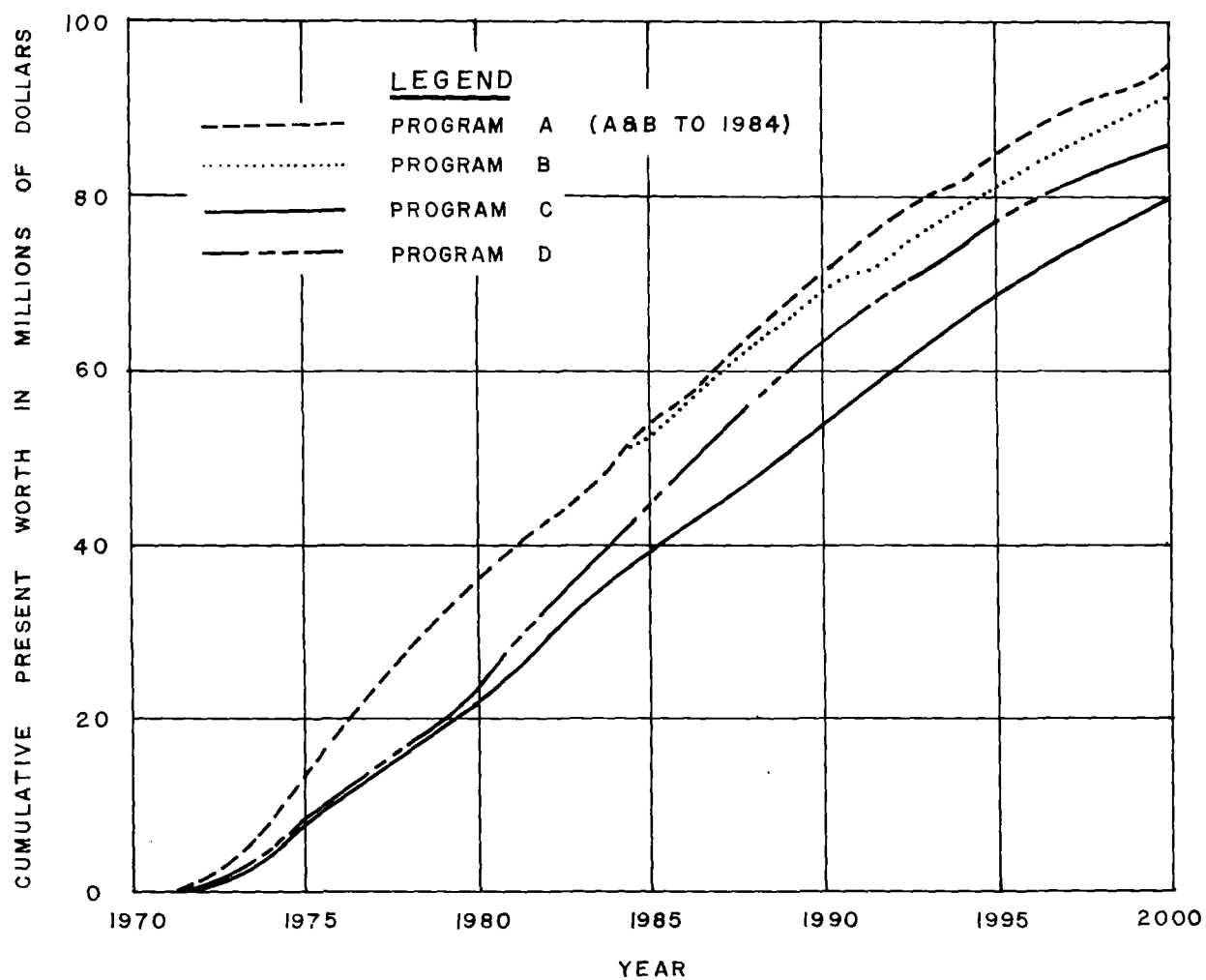
To permit the use of this source, it is obvious that the basin must be made as sanitary as possible. Figure 33 shows the present sanitary condition of the watershed, which has an estimated population of 40,000. Some of the required improvements will be needed for the general benefit of the country, but even if a more costly alternative water supply source were selected it would only be a question of time before the Caroni water would be needed and the required work would thus merely have been deferred to a later date.

A program to clean up the basin would include, but not necessarily be limited to, the following items:

1. Redesign the presently planned sewage treatment plant at Piarco south of the existing terminal as a lift station to pump the raw sewage to treatment works at the proposed new terminal facilities at the north side of the field, or add chlorination equipment to the presently planned plant. It is recommended that effluent from the north terminal, when developed, be discharged into the Caroni River downstream from Kelly by use of the Oropuna River.
2. Chlorinate all sewage disposal plant effluent. This would include that from the WASA plant at Arima, that from the Mausica Teachers College plant, and that from the

various private industrial waste disposal facilities, existing or to be installed.

3. Discharge textile mill and other industrial wastes to existing system where feasible. Special waste treatment may be required by the industries before discharge to the public system or to any open drain or stream.
4. Regulate the storage and use of animal and poultry manure and continue the requirement of the Public Health Inspectors that all rubbish, feathers, and entrails be buried at dumps. Effect strict control of dumping procedures both at dumps and at unauthorized places. Prevent dumping of rubbish and garbage into streams.
5. Extend planned Piarco sewer to collect sewage from Piarco Village, guest houses, police station, radio complex, and other structures in the area.
6. Construct new sewage treatment plant south of Churchill Roosevelt Highway near confluence of Arima and Guanapo Rivers. (Refer to Page 59 of Report to WASA upon Sewerage Facilities, dated September 23, 1968).
7. Construct settling ponds at quarry and gravel-washing operations to reduce turbidity in wash-water effluent.



**FIG. 31 CUMULATIVE PRESENT WORTH OF
ALTERNATIVE PROGRAM COSTS**

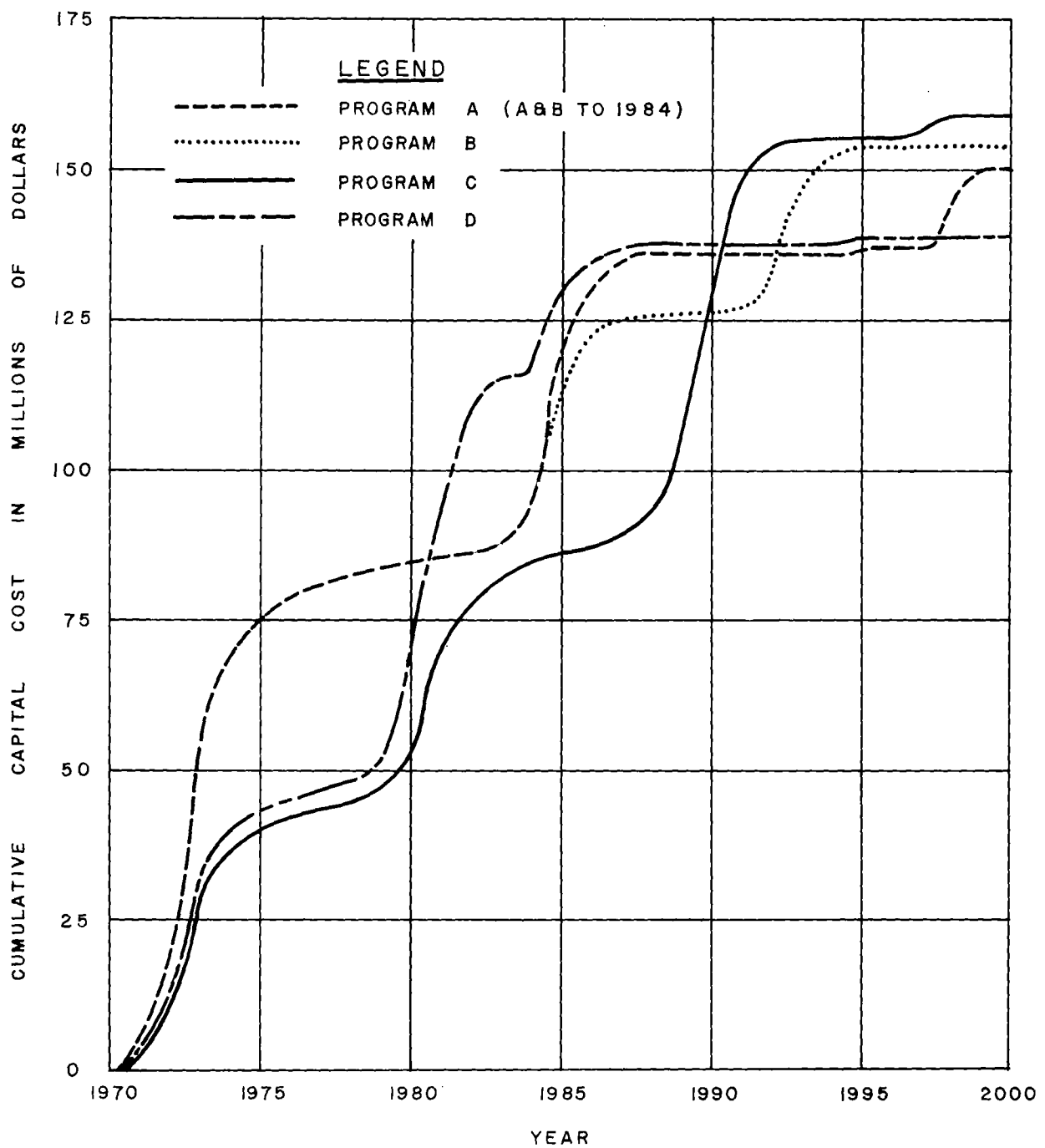


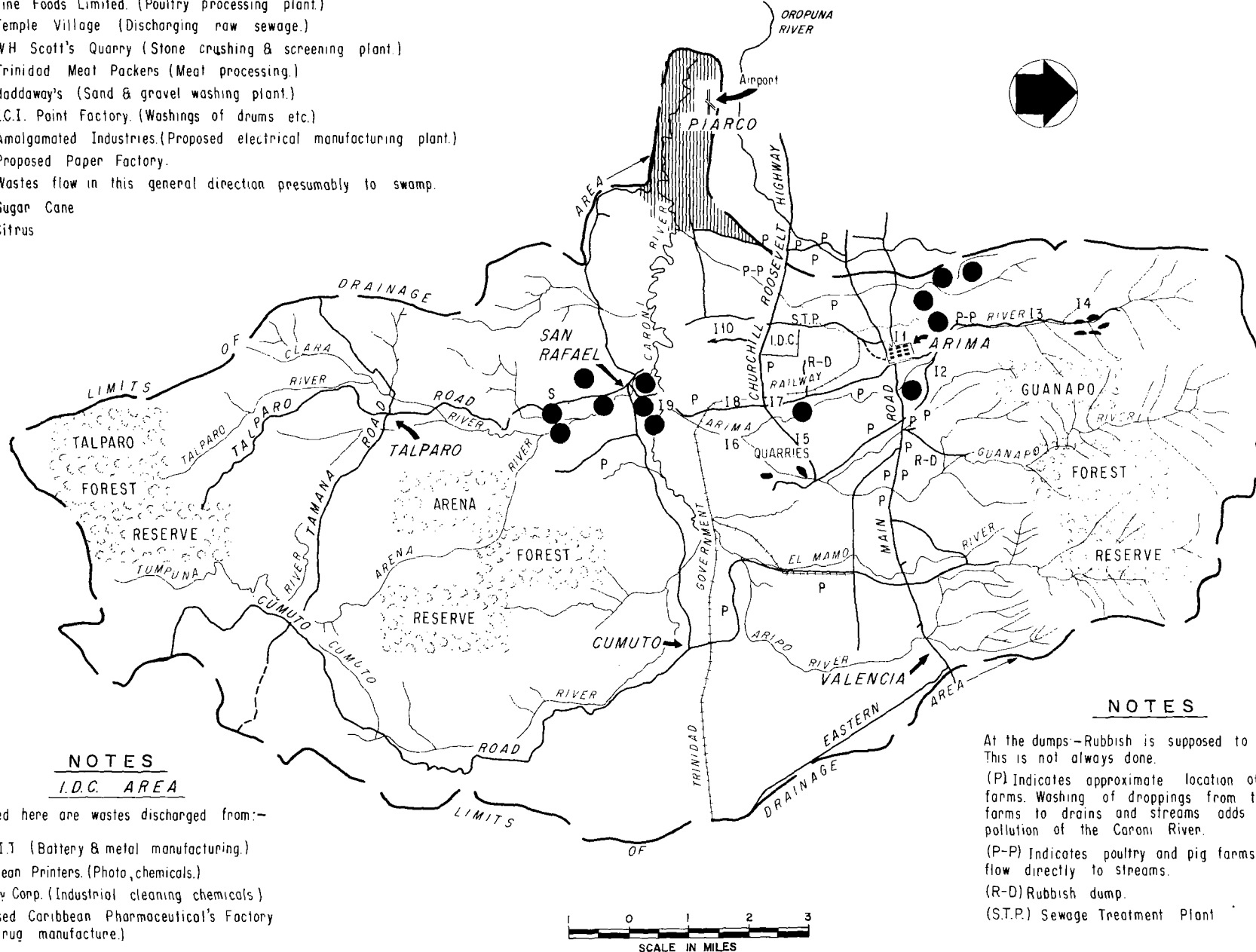


FIG. 32 CUMULATIVE CAPITAL COSTS OF ALTERNATIVE PROGRAMS

- 11 Trinidad Textile Mills (Dyes, acid etc.)
- 12 Fine Foods Limited. (Poultry processing plant.)
- 13 Temple Village (Discharging raw sewage.)
- 14 WH Scott's Quarry (Stone crushing & screening plant.)
- 15 Trinidad Meat Packers (Meat processing.)
- 16 Haddaway's (Sand & gravel washing plant.)
- 17 I.C.I. Point Factory. (Washings of drums etc.)
- 18 Amalgamated Industries. (Proposed electrical manufacturing plant.)
- 19 Proposed Paper Factory.
- 110 Wastes flow in this general direction presumably to swamp.

-  Sugar Cane
 Citrus



NOTES

I.D.C. AREA

Included here are wastes discharged from:-

- A.B.M.I.T (Battery & metal manufacturing.)
- Caribbean Printers. (Photo, chemicals.)
- Diversy Corp. (Industrial cleaning chemicals.)
- Proposed Caribbean Pharmaceutical's Factory (for drug manufacture.)

NOTES

At the dumps:-Rubbish is supposed to be buried. This is not always done.

(P) Indicates approximate location of poultry farms. Washing of droppings from these farms to drains and streams adds to the pollution of the Caroni River.

(P-P) Indicates poultry and pig farms, washings flow directly to streams.

(R-D) Rubbish dump.

(S.T.P.) Sewage Treatment Plant

FIG. 33 POTENTIAL SOURCES OF POLLUTION ON CARONI WATERSHED ABOVE KELLY HEADWORKS

8. Clean up village areas by installation of sewage treatment works, by use of well-designed septic tanks, or by a controlled privy program. Temple Village, for example, should either be relocated or piped water and a water-borne sewerage system should be developed, even if only for communal baths and latrines.
9. WASA should be given the authority to regulate the use and application of chemicals, fertilizers, herbicides, pesticides, etc. on the portion of the Caroni River watershed and any other watershed used or to be used for potable water supply.
10. Provide careful and continuing sanitary inspection of all drainage areas and basins used as sources of either surface water or groundwater supply, and vigorously enforce the elimination of conditions that are likely to affect water quality adversely.

It is recommended that necessary steps be taken to ensure the most economical development of the Caroni project, so as to benefit from the substantial savings derived from using this project rather than an alternative. It may be reiterated that the water from this source will be needed one day in any event and that clean-up procedures will assuredly be more expensive if deferred to a later date.

Sensitivity of Second-Stage Development to Changes

Since each program is based on projections of demand, any major change in demand requirements could alter the choice of the second-stage project. This could easily happen because the difference in present worth between the recommended program with the Moruga as the second-stage supply and Program D with the Oropouche as the second-stage supply is less than 10 percent by the year 2000. Should the increase in demand in the south be less than our studies anticipate, the Moruga project may no longer be the most advantageous second-stage project. The principal economic advantage of the Moruga over the Oropouche is that it eliminates the need to reinforce the main from Caroni to San Fernando. If the future increase in demand is concentrated in the north and reinforcement of the main from Caroni to San Fernando does not become necessary regardless of source, then the Oropouche will be the more economical source for second-stage development. Accordingly, before proceeding with the second-stage development, final selection of the second-stage source will require a comparison of the then existing and anticipated future conditions with the projections made in this study and re-analysis if there is a substantial difference.

The importance of the second-stage project at the present time lies in the sizing of the transmission main from the Caroni water treatment plant south to California. With Moruga as the second-stage project, this should be a 36-inch main. Had the Oropouche been a more economic second-stage project, a 42-inch main would prove a better choice.

CHAPTER 10

COMPARISON OF MAJOR FIRST-STAGE PROJECTS

General

In the preceeding chapter it was established that provided growth in population, industry, and resulting water demands occur as projected in Chapter 4, WATER REQUIREMENTS, the long-term program with the Caroni-Arena as the first stage and the Moruga as the second stage is the most economical of the alternative programs. Furthermore, in Chapter 8, DEVELOPMENT OF POTENTIAL SOURCES, it was indicated that the only economical major first-stage alternatives are the Oropouche and the Caroni-Arena systems.

In this chapter the recommended program of first-stage initial projects comprising the metering of all connections, construction of the Navet pumped-storage project, and construction of the Caroni-Arena project is compared with an alternative program of first-stage projects substituting the Oropouche for the Caroni-Arena project. First-stage initial projects are those which will meet projected additional water demands of Trinidad and Tobago until about 1978 and can be designed and constructed in a four- to five-year period.

Project Descriptions

Projects making up the recommended program and its alternative are independent. A general description of the recommended and alternative projects has already been

presented, and more specific details are given below.

Metering Program. In order to reduce consumption and water waste and to provide a basis for a new rate structure, domestic meters would be purchased and installed on all direct connections. The program would take two years and would require the purchase and installation of approximately 100,000 meters. Installation should be accomplished by contract.

Navet Pumped-Storage Project. The existing Navet Reservoir has an estimated dependable yield of 7 mgd. The proposed pumped-storage project would expand the capacity of the existing facilities to 17 mgd. The features of design are as follows:

1. A 25-foot high diversion dam, approximately two miles downstream of the existing dam and reservoir. The dam would increase the controlled drainage area by 11 square miles and would back water up to the toe of the existing dam.
2. An intake and pumping station at the toe of the existing dam to pump water from the diversion dam through a short length of conduit over the dam and into the existing reservoir.

3. Expansion of the existing water treatment plant from its existing capacity of 12 mgd to 17 mgd maximum day capacity.
4. A booster pumping station at Malgretoute to increase the capacity of the existing transmission main from 11 mgd by gravity flow to 17 mgd.

Caroni-Arena System. The initial construction of the Caroni-Arena system would consist of a pumped-storage reservoir, a river intake, a water treatment plant with low-lift and high-lift pumping, and a transmission system to serve areas of demand in the north and south. Dependable yield of the initial construction would be 33 mgd. Treatment plant and pumping capacity would be designed for a maximum day production rate of 42 mgd. Future construction would add two impounding reservoirs in the Caroni watershed to increase the dependable yield of the system to the 42 mgd maximum day rate.

Principal components of the project are shown on Figure 34 and are as follows:

1. A 63-foot high earth-fill dam and reservoir on the Arena River with usable storage of 3,500 million gallons to augment low flows in the Caroni River downstream of San Rafael.
2. A river intake and pumping station on the Caroni River near San Rafael to pump water to the proposed reservoir during periods of high-river flow.
3. A 36-inch transmission main from the pumping station near San Rafael to the proposed reservoir.
4. A river intake and water treatment plant with low-lift and high-lift pumping at Kelly Village to extract water from the Caroni River, treat it, and pump it to distribution.
5. A 36-inch transmission main from the water treatment plant to Tunapuna with a 24-inch and a 30-inch main to sumps at the Valsayn water works and the El Socorro pumping station, respectively.
6. A booster pumping station to pump water from the 36-inch transmission main at Tunapuna to local distribution.
7. A 36-inch transmission main from the water treatment plant southward to California.
8. A four-million gallon distribution reservoir at California with a 30-inch connecting main from the 36-inch California main.
9. A booster pumping station at Pointe-a-Pierre on the existing 20-inch main from Freeport to San Fernando to pump water from the California reservoir to existing reservoirs in San Fernando.
10. Approximately 10,400 feet of 30-inch main and 13,500 feet of 24-inch main to reinforce

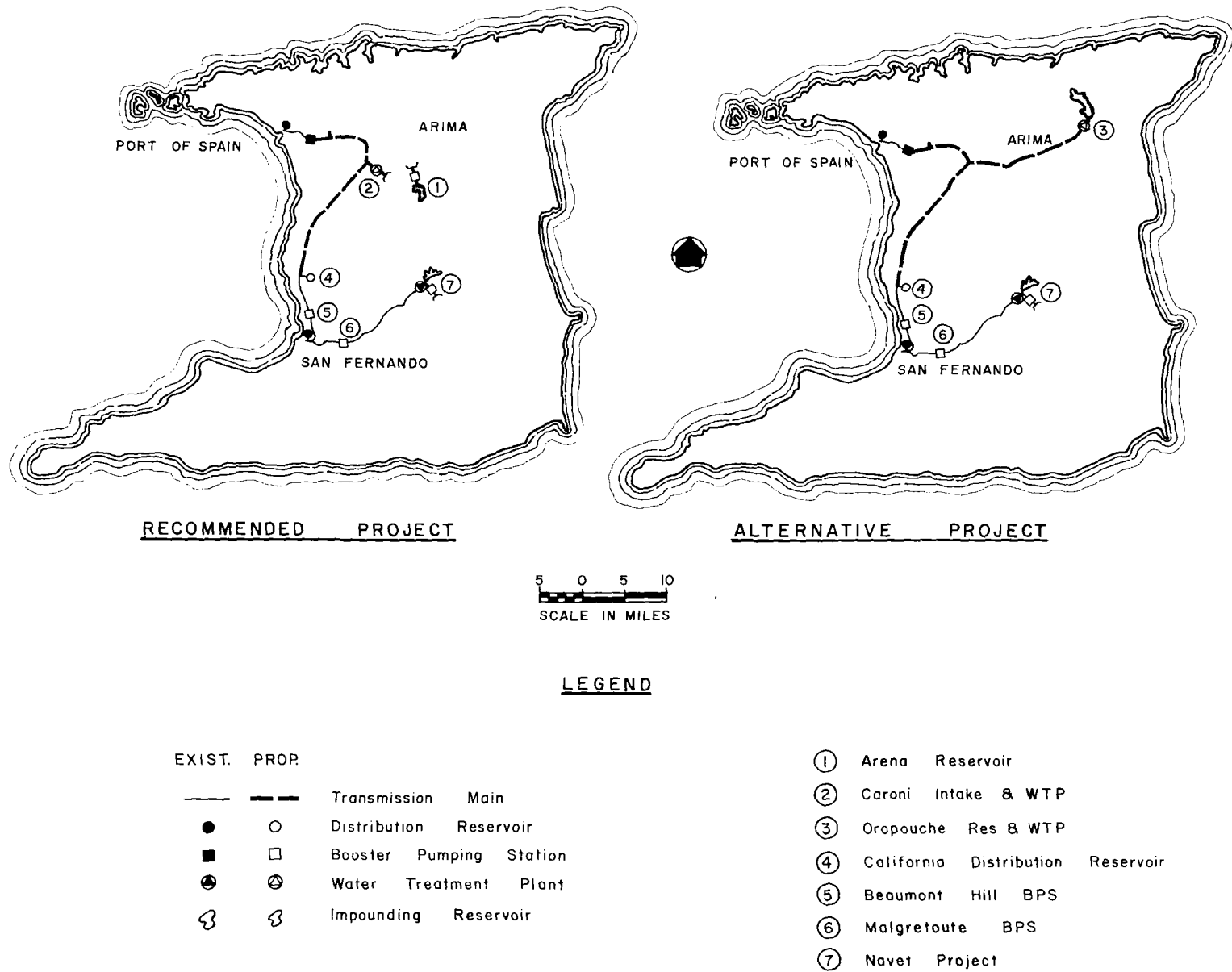


FIG. 34 RECOMMENDED AND ALTERNATIVE FIRST-STAGE INITIAL PROJECTS

transmission south of San Fernando. These mains are part of the Point Fortin transmission main scheduled for construction by 1978.

Oropouche System. The initial construction of the Oropouche system would consist of an impounding reservoir on the North Oropouche River, a low-lift pumping station to pump water from the reservoir to a water treatment plant, and gravity flow transmission mains to the major areas of demand. Dependable yield of the reservoir would be 45 mgd. The treatment plant and low-lift pumping station would be sized for a maximum day production rate of 33.5 mgd initially, expandable to 67 mgd in the future. Maximum flow obtainable by gravity through the transmission system would be 35 mgd. Pumping stations proposed for construction at a later date would increase transmission capacity to 55 mgd.

Principal components of the project are shown on Figure 34 and are as follows:

1. A 258-foot high rock-fill dam and a reservoir on the North Oropouche River with a usable storage capacity of 10,000 million gallons.
2. A low-lift pumping station to pump water from the reservoir to a water treatment plant located on a hill approximately 100 feet higher than the high-water level in the reservoir.
3. A 33.5-mgd water treatment plant on a hill above the reservoir.

4. A 48-inch transmission main from the clearwell of the water treatment plant to Tacarigua.
5. A 36-inch transmission main from Tacarigua to Tunapuna with 24-inch and 30-inch branch mains from Tunapuna to the discharge headers at the Valsayn water works and the El Socorro pumping station, respectively.
6. A 36-inch transmission main from Tacarigua south to California.
7. A two-million gallon distribution storage reservoir at California with a 30-inch connecting main from the end of the 42-inch California main.
8. A booster pumping station at Pointe-a-Pierre on the existing 20-inch main from Freeport to San Fernando to pump water from the California Reservoir to San Fernando.
9. Approximately 10,400 feet of 30-inch main and 13,500 feet of 24-inch main to reinforce transmission south of San Fernando. These mains are part of the Point Fortin transmission improvements scheduled for construction in 1978.

Capital Cost Comparison

Cost estimates are shown in Tables 33 and 34 for the recommended and alternative first-stage initial projects, respectively. Individual items include price escalation and

land, where appropriate. Contingencies and engineering costs are listed separately. A comparison of the total capital costs for the recommended and alternative projects, \$57,930,000 and \$90,924,000, respectively, shows that the recommended projects require a capital expenditure of less than two-thirds as much as the alternative projects.

Annual Cost Comparison

Debt service, operation and maintenance costs were estimated for both the recommended and the alternative projects for a period of seven years starting in 1975.

Table 33. Capital Cost of Recommended First-Stage Initial Projects

Item	Estimated cost in \$1,000 TT		
	Foreign	Local	Total
Metering program	5,900	500	6,400
Navet project	1,470	933	2,403
Caroni-Arena waterworks and intakes(1)	7,650	4,312	11,962
Arena dam	2,932	4,053	6,985
Transmission mains and reservoirs	8,852	4,792	13,644
Contingencies	5,360	3,597	8,957
Engineering(2)	3,587	3,992	7,579
Total	35,751	22,179	57,930

1. Includes low-lift and high-lift pumping stations.

2. Includes topographic surveys and surveys for land acquisition, subsurface exploration, soil testing, design, preparation of contract documents, shop drawing review, and monitoring of construction.

The average annual operating and maintenance costs for each year of the seven-year period are listed in Appendix A, Tables A-2 and A-3. Operating cost for chemicals and power are based on the

Table 34. Capital Cost of Alternative First-Stage Initial Projects

Item	Estimated cost in \$1,000 TT		
	Foreign	Local	Total
Metering program	5,900	500	6,400
Navet project	1,470	933	2,403
Oropouche WTP and raw-water pumping station	9,485	5,623	15,108
Oropouche dam	4,138	11,298	15,436
Transmission	16,298	9,098	25,396
Contingencies	9,428	6,821	16,249
Engineering(1)	4,861	5,071	9,932
Total	51,580	39,344	90,924

1. Includes topographic surveys and surveys for land acquisition, subsurface explorations, soil testing, design, preparation of contract documents, shop drawing review, and monitoring of construction.

estimates of annual production. Salary costs are based on estimates of manpower requirements and current pay scales. Maintenance costs are based on a percentage of the construction cost for each of the proposed facilities.

Table 35 compares total annual costs of the recommended and alternative projects. Debt service costs shown in this table are based on an 8 percent interest rate and a 25-year repayment period. In terms of average annual cost during this seven-year period, the recommended projects are about 70 percent as costly as the alternative projects, in spite of higher operating and maintenance costs for the recommended projects.

Pollution Control

There are more sources of water pollution on the Caroni catchment than there are on the Oropouche catchment. Before

CHAPTER 11

RECOMMENDED DEVELOPMENT PROGRAM

General

In Chapter 4, system demands until the year 2000 have been established on the basis of the proposed universal metering of both domestic and industrial supplies and increased rates for metered water.

These demands can only be partly met by the maximum economic development of supplies in local areas. The additional supplies required will come from four major projects. This chapter describes the phased development of these major projects, the local supplies, distribution improvements, the metering program, and continuing works required to meet projected demands to the year 2000.

The metering program is scheduled for immediate implementation, with the local supplies and continuing works being developed on a schedule dictated by local requirements and the economics of developing major transmission system extensions. To meet system demands up to the end of 1980 will require the substantial development of all local supplies, and also supplies from two of the major projects, Navet pumped storage and the Caroni-Arena project. The average capacity of these sources is expected to be:

Local sources	15 mgd
Navet pumped storage	10 mgd
Caroni-Arena	33 mgd

By 1983 it will be necessary to increase the Caroni-Arena supply by 9 mgd to 42 mgd, construct the Moruga project, and add 5 mgd of local supplies. By 1992 further system demands will require additional local supplies of 4 mgd and a supply of 45 mgd from the North Oropouche project, which will satisfy requirements to the year 2000.

The recommended program would be constructed in three stages to meet the estimated water requirements for 1980, 1992, and 2000.

The first-stage improvements to 1980 comprise a complete program for meeting supply, transmission, primary distribution, and distribution storage needs. The second and third-stage improvements are linked to the development of the supply facilities of the major projects and comprise a program to meet mainly supply and major transmission requirements. The recommended improvements are shown on Figure 35 (at the back of the report) for the three stages of development. How these improvements would meet the supply requirements of all of Trinidad and Tobago for each stage is shown graphically on Figure 36.

Appendix Table A-4 shows the allocation of water from each source of supply to the various water service areas at each stage of development. The production rates shown are for the years just prior to the introduction of a new major source, when

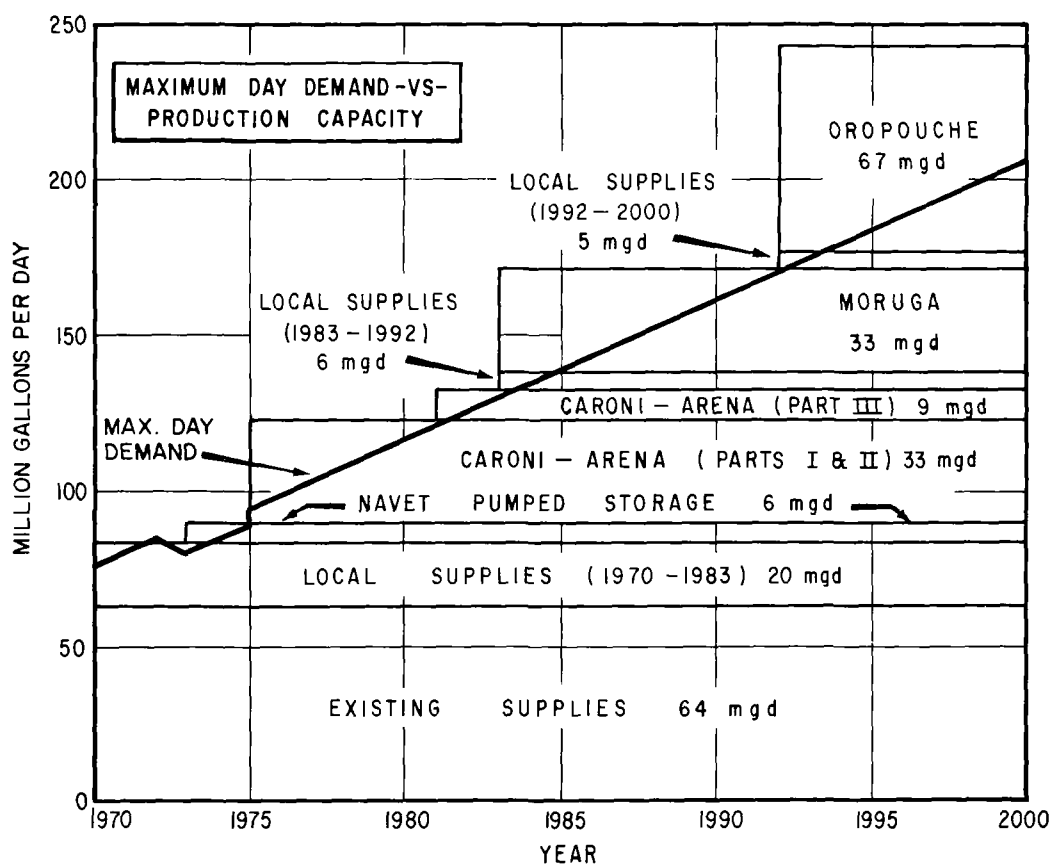
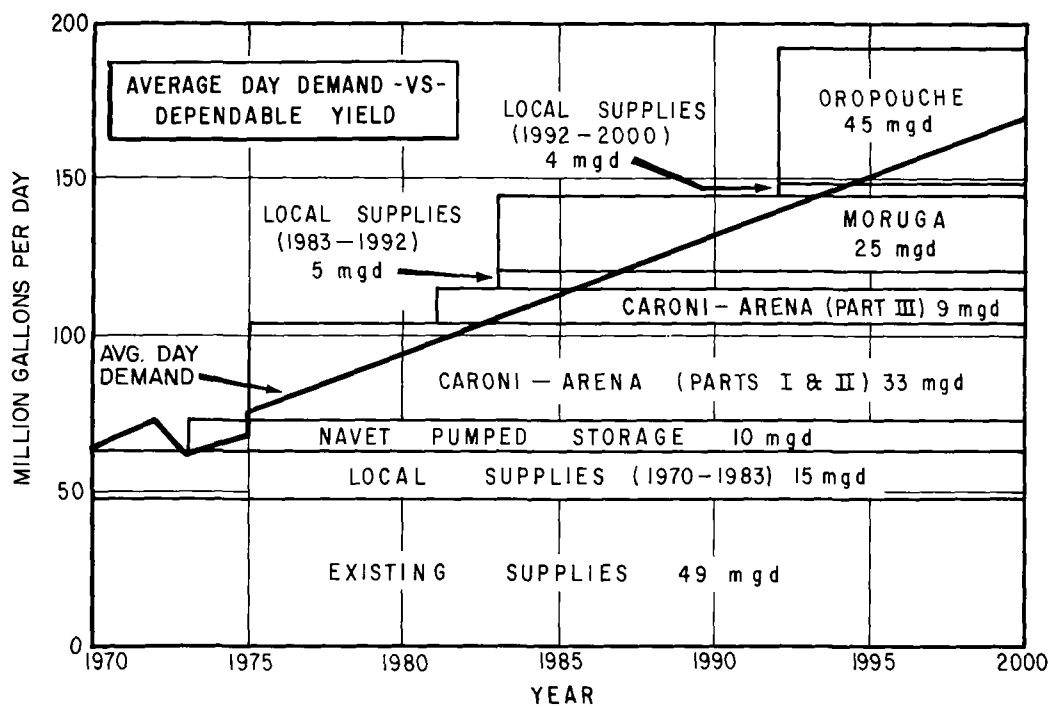


FIG. 36 RECOMMENDED PROGRAM

the existing Navet Reservoir. The proposed improvements would add 11 square miles to the Navet drainage area and increase the dependable yield from 7 mgd to 17 mgd. The capacity of the existing Navet trunk main would be increased to 17 mgd by construction of a booster pumping station at Malgretoute. Additional treatment capacity would also be provided.

The Caroni-Arena system would be constructed in three parts. Part I would be started at the same time as the Navet pumped-storage project but would not be completed until 1975. When all three parts are completed, this system will provide water to the Eastern Main Road communities and Port of Spain in the north, and to central and southern Trinidad as far south as Point Fortin.

Part I would consist of an intake on the Caroni River at San Rafael with pumping and transmission facilities for supplying a reservoir on the Arena River. Water from this reservoir would augment the dry-season flows in the Caroni River to provide a dependable yield of 33 mgd. A second intake on the Caroni at Kelly Village would feed a water treatment plant at this location with pumping facilities to supply transmission mains to both the north and south. These works would be built initially to their ultimate capacity of 42 mgd.

Transmission to serve the north would consist of a 36-inch main laid as far as Curepe on the Churchill-Roosevelt Highway and a 30-inch main from there to the existing El Socorro pumping station. The section of this main between Tunapuna and El Socorro is scheduled for early completion to facilitate the maximum output from local sources. Part

I transmission to serve the south would extend only as far as a new distribution storage reservoir at California. The transmission main would be 36-inch and would provide sufficient capacity to meet anticipated demands at the Pt. Lisas industrial complex and also provide a limited supply to the south through the existing Freeport 20-inch main. A temporary booster pumping station at Pointe-a-Pierre on the 20-inch main would provide the necessary lift to the existing Marryat Street reservoir at El 260 at San Fernando. A section of the San Fernando to Pt. Fortin transmission main would also be constructed to reinforce local distribution between San Fernando and La Romain. The remainder would be constructed under Part II.

Construction of the Navet pumped-storage project together with development of local groundwater supplies in the south and the limited supply available from California are expected to meet demands in south Trinidad and in San Fernando until 1978. About that time it will be necessary to construct Part II of the Caroni-Arena system in which a 30-inch main would be extended from California to San Fernando. It would then be necessary to extend and complete the transmission main from San Fernando to Point Fortin and construct a terminal storage reservoir in Pt. Fortin.

Initially, a high-lift pumping station at the Caroni water treatment plant would meet all pumping requirements. This station would have two separate sets of pumps. One set would pump water to the El Socorro pumping station, and the other set would pump against the head established by the proposed reservoir

at California. Additional pumping stations would be required to boost pressure at California, San Fernando, Chaguanas and at St. Mary's as the system is extended southward. The California booster pumping station would pump water to a new reservoir to be constructed in San Fernando at El 160. A pumping station at the new reservoir would then lift water to the Marryat Street Reservoir for distribution south. Both stations would be constructed in Part II. The St. Mary's and Chaguanas booster pumping stations would not be needed until the second stage.

Second-Stage Development. By 1981, production demands at Caroni would reach the 33-mgd dependable yield of the Arena pumped-storage facility. At that time, the Tumpuna and Talparo reservoirs would be constructed to increase the dependable yield to 42 mgd.

To deliver the increased supply, the booster pumping stations at Chaguanas and St. Mary's would be constructed. These projects are included in Part III of the Caroni-Arena system. When the need develops for using the Caroni-Arena system at its maximum capacity, the Moruga supply would be developed in two parts for an average capacity of 25 mgd and a maximum day production capacity of 33 mgd. Part I would include the dam, water treatment plant, low-lift and high-lift pumping facilities, and a 42-inch transmission main to deliver water to a 4-million gallon distribution reservoir and pumping station at Palmiste. From here a 36-inch main would connect the pumping station to the Point Fortin transmission main constructed in the first stage. Initially, the high-lift pumping station at the Moruga Reservoir would pump water the entire

distance from the water treatment plant to Palmiste. Part II of the Moruga project would consist of a booster pumping station and 2-million gallon distribution reservoir at Penal.

About 1987, transmission capacity from the Caroni water treatment plant to Port of Spain would be inadequate. A new booster pumping station at El Socorro and a parallel 36-inch main from Tacarigua to Port of Spain would then be constructed.

About the same time the main is constructed additional storage would be required in Port of Spain. This would be constructed at the existing Knaggs Hill site and would require demolition of the existing reservoir. The new reservoir would have a capacity of 10 million gallons and would be filled via the new 36-inch main from Tacarigua.

Third-Stage Development. In the third stage, the North Oropouche supply would be developed for an average capacity of 45 mgd and a maximum day production capacity of 67 mgd. A 54-inch transmission main would be constructed to deliver water from the water treatment plant to a connection to the Caroni-Arena mains at Tacarigua. Upon completion, the Oropouche supply would supplant the Caroni major source serving the Eastern Main Road and Port of Spain areas. The pumping stations at El Socorro would be taken out of service since Port of Spain could be supplied by gravity. The Caroni supply would be used to serve only the southern area. Production at Caroni would be cut back to about 20 mgd initially but would increase gradually as demands in the south continued to increase.

Schedule. Table 36 is a summary with costs of the recommended major supply projects described in the preceding paragraphs.

Local Supply Development

Chaguaramas. By the year 2000, 4.7 mgd will be required in Chaguaramas on the maximum day. The potential of existing groundwater aquifers in this area is more than adequate to meet this demand; therefore, it is proposed to meet all future demands in this area by locally developed groundwater. The existing rate of 1.5 mgd in Chaguaramas is excessive for the present number of users. It is estimated that most of the production goes to waste and that with effective waste and loss control, production can be reduced considerably. If this is possible, no additional boreholes in the Chaguaramas area would be required for approximately ten more years.

This section describes the development of new local supplies and distribution improvements recommended to meet future demands.

Improvements to the distribution system and location of new boreholes will depend on future development which cannot be projected at this time.

Diego Martin. The demand in Diego Martin will continue to be met from local groundwater supplies. The present groundwater withdrawal is about 6 mgd. Another 0.5 mgd is imported from Tucker Valley, making a total supply to the area of almost 7 mgd. However, this rate can be

maintained only as long as secondary recharge continues at present levels. We estimate that repair of leaks and the completion of the sewerage program in Diego Martin will reduce production from this aquifer to about 4.5 mgd. At this rate, importation of water to Diego Martin would be required by 1980.

Water could be imported through the existing 21-inch Cocorite main which is now used to deliver water to the Knaggs Hill Reservoir from the Cocorite and Four Roads boreholes.

Major problems in the Diego Martin area are excessively high pressures in the southern end of the valleys, excessive leakage and water waste, and lack of service in high areas above the gradient. Recommended improvements include dividing the service area at Sierra Leone Road into north and south service areas, and constructing a new reservoir in the southern area. The southern service area would be supplied by pumping water from the Four Roads boreholes to the proposed reservoir. The Cocorite borehole field would eventually be abandoned and new boreholes drilled at Four Roads to replace the loss in capacity at Cocorite. A new high-lift pumping station would be constructed at Four Roads with pumps capable of supplying local demands.

Most of the future increase in demand is anticipated in the northern service area. When demands in this area exceed the capacity of the River Estate boreholes, a booster pumping station would be constructed at Sierra Leone Road to pump water from the southern service area to the northern service area.

Port of Spain. Present withdrawal of water from the Port of Spain aquifer system is about 5 mgd. As leakage is reduced in the

Table 36. Schedule of Recommended Major Supply Projects

<i>Priority No.</i>	<i>Project description</i>	<i>Construction period</i>	<i>Cost in \$1,000 TT</i>
First-Stage Program			
1	Installation of domestic meters.	1970-1973	8,000
2	Navet pumped storage. Low dam, intake, pumping station, transmission main, and booster pumping station at Malgretoute.	1970-1973	4,084
3	Caroni-Arena, Part I. Transmission main from Tunapuna to El Socorro.	1970-1972	1,913
4	Caroni-Arena, Part I. Arena dam, intake, and pumping station on the Caroni River at San Rafael, and transmission main to Arena dam. Intake, low-lift pumping station, water treatment plant, and high-lift pumping station at Kelly Village, north transmission main from water treatment plant with takeoff to the Valsayn waterworks, south transmission main to California, California reservoir, booster pumping station at Pointe-a-Pierre, and a transmission main from San Fernando through Cross Crossing to La Romain.	1970-1975	43,933
5	Caroni-Arena, Part II. Transmission main from California to San Fernando, booster pumping station at California, new reservoir at San Fernando, transmission main from La Romain to Point Fortin, and a reservoir at Point Fortin.	1976-1978	12,796
	First-Stage Cost		70,726
Second-Stage Program			
6	Caroni-Arena, Part III. Tumpuna and Talparo dams and a booster pumping station at both Chaguanas and St. Mary's.	1978-1981	9,950
7	Moruga, Part I. Moruga dam, water treatment plant, and pumping station. Transmission main through Penal to Palmiste, reservoir and pumping station at Palmiste, and a transmission main to join the San Fernando-Point Fortin main at Cross Crossing.	1977-1983	33,320
8	Tacarigua to Port of Spain transmission main. New main parallel to existing and proposed transmission mains from Tacarigua to Port of Spain continuing through Port of Spain to a new reservoir at Knaggs Hill, and a new booster pumping station at El Socorro.	1985-1987	10,325

Table 36 (Continued). Schedule of Recommended Major Supply Projects

<i>Priority No.</i>	<i>Project description</i>	<i>Construction period</i>	<i>Cost in \$1,000 TT</i>
9	Moruga, Part II. Booster pumping station and reservoir at Penal.	1984	1,885
	Second-Stage Cost		55,480
	Third-Stage Program		
10	North Oropouche. Oropouche dam, water treatment plant, and pumping station. Transmission main to join Caroni-Arena transmission mains at Tacarigua.	1987-1992	62,753
	Third-Stage Cost		<u>62,753</u>
	Total Program Cost		188,959

water system and the sewer system is expanded to cover new areas, this rate of production will drop back to an estimated yield of 4 mgd. For planning purposes, it has been assumed that this will not occur before completion of the first stage of the Caroni-Arena project. To meet demands until that time, an additional 3.9 mgd would be made available from Hollis Reservoir. After construction of the Caroni-Arena system, additional supplies to Port of Spain would be delivered through the El Socorro system. The new transmission main from the Caroni water treatment plant would be designed to deliver water to the existing sump at El Socorro pumping station. With ample supply, this pumping station could deliver up to 15 mgd to Port of Spain and the intervening areas. Water would continue to be pumped to the existing reservoirs on Picton Hill and then distributed to Port of Spain. The additional supply available at this location would reduce the draft from the Knaggs Hill Reservoir.

Existing production at Hollis is about 6.5 mgd. At present approximately 1.2 mgd of Hollis water is delivered to Port of Spain. To increase the flow by approximately 3.9

mgd, it is proposed that the production from Hollis be increased by approximately 1.5 mgd and that 2.4 mgd of Hollis water now being used in the Caroni and Eastern Main Road areas be diverted to Port of Spain. The diversion of Hollis water from these areas will be made possible by the completion of the new Las Lomas supply and increasing production from the Tacarigua borehole field.

Increased production from Hollis would be accomplished in two phases. Initially, the standby pump at the Tunapuna pumping station would be relocated to a new pumping station at Success. The new pumping station in series with the remaining pump would double the pumping head available between Tunapuna and Picton Reservoir No. 1. This should increase the flow by an additional 1.0 mgd. The remaining 2.9 mgd would be delivered to Port of Spain by a new route which would require early construction of a section of the Caroni-Arena transmission main between Tunapuna and the El Socorro pumping station. With this section of main in place, Hollis water could be diverted from the 24-inch main at Tunapuna through a connection to the north-south 20-inch Hollis

main to the sump of the El Socorro pumping station. Once in the sump at El Socorro, Hollis water would be mixed with the supply from the El Socorro boreholes and pumped to Picton reservoir No. 2 in Port of Spain. Las Lomas water could be delivered to Port of Spain by the same method in emergencies.

Other improvements in Port of Spain include a proposed pumping station at Knaggs Hill to supplement the present supply to the St. Ann's and Cascade areas, and reinforcements to strengthen distribution in the Dundonald Hill, Fort George and St. Barbs areas, and in Maraval.

Eastern Main Road Area. Prior to the completion of the Caroni-Arena project, increased demands in the Eastern Main Road area would be supplied from the Tacarigua borehole field. New boreholes and a high-lift pumping station are proposed at Tacarigua to increase the maximum day production rate from the present 3.2 mgd to 6.2 mgd. The high-lift pumping station would pump water through existing distribution mains, with minor reinforcements, to the St. Joseph Reservoir. Excess water that could not be used locally or pumped to storage would be pumped directly to the Hollis transmission main and repumped at either the Tunapuna or El Socorro pumping stations. Eventually the Tacarigua high-lift pumping station would pump through new mains to proposed reservoirs at Tunapuna and Lopinot.

After completion of the Caroni-Arena system, Hollis water would be used exclusively to meet demands within the Eastern Main Road area, and would serve as the principal source of supply for a new low-service area south of Eastern Main Road

between St. Augustine and Port of Spain now included in the Valsayn system service area. This new service area would be served by the 18-inch Hollis main, which would be supplied from the St. Joseph Reservoir. The reservoir would be filled initially by gravity from Hollis and in the long term by re-arrangement of the pumping facilities at the Tunapuna booster station. Areas along the Churchill-Roosevelt Highway would be served by a takeoff from the Caroni-Arena transmission main through a booster pumping station at Curepe.

The Valsayn system would continue to serve only those areas north of Eastern Main Road including Morvant. Supply to this area would be supplemented by water from the Caroni-Arena system through a 24-inch connection from the Caroni-Arena transmission main to the sump at the existing Valsayn water works. Additional pumps would be installed at this station in the space previously provided, to deliver this additional water to the distribution system. When the Valsayn system demand reaches maximum system capacity, supply to San Juan and Morvant would be supplemented through a new main off the existing El Socorro main, or the parallel 36-inch main at Barataria, to a proposed reservoir at Malick.

Mains to the Maracas and Santa Cruz Valleys will require reinforcement in Stages 2 and 3, respectively. A 12-inch main would be adequate to meet increased demands in the Maracas Valley. Additional distribution storage would also be provided. The main to Santa Cruz would be a 16-inch with 12 and 8-inch branches.

The Waller Field system would continue to operate as a separate system. Sufficient

water is available in this area to meet local demands until Stage 3 is built. Supply to this area would then be supplemented from Hollis.

Caroni. Prior to completion of the Caroni-Arena project, Caroni would continue to be supplied by the Carlsen Field and Freeport systems. The limited supply from Hollis would be replaced by a supply from the new boreholes at Las Lomas. The Carlsen Field supply would serve as the exclusive supply for a new service area which would include Caparo, Carlsen Field, Freeport, and Flanagan Town. Pressure in this area would be controlled by the level in the existing Freeport Reservoir, which would be maintained by pumping from the Carlsen Field supply to the reservoir through new mains.

The remaining areas in Caroni would be supplied initially from the Freeport and Las Lomas sources. After completion of the Caroni-Arena project, these areas would be supplied by direct connection to the new transmission main to California.

Montserrat. The supply to Montserrat would continue to be from the Freeport water works. By cutting back pumpage to the Caroni area, sufficient supply will be available until the year 2000. Except for additional distribution storage, no improvements are anticipated for this system for either the near or long term.

San Fernando. San Fernando and its suburbs would continue to be served from the reservoirs on Naparima Hill, including the new reservoir proposed in the major works program. Initially, these reservoirs would continue to be supplied from Navet. In the

future they would also be supplied from the Caroni and Moruga projects.

South Trinidad. Areas close to the Navet trunk main would continue to be served from Navet with limited distribution reinforcements. Increased demands in Princes Town that could not be met from the Dunmore Hill Reservoir in Hindustan through existing mains would be supplied from pumps at the Malgretoute booster pumping station and a 16-inch main to a new reservoir in Princes Town. Local groundwater supplies at Clarke Road, Penal and Palo Seco and water supplied from Navet through existing mains would be adequate to meet local demands in this area until construction of the Moruga supply in 1983. After this date, a takeoff at Penal from the Moruga main would meet increasing demands in these areas. By 1978 demands in La Brea, Point Fortin, and Fyzabad are expected to exceed local supplies plus the water supplied through an existing transmission main from San Fernando. To meet these increasing demands, a 24-inch transmission main from San Fernando would be constructed under Part II of the Caroni-Arena project. The size of this main may be increased or decreased at the time depending on the potential for industrial development in Point Fortin. The supply to the Granville area would continue to be met from the Granville water works. In the long term, additional water would be brought in from the Cap-de-Ville Reservoir. Moruga would be served by a limited groundwater development. If this proves unsuccessful, it will be necessary to reinforce existing mains to Moruga to meet demands until 1983 when the Moruga supply would be constructed. Rio Claro would be served by a takeoff from the

Navet main at Tabaquite and a new distribution main to Rio Claro.

Mayaro. Mayaro would continue to be served by local groundwater supplies as long as such supplies can be developed economically. The estimated potential of the Mayaro sandstone aquifers indicates that sufficient water is available; however, this water may prove difficult to develop. Should water from an outside source be required, the logical source would be Navet. Importation of Navet water would require a transmission main from Rio Claro to Mayaro.

Sangre Grande. Completion of the 0.5-million gallon reservoir under construction at Guaico will solve immediate problems at Sangre Grande by increasing the average flow in the existing mains from Valencia to 1.5 mgd. To overcome deficiencies in both supply and distribution in the Guaico and Four Roads-Tamana area, boreholes would be drilled at Los Armadillos and reservoirs would be constructed at Los Armadillos, Nestor, and Tamana Hill. When an additional supply is required, it would be obtained from the Oropouche River, just north of Sangre Grande unless other groundwater development is found to be feasible. After construction of the Oropouche Reservoir, the estimated minimum flow of the river at this point will be 5.0 mgd. This source would be adequate to meet demands in the Sangre Grande area until the year 2000.

Toco. Resort type development in Toco and along the North Coast is expected to increase demands in this area to 1.2 mgd by the year 2000. The existing works on the Tompire River can be expanded to a capacity of 0.5 mgd by new pumping and treatment

facilities. To reduce transmission costs and to supplement the Tompire supply, it is proposed to develop groundwater at Grand Riviere and upgrade the intake at Salybia.

North Coast. The recently completed Tyrico Bay scheme and newly drilled boreholes at Yarra will be adequate to serve future North Coast demands until about 1980. The construction of local intakes similar to the one at Tyrico is proposed to meet demands until the year 2000. Should a large demand develop as a result of intensive resort type development, the construction of the Yarra Dam and Reservoir would be the logical means to develop a large dependable supply of water.

Southwest Tobago. With expected decreases in demand as a result of waste and loss control measures and metering, the existing supply in southwest Tobago would be adequate to meet demands in this area until after 1980. Minor problems that now exist can easily be overcome with the completion of the Courland project. At the present time this system is functioning inadequately due to the lack of distribution storage. Tenders have already been submitted for the construction of a 0.5-million gallon reservoir on Bad Hill. Operational difficulties now being experienced should end with the completion of this reservoir. A conventional treatment plant will be required for the Courland supply since the existing roughing filter has not been able to reduce turbidity to acceptable levels.

At present the Courland transmission main is only half complete. When completed, this main will extend to the opposite side of the island to a proposed reservoir on Lambeau Hill. This reservoir would be used to serve

Scarborough by gravity, but would require a pumping station to fill it from the Courland transmission main.

A booster pumping station on the Hillsborough transmission main would increase the supply to areas of Patience Hill and Bethel. The additional supply at Hillsborough would be made available by repairing the leaks and lowering pressures in the existing 8-inch main between Greenhill and Bacolet. Eventually, the main should be replaced. Lower pressures would mean that this main would no longer be able to supply Scarborough. This source would be replaced initially by increasing the flow from the Hillsborough transmission main at Harmony Hall and later by an extension to the Courland system.

The Hillsborough supply would continue to serve the high-level areas and should be adequate to meet demands in this area to the year 2000 as long as increasing demands in the lower areas are met from the Courland supply. Eventually, a dam and storage reservoir will be required on the Courland River to increase the yield of this source to 4.0 mgd.

Windward Coast. The Richmond water supply, which is the only supply for the Windward Coast area of Tobago, is at present inadequate to meet demands in the dry season. It is proposed to increase the dependable yield of this source by taking surface water from the Richmond River. This would increase the yield of this source from its present 0.2 mgd dependable yield to 0.6 mgd. The existing treatment plant can be expanded to carry this additional load; however, sedimentation may be required.

Eventually this system would be linked with the Hillsborough system by an 8-inch main from the Greenhill Reservoir.

Rural Tobago. It is doubtful if future growth in rural Tobago will justify any major water system construction in areas now served by rural intakes. Improvement in service to areas would consist primarily of providing new local supplies and improving water quality by the addition of slow sand filters at existing intakes. Plans for these filters are included in Appendix B.

Schedule. Appendix Table A-7 presents the estimated costs of the recommended local supply projects described in the preceding paragraphs. The projects are listed in order of priority and by construction stage. By construction stages, the total costs are summarized as follows:

Stage 1	\$69,738,000
Stage 2	17,179,000
Stage 3	<u>9,497,000</u>
Total	\$96,414,000

Alternative Projects. Several of the recommended local projects are contingent on developing substantial groundwater yields. In most cases if adequate groundwater cannot be found, it will mean that other projects must be constructed earlier than would otherwise be necessary. However, for three of the recommended projects there are specific alternatives if the yields required cannot be developed. These alternatives are listed in Appendix Table A-8.

Continuing Works

Appendix Table A-9 lists continuing works which comprise items of capital expenditure required annually for the operation and improvement of supply and distribution systems. Also included is an item for completion of projects in progress at 1970

which have not been covered under local supply projects. These projects are shown as completed on all maps of the system. Cost estimates are presented only for the first stage since items of this nature are of concern primarily for cash flow studies which for this report are made only for the first stage. The total first-stage cost is estimated to be \$20,800,000 TT.

CHAPTER 12

RECOMMENDED FIRST-STAGE PROGRAM

General

In this chapter cost estimates and a design and construction schedule for the recommended Stage I program are presented. For convenience, the Stage I projects are divided into two categories, major projects and local supply projects. These categories are subdivided into initial and final construction programs.

The initial construction program comprises a group of Stage I facilities which together with existing facilities will meet the projected water demands of Trinidad and Tobago until about 1978 and can be designed and constructed in a four- to five-year period.

The final Stage I construction program can be designed and constructed in a similar period of time and will increase water supply and transmission capacity sufficiently to meet projected water demands until about 1981.

The recommended facilities listed as major projects are those which would supply more than one water area. Those facilities listed as local supply projects would serve only the areas in which they are located.

The major projects and the local supply projects are listed in Table 36 and Appendix Table A-7, respectively. With the exception of the metering project, they are described in Chapter 11.

Initial Construction Program

Metering Project. The metering project would be accomplished in a two-year period by contract. During the contract period and after the contract is completed, WASA forces would install meters on all new service connections, including construction connections as a continuing annual operation. Meters installed on construction connections would be read and all water used during or after construction billed to the owner. When the new structure is completed, the construction connection would become the permanent service.

Each meter installation, whether made under contract or by WASA forces, would be inside a lock-type buried meter box located outside the property line or fence line. The meter box for 1/2- and 5/8-inch meters would be equal to the Inter-America Box, manufactured by the Ford Meter Box Co., Inc., Wabash, Indiana, U.S.A. Boxes for 3/4- and 1-inch services would be equal to the appropriate yoke-box, manufactured by Ford. Large meters would be installed in concrete vaults equipped with a lock-type access manhole cover directly over the meter.

Upon completion of each meter installation, the contractor or WASA, depending upon which installed the meter, would complete a report and sketch showing the location of the meter, the street address,

the owner's name, the meter size and number, the meter reading, and the installation date. Copies of this report and sketch would be forwarded to the appropriate meter reader through the district engineer and to the billing department.

As a part of the metering contract or before letting the contract, a canvass of the system to determine the actual number of connected premises, the location of each, and the owner's name and legal address would be undertaken. It is estimated that the metering contract would cover installation of approximately 100,000 meters, most of which would be 5/8-inch or 3/4-inch size.

Timetable - Major Supplies. The timetable or time schedule for design and construction of the Stage I major facilities recommended for initial construction, excepting the metering project, has been developed by the critical path method and is presented as critical path diagrams.

The critical path schedule allows rapid and accurate evaluation of the effects of delay in any activity upon the project completion time and identifies those activities where delay is reflected in the completion time of the entire project.

A separate critical path schedule (Figure 38) has been prepared for the Navet pumped-storage project to allow evaluation of an early start on this portion of the work if WASA deems this advisable. Figure 39 is a critical path schedule for the remaining first-stage major projects recommended for initial construction. This schedule is based on building these facilities under six separate construction contracts: four transmission

main contracts (including the raw-water main from San Rafael to Arena dam and the California reservoir); a contract for Arena dam and reservoir; and one including the Caroni intakes and the water treatment plant.

The metering project would require less lead time for design than would the other major projects and is not critical insofar as scheduling of the entire major works program is concerned. It is anticipated that WASA forces would start a canvass of the system in early 1970 completing it before 1971. In 1971 the metering contractor would start installation of meters, completing the installation by 1973.

Timetable - Local Supply Projects. Priorities 1 through 59 inclusive in Appendix Table A-7 comprise the local supply projects recommended for initial construction. WASA has started preliminary planning, design, or construction work on 31 of these projects. The estimated total cost of the 59 projects is \$52,292,000 TT. It is apparent that the WASA engineering and construction staff is not large enough to accomplish this amount of work in addition to their normal work load before 1975. Accordingly, it is recommended that WASA accomplish at least a portion of the engineering and construction for these projects by contract.

These local supply projects have been divided into 18 groups in each of which the projects comprising a group would be designed concurrently and could be constructed under a single contract or separate contracts or as concurrent force account projects. Table 37 shows the adopted grouping of projects, and Figure 40 is a bar graph showing a design and construction

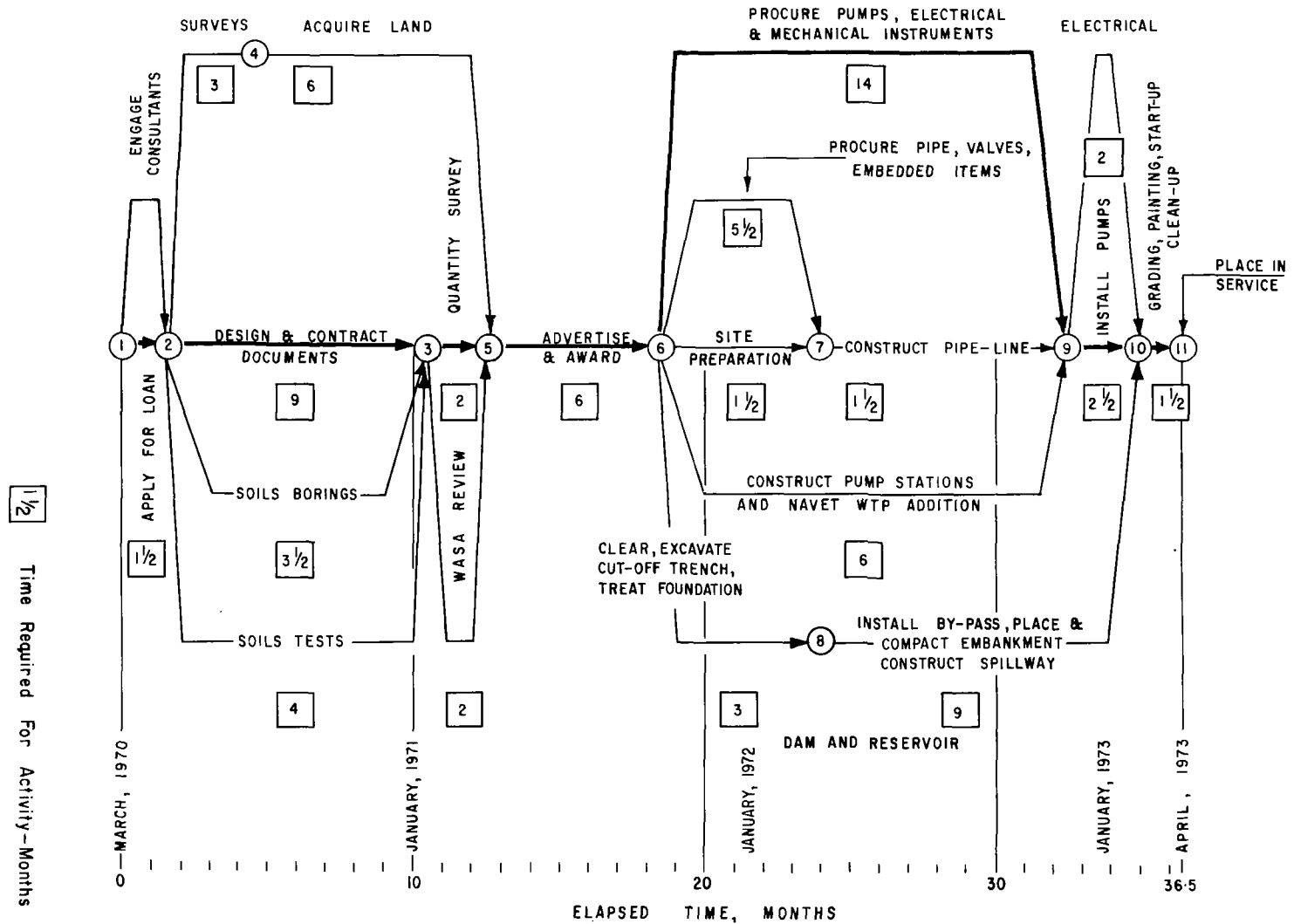
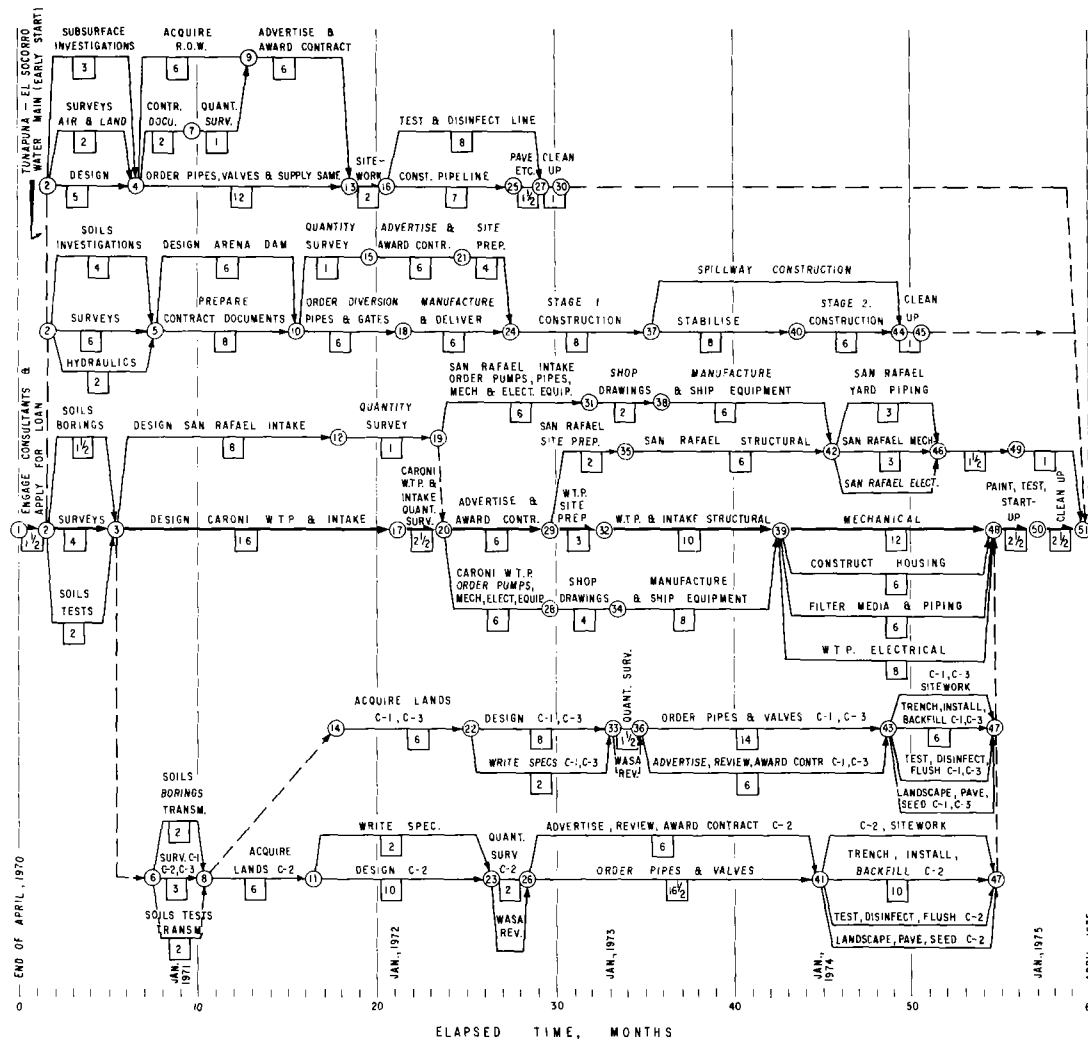


FIG. 38 NAVET PUMPED-STORAGE PROJECT — CRITICAL PATH SCHEDULE



- C-1 { 36" Transmission Main from Caroni W.T.P. to Tunapuna.
24" Transmission Main from Tunapuna to Valsayn Sump.
- C-2 { 36" Transmission Main from Caroni W.T.P. to California
36" Raw Water Main from San Rafael to Arena Dam
- C-3 { 30" Transmission Main from California to Reservoir.
30" Transmission Main from San Fernando to Cross Station
24" Transmission Main from Cross Station to La Romain.

FIG. 39 FIRST STAGE MAJOR PROJECTS CRITICAL PATH SCHEDULE

Table 37. Groupings of Local Supply Projects Recommended for Initial Construction

<i>Group</i>	<i>Priorities (Appendix Table A-7)</i>	<i>Description</i>
1	1, 2 & 3	Tacarigua boreholes, HLPS and mains, Success BPS, and Arima BPS.
2	4, 5 & 6	Las Lomas, Carlsen Field, and Fyzabad projects.
3	7, 8 & 9	Cap de Ville addition, Palo Seco boreholes and WTP, and Clarke Road boreholes.
4	10, 11 & 13	Granville boreholes, Rochard Douglas BPS, and Buen Intento BPS.
5	12 & 14	Rio Claro, Tableland and Palmiste Distribution Reservoir.
6	15, 17, 18 & 19	Forres Park main, Cleaver Road main, Gonzales main, and Toco improvements.
7	16, 26 & 31	California boreholes and WTP, Courland WTP, and Mayaro boreholes.
8	20, 22, 23 & 24	Bad Hill Res., Plymouth main, Greenhill main rehab., and Tobago PRV.
9	21, 25 & 28	Blanchisseuse system improvements, Four Roads main, and Diego Martin.
10	27, 29 & 30	Tobago high service improvements, Knaggs Hill PS, and Maraval PS.
11	32, 33, 34, 35 & 36	Mayaro, Piarco and Cumuto mains, and Gasparillo and Manzanilla mains and Reservoir.
12	37, 38, 39 & 40	Los Armadillos boreholes and mains, and Guaico, Debe and St. John-Palmiste mains.
13	42, 43 & 44	Point Fortin, Penal and La Brea boreholes and treatment works.
14	41, 45, 46 & 47	Brieves Road BPS and mains, Flanagan Town Res., and Lady Chancellor and Knaggs Hill mains and Reservoir.
15	48, 49 & 50	St. Barbe' system, La Platte Village system, and Erin main.
16	51, 52 & 53	Rio Claro and Hindustan mains, and Moruga main and Reservoir.
17	54, 55 & 56	Penal-Siparia main, Balandra water system and Valsayn PS addition.
18	57, 58 & 59	Morvant Res. addition, Hololo addition and El Socorro interim PS addition.

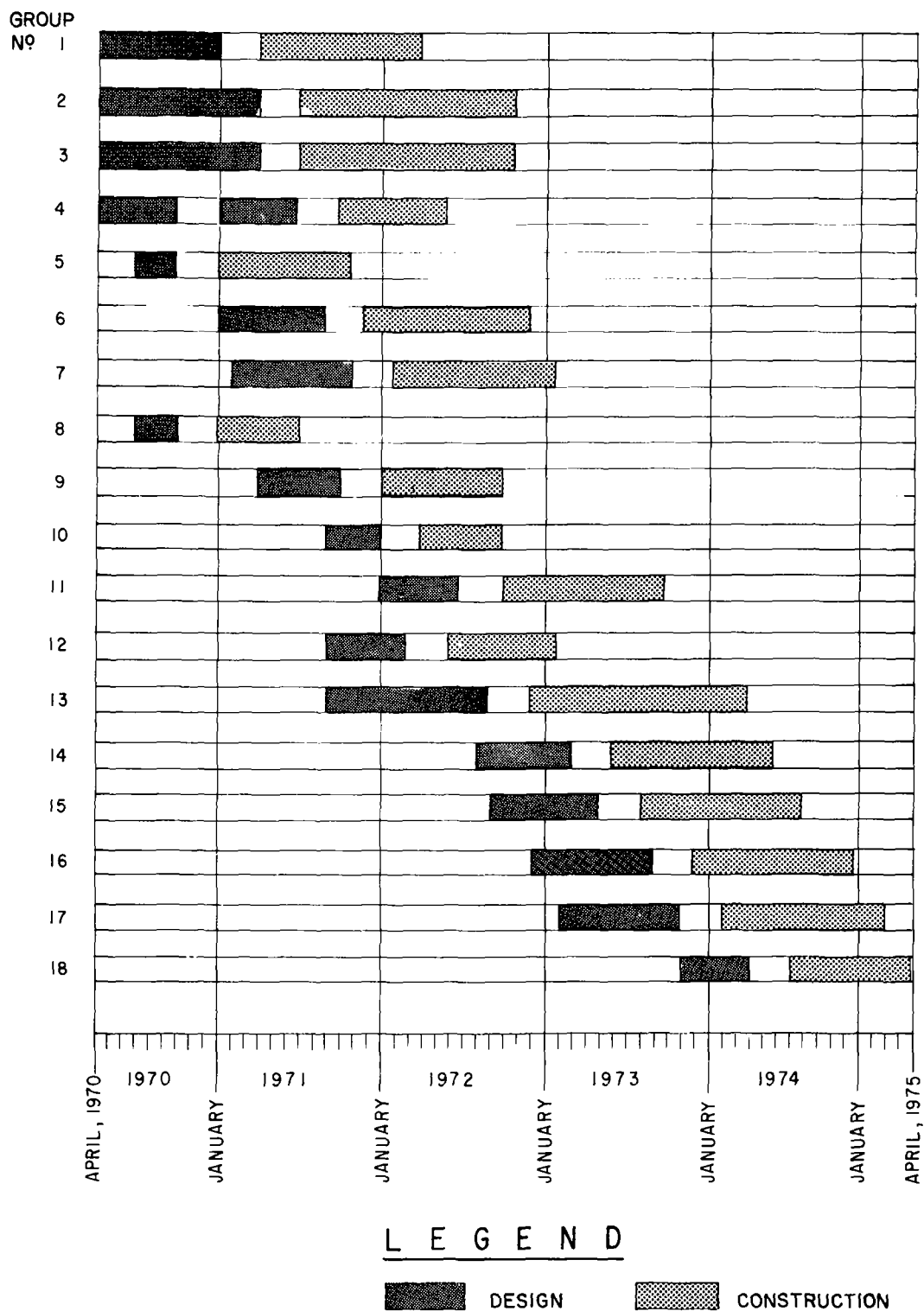


FIG. 40 DESIGN AND CONSTRUCTION SCHEDULE
FOR LOCAL SUPPLY PROJECTS BY GROUPS

schedule for each group. Planning, design, and construction which WASA has completed or has in process has been taken into account in making time allotments for each group of projects. The design and construction schedule shows the minimum time in which the listed projects can be completed assuming that consultants with the requisite design experience are immediately available and that Trinidad and Tobago has enough qualified contractors who are not working to capacity.

Should financing or availability of qualified personnel make it impossible for WASA to complete the local supply projects recommended for initial construction prior to 1975, the usefulness of the major projects would not be changed. However, there would be areas of the country which would continue to suffer from low pressure or intermittent service upon completion of the major supply projects.

Costs. Cost summaries for the first-stage facilities recommended for initial construction are presented in this section. All cost estimates are at January 1970 prices, and Engineering News-Record (ENR) Construction Cost Index of 1310. Costs should be reviewed and updated when new construction is being considered. The cost summaries list estimated foreign and local costs of construction, contingencies, and engineering for each construction contract or group of projects. Table 38 is the cost summary for the major initial construction projects by contracts, and Table 39 the summary for initial construction of local supply projects by groups. The total costs of the initial construction projects, major and local supply, are shown in Table 40.

In these estimates, land costs are included in the construction costs. Engineering includes land acquisition and topographic surveys, subsurface investigations and soil testing, design and preparation of contract documents, review of bids and recommendations upon award of contract, review of shop drawings, and monitoring of construction including full-time inspection. A portion of the engineering cost is shown as foreign cost because it is expected that local engineers cannot complete the designs and carry out construction monitoring of the major and local supply projects in the initial construction period (by 1975) without bringing in foreign personnel.

Final Construction Program

Major Projects. The final first-stage construction program increases the Caroni River developed dependable yield from 33 mgd to 42 mgd and increases transmission capacity to the south and west. Table 41 lists the recommended projects with the dates they should be started and completed.

Local Supply Projects. The final construction program of first-stage local supply projects includes those in priorities 60 through 76 inclusive in Appendix Table A-7. The total estimated cost of these facilities is \$17,446,000 TT. It is recommended that these projects be constructed as a continuing program of development financed primarily from revenue. To complete the program by 1980 will require an annual capital expenditure of about \$3,490,000 TT in excess of the annual capital works expenditures for distribution system reinforcement and expansion, and such items as the expansion of the WASA transport fleet

Table 38. Cost Summary for Major Projects – First-Stage Initial Construction

Contract	\$1,000 TT											
	Construction			Contingencies			Engineering			Total		
	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total
Metering	5,900	500	6,400	1,180	120	1,300	60	240	300	7,140	860	8,000
Navet Pumped-Storage	1,470	933	2,403	294	234	528	559	594	1,153	2,323	1,761	4,084
Caroni Water Treatment Plant and intakes	7,650	4,312	11,962	1,530	1,078	2,608	1,366	1,428	2,794	10,546	6,818	17,364
Arena Dam and Reservoir	2,932	4,053	6,985	586	946	1,532	749	614	1,363	4,267	5,613	9,880
Early Start Transmission	950	408	1,358	190	102	292	108	155	263	1,248	665	1,913
Contract 1 Transmission	1,437	671	2,108	287	143	430	145	218	363	1,869	1,032	2,901
Contract 2 Transmission	5,005	2,256	7,261	1,001	564	1,565	394	486	880	6,400	3,306	9,706
Contract 3 Transmission	1,460	1,383	2,843	292	410	702	206	257	463	1,958	2,050	4,008
Land Acquisition Transmission	-	74	74	-	-	-	-	-	-	-	74	74
Total	26,804	14,590	41,394	5,360	3,597	8,957	3,587	3,992	7,579	35,751	22,179	57,930

Table 39. Cost Summary for Local Supply Projects – First-Stage Initial Construction

Project Group	\$1,000 TT											
	Construction			Contingencies			Engineering			Totals		
	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total
1	606	699	1,305	121	174	295	184	271	455	911	1,144	2,055
2	4,036	4,182	8,218	808	1,042	1,850	1,048	1,297	2,345	5,892	6,521	12,413
3	1,178	1,853	3,031	236	458	694	465	720	1,185	1,879	3,031	4,910
4	238	245	483	44	58	102	101	108	209	383	411	794
5	72	240	312	7	35	42	18	60	78	97	335	432
6	442	517	959	82	117	199	152	183	335	676	817	1,493
7	872	1,175	2,047	174	290	464	430	564	994	1,476	2,029	3,505
8	115	209	324	20	40	60	39	60	99	174	309	483
9	454	707	1,161	91	177	268	156	269	425	701	1,153	1,854
10	211	216	427	41	55	96	68	92	160	320	363	683
11	696	789	1,485	139	196	335	220	301	521	1,055	1,286	2,341
12	606	651	1,257	121	163	284	186	279	465	913	1,093	2,006
13	2,453	2,743	5,196	490	686	1,176	665	996	1,661	3,608	4,425	8,033
14	307	601	908	59	143	202	139	209	348	505	953	1,458
15	662	779	1,441	133	195	328	221	331	552	1,016	1,305	2,321
16	1,540	1,189	2,729	308	300	608	394	501	895	2,242	1,990	4,232
17	632	745	1,377	126	186	312	235	301	536	993	1,232	2,225
18	233	448	681	43	97	140	93	140	233	369	685	1,054
Total	15,353	17,988	33,341	3,043	4,412	7,455	4,814	6,682	11,496	23,210	29,082	52,292

Table 40. Cost Summary for All First-Stage Initial Construction

Projects	\$1,000 TT		
	Foreign	Local	Total
Major projects	26,804	14,590	41,394
Local supply projects	15,353	17,988	33,341
Contingencies	8,403	8,009	16,412
Engineering	8,401	10,674	19,075
Total	58,961	51,261	110,222

and the improvement of the communications system.

The priorities are based on projected demands throughout the country. Should population growth patterns differ from the projected patterns, the order of development may be altered or the rate of development adjusted, hastened or slowed, as is indicated. However, no project should be delayed beyond that time when the average day water use reaches the dependable yield of the local supply or when pressure problems begin to occur during peak hours in the dry season. Appendix Table A-10 lists the recommended projects in order of priority, with the cost of each.

Table 41. Major Projects in First-Stage Final Construction Program

Projects	Project dates		\$1,000 TT		
	Start	End	Foreign	Local	Total
Transmission mains					
California-San Fernando and La Romain to Point Fortin	1976	1978	4,199	2,251	6,450
BPS California (Q= 24 mgd h= 150 feet)	1976	1978	360	240	600
BPS San Fernando (Q= 24 mgd h= 150 feet)	1976	1978	360	240	600
Point Fortin reservoir, 2 mil gal	1977	1978	120	300	420
San Fernando reservoir, 5 mil gal	1977	1978	250	650	900
Construction total			5,289	3,681	8,970
Land acquisition			-	36	36
Contingencies			1,060	930	1,990
Engineering			720	1,080	1,800
Grand total			7,069	5,727	12,796

Table 42 presents a summary of the first-stage construction costs of the major and local supply projects.

alternative first-stage program are presented in Appendix B.

Terms of Reference for Final Design

Preliminary Design

Design criteria and preliminary design drawings for the facilities included in the recommended first-stage program and the

Terms of reference setting forth the work required for the preparation of the final engineering plans and the documents needed for the final engineering project are given in Appendix C.

Table 42. Summary of Costs of First-Stage Construction

Projects	\$1,000 TT ⁽¹⁾								
	Initial construction			Final construction			Total		
	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total
Major projects	35,751	22,179	57,930	7,069	5,727	12,976	42,820	27,906	70,726
Local supply projects	23,210	29,082	52,292	7,790	9,656	17,446	31,000	38,738	69,738
Total	58,961	51,261	110,222	14,859	15,383	30,242	73,820	66,644	140,464

1. Includes engineering and contingencies.

CHAPTER 13

CONCLUSIONS AND RECOMMENDATIONS

As a result of our investigations, we present the following summary of our more important conclusions and recommendations:

1. The existing water system operated by the Water and Sewerage Authority serves 90 percent of the total population. The estimated present and future populations of Trinidad and Tobago are:

<u>Year</u>	<u>Population</u>
1970	1,130,000
1975	1,268,000
1980	1,400,000
1985	1,546,000
2000	2,020,000

2. Water production at the start of 1970 was 60 mgd, 11.2 mgd in excess of developed dependable yield. Presently developed dependable yield by type of source is:

<u>Type of source</u>	<u>Number of sources</u>	<u>Dependable yield, mgd</u>
Trinidad		
Groundwater	31	29.8
Surface water	<u>31</u>	<u>16.7</u>
Trinidad Total	62	46.5

Tobago

Groundwater	1	0.2
Surface water	<u>3</u>	<u>2.1</u>
Tobago Total	4	2.3
Total	66	48.8

3. Present domestic demand which includes waste and loss but not industrial use, is estimated to average 57 gallons per capita daily. The 1968 per capita production for domestic use was 46 gpd. Both figures are considered excessive for the service provided and indicate a large amount of system leakage and water waste.
4. Metering of all direct connections, a substantial increase in metered water rates, and a continuing leak-control program are recommended to reduce per capita consumption. These steps are essential not only to minimize capital and operating costs but also to secure international financing for proposed projects. Projections of future demands assume that these steps will be taken promptly and that their effect will be felt no later than 1973.

5. Future water supply requirements of Trinidad and Tobago to be supplied by WASA are estimated as follows:

Year	Million gallons per day	
	Average day	Maximum day
<u>Trinidad</u>		
1975	75.5	92.1
1980	92.2	112.3
1985	109.7	133.5
2000	165.1	201.1
<u>Tobago</u>		
1975	1.9	2.2
1980	2.2	2.7
1985	2.8	3.3
2000	4.6	5.5

6. To meet the anticipated demands listed above will require development of the following additional dependable yields:

Year	Required additional dependable yield, mgd	
	<u>Trinidad</u>	<u>Tobago</u>
1975	29.0	—
1980	45.7	—
1985	63.2	0.5
2000	118.6	2.3

7. The total groundwater potential of Trinidad and Tobago is estimated at 72 mgd, of which 30.0 mgd has already been developed.

8. The dependable yield of the Navet reservoir is estimated at 7.0 mgd. Construction of a downstream diversion dam and pumping station is recommended to increase the yield of this source to 17 mgd.

9. Generally, groundwater and surface water sources within a service area are the most economically developable sources to serve that area. We estimate that about 22 mgd of additional dependable yield with a maximum day capacity of 25 mgd should be developed from these sources to help meet the year 2000 demand in rural and remote urban areas.

10. To meet suggested water quality goals, it is recommended that presettling basins and slow sand filters be constructed to treat the water from several small local supplies that are presently untreated. Suggested designs for 10,000, 30,000 and 100,000 gpd plants are provided.

11. The construction of new large surface water reservoirs will be required to meet the majority of future requirements between 1975 and the year 2000. The following reservoirs are recommended for development in the order listed:

<u>Supply</u>	<u>Potential dependable yield, mgd</u>
Arena reservoir (Caroni River)	33
Talparo reservoir)	9
Tumpuna reservoir)	
Moruga reservoir	25
North Oropouche reservoir	45

The Arena, Talparo and Tumpuna reservoirs will augment low flows in the Caroni River for downstream withdrawal. These three reservoirs form the Caroni-Arena system. Although only 19.1 mgd of the North Oropouche supply will be required at the year 2000, the reservoir should be constructed for the entire 45-mgd yield.

12. A three-stage construction program is recommended. The first-stage program would include the construction of the Arena reservoir and would meet demands projected for 1980. The second-stage program would include expansion of the Caroni-Arena system by construction of the Talparo and Tumpuna reservoirs, and construction of the Moruga and Courland reservoirs. The third-stage program would include construction of the North Oropouche reservoir and would meet the demands projected for the

year 2000. The first-stage program includes required primary transmission and distribution system improvements. The second and third-stage programs include new sources to satisfy projected demands, necessary transmission system improvements, and only those primary distribution system improvements which satisfy presently obvious future needs.

13. The first-stage program (1970-1980) includes the following improvements in addition to the Arena reservoir:

- a. Development of 15-mgd dependable yield from groundwater and small local surface water supplies.
- b. Metering of all domestic connections.
- c. Increase of 10 mgd in the dependable yield of the Navet River reservoir.
- d. A raw-water intake on the Caroni River at San Rafael with a pumping station and a raw-water main to Arena reservoir.
- e. The Caroni water treatment plant and intake.
- f. Transmission mains from the Caroni water treatment plant to El Socorro in the north and California in the south.

g. Reinforcements and improvements to the primary distribution system.

h. The Courland water treatment plant.

i. Extension of the Caroni-Arena transmission system to San Fernando and Point Fortin in the latter part of the first-stage program.

j. An intake and water treatment plant on the lower North Oropouche to serve Sangre Grande.

14. The second-stage program (1980-1992) includes the following improvements in addition to the Talparo, Tumpuna, Moruga and Courland reservoirs:

a. An addition to the Caroni water treatment plant.

b. Development of 2.7-mgd capacity from groundwater and local sources.

c. The Moruga water treatment plant.

d. A transmission main from the Moruga water treatment plant to Palmiste.

e. Reinforcements and additions to the primary distribution system.

15. The third-stage program (1992-2000) includes the following improvements in addition to the North Oropouche reservoir:

a. The Oropouche water treatment plant.

b. A transmission main from the Oropouche water treatment plant to Tacarigua.

c. Reinforcements and additions to the primary distribution system.

d. Development of 4 mgd of capacity from groundwater and local supplies.

16. The estimated overall construction cost of the three-stage development program is \$285,373,000 at 1970 construction cost levels. The cost by construction stage for major and local projects is as follows:

Stage	Estimated cost (\$1,000 TT)		
	Major projects	Local projects	Total
First	\$70,726	69,738	140,464
Second	\$55,480	17,179	72,659
Third	\$62,753	9,497	72,250

17. In addition to capital expenditures for the recommended development program, WASA must complete projects already under construction and meet continuing capital requirements for expansion of the secondary system, housing and office quarters, and transportation. These expenses in the first-stage program are estimated at \$20,800,000.

18. Certain construction projects in the first-stage program, considered eligible for international bank financing are needed immediately. The estimated costs of these initial projects are:

Estimated cost (\$1,000 TT)		
<u>Foreign</u>	<u>Local</u>	<u>Total</u>

Major Projects

Metering	\$ 7,140	\$ 860	\$ 8,000
Navet			
Project	2,323	1,761	4,084
Caroni-			
Arena			
System	<u>26,288</u>	<u>19,558</u>	<u>45,846</u>
Subtotal	\$35,751	\$22,179	\$ 57,930

Local Projects

Priorities			
1 through			
59, inclu-			
sive	<u>23,210</u>	<u>29,082</u>	<u>52,292</u>
Total	\$58,961	\$51,261	\$110,222



Respectfully submitted,

METCALF & EDDY INTERNATIONAL, INC.

Harry L. Kinsel

Harry L. Kinsel
President

Registered Professional Engineer
Massachusetts No. 6763

Table A-1. Groundwater Available from Major Aquifers in Trinidad

Aquifer	Available dependable yield, mgd	Well field	Draft, mgd				Comments
			1968		Recommended		
			Field	Aquifer	Field	Aquifer	
NORTHERN VALLEY AQUIFERS							
Chaguaramas	1.8	Chaguaramas	0.5	0.5	1.8	1.8	Develop as needed in Chaguaramas; no export
Tucker Valley	6.0	Tucker Valley	1.4	1.4	6.0	6.0	Develop as needed in Chaguaramas and stop export when major supply is available
Diego Martin	4.5	River Estate Four Roads Cocorite Private	0.5) 2.9) 2.2) 0.1	5.7	4.4 0.1	4.5	Reduce production uniformly as reduction in recirculated water results in salt-water intrusion
Port of Spain-Maraval	4.0	Brieves Road Wharf Docksite St. Clair Sevannah George V Private	0.1) 1.0) 1.0) 0.3) 0.8) 1.5) 1.0	5.7	2.3 1.7	4.0	Cut back of pumping to 4.0 mgd total should be accomplished only as reduction in recirculated water results in salt-water intrusion
ALLUVIAL FAN AQUIFERS							
El Socorro	4.5	El Socorro Private	7.2 0.2	7.4	4.2 0.3	4.5	Cut back production to reduce salt-water intrusion
Valsayn	5.0	Valsayn Private	6.0 0.1	6.1	4.7 0.3	5.0	May be mined on short term Capacity private wells is 0.3 mgd
Tacarigua	5.0	Tacarigua Private	2.6 0.1	2.7	4.8 0.2	5.0	Increase number of wells
Arima	2.0	Arouca Arima Private	0.2 0.5 0.2	0.9	0.2 1.6 0.2	2.0	Increase Arima wells and capacity to 1.6 mgd
CENTRAL ARTESIAN AQUIFERS							
Sum Sum Sand							
Area 1	6.5	Waller Field	0.9		3.0		New well and treatment works proposed New wells and treatment works proposed
		Las Lomas	—	0.9	3.0	6.0	
Area 2	1.0	Carlsen Field	—	—	1.0	1.0	

Table A-1 (Continued). Groundwater Available from Major Aquifers in Trinidad

Aquifer	Available dependable yield, mgd	Well field	Draft, mgd				Comments
			1968		Recommended		
			Field	Aquifer	Field	Aquifer	
Area 3	2.0	Carlsen Field Freeport	1.0 1.0	2.0	1.0 1.0	2.0	Pumping capacity with Freeport exceeds yield; may be mined temporarily
Area 4	0.6	California	—	—	0.6	0.6	Proposed development
Area 5	0.8	Texaco	0.6	0.6	0.6	0.6 ±	No future WASA development proposed
Durham Sand							
Area 1	2.0		—	—	—	—	Reserve for future needs
Area 2	1.5	Freeport (Todds Road)	0.6	0.6	1.5	1.5	Development planned in connection with WTP expansion
Area 3	0.2		—	—	—	—	Reserve for local supply
CENTRAL RANGE LIMESTONE							
Montserrat Hill Area	1.0	Springs	0.3	0.3	0.3	0.3	No further development recommended
Tamana Hill Area	0.8	Los Armadillos	—	—	0.5	0.5	Propose well development if possible
SOUTHERN AQUIFERS							
Erin-Morne L'Enfer	18.0	Penal	0.7		2.0		Proposed development at Penal with new wells
		Point Fortin	0.3		1.0		Proposed development with new wells
		Cap-de-Ville	0.2		1.0		Proposed development with new inland wells
		Granville	0.5		0.5		No change proposed
		Fyzabad	—	—	1.0		New well field and treatment plant proposed
		Clarke Road	—	—	1.0		New well field and treatment plant proposed
		Palo Seco	—	—	0.5		New well field and treatment plant proposed

Table A-1 (Continued). Groundwater Available from Major Aquifers in Trinidad

Aquifer	Available dependable yield, mgd	Well field	Draft, mgd				Comments
			1968		Recommended		
			Field	Aquifer	Field	Aquifer	
Erin-Morne L'Enfer (Continued)		La Brea	—	—	1.0		From new inland wells with new treatment plant
		Private	2.0	3.7	3.2	11.2	It appears that this is optimum development due to physical limitations on well fields (6 wells/mgd = 10,000 ft)
Mayaro Sandstone							
Area 1	1.0	None	—	—	—	—	Reserve for future local demands
Area 2	1.2	None	—	—	—	—	Reserve for future local demands
Area 3	1.2	Mayaro	0.2	0.2	1.2	1.2	Provide additional wells
Area 4	0.5	None	—	—	—	—	Reserved for future local demands
Area 5	0.5	Guayaguayare				0.5	Proposed future wells for local water demands
Totals	71.6		38.7	38.7	58.2		

Table A-2 Annual Operating and Maintenance Costs of Recommended First-Stage Initial Projects

Item	Annual cost in \$1,000 TT							1975-81 Avg
	1975	1976	1977	1978	1979	1980	1981	
Metering Program								
Meter reading	56	59	62	65	68	71	74	65
Test and repair	168	177	186	195	204	213	222	195
Navet Project(1)								
Salaries	62	62	62	62	62	62	62	62
Maintenance	38	38	38	38	38	38	38	38
Power	201	201	201	201	201	201	201	201
Chemicals	88	88	88	88	88	88	88	88
Caroni-Arena Project(2)								
Salaries	368	368	368	368	368	368	368	368
Maintenance	329	329	329	329	329	329	329	329
Power	168	200	244	285	340	407	490	305
Chemicals	209	277	345	414	482	550	617	413
Total	1,687	1,799	1,923	2,045	2,180	2,327	2,489	2,064

1. Power and chemical costs based on an incremental increase in production of 6.0 mgd. Existing average annual production is 11.0 mgd, 4 mgd in excess of estimated dependable yield.
2. Power and chemical costs based on an annual average production of 9.5 mgd in 1975 increasing at a rate of 3.1 mgd annually to 28.1 mgd in 1981.

Table A-3. Annual Operating and Maintenance Costs of Alternative First-Stage Initial Projects

Item	Annual cost in \$1,000 TT							1975-81 Avg
	1975	1976	1977	1978	1979	1980	1981	
Metering Program								
Meter reading	56	59	62	65	68	71	74	65
Test and repair	168	177	186	195	204	213	222	195
Navet Project(1)								
Salaries	62	62	62	62	62	62	62	62
Maintenance	38	38	38	38	38	38	38	38
Power	201	201	201	201	201	201	201	201
Chemicals	88	88	88	88	88	88	88	88
Oropouche Project(2)								
Salaries	184	184	184	184	184	184	184	184
Maintenance	506	506	506	506	506	506	506	506
Power	57	76	94	113	131	150	168	113
Chemicals	139	184	230	275	320	365	410	274
Total	1,499	1,575	1,651	1,727	1,802	1,878	1,953	1,726

1. Power and chemical costs based on an incremental increase in production of 6.0 mgd. Existing average annual production is 11.0 mgd, 4 mgd in excess of estimated dependable yield.
2. Power and chemical costs based on an annual average production of 9.5 mgd in 1975 increasing at a rate of 3.1 mgd annually to 28.1 mgd in 1981.

Table A-4. Future Production to Serve Major Water Service Areas

Area and source	Production, mgd							
	1974		1983		1992		2000	
	Avg day	Max day	Avg day	Max day	Avg day	Max day	Avg day	Max day
TRINIDAD								
Chaguaramas	1.0	1.2	1.9	2.6	3.1	3.8	3.9	4.7
Tucker Valley Boreholes	0.5	0.7	1.4	2.1	2.6	3.3	3.4	4.2
Chaguaramas Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Diego Martin	3.3	4.1	4.4	5.5	5.9	7.2	6.9	8.6
Carenage Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
River Estate Boreholes	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Four Roads-Cocorite Boreholes	0.7	1.5	1.8	2.9	2.5	3.7	2.5	3.7
Tucker Valley Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Caroni-Arena Reservoir	—	—	—	—	0.8	0.9	—	—
Oropouche Reservoir	—	—	—	—	—	—	1.8	2.3
Port of Spain	15.2	18.6	19.0	23.0	23.0	28.0	26.0	31.8
Four Roads-Cocorite Boreholes	1.8	2.2	0.7	0.8	—	—	—	—
Hollis Reservoir	5.4	5.4	—	—	—	—	—	—
St. Ann's Intake	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cascade Intake	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dibe Intake	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
El Socorro Boreholes	3.0	5.0	1.5	5.0	1.5	5.0	1.5	5.0
Caroni-Arena Reservoir	—	—	11.8	11.2	16.5	17.0	—	—
Oropouche Reservoir	—	—	—	—	—	—	19.5	20.8
Haleland Park Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Maraval Intake	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
St. Clair Borehole	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Savannah Boreholes	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Wharf Boreholes	0.9	1.4	0.9	1.4	0.9	1.4	0.9	1.4
Docksite Boreholes	—	0.5	—	0.5	—	0.5	—	0.5
George V Boreholes	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Eastern Main Road	16.7	20.6	24.0	29.5	32.1	39.4	39.2	48.2
Valsayn Boreholes	5.0	6.2	5.0	6.2	5.0	6.2	5.0	6.2
Tacarigua Boreholes	5.0	6.2	5.0	6.2	5.0	6.2	5.0	6.2
El Socorro Boreholes	1.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Las Lomas Boreholes	0.5	0.2	—	—	—	—	—	—

Table A-4 (Continued). Future Production to Serve Major Water Service Areas

Area and source	Production, mgd							
	1974		1983		1992		2000	
	Avg day	Max day	Avg day	Max day	Avg day	Max day	Avg day	Max day
Hollis Reservoir	2.6	2.6	6.0	6.5	6.0	6.5	6.0	6.5
Arouca Boreholes	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Arima Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Waller Field Boreholes	1.1	1.3	1.7	2.2	2.2	2.8	2.8	3.5
Caroni-Arena Reservoir	—	—	2.3	4.4	9.9	13.7	—	—
Santa Cruz Borehole	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Oropouche Reservoir	—	—	—	—	—	—	16.4	21.8
Local Intakes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Deficit	—	0.1	—	—	—	—	—	—
Caroni-Montserrat	5.8	7.3	8.3	10.3	11.7	14.5	14.3	17.8
Carlsen Field Boreholes	2.0	2.5	2.0	2.5	2.0	2.5	2.0	2.5
Freeport Boreholes	0.8	0.7	2.5	3.0	2.5	3.0	2.5	3.0
Las Lomas Boreholes	2.5	3.5	3.0	3.7	3.0	3.7	3.0	3.7
Caroni-Arena Reservoir	—	—	0.3	0.5	3.7	4.7	6.3	8.0
California Boreholes	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6
San Fernando	5.6	6.9	7.3	8.9	9.1	11.0	10.5	12.7
Navet Reservoir	5.6	6.9	7.3	8.3	7.6	5.1	5.2	2.4
Caroni-Arena Reservoir	—	—	—	0.6	—	—	5.3	9.6
Oropouche Reservoir	—	—	—	—	—	—	—	—
Moruga Reservoir	—	—	—	—	1.5	5.9	—	0.7
South Trinidad	15.6	19.1	25.8	31.5	36.6	44.0	46.7	57.0
Navet Reservoir	8.2	10.1	9.7	8.7	9.4	11.9	11.8	14.6
Penal Boreholes	2.0	2.5	2.0	2.5	2.0	2.5	2.0	2.5
Point Fortin Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
La Brea Boreholes	—	—	1.0	1.2	1.0	1.2	1.0	1.2
Clarke Road Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
Granville Boreholes	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6
Cap-de-Ville Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
Morichal Springs	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Guaracara Springs	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Palo Seco Boreholes	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6
Moruga Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table A-4 (Continued). Future Production to Serve Major Water Service Areas

Area and source	Production, mgd							
	1974		1983		1992		2000	
	Avg day	Max day	Avg day	Max day	Avg day	Max day	Avg day	Max day
Caroni-Arena Reservoir	—	—	7.7	12.7	—	—	1.5	—
Moruga Reservoir	—	—	—	—	18.8	22.0	25.0	32.3
Fyzabad Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
Freeport Boreholes	—	0.1	—	—	—	—	—	—
Mayaro	0.4	0.5	0.8	0.9	1.1	1.3	1.4	1.7
Mayaro Boreholes	0.4	0.5	0.8	0.9	1.1	1.3	1.4	1.7
North Coast	0.3	0.3	0.6	0.7	0.8	0.9	1.0	1.2
Tyrico Bay Intake	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Maracas Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Yarra Boreholes	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Local Intakes	—	—	0.1	0.2	0.3	0.4	0.5	0.7
Toco	0.4	0.5	0.7	0.8	0.8	1.0	1.0	1.2
Tompire Water Works	0.2	0.3	0.4	0.5	0.4	0.5	0.4	0.5
Grande Riviere Boreholes	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Local Intakes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Salibya Intake	—	—	0.1	0.1	0.2	0.2	0.3	0.4
Sangre Grande	1.7	2.1	2.6	3.2	3.5	4.4	4.2	5.2
Valencia Intake	1.3	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Waller Field Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Los Armadillos Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Oropouche Intake	—	—	0.6	1.2	1.5	2.4	2.2	3.2
Biche Water Works	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Coryal Boreholes	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Deficit	—	0.1	—	—	—	—	—	—
Petrochemical Demand	2.0	2.2	7.0	7.7	8.8	9.7	10.0	11.0
Navet Reservoir	0.3	—	—	—	—	—	—	—
Freeport Boreholes	1.7	2.2	—	—	—	—	—	—
Caroni-Arena Reservoir	—	—	7.0	7.7	5.6	5.7	10.0	11.0
Moruga Reservoir	—	—	—	—	3.2	4.0	—	—
Trinidad Total	68.0	83.4	102.4	124.6	136.5	165.2	165.1	201.1

Table A-4 (Continued). Future Production to Serve Major Water Service Areas

<i>Area and source</i>	<i>Production, mgd</i>							
	<i>1974</i>		<i>1983</i>		<i>1992</i>		<i>2000</i>	
	<i>Avg day</i>	<i>Max day</i>	<i>Avg day</i>	<i>Max day</i>	<i>Avg day</i>	<i>Max day</i>	<i>Avg day</i>	<i>Max day</i>
TOBAGO								
Southwest	1.4	1.6	2.0	2.4	2.9	3.5	3.7	4.4
Courland Intake	0.1	0.2	—	—	—	—	—	—
Hillsborough Reservoir	1.3	1.4	1.5	1.5	1.5	1.4	1.4	1.3
Courland Reservoir	—	—	0.5	0.9	1.4	2.1	2.3	3.1
Windward Coast	0.2	0.2	0.3	0.4	0.5	0.6	0.6	0.7
Richmond Intake	0.2	0.2	0.3	0.4	0.5	0.5	0.5	0.5
Hillsborough Reservoir	—	—	—	—	—	0.1	0.1	0.2
Rural	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4
Local Intakes	<u>0.1</u>	<u>0.1</u>	<u>0.1</u>	<u>0.2</u>	<u>0.2</u>	<u>0.3</u>	<u>0.3</u>	<u>0.4</u>
Tobago Total	1.7	1.9	2.4	3.0	3.6	4.4	4.6	5.5
Total	69.7	85.3	104.8	127.6	140.1	169.6	169.7	206.6

Table A-5. Future Surface Water Production by Source

Source	Production, mgd							
	1974		1983		1992		2000	
	Avg day	Max day	Avg day	Max day	Avg day	Max day	Avg day	Max day
Trinidad								
Caroni-Arena Res.	—	—	29.1	37.1	36.5	42.0	23.1	28.6
Oropouche Res.	—	—	—	—	—	—	37.7	44.9
Hollis Res.	8.0	8.0	6.0	6.5	6.0	6.5	6.0	6.5
St. Ann's Intake	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cascade Intake	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dibe Intake	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Maraval Intake	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Navet Res.	14.1	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Tyrico Intake	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Tompson Waterworks	0.2	0.3	0.4	0.5	0.4	0.5	0.4	0.5
Salybia Intake	—	—	0.1	0.1	0.2	0.2	0.3	0.4
Valencia Intake	1.3	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Oropouche Intake	—	—	0.6	1.2	1.5	2.4	2.2	3.2
Biche Waterworks	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Moruga Res.	—	—	—	—	23.5	31.9	25.0	33.0
Local Intakes	<u>0.2</u>	<u>0.2</u>	<u>0.3</u>	<u>0.4</u>	<u>0.5</u>	<u>0.6</u>	<u>0.7</u>	<u>0.9</u>
Trinidad Total	25.0	28.2	56.3	65.6	88.4	103.9	115.2	137.8
Tobago								
Courland Intake	0.1	0.2	—	—	—	—	—	—
Richmond Intake	0.2	0.2	0.3	0.4	0.5	0.5	0.5	0.5
Courland Res.	—	—	0.5	0.9	1.4	2.1	2.3	3.1
Hillsborough Res.	1.3	1.4	1.5	1.5	1.5	1.5	1.5	1.5
Local Intakes	<u>0.1</u>	<u>0.1</u>	<u>0.1</u>	<u>0.2</u>	<u>0.2</u>	<u>0.3</u>	<u>0.3</u>	<u>0.4</u>
Tobago Total	1.7	1.9	2.4	3.0	3.6	4.4	4.6	5.5
Total	26.7	30.1	58.7	68.6	92.0	108.3	119.8	143.3

Table A-6. Future Groundwater Production by Source

Source	Production, mgd							
	1974		1983		1992		2000	
	Avg day	Max day	Avg day	Max day	Avg day	Max day	Avg day	Max day
Tucker Valley Boreholes	0.5	0.7	1.4	2.1	2.6	3.3	3.4	4.2
Chaguaramas Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
River Estate Boreholes	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Four Roads-Cocorite Boreholes	2.5	3.7	2.5	3.7	2.5	3.7	2.5	3.7
Carenage Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
El Socorro Boreholes	4.5	8.0	4.5	8.0	4.5	8.0	4.5	8.0
Las Lomas Boreholes	3.0	3.7	3.0	3.7	3.0	3.7	3.0	3.7
Haleland Park Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
California Boreholes	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6
Brieves Road Borehole	—	—	—	—	—	—	—	—
St. Clair Borehole	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Savannah Boreholes	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Wharf Boreholes	0.9	1.4	0.9	1.4	0.9	1.4	0.9	1.4
Docksite Boreholes	—	0.5	—	0.5	—	0.5	—	0.5
George V Boreholes	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Valsayn Boreholes	5.0	6.2	5.0	6.2	5.0	6.2	5.0	6.2
Tacarigua Boreholes	5.0	6.2	5.0	6.2	5.0	6.2	5.0	6.2
Arouca Boreholes	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Arima Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Waller Field Boreholes	1.2	1.4	1.8	2.3	2.3	2.9	2.9	3.6
Santa Cruz Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Carlsen Field Boreholes	2.0	2.5	2.0	2.5	2.0	2.5	2.0	2.5
Freeport Boreholes	2.5	3.0	2.5	3.0	2.5	3.0	2.5	3.0
Clarke Road Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
Penal Boreholes	2.0	2.5	2.0	2.5	2.0	2.5	2.0	2.5
Point Fortin Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
La Brea Boreholes	—	—	1.0	1.2	1.0	1.2	1.0	1.2
Granville Boreholes	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6
Cap-de-Ville Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
Morichal Springs	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Guaracara Springs	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table A-6 (Continued). Future Groundwater Production by Source

Source	Production, mgd							
	1974		1983		1992		2000	
	Avg day	Max day	Avg day	Max day	Avg day	Max day	Avg day	Max day
Palo Seco Boreholes	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6
Moruga Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Fyzabad Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
Coryal Boreholes	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Mayaro Boreholes	0.4	0.5	0.8	0.9	1.1	1.3	1.4	1.7
Maracas Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Yarra Boreholes	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Grande Riviere Boreholes	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Los Armadillos Borehole	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	42.5	54.5	45.6	58.5	47.6	60.8	49.4	62.8

O.H. not important

*HP High Priority
LP Low Priority*

Table A-7. Priority List of Recommended Local Supply Projects

Priority No.	Water service area	Project description	Cost in \$1,000 TT
First-Stage Program			
<i>Q</i> 1	Eastern Main Road	Additional boreholes and a new HLPS (high-lift pumping station) at Tacarigua. Added capacity 2.4 mgd. New 12-inch distribution mains at St. Augustine and Curepe. Connection to Hollis system at site of HLPS. <i>Done 1</i>	1,892
2	Eastern Main Road	New BPS (booster pumping station) on the Hollis main at Success. <i>Done</i>	47
3	Eastern Main Road	New BPS on the 12-inch Arima takeoff from Hollis main. <i>Not necessary</i>	116
<i>Q</i> 4	Caroni	<i>4MGD.</i> New boreholes, WTP (water treatment plant) and HLPS at Las Lomas. Capacity 3.0 mgd. New 2.0-mil gal. reservoir at Las Lomas. New 20-inch distribution main from Las Lomas to the Hollis system at Chaguanas and a new 12-inch main to Las Lomas. <i>Temp Greater w/ Plant soon in operation</i>	6,701
<i>Q</i> 5	Caroni	Additional boreholes at a new WTP and HLPS at Carlsen Field. Added capacity 1.0 mgd. New 16-inch transmission and distribution mains to Freeport area and 8-inch distribution reinforcement from Freeport Reservoir. <i>HP</i>	3,014
<i>Q</i> 6	South Trinidad	New boreholes, WTP and HLPS at Fyzabad. Capacity 1.0 mgd. New 0.5-mil gal. reservoir and 12-inch connecting mains. <i>in work HP</i>	2,698
<i>Q</i> 7	South Trinidad	Additional boreholes and a new WTP and HLPS at Cap-de-Ville. Added capacity 0.8 mgd. Additional storage of 0.2 mil gal. at the Cap-de-Ville Reservoir. <i>HP</i>	1,976
<i>Q</i> 8	South Trinidad	New boreholes, WTP and HLPS at Palo Seco. Capacity 0.5 mgd. New 0.5-mil gal. reservoir. <i>HP.</i>	1,867
9	South Trinidad	Additional boreholes and a new WTP and HLPS at Clarke Road. Added capacity 0.8 mgd. <i>OUT X</i>	1,067
10	South Trinidad	Additional borehole at Granville and a 6-inch reinforcing main from Bonasse to Los Gallos. <i>LP</i>	606
11	South Trinidad	New BPS at Rochard Douglas Road to augment the supply to Moruga. Capacity 0.1 mgd. <i>LP</i>	78
12	South Trinidad	New 0.2-mil gal. reservoirs at Tableland and Rio Claro. <i>MANY PUMP ST.</i>	284
13	South Trinidad	New temporary BPS at Buen Intento Road. Capacity 0.5 mgd. <i>OUT X</i>	110
14	South Trinidad	New 0.2-mil gal. reservoir at Palmiste. <i>HP.</i>	148
15	Caroni	New 10-inch distribution main from California Reservoir to Forres Park. <i>LP</i>	509
16	Caroni	New boreholes, WTP and HLPS at California. Capacity 0.5 mgd. <i>re affected by 1000/1</i>	1,369

Table A-7 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water service area	Project description	Cost in \$1,000 TT
17	Toco	New pumping and treatment facilities at existing Tompire waterworks. Added capacity 0.3 mgd. Additional storage of 0.2 mil gal. at the Toco Reservoir and 8-inch reinforcements to the main between Toco Village and Sans Souci. <i>in P. HP</i>	665
18	Eastern Main Road	New 0.2-mil gal. reservoir at Cleaver Road with a new 8-inch main from the Arima system. <i>HP 75% complete</i>	283
19	Port of Spain	New 6-inch distribution main at Gonzales. <i>? out</i>	36
20	Tobago (Southwest)	New 0.5-mil gal. reservoir at Bad Hill.	229
21	North Coast	New water system with boreholes on the Yarra River. Capacity 0.2 mgd. New 8-inch transmission main to new 0.2-mil gal. reservoir in Blanchisseuse.	614
22	Tobago (Southwest)	New 8-inch distribution main from Courland to Plymouth.	96
23	Tobago (Southwest)	Leak survey and rehabilitation of existing 8-inch main between Greenhill and Bacolet.	150
24	Tobago (Southwest)	Pressure-regulating valves at Scarborough and Les Coteaux.	8
25	Diego Martin	A new borehole at Four Roads and a new 8-inch transmission main from the borehole to the existing Cocorite HLPS.	105
26	Tobago (Southwest)	Addition to the intake at Courland. New WTP and HLPS. Added capacity 0.6 mgd.	1,933
27	Tobago (Southwest)	New 0.2-mil gal. reservoir at the Hillsborough WTP and a BPS on the Hillsborough transmission main to Harmony Hall. Installation of control valves at the Harmony Hall and Greenhill takeoffs.	274
28	Diego Martin	New 16-inch distribution main from Four Roads HLPS to a new 1.0-mil gal. reservoir. <i>LESS 1 MP?</i>	1,135
29	Port of Spain	New BPS at Knaggs Hill Reservoir. Capacity 1.0 mgd. New 12-inch transmission main from BPS at St. Ann's.	299
30	Port of Spain	New BPS at Maraval Reservoir.	110
31	Mayaro	Additional boreholes at Mayaro. New aeration and chlorination facilities for new and existing boreholes.	203
32	Mayaro	New 8-inch reinforcing main from existing Mayaro boreholes to reservoir and from reservoir to system.	194
33	South Trinidad	New 0.5-mil gal. reservoir at Gasparillo and 8-inch supply main from Reform to reservoir.	646
34	Eastern Main Road	New 10-inch distribution main from Madras Settlement to Piarco Airport.	493

Table A-7 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water service area	Project description	Cost in \$1,000 TT
35	Sangre Grande	New 0.2-mil gal. reservoir at Comparo and an 8-inch distribution reinforcing main between Comparo and Manzanilla.	872
36	Sangre Grande	New 8-inch main from Waller Field WTP to Cumuto.	136
37	Sangre Grande	New boreholes at Los Armadillos. New 0.1-mil gal. reservoir and 6-inch distribution main from Los Armadillos to road junction west of Four Roads intake.	516
38	Sangre Grande	New 8-inch reinforcing main from Guaico Reservoir to Coryal.	638
39	South Trinidad	New 10-inch and 8-inch main from the Barrackpore main at St. John to the Palmiste Reservoir.	535
40	South Trinidad	New 8-inch distribution main from the Barrackpore main at Barrackpore to Wellington.	317
41	South Trinidad	New 0.2-mil gal. reservoir at Flanagan Town.	141
42	South Trinidad	Additional boreholes and additions to the WTP and HLPS at Point Fortin to bring total capacity to 1.0 mgd. Added capacity 0.7 mgd. New 8-inch transmission main to KTO Reservoir. New 10-inch distribution main from existing 10-inch main from Cap-de-Ville along Point Fortin Road to the Point Fortin WTP.	2,654
43	South Trinidad	Additional boreholes, WTP and HLPS at Penal to bring capacity to 2.5 mgd. New 12-inch main from the WTP to Penal Village. Added capacity 1.7 mgd.	3,188
44	South Trinidad	New boreholes, WTP and HLPS at La Brea. Capacity 1.0 mgd.	2,191
45	Port of Spain	New boosted supply system to serve the north end of Lady Chancellor Road. Capacity 0.1 mgd.	440
46	Port of Spain	New boosted supply system to serve the south end of Lady Chancellor Road and Knaggs Hill. Capacity 0.1 mgd.	303
47	Port of Spain	New BPS at Brieves Road with a new 12-inch main from the existing Maraval 27-inch main. New 6-inch and 8-inch transmission and distribution mains to Dundonald Hill and Fort George area. New 0.2-mil gal. reservoir at Dundonald Hill.	574
48	Port of Spain	Addition to the Picton BPS to increase total capacity to 1.0 mgd. New 12-inch and 8-inch transmission and distribution mains to St. Barbs. Additional storage of 0.2 mil gal. at the St. Barbs Reservoir. Added capacity 0.8 mgd.	965
49	Port of Spain	New boosted supply system to serve La Platte and Paramin villages.	556
50	South Trinidad	New 8-inch distribution main between Palo Seco and Erin.	800

BETTER
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2,654

Table A-7 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water service area	Project description	Cost in \$1,000 TT
51	South Trinidad	New 8-inch and 6-inch distribution main from the intersection of the Moruga and Rochard Douglas roads to La Lune. New 0.2-mil gal. reservoir at site of existing Moruga Reservoir.	1,598 800
52	South Trinidad	New 16-inch distribution main off the Navet main at Tabaquite along the Tabaquite Rio Claro Road to the proposed Rio Claro Reservoir.	2,049
53	South Trinidad	New 12-inch distribution main from Hindustan south along Moruga Road.	585
54	South Trinidad	New 16-inch transmission main from Penal WTP to Siparia.	791
55	Toco	New intake, WTP and HLPS at Salybia. Capacity 0.2 mgd. New 8-inch transmission and distribution main to new 0.2-mil gal. reservoir at Balandra.	1,302
56	Eastern Main Road	Additional pumping facilities at the Valsayn HLPS to bring total capacity to 10.0 mgd. Added capacity 3.0 mgd.	132
57	Eastern Main Road	Additional storage of 0.4 mil gal. at Morvant Reservoir.	250
58	Port of Spain	Additional storage of 0.25 mil gal. at Hololo Reservoir. New 0.1-mil gal. high-level reservoir with new 8-inch main in Hololo Road. Addition to Hololo BPS to increase capacity to 0.3 mgd.	391
59	Eastern Main Road	New pumping facilities at the El Socorro interim PS to increase capacity to 3.0 mgd. Added capacity 1.0 mgd.	413
60	Tobago (Southwest)	New 16-inch transmission main from Mt. Irvine to Lambeau. New BPS and 1.0-mil gal. reservoir at Lambeau.	1,736
61	Tobago (Southwest)	New 12-inch distribution main from proposed Lambeau Reservoir to Scarborough.	653
62	Eastern Main Road	New 16-inch inlet main from Hollis trunk main to the St. Joseph Reservoir. New 20-inch outlet main from St. Joseph Reservoir to the Hollis trunk main.	384
63	Eastern Main Road	Aeration and chlorination facilities for water quality control at the Tacarigua and the El Socorro interim HLPS.	319
64	Mayaro	Additional boreholes at Mayaro to bring total borehole capacity to 0.8 mgd. New HLPS including aeration and chlorination facilities with a rated capacity of 1.0 mgd. New 0.5-mil gal. reservoir at Pierreville. New 10-inch reinforcing main between Pierreville and Maloney Road.	1,975
65	South Trinidad	New 0.5-mil gal. reservoir at Penal. New 10-inch distribution main between Penal Village and Debe.	826

Table A-7 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water service area	Project description	Cost in \$1,000 TT
66	Eastern Main Road	New 2.0-mil gal. reservoir at Tunapuna with new 16-inch connecting main from the Eastern Main Road.	844
67	Eastern Main Road	A 0.5-mil gal. additional reservoir at the Arima Reservoir.	335
68	Tobago (Windward Coast)	New intake and WTP addition at Richmond to increase supply capacity to 0.6 mgd. Added capacity 0.4 mgd.	232
69	Sangre Grande	New intake, WTP and HLPS on the lower Oropouche River. Capacity 2.5 mgd. New 16-inch transmission main to Sangre Grande.	3,307
70	Toco	New boreholes at Grande Riviere and a new 0.2-mil gal. reservoir and 8-inch distribution main from boreholes to the reservoir.	806
71	South Trinidad	New 16-inch transmission main from St. Mary's to Fyzabad.	864
72	South Trinidad	New 16-inch transmission main off the Navet trunk main at Malgretoute to a new 1.0-mil gal. reservoir at Sainte Croix. New BPS at Malgretoute.	1,076
73	South Trinidad	A 0.5-mil gal. additional reservoir at the Gonzales Street reservoir in Siparia. A new 12-inch distribution main between Siparia and Palo Seco.	1,603
74	Montserrat	New 0.2-mil gal. reservoir at Caratal.	141
75	Sangre Grande	New 12-inch distribution main from Sangre Grande Reservoir to Comparo Reservoir.	867
76	Sangre Grande	New 8-inch distribution main from Sangre Grande to Tamana Hill Reservoir. New 0.2-mil gal. reservoir at Nestor.	1,478
		First-Stage Cost	69,738
		Second-Stage Program	
77	Tobago (Southwest)	New 10-inch and 8-inch distribution main between Greenhill, Bacolet, and Scarborough.	1,189
78	Chaguaramas	New boreholes at Chaguaramas and Tucker Valley.	542
79	Tobago (Southwest)	Courland dam and expansion of WTP from 1.5 to 3.0 mil gal.	4,337
80	Toco	New 6-inch distribution main from Toco Reservoir to Toco Village and 8-inch reinforcements to the main between Toco Village and Montevideo.	1,070
81	Diego Martin	New boreholes, HLPS and WTP at Four Roads.	814
82	South Trinidad	New 12-inch distribution main from Palmiste Reservoir to Esperance, and from Debe to Wellington. New 8-inch distribution main from Palmiste Reservoir to Rambert.	678

Table A-7 (Continued). Priority List of Recommended Local Supply Projects

<i>Priority No.</i>	<i>Water service area</i>	<i>Project description</i>	<i>Cost in \$1,000 TT</i>
83	Mayaro	New boreholes in Mayaro to bring total borehole capacity to 1.5 mgd. New 12-inch transmission main along Cedar Grove Road. Additions to HLPS and treatment facilities to bring capacity to 1.5 mgd. Added capacity 0.5 mgd. New 0.5-mil gal. reservoir at Maloney Road.	1,744
84	Eastern Main Road	New 0.5-mil gal. reservoir on Aripo Road in Waller Field and a BPS to the existing reservoir to allow pressure zoning of Waller Field system.	367
85	South Trinidad	New 12-inch distribution main off the California to San Fernando transmission main to the proposed Gasparillo Reservoir.	328
86	South Trinidad	New 8-inch distribution main between Granville WTP and Bonasse. A 0.2-mil gal. addition to the reservoir capacity at Los Gallos.	1,093
87	South Trinidad	Additional capacity of 0.5 mil. gal. at Fyzabad Reservoir.	229
88	South Trinidad	Additional capacity of 0.5 mil gal. at the Rio Claro Reservoir.	229
89	Eastern Main Road	A 12-inch distribution main in the Maracas Valley from St. Joseph Reservoir to Loango. New 0.5-mil gal. reservoir at Loango and new BPS at the St. Joseph Reservoir.	2,155
90	San Fernando	New 20-inch distribution main to Chacon Street Reservoir from proposed 4.0-mil gal. San Fernando Reservoir.	278
91	Port of Spain	New 8-inch distribution main from Haleland Park to a new 0.5-mil gal. reservoir at Perseverance.	385
92	Diego Martin	New BPS at Sierra Leone Road. Capacity 1.0 mil gal.	136
93	Eastern Main Road	New 1.0-mil gal. reservoir at Lopinot with a new 16-inch main to Eastern Main Road.	604
94	Sangre Grande	Additional 0.5-mil gal. reservoir at Guaico Reservoir and a new 0.2-mil gal. reservoir at Tamana Hill.	369
95	South Trinidad	Additional 0.5-mil gal. reservoir at Dunmore Hill and a 1.0-mil gal. addition to reservoir at Sainte Croix serving Princes Town.	632
		Second-Stage Cost	17,179
		Third-Stage Program	
96	Eastern Main Road	New 0.5-mil gal. reservoir at Success and 12-inch connecting main.	314
97	South Trinidad	New 0.5-mil gal. reservoir with 8-inch distribution main to La Brea.	542
98	Port of Spain	New 0.2-mil gal. reservoir at Fort George.	142

Table A-7 (Continued). Priority List of Recommended Local Supply Projects

<i>Priority No.</i>	<i>Water service area</i>	<i>Project description</i>	<i>Cost in \$1,000 TT</i>
99	Mayaro	New boreholes at Mayaro to bring total borehole capacity to 1.8 mgd. Expand HLPS and WTP from 1.5 mgd to 2.0 mgd. Added capacity 0.5 mgd.	587
100	Tobago (Windward Coast)	New 8-inch distribution main from Greenhill Reservoir through Studley Park.	734
101	Eastern Main Road	New 16-inch distribution main from Eastern Main Road to La Canoa BPS in Santa Cruz Valley. Increased booster capacity and a new 12-inch main to a new 1.0-mil gal. reservoir at La Pastora. New 8-inch main along La Canoa Road to a new 0.2-mil gal. reservoir at La Canoa.	2,557
102	Port of Spain	New 2.0-mil gal. reservoir at Cocorite.	831
103	Eastern Main Road	New 2.0-mil gal. reservoir at Malick with a 20-inch connection from the El Socorro to Port of Spain transmission mains.	916
104	Tobago (Southwest)	Expansion of Courland WTP to 4.5 mgd. Added capacity 1.5 mgd. A 1.0-mil gal. reservoir addition at Bad Hill with a new 16-inch transmission main from Courland to Mt. Irvine parallel to the existing 15-inch main.	2,874
		Third-Stage Cost	9,497
		Total Program Cost	96,414

Table A-8. Alternatives to Recommended Local Supply Projects

<i>Recommended project No.</i>	<i>Description of alternative project</i>	<i>Cost in \$1,000 TT</i>
9	Rochard Douglas BPS. The proposed Clarke Road boreholes are estimated to provide up to 1 mgd. If the yield obtained falls short of that estimated, it will be necessary to make up the deficiency from the Barrackpore main by constructing a booster pumping station with a capacity of 1.0 mgd immediately north of the Rochard Douglas Road.	116
39	Los Armadillos Supply. The proposed Los Armadillos boreholes are estimated to provide up to 0.5 mgd. However, results that may be obtained in the Guaracara Formation cannot be predicted; if, therefore, the yield is unsatisfactory, it will be necessary to bring water from the Sangre Grande-Guaico system to meet the requirements of the area, by laying a 6-inch main from Coryal to Los Armadillos and constructing a booster pumping station. The estimated cost of this alternate includes the 0.1-mil gal. reservoir scheduled for construction in Project 37.	763
31, 64, 99 & 83	Mayaro Transmission Main. The proposed Mayaro (Cedar Grove Road) boreholes are estimated to provide up to 1.8 mgd to meet the estimated maximum day demand at year 2000. The 1975 estimated maximum day demand is 0.5 mgd. The yield of the new boreholes proposed for 1975 will indicate whether local demand can be met from this source. If there is a shortfall in production, it will be necessary to make up the deficiency by providing the additional water from the Navet system at Rio Claro by laying a 12-inch main from Rio Claro to Pierreville, Mayaro, and constructing a booster pumping station. The estimated cost of this alternate includes two 0.5-mil gal. reservoirs scheduled for construction in projects 64 and 83.	3,606

Table A-9. Continuing Works in First-Stage Program

<i>List No.</i>	<i>Description</i>	<i>First-Stage Cost in \$1,000 TT</i>
1	Leak detection and systems investigation.	1,000
2	Continuation of domestic metering program.	3,000
3	Rural water system improvements at existing sources which are either untreated or inadequate.	750
4	A rural water supply program providing intakes, small wells, and well point systems in areas without a piped supply.	500
5	Groundwater exploration of known aquifers related to yield and water quality and investigation of aquifers which have not yet been explored.	750
6	The provision of observation wells for monitoring of existing groundwater aquifers.	300
7	Reinforcement of mains where capacity is deficient.	1,750
8	Extension of mains to areas without a piped supply.	7,000
9	Installation of master meters at service area boundaries and at major transmission system takeoffs.	150
10	Installation of fluoridation equipment at major sources of supply.	150
11	Purchase of specialized equipment for investigations, surveys, research, and system operation.	500
12	Surveys and investigations including special studies related to development projects.	1,500
13	Expansion of transport fleet and communication system.	500
14	Refurbishing of area offices and construction of new offices.	2,000
15	WASA 1970 commitments on projects in process of completion and which have not been covered under the local supply development program. These projects include the following:	
	<ul style="list-style-type: none"> Dunmore Hill reservoir St. Julien Road BPS Waller Field WTP Maraval WTP Tyrico WTP Guaico reservoir and BPS River Estates HLPS Freeport WTP addition 	950
	Total First-Stage Cost	20,800

Table A-10. Local Supply Projects – First-Stage Final Construction

Project	Cost \$1,000 TT(1)		Total
	Foreign	Local	
16-inch main Mt. Irvine to Lambeau new BPS and 1.0-mil gal. Lambeau reservoir	684	1,052	1,736
12-inch main Lambeau reservoir to Scarborough	285	368	653
16-inch inlet main from Hollis main to St. Joseph reservoir; 20-inch outlet from St. Joseph reservoir to Hollis main	188	196	384
Aeration and chlorination facilities for the Tacarigua and the El Socorro interim HLPS	170	149	319
Boreholes at Mayaro; new HLPS, aeration and chlorination at 1.0 mgd; 0.5-mil gal. reservoir at Pierreville; and 10-inch reinforcing main Pierreville to Maloney Road	865	1,110	1,975
0.5-mil gal. reservoir at Penal and 10-inch main Penal to Debe	381	445	826
2.0-mil gal. reservoir at Tunapuna and 16-inch connecting main to Eastern Main Road	291	553	844
0.5-mil gal. additional capacity at Arima reservoir	82	253	335
Intake and WTP addition at Richmond (0.4 mgd)	84	148	232
Intake, WTP and HLPS on Oropouche east of Sangre Grande (2.5 mgd) with 16-inch main to Sangre Grande	1,517	1,790	3,307
Boreholes at Grande Riviere, new 0.2-mil gal. reservoir and 8-inch main boreholes to reservoir	308	498	806
16-inch main St. Marys to Fyzabad	479	385	864
16-inch main with BPS from Navet main at Malgretoute to 1.0-mil gal. reservoir at St. Croix	455	621	1,076
0.5-mil gal. additional capacity at Siparia Gonzales Street reservoir and 12-inch main Siparia to Palo Seco	809	794	1,603
0.2-mil gal. reservoir at Caratal	36	105	141
12-inch main Sangre Grande to Comparo reservoir	471	396	867
8-inch main Sangre Grande to Tamana Hill reservoir and 0.2-mil gal. reservoir at Nestor	685	793	1,478
Totals	7,790	9,656	17,446

1. Includes engineering and contingencies.

APPENDIX B

APPENDIX B

PRELIMINARY DESIGN

General

This appendix presents design criteria and preliminary designs for the facilities included in the recommended first-stage program and the alternative first-stage program.

Design criteria and considerations for each type of facility are listed, and preliminary design drawings for each project are presented.

Standards referred to in this appendix are as follows:

ANS — The American National Standards
Institute

AWWA — American Water Works Association

BS — British Standards Institution

Design Criteria

Mains. All pipelines should be designed for a maximum operating pressure of 150 psi (pounds per square inch) and an external loading consistent with probable truck loads. The minimum recommended cast-iron thickness class conforming to ANS 21.6 is Class 22 for mains 4 inches to 14 inches inclusive.

The use of welded-steel pipe conforming to AWWA Standards C-201 and C-202 is recommended for mains 16 inches and over in diameter. All mains should be cement-lined, and coated with coal-tar enamel single-wrap coating conforming to AWWA Standard C-203. The minimum recommended wall thickness for steel pipe is as indicated in the tabulation below.

<u>Minimum wall thickness, inches</u>	<u>Pipe diameter, inches</u>
0.250	16 to 24
0.312	30 to 36
0.375	42 to 48
0.438	54
0.500	60
0.562	66

These recommended thicknesses conform to the BS 534 and AWWA C-201 and C-202 recommendations for minimum thickness.

Manual air-release valves should be provided at minor high points and automatic air-release valves at major high points. Minimum recommended pipe cover for pipes 4 to 16-inch diameter is 2-1/2 feet, and for 16- to 66-inch diameter, 3 feet.

Corrosion protection should be provided as indicated necessary by field soil conductivity surveys along the routes of the pipes. Where possible the protection should be of the sacrificial anode type for reliability and ease of maintenance.

Maximum recommended spacing of shutoff valves in transmissions mains 16 inches and larger is 3,000 feet. Small-main valve spacing should be less. Gate valves are recommended for 4-inch diameter and 14-inch diameter mains. For mains 16-inch diameter and larger, direct burial butterfly valves are recommended. The butterfly valve in sizes 16 inches and larger operate more easily than do gate valves, initial cost is less, and maintenance costs are comparable to those for gate valves.

Dams. Design considerations and criteria for dams are concerned primarily with the safety of the structure under conditions which may reasonably be expected to occur. They are:

1. Earthquake conditions - magnitude 7.5 (Richter Scale)
2. Stability under drawdown conditions
3. Spillway capacity for 100-year storm
4. Foundation - ability to support the dam and low permeability.

Pumping Stations. Recommended design criteria for pumping stations include the following:

Earthquake Design:	For a magnitude of 7.5 (Richter Scale)
Superstructures:	Steel frame with corrugated metal roof and masonry walls or concrete roof and masonry walls
Substructures:	Reinforced concrete

Pumps: Vertical turbine type for operation over a wide range of heads and single-stage horizontal centrifugal-type pumps for constant head or narrow range of head conditions

Surge protection: Installation of valves with controlled closing rate, automatic surge-relief valves as indicated necessary in final design

Water Treatment Plants. Recommended design criteria for water treatment plants are as follows:

Chemical Mixing: Number of basins — two

Detention time — 20 seconds

Type mixing — mechanical agitation and inlet turbulence

Flocculation: Type — mechanical (walking beam)

Detention time — 40 minutes

Sedimentation: Type — horizontal flow

Detention time — four hours

Surface loading (overflow rate) — 500 gpd*/sq ft

Sludge removal — mechanical on lower deck of multideck units and manual on all others

Weir loadings — 16,667 gpd*/lin ft

Chemical storage: Capacity for six months at average demand for all chemicals

*Imperial gallons.

Filters: Type – rapid sand

Rate – 3-1/3 gpm*/sq ft

Media--	Effective size	Uniformity coefficient
Coal or activated carbon	0.9 to 1.0 mm	1.35
Sand	0.5 to 0.6 mm	1.35 to 1.5
Wash	Air and water, maximum expansion 50 percent	

Buildings: Same as for pumping stations

Preliminary Design – Recommended Program

Navet Project. Figures B-1, B-2, B-3, B-4, and B-5 depict the principal features of the Navet pumped-storage project and related transmission main. The pumping station is designed to deliver 40 mgd against a head of 93 feet. Four 10-mgd and two 5-mgd pumps are provided to allow a wide range of flexibility in pumping rates between 5 and 40 mgd. The discharge main from the proposed raw-water pumping station to Navet Reservoir is designed to reduce stratification in the reservoir by promoting circulation while water is being pumped into the reservoir. This should reduce the present need to scour the reservoir by wasting stored water through the lowest outlet.

Arena Dam and Reservoir. The principal features of the Arena Dam and Reservoir are shown on Figures 15 through 20 in Chapter 8. Area-capacity curves for the Arena Reservoir are shown on Figure B-6.

San Rafael Intake. The San Rafael intake and pumping station are designed for a maximum pumping rate of 20 mgd. The pumping head is 167 feet. Figures B-7, B-8, and B-9 show the major features of this design. The degritter is sized to remove suspended material of 0.05-mm (millimeter) diameter and larger, to reduce the danger of pump impeller erosion.

*Imperial gallons.

Caroni Water Treatment Plant and Intake. The Caroni water treatment plant would be located at Kelly Village on the south bank of the Caroni River as shown on Figure 15 in Chapter 8. Since there are chances of raw-water contamination by oil spills, agricultural chemicals, or industrial wastes, and taste and odor problems due to algae blooms may occur, the filters in this plant are to have dual filter media consisting of granular activated carbon and silica sand. Provision is made for regeneration of the activated carbon, utilizing either oil or natural gas as a fuel depending upon which proves more economical in final design studies.

Figures B-10, B-11, and B-12 show the principal design features of the treatment plant and high-lift pumping station. The intake, degritter, and low-lift pumping station designs are similar to those of the San Rafael facility.

The low-lift pumps are sized to supply 42 mgd to the plant at a lift of 40 feet. There are three 18-mgd pumps and two 6-mgd pumps, which provide one spare unit of each size.

The high-lift station is designed to deliver water to both the San Fernando area and the Port of Spain area. Accordingly, there are two sets of pumps with a common header connected to two discharge mains. The maximum pumping rates are 28 mgd to San Fernando and 18 mgd to Port of Spain. The pumping heads at the above rates are 250 feet to San Fernando and 110 feet to Port of Spain. The design provides for a total of six pumps. Initially, two 14-mgd, 250-foot head pumps, and three 9-mgd, 110-foot head pumps would be installed. When the Chaguanas booster pumping station is added, a third 14-mgd, 250-foot head pump would be added. After the Moruga supply is constructed and the demand in the south is supplied from this source, one of the 14-mgd, 250-foot head pumps and one of the 9-mgd, 110-foot head pumps would be replaced with larger pumps to increase the pumpage rate to the Port of Spain area to about 30 mgd.

Transmission Mains. The first-stage transmission main locations and profiles are shown on Figures B-13, B-14, and B-15. They show the route of each pipeline, its profile, and the head characteristics under maximum first stage flow conditions.

Preliminary Design — Alternative Programs

Oropouche Dam and Reservoir. The major features of the Oropouche Dam and Reservoir are shown on Figures 22, 23, and 24 in Chapter 8. Area-capacity curves for the reservoir are shown on Figure B-16.

Oropouche Low-Lift Pumping Station. The Oropouche low-lift pumping station is located immediately downstream from the toe of the proposed dam on the west bank of the river. The wide range of possible water levels makes it necessary to install two sets of pumps: one set for operation when the reservoir level is between El 190 and 260, and the other when the level is between El 260 and 350. The principal features of design are shown on Figures B-17 through B-21.

Oropouche Water Treatment Plant. This plant is located on a hill above the low-lift pumping station and the proposed reservoir. The principal features of the plant design are shown on Figures B-22, B-23, and B-24. The settling basins are two-story horizontal-flow units as the available site is too small for single-story units. The lower compartment would be equipped with mechanical sludge removal equipment and automatic sludge drawoff valves. The upper compartment would be cleaned by partially draining the basin and manually scraping the alum sludge into the lower compartment or sluicing it there by hydraulic means, meanwhile operating the sludge removal equipment in the lower compartment.

Transmission Mains. Oropouche transmission mains would be as shown on Figure 26 and described in Chapter 9. Generally, the mains southward from Caroni would follow the same routes as the Caroni-Arena mains; however, they would be larger.

Treatment of Local Supplies

Sedimentation and slow sand filtration in conjunction with disinfection by hydraulically operated chlorinators are recommended for the treatment of local surface water supplies with capacities of 10,000 gpd. Figures B-25, B-26, and B-27 show suggested designs for 10,000, 20,000, and 100,000 gallon-per-day units. Figure B-28 is a cost curve giving approximate costs of such plants per gallon per day of capacity. Figures B-25 and B-26 show the top of the clearwell lower than the top of the rest of the plant while Figure B-27 shows the top of the clearwell at the same elevation as the rest of the plant. The latter is preferable for plants of all sizes unless the topography is too steep to allow such a configuration.

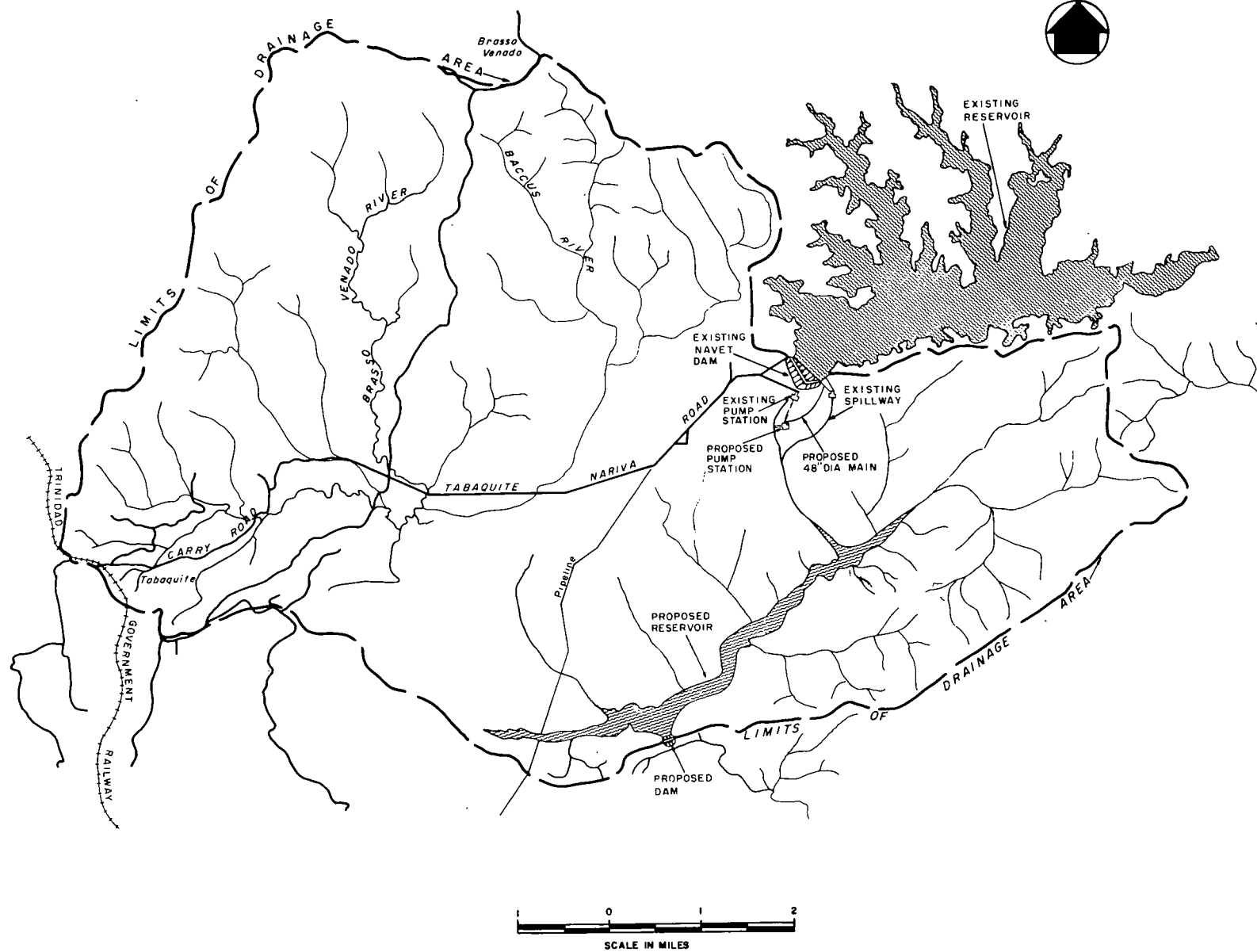


FIG. B-1 RESERVOIR FOR NAVET PUMPED-STORAGE PROJECT

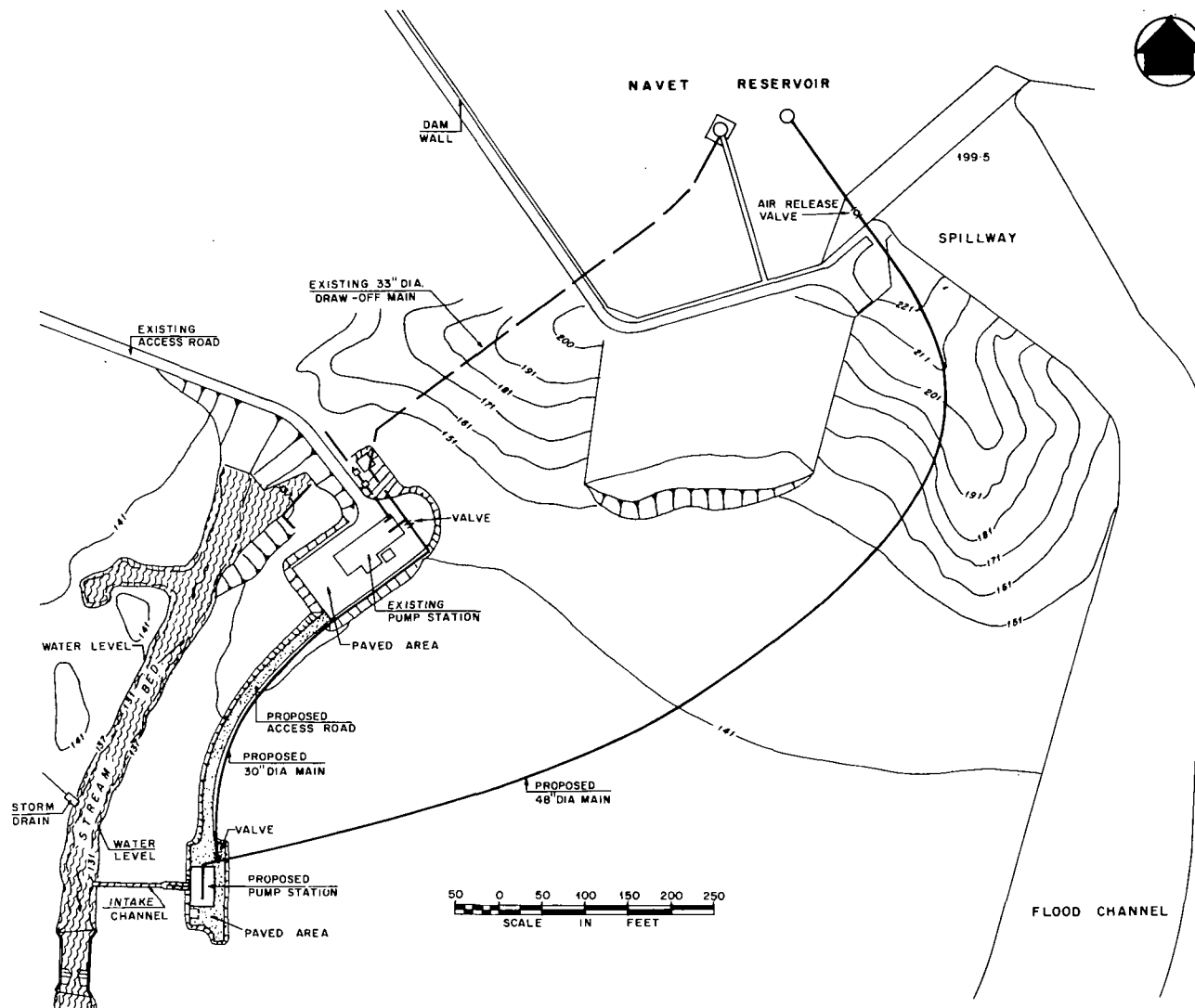


FIG. B-2 NAVET INTAKE AND PUMP STATION – SITE PLAN

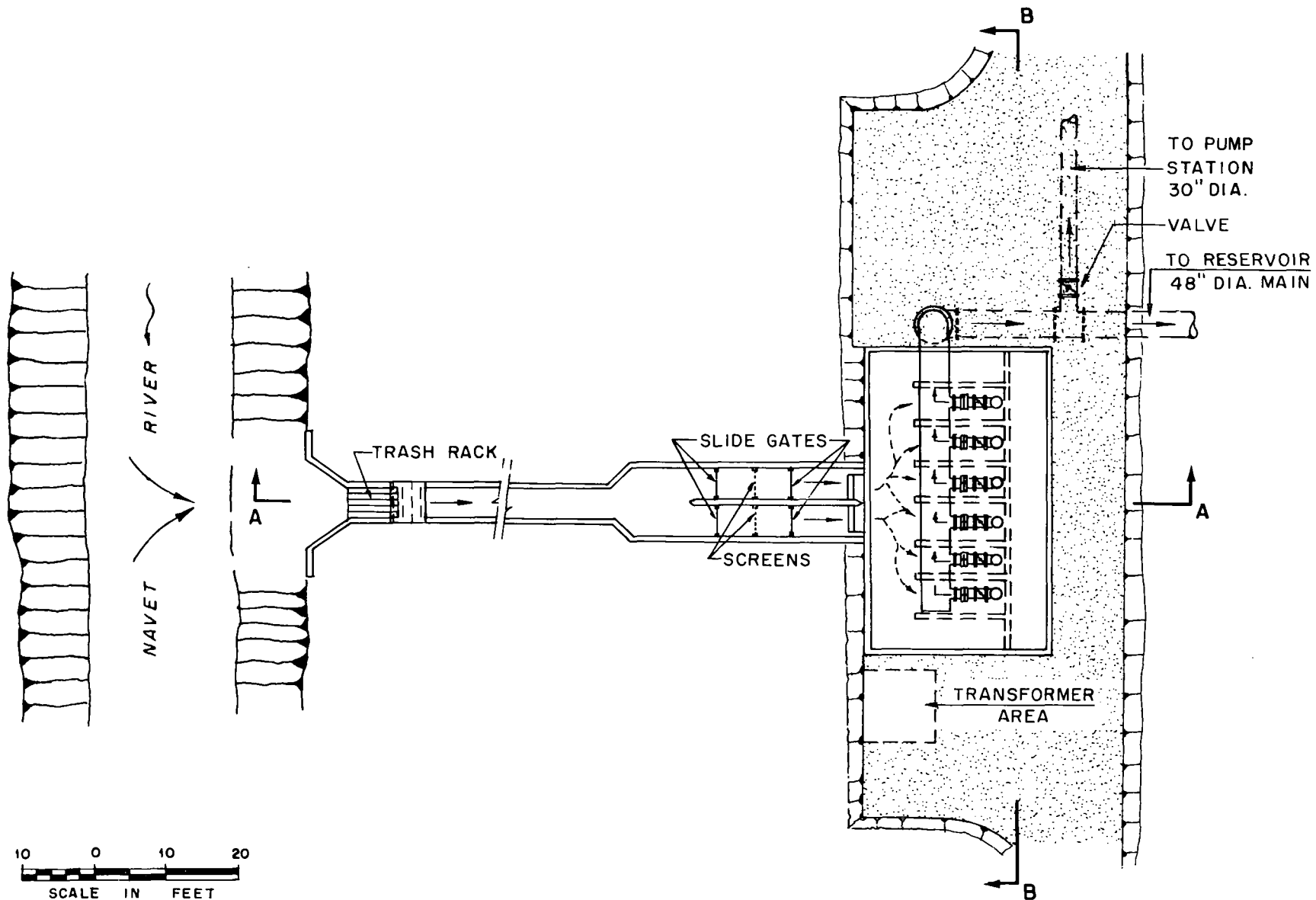


FIG. B-3 NAVET INTAKE AND PUMP STATION – PLAN

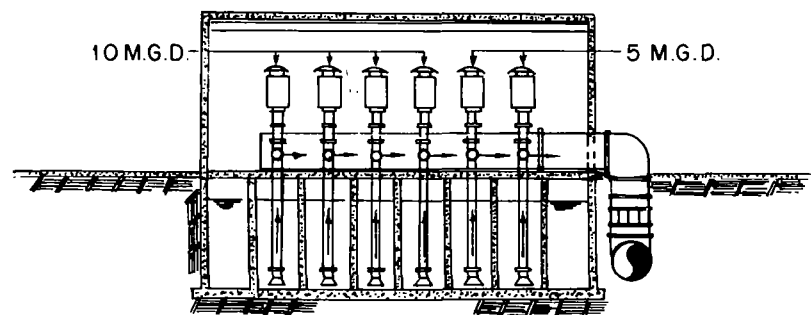
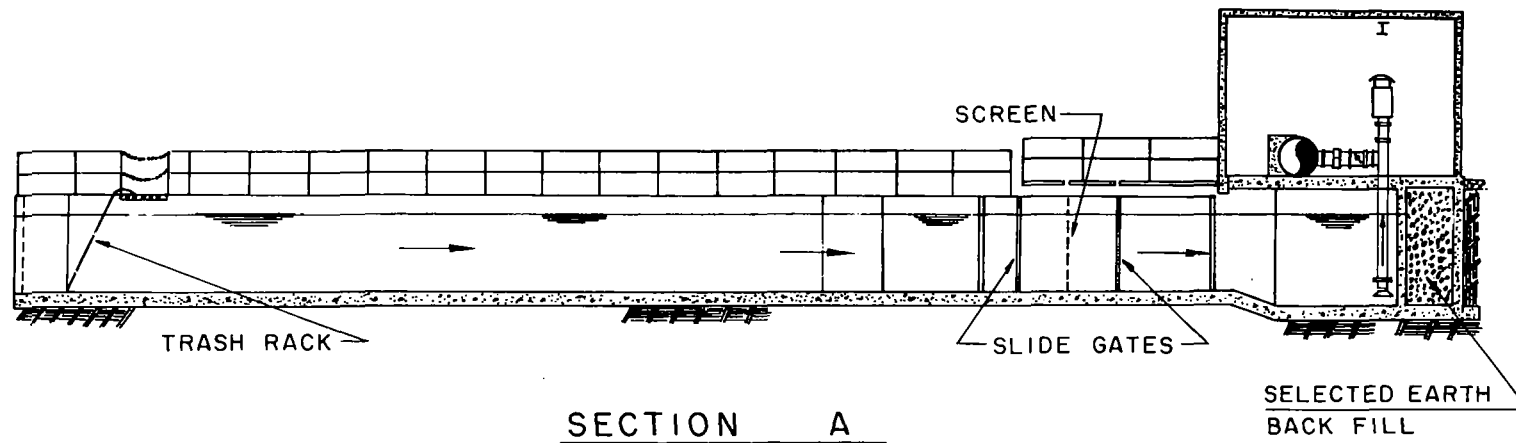


FIG. B-4 NAVET INTAKE AND PUMP STATION – SECTIONS

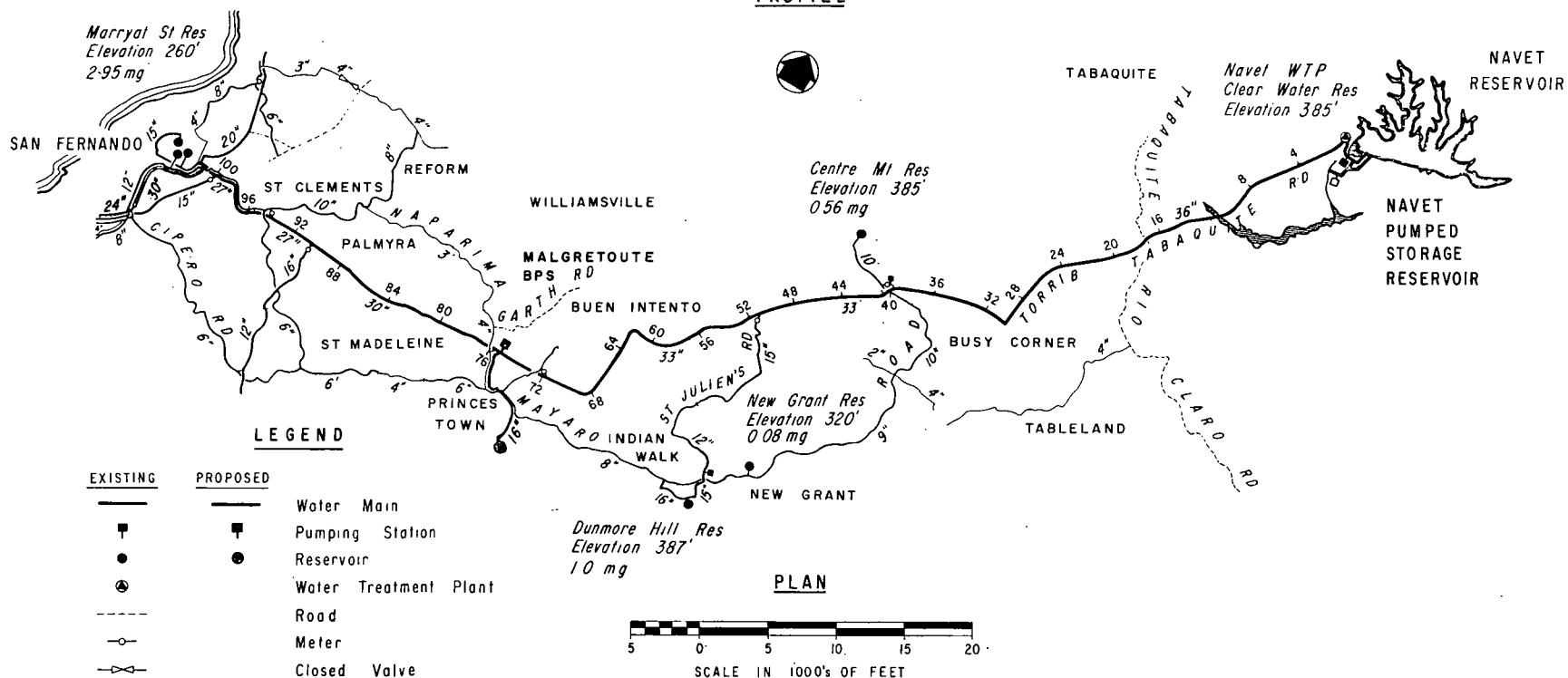
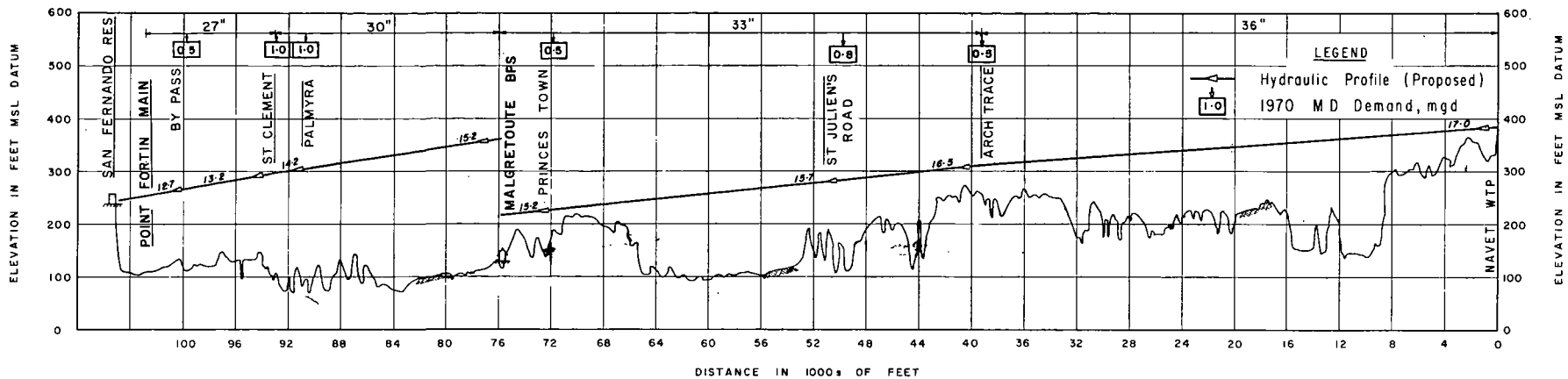


FIG. B-5 NAVET TRANSMISSION MAIN

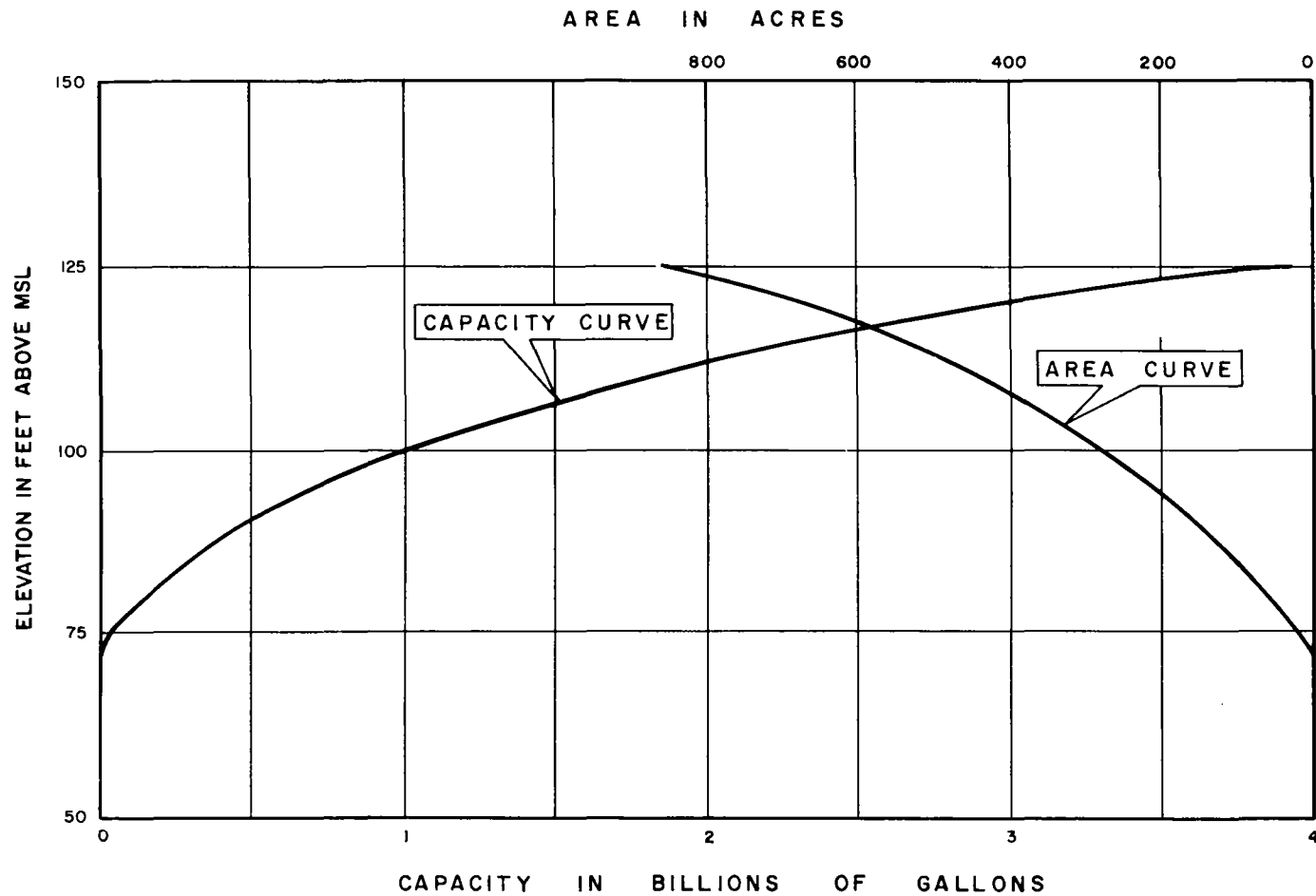


FIG. B-6 ARENA RESERVOIR AREA-CAPACITY CURVES

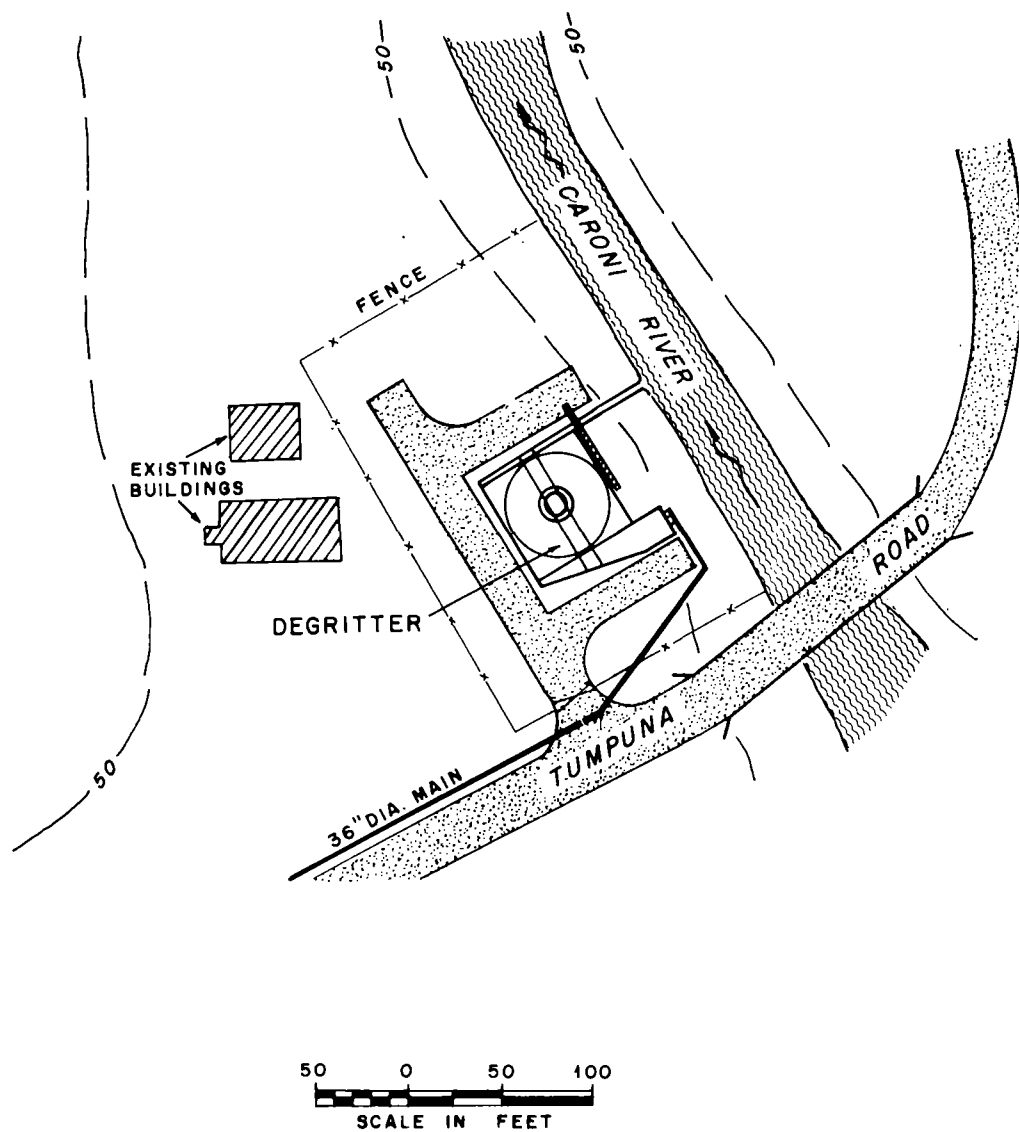


FIG. B-7 SAN RAFAEL INTAKE – SITE PLAN

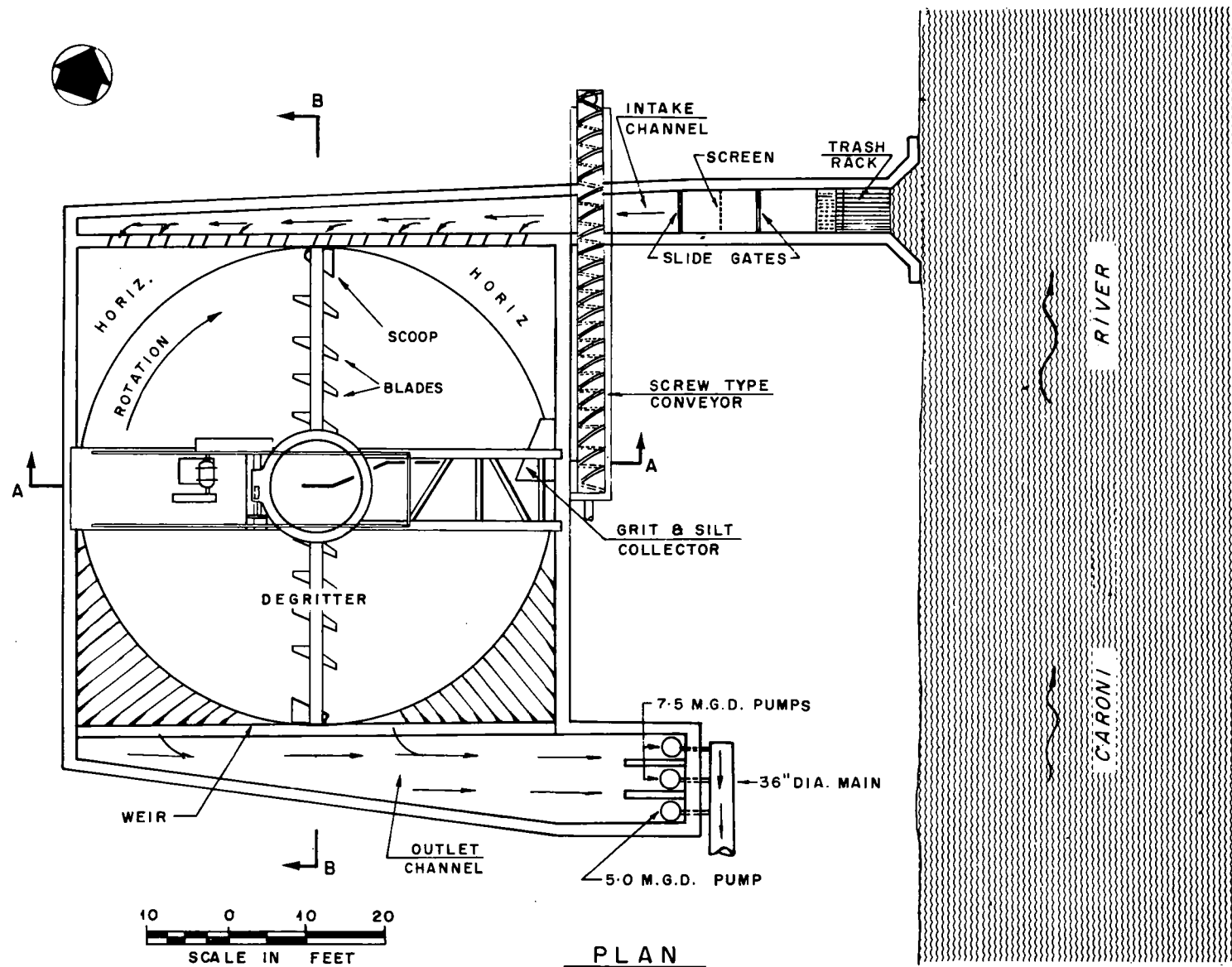


FIG. B-8 SAN RAFAEL DEGRITTER – PLAN

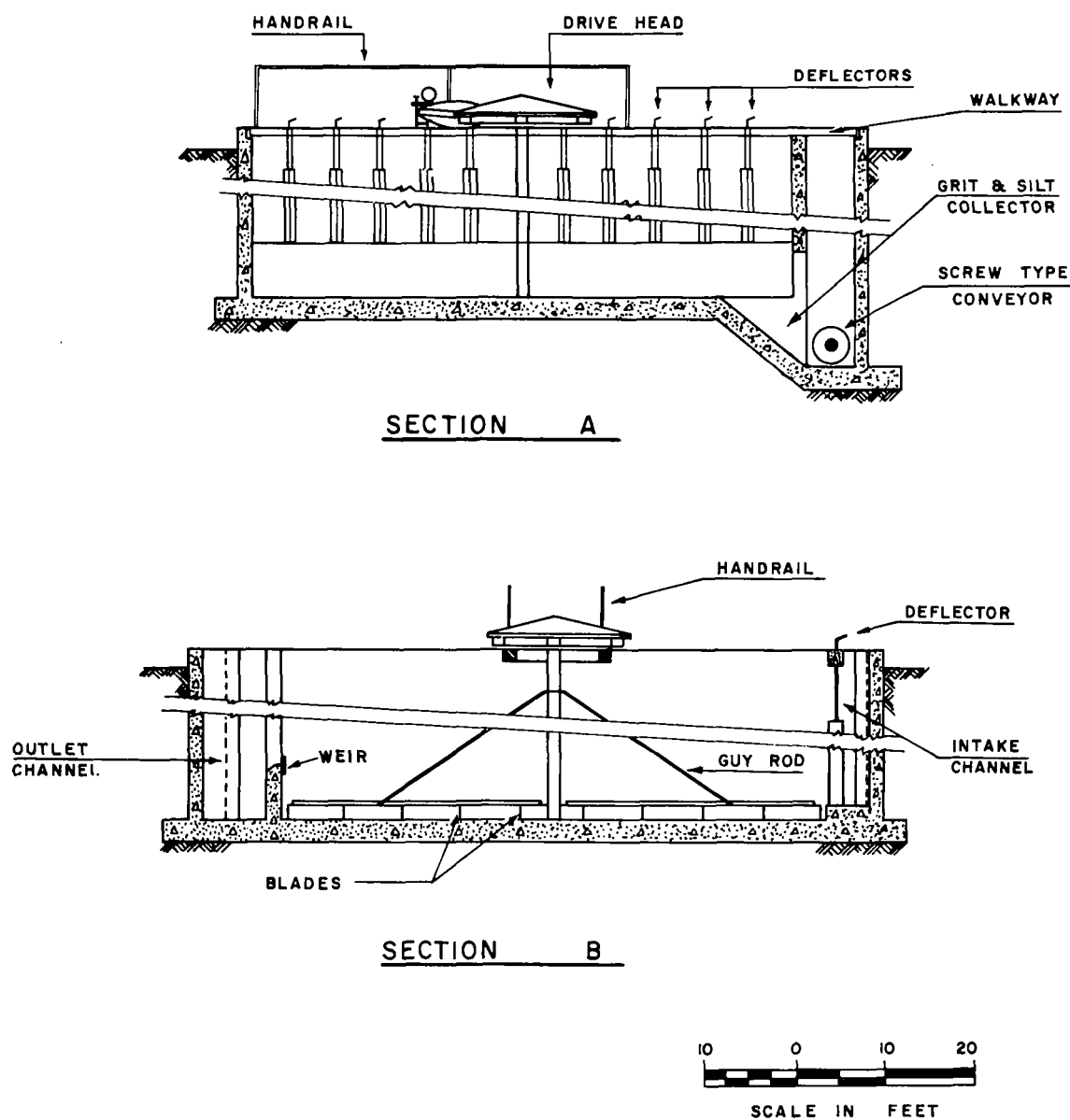


FIG. B-9 SAN RAFAEL DEGRITTER – SECTIONS

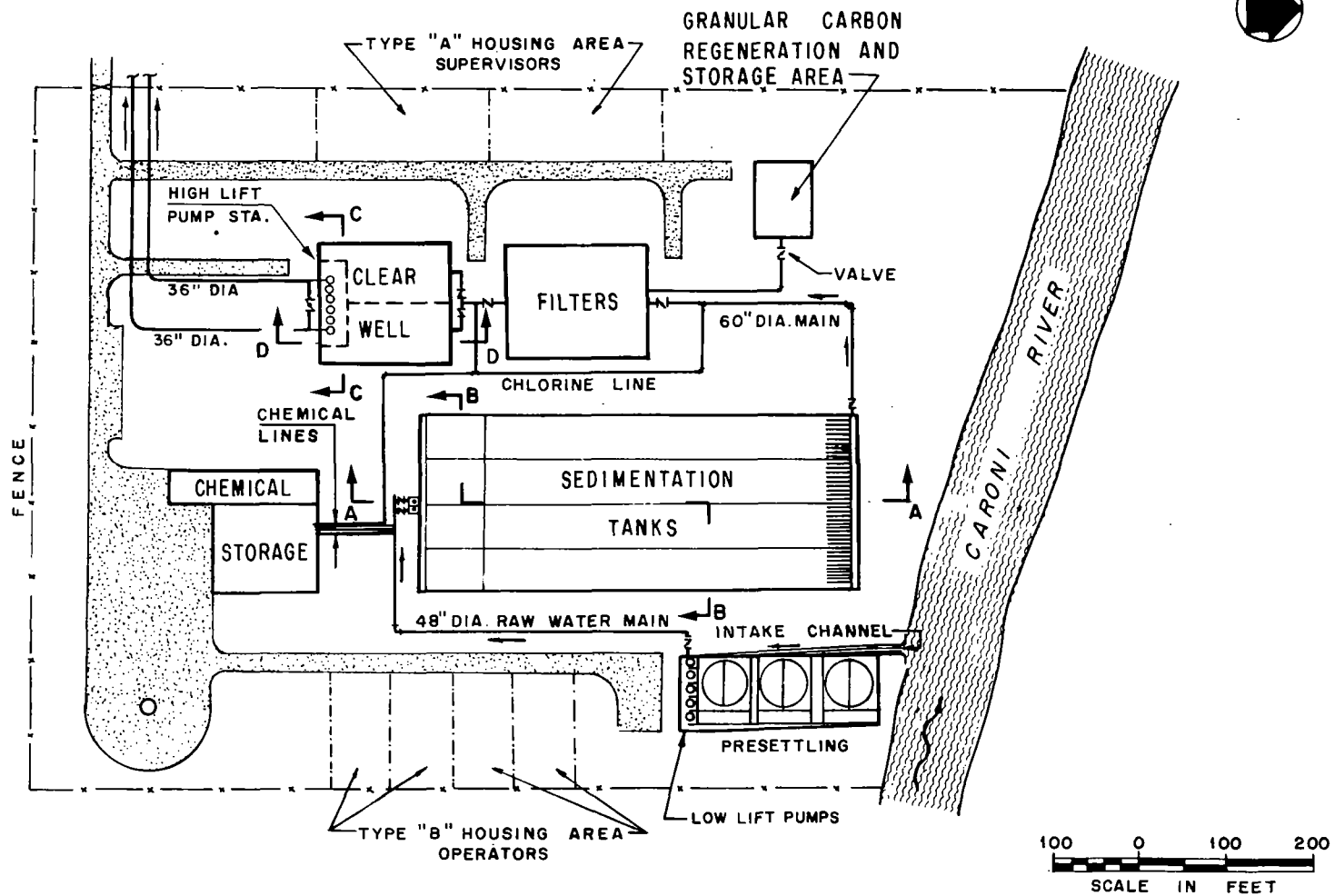


FIG. B-10 CARONI WATER TREATMENT PLANT – PLAN

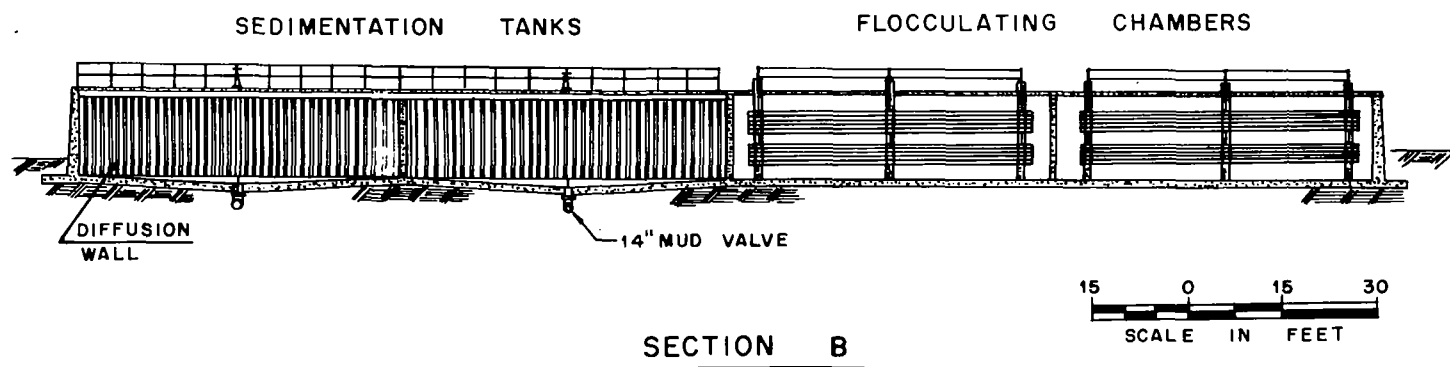
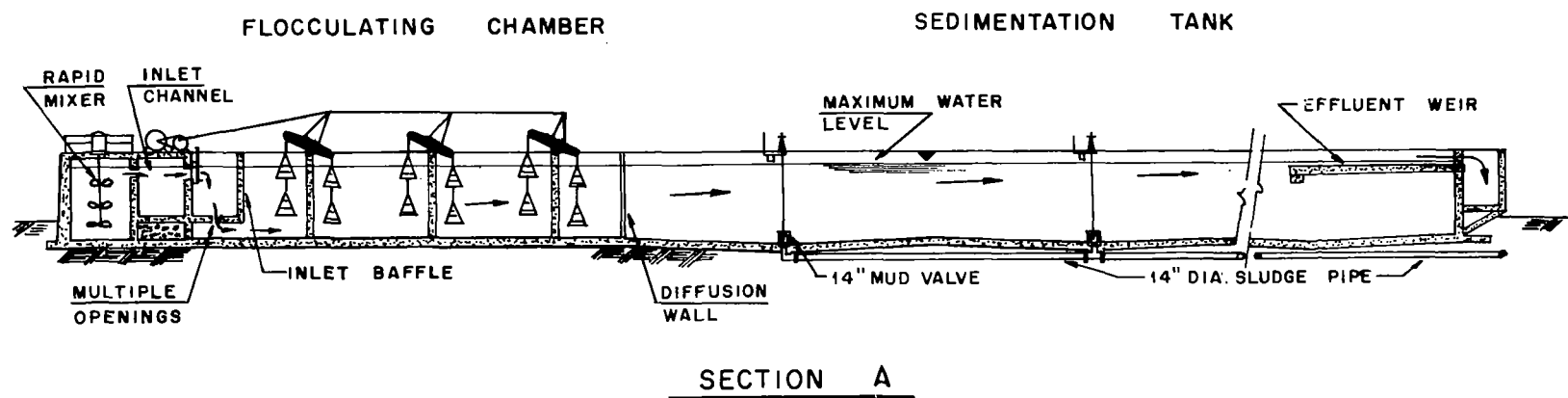
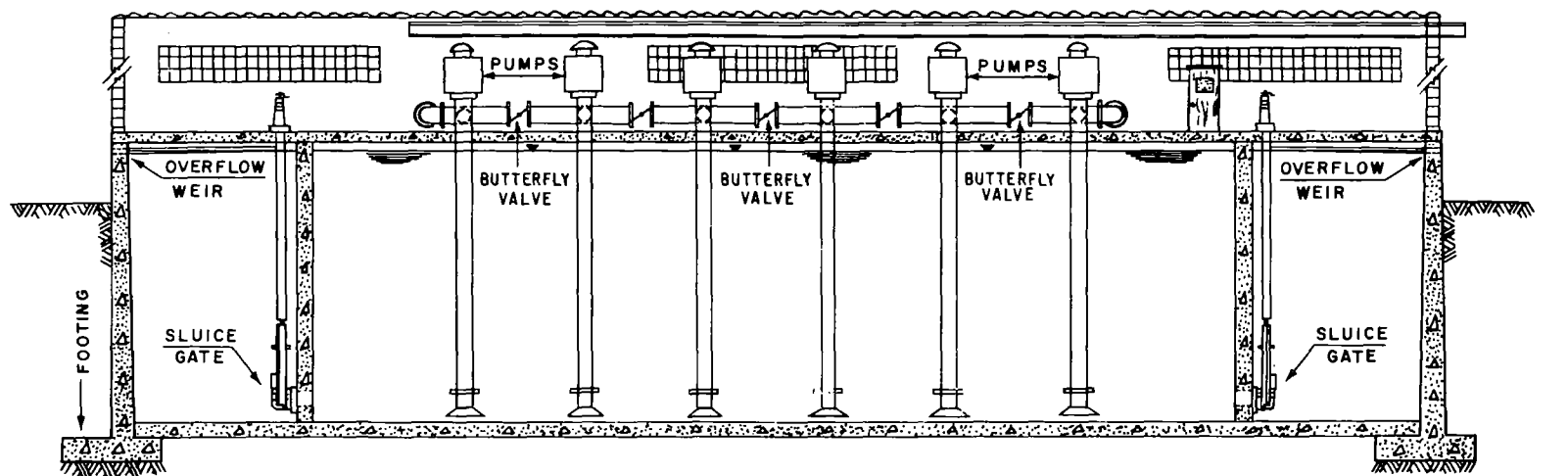
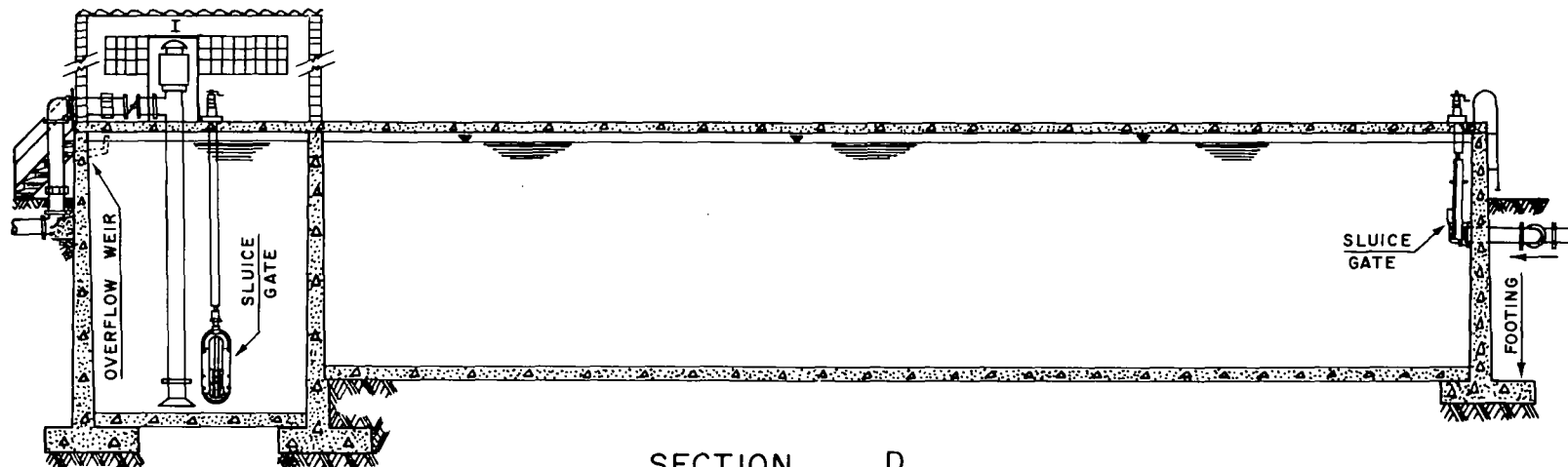


FIG. B-11 CARONI WATER TREATMENT PLANT – SECTIONS



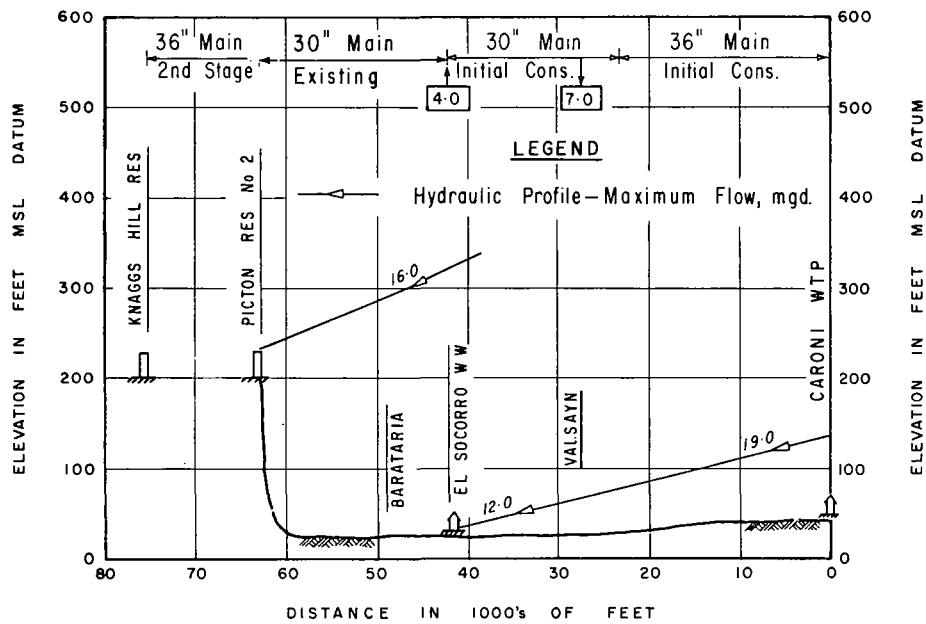
SECTION C



SECTION D



FIG. B-12 CARONI WATER TREATMENT PLANT – SECTIONS



PROFILE

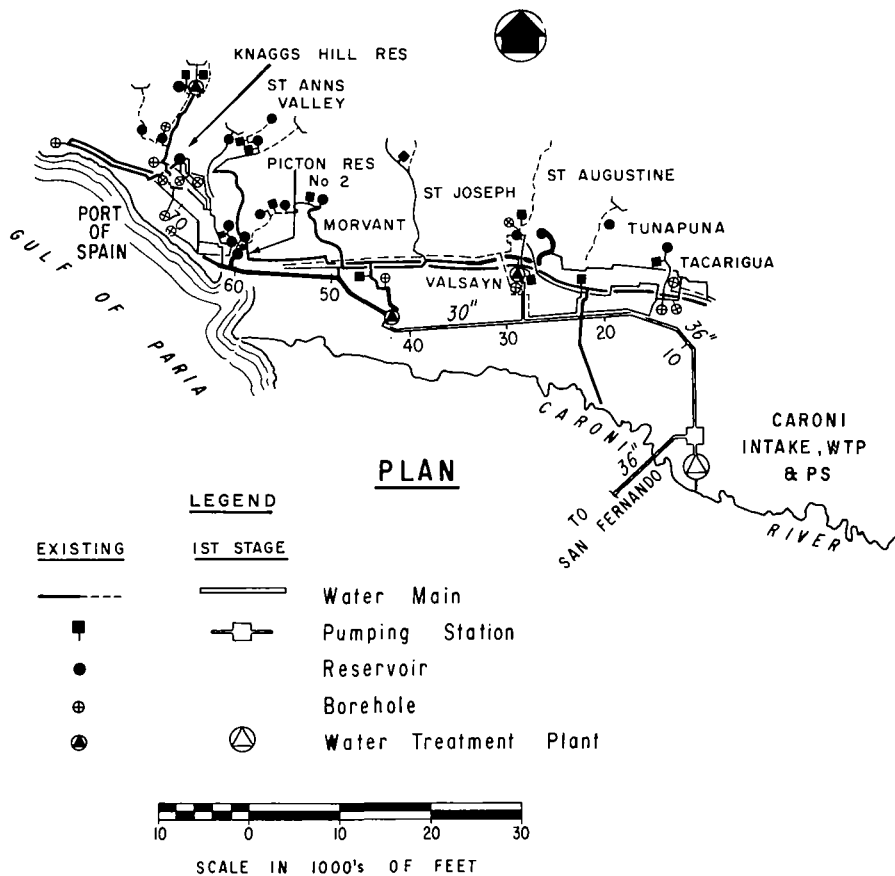
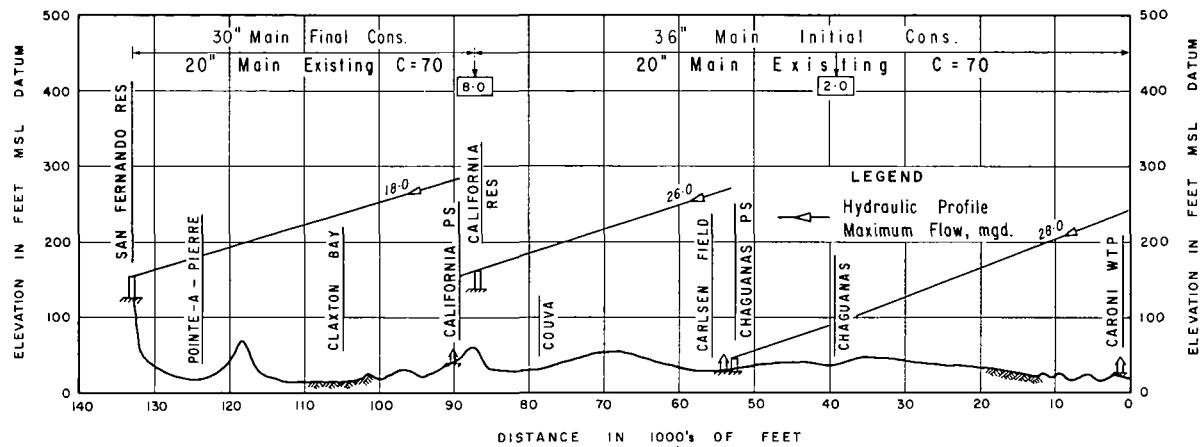
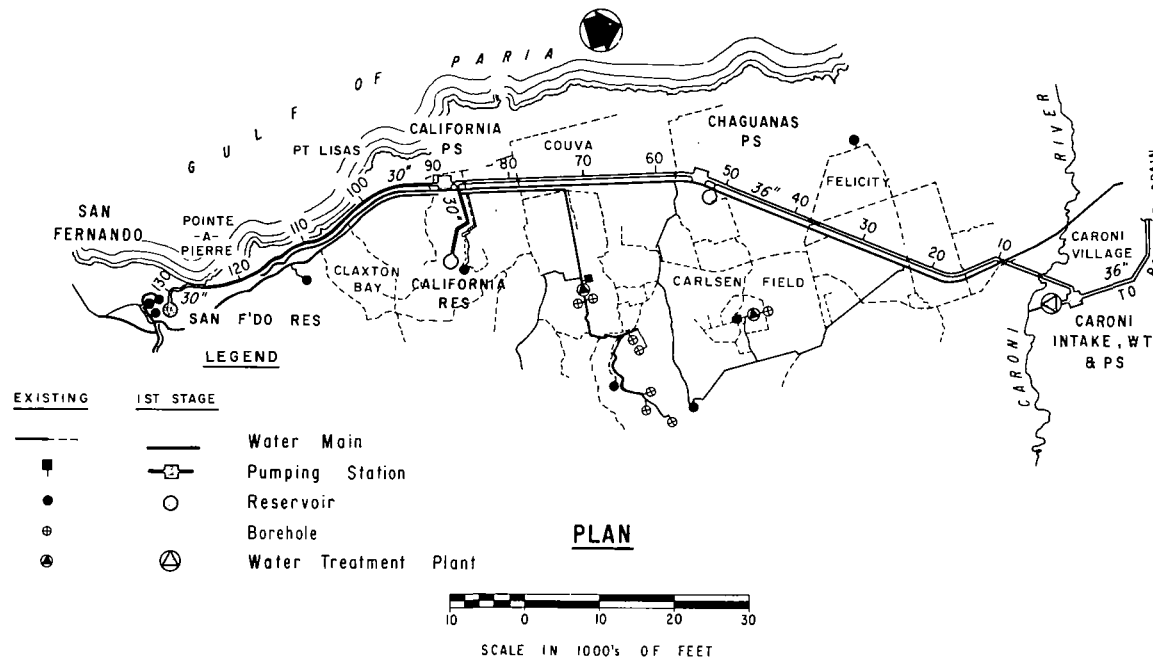


FIG. B-13 CARONI TRANSMISSION MAIN CARONI TO PORT OF SPAIN

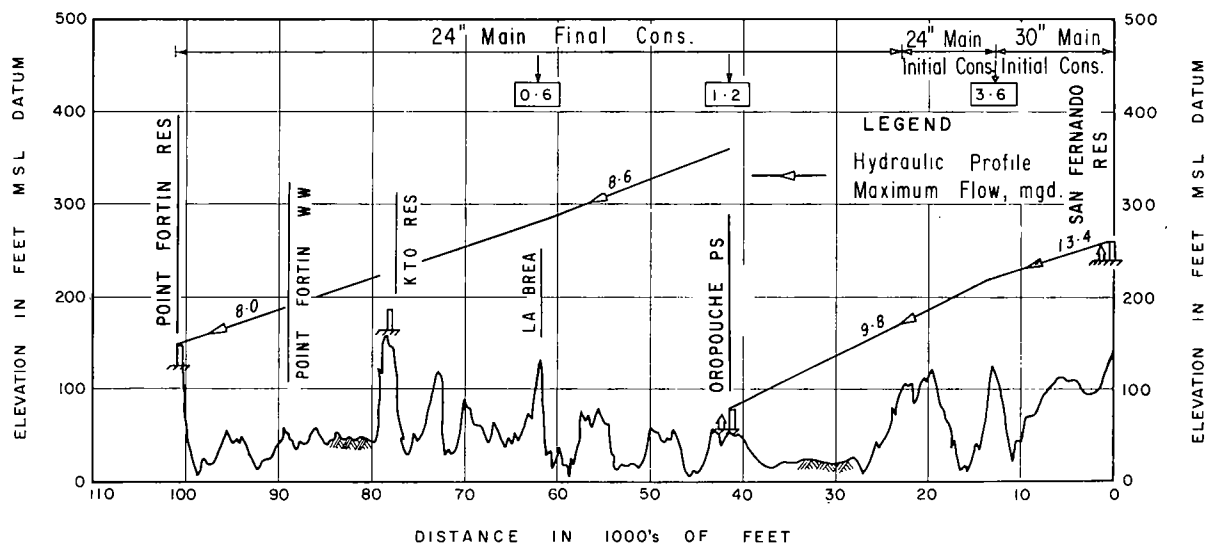


PROFILE

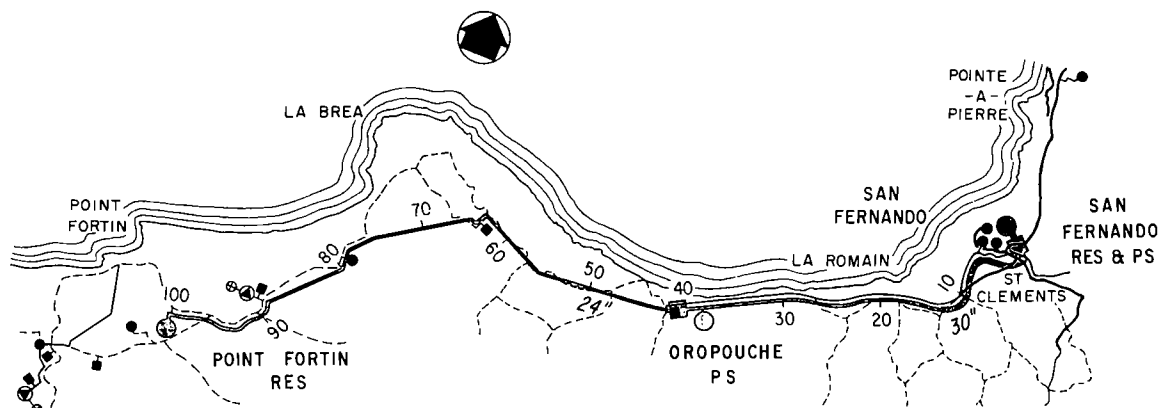


PLAN

FIG. B-14 CARONI TRANSMISSION MAIN CARONI TO SAN FERNANDO



PROFILE



PLAN

LEGEND

EXISTING

1ST STAGE

- Water Main
- Pumping Station
- Reservoir
- ⊕ Borehole
- ⊙ Water Treatment Plant

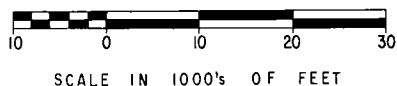


FIG. B-15 POINT FORTIN TRANSMISSION MAIN

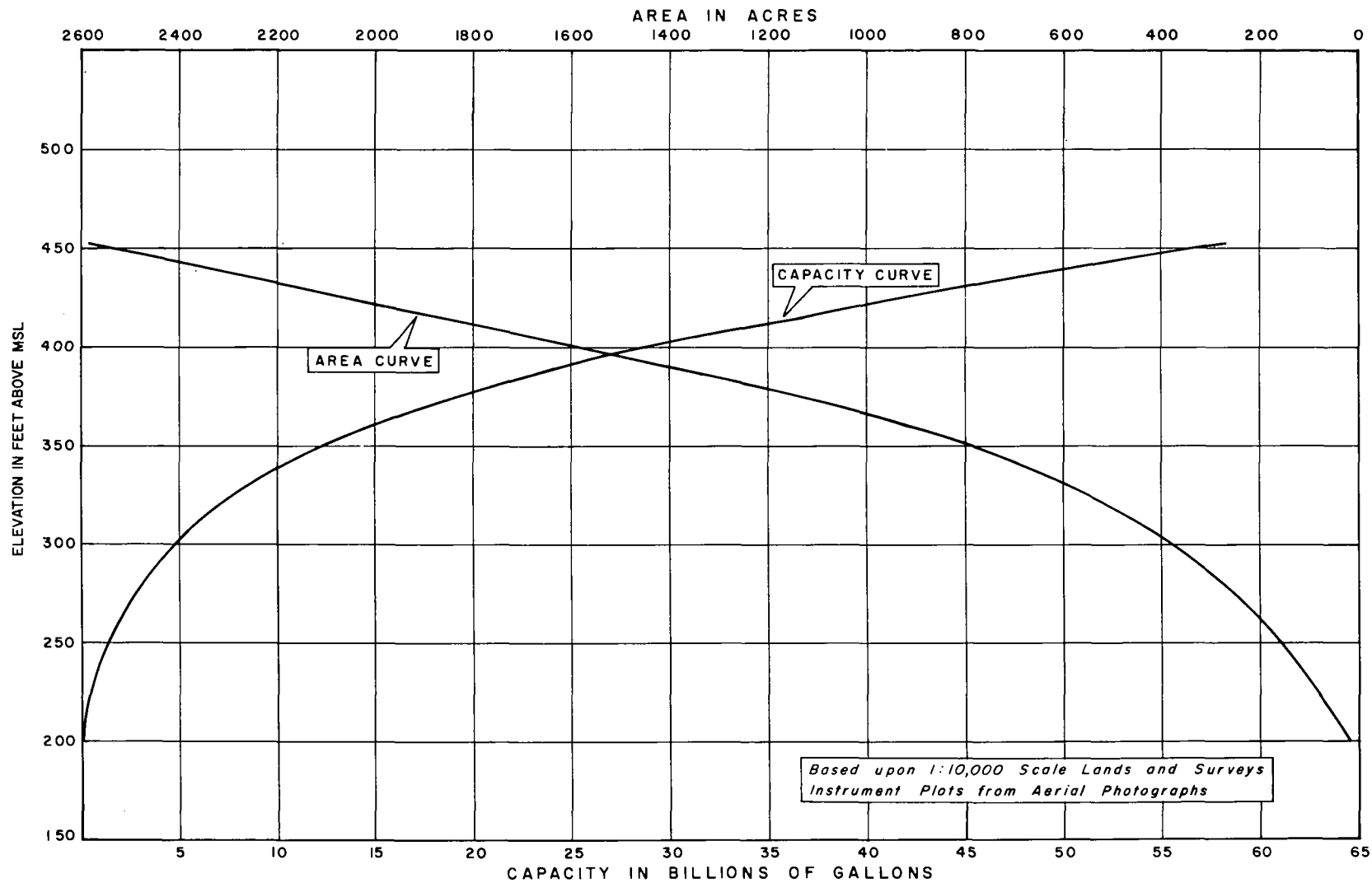


FIG. B-16 OROPOUCHE RESERVOIR – AREA-CAPACITY CURVES

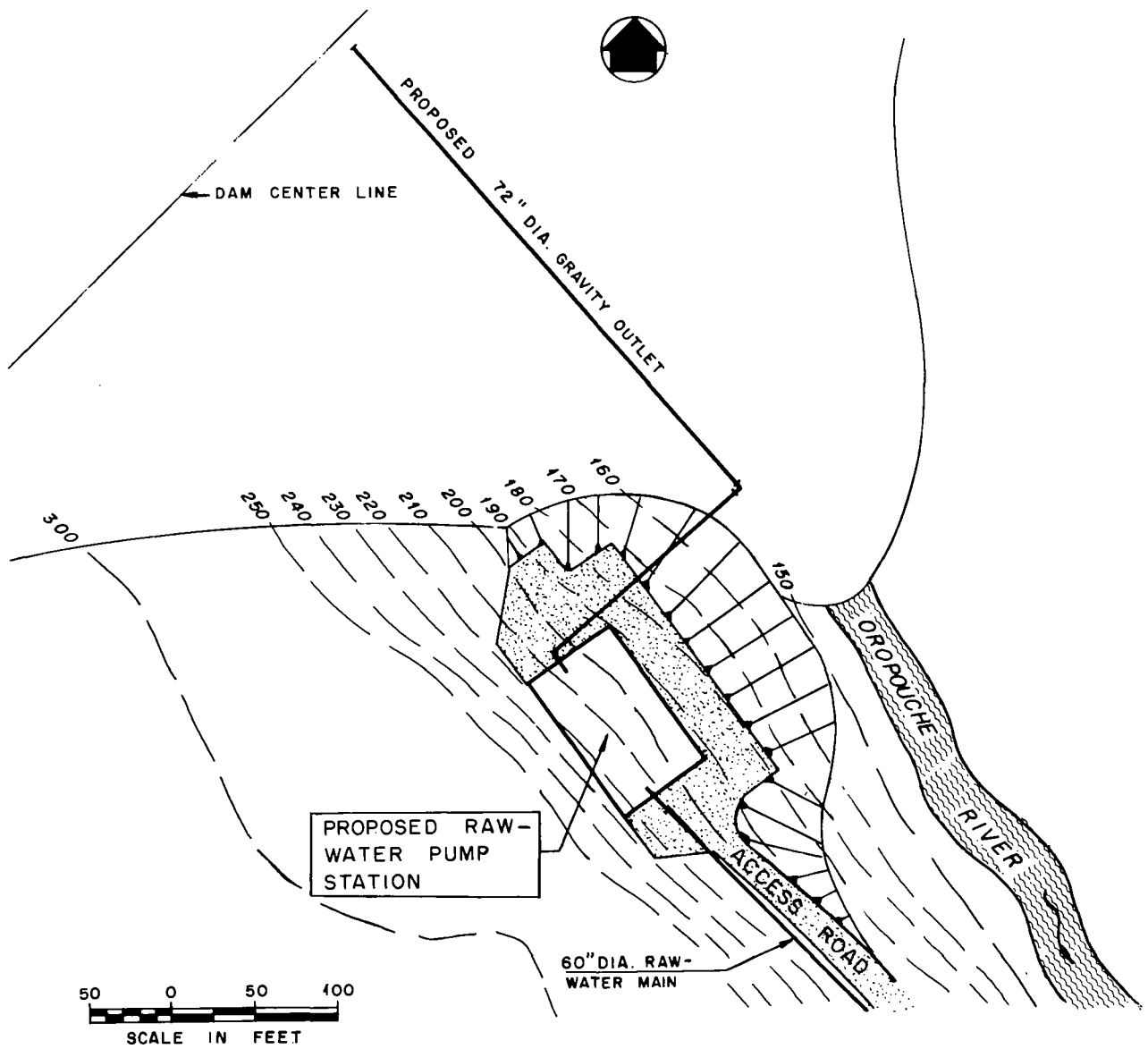


FIG. B-17 OROPOUCHE RAW-WATER PUMP STATION – SITE PLAN

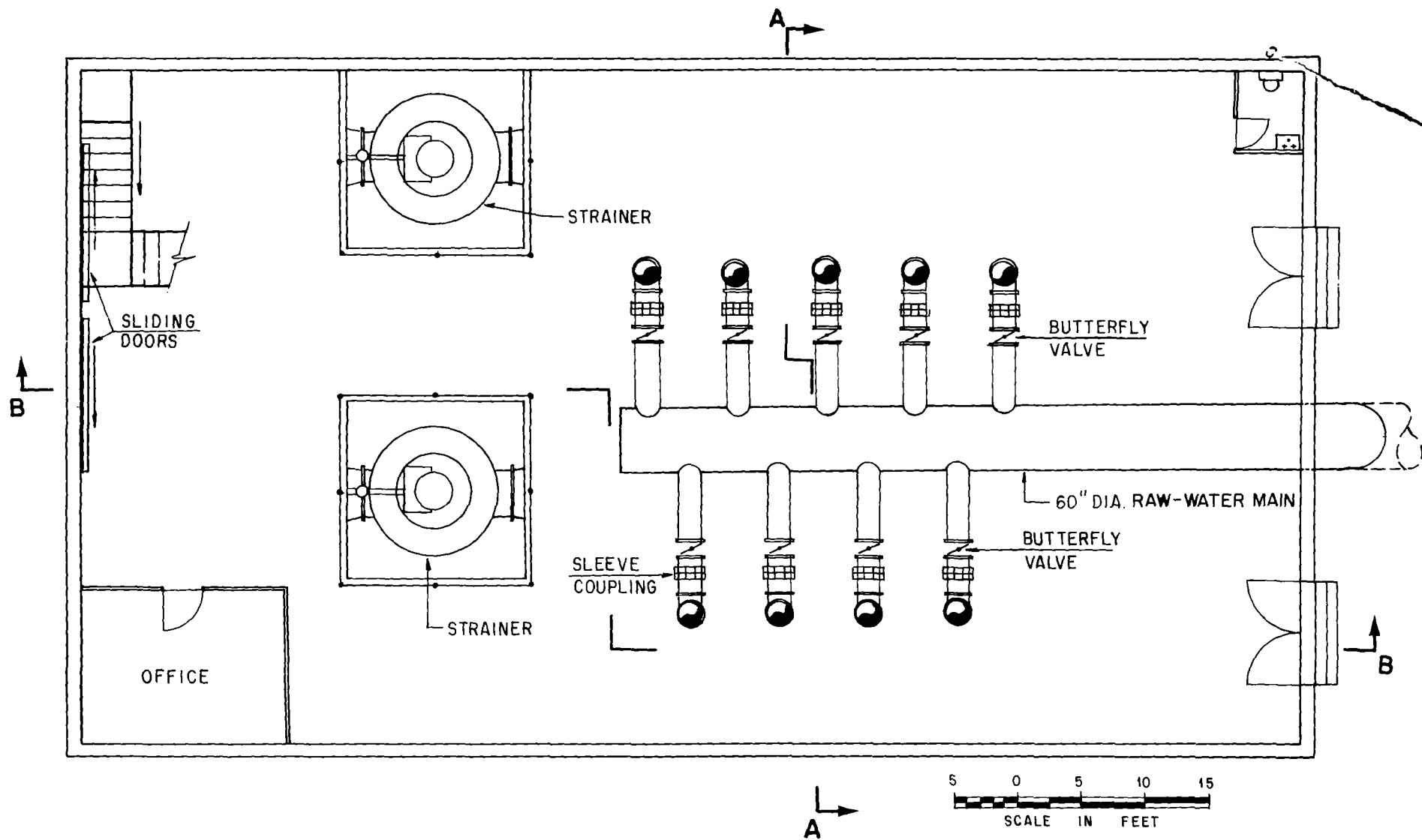


FIG. B-18 OROPOUCHE RAW-WATER PUMP STATION -- PLAN AT ELEVATION 202

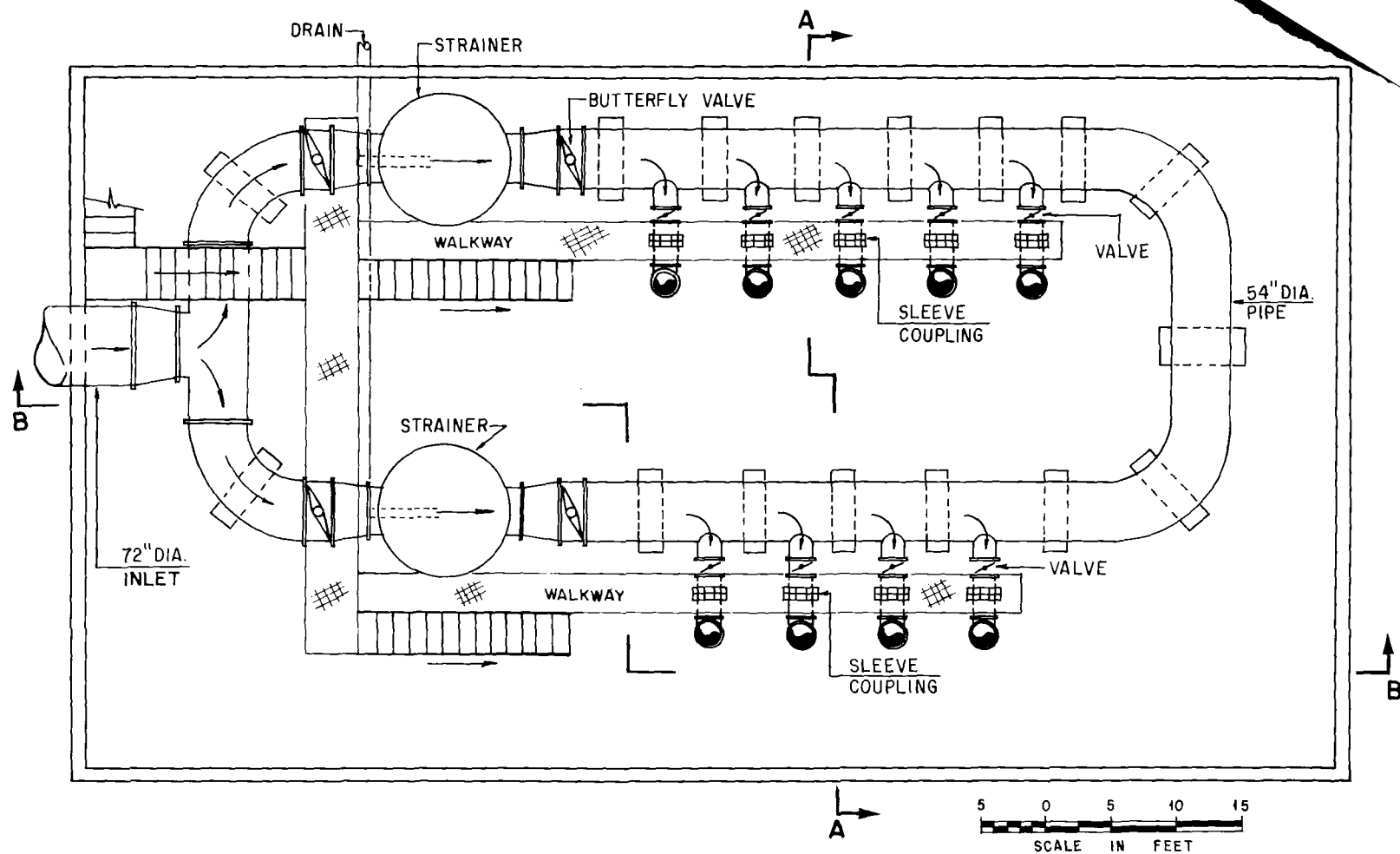


FIG. B-19 OROPOUCHE RAW-WATER PUMP STATION – PLAN AT ELEVATION 176

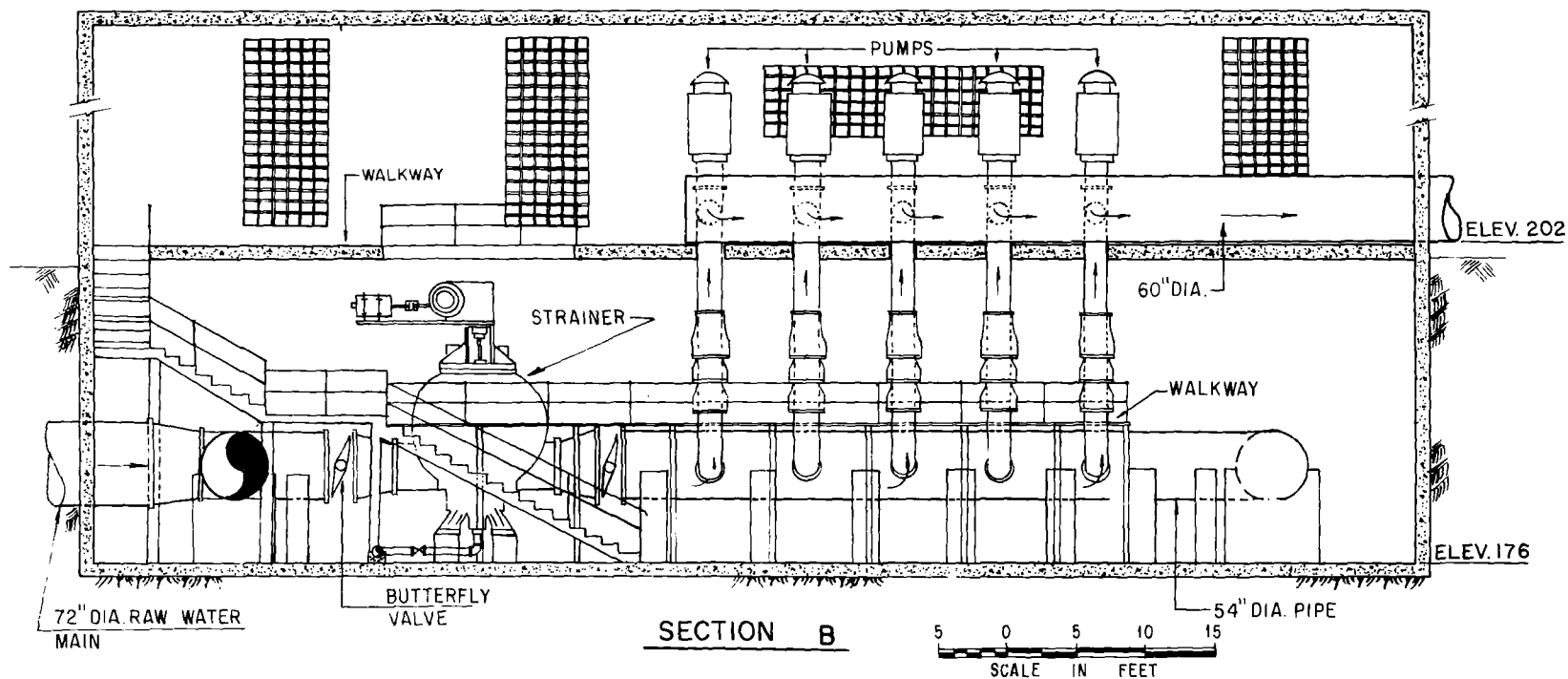


FIG. B-20 OROPOUCHE RAW-WATER PUMP STATION — SECTION

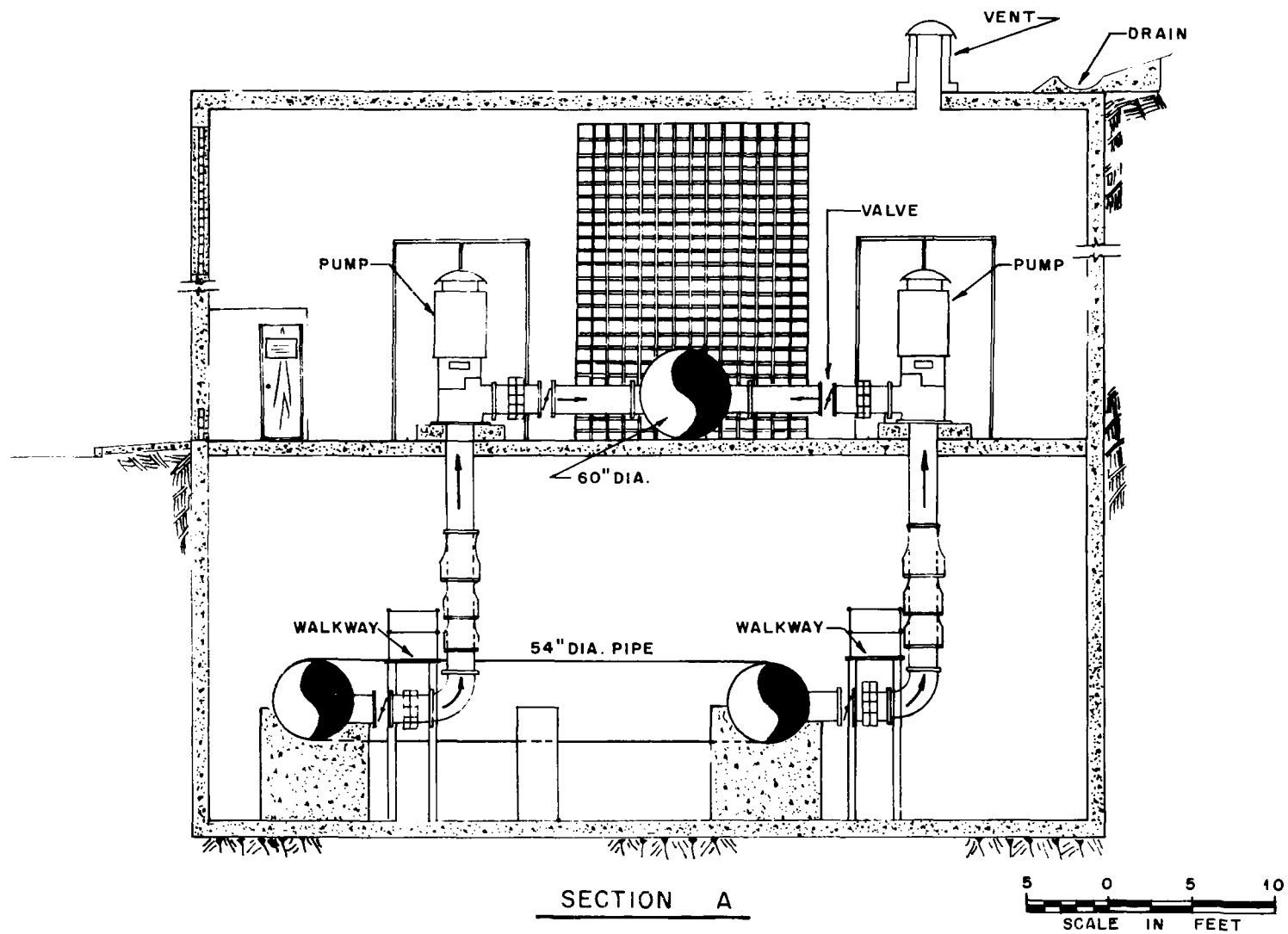


FIG. B-21 OROUCOUCHE RAW-WATER PUMP STATION — SECTION

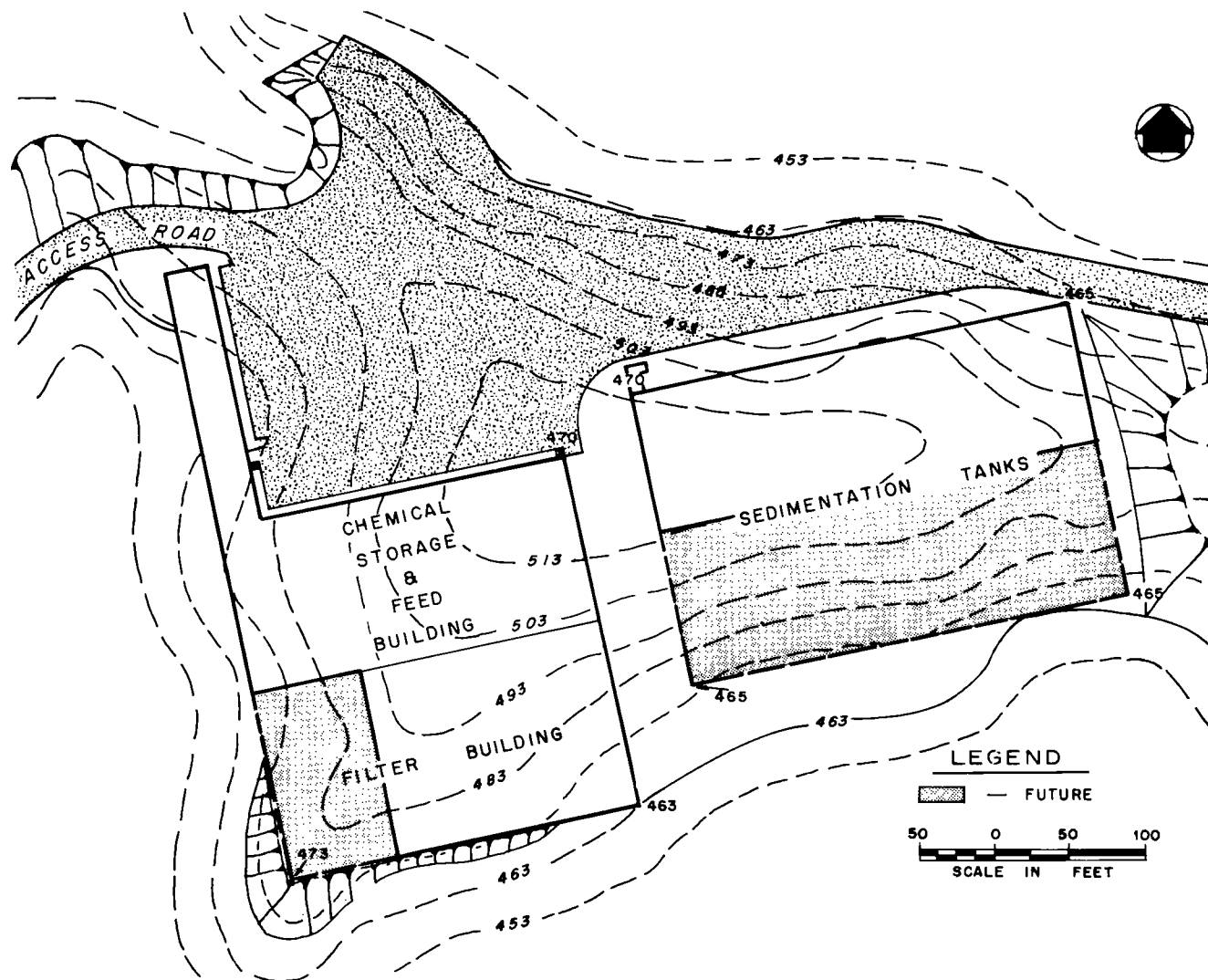


FIG. B-22 OROPOUCHE WATER TREATMENT – SITE PLAN

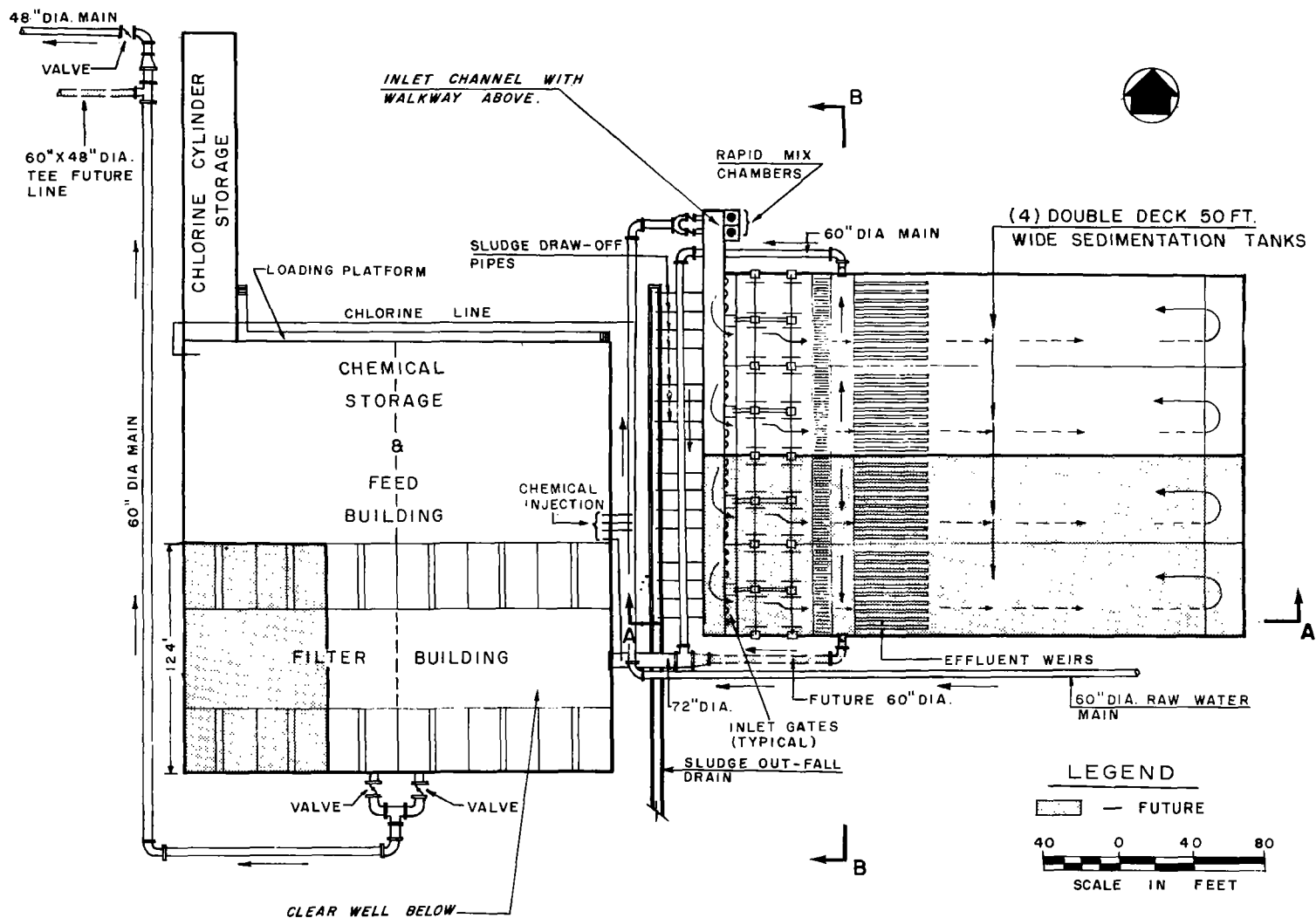


FIG. B-23 OROPOUCHE WATER TREATMENT PLANT — PLAN

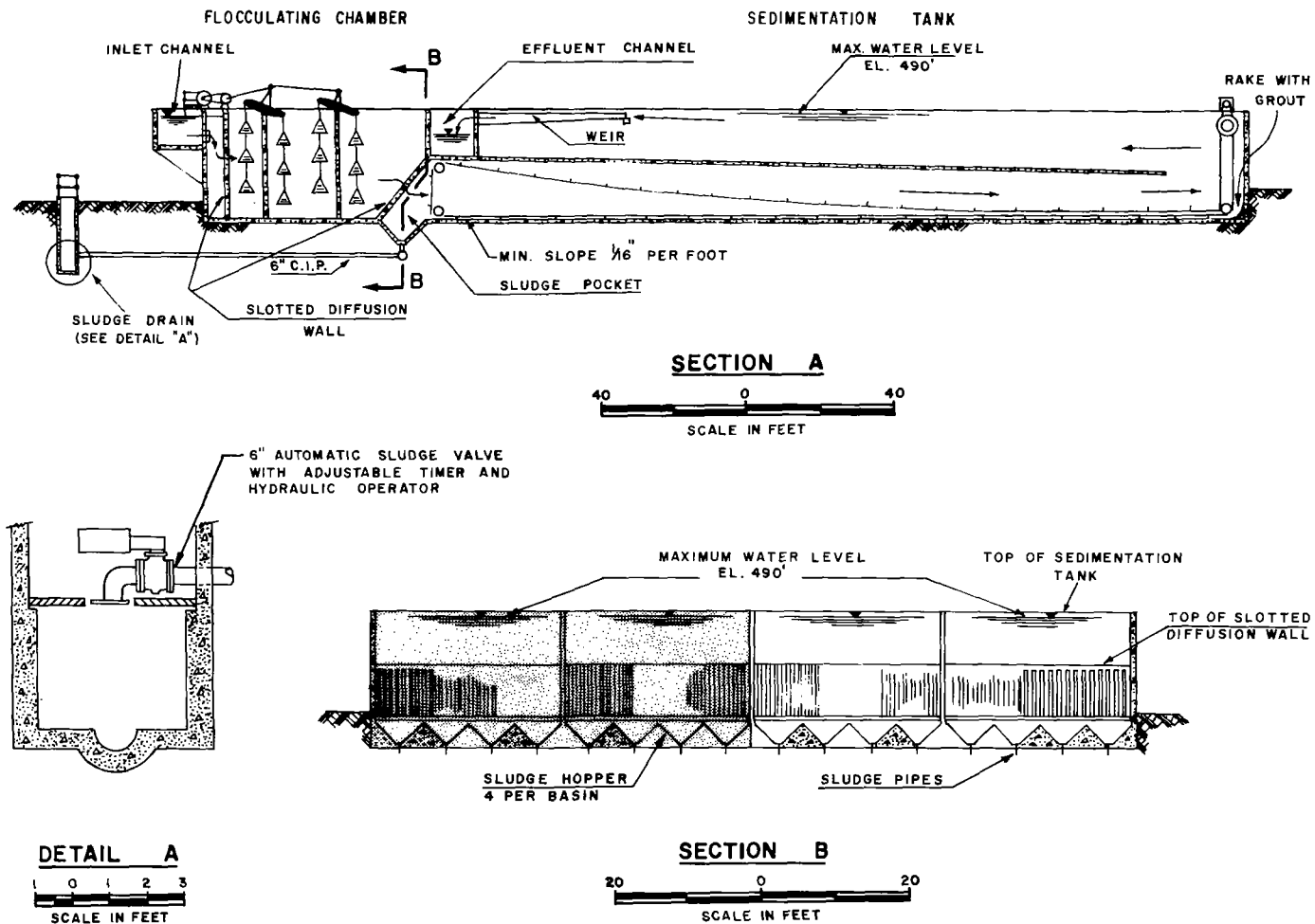
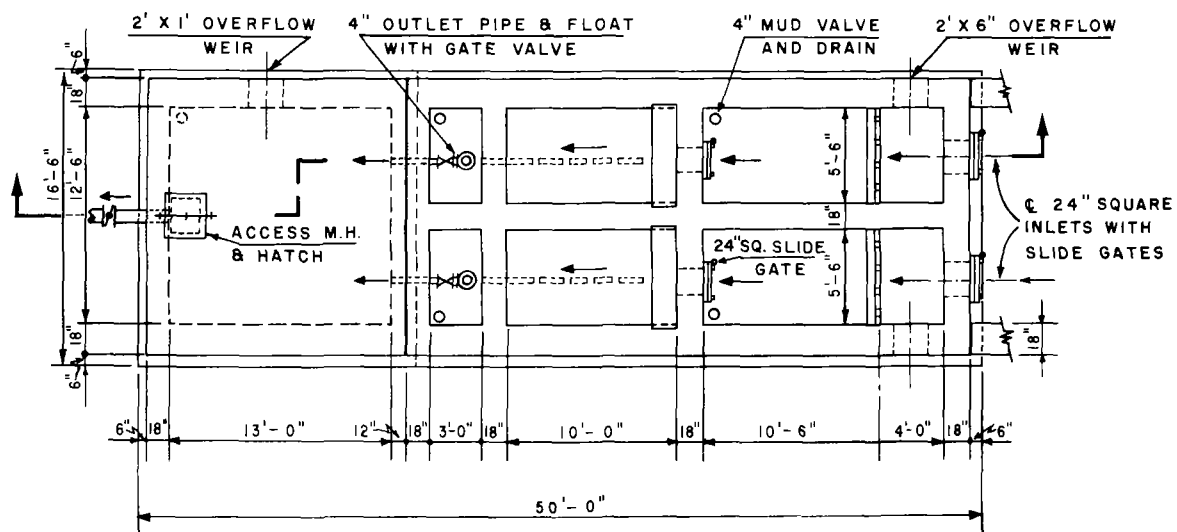
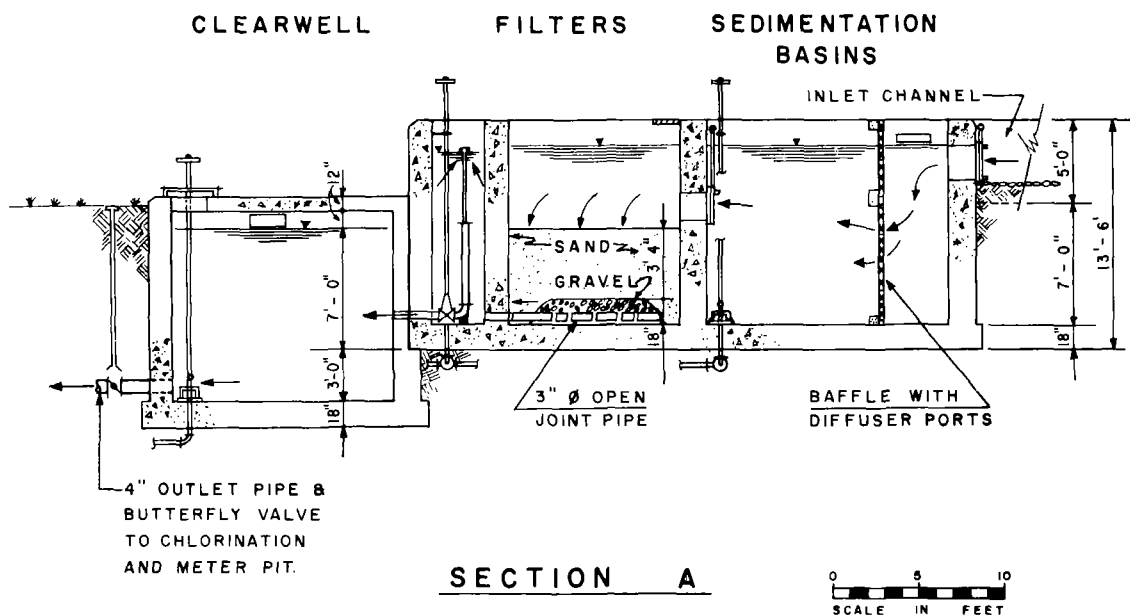


FIG. B-24 OROPOUCHE WATER TREATMENT PLANT — SECTIONS



PLAN



SECTION A

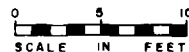
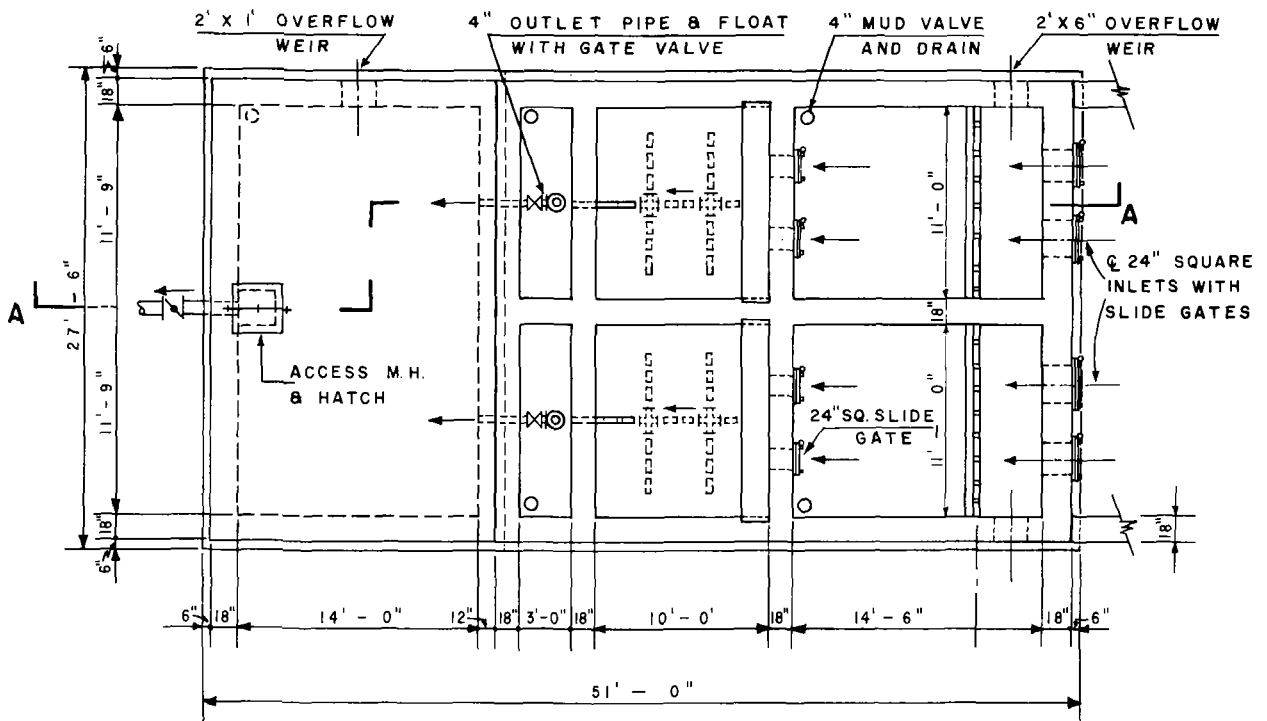


FIG. B-25 TYPICAL 10,000 GPD SLOW SAND FILTER



PLAN

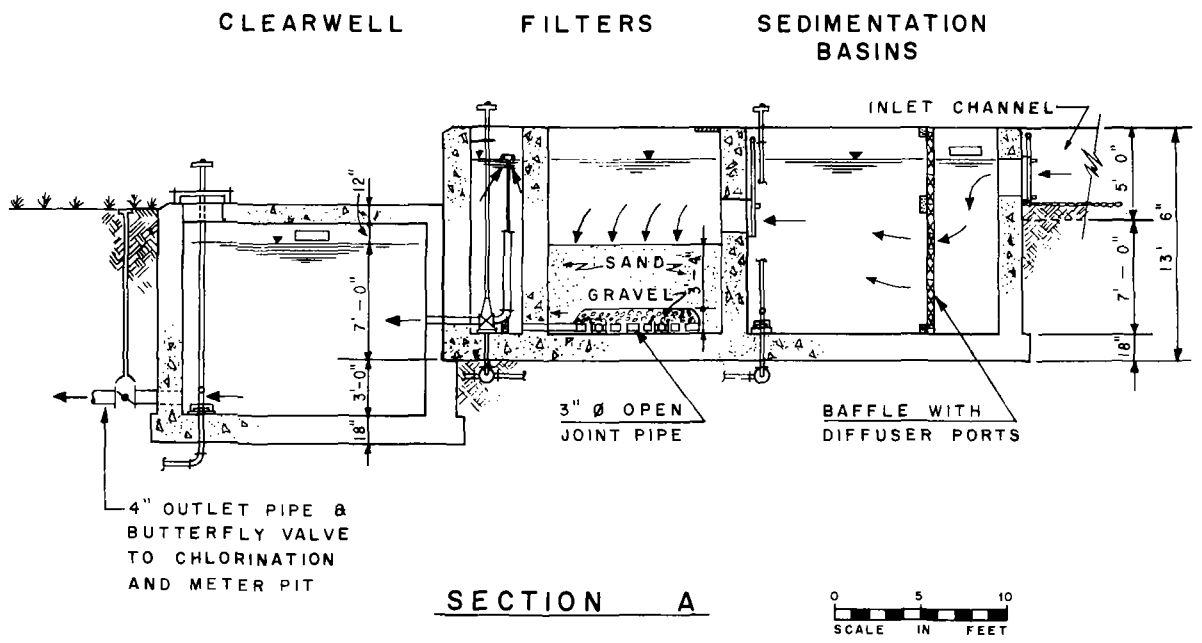
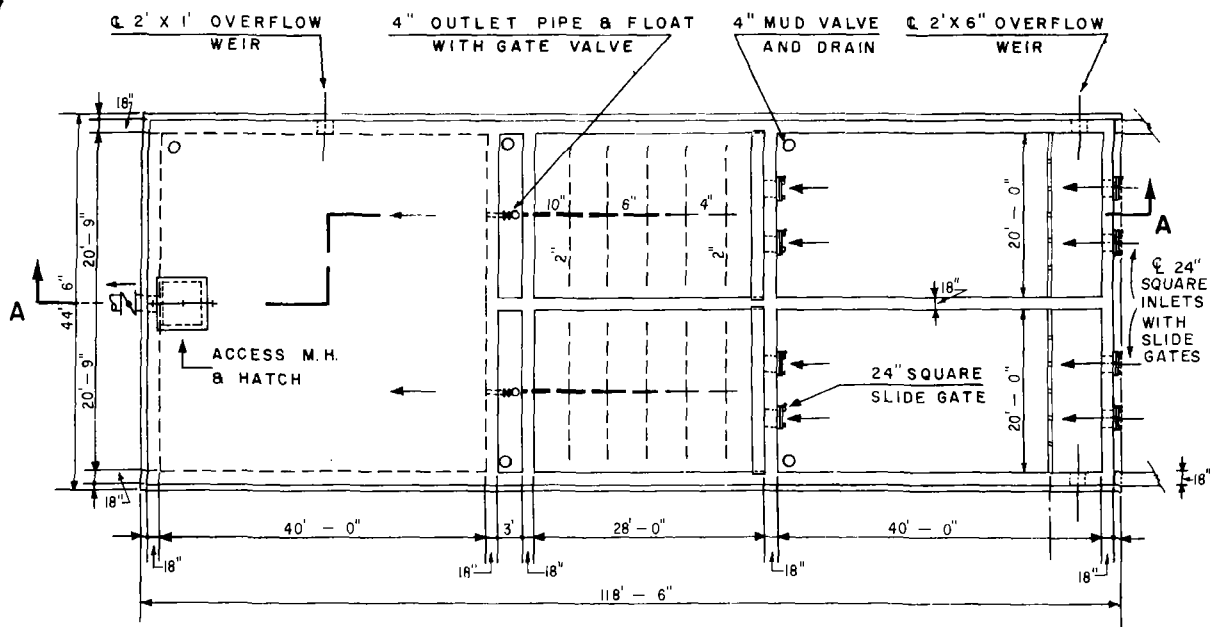
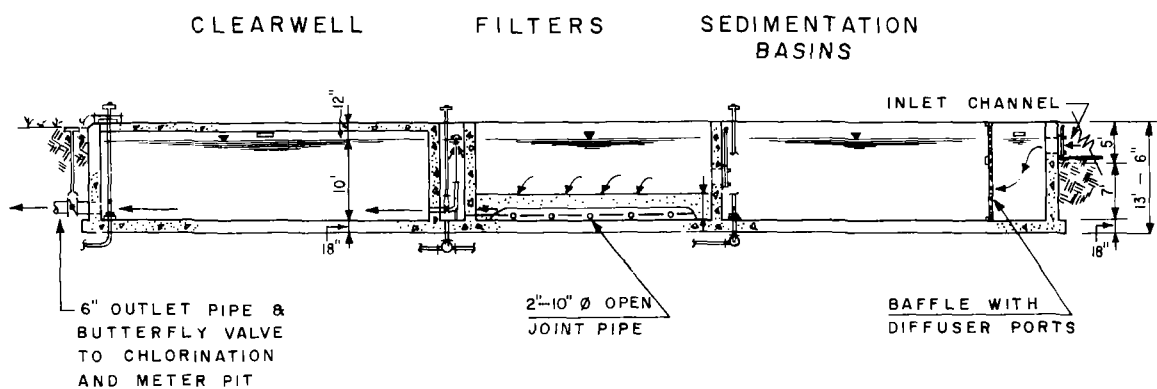


FIG. B-26 TYPICAL 20,000 GPD SLOW SAND FILTER



PLAN



SECTION A



FIG. B-27 TYPICAL 100,000 GPD SLOW SAND FILTER

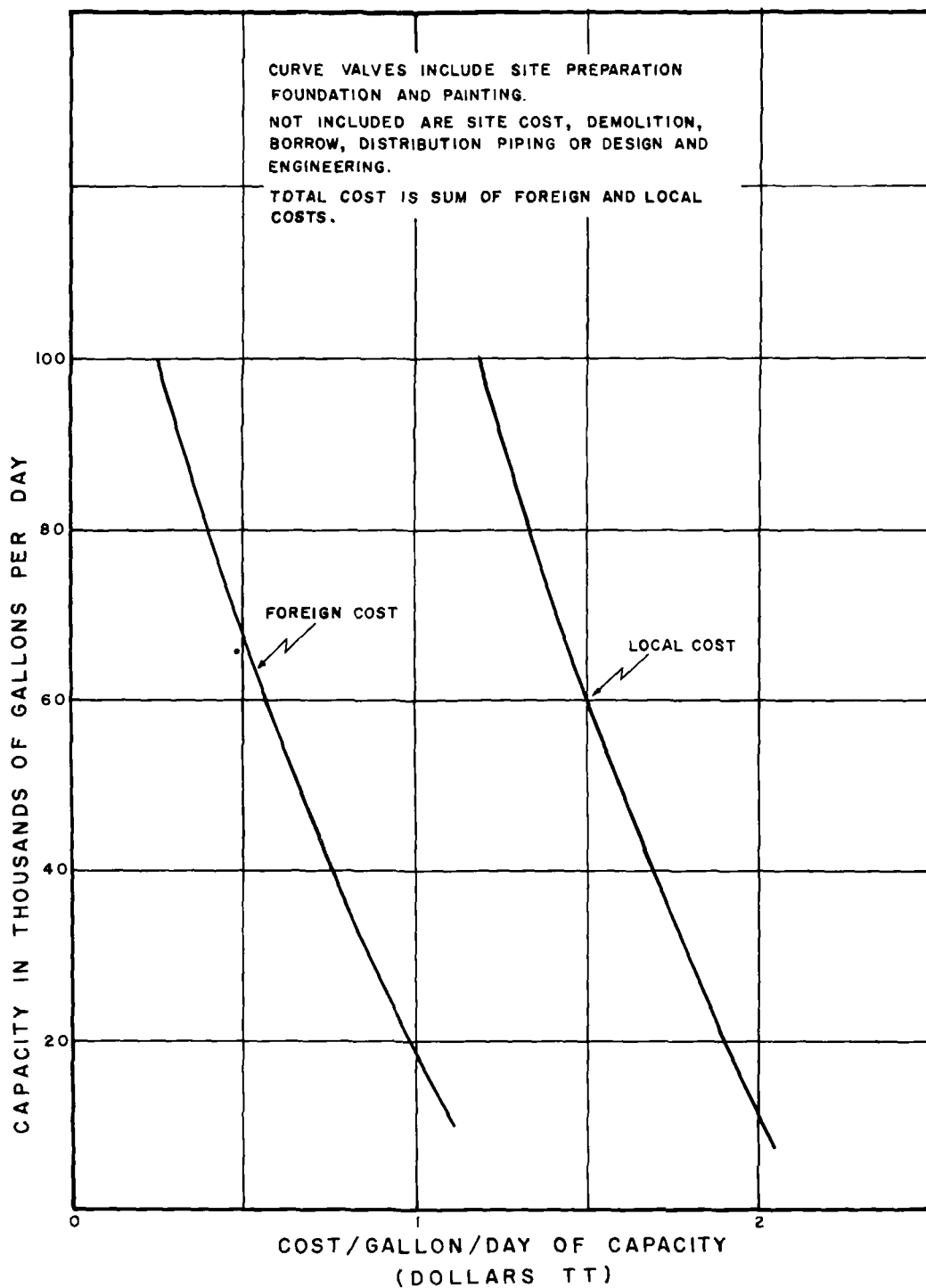


FIG. B-28 COST OF SLOW SAND FILTER PLANTS

APPENDIX C

APPENDIX C

TERMS OF REFERENCE FOR FINAL DESIGN

General

The agreement authorizing the study contains the following provision: "Terms of reference will be presented for the work necessary for the preparation of the final engineering plans. These terms of reference should specify in detail every piece of field work that will be necessary and all the documents and plans that will comprise the final engineering project." This appendix contains these terms of reference.

Two alternate sets of projects have been considered for inclusion in the first-stage program. The first set is the alternative program and includes the Navet pumped-storage scheme plus the North Oropouche dam and transmission mains; the second set is the recommended program. It includes the Navet pumped-storage and the Caroni-Arena projects.

Terms of reference have been developed and are presented for each project.

Engineering Services — Oropouche Project

Design Phase.

1. Preparation of contract documents for detailed topographic surveys of sites or routes for:

- a. Oropouche dam and appurtenances.
- b. Oropouche reservoir below flow line.
- c. Oropouche water treatment plant and appurtenances.
- d. Oropouche raw-water pumping station and appurtenances.
- e. The transmission mains indicated on Figure 25 for construction by 1975.
- f. California reservoir and appurtenances.

2. Preparation of contract and bidding documents for subsurface explorations for the following facilities:

- a. Oropouche dam and appurtenances.
- b. Oropouche water treatment plant and appurtenances.
- c. Oropouche raw-water pumping station and appurtenances.
- d. The transmission mains indicated on Figure 25 for initial construction (by 1975).

3. Preparation of contract documents for furnishing qualified personnel for on-site laboratory and off-site laboratory for the testing of soils samples taken by the subsurface exploration contractors.

4. Monitoring the subsurface explorations and interpreting the soil test results.

5. Design of, and preparation of contract and bidding documents and construction cost estimates for, the following facilities:

- a. Oropouche dam and appurtenances.
- b. Oropouche water treatment plant and appurtenances.
- c. Oropouche raw-water pumping station and appurtenances.
- d. California distribution reservoir and appurtenances.
- e. The transmission mains indicated on Figure 25 for construction by 1975.

6. Preparation of bills of materials and equipment and purchase specifications and bidding documents for international tenders to supply the materials of foreign manufacture necessary to construct the above-listed facilities.

7. The Engineer shall give particular attention to the following in connection with Oropouche dam design:

- a. Stability of the proposed structure under earthquake conditions (magnitude of 7.5 on Richter scale).
- b. Possibility of over-topping by waves generated by either landslides or seismic forces.
- c. The types of materials available and the time schedule under which the dam will be constructed.
- d. The Engineer shall retain one or more consultants who are recognized authorities on design and construction of large rock-fill dams in deeply weathered rock environments, such consultants to review exploration, concept and final design, tendering comments and recommendations at each stage.
- e. Hydraulic model tests of the spillway structures with particular emphasis upon erosion problems and capacity.*

8. In connection with the Oropouche water treatment plant design, the Engineer shall give particular attention to the following:

- a. Dependability of power supply to assure continuous operation or minimize shutdowns.
- b. Provision of on-site chemical storage capacity sufficient to meet plant needs for a period of at least 6 months.
- c. Provision of quarters for resident staff.
- d. Provision of adequate access to the plant by large trucks delivering chemicals.
- e. Provision for unloading trucks, including special cranes for chlorine cylinders and fork-lift trucks, both hand trucks and electric powered.

**The Engineer would arrange for the model tests with a reliable hydraulic laboratory and said tests would be performed under direct contract to WASA (separate contract).*

Bidding Phase.

1. Provision of 100 copies of each set of contract drawings, specifications, and other bidding documents for each project.
2. Review of all written questions received from prospective bidders during the bidding period and issuance to all bidders prior to the due date for bids of any addenda deemed appropriate in response to said questions.
3. Review of at least the two lowest bids submitted for each project and submission of a recommendation regarding award of each contract.

Construction Period.

1. Review and approval of shop drawings submitted by the contractors.
2. Provision of main office back-up for resident representatives.
3. Provision of resident representatives to monitor the various contractors' work.
4. Review and approval of the quantity surveyor's progress payment estimates.

Field Work — Oropouche Project

In general, the field work required for the final engineering plans consists of survey and subsurface exploration for the impounding structures, reservoir, and treatment facilities. The impounding structures consist of the main dam, spillway, diversion structure, inlet works, and dikes. The reservoir consists of the watershed area, principally the area below the flow line. The treatment facilities consist of the treatment plant, pumping station, access roads, and all interconnecting pipelines. Field work for transmission mains is discussed in a later section of this appendix.

It is envisioned that several camps would be set up to provide quarters, storage, laboratory, and field office spaces to conduct the work more efficiently in the short dry season. The main camp should be located at the

site of the present WASA field survey camp adjacent to the Oropouche River just above the proposed dam site. The camp would contain quarters for all survey and drill crews as well as for supervisory personnel, storage space for dynamite and spare equipment, soil laboratory for performing the necessary soil tests on samples as they are extracted from the borings, and offices needed in connection with this work.

The required tasks are outlined below.

Survey.

1. Conduct a complete topographic survey of the reservoir area and prepare a topographic plan at 1:2400 scale with a contour interval of 10 feet.
2. Prepare a land acquisition map showing in detail the ownership of all land parcels affected by the dam, reservoir, pumping station, treatment plant, and interconnecting pipelines at a scale of 1:2500.
3. Establish monumented vertical and horizontal control and lay out baselines as required.
4. Prepare complete detailed topographic plans at 1:600 scale with 2-foot contours covering the following structures:
 - a. Dam site and spillway.
 - b. Inlet works.
 - c. Diversion structure.
 - d. Dike areas.
 - e. Treatment plant.
 - f. Pumping station.
 - g. Access roads.
 - h. Quarry sites.

5. Conduct a perimeter survey of the reservoir flow line, noting any thin ridges or other detrimental topographic features. Thin ridges or areas which may require design of reservoir wall protection shall be surveyed with sufficient coverage to produce 1:600 scale topography for preparation of design drawings.

6. Lay out all boreholes and geophysical survey lines prior to subsurface exploration. Prepare plots of the final location of the borings on 1:600 scale topographic base.

7. Make any additional traverses, topographic survey, or field stake out required to produce the final design drawings.

8. All survey data shall be taken in such a manner that data reduction and plotting can be done by digital computer. In addition, all field survey data shall be taken in a form suitable for earthwork design by digital computer.

Subsurface Investigation.

1. Test borings shall be made by an experienced drilling contractor who can demonstrate recent experiences on projects of similar type and size. He should be able to supply at least 4 rigs in good repair with suitably experienced crews to run them.

2. Machines and crews shall be capable of efficient drilling and careful sampling in soft fine-grained soil and of maximum recovery of cored sound and decomposed rock. It is anticipated that, in addition to Standard Penetration Tests, undisturbed samples will have to be taken of a size suitable for laboratory testing.

3. Test borings are anticipated to be not less than 2-1/2 inches in diameter in soil and not less than 3 inches in diameter in rock.

4. The following structures will require test borings for final design:

- a. Main dam and spillway.
- b. Dike.
- c. Inlet structure.

- d. Diversion structure.
- e. Pumping station.
- f. Treatment plant.
- g. Access roads.
- h. Unstable areas around reservoir or dam site.
- i. Quarry.
- j. Borrow areas.

5. In addition to the test borings, it is recommended that the thin ridge areas in the vicinity of the main dam and any other similar areas as well as the quarry site be explored by geophysical methods. The work should be contracted as professional services to a reliable firm specializing in shallow seismic surveys for civil engineering purposes that can demonstrate recent experience in deeply weathered rock environments.

6. Tests on soils sampled in the boring program are required to determine values for the physical characteristics of the in-place soil to be used in the final design. The laboratory should be located in close proximity to the job site so that samples, particularly undisturbed samples, can be tested soon after extraction with as little disturbance as possible. The laboratory work should be contracted to a firm of recognized standing in the field of soil testing and be performed under the direction of a qualified soil engineer.

Engineering Services — Caroni-Arena Project

Design Phase.

1. Preparation of contract documents for detailed topographic surveys of sites or routes for:

- a. Arena dam and appurtenances.
- b. Arena reservoir flow line.

- c. Caroni water treatment plant and appurtenances.
- d. The transmission mains indicated on Figure 37 for initial construction.
- e. San Rafael and Kelly raw-water pumping stations and appurtenances.
- f. California distribution reservoir and appurtenances.

2. Preparation of contract and bidding documents for subsurface explorations for the following facilities:

- a. Arena dam and appurtenances.
- b. Caroni water treatment plant and appurtenances.
- c. California distribution reservoir and appurtenances.
- d. San Rafael and Kelly water pumping stations and appurtenances.
- e. The transmission mains indicated on Figure 37 for initial construction.

3. Preparation of contract documents for the testing of soil samples taken by the subsurface exploration contractors.

4. Monitoring the subsurface explorations and interpreting the soil test results.

5. Design of, and preparation of contract and bidding documents and construction cost estimates for, the following facilities:

- a. Arena dam and appurtenances.
- b. Caroni water treatment plant and appurtenances.
- c. San Rafael and Kelly water pumping stations and appurtenances.

- d. California distribution reservoir and appurtenances.
- e. The transmission mains.

6. Preparation of bills of materials and equipment and purchase specifications and bidding documents for international tenders to supply the materials of foreign manufacture necessary to construct the above-listed facilities.

7. The Engineer shall give particular attention to the following in connection with Arena dam design:

- a. Stability of the proposed structure under earthquake conditions (magnitude of 7.5 on Richter scale).
- b. Possibility of over-topping by waves generated either by landslides or seismic forces.
- c. Hydraulic model tests of the spillway structure with particular emphasis upon erosion problems and capacity.*

8. In connection with the Caroni water treatment plant design the Engineer shall give particular attention to the following:

- a. Dependability of power supply to assure continuous operation or minimize shutdowns.
- b. Provision of on-site chemical storage capacity sufficient to meet plant needs for a period of at least 6 months.
- c. Provision of quarters for resident staff.
- d. Provision of adequate access to the plant by large trucks delivering chemicals.
- e. Provision for unloading trucks, including special cranes for chlorine cylinders and fork-lift trucks, both hand trucks and electric-powered.

**The Engineer would arrange for the model tests with a reliable hydraulic laboratory and said tests would be performed under direct contract to WASA (separate contract).*

Bidding Phase.

1. Provision of 100 copies of each set of contract drawings, specifications, and other bidding documents for each project.
2. Review of all written questions received from prospective bidders during the bidding period and issuance to all bidders prior to the due date for bids of any addenda deemed appropriate in response to said questions.
3. Review of at least the two lowest bids submitted for each project and submission of a recommendation regarding award of each contract.

Construction Period.

1. Review and approval of shop drawings submitted by the contractor.
2. Provision of main office back-up for resident representatives.
3. Provision of resident representatives to monitor the various contractor's work.
4. Review and approval of the quantity surveyor's progress payment estimates.

Field Work – Caroni-Arena Project

The field work required for the final engineering plans consists of survey and subsurface exploration for the impounding structures, reservoir, and treatment facilities. The impounding structures consist of a 70-foot high dam, spillway, diversion structure, and inlet works. The reservoir consists of the watershed area, principally the area below the flow line. The treatment facilities consist of the treatment plant, which will be close to the Kelly Headworks, the San Rafael pumping station, access roads, and interconnecting pipelines.

In the case of the Arena dam, it will not be necessary to establish a camp for survey, exploration, and testing activities in view of the proximity of the proposed dam to the main centers of population concentration and the short travel time involved. One building will, however, be required to provide accommodations for a soil laboratory for performing the necessary soil and materials tests.

In contrast with the North Oropouche dam, considerably more attention to the foundation and abutments of the dam and spillway are required in view of the relatively low strength of the underlying silts and clays.

The required tasks are outlined below.

Survey.

1. Conduct a complete topographic survey of the reservoir area and prepare a topographic plan at 1:4800 scale with a contour interval of 5 feet.
2. Prepare a land acquisition map showing in detail the ownership of all land parcels affected by the dam, reservoir, treatment plant, San Rafael pumping station, and interconnecting pipelines at a scale of 1:2500.
3. Establish monumented vertical and horizontal control and lay out baselines as required, utilizing to the fullest extent possible the Trinidad and Tobago Lands and Surveys control grid.
4. Prepare complete detailed topographic plans at 1:600 scale with 2-foot contours covering the following structures:
 - a. Dam site and spillway.
 - b. Inlet works.
 - c. Diversion structure.
 - d. Treatment plant.
 - e. Pumping station.
 - f. Access roads.
 - g. Borrow site.
5. Conduct a perimeter survey of the reservoir flow line, noting any thin ridges or other detrimental topographic features. Thin ridges or areas which may require design of reservoir wall protection shall be surveyed with sufficient coverage to produce 1:600 scale topography for preparation of design drawings.

6. Lay out all boreholes, test sections, and instrument locations prior to subsurface exploration. Prepare plots of the final location of the borings, test sections, and instrumentation on 1:600 scale topographic base.

7. Make any additional traverse, topographic survey, or field stake out required to produce the final design drawings.

8. All survey data shall be taken in such a manner that data reduction and plotting can be done by digital computer. In addition, all field survey data shall be taken in a form suitable for earthwork design by digital computer.

Subsurface Investigation.

1. Test borings shall be made by an experienced drilling contractor who can demonstrate recent experiences on projects of similar type and size. He should be able to supply at least 3 rigs in good repair with suitably experienced crews to run them.

2. Machines and crews shall be capable of efficient drilling and carefully sampling in soft fine-grained soil. It is anticipated that a large number of undisturbed samples will have to be taken of a size suitable for recovery of soil for laboratory testing. In addition, test sections of surcharge with installation of piezometers and settlement plates may be required as well as observation wells and slope indicators. The installations of these sections and instrumentation should be performed by the test boring contractor under the direction of a qualified soil engineer.

3. Test borings are anticipated to be not less than 2-1/2 inches in diameter in soil and not less than 3 inches diameter in rock.

4. The following structures will require test borings for final design:

- a. Main dam and spillway.
- b. Inlet structure.
- c. Diversion structure.
- d. Treatment plant and intake at Kelly Village.
- e. Raw-water intake and pumping station at San Rafael.

- f. Access roads.
- g. Unstable areas around reservoir or dam site.
- h. Borrow areas.

5. Tests on soils sampled in the boring program are required to determine values for the physical characteristics of the in-place soil to be used in the final design. The laboratory should be located in close proximity to the job site so that samples, particularly undisturbed samples, can be tested soon after extraction with as little disturbance as possible. The laboratory work should be contracted to a firm of recognized standing in the field of soil testing and be performed under the direction of a qualified soil engineer.

Engineering Services — Navet Pumped-Storage Project

Design Phase. Design and prepare plans, specifications, documents for tender, and construction cost estimates for the following facilities:

- 1. Low dam, spillway, and mudgate.
- 2. Intake and pumping station.
- 3. Pipeline and outlet into present reservoir.
- 4. Slope protection as required.
- 5. Booster pumping station at Malgretoute.

Consider types of dam (earth, rockfill or concrete), slope protection (riprap, soil cement, or asphalt cement), and cut-off trench or grout curtain.

Field Work — Navet Pumped-Storage Projects

The field work required for the final engineering plans consists of survey and subsurface exploration for the impounding structure, reservoir, and pumping facilities. The impounding structure consists of the dam, stilling basin, check dam, and intake works. The reservoir consists of the watershed below the flow line. The pumping facilities consist of the pumping station, associated pipelines, and access roads.

Consider whether the work can be done most efficiently by setting up a field camp near the Navet Water Treatment Plant and conducting all survey, exploration, and testing from the camp. The camp would contain quarters for all survey crews, drill crews, supervisory personnel, and a soil laboratory to perform the necessary soil tests.

The required tasks are outlined below.

Survey.

1. Conduct a complete topographic survey of the reservoir area and prepare a topographic plan at 1:4800 scale with a contour interval of 5 feet.
2. Prepare a land acquisition map showing in detail at a scale of 1:2500 the ownership of all land parcels affected by the impounding structures, reservoir, pipeline, and pumping station.
3. Establish monumented horizontal and vertical control consistent with datum existing at the Navet Treatment Plant.
4. Prepare detailed topography, i.e. maps at 1:600 scale with 1-foot contours, covering the following structures:
 - a. Dam and spillway.
 - b. Pumping station.
 - c. Inlet and outlet works.
 - d. Access roads.
 - e. Pipeline route.
5. Conduct a careful perimeter survey of the flow line since low relief of basin causes large horizontal movements of flow line with small vertical changes in water surface.
6. Lay out all boreholes prior to subsequent exploration, prepare plots of the final location of borings on 1:600 scale topographic base.
7. Make any additional traverses, topographic survey, or field stakeout as required to produce the final design drawings.

Subsurface Investigation.

1. Test borings shall be made by an experienced drilling contractor. He should be able to supply at least two rigs in good repair with suitable experienced crews to run them.

2. Machines and crews shall be capable of efficient drilling and sampling in soft fine-grained soil and decomposed rock and of maximum recovery in cored rock. It is anticipated that undisturbed samples will have to be taken of a size suitable for laboratory testing.

3. Test borings are anticipated to be not less than 2-1/2 inches in diameter in soil and not less than 3 inches in diameter in rock.

4. The following structures will require test borings for final design:

- a. Dam and spillway.
- b. Stilling basin.
- c. Bank protection areas.
- d. Pipeline.
- e. Pumping station.
- f. Access roads.
- g. Borrow areas.
- h. Malgretoute pumping station.

5. The impoundment is in an area of highly erosive soils which will be subject to rapid movement with only subtle changes in stream regimen. It is felt that a careful hydrologic study should be made to determine the effect of the proposed change on the basin soils so that proper final design of the pumped-storage system with adequate protection of facilities and basin can be achieved.

6. Tests on soils sampled in the boring program are required to determine values for the physical characteristics of the in-place soil to be used in the final design. The laboratory should be located in close proximity

to the job site so that samples, particularly undisturbed samples, can be tested soon after extraction with as little disturbance as possible. The laboratory work should be contracted to a firm of recognized standing in the field of soil testing and be performed under the direction of a qualified soil engineer.

Field Work — Transmission Mains

The field work required for the final engineering plans consists of aerial photographic survey, ground survey, and subsurface exploration for the installation of large-size water mains from the water source at Oropouche to the distribution centers of Port of Spain and San Fernando.

It is anticipated that the field work would be done in the dry season from March through May. Some of the profile work has been done by WASA, especially through the forested section from the treatment plant area to Valencia Road. The rest of the route lends itself very nicely to photogrammetric survey.

The required tasks are outlined below.

Survey.

1. Contract for aerial photographic survey of the pipeline route from the point of intersection of the treatment plant access road west to the various termini. The contract should include all services from establishment of ground control to ultimate production of strip topographic coverage of the pipeline route on transparent plan and profile drawing sheets at 1:600 scale for congested areas, and 1:1250 for relatively open country. The contract should be made with a survey firm of recognized standing in preparation of topographic maps from aerial photographs.

2. The photogrammetric maps shall be suitable for preparation of land acquisition maps at a scale of 1:2500.

3. Field survey will be required for all stream crossings, boring locations, existing underground utilities, and miscellaneous route study as necessary.

Subsurface Investigation

1. Test borings shall be made by an experienced drilling contractor who can demonstrate recent experience on projects of similar type and magnitude. Due to the length of the pipeline and the relatively short dry season it will be necessary for the contractor to supply a minimum of 4 rigs and crews.

2. Test borings should consist of two types of borings: auger borings and drive-sample borings. Auger borings will be used as a rapid means of determining the nature of the subsurface material along the pipeline route. The drive-sample borings will be used for obtaining specific foundation design information at stream crossings and special design sections.

3. In addition, special borings may be required in areas of extremely soft soils where undisturbed samples will be taken and vane shear tests conducted.

4. Tests on soils samples in the boring program are required to determine values of the physical character of the in-place soil for use in final design. The laboratory work should be contracted to a firm of recognized standing in the field of soil testing and be performed under the direction of a qualified soil engineer.

5. The following type areas will require test borings for final design:

- a. Major stream crossings.
- b. Major highway crossings.
- c. Areas of soft soil such as swamps.

Corrosion Control

1. Final design of the corrosion control of the pipeline will require soil resistivity measurements along the route of the pipeline. Since this is a very specialized field, the engineer should retain a recognized authority in the field of corrosion control in relation to pipelines.

2. The consultant should conduct the necessary field investigation, make design recommendations, including specifications, and review the final design with respect to the suitability of the overall corrosion protection system.

3. The consultant's recommendations on corrosion protection will consider such things as the availability of protection and the labor skills required for installation.

Contract Documents

The contract documents shall be sufficiently complete to provide all the information necessary to obtain international tenders for the proposed work. They shall include information normally furnished under the following sections:

Notice to Contractors

Information for Bidders

Bids

Agreement

Contract Bonds

General Conditions

Special Conditions

Detailed Specifications

Appendix

Notice to Contractors. This shall begin the form of an advertisement required for publication inviting bids for the construction work. It shall contain all the information needed by the prospective bidders to understand the location and scope of the project. Certain additional details and the location where documents may be procured shall also be included.

Information for Bidders. This section shall give additional information necessary for the bidder to prepare his bid, including the location and date of the bid opening, time for completion of the work, and other detailed requirements and conditions governing the submission of bids.

Bids. This section of the documents provides a schedule of items with appropriate blanks for insertion of the itemized bid figures by the prospective bidders. It also contains certain conditions governing the basis for bidding, including the time requirements for completion of the work.

Agreement. This section sets forth in detail the legal basis for the agreement between the owner and the contractor and defines the legal and technical commitments of both parties with regard to the execution of the work, and payment therefore.

Contract Bonds. This section sets forth the requirements of the bonds for performance and labor and materials.

General Conditions. This section specifies the general conduct of the work, including specific instructions and operating procedures common to contracts of like character. It includes material sampling and inspection procedures, shop drawing requirements, rules governing contractors' operations, safety and sanitary requirements, provisions for laying out the work and definitions of the basis of payment and other general requirements governing the contractors' operations.

Special Conditions. This section sets forth in detail the data and conditions peculiar to the contract. These conditions include such items as liquidated damages, basis for progress estimates and money retained, insurance requirements and other special requirements of the project.

Detailed Specifications. These specifications describe the various classes of work to be performed, the types, kinds, and quality of materials and equipment to be furnished under the contract, and the required results. They also define the basis of payment for the work.

Appendix. This shall include additional reference information such as typical details, boring logs, and the like.

Contract Drawings

These drawings shall show sufficient detail to indicate clearly the types and extent of construction included in the contract. The designer should produce sheets which will include the following details in conformity with the following standards.

1. Drawings to be size 24-inch by 36-inch with standard title, revision, scale and approval block in lower right-hand corner.

2. Cover sheet with name of owner, agency, and principal officer; title of project; contract number; index of drawings; and title of engineering firm.

3. Sheet showing vicinity map, general notes, and legend. Quarry site and borrow pit locations to be shown on vicinity map if not in reservoir area.

4. Sheets showing topography of reservoir area, scale 1:4800, contour interval 5 feet, with outline of dam and spillway, dikes, reservoir rim protection, normal pool line, timber clearing limits, owner's property lines, existing buildings, access roads, and coordinate grid indicated thereon. Location of quarries and borrow areas to be indicated if in the reservoir area.

5. Sheets showing detailed topography of the following areas (scale 1:600, contour interval 2 foot):

- a. The damsite with plan of dam and spillway, outlet conduit (or tunnel), channels, dikes, gate structure (if applicable).
- b. Treatment plant sites with layout and grading plan of site, location of buildings, drainage of area, and access roads.
- c. Pumping station sites with plan and grading of area, inlet and outlet piping, drainage, and access roads.
- d. Service reservoir sites with location and grading plan, location of piping, drainage, and access roads.
- e. Housing areas with layout, grading, drainage, access roads, and sewage disposal.

- f. Pipeline routes with river, drains, and other utility crossings and location.

6. Sheets showing typical cross sections of dams, dikes, channels, treatment plants, pumping stations, service reservoirs, houses, pipelines, and access roads, together with all pertinent details. Scales as appropriate.

7. Sheets showing longitudinal profile of dams including ground and rock lines. Profile and typical cross section of tunnel (if applicable) at appropriate scales.

8. Sheets showing structural design and details of treatment plants, pumping stations, houses, service reservoirs, spillways, intake structures, outlet conduits, and gate structures. Scales as appropriate.

9. Sheets showing architectural design and details of treatment plants, pumping stations, houses, gate houses (if applicable), etc., at appropriate scales.

10. Sheets showing all mechanical and electrical details for all the above structures.

11. Sheet or sheets showing plan, profile, and details of any special pipeline crossings or supports. Scales as appropriate.

Other Considerations

The designer shall give careful consideration to dealing with unanticipated site and construction conditions.

Dams and Appurtenances – Changed Conditions. Despite preconstruction boreholes, test pits, seismic studies, and geological work, it is well known that subsurface conditions may be found which differ from those expected. The designer should do as much as possible to prevent such changed conditions from penalizing the contractor or causing excessive charges to the owner. Bid items for overbreak, extra depth excavation, and extra backfill with either concrete or other materials should be well defined and allow for reasonable prices, either preset or negotiated.

Information developed during the investigation does not appear to indicate that grouting will be required. After further investigation, the designer should design for cement or chemical grouting if required. The

designer should provide for test fills, either in the design stage or the construction stage, so that such items as compaction and gradation, roller sizes, types, and passes, as well as thickness of lifts and quantity of sluicing water, will be clearly defined and may be economically priced.

Instrumentation. It is recommended that the designer clearly define the required instrumentation and set up unit prices in the bill of quantities for such work so that the contractor will install such instrumentation as piezometers, observation wells, inclinometers, vertical cross arms, bench marks, surface reference points, horizontal extensometers, seismoscopes, etc. Description and estimated frequency of compaction, gradation, and any other required tests should be such as to enable the contractor to estimate and plan construction procedures.

Pipelines – Changed Conditions. Subsurface explorations for pipelines should, because of depths involved, more positively define existing conditions. However, the final design must include such items as found necessary to provide maximum protection for both parties to the contract.

Optimum locations for pipelines will be in areas where rock and excessively soft material are at a minimum and in public rights-of-way or on government property.

Pipelines should be laid in cut, never in fill, or placed on suitable foundations for overhead crossings. Side-hill cuts should be avoided if possible; if used, the geology and soil conditions of the area must be studied to determine the type of protection if any is required.

Buildings and Structures

The designer shall ensure that all buildings and structures to be erected will be able to withstand:

- (i) Seismic loads of a magnitude of 7.5 (Richter scale) from earthquakes off the northern coast and for adjustments along the Arima fault; and
- (ii) Winds of up to 60 miles per hour.

Standards

All plant, machinery, equipment, materials, fittings, and furnishings to be used shall conform to the applicable standards and specifications of the

following international societies and associations. Materials and equipment conforming to these standards have been successfully utilized in the past in Trinidad and Tobago.

The American National Standards Institute

British Standards Institution

American Water Works Association

American Society for Testing and Materials

National Electrical Manufacturers Association (U.S.).

Mr. Ponas
Compliments of

METCALF & EDDY INTERNATIONAL
INC.
ENGINEERS

JOHN J. SCHEUREN, JR.
VICE PRESIDENT

Jack

5 QUEEN'S PARK EAST
PORT OF SPAIN, TRINIDAD
TELEPHONE 34018

160/SF-7T
PRELIMINARY REPORT
TO

WATER AND SEWERAGE AUTHORITY
GOVERNMENT OF TRINIDAD AND TOBAGO
UPON

WATER FACILITIES

MARCH, 1970



METCALF & EDDY INTERNATIONAL, INC.

ENGINEERS

BOSTON • NEW YORK • PALO ALTO

PRELIMINARY REPORT

upon

THE LONG TERM PROGRAM

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METCALF & EDDY INTERNATIONAL

INC.
ENGINEERS 5 QUEEN'S PARK EAST, PORT OF SPAIN, TRINIDAD, W.I.

CABLE ADDRESS:- METEED - PORT OF SPAIN

28th. March, 1970

Mr. Wilfred D. Best,
Chairman of the Board of Commissioners,
Water and Sewerage Authority,
Government of Trinidad and Tobago,
Valseyn.

Dear Mr. Best:

We are pleased to submit this Preliminary Report covering surveys, studies, preliminary designs and recommendations concerning a long term program for development of water facilities in Trinidad and Tobago.

This report is the result of work performed in accordance with the provision of our Agreement dated 23 January, 1969.

I N T R O D U C T I O N

History

Previous to 1853 there were no organized water supply systems in Trinidad and Tobago. However, with the construction and commissioning of the Maraval waterworks in that year as a source of supply for the city of Port of Spain, the history of organization began. During the 1920s there was considerable activity in the development of supplies for the three main cities of Port of Spain, San Fernando and Arima in Trinidad, and for Scarborough in Tobago. By the end of the 1930s the Hollis waterworks had been developed and water from this source was piped to remote areas to the east, west and south.

There was much activity in the development of groundwater supplies during the early forties to provide the wartime requirements of the military and naval personnel of the British and American governments stationed in Trinidad at the time. The U.S. Forces provided for their own requirements and handed over all facilities to the local Government at the end of the war. At the end of the forties, total production was approximately 15 mgd. (million gallons per day) for a population of about 620,000.

In 1950 Government issued a council paper setting out its policy for the provision of an adequate supply of wholesome water for domestic and other uses for every inhabitant of the country at rates as low as possible. This council paper marked the beginning of a comprehensive program of development of the water resources of Trinidad and Tobago.

Implementation of the physical program commenced in 1953. By the middle of 1965, significant gains had been made. The development of new borehole fields, including in particular the El Socorro waterworks, together with the installation of a number of small intakes throughout the country had been completed, and the construction of the Navet waterworks was nearing completion. The new facilities increased daily production from 16 million gallons at the end of 1953 to 47 million gallons by mid-1965. Unfortunately, however, this increase in supply did not keep pace with the increasing demand, and Government took steps to expedite establishment of a single agency for the development and management of the country's water resources.

The Water and Sewerage Authority

In the Second Five-Year Plan, 1963-1968, the Government of Trinidad and Tobago declared its intention to establish a national Water and Sewerage Authority to take the place of the six agencies which at the time were individually responsible for the production and/or distribution of water, each within its own corporate or geographical boundaries.

With technical guidance provided by the Pan American Health Organization (PAHO), a Bill for the establishment of the new Authority was completed by the middle of 1965 and presented to Parliament. On 1st September 1965, Act No. 16 of 1965 establishing the Water and Sewerage Authority (WASA) as a statutory body was proclaimed.

The new Authority was added to the portfolio of the Minister of Public Utilities and became the sole agency responsible

for the development of the water resources of Trinidad and Tobago, the conservation and proper use of water, and the collection, treatment and disposal of sewage.

Purpose and Scope of the Study

Over the past decade the annual increase in water demand for domestic and industrial uses has constantly exceeded the annual increment to supply. Consequently a large deficit has developed and will continue to grow unless a significant addition to supply is made in the shortest possible time.

Shortly after the Navet waterworks was placed in operation during 1966, it became apparent that this supply was insufficient to do more than reduce the then deficit, and that water demand was developing faster than supply and transmission facilities were being increased.

Recognizing, therefore, that a major source was necessary and a comprehensive plan of development desirable, the Government of Trinidad and Tobago negotiated an Inter-American Development Bank (IDB) loan late in 1967 for part-financing of the needed Study, and WASA, the Executing Agency for Government, selected Metcalf & Eddy International Inc. to conduct the Study.

The "Description of the Project" calls for a far-reaching investigation of the production and distribution of water throughout Trinidad and Tobago as a basis for recommendations for the development of a system to meet the requirements of the Act which established the Authority. It also calls for an examination of WASA's

organizational structure and for proposals for strengthening it to provide for greater efficiency in the management of a growing complex.

Purpose and Scope of Present Report

Present water needs in Trinidad and Tobago are estimated at about 68 mgd, or about 8 mgd in excess of production of 60 mgd.

Water requirements for all purposes except irrigation are expected to be about 115 mgd by 1985, and 170 mgd by 2000. Short and long-term plans are therefore necessary prerequisites to the construction of the facilities required for the production and transport of water in sufficient quantities to meet these requirements.

This report covers the following:

1. Appraisal of existing facilities and systems;
2. Determination of existing and future requirements;
3. Identification of new sources of supply for development;
4. Arrangement of priorities;
5. Proposals for a program of immediate improvements;
6. Preparation of a long-term program of development;
7. Cost estimates, and
8. Revenue requirements and financing.

It is designed to serve two purposes. First, it sets out a comprehensive program of construction scheduled for parallel implementation of improvement works and the development of new sources, as a means of providing the population with an adequate supply of wholesome water for all purposes. Secondly, it provides

the required support to an application for a bank loan for part-financing of one or a set of projects contained in the program of construction deemed necessary to improve the situation.

Previous Reports

Numerous reports, old and new, directly and indirectly related to the development of the country's water resources have been obtained and perused. In general, the data collected dealt with such subjects as the geology of specific geographical areas throughout the country, rainfall, land use, population and other related subjects.

Useful background information was provided in the "Outline Report on Water Supply in Trinidad and Tobago - 1964" prepared by Ian G. de Verteuil, who at the time was Chief Technical Officer (Water) in the Ministry of Public Utilities, and who in 1965 became Superintendent Engineer (Water) in the newly established Water and Sewerage Authority. This report projected the country's requirements to 1980, and identified areas for development to meet those requirements.

Additional useful information was provided in two reports prepared by Howard Humphreys & Son, Consulting Engineers, of London, England. The two reports, "**Notes** on the Investigation into the Water Supply of Port of Spain, 1959-1960" and "Brief Notes on Impounding Potentialities in the Central Range of Trinidad" were published in 1962 and 1965, respectively. The contents of these reports are summarized in the titles.

By an agreement concluded between the Canadian Government and the Government of Trinidad and Tobago, M. M. Dillon Ltd.,

Consulting Engineers of London, Ontario, were engaged by the Canadian Government to conduct a Water Resources Survey in Trinidad between 1966 and 1969. Dillon's third report, dated December 1968, presented geological data on the Sum Sum sand aquifers and updated the previous two reports, which covered stream-gauging, rainfall and other aspects of the hydrological cycle. Their fourth report, dated August 1969, covered the northern gravel aquifers and updated previous reports.

We have studied the Preliminary Report submitted by PAHO after a month's study of WASA's operations in September 1968. We have reviewed the recommendations and have examined the extent to which they have been implemented to date.

A listing of the numerous other reports obtained and studied is given in Appendix A.

DESCRIPTION OF THE STUDY AREA

Geography

The area to which the study applies covers the islands of Trinidad and Tobago. The island of Trinidad lies approximately 8 miles off the northwestern corner of Venezuela on the South American continent. It is located about 10 degrees north of the equator between 61 and 62 degrees west longitude and is the southernmost island in the Caribbean Archipelago.

The sister island of Tobago lies northeast of Trinidad and is separated therefrom by a channel about 18 miles wide. It is situated about 11 degrees north of the equator at about 60 degrees west longitude.

Topography

The island of Trinidad is approximately 65 miles long by 48 miles wide with an area of about 1,863 square miles (See Figure 1). The physical features include three mountain ranges: the Northern Range which runs the full length of the northern coast, the Central Range which runs diagonally across the island in a northeasterly direction from California, a little more than halfway down the west coast, to Caigual in the east, and finally, the Southern Range which follows the southern coast in a broken line. The area between the Northern and Central Ranges is flat and comprises about 400 square miles. In the rest of the island, that is, between the Central and the Southern Ranges, the topography is broken and represents an irregular pattern of flat, partly rugged and partly mildly undulating terrain.

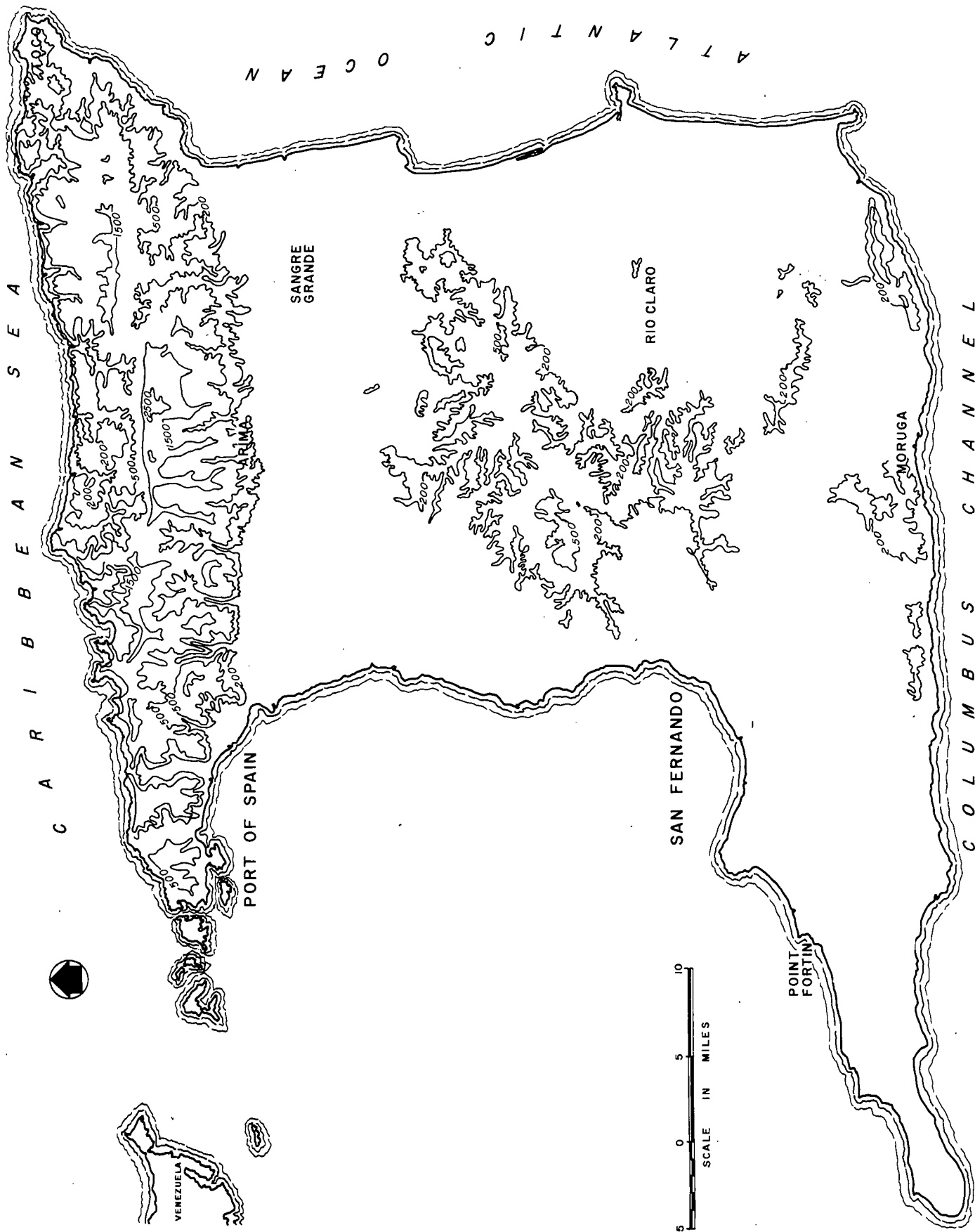


FIG. 1 RELIEF MAP OF TRINIDAD

METCALF & EDDY

The island of Tobago is some 32 miles long by 11 miles wide with an area of about 116 square miles. The topography of Tobago is broken with a chain of peaks running along the centre of the island. The highest point in the main ridge is about 1,880 feet above sea level (See Figure 2).

Climate

The climate of the two islands is tropical with two clearly defined seasons - the dry season and the wet season. The dry season begins in January and ends between mid-May and June first with March usually the driest month. The wet season begins in May or June and runs into December with July and August usually the wettest months. A dry period of about three weeks' duration occurs in September/October. This season is known as the "petit carême".

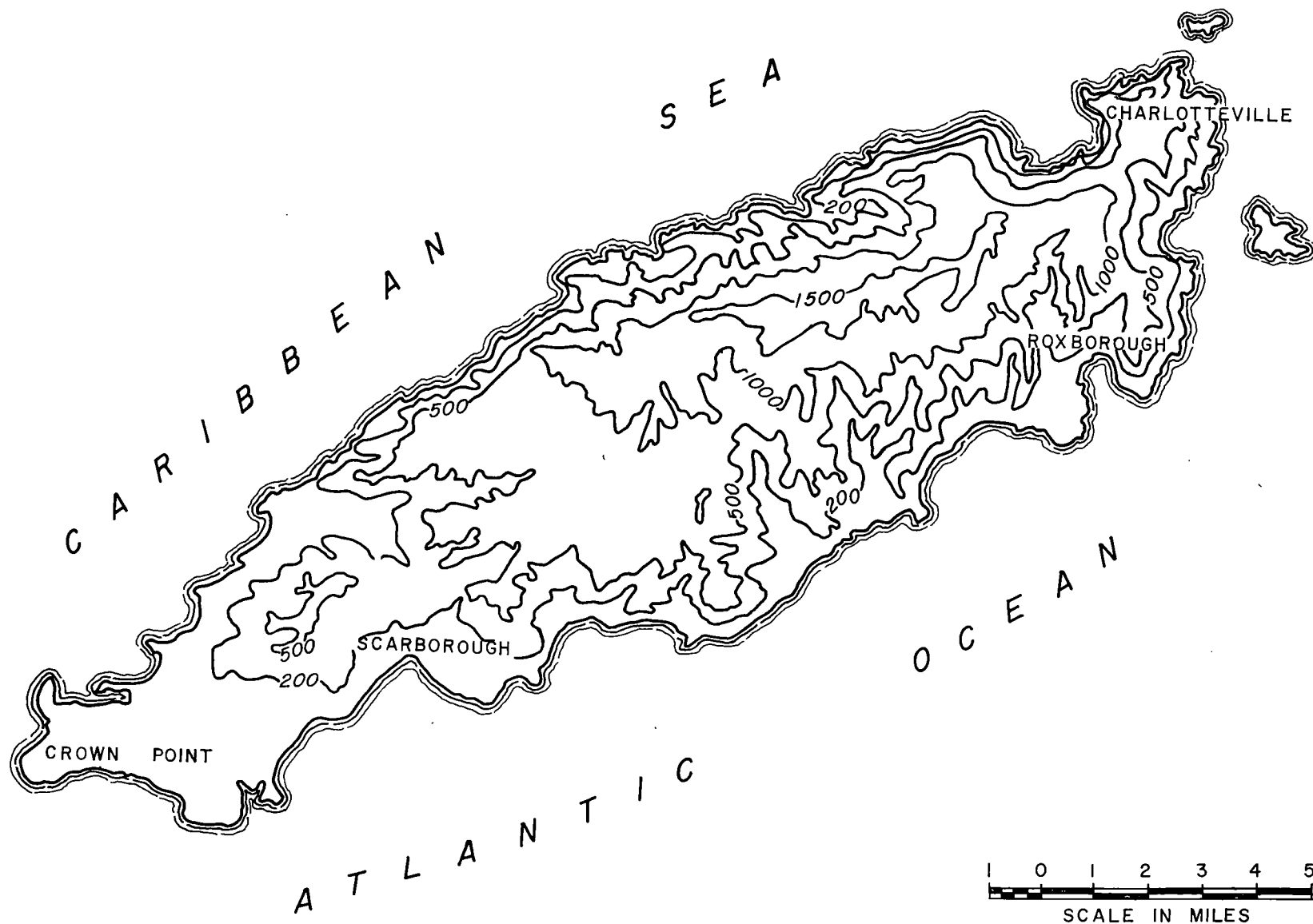
In Trinidad, precipitation is greater in the eastern half of the island than in the western half with the highest degree of intensity occurring in the eastern end of the Northern Range and the north-east end of the Central Range. In Tobago, precipitation is greatest in the higher elevations and near the centre of the island.

On both islands mean temperatures range between 71.4°F and 87.5°F. March and September are the hottest months of the year. During these months peak temperatures of 93° are often experienced.

Relative humidity ranges between 87 percent at 8:00 a.m. and 65 percent at 2:00 p.m.

Annual mean wind speed is approximately 6 miles per hour.

FIG. 2 RELIEF MAP OF TOBAGO



Highest velocities up to about 10 miles per hour occur during the months of March to May, inclusive, and wind direction shifts from southeasterly in April/May to northeasterly in November/December.

Land Use

Indications are that population densities will increase most significantly in the presently developed areas. Any dispersion will be the result of expansion of agricultural and industrial activity, and the location of housing estates.

Insofar as agriculture is concerned, activities under the Crown Lands Program are at present confined to the completion of developments at Waller Field and Carlsen Field while future plans will include large acreages distributed throughout Trinidad and Tobago.

In industry, as in agriculture, Government's efforts are being directed to the consolidation of existing estates throughout the country. The same approach is being taken by private developers who have established large industrial estates in north and south Trinidad.

In the field of housing development, Government is spending large sums of money on the construction of low-cost housing throughout Trinidad and Tobago. Private developers are also active in the development of sites for housing for the higher income brackets.

The provision of tourist facilities presents a slightly different picture in that they are planned for the coastline away from the centres of population. The development of hotels, marinas and bathing beaches bring into focus such places as Maracas Bay, Tyrico

Bay, Blanchisseuse, Toco, Chaguaramas, Carenage, Scotland Bay, Manzanilla and Mayaro in Trinidad, and the southwestern corner of Tobago.

The Economy

Up to the beginning of the twentieth century the economy of Trinidad and Tobago was essentially an agricultural economy in which the production of cane sugar played the dominant role with the cultivation of cocoa, coconuts and coffee playing lesser parts. However, with the discovery of oil early in the twentieth century and the stupendous growth in the drilling and refining operations that followed, the economy was quickly transformed into an oil economy with the production of cane sugar occupying second place in spite of a considerable increase in output during the same period.

Government derives thirty percent of its recurrent revenues from the oil industry. Petroleum products constitute eighty-three percent of the Country's gross exports and twenty-six percent of the Gross Domestic Product.

In the early sixties, however, a decline in the daily production of crude started and there was fear or suspicion of a significant depletion of reserves. There followed a reduction in drilling and refining activity and a consequent retrenchment in employment in the industry.

Economic Diversification. Fortunately, this turn of events did not immediately affect the industry's contribution to economic development, but it served to expedite implementation of

Government's long-considered plans for economic diversification.

The main aim of the policy of diversification was to reduce the degree of dependence upon the oil industry by intensive development of the other sectors of the economy while still encouraging continued development of the oil industry as evidenced in the intensification of off-shore drilling. Accordingly, in the Second and Third Five-Year Plans, respectively, 1963-1968 and 1969-1973, vast provisions were allocated for the development of agriculture, industrialization and tourism, mainly. The new strategy of economic development, as outlined in the Third Plan included:-

- 1 Greater exploitation of the mineral and agricultural resources of the country;
- 2 Increased manufacturing output; and
- 3 Expansion of service industries, with particular reference to tourism.

The Place of Water in the Economy. Development of the necessary climate for industrial expansion was another objective of both the Second and the Third Five-Year Plans, 1963-1968 and 1969-1973 respectively. Accordingly, large provisions were made for, inter alia, the construction of highways, the expansion of electricity generating capacity, and the expansion and modernization of telephone and telecommunication facilities.

Comparably large provisions were included in the social overheads for increasing the production of water primarily to meet increasing domestic requirements, but there was no doubt that the

provision of an adequate supply of water for all purposes was necessary for stimulating economic development.

EXISTING SYSTEMS

General

A clear understanding of the existing systems is essential for an appreciation of the nature of the problems involved and the reasons for the solutions proposed. This chapter presents a description of the existing facilities as well as those under construction. A more detailed description of the existing facilities appears in Appendix B.

Water Service Areas

For purposes of describing the existing water system, projecting future demands and recommending improvements, Trinidad and Tobago have been sub-divided into the areas and sub-areas shown on Figure 3. The boundaries of the sub-areas were made to coincide with WASA's administrative districts and areas, and the 15 water areas established by Mr. Ian de Verteuil in his reports of 1964 and 1968, so that the data for any one or more of the sub-areas could be combined to describe these areas also. In establishing the boundaries for the sub-areas, the following guide lines were used:

- (1) Topography;
- (2) Number of inter-connections to adjoining areas;
- (3) Proposed future improvements; and
- (4) Boundaries of existing administrative areas.

If desired, each area could be operated as a separate distribution system, and with the installation of a few meters, records of area consumption could be maintained. The regional or main areas

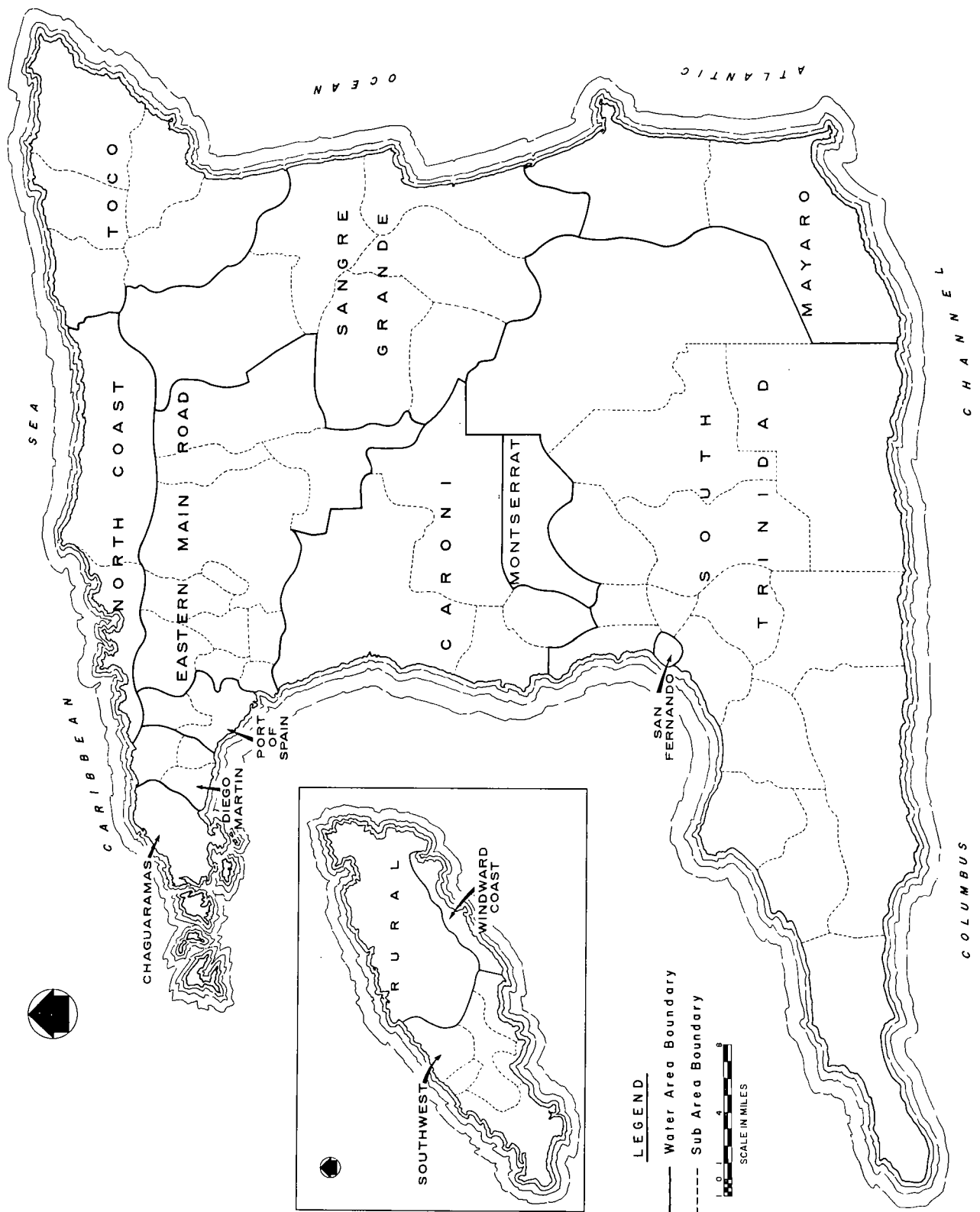


FIG. 3 WATER AREAS

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were selected on the basis of the availability of historical water use data. It is not intended that these areas should represent possible boundaries for operational areas.

Sources of Supply

Total production capacity at the beginning of 1970 was 60-mgd. Approximately 22 mgd came from surface water sources, and the remainder from groundwater sources. The earliest public water supplies in Trinidad and Tobago came exclusively from surface water sources. The use of groundwater was initiated shortly after World War II as a result of successful development of groundwater aquifers by the U.S. Forces then based in Trinidad.

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22/6

Surface Water Sources. Large-scale development of surface water has been limited to three rivers in Trinidad and Tobago. These are the Quare River in the Northern Range, and the Navet River in the Central Range in Trinidad, and the Hillsborough River in Tobago. The largest river systems in the country still remain undeveloped, except for limited withdrawals for irrigation, industrial use, and gravel-washing.

The Quare River is a tributary of the North Dropouche River, which drains to the east. The Hollis Dam in the upper reaches of the Northern Range forms an impoundment with a catchment area of 6.6 square miles. ^{17 km²} ^{21.5 sq km} The dependable yield of this source is 7 mgd. The Quare River downstream of the dam is also used as a source of supply. The flow at the point of withdrawal is approximately 1.5 mgd.

The Navet River has been developed in its upper reaches by

18.4 km²

an earth-fill dam and reservoir with a catchment of 7.2 square miles.

It was chosen for development on the basis of its location in relation to the demand in south Trinidad and suitability of the dam site.

Only a very small portion of the Hillsborough catchment area in Tobago has been developed. Here, where the demand was small, emphasis was placed on developing a supply at a high enough level to serve most of the distribution system by gravity.

Intakes have been constructed on many other small rivers and streams. Most of these intakes are located in catchment areas in the Northern Range of Trinidad where seepage from groundwater aquifers maintains substantial dry-season base flows. The principal rivers serving as sources for direct intakes, as well as those with impoundments, are listed in Table 1.

Table 1. Rivers Serving as Sources of Supply in Trinidad and Tobago

River	Catchment area, sq.m.	Dependable yield mgd.	Storage mg.
<u>Trinidad</u>			
Quare at Hollis Dam	6.6	7.0 ^{31,500 m³/d}	1,050 ^{4,700,000 m³ ≈ 3.900}
Quare at Intake	8.9	1.5	none
Navet at Dam	7.2	7.0 ^{31,500 m³/d}	4,200 ^{≈ 15,000 m³ 18,800,000 m³}
Maraval at Intake	3.2	1.5	none
St. Ann's at Intake	.7	0.2	none
Cascade at Intake	.4	0.1	none
Tompson at Intake	11.3	0.7	none
Tyrice at Intake	0.6	0.2	none
<u>Tobago</u>			
Hillsborough at Dam	.8	1.5	200
Courland at Intake	10.7	0.8	none

Water from the Northern Range is low in turbidity but tends to be high in dissolved solids. For example, the water from the Quare River has an average hardness of 130 mg/l (milligrams per liter). Total dissolved solids average 150 mg/l. Except following heavy rains, practically all the Northern Range sources are low in turbidity. Navet and Hillsborough water tends to be high in turbidity and colour all year round.

Groundwater Sources. The total groundwater potential of Trinidad is estimated at 72 mgd. The Authority has an existing borehole

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pumping rate of 38 mgd. Private groundwater supplies account for another 5 mgd. The Authority's groundwater potential has been developed from the seven aquifers listed in Table 2. The most extensive development has taken place in the Northern Valley and Alluvial Fan Aquifers in the north, and the Sum Sum and Durham Aquifers in Central Trinidad. A more complete description of these aquifers is given in the chapter "GROUNDWATER SOURCES".

Table 2. Groundwater Aquifers in Trinidad

Aquifer	Estimated yield, mgd	Existing borehole pumping rate, mgd
Northern Valleys	16	12
Alluvial Fan	17	17
Sum Sum	11	2
Durham	4	2
Limestone	2	less than 1
Erin-Morne L'Enfer	18	3
Mayaro Sandstone	<u>4</u>	less than <u>1</u>
Total	72	38

Water from the northern gravels is free of iron but high in carbon dioxide. In some areas it is used without treatment other than disinfection. Iron in excessive quantities is found in water from all the other groundwater aquifers.

Major Surface Water Facilities. There are three surface supply systems which are considered as major systems. They are the Navet and the Hollis systems in Trinidad, and the Hillsborough system in Tobago. Each of these systems consists of a dam and impounding reservoir, treatment facilities and an extensive transmission system.

The Navet impoundment is created by a 100-foot high earth-fill dam. A raw-water pumping station delivers water from an intake tower to a conventional water treatment plant rated at 12.0 mgd. Upflow clarifiers provide flocculation and sedimentation. Activated carbon is used for taste and odour control. From the treatment plant clearwell water flows by gravity through a 20-mile trunk main to San Fernando. The estimated dependable yield is 7 mgd. Production in 1969 exceeded the dependable yield by 3 mgd. The Navet system is the principal source of supply for San Fernando and south Trinidad.

The Hollis supply system is the second largest in Trinidad. This system was completed and brought into service in 1936. It consists of the Hollis Dam and Reservoir on the Quare River, a pressure-filter plant and a transmission network which originally carried water by gravity as far south as Penal. At present the Hollis system serves Port of Spain, the Eastern Main Road communities, Caroni and, on occasions, Sangre Grande. A booster pumping station has been added at Tunapuna to achieve maximum production. The station is used exclusively to pump to Port of Spain. What remains of the original transmission system south of Caroni has been incorporated into other supply systems.

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Supply, Treatment and Transmission Facilities

There are 66 separate water supply systems in Trinidad and Tobago. These systems range from the isolated rural intakes supplying less than 10,000 gpd (gallons per day) to the Navet waterworks and transmission system, which can produce and deliver up to 11 mgd at maximum output. Tables 3 and 4 list the supply systems and summarize the rural intakes under a single system. Table 5 lists the rural intakes separately. The major supply and transmission systems are shown on Figure 4.

Table 3. Existing Surface Water Supply Systems

System	Source	Treatment (1)	Capacity, mgd		
			Dependable yield		Installed production
			Potential	Developed	
Navet Reservoir	Navet River	Sed, Fil, Car, Chl	7.0	7.0	11.0
Hollis Reservoir	Quare River	Fil, Chl	7.0	6.5	6.5
Maraval Intake	Maraval River	Chl	0.6	0.6	2.5
St. Ann's Intake	St. Ann's River	Fil, Chl	0.2	0.2	1.0
Cascade Intake	Cascade River	Fil, Chl	0.1	0.1	0.3
Valencia Intake	Quare River	RFil, Chl	1.5	1.5	1.5
Tompson Water Works	Tompson River	RFil, Chl	1.5	0.2	0.2
Biche Water Works	Local catchment	Sed, Fil, Chl	0.1	0.1	0.1
Dibe Intake	Dibe River	Chl	0.1	0.1	0.1
Tyrice Bay Intake	Tyrice River	Chl	0.2	0.2	0.2
Hillsborough Reservoir	Hillsborough River	Sed, Fil, Chl	1.5	1.5	1.5
Courland Intake	Courland River	RFil, Chl	0.8	0.5	0.5
Charlotteville Intake	Local catchment	RFil, Chl	0.1	0.1	0.1
Rural Intakes	Local catchment	-	0.2	0.2	0.3
Total			20.9	18.8	25.8

1. Aer = Aeration; Fil = Filtration; Chl = Chlorination; RFil = Filtration by roughing filter; Car = Carbon addition; Cal = Calgon addition.

Table 4. Existing Groundwater Supply Systems

System	Source	Treatment (1)	Capacity, mgd		
			Dependable yield		Installed production
			Potential	Developed	
Morichal Spring	Limestone Aquifer	Chl.	0.2	0.2	0.2
Guaracara Spring	Limestone Aquifer	Chl	0.1	0.1	0.3
Chaguaramas	Northern Valley Aquifer	Chl, Cal	3.5	0.5	0.5
Tucker Valley	Northern Valley Aquifer	Aer, Chl	6.0	1.5	1.5
Carenage	Northern Valley Aquifer	-	0.1	0.1	0.1
River Estate	Northern Valley Aquifer	Chl.	4.5	4.5 ⁽²⁾⁽³⁾	2.0 ✓
Four Roads	Northern Valley Aquifer	Chl.			2.9 ✓
Cocorite	Northern Valley Aquifer	Chl.			2.2 ✓
Brievae Road	Northern Valley Aquifer	Chl.	4.0	4.0 ⁽³⁾	0.1
Wharf	Northern Valley Aquifer	Chl			1.6
Docksite	Northern Valley Aquifer	Chl			1.0
St. Clair	Northern Valley Aquifer	Chl.			0.3
Savannah	Northern Valley Aquifer	Chl			0.8
George V Park	Northern Valley Aquifer	Chl			1.5
Haleland Park	Northern Valley Aquifer	-	4.5	4.5 ⁽²⁾	0.5
El Socorro	Alluvial Fan Aquifer	Aer, Chl			9.0 ✓
Santa Cruz	Northern Valley Aquifer	Chl			0.1
Valsayn	Alluvial Fan Aquifer	Aer, Chl	5.0	5.0 ⁽²⁾	5.6 ✓
Tacarigua	Alluvial Fan Aquifer	-	5.0	3.2 ⁽²⁾	3.2 ✓
Arouca	Alluvial Fan Aquifer	-	2.0	0.8	0.3
Arima	Alluvial Fan Aquifer	Chl			0.5
Waller Field	Sum Sum Aquifer	Cal, Chl	3.0	1.0	1.0
Maracas Bay	Alluvial Fan Aquifer	Chl	0.1	0.1	0.1
Carlsen Field	Sum Sum Aquifer	Aer, Sed, Fil, Chl	2.0	1.0	1.2
Freeport	Sum Sum/Durham Aquifer	Aer, Sed, Fil, Chl	2.5	1.6	2.0 ✓
Penal	Erin-Morne L'Enfer Aquifer	Aer, Sed, Fil, Chl	2.0	0.8	0.8
Point Fortin	Erin-Morne L'Enfer Aquifer	Aer, Sed, Fil, Chl, Car.	1.0	0.3	0.3
Cap de Ville	Erin-Morne L'Enfer Aquifer	Aer, Chl	1.0	0.2	0.2
Granville	Erin-Morne L'Enfer Aquifer	Aer, Sed, Fil, Chl	0.5	0.5	0.5
Clarke Road	Erin-Morne L'Enfer Aquifer	-	1.0	0.3	0.3
Mayaro	Mayaro Sandstone Aquifer	Aer, Chl.	1.5	0.2	0.2
Richmond Water Works	Valley Aquifer	Aer, Fil, Chl	0.6 ⁽⁴⁾	0.2	0.2
Total			47.1	30.6	41.0

1. Aer = Aeration; Fil = Filtration; Chl = Chlorination; RFil = Filtration by roughing filter;
Car = Carbon addition; Cal = Calgon addition.

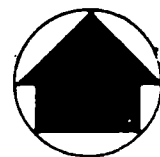
2. Does not include private capacity

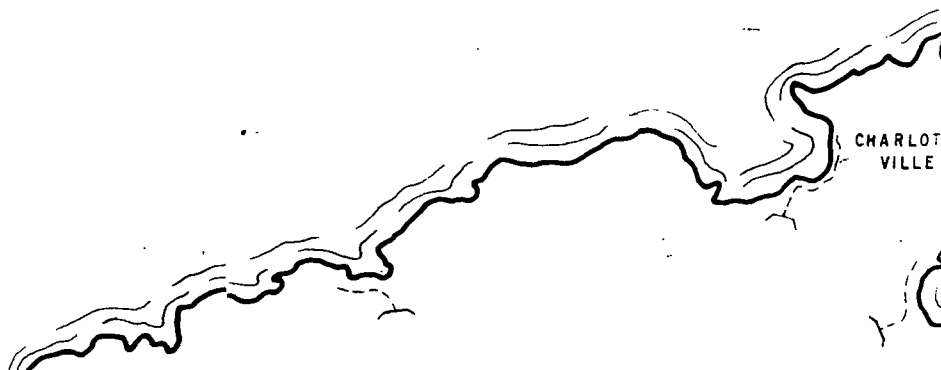
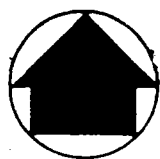
3. Draught may be greater than dependable yield due to recirculated water.

4. Flow of stream.

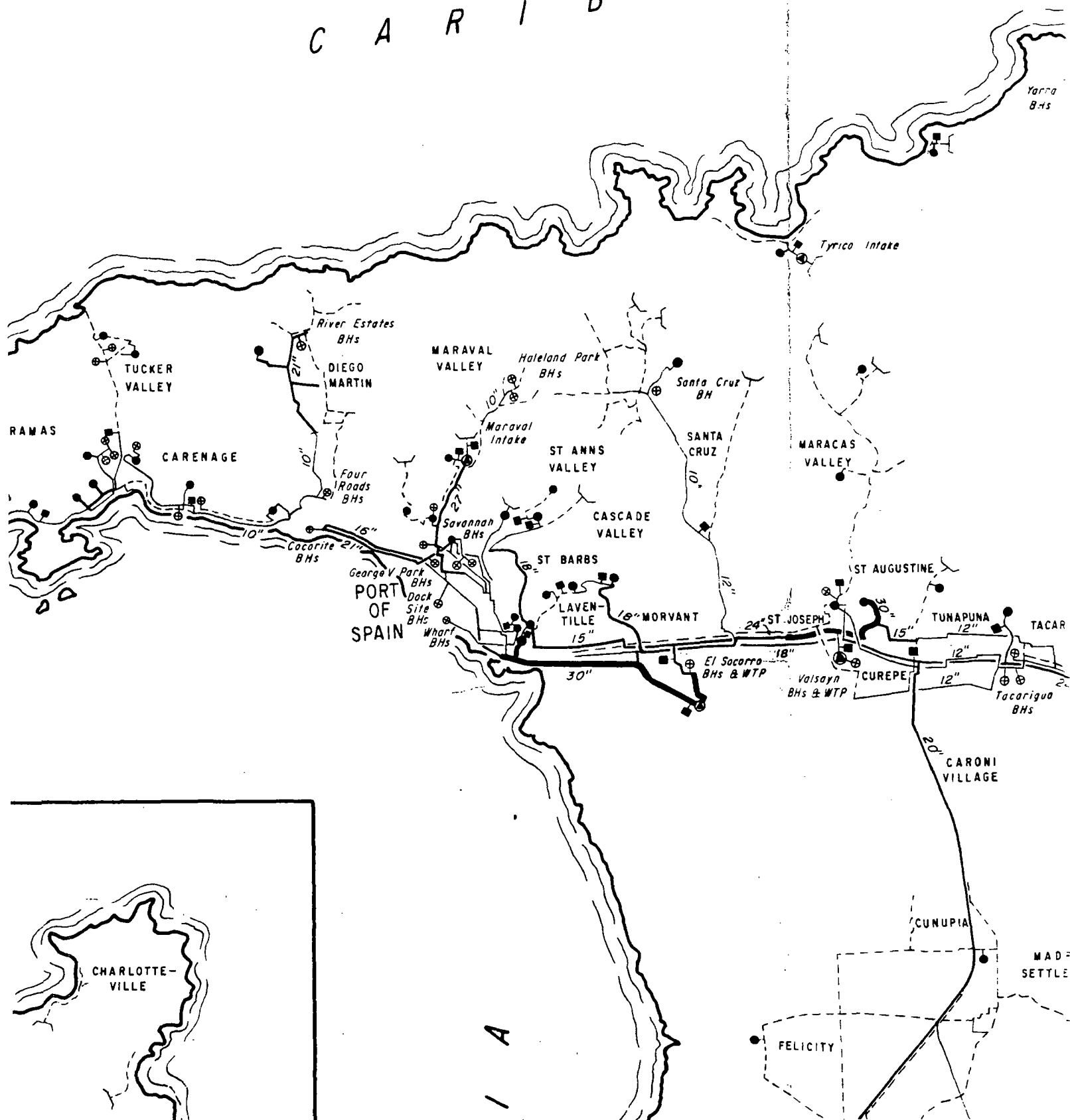
Table 5. Existing Rural Intakes

Name	Area	Capacity, gpd.
Tamana	Sangre Grande	10,000
La Pastora No. 1	Eastern Main Road	50,000
La Pastora No. 2	Eastern Main Road	40,000
Los Armadillos	Sangre Grande	8,000
Matelot	Toco	8,000
Sans Souci	Toco	8,000
Grande Riviere	Toco	10,000
Montevideo	Toco	10,000
Salybia	Toco	10,000
Matura	Toco	10,000
Cumana	Sangre Grande	12,000
Lopinot Spring	Eastern Main Road	3,000
Surrey Village	Eastern Main Road	10,000
La Canoa	Eastern Main Road	6,000
St. John's Road	Eastern Main Road	10,000
Blanchisseuse	North Coast	10,000
Lloango	Eastern Main Road	15,000
Maracas Valley	Eastern Main Road	10,000
Brasso Seco	Eastern Main Road	5,000
Aripo Spring	Eastern Main Road	12,000

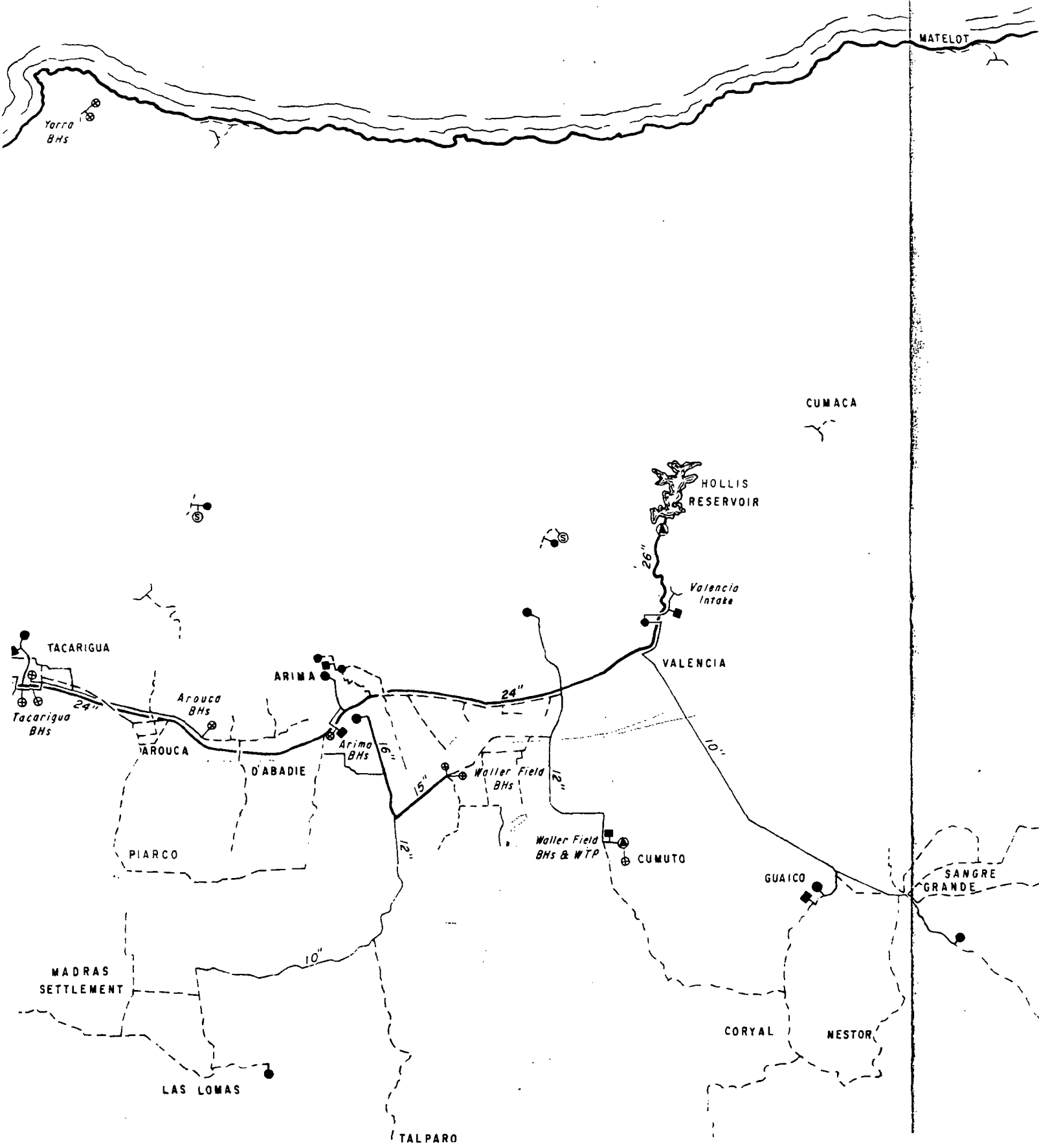


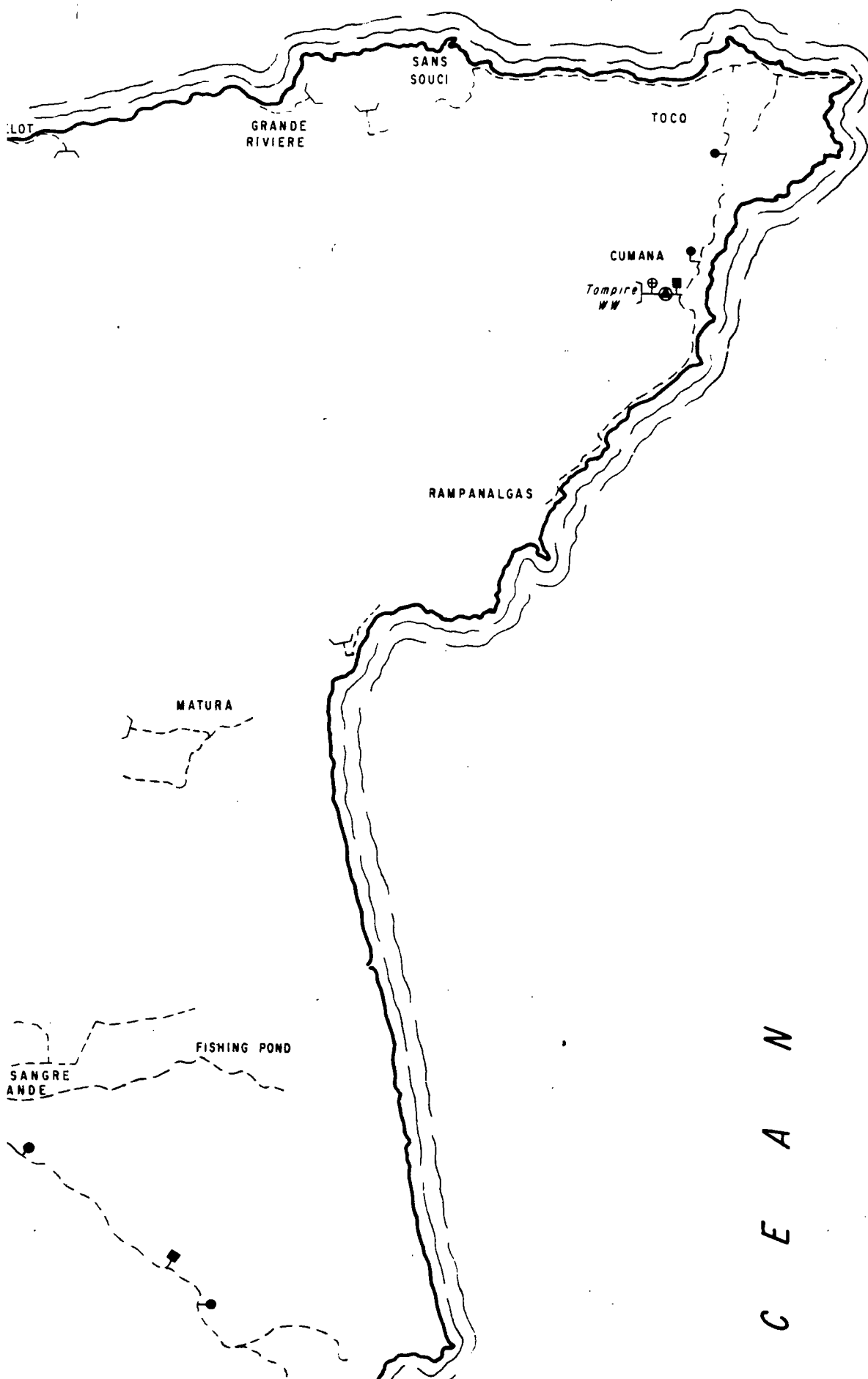


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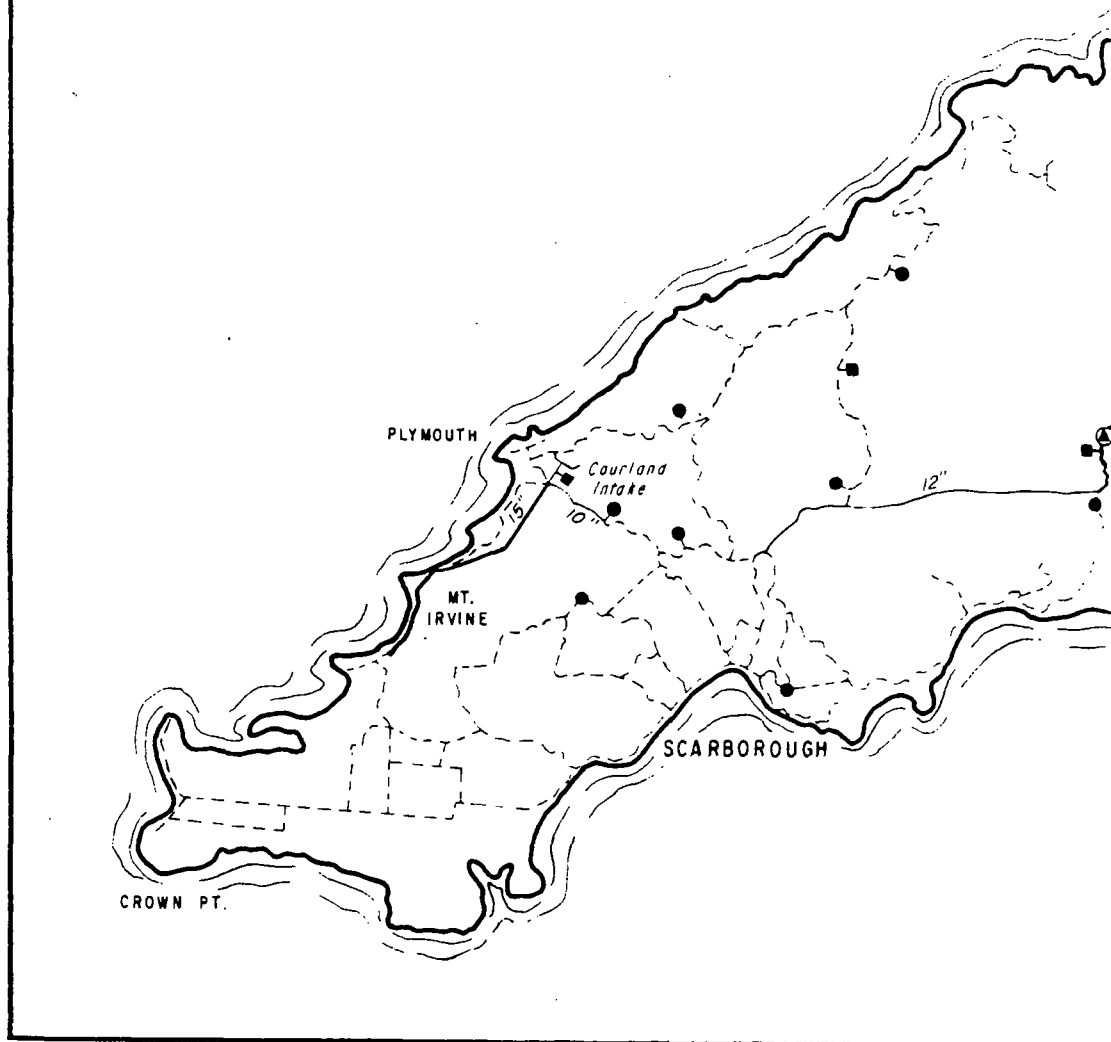


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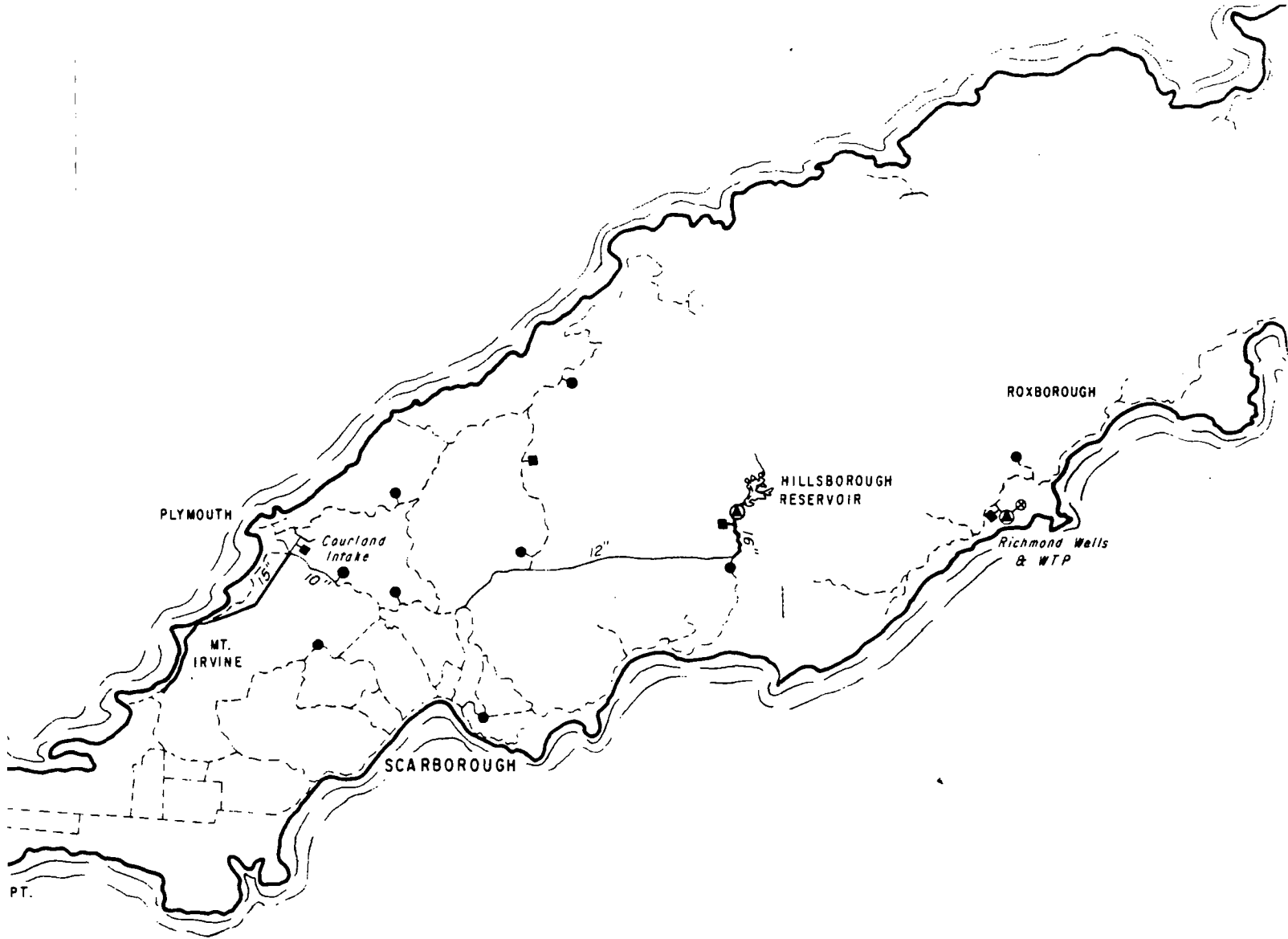


C E A N



LEGEND

-----	Mains 8" and smaller
—————	Mains 9" and larger
⊕	Borehole
●	Water Treatment Plant
■	Pumping Station
⌒	Intake
●	Distribution Reservoir
⑤	Spring



LEGEND

Mains 8" and smaller

Mains 9" and larger

Borehole

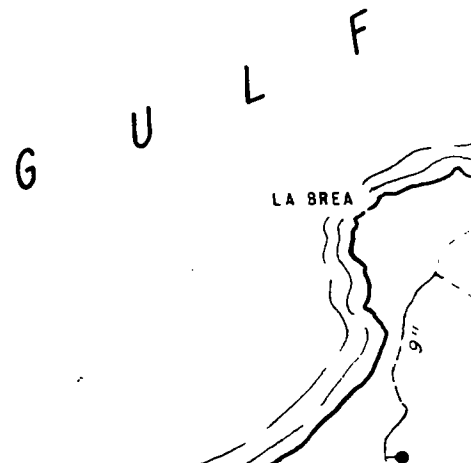
Water Treatment Plant

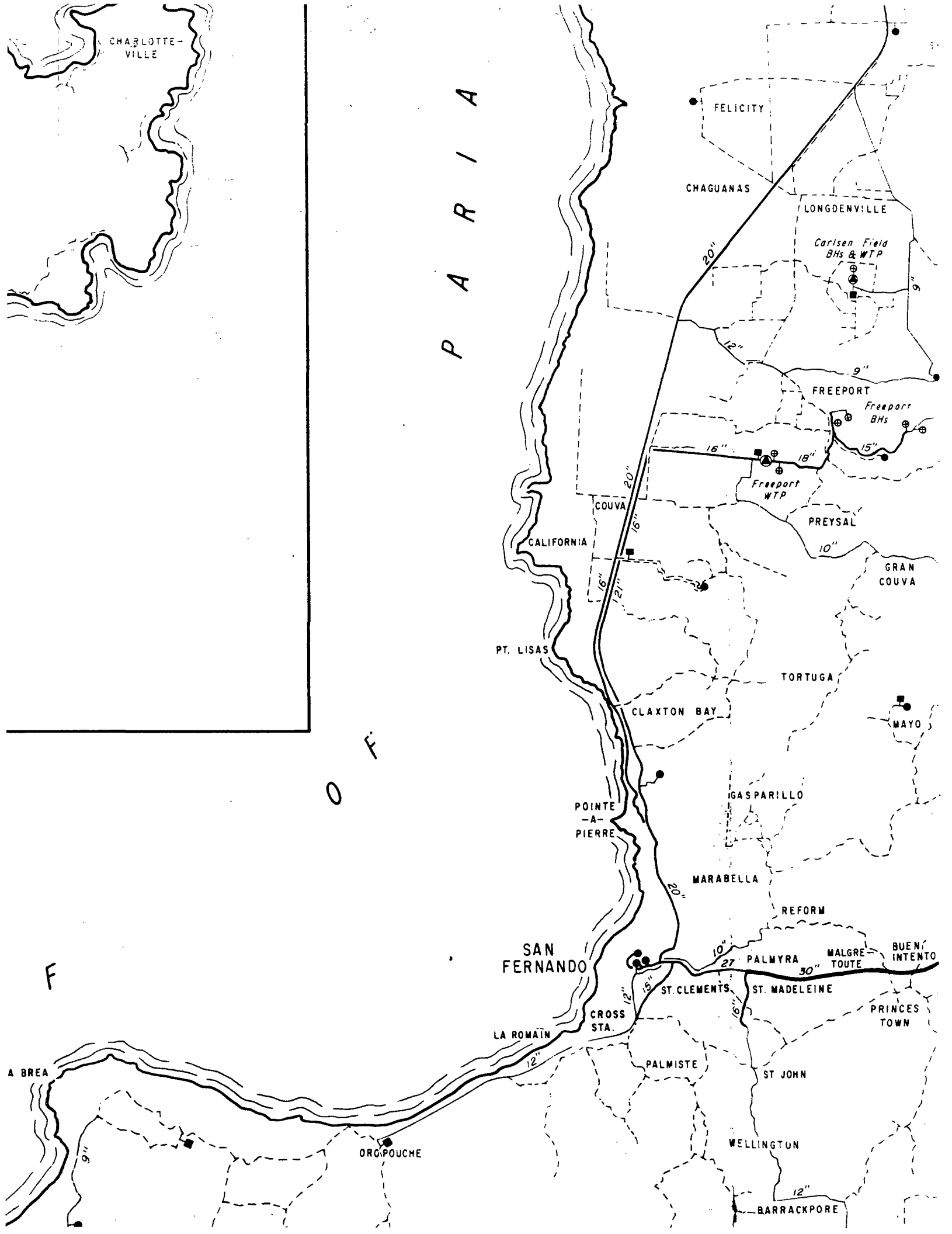
Pumping Station

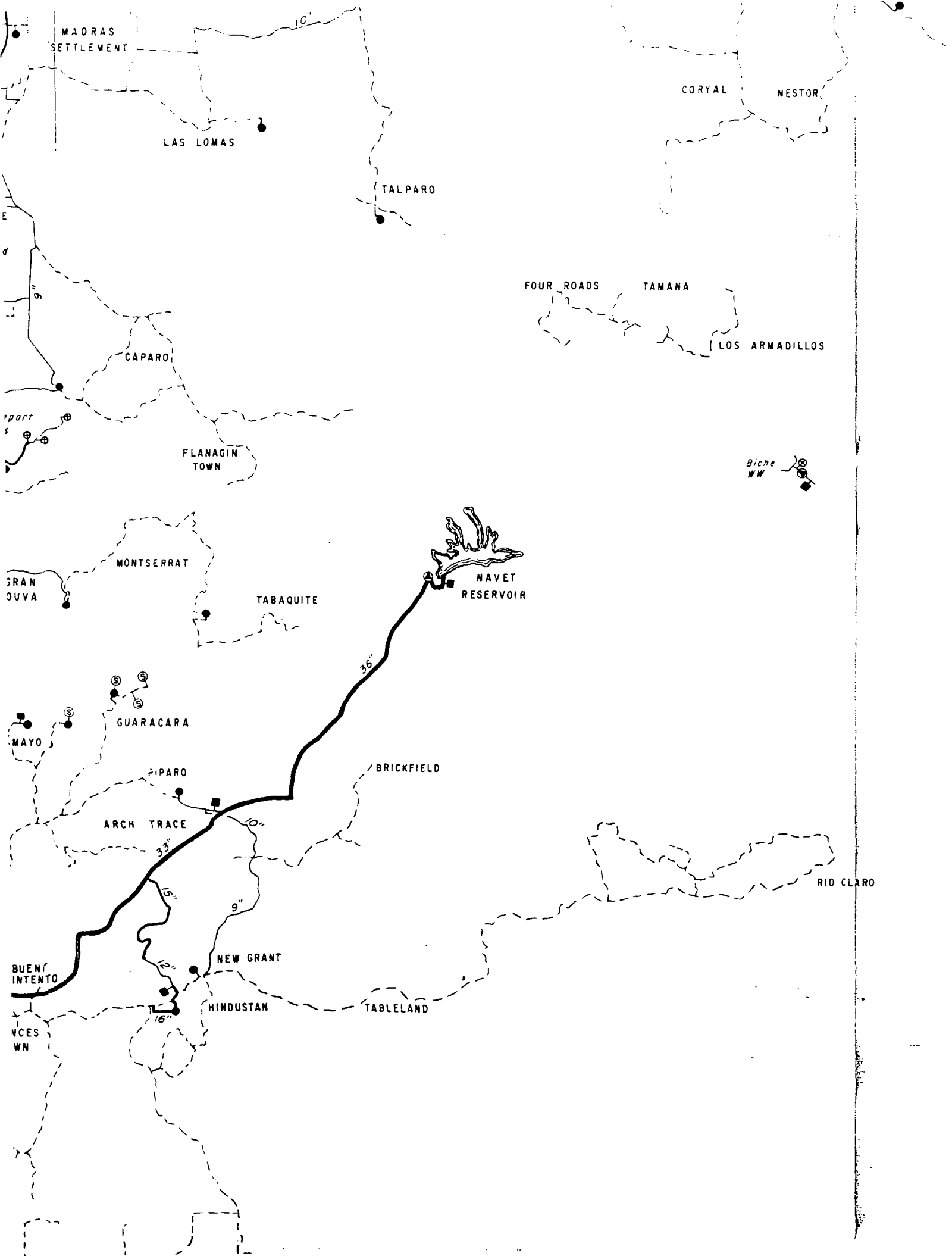
Intake

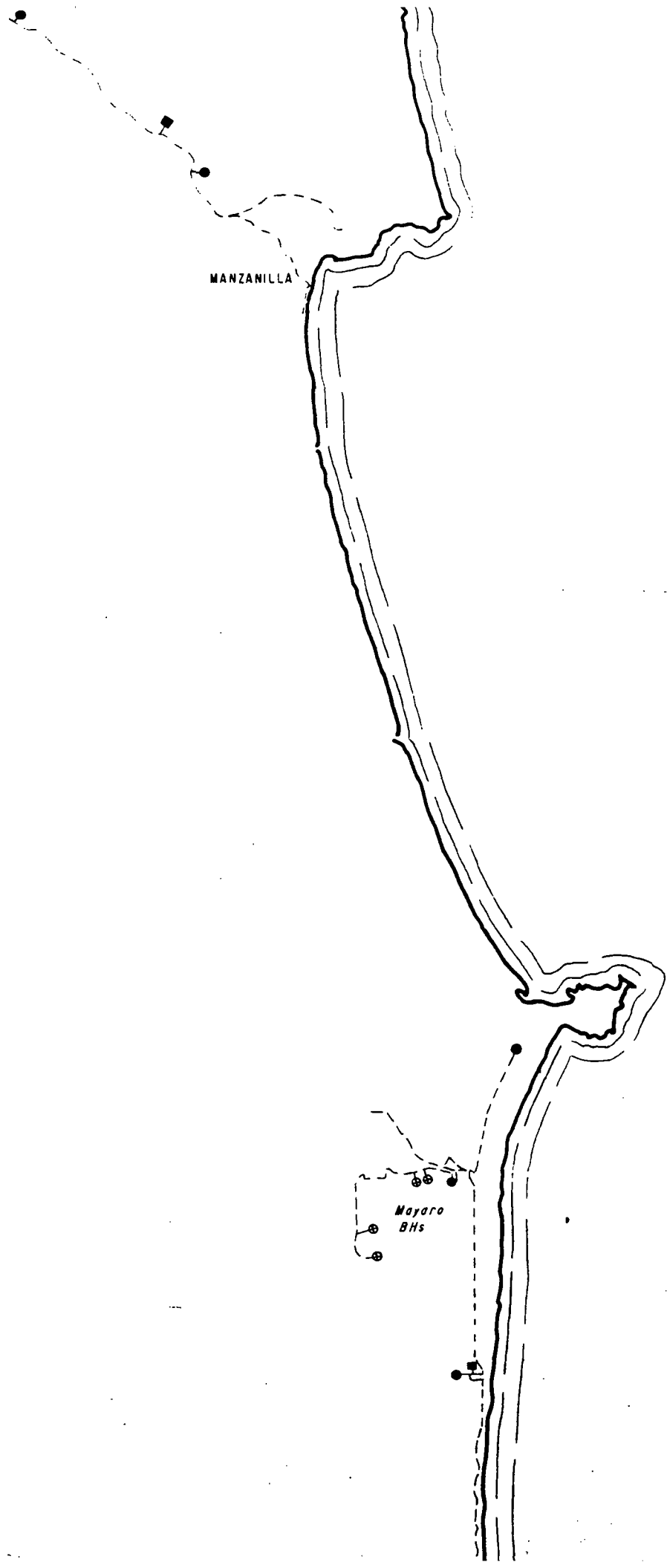
Distribution Reservoir

Spring







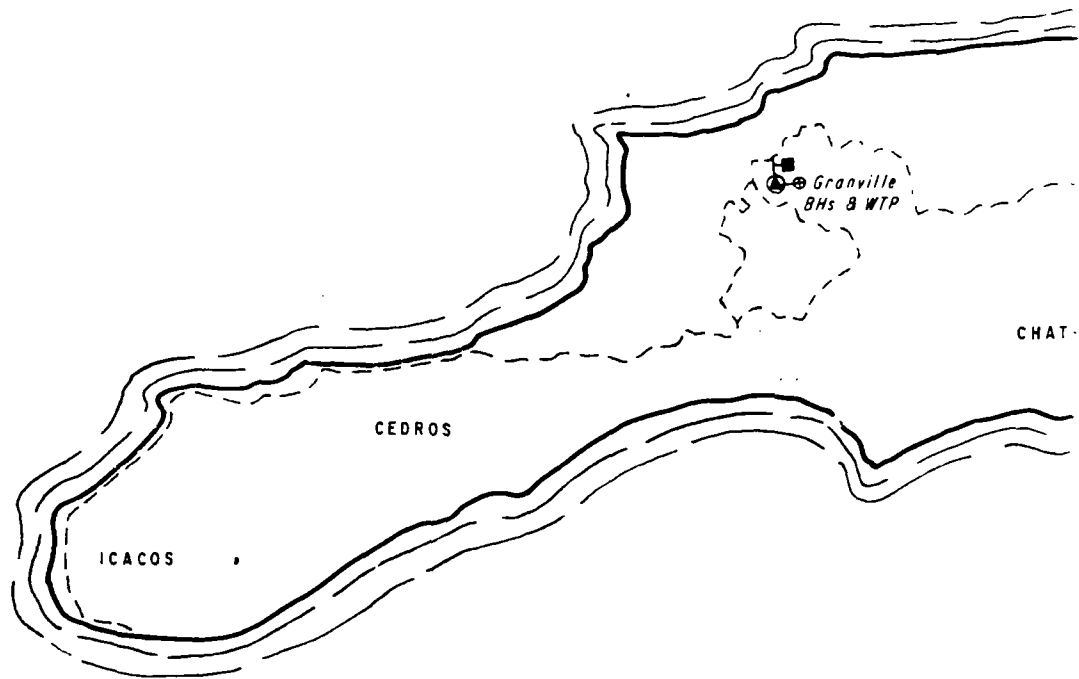


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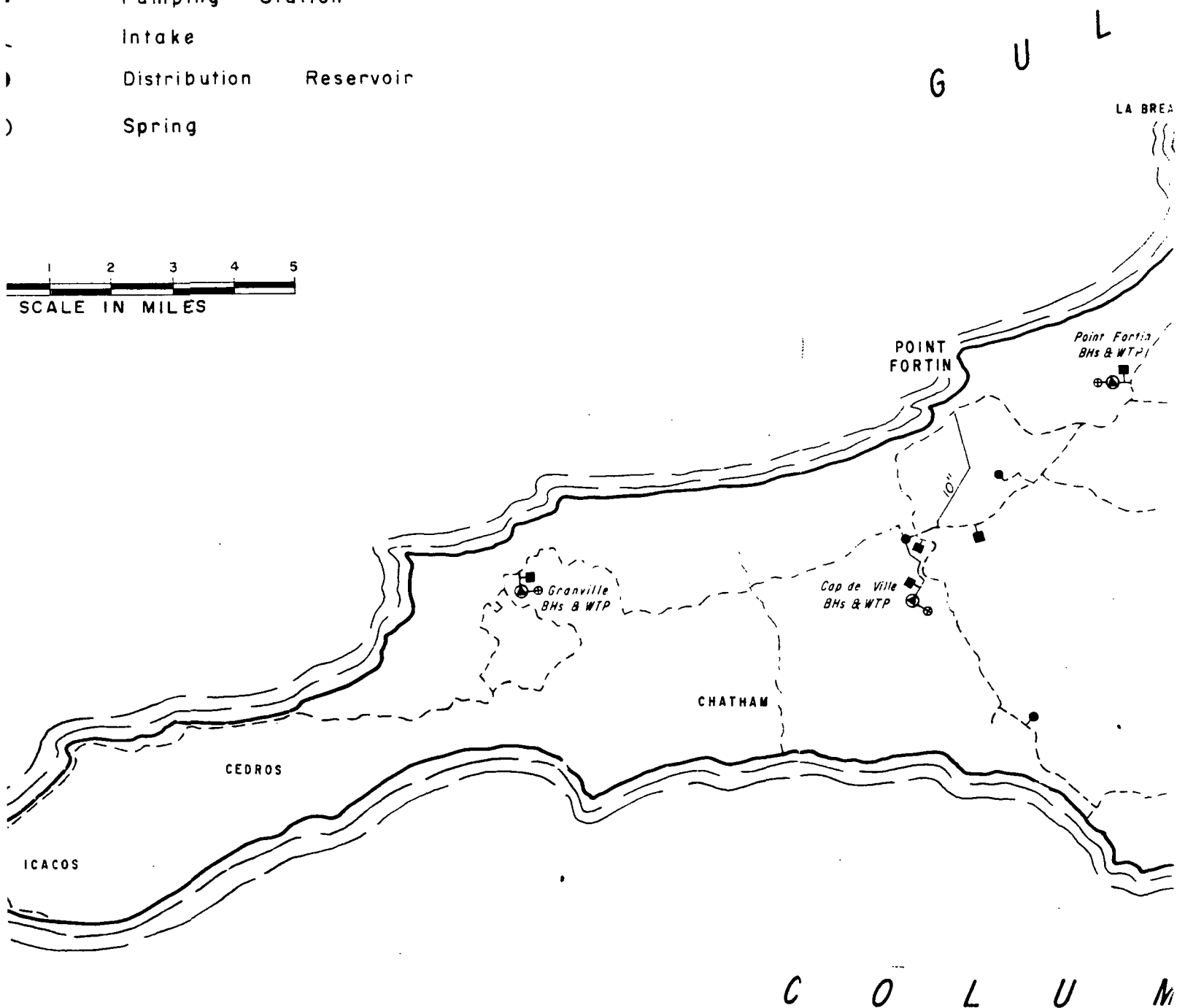
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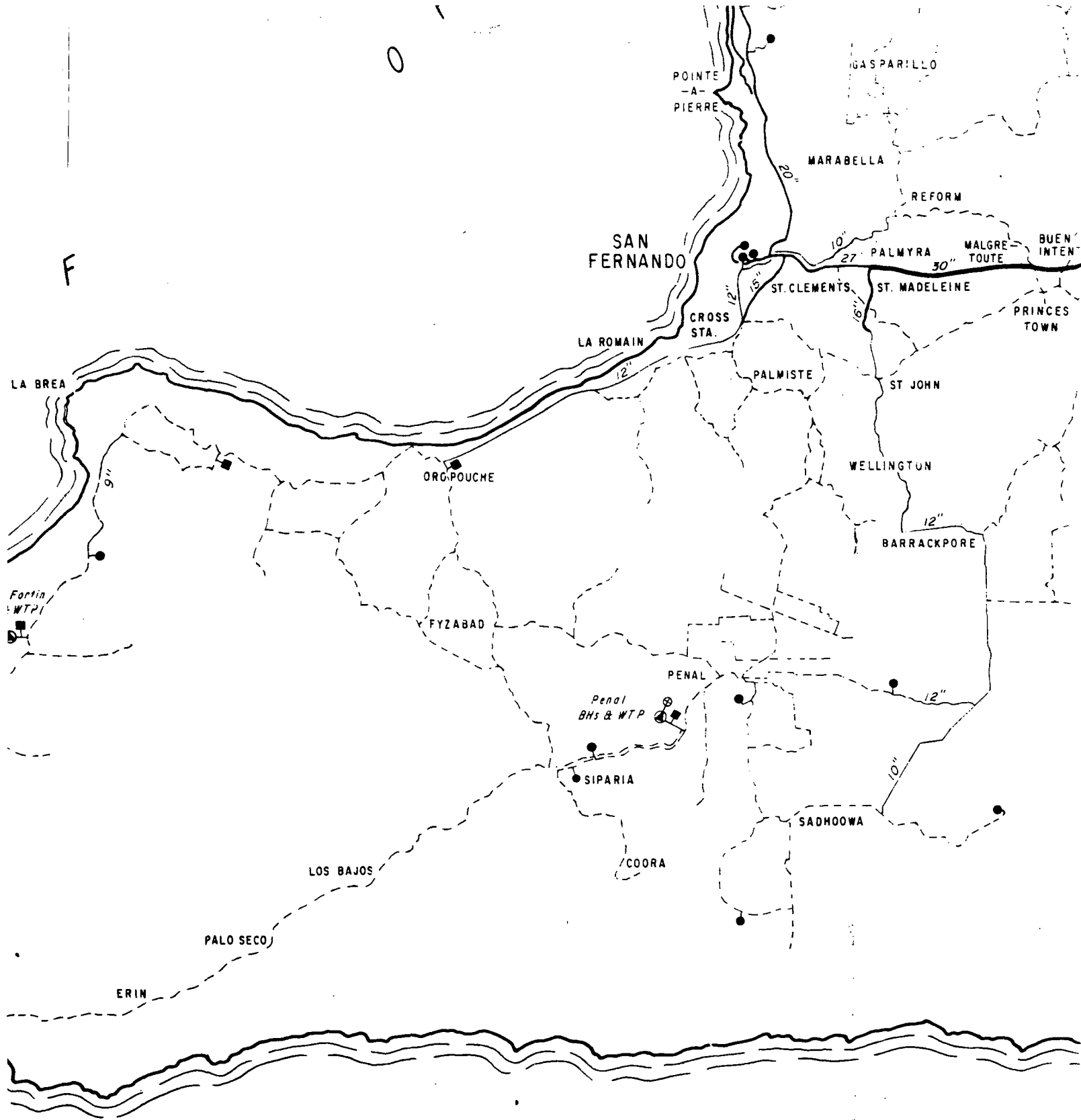
-----	Mains 8" and smaller
————	Mains 9" and larger
⊕	Borehole
⊙	Water Treatment Plant
■	Pumping Station
⌒	Intake
●	Distribution Reservoir
⑤	Spring

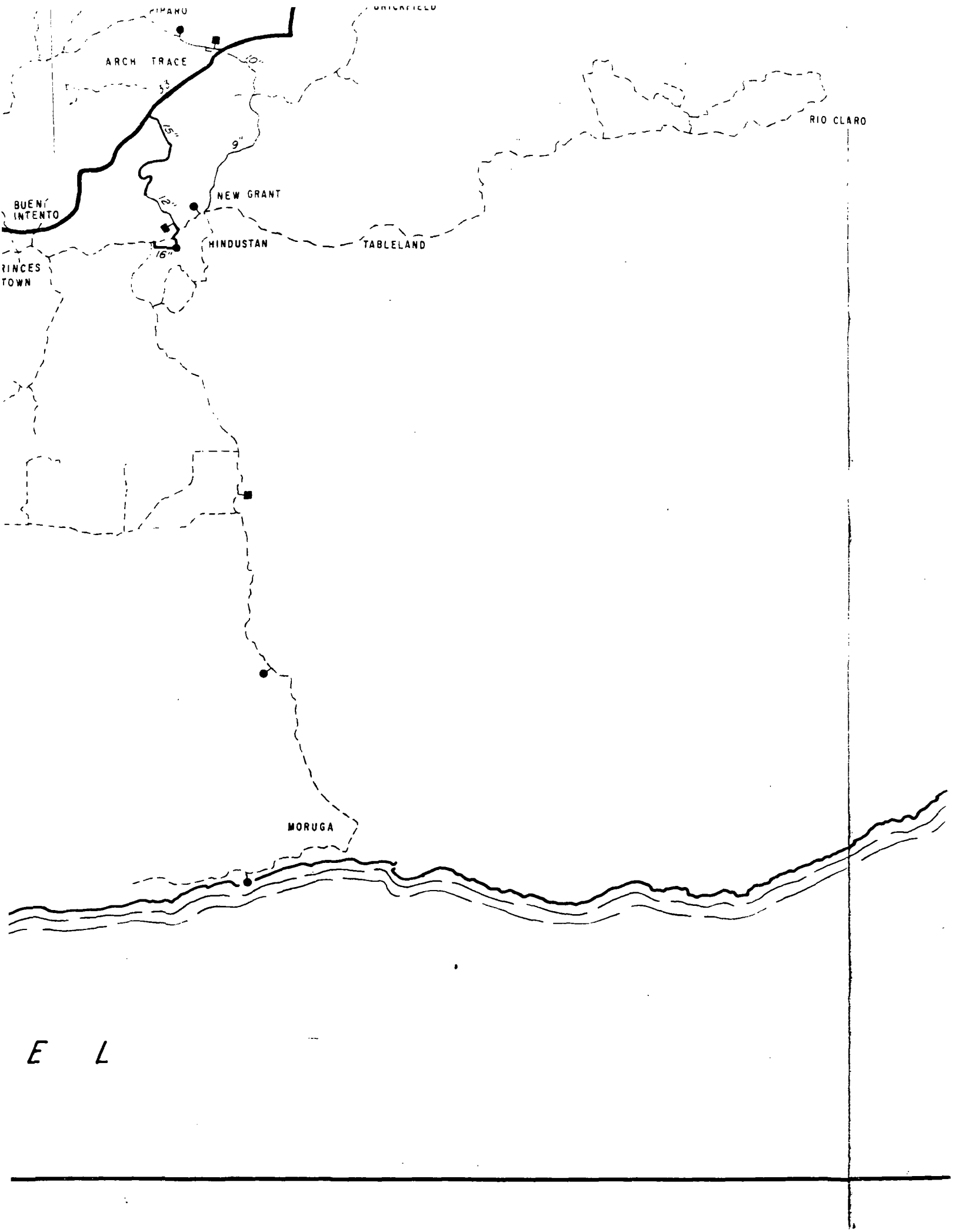


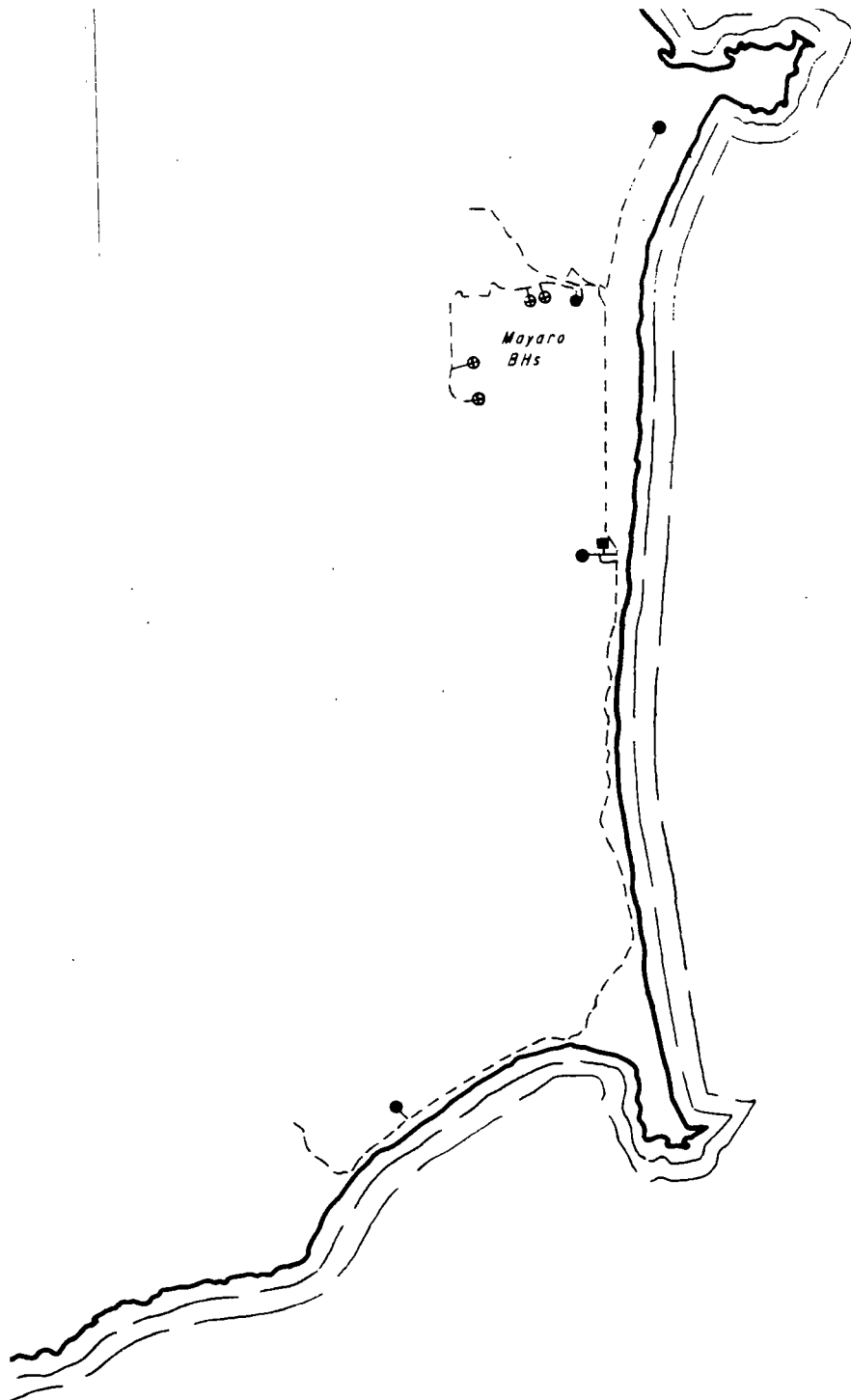
LEGEND

- Mains 8" and smaller
- Mains 9" and larger
-) Borehole
-) Water Treatment Plant
- | Pumping Station
- Intake
-) Distribution Reservoir
-) Spring









A T L A

FIG. 4 EXISTING SYSTEM
TRINIDAD AND TOBAGO
METCALF & EDDY

DATE: 1970

The third major surface supply is the Hillsborough system in Tobago. This system is the principal source of supply for Scarborough and southwest Tobago. It consists of the Hillsborough impounding reservoir, a conventional water treatment plant, and a high-lift pumping station which pumps to a 16- and 12-inch transmission main. The existing facilities are designed for an output of 1.5 mgd.

Major Groundwater Facilities. As of January 1, 1970 there were 113 producing boreholes in Trinidad. Fifty of these operate as independent sources of supply water being pumped directly to distribution. The remainder operate as sources for larger supply systems. A typical groundwater supply system consists of two or more wells which pump to a central treatment plant, a clearwell, and a high-lift pumping station which takes suction from the clearwell and pumps through a transmission system to distribution. Minimum treatment provided is chlorination, although at some independent boreholes there are no treatment facilities. The Valsayn and El Socorro Waterworks have treatment facilities for forced-draft aeration to reduce carbon dioxide. Where iron is present in excessive quantities, treatment facilities consist of aeration and sedimentation followed by rapid sand filtration. Four groundwater systems are considered major because of their capacities and the extent of their transmission systems. These are the Valsayn, El Socorro, Cocorite and Freeport groundwater systems.

The El Socorro waterworks comprises 7 boreholes in the northern gravels at the mouth of the Santa Cruz Valley. Water is pumped from the boreholes to the El Socorro Water Treatment Plant where it is

aerated and chlorinated. A high-lift pumping station delivers the treated water from a 0.5-million gallon clearwell reservoir to two 2.5-million gallon reservoirs on Picton Hill in Port of Spain via a 30-inch steel transmission main. The estimated dependable yield of the El Socorro borehole field is ^{20,000 m³/d} 4.5 mgd. The high-lift pumping station and 30-inch transmission main, however, have a capacity each of 12 mgd, or more than double the requirements for this yield. The construction of such excess capacity is attributable to an overly optimistic estimate of the yield of the aquifer prior to construction.

The Valsayn system consists of 8 boreholes also in the northern gravels. Water from the boreholes is aerated by forced-draft aerators for carbon dioxide removal and stored in a 0.5-million gallon clearwell. From the clearwell, high-lift pumps deliver treated water to the Eastern Main Road communities as far as Success Village to the west and Tunapuna to the east. The transmission system consists of a 30-, 24-, and 18-inch main to the west from the high-lift pumping station with a 30-inch connection to the 3.7-million gallon St. Augustine Reservoir. A 15-inch main from the 30-inch St. Augustine Reservoir connecting main supplies water to Tunapuna. The existing system was brought into full service in 1955. The high-lift pumping station is designed to pump at 9 mgd. Existing installed capacity limits pumping to 7.5 mgd. ^{33,500 m³/d}

The Freeport system consists of 7 boreholes, an extensive raw-water transmission system, an iron-removal plant a 0.5-million clearwell and a high-lift pumping station. Treated water is pumped

through a 16-, 21-, and 20-inch transmission main to San Fernando. A separate pumping system delivers water to the Montserrat service area through a 10-inch main. A separate small pumping station next to the high-lift pumping station delivers untreated water to the Trinidad Cement Company at Claxton Bay. This system is owned and operated by the Company. The present pumpage from the boreholes is 1.8 mgd. The treatment plant is being expanded to a capacity of 3.0 mgd by the addition of another sedimentation basin. 9.0 mgd

The Cocorite system obtains water from shallow wells and two boreholes at the southern end of the Diego Martin Valley. Water from the wells and boreholes go to two separate pumping sumps at the Farrell Pumping Station. Water from one sump is pumped to the Knaggs Hill Reservoir through a 21-inch transmission main laid in 1903 as part of an original supply system from the River Estate wells at the north end of the valley. A 16-inch cast-iron main laid in 1922 takes water pumped from the other sump directly to distribution in Port of Spain. Two boreholes at King George V Park, drilled in 1957, are considered part of the Cocorite system since water from them is pumped to Knaggs Hill through the same 21-inch main which conveys the supply from the Farrell Pumping Station. The combined output from both sources is 4.0 mgd. The supply from the Cocorite boreholes is supplemented by 18,000 cu 3d approximately 0.5 mgd. from 2 boreholes at Four Roads. The supply from these two boreholes is delivered through a 6-inch main to one of the sumps at the Farrell Pumping Station.

Minor Groundwater Facilities. Individual boreholes from which water is pumped directly to distribution with little or no

transmission have been classified as minor groundwater supplies.

These facilities are best described by the areas they serve. Areas with minor groundwater supplies are: Chaguaramas, Diego Martin, Port of Spain, Eastern Main Road, Caroni, Mayaro and south Trinidad.

The Chaguaramas Area is served by a water system constructed by the U.S. Forces during World War II. This system is supplied entirely by groundwater from over 43 boreholes. At present only 11 of these boreholes are in production.

Two of the producing boreholes located in the Chaguaramas area are used exclusively to serve the Diego Martin area. Water from the boreholes in the Tucker Valley Aquifer is pumped to a service reservoir from which it flows through a 10-inch main by gravity to a booster station at Carenage, where it is pumped to the Point Cumana Reservoir through another 10-inch main.

Two borehole fields serve the Diego Martin area. One is located at River Estate at the north end of the valley and the other at Four Roads at the southern end of the valley. At River Estate there are 4 boreholes and 2 dug wells, the boreholes discharge directly through a 21-inch main to reservoirs at Covigne. A high-lift pumping station rated at 2.5 mgd is now under construction at River Estate. At Four Roads water is pumped from 5 boreholes to a small contact tank from which a high-lift pumping station with a rated capacity of 4.0 mgd pumps water to the system. The pumping head at Four Roads is controlled by the level in the Covigne Reservoir.

There are 14 boreholes within the Port of Spain area which

together produce over 4.2 mgd. These boreholes were constructed between 1942 and 1969. The King George V Park boreholes have already been mentioned as part of the Cocorite supply system. There are 5 boreholes in the port area. From two of these boreholes called the Docksite boreholes water is pumped directly to supply in the wharf area. The remaining 3, called the Wharf boreholes, deliver water to a central booster station where it is pumped to a reservoir on Laventille Hill. There are 3 boreholes located in the Queen's Park Savannah. These, together with a borehole at St. Clair, supply water to the Knaggs Hill Reservoir. The least productive of the boreholes is located at Brieves Road and supplements the supply to the Dibe area northwest of Port of Spain. Two wells were recently drilled at Haleland Park in the Maraval Valley to supply local demands.

There are three areas of borehole development along the Eastern Main Road. The largest is at Tacarigua where the pumps at 9 boreholes, each operating independently, pump water to the system. Average production at Tacarigua is 2.6 mgd. Approximately 1.2 mgd is used to supply the industrial area along the Churchill-Roosevelt Highway, the University of the West Indies, and domestic demands in Curepe; the remainder is used locally. Three boreholes at Arouca are connected to the same system. The remaining groundwater development in the Eastern Main Road area consists of 3 boreholes at Arima from which water is pumped to a small sump. It is then repumped through a 12-inch main to the new Arima Reservoir where it flows by gravity to the Arima distribution system.

Two boreholes at Waller Field supply water directly to a reservoir at Malabar through a 15-inch main. These boreholes are the principal source of supply to the Piarco service area.

In Caroni 3 boreholes at Carlsen Field produce about 1.0 mgd which is treated at an iron-removal plant and repumped through a high-lift pumping station direct to distribution and to the Freeport Reservoir, which was originally part of the Hollis system. Treatment consists of aeration, settling and rapid sand filtration. Lime is used for coagulation and pH control.

There are 4 minor supplies in south Trinidad, located at Penal, Point Fortin, Cap-de-Ville and Granville. Each of these 4 supplies has similar treatment facilities for iron removal. The treatment facilities at Point Fortin and Granville are permanent installations. The treatment works at Penal is a temporary plant; however, it is well maintained and has many years of useful service left. The boreholes at Cap-de-Ville are a relatively new source. The temporary treatment plant here is soon to be replaced with a permanent treatment plant with pressure filters. Each system has a high-lift pumping station and some form of transmission. The Point Fortin waterworks has the smallest production capacity. Water from this source is pumped through a 7-inch main to a reservoir at Guapo and then distributed to La Brea. Water from the Cap-de-Ville boreholes is pumped to the Cap-de-Ville Reservoir from which it flows by gravity through a 10-inch main to Point Fortin. A small booster pumping station at the reservoir pumps a limited amount of water south to

Buenos Aires through a 4-inch main. Water from the Granville plant is pumped to a reservoir at Granville for supply to Cedros and Icacos. A limited supply is pumped through a reservoir at Cap-de-Ville for use in Point Fortin. The Penal waterworks is the principal source of supply for Siparia and Palo Seco. A small supply is also pumped to Penal via a separate high-lift pumping station and transmission main. Water for Siparia and Palo Seco is first pumped to a reservoir in Siparia from which it is distributed by gravity to the areas of demand.

The Mayaro borehole supply consists of 5 boreholes connected directly to storage in Mayaro through a single transmission main. Water for Guayaguayare is pumped by a small booster station to a tank at Maloney Road. Treatment consists of chlorination.

Surface Water Intakes. There are over 12 river and stream intakes supplying the systems. Most of these serve small rural systems which supply untreated water through 2-, 3-, and 4-inch pipes. Seven of these intakes produce substantial quantities of water and are worthy of note. These are: the Maraval, St. Ann's and Cascade intakes in Port of Spain, the Tompire River intake serving the Toco area, the Valencia intake serving Sangre Grande, the Richmond River intake in Tobago serving the Windward Coast area and the Courland River intake which serves the southwest part of Tobago.

The most productive intake is located on the Maraval River. This intake has been supplying Port of Spain off and on since 1853. Water is taken directly from the river into an open storage tank, chlorinated, then supplied to Port of Spain by gravity through a

27-inch main constructed in 1853 as part of the original supply. Water used to supply the upper Maraval Valley is first pumped to a tank on a hill above the intake.

The Cascade and St. Ann's intakes were also part of the original supply system for Port of Spain. Water from each source is chlorinated and stored in a reservoir before being released to the distribution system.

The Valencia intake on the Quare was first constructed in 1922, to serve Sangre Grande. It was taken out of service in 1936 with the completion of the Hollis supply system, but reactivated in 1968 to conserve Hollis water for other areas. Supply is obtained from the intake through a roughing filter and then pumped to a tank from which it is distributed by gravity to Sangre Grande. Water can also be drawn from the Hollis system either to supplement the supply from the intake or to replace it when the intake is out of service.

The Tompore River intake is the principal source of supply for Toco. Supply from the intake is supplemented by water from 3 shallow wells which draw directly from the river through a natural gravel formation. Water from both the wells and the intake flows by gravity to a pumping sump where it is repumped through an 8-inch main to storage in Toco. Chlorination is the only form of treatment.

In Tobago a major intake supply has recently been constructed on the Courland River. Water is withdrawn through a roughing filter consisting of cylindrical pipe screens buried in the stream bed, which are connected to a concrete sump. Water is pumped from the sump directly

to a distribution system through a new 15-inch asbestos-cement main. The existing intake and roughing filter is a temporary arrangement. Plans and specifications have already been prepared for the construction of distribution storage near the intake. Long-term plans call for the construction of a conventional water treatment plant. When completed this system will have a capacity of 0.8 mgd.

Rural Intakes. Scattered throughout the Northern Range and central Trinidad are 20 rural intakes operated by the Authority. These are untreated gravity supplies with limited distribution. None of these supplies produce more than 50,000 gpd and the majority are rated at less than 10,000 gpd. In addition, there are a few smaller intakes that were constructed and are operated by the County Councils.

Distribution

The distribution system is comprised of those mains which deliver water from the principal transmission mains or distribution storage reservoirs to the customers' service connections. In general, these mains are smaller than 12-inches except in the rural areas where transmission and distribution mains are one and the same. Total length of mains less than 12-inches in Trinidad and Tobago is 1,375 miles. These mains account for 87 percent of the length of mains of all sizes. It is only in the well developed urban areas that a true distinction can be made between transmission and distribution. These areas are: Port of Spain, Diego Martin, San Fernando, Arima and the Eastern Main Road communities. Since most of the recommended improvements deal primarily with supply and transmission, a detailed knowledge of the

individual distribution systems is not necessary for an understanding of the recommended improvements. However, descriptions of these systems are presented in Appendix B.

Distribution Storage

There are over 106 distribution storage facilities throughout the system. These range in size from the 5,000-gallon, horizontal, cylindrical, steel tanks serving small high-service areas to the 3.09-million gallon reinforced-concrete storage reservoir at Knaggs Hill in Port of Spain. Most of the distribution storage is located in areas with well developed distribution systems. There are 11 storage tanks and reservoirs of reinforced-concrete or prestressed-concrete construction with a capacity exceeding 1.0 (mgd). Reinforced concrete is also used in the construction of many of the smaller reservoirs including those serving as clearwell storage at the various treatment plants. Many of the older reservoirs, 1 mgd and smaller, are prefabricated bolted steel tanks. The last reservoir of this type was constructed in 1958; since then the Authority has been using cylindrical welded-steel reservoirs similar to those used in the oil industry. At one time, there were two elevated storage tanks in service in Trinidad and Tobago. At present only one is in use with a capacity of 20,000 gallons. The use of elevated storage tanks has proved unnecessary in Trinidad because of the many hills near the areas of major demand. Table 6 lists the total distribution storage reservoirs by area and reservoirs of 1.0-million gallons capacity and larger. A complete listing of all reservoirs and storage facilities is given in Appendix B.

Table 6. Existing Distribution Storage by Area

Area	Reservoir	Capacity, mil.gal	Elevation, ⁽¹⁾ ft
<u>Trinidad</u>			
Chaguaramas	13 Reservoirs	3.14	-
Diego Martin		2.72	-
	Covigne Reservoir	2.00	315
	3 Reservoirs	.72	
Port of Spain		13.69	-
	Picton No. 1 Reservoir	3.00	355
	Picton No. 2 Reservoir	5.00	229
	Knaggs Hill Reservoir	3.09	229
	Laventille Reservoir	1.30	189
	9 Reservoirs	1.30	-
Eastern Main Road		10.96	-
	St. Augustine Reservoir	3.70	363
	St. Joseph Reservoir	3.00	258
	Fort Read Reservoir	1.70	333
	13 Reservoirs	2.56	-
Sangre Grande	6 Reservoirs	0.81	-
Toco	3 Reservoirs	0.22	-
North Coast	1 Reservoir	0.22	-
Caroni		2.42	-
	Freeport Reservoir	1.00	283
	5 Reservoirs	1.42	-
Montserrat	2 Reservoirs	0.45	-
San Fernando		6.55	-
	Marryat St. Reservoir	2.95	260
	Naparima Reservoir	2.00	243
	Chacon St. Reservoir	1.60	158
South Trinidad		7.09	-
	Navet WTP	3.00	485
	23 Reservoirs	4.09	-
Mayaro	4 Reservoirs	0.34	-

1. Mean Sea level datum

Table 6 (Continued). Existing Distribution Storage by Area

Area	Reservoir	Capacity, mil gal	Elevation feet
<u>Tobago</u>			
Southwest	9 Reservoirs	0.68	-
Windward Coast	2 Reservoirs	<u>0.42</u>	-
Total capacity		50.17	

Service Connections and Standpipes

Approximately 48 percent of the population is served by direct connections. The remainder gets its supply from standpipes, from private sources, or by truck. Table 7 lists the estimated number of direct connections and standpipes as supplied by the Authority, and the number of persons served in each category. Most direct connections are charged a flat fee based on the Annual Rateable Value of the property. However, some domestic connections in Port of Spain are metered. Outside of Port of Spain only large industrial users are metered. The total number of meters in service is about 8,900.

Table 7. Type and Number of Service Connections

Type	Services	Population served
Direct connections	115,000 ✓	500,000 ✓
Standpipes	5,200 ✓	470,000 ✓
Truck (County Council)		30,000 ✓
Other		40,000 ✓
Total	120,200	1,040,000

Existing Plans for System Improvements

The basis for the Authority's present capital expenditure improvement program is a report prepared for the Authority at its request in 1968 by Mr. Ian de Verteuil. The purpose of the report was to outline the capital requirements of the Water and Sewerage Authority for the Third Five-Year Plan 1969-1973. The report recommended improvements to alleviate the present shortage of supply and to maintain an adequate supply until 1973 or until the anticipated impact of the improvements recommended in this study could be realized. The report defined over 24 separate projects. Incorporating these improvements with their own, the Authority has scheduled a total of 74 projects which include additional sources of supply and numerous extensions to the distribution system. A list of these projects appears in Appendix H. Of these 74 projects, 5 had been completed by the end of December 1969, and another 25 were in progress.

The completed projects have increased production capacity by

an estimated 3 mgd. Of the 44 projects that have not yet been started or completed, 34 have been incorporated, generally with modifications, in the recommended development program described in chapter RECOMMENDED DEVELOPMENT PROGRAM. These modifications have been made on the basis of additional data now available on groundwater and surface sources and long term projections on water requirements. Of the remaining 10 projects 3 are not recommended, 2 have been replaced by alternative projects, and 5 are maintenance items which have not been investigated.

Included in the above projects is the secondary distribution extension program at present proceeding at the rate of about 20 miles per year.

Sewerage System

The first underground sewerage system in Trinidad was constructed in Port of Spain in 1861. It was extended in 1902 and again in 1937. The largest single sewerage project was undertaken in 1962, when the Port of Spain system was improved and extended to areas outside the City, and new systems were constructed in San Fernando and Arima. In Port of Spain an east-west trunk main collects sewage from as far as Diego Martin in the west and San Juan in the east, and conveys it to a pumping station on the outskirts of Port of Spain. From this pumping station the raw sewage is pumped to oxidation ponds located in the Caroni Swamp about three-quarters of a mile from the pumping station.

In San Fernando, a gravity system conveys sewage to a high-rate trickling-filter type plant. The treated effluent is discharged to the Cipro River. A similar plant of this type is used to treat

water collected by the sewer system in Arima. Effluent from the Arima plant flows into the Mausica River, which eventually reaches the Caroni.

The San Fernando sewage treatment plant currently serves as a source of industrial water supply for the Texaco Refinery at Pointe-a-Pierre. A pumping station owned and operated by Texaco, pumps water from the final settling tank through a reconditioned portion of the original Hollis trunk main to storage reservoirs at the Texaco Refinery. This water is used to supplement Texaco's supply from the Guaracara River, which in recent years has been found to be insufficient to meet its industrial requirements during the dry season.

WATER REQUIREMENTS

General

Estimates of future water requirements are based on population projections, trends in past water use, and economic forecasts of industrial development. These estimates are made according to use classification. Based on availability of data, we have identified the following classifications of water use in Trinidad and Tobago:

Domestic

Industrial

Irrigation.

These classifications are sub-divided into WASA supplied water and water supplied by private or other Government agencies. Requirements met outside the WASA system are considered since requirements supplied from private sources lower the demand upon WASA's system. Also, other interests are in most cases in competition with WASA for the same sources of supply.

Locations of future demands are as important as magnitude since a major portion of the cost of developing new supplies will be for transmission and distribution. For estimating area demands the water areas identified in "EXISTING SYSTEMS" have been used (See Figure 3).

Variations in demand are also important. Projections of future requirements are based on annual average quantities. In practice demand rates can vary as much as three to four times the

average. For purposes of design, these variations must be considered along with average requirements.

This chapter reviews past trends in water use, estimates future population, projects future water requirements to be supplied by WASA, and defines criteria for estimating variations in demand.

Population

The population of Trinidad and Tobago has increased steadily since 1900 as indicated by the Census figures listed in Table 8.

Table 8. Population of Trinidad and Tobago

Year	Population
1901	255,148
1911	333,552
1921	365,913
1931	412,783
1946	557,970
1950	646,000
1960	827,957
1965	974,000

Projection of future population growth is based on recent trends in the birth rate, death rate and migration. Recently, the birth rate has dropped from a high of 39 per 1000 in 1965 to 30 per 1000 in 1968. Taking the difference between births and deaths, the natural increase in population fell from 30 per 1000 in 1960 to 23

per 1000 in 1968. A Family Planning Program which was started in 1965 is expected to reduce the natural increase in the years ahead. For purposes of population projection it is assumed that the natural rate of increase will remain at 23 persons per 1000 until 1983, after which it is expected to fall even further to 20 persons per 1000.

Migration can be closely related to employment opportunities. For the ten-year period ended in 1963 migration produced a net annual gain of about 2000. Since 1964 the trend has reversed and migration has resulted in a net loss of about 30,000 between 1964 and 1968. This shift can be attributed to high unemployment which in 1968 was 14 percent. The Third Five-Year Plan, 1969-1973, estimates that full employment will be reached in 1983 and that during the Plan period 60,000 persons will have gone abroad permanently. For purposes of projection this pattern of outward movement has been taken into consideration and a net migration of zero following 1983 has been assumed.

The population estimate for the year 2000 based on the above assumptions is 2.0 million.

Trinidad's existing population of one million is concentrated around its two largest cities, Port of Spain and San Fernando. Around Port of Spain in County St. George the direction of growth has been both east and west of the City such that an urban strip exists between Chaguaramas to the west and Arima to the east. In the south, growth has been in a radial direction from San Fernando. Strip development has also occurred along the Gulf coast extending northward from San Fernando to Chaguanas and southward to Point Fortin. The Gulf coast

development is not as dense as the strip development in County St. George and tends to cluster in towns and villages.

Except for a few urban areas, the largest of which are Sangre Grande, Toco, Princes Town, Rio Claro and Siparia, the rest of Trinidad can be described as rural.

Future population growth is expected to occur in the established urban areas where employment opportunities, educational and other facilities are located.

In Tobago the population is located in scattered settlements in the southwestern half of the island. Scarborough has the only large concentration of population. In the future Scarborough and the coastal areas in the southwest and southeast are expected to experience the greatest growth due mainly to resort development.

Figure 5 shows projections of future population growth by counties. Future population distribution by water service area is given in Table 9. A more detailed distribution by sub-area is given in Appendix C. Figure 5a is a graphic representation of present and projected future population distribution in Trinidad and Tobago.

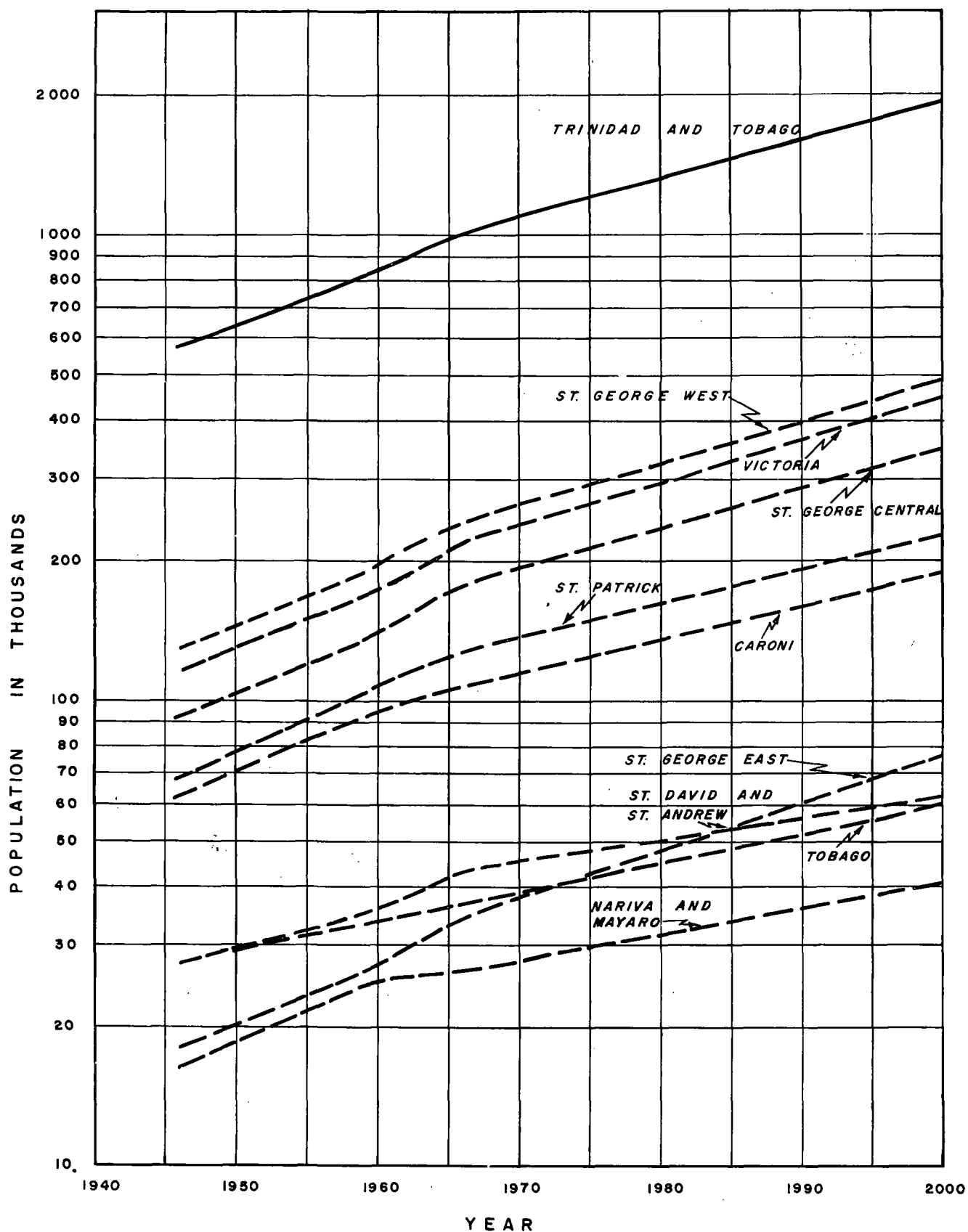


FIG. 5 POPULATION TRENDS AND PROJECTIONS

1940 — 2000

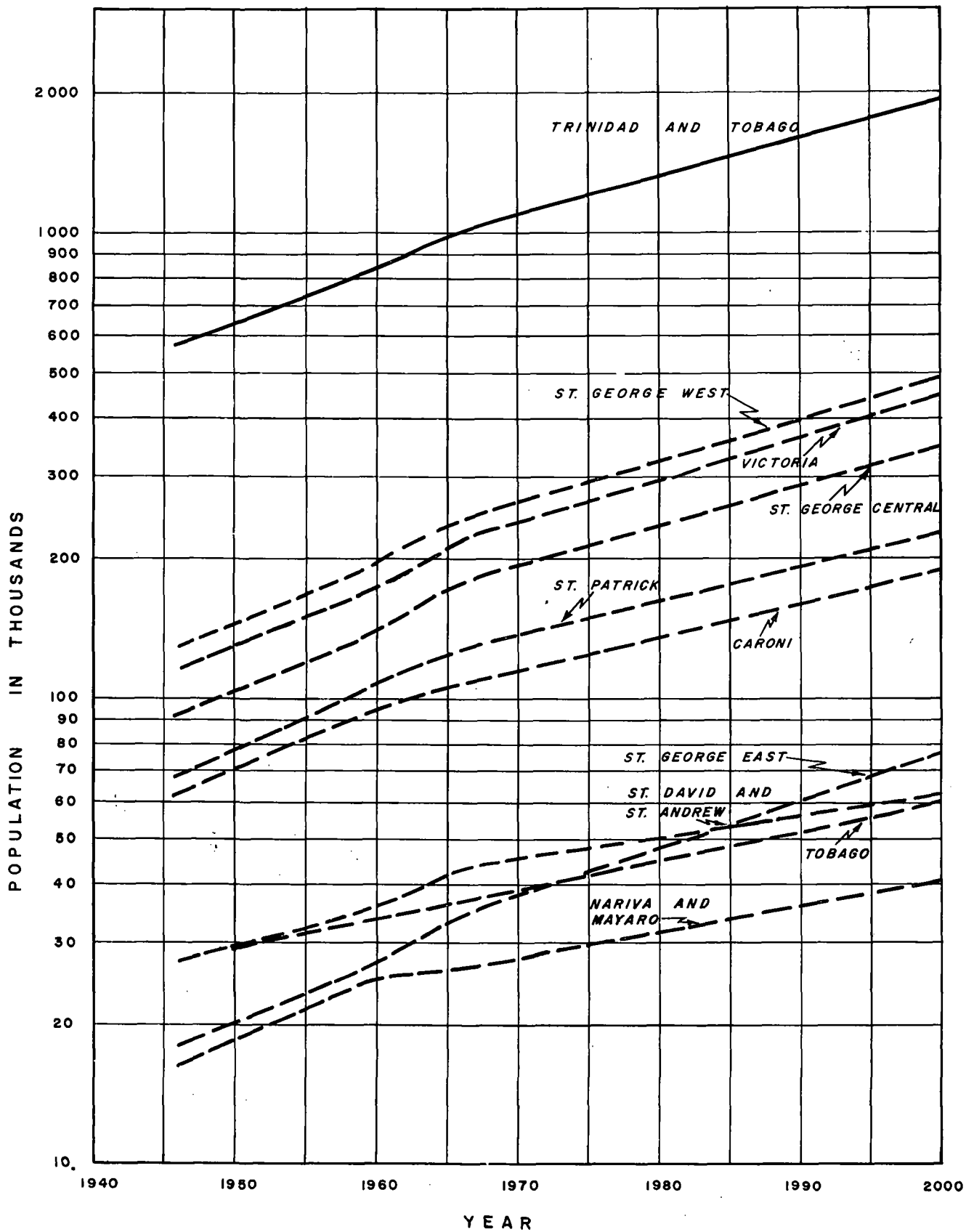


FIG. 5 POPULATION TRENDS AND PROJECTIONS

1940 — 2000

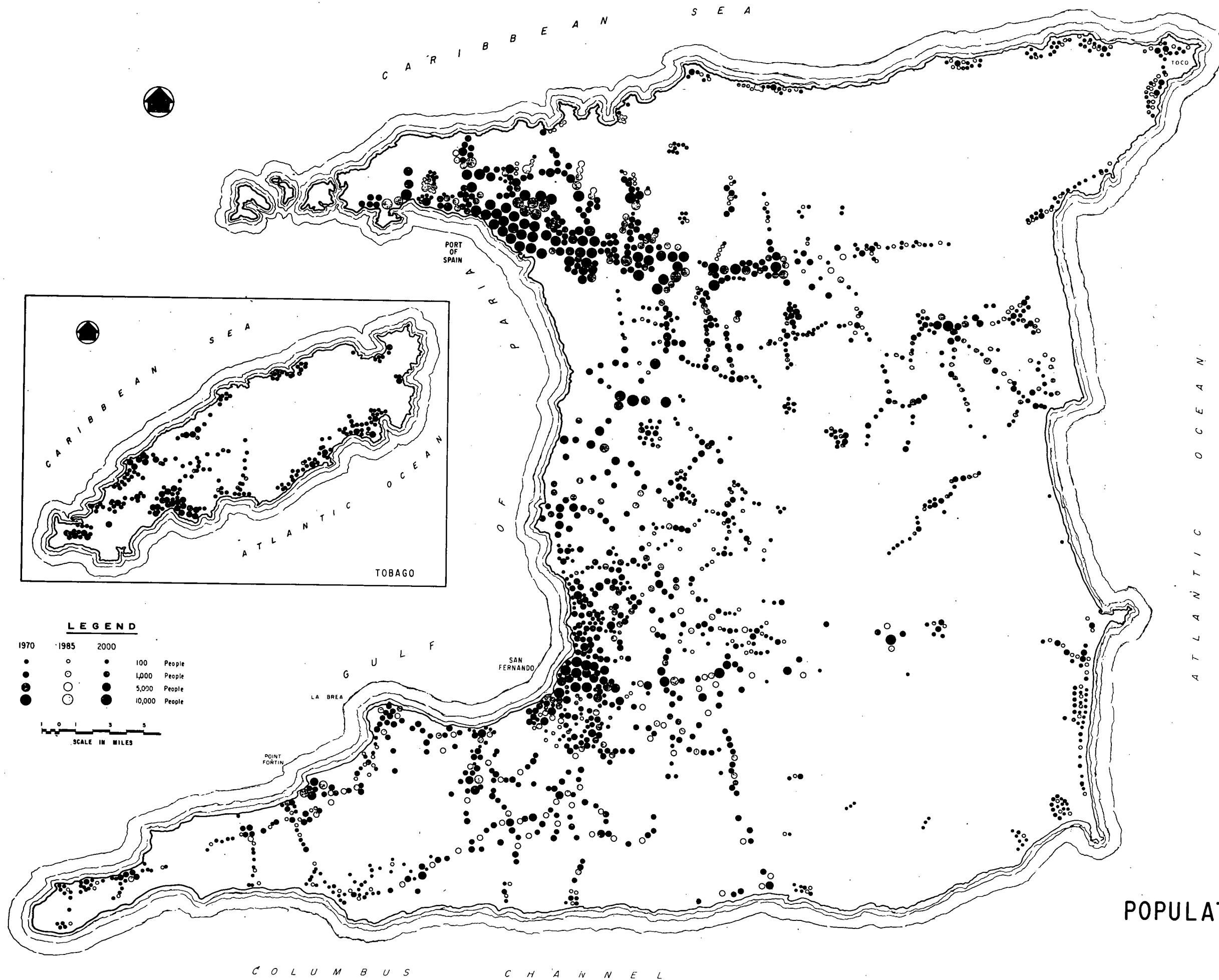


FIG. 5A
POPULATION DISTRIBUTION

Table 9. Future Population by Water Area

Area	Population				
	1970	1975	1980	1985	2000
<u>Trinidad</u>					
Chaguaramas	-	5,400	11,300	18,200	39,000
Port of Spain	179,000	198,000	215,000	232,000	280,000
Eastern Main Rd.	280,000	315,000	350,000	392,000	522,000
Caroni	120,000	138,000	155,000	173,000	222,000
Sangre Grande	44,000	48,000	51,000	54,000	64,000
Diego Martin	43,000	51,000	59,000	67,000	88,000
Montserrat	6,200	7,100	7,900	9,000	12,200
San Fernando	72,000	78,000	82,000	86,200	100,000
South Trinidad	328,000	365,000	400,000	440,000	600,000
Mayaro	9,100	9,600	10,500	11,300	14,800
Toco	7,700	8,600	9,600	10,500	12,300
North Coast	3,700	4,400	5,300	6,000	7,000
<u>Tobago</u>					
Southwest	26,000	28,000	30,900	33,600	44,000
Windward Coast	7,400	7,800	8,200	8,600	10,000
Rural	<u>4,200</u>	<u>4,400</u>	<u>4,600</u>	<u>4,700</u>	<u>5,000</u>
Total	1,130,300	1,268,300	1,400,300	1,546,100	2,020,300

Population Served

A housing survey made in 1964 by the Central Statistical Office placed the number of persons served by a piped water system at 93 percent of the population. The breakdown by percentage from this

survey is as follows:

Type of Service	Percent
Direct connections	48 ✓
Standpipe	45
Springs, streams, ponds or truck	<u>7</u>
Total	100

WASA is estimated to serve 90 percent of the population directly from its system. The remaining 3 percent with piped water are supplied by the three major oil companies: Texaco Trinidad Inc., Shell Trinidad Ltd., and Tesoro Trinidad Ltd., and by other private concerns which together produce approximately 1.8 mgd for domestic use. The County Councils as agents of WASA serve another 3 percent by truck, leaving only 4 percent or 40,000 persons so isolated as not to be supplied either directly or indirectly with piped water. The fact that more than 90 percent of the population is served in some way by WASA is a remarkable accomplishment when compared with conditions in the U.S.A. where about 80 percent of the population receives a direct supply from both public and private concerns combined.

Past and Present Water Use

Historical data on total water production by WASA and its predecessor agencies from 1950 are listed in Table 10.

Table 10. Past Water Production for Trinidad and Tobago

Year	Production, mgd.	Year	Production, mgd.
1950	14.5	1960	29.3
1951	14.9	1961	32.0
1952	15.5	1962	34.9
1953	16.2	1963	39.2
1954	17.2	1964	42.3
1955	18.1	1965	48.1
1956	18.5	1966	48.1
1957	20.1	1967	50.7
1958	22.9	1968	54.1
1959	26.8	1969	59.9 ✓

Records which indicate production by source are available only from 1962 onward. Except for Port of Spain, no records are available which reflect use by area, however, in view of the isolation of the regional service areas, estimates of area use can be determined from production records, and are presented in Table 11. No historical data are available which give a breakdown of WASA's production by use or which list production from private sources. Accordingly, estimates have been made from the limited information available for 1968.

Table 11. Annual Average Daily Water Use by Area⁽¹⁾

	Use, mgd						
	1962	1963	1964	1965	1966	1967	1968
<u>Trinidad</u>							
San Fernando	3.2	3.3	3.4	3.5	3.6	3.7	3.8
Port of Spain	11.8	11.5	12.0	14.8	13.6	14.6	14.9
Diego Martin	3.1	3.7	3.8	4.0	3.6	3.5	3.9
Chaguaramas	-	-	-	-	-	0.5	1.3
Eastern Main Road	10.6	10.7	12.3	14.3	14.6	15.0	15.6
Sangre Grande	0.7	0.6	0.8	0.9	0.9	1.0	1.0
Caroni	1.6	2.7	3.0	2.8	2.8	2.8	3.4
Montserrat	0.1	0.1	0.1	0.1	0.2	0.4	0.5
South Trinidad	2.6	4.9	5.2	5.9	7.1	7.5	7.7
Mayaro	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Toco	0.1	0.2	0.2	0.2	0.2	0.2	0.2
<u>Tobago</u>							
Southwest	1.0	1.2	1.4	1.4	1.3	1.3	1.4
Southeast	-	-	-	-	-	-	0.2
Total	34.9	39.0	42.3	40.1	48.1	50.7	54.1

1. Exclusive of unmetered rural intakes.

Domestic Water Use. In analyzing present use, domestic use, small commercial use and waste and loss have been considered together under domestic use. In order to separate domestic, small commercial use and waste from total use, WASA's meter records were reviewed and the figures for industrial and large commercial metered water use were subtracted from total production. The remainder was assumed to be domestic use and the 1968 estimates of such are given in Table 12.

Table 12. 1968 Domestic Water Use by Area Supplied by WASA ⁽¹⁾

Area	Population (2)	Water use	
		Total, mgd (3)	Per capita, gpd
<u>Trinidad</u>			
Port of Spain	172,800	12.7	74
Diego Martin	43,900	3.8	87
Eastern Main Road	259,100	14.4	56
Sangre Grande	36,600	1.0	27
Caroni	116,400	3.4	29
Montserrat	9,000	0.5	55
South Trinidad	301,600	6.3	21
San Fernando	48,500	3.3	66
Mayaro	6,800	0.2	29
Toco	6,200	0.2	32
<u>Tobago</u>			
Southwest	25,000	1.4	55
Windward Coast	7,400	0.2	27
Total	1,033,300	47.4	46 (Avge.)

1. Does not include Chaguaramas, or areas served by minor intakes.
2. Includes total population within area served.
3. Does not include industrial use.

As mentioned earlier, domestic water supplied by the major oil companies and other private concerns is estimated at 1.8 mgd.

Industrial Water Use. Present industrial use is estimated at 20.4 mgd. Approximately 6 mgd is supplied by WASA. The remainder comes from private supplies and includes 1 mgd of sewage effluent which WASA sells to Texaco. Texaco is the island's largest industrial user with a demand of approximately 7.8 mgd. All but 0.2 mgd purchased from WASA at Barrackpore is supplied from Texaco's own sources. The areal distribution of the industrial demand supplied by WASA is given in Table 13.

Table 13. 1968 Industrial Water Use by Area Supplied by WASA

Area	Use, mgd
<u>Trinidad</u>	
Port of Spain	2.2
Diego Martin	0.1
Eastern Main Road	1.2
Sangre Grande	-
Caroni	-
Montserrat	-
South Trinidad	1.4
San Fernando	0.5
Mayaro	-
Toco	-
Chaguaramas	0.6
<u>Tobago</u>	
Southwest	-
Windward Coast	-
Total	6.0

Federation Chemicals is the largest single user depending entirely on WASA. Their demand is approximately 1⁺ mgd. The Port Authority and Trinidad Cement Ltd. are respectively, the second and third largest users of WASA water. WASA's remaining industrial customers numbering about 150 use small quantities.

Besides Texaco, other large users with private supply sources are Shell Trinidad Ltd., Tesoro Trinidad Ltd., Caroni Estates Ltd., The Trinidad Sugar Estates Ltd., and the Trinidad and Tobago Electricity Commission. Together these companies produce and use approximately 5.2 mgd. The remaining 1.6 mgd produced privately comes from groundwater and is divided among about 30 different concerns.

Water for gravel-washing is withdrawn from the Arima, North Oropouche and Caroni Rivers in Trinidad, and the Courland River in Tobago. However, gravel-washing is a non-consumptive use since the water is returned to its source immediately after use downstream of the point of withdrawal. Although gravel-washing is of major concern as a source of pollution, it does not affect the quantity delivered by the source from which the water is withdrawn. Pollution caused by gravel-washing is not a threat to health. Its worst effects are that it increases the cost of treatment and would increase silting if practised upstream from a reservoir.

Irrigation. Irrigation is practised widely in Trinidad, and consists primarily of small diversions from creeks and streams built by private individuals. Some irrigation is also practised in floodplains where part or all of the streamflow can be diverted by gravity flow. This type of irrigation takes place on a small scale on the Guanapo, Aripo and San Juan Rivers, and on a large scale on the Caroni and South Oropouche Rivers. The largest engineered irrigation system is the Caroni System constructed in 1949 to serve the surrounding rice fields. This system diverts up to 12 mgd from the Caroni River at

the Kelly Headworks via a feeder canal to the Guayamare River from which feeder canals distribute the water over an area of about 3,000 acres. Similar projects are planned for the Oropouche Lagoon and the Nariva Swamp. Total irrigation use is estimated at 20 mgd during the dry season.

WASA does not furnish irrigation water, nor do any of the proposed projects include irrigation as a benefit. However, as the principal water resource agency in Trinidad and Tobago, WASA is responsible for approving the withdrawal of water from any stream or groundwater aquifer. This procedure is designed to prevent indiscriminate development from interfering with the existing and proposed supplies of the Authority. To date the Authority has not been faced with the problem of irrigation as a competitive use for any of the proposed sources. However, it is suspected that irrigation will be a problem in the future when the available groundwater resources become fully exploited and the Authority must turn to surface supplies to meet increasing demands.

Waste and Loss. In systems that are fully metered there is usually a difference between metered production and water use as measured by the customer's meter. This difference is usually referred to as 'unaccounted for' water and includes leakage, fire-fighting and flushing water and under-registration of meters. Unaccounted for water may range from 5 to 50 percent of total production. In well managed systems it rarely exceeds 20 percent.

In unmetered systems leakage is the primary concern. In a

tight transmission and distribution system, 10 percent leakage is considered a reasonable figure. This figure does not include leakage in the customers' system, which can be excessive when billing is not based on the amount used. Leaks that do not cause much inconvenience to the customer, such as a leaking water closet or a broken float valve on a storage tank are not readily repaired since wasting the water costs less than fixing the leak. Even when the customer has the best of intentions many leaks go unnoticed, but in a metered system such leaks would eventually be recognized through a large water bill.

Complete information on waste and loss in the present system is not available. Therefore, as mentioned earlier, estimates of waste and loss have been included with domestic use in the analysis of present water use. Some idea of the amount of waste can be determined by studying the per capita consumption figures listed in Table 12. In areas with 100 percent plumbing studies of recent meter records in Port of Spain indicated that 60 gpd should be a reasonable usage. In Diego Martin where daily per capita use in 1968 was estimated at 89 gallons, a waste and loss survey conducted for this study found 161 leaks representing an estimated loss of 1 mgd. After most of these leaks were repaired, production dropped by about 28 percent. Minimum controllable system loss is estimated to be 20 percent, that is to say, the minimum reduction in demand that could be achieved by an effective program of leak detection and repair, and metering of all direct connections.

Future Water Requirements

Future water requirements are projected for domestic and

industrial demands. It is assumed that private supplies will continue to operate at the present level and will neither increase nor decrease production in the future. The largest of the existing private supplies were constructed by the oil companies because there was no public water system that could meet their requirements. Most of the areas served by private systems are now served by WASA as well, and the need for new private supplies or expansion of existing supplies no longer arises. Projections assume that all future water requirements over and above existing production from both WASA and private sources will be provided by WASA through its pipe-borne water system. No projections have been made for irrigation water since WASA, as pointed out before, is not expected to supply water for this type of use.

Domestic Water Requirements. Estimates of future domestic water requirements are based on population projections and estimates of per capita demand in each sub-area. Area domestic water requirements are the sum total of the sub-area requirements. Table 14 lists future domestic requirements by area. In computing demands, total population instead of population served was used since the demand of the unserved population is small and undefined as to location. Therefore, figures for demand represent the total requirements in all areas rather than the system demand, and the difference between the two is less than 2.0 mgd for all of Trinidad and Tobago. In areas where the percentage of the unserved population is high and where the majority of users are on standpipes or served by truck, these conditions are reflected in the per capita use value selected for the area.

Table 14. Future Domestic Average Annual Demand

Area	1975		1980		1985		2000	
	Per capita, Total,		Per capita, Total,		Per capita, Total,		Per capita, Total,	
	qcd	mgd	qcd	mgd	qcd	mgd	qcd	mgd
<u>Trinidad</u>								
Chaguaramas	63	0.3	65	0.7	68	1.2	75	2.9
Port of Spain	63	12.4	66	14.1	69	16.0	75	21.0
Eastern Main Road	50	15.8	54	19.0	57	22.3	65	33.9
Caroni	37	5.1	43	6.7	49	8.4	60	13.3
Sangre Grande	37	1.7	43	2.2	49	2.6	60	3.8
Diego Martin	63	3.2	66	3.9	69	4.6	75	6.6
Montserrat	48	0.3	51	0.4	55	0.5	68	0.8
San Fernando	63	4.9	66	5.4	69	5.9	75	7.5
South Trinidad	41	15.0	45	18.0	50	22.0	62	37.2
Mayaro	49	0.5	52	0.6	56	0.6	66	1.0
Toco	39	0.3	40	0.4	42	0.4	50	0.6
North Coast	49	0.2	53	0.3	56	0.3	66	0.5
<u>Tobago</u>								
Southwest	39	1.1	40	1.2	42	1.4	50	2.2
Windward Coast	31	0.2	32	0.3	33	0.3	36	0.4
Rural	30	0.1	30	0.1	30	0.1	30	0.1
Total	48	61.1	52	73.3	56	86.6	65	131.1

Estimated per capita production in 1968 for domestic use was 46 gallons per day. Although this value should have been adequate, demands were not satisfied in all the areas served. It is estimated that the actual per capita demand at present is 58 gallons per day. This value is excessive and the reasons for such a high per capita demand are: excessive system leakage due partly to high pressures in some areas of the system, leakage in private plumbing systems and wasteful water use practices. The Authority can control pressures and system leakage, but can do very little about the customers' plumbing or water use habits. Waste and loss can only be controlled by charging realistic water rates based on metered use. In assigning per capita demands it has been assumed that new water rates will be implemented on the basis of metered use, and that the meter rates charged will be high enough to encourage water conservation and thereby reduce per capita demand. Establishment of future per capita demand on an average value of 58 gallons per day would result in expenditure that the Authority could not afford to pass on to users. It is also a fact that most lending institutions make the adoption of adequate rates based on metered water sales a prerequisite to granting loans for water system improvements. Therefore, it can be assumed that metering and an increase in rates will occur out of economic necessity.

Per capita demand values selected for design by sub-area are listed in Appendix C. The selected values and the weighted averages for each area and for Trinidad and Tobago are listed in Table 14.

Per capita use is expected to increase in all areas from

the initial values. Increases will be greatest in areas with a higher percentage of standpipes, as the percentage of direct connections and the number of houses with plumbing increase. Figure 6 shows the projected increase in the maximum, minimum and average per capita demand values selected for design.

Industrial Requirements. Industrial consumption can be expected to increase at a greater rate than the growth in population. Industrial use is now equal to 20 mgd. By the year 2000 it is estimated that per capita industrial use will increase to 29 gpd, equivalent to 58 mgd of which 38 mgd must be supplied by WASA.

Studies and investigations indicate that the greater proportion of the industrial growth, and consequently the demand for industrial water will occur along the Eastern Main Road near Port of Spain, and southward between Port of Spain and San Fernando. Table 15 shows the allocation of the future industrial demand by water service area.

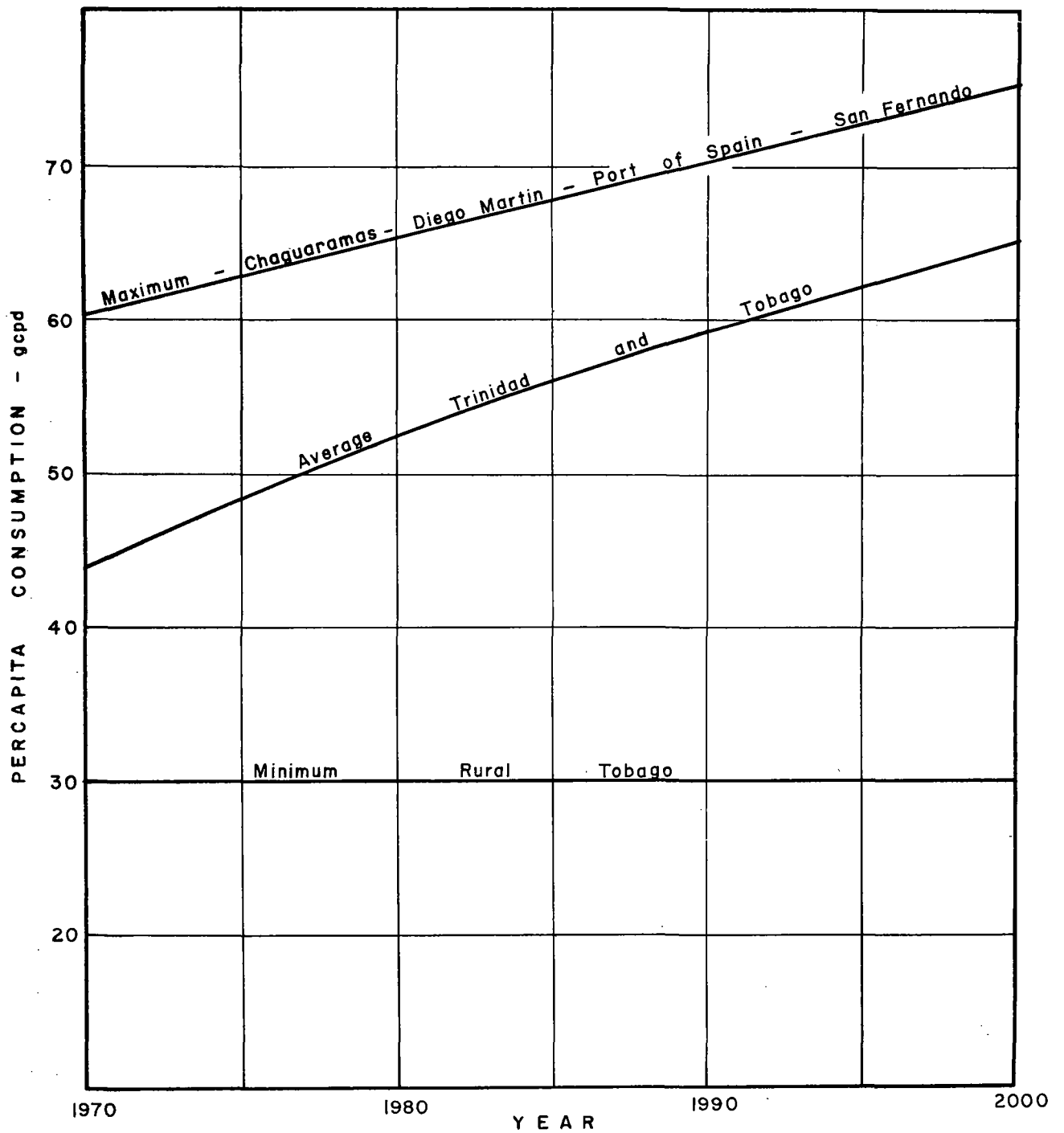


FIG. 6 PROJECTED PER CAPITA DEMAND

Table 15. Future Industrial Water Allowance

Area	Allowance, mgd				
	1970-74	1975	1980	1985	2000
<u>Trinidad</u>					
Chaguaramas	0.7	0.7	0.9	1.0	1.5
Port of Spain	2.8	2.8	3.3	3.7	5.0
Eastern Main Road	1.4	2.3	2.9	3.5	5.3
Caroni	0.1	0.2	0.2	0.2	0.2
Sangre Grande	-	0.1	0.1	0.2	0.4
Diego Martin	0.1	0.1	0.1	0.2	0.3
Montserrat	-	-	-	-	-
San Fernando	0.9	0.9	1.4	1.8	3.0
South Trinidad	2.7	3.2	4.6	6.0	9.5
Mayaro	-	0.1	0.1	0.2	0.4
Toco	0.1	0.2	0.2	0.3	0.4
North Coast	0.1	0.2	0.2	0.3	0.5
Petrochemical Demand	2.0	5.0	6.5	7.5	10.0
<u>Tobago</u>					
Southwest	0.4	0.5	0.6	0.8	1.5
Windward Coast	-	-	-	0.1	0.2
Rural	-	-	-	0.1	0.1
Total	11.3	16.3	21.1	25.9	38.3

The projections of industrial use shown in Table 15 are called allowances rather than demands in view of the uncertainties of future industrial development. It is felt that they will allow for a reasonable rate of growth in the manufacturing and industrial capability in Trinidad. However, it should be remembered that one large industry could easily change these requirements. The recent off-shore oil and gas find by AMOCO (formerly Pan American Oil) represents such a situation. AMOCO is currently considering the feasibility of constructing a gas liquefaction plant or petrochemical plants in Trinidad to utilize the gas from their find. The requirements for such plants are estimated at 2 mgd. initially, increasing to 5 mgd. within a three year period and later reaching 10 mgd. or more. Since the need for this water is a definite possibility, ample allowance for a large petrochemical industry has been made in the projections. The precise location of the industry or industries is not yet fixed, However, both Point Fortin and Point Lisas are under consideration, and for purposes of sizing future transmission mains, capacity has been provided for making this quantity of water available at San Fernando, that is, midway between the two areas under consideration.

Included in the estimates of industrial use are institutional water, Government use, farm use and hotel use, which were all included with industrial use primarily because of their unpredictability and the amount involved. Industrial demands in Tobago and along the Mayaro, Nariva, Balandra, the north and east coasts of Trinidad are hotel demands. Agricultural demands, which include water for livestock

but not for irrigation, are located in Waller Field, Carlsen Field and Tobago. Industrial demand in the Eastern Main Road area, Port of Spain, San Fernando and Point Fortin includes manufacturing, institutional and hotel requirements.

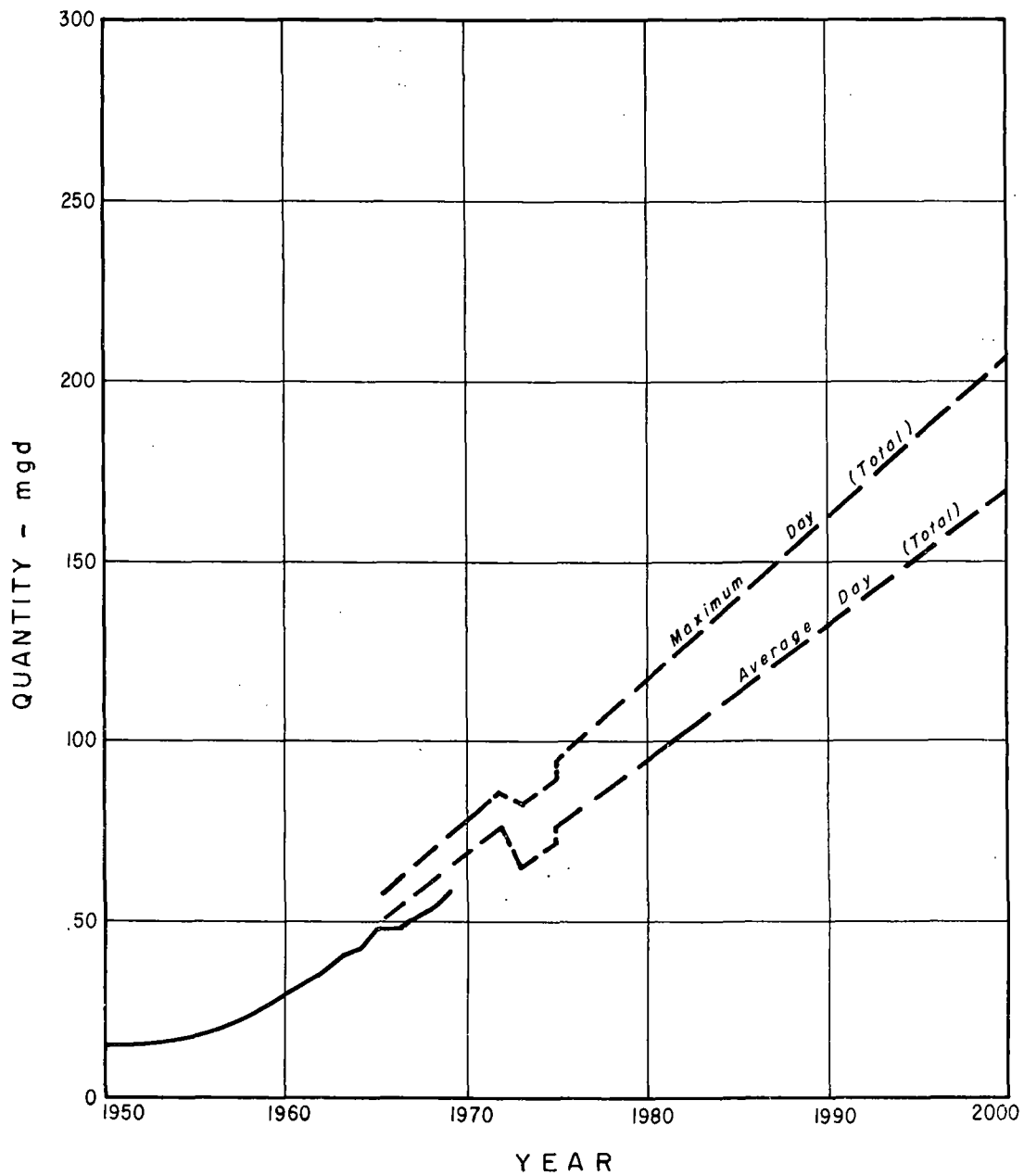
Total Requirements

Total annual average water requirements for Trinidad and Tobago are shown graphically in Figure 7 and listed by area in Table 16. The quantities shown are the sum total of projections for domestic and industrial requirements to be supplied by WASA. WASA's past production is also shown.

Variations in Demand

So far, only annual average water requirements have been discussed. In actual practice the demand for water does not remain constant but varies from season to season and from day to day, and even from hour to hour. In order to meet daily fluctuations, water treatment plants and certain distribution facilities are commonly designed to meet the maximum demand that could occur over a 24 hour period, that is to say, the average during the period. Secondary distribution facilities are designed to meet the highest one-hour average rate of demand that could occur.

Maximum one-day and maximum one-hour demands are generally expressed as a percentage of the annual average daily demand. Estimates of future maximum one-day demands assume a ratio of 125 percent for domestic demands while industrial demands are assumed to be 200 percent of the annual average daily demand, regardless of the type of use.



LEGEND

- Past Production
- - - - - Future Demand

FIG. 7 PAST WATER PRODUCTION & FUTURE DEMAND
TRINIDAD & TOBAGO

Table 16. Future Average and Maximum Day Requirements

Area	1975		1980		1985		2000	
	Ave.	Max.	Ave.	Max.	Ave.	Max.	Ave.	Max.
<u>Trinidad</u>								
Chaguaramas	1.0	1.2	1.6	1.9	2.2	2.6	3.9	4.7
Port of Spain	15.2	18.6	17.4	21.2	19.7	24.1	26.0	31.8
Eastern Main Road	18.1	22.3	21.9	26.9	25.8	31.7	39.2	48.2
Caroni	5.3	6.6	6.9	8.6	8.6	10.7	13.5	16.8
Sangre Grande	1.8	2.2	2.3	2.9	2.8	3.5	4.2	5.2
Diego Martin	3.3	4.1	4.0	5.0	4.8	6.0	6.9	8.6
Montserrat	0.3	0.4	0.4	0.5	0.5	0.6	0.8	1.0
San Fernando	5.8	7.1	6.8	8.3	7.7	9.4	10.5	12.7
South Trinidad	18.2	22.3	22.6	27.6	28.0	34.1	46.7	57.0
Mayaro	0.6	0.7	0.7	0.9	0.8	1.0	1.4	1.7
Toco	0.5	0.6	0.6	0.7	0.7	0.8	1.0	1.2
North Coast	0.4	0.5	0.5	0.6	0.6	0.7	1.0	1.2
Petrochemical demand	5.0	5.5	6.5	7.2	7.5	8.3	10.0	11.0
<u>Tobago</u>								
Southwest	1.6	1.9	1.8	2.2	2.2	2.6	3.7	4.4
Windward Coast	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.7
Rural	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.4
Total	77.4	94.3	94.4	115.0	112.5	136.8	169.7	206.6

Fire Flow Requirements

Good design practice requires that a distribution system be capable of providing the maximum daily demand plus the required fire flow. In small distribution systems fire flows are the controlling factor in the design. However, since fire flows are generally supplied from distribution storage, they are not considered as a factor in the design of major transmission or supply systems.

ADEQUACY OF THE EXISTING SYSTEM

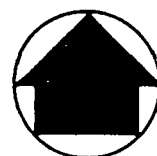
General

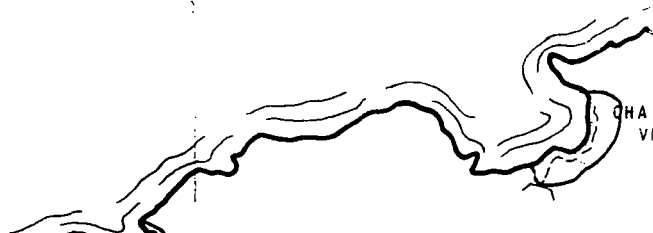
The existing system was evaluated primarily on its ability to supply present and future demands within the existing service area. Other factors considered were the quality of the water produced and the material condition of the existing facilities. The evaluation procedure consisted of interviews with WASA's engineers and operating personnel, pressure surveys, pipe condition tests, visual inspection of existing facilities, and analyses of operating records. In order to get the customers' point of view, questionnaires were sent out to the heads of Village Councils throughout Trinidad and Tobago requesting comments on the adequacy of the water supply in their respective areas. Response to the questionnaires was 51 percent. Of the replies received 75 percent indicated dissatisfaction with the present service. These complaints were cross-checked with known problem areas to ensure that each problem would be eliminated by the recommended improvements where correction was economically feasible. A summary of the results of this survey is included in Appendix D.

Supply

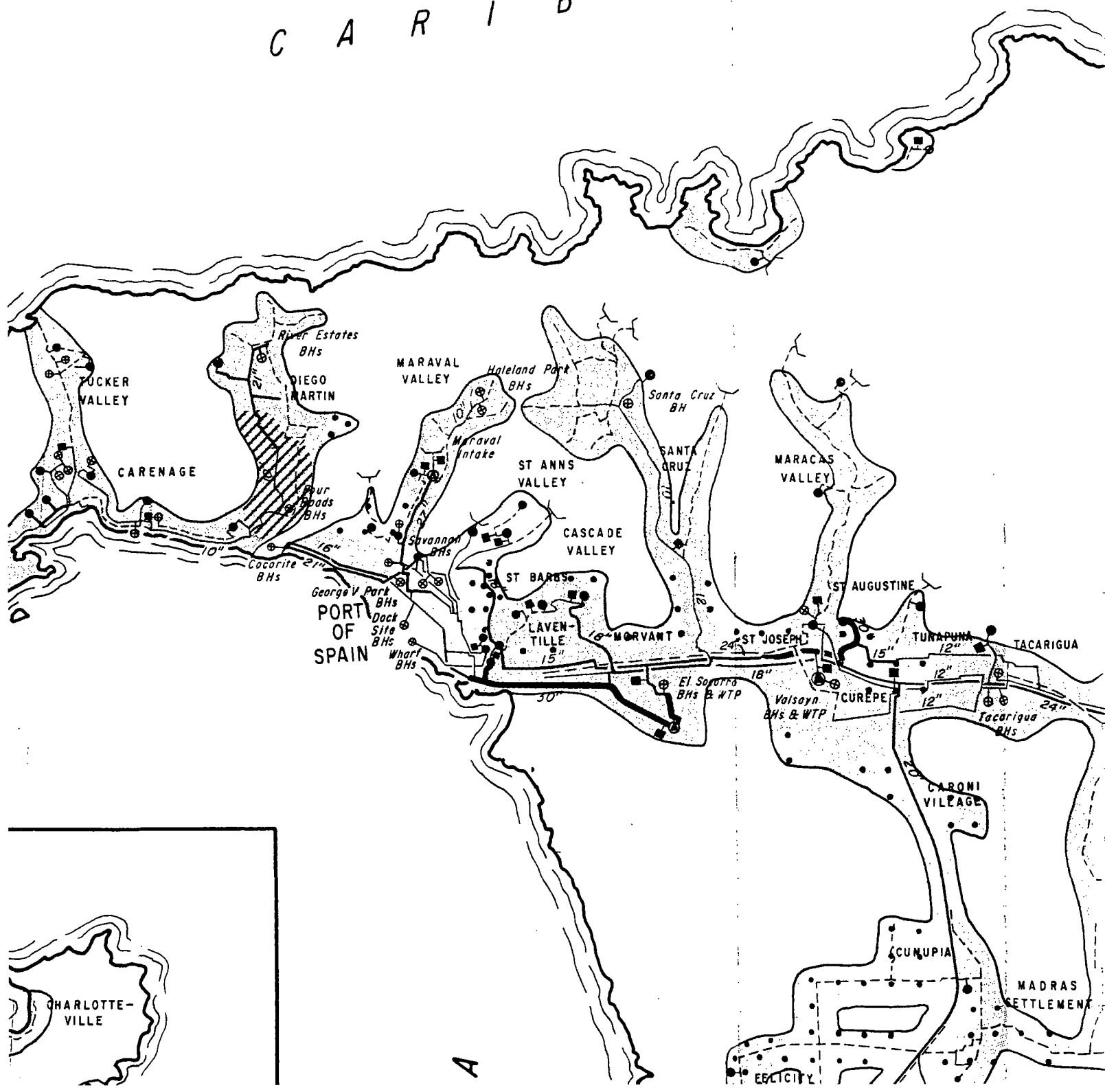
The demand curve for Trinidad and Tobago shown in Figure 6 indicates a 1970 maximum day demand of 78 mgd. Existing production - 18 mgd capacity, both maximum and average, is only 60 mgd. Demands will continue to increase until 1973 when a 20 percent reduction is expected from metering. Before metering becomes effective in 1973, however,

average and maximum day demands are expected to reach 75 and 85 mgd. respectively. These are the critical demands that must be met before completion of a major supply project. Table 17 lists the available supply to the major water areas and the additional supply required to meet average and maximum day demands in the years immediately prior to the construction of a major source of supply, and for the long term. Water deficient districts within the existing service areas are shown on Figure 8.

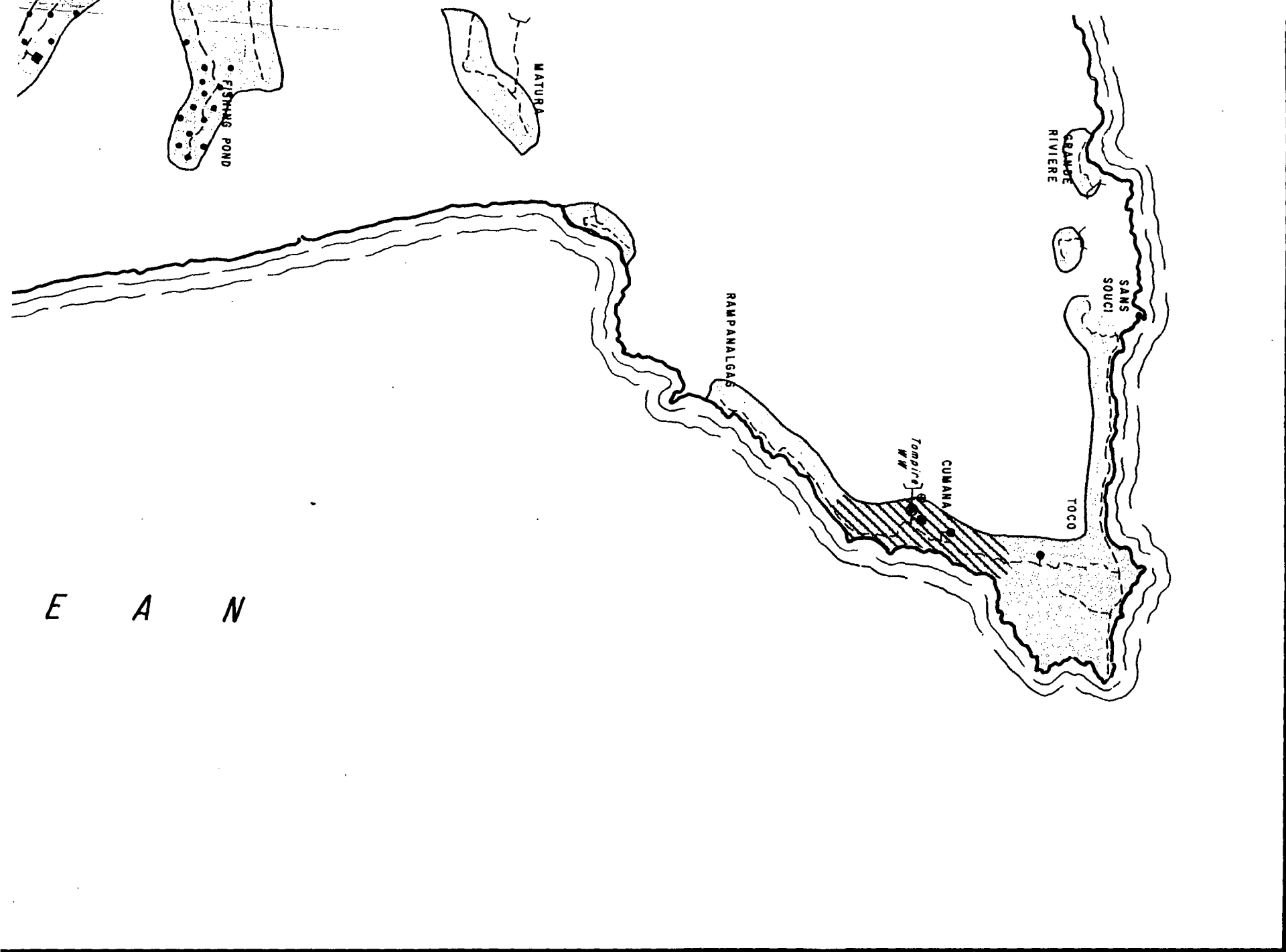


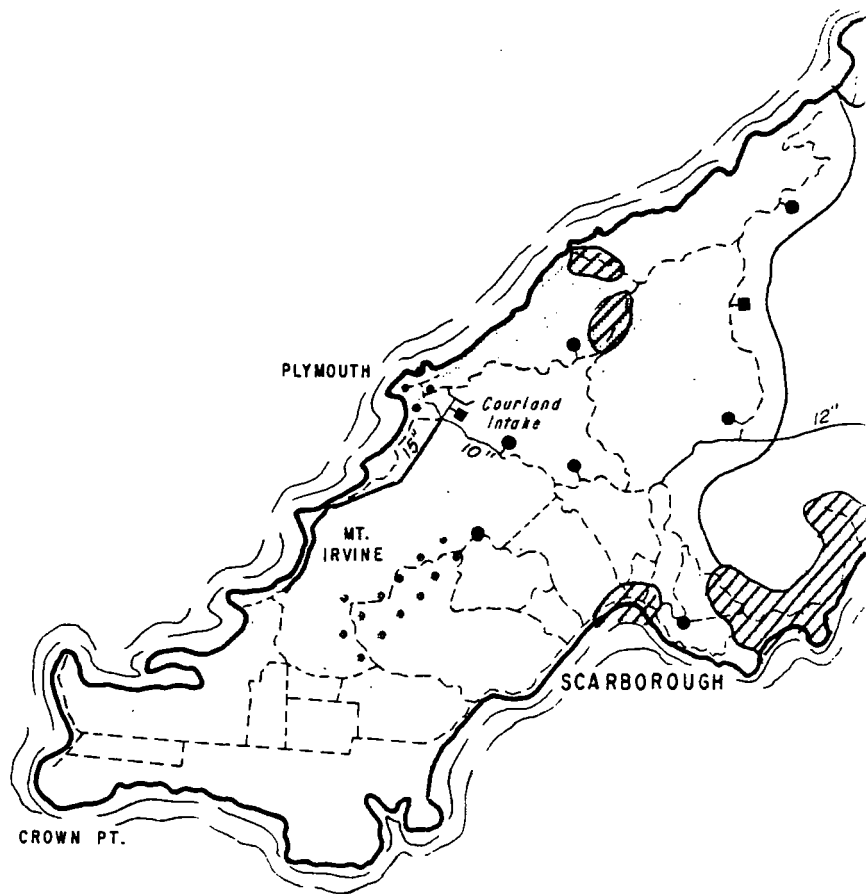


C A R I B B E A N



This map illustrates the water supply infrastructure in the Arica region. A network of lines, some solid and some dashed, represents water pipelines. Key locations marked include TACARIGUA, AROUCA, D'ABADLE, ARIMA, VALENCIA, CUMUTO, GUAICO, CORYA, NESTOR, SANGRE GRANDE, and MADRAS SETTLEMENT. Specific points of interest are labeled as 'Arica BHs', 'Waller Field BHs', 'Waller Field BHs & WTP', and 'HOLLIS RESERVOIR'. Pipeline diameters are indicated by numbers in quotes (e.g., 24", 15", 10", 12", 26"). The map also shows the coastline and several islands, including MATELOT and CUMACA.





LEGEND



Infrequent interruptions in supply usually during season resulting from supply shortage at the source



Frequent interruptions in supply during both wet seasons resulting from supply shortage at source or minor distribution deficiencies.



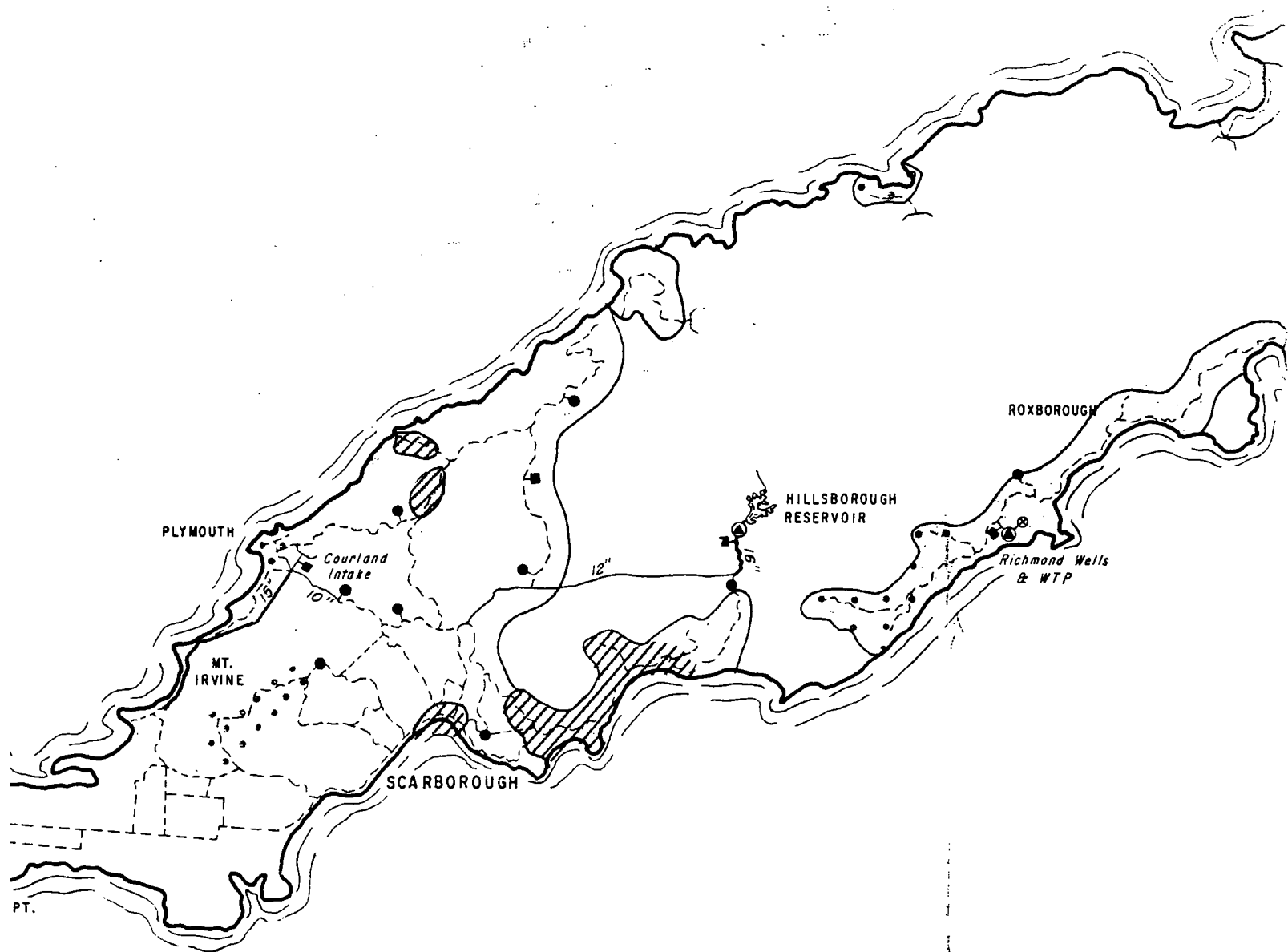
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Service good.



Excessive pressure.



LEGEND

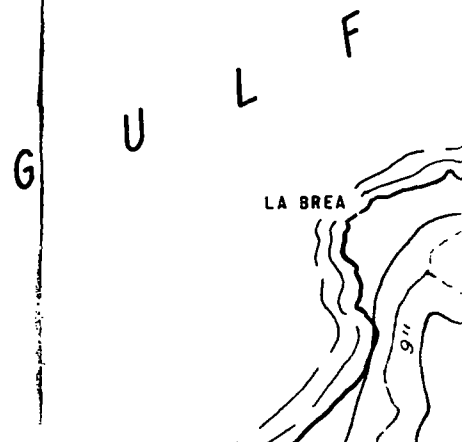
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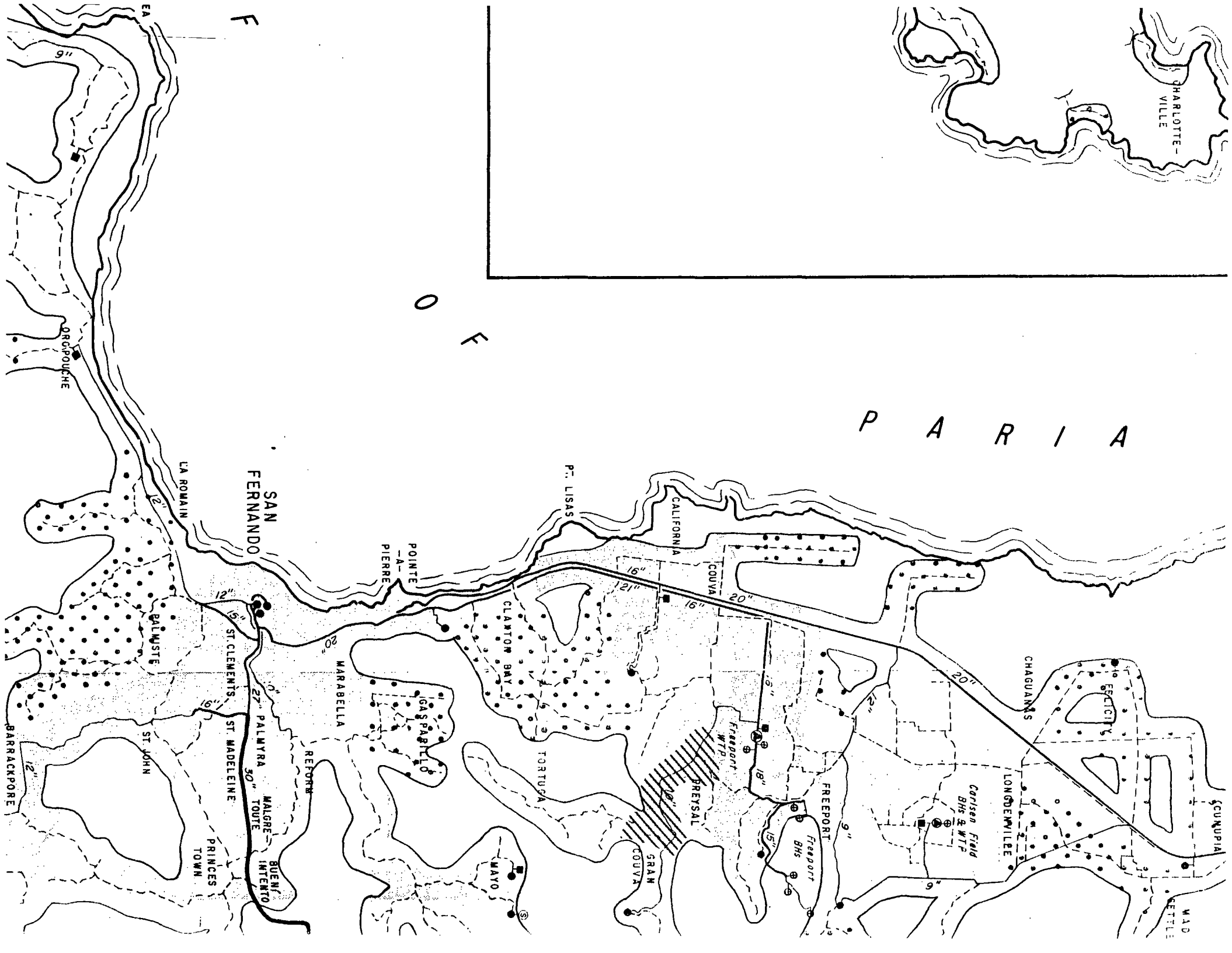
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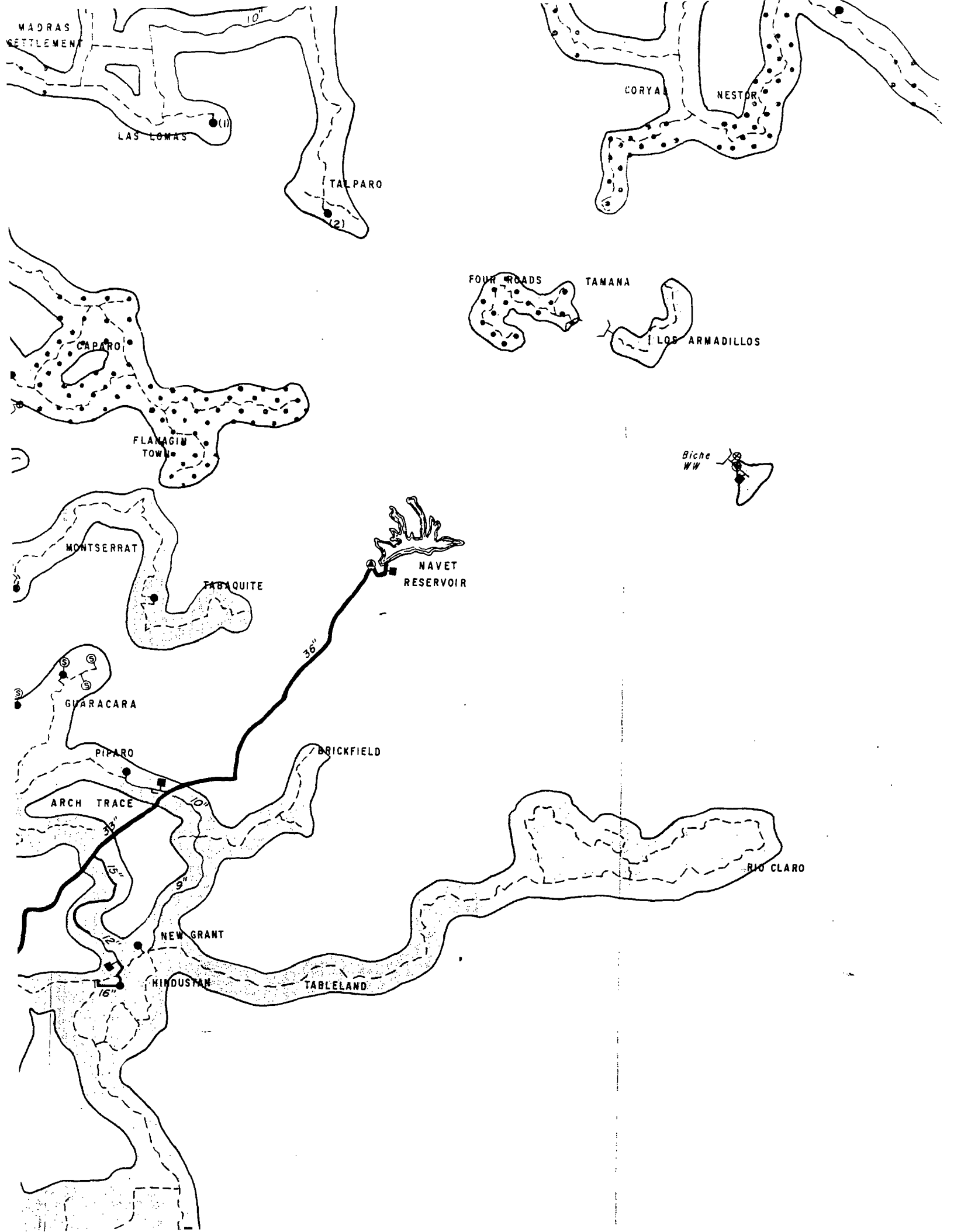
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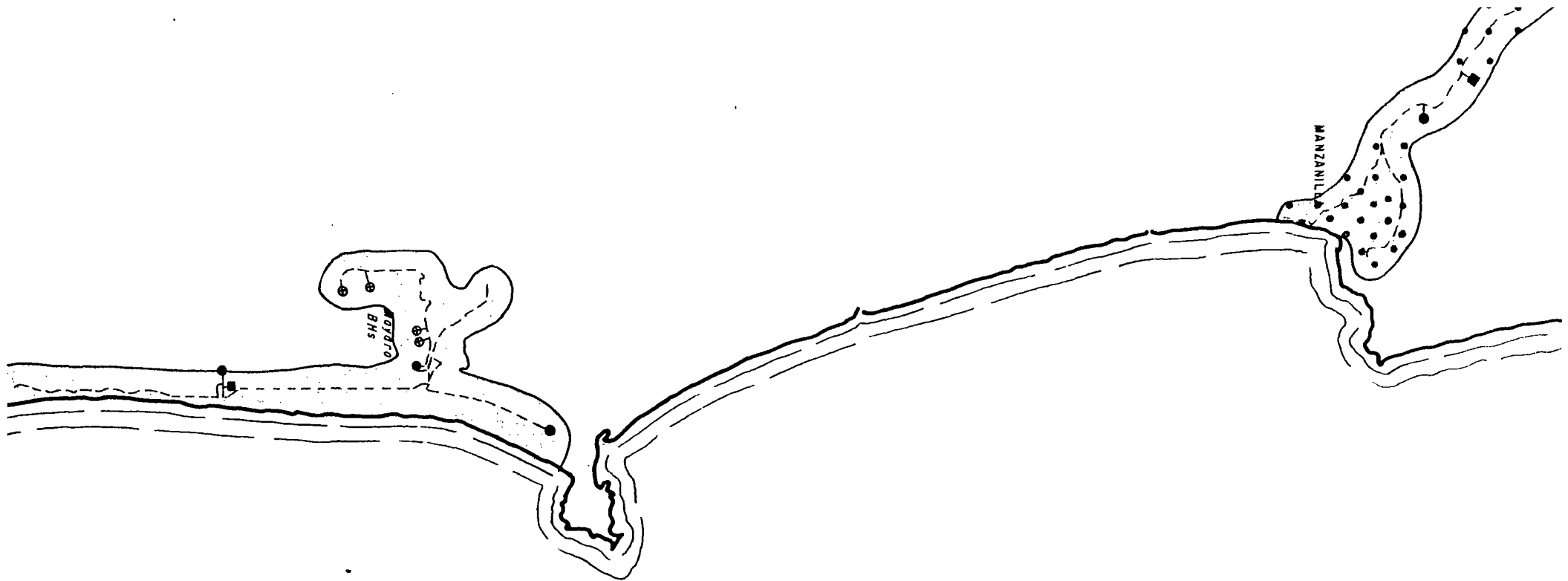
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





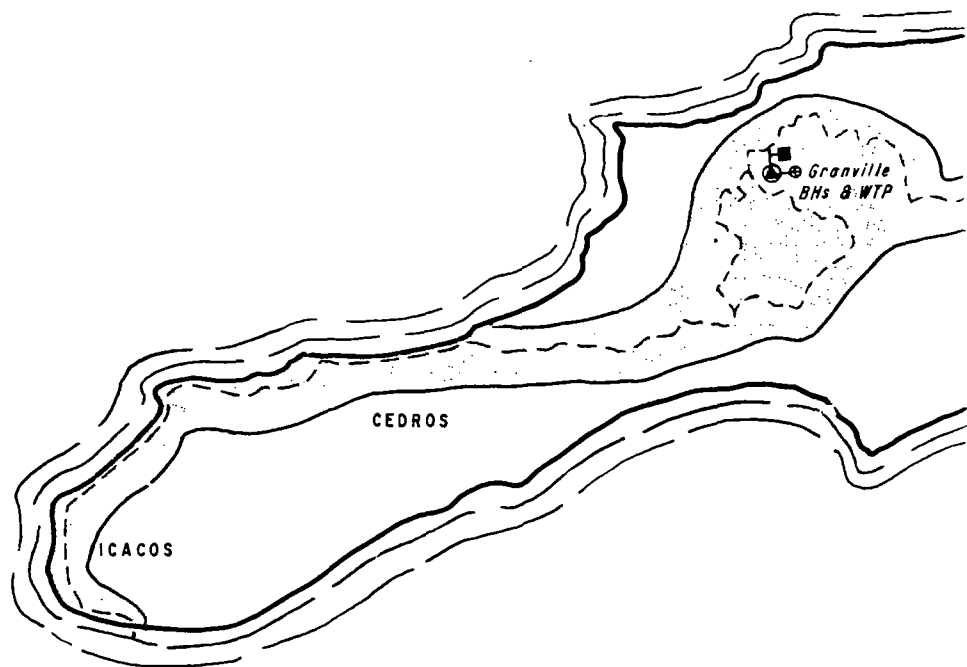
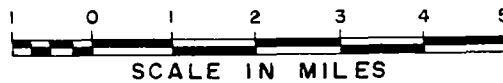


A T L A N T I C

O C E



-  Infrequent interruptions in supply usually during season resulting from supply shortage at the source.
-  Frequent interruptions in supply during both wet seasons resulting from supply shortage at source or minor distribution deficiencies.
-  Service shortage during wet and dry seasons with being available less than 20% (percent) of the time. Resulting from distribution system inadequacy as well as shortage at the source.
-  Service good.
-  Excessive pressure.



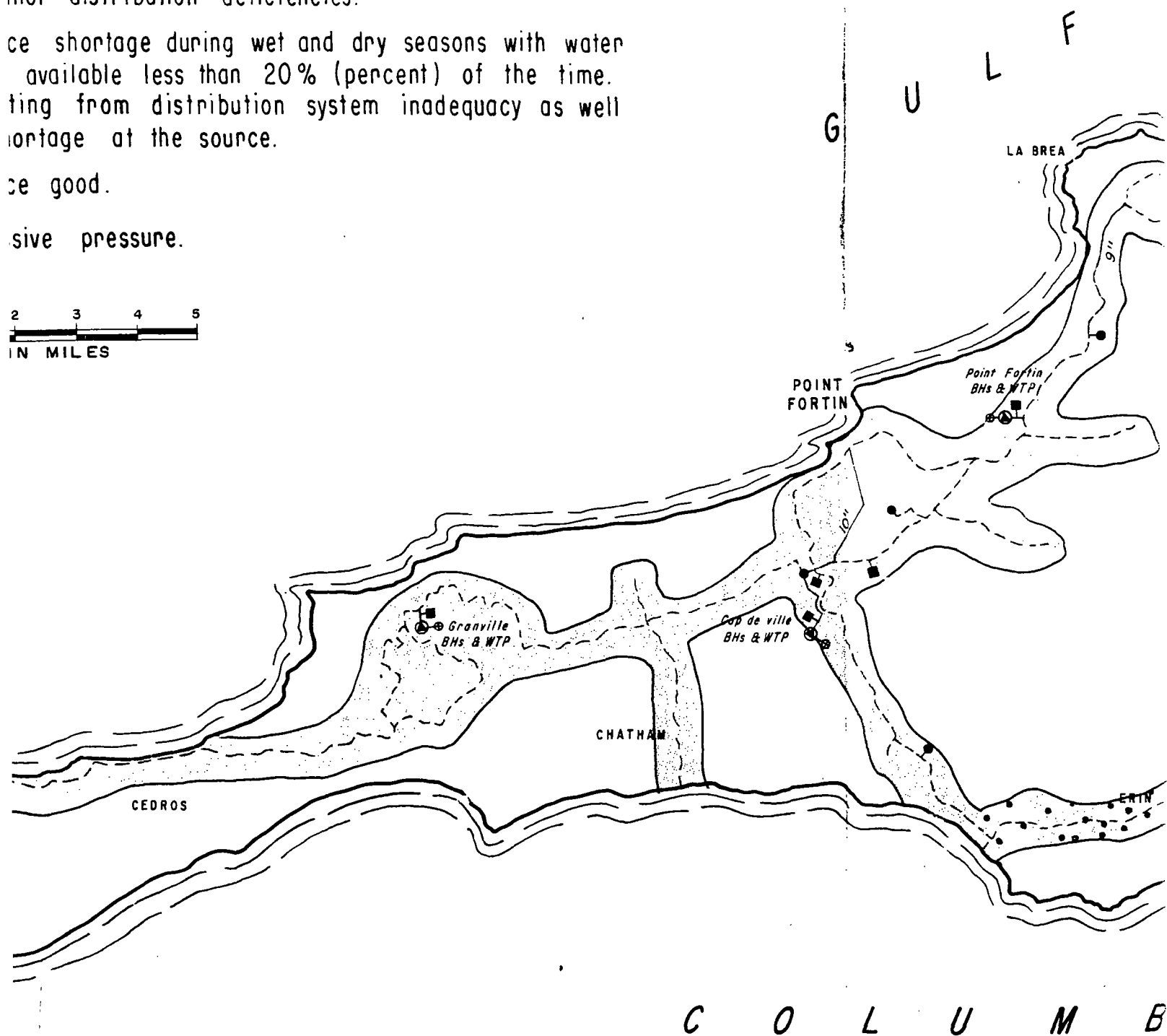
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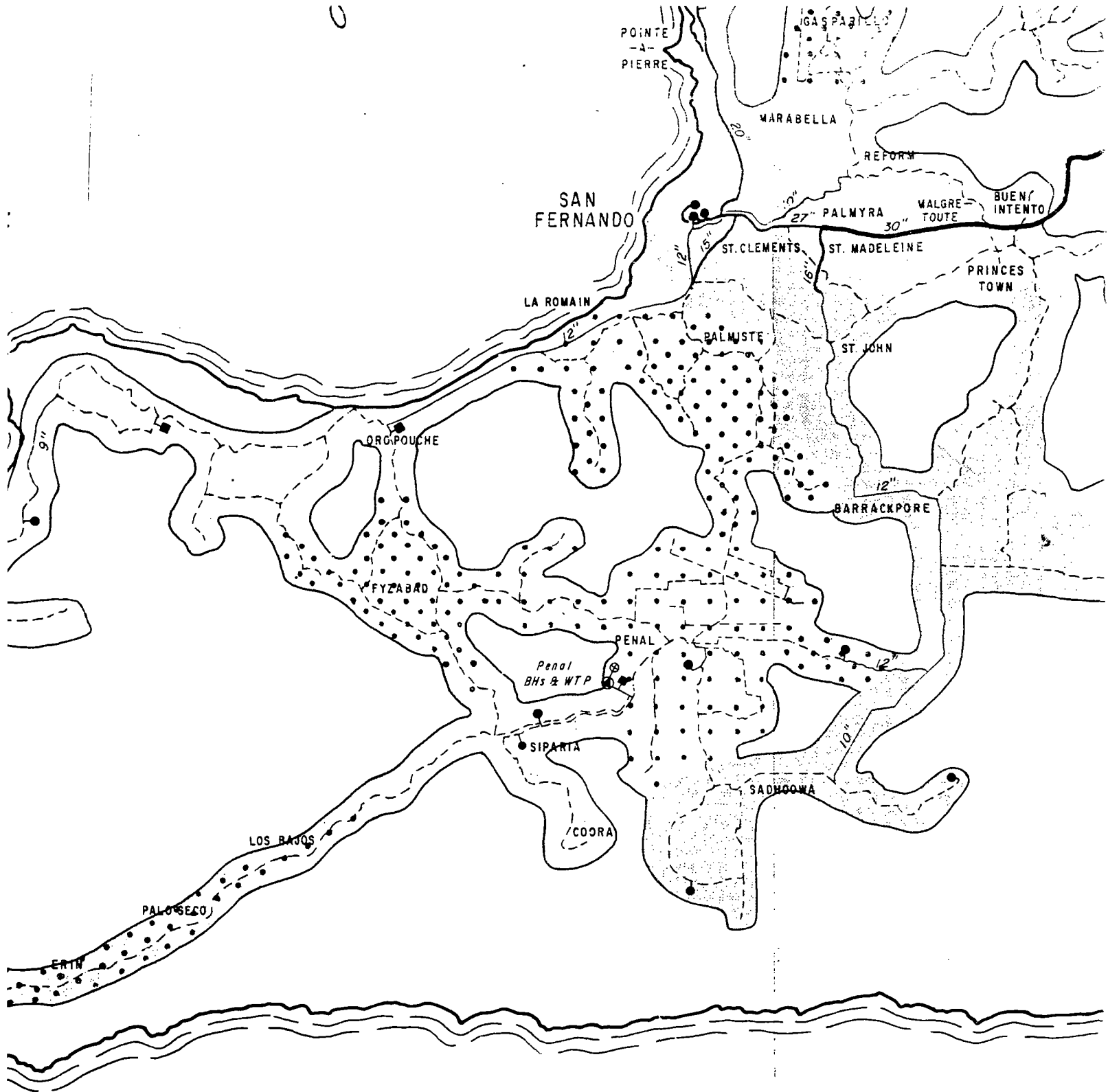
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B U S

C H A N N E L

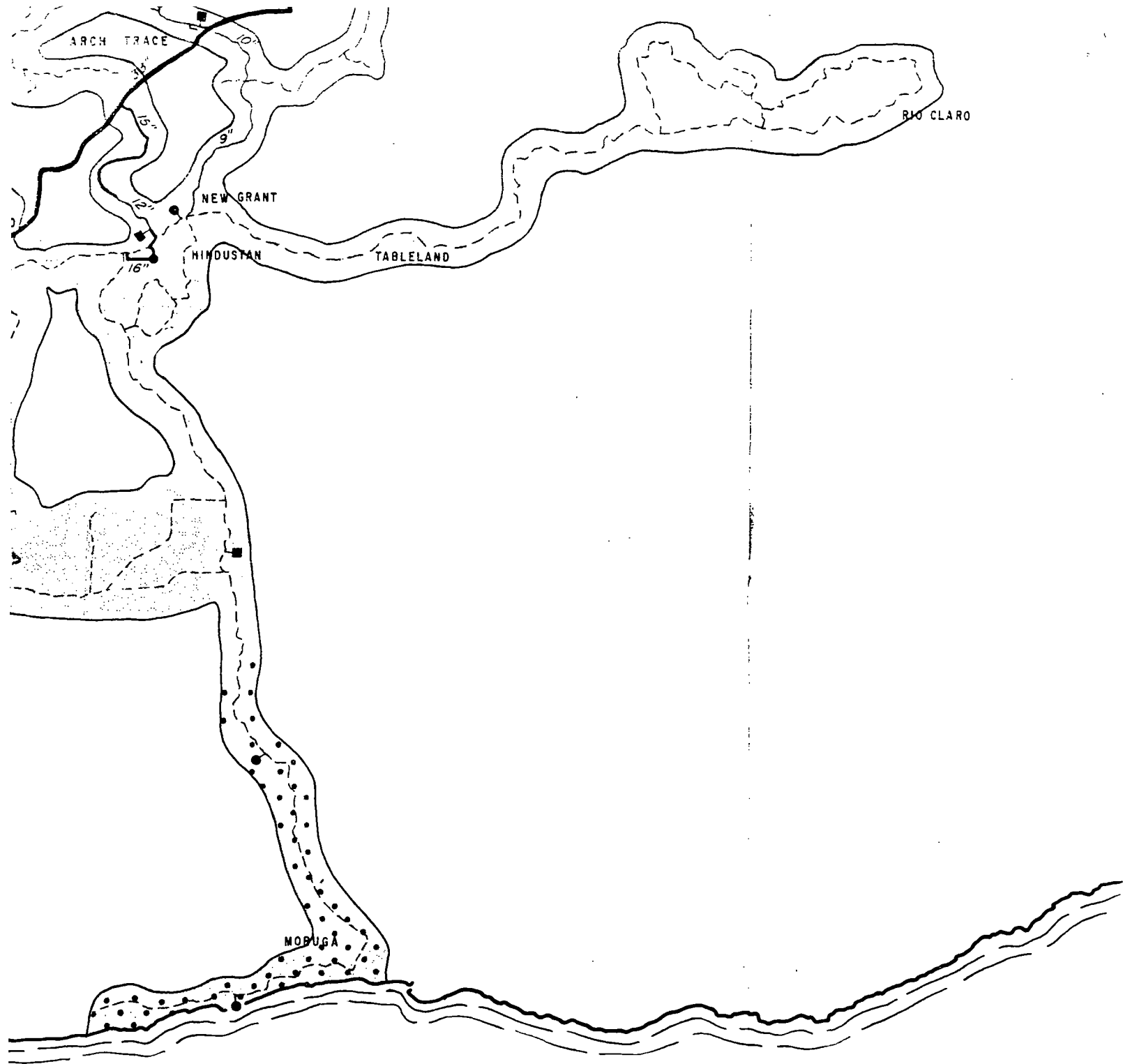
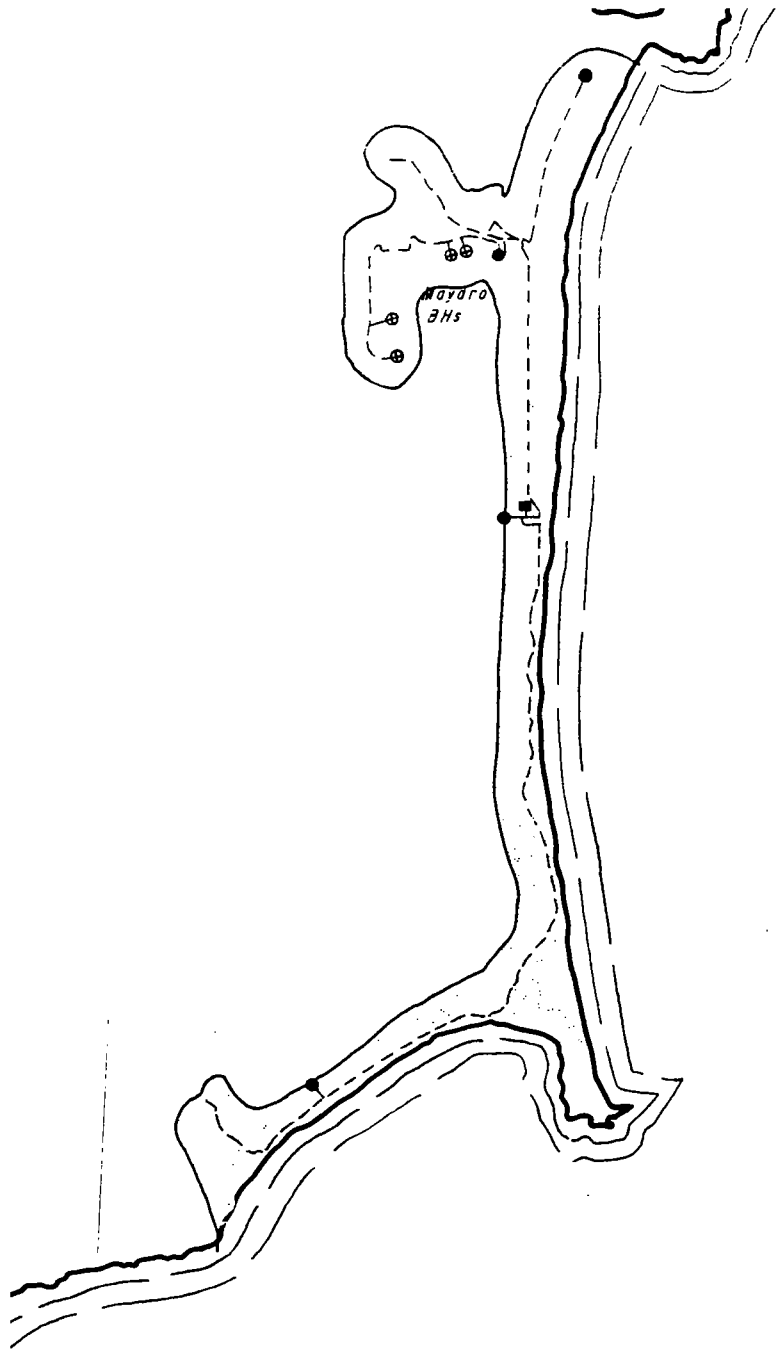


FIG.8 PROBI

L



A T L A

PROBLEM AREAS - TRINIDAD AND TOBAGO

METCALF & EDDY

Table 17. Supply Deficiencies by Water Area

Area	Developed supply (1) mgd		Supply deficiency, mgd							
			1970		1973		1974		2000	
	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.
<u>Trinidad</u>										
Chaguaramas	1.5	1.5	-	-	0.1	0.2	-	-	2.4	3.2
Diego Martin	3.9	4.7	-	-	0.5	0.6	-	-	3.0	3.9
Port of Spain	10.4	17.0	8.1	2.9	9.4	4.4	4.8	1.6	15.6	14.8
Eastern Main Rd.	15.6	17.7	1.2	2.6	3.6	5.2	1.1	2.9	23.6	30.5
Sangre Grande	1.6	1.6	-	-	-	0.2	0.1	0.5	2.6	3.6
Toco	0.3	0.3	-	0.1	0.1	0.2	0.1	0.2	0.7	0.9
North Coast	0.3	0.3	-	-	-	-	-	-	0.7	0.9
South Trinidad	3.0	6.4	8.5	7.7	10.4	10.4	12.6	12.7	43.7	50.6
Caroni	3.3	3.9	1.5	1.9	2.1	2.6	2.2	3.0	10.2	12.9
Montserrat	0.6	0.6	-	-	-	0.1	-	-	0.2	0.4
San Fernando	6.4	7.0	-	-	0.5	0.6	-	-	4.1	5.7
Mayaro	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.2	1.2	1.4
Petrochemical demand	-	-	-	-	-	-	2.0	2.2	10.0	11.0
<u>Tobago</u>										
Southwest	2.0	2.0	-	-	-	0.7	-	-	1.7	2.4
Windward Coast	0.2	0.2	0.1	0.2	0.1	0.2	-	-	0.4	0.5
Rural	<u>0.1</u>	<u>0.1</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>0.2</u>	<u>0.3</u>
Total	49.4	63.6	19.6	15.6	27.1	25.7	23.1	23.3	120.3	143.0

1. Based on capacities listed in Tables 3 and 4. Maximum day capacities of surface water intakes assumed equal to dependable yield. Maximum day capacities of other sources assumed equal to installed production capacity. Average day capacities are based on developed dependable yield.

Treatment

Except for the rural intakes which are all small, there are only two large supplies that do not receive some form of treatment other than disinfection. These are the boreholes at Tacarigua and Arouca. While bacterial tests show that the water is safe, chlorination should be practised for preventive reasons, and aeration facilities should be provided for stabilization.

Treatment methods employed for iron removal, turbidity and stabilization are in general adequate and should be continued. Equipment at the temporary plants at Carlsen Field and Penal is antiquated or inoperative and should be replaced. Treatment problems exist at the surface water intakes, particularly at Maraval, Tompire, and Courland. At Courland, turbidity is a constant problem caused by gravel-washing operations upstream of the intake. The existing roughing filter can partly cope with this turbidity with constant maintenance. It is completely inadequate for handling the increased turbidity that occurs after heavy rainfalls. This same problem of turbidity after rains exists at all the other intakes. A water treatment plant is currently under construction at the Maraval Intake in order to allow continuous withdrawals from this source. Similar plants are required at Tompire and at Courland. A treatment plant for Valencia is not recommended since the Hollis Reservoir can be used as an alternate supply during periods of high turbidity with very little effect in the flow rate to other areas of the system.

Transmission and Primary Distribution

Areas shown on Figure 8 as having the greatest supply deficiency are generally the same areas with inadequate transmission and distribution systems. An increase in supply in these areas is not expected to solve the water shortage problem. Deficient pressures in general result from long lengths of undersize mains and inadequate storage capacity. In areas such as Diego Martin, high pressures are a problem. High pressures result from inadequate segregation of the system into low- and high-pressure service areas. Specific deficiencies are discussed in detail in Appendix D.

Storage

Supply and treatment facilities are sized to meet maximum one-day demands. The additional water to meet peak demands of short duration normally comes from distribution storage. Existing operational storage facilities have a total capacity of 51 mg in Trinidad and Tobago which is 65 percent of the estimated 1970 maximum day demand. At least 25 percent of the maximum day demand is required to meet peak demands. Storage must also be provided to meet fire-fighting requirements and to provide an emergency supply in case of a breakdown in supply or treatment facilities. Storage provided for these purposes is in effect insurance against the unexpected, and thus the criterion "as much as you can afford" is sometimes used. We recommend that in the future, storage required for fire-fighting and emergencies together with dead storage be at least 25 percent of the maximum day demand in areas served by two or more sources. Total storage requirements in

these areas would thus be about 50 percent of the maximum one-day demand. In areas where the demand is small and the supply is from a single source, emergency storage equal to 75 percent of the maximum one-day demand is not unreasonable.

The existing storage appears to be sufficient when comparing total storage with total demand. To be adequate, however, storage must be properly located. Table 18 lists the existing storage capacity by area and future requirements considering location as well as total capacity.

Table 18. Storage Deficiencies by Water Area

Area	Deficiency, mg	
	1974	2000
<u>Trinidad</u>		
Chaguaramas	-	-
Diego Martin	0.4	1.6
Port of Spain	1.0	2.1
North Coast	0.1	0.3
Eastern Main Road	3.5	15.2
Toco	0.2	0.4
Sangre Grande	0.3	1.9
Mayaro	0.1	0.9
San Fernando	-	-
South Trinidad	9.7	22.0
Montserrat	-	0.2
Caroni	2.0	5.4
<u>Tobago</u>		
Southwest	0.3	1.3
Windward Coast	-	-
Rural	0.1	0.2
Total	17.7	51.5

Secondary Distribution System

Within the corporate limits of Port of Spain and San Fernando the secondary distribution system is generally adequate. In these areas there are very few mains smaller than 4-in. However, in other areas 1½- and 2-in. pipes are common and are the primary cause of low pressure.

The adequacy of the secondary distribution system depends to a great extent on whether or not it must meet fire-fighting requirements. The inclusion of fire-fighting facilities in the distribution system is recommended only in urban areas. Standards for sizing secondary distribution mains for fire-fighting are listed in Appendix D. In general these standards require a minimum main size of 6-in. In rural areas smaller main sizes can be used. Flow requirements for sizing secondary distribution mains for domestic use only are also given in Appendix D.

Condition of Mains and Valves

The condition of a distribution main refers both to its hydraulic carrying capacity and its material condition. The evaluation of the hydraulic condition of a main is determined by flow and pressure measurements. The material condition is determined by inspection and review of maintenance records.

Hydraulic Flow Tests. As part of the Waste and Loss Study, pipe condition tests were made on the Hollis Trunk Main, the 21-in. Cocorite Main from Farrell Pumping Station, and a 12-in. main in Tacarigua. The hydraulic condition of the 36-in. section of the

Navet Trunk Main was also determined from available data. The condition of these mains expressed in terms of the Hazen-Williams C value is listed in Table 19. The Hazen-Williams C value is an indication of pipe capacity. The C value of a new pipe approximates 140. The capacity of the main varies directly with the C value; therefore, the Hollis Trunk Main which has a C value of 88 has only $88/140$ th of its original carrying capacity or 73 percent. The reduction in carrying capacity measured in the mains tested is considered normal for their type and age. Measures to restore the original carrying capacity of these or other mains are not recommended.

Material Condition of Mains and Valves. Main breaks are common throughout the system; however, only in a few areas are they considered excessive. Diego Martin is one area where breaks are common due to excessive pressures. Some of the pipes in this system are thin-walled steel pipes which are unsuitable for the service pressures being experienced. Breaks on steel mains have occurred. Valve maintenance appears to be ineffective. The Waste and Loss Study in Diego Martin indicated that many of the leaks were occurring through valve stuffing boxes. A continued program of valve maintenance which includes an effective and up-to-date system of record-keeping is required.

Table 19. Pipe Condition Test Results

Main	Diameter, in.	Test length ft.	Material	Age, yrs.	C value
Hollis Trunk Main - Valencia to Tunapuna	24	75,000	Steel	33	88
Navet Trunk Main - Navet Dam to Arch Trace	36	39,999	Steel	7	120
Cocorite Main - Cocorite to Port of Spain	21	11,000	Cast- iron	66	70
Tacarigua South Main - Tacarigua Boreholes to Trincity Industrial Park	12	3,000	Steel	7	150

POTENTIAL ADDITIONAL SURFACE SOURCES

General

Potential surface water sources in Trinidad and Tobago are more than adequate to meet projected demands beyond the year 2000. However, most sources investigated will require development of an impounding reservoir for any significant yield, and all should be provided with treatment (disinfection, coagulation, sedimentation and filtration) in order to ensure a safe, palatable water supply.

Trinidad's most productive watersheds lie in the eastern portion of the Northern Range. In this area total runoff ranges from 40 to about 70 percent of rainfall, and dry season (January to May, inclusive) runoff is around 20 to 30 percent of the annual total. Generally, the annual runoff from watersheds in other areas of Trinidad is between 20 and 40 percent of annual rainfall and the dry season runoff ranges from 1 to about 14 percent of total runoff. Table 20 is a summary of runoff distribution for those rivers for which limited stream gauging data and fairly long term rainfall records are available.

Table 20. Runoff Distribution by Season

Stream	Year	Total Rainfall inches	Runoff			
			Total		Percent Dry season	Percent Wet season
			Inches	Percent rainfall		
<u>Northern Range</u>						
St. Joseph River	1968	64.02	14.01	21.9	30.5	69.5
Caura River	1968	68.52	-	-	25.0 ⁽¹⁾	75.0 ⁽¹⁾
North Oropouche R.	1968	126.00	86.33	68.5	27.5	72.5
" " "	1967	119.34	63.68	53.0	22.4	77.6
El Mamo River ⁽²⁾	1968	94.54	38.64	41.0	10.6	89.4
<u>Central Region</u>						
Pure River	1968	83.70	23.51	28.0	1.4	98.6
Navet River	1963	94.60	26.88	28.4	9.2	90.8
" "	1964	112.47	49.02	43.5	1.7	98.3
" "	1965	97.65	31.71	32.5	9.5	90.5
" "	1966	103.95	38.37	36.9	1.5	98.5
" "	1967	95.82	36.20	37.7	4.0	96.0
" "	1968	93.61	42.09	45.0	5.7	94.3
Cunapo River ⁽²⁾	1968	97.68	44.29	45.3	14.7	85.3
Couva (Chickland)	1968	75.19	15.11	20.0	2.5	97.5
<u>Southern Area</u>						
Ortoire River	1968	91.41	28.22	31.0	12.0	88.0
<u>Northern Range/Central Region</u>						
Caroni River (Kelly)	1968	90.24	34.24	37.0	10.5	89.5

1. Partial record (estimated)

2. Catchment differs from others in zone.

While the percentage of rainfall which runs off is dependent upon soil types, topography, land use and rainfall patterns, there is sufficient similarity between the streams listed in Table 20 (and their catchment areas), with the exception of the St. Joseph River, to allow a comparison of runoff. St. Joseph River Valley contains a thick valley fill of sands and gravels. Consequently, a considerable portion of the annual rainfall infiltrates and travels seaward as groundwater. This groundwater has been developed by the Valsayn well field.

Rainfall

Rainfall patterns in Trinidad and Tobago are largely determined by the seasonal movement of the trade wind belt and the equatorial trough. During the wet season the equatorial trough advances northward toward Trinidad reaching its northernmost position around September or October. As the trough shifts northward and again southward (after September or October) the track of vortical type disturbances crosses and re-crosses Trinidad and Tobago. During the wet season shower type precipitation is caused by regional vortical type disturbances and by moisture-laden unstable air masses crossing the islands, lifted or raised by topography or convection currents.

During the dry season the northeasterly trade winds bring dry air to the islands resulting in a virtual absence of rainfall. Such rainfall as does occur in this period is primarily due to convection or orographic lifting, whereas during the wet season regional vortical disturbances contribute mainly to the rainfall.

Consequently, during the dry season, precipitation follows the relief of the island quite closely. However, nowhere is rainfall greater than about 8 percent of the annual precipitation.

Canvass of Potential Sources

Figures 9 and 10 are isohyetal maps of mean annual rainfall for Trinidad and Tobago, respectively. The pattern of rainfall indicated by these maps was used together with topographic maps to make a preliminary selection of potential surface water sources for additional investigation.

First, the topography of the watersheds within the high precipitation zones was studied and tentative dam sites selected. Next, working with Lands and Surveys instrument plots and topographic maps at 1:10,000 scale, the watershed area and possible storage capacities were determined.

The third step in the selection process involved a study of known geologic features at the selected sites followed up by a field trip to each site which appeared geologically satisfactory, and was so situated geographically as to be considered for first stage development.

As previously indicated, Trinidad's present water requirements and projected future demand are geographically concentrated in a T-shaped area with the stem extending from Curepe southward to the San Fernando Area, and the top extending in an east/west direction along the base of the Northern Range from Arima to Chaguaramas.

The zones of highest precipitation contiguous with this area are along the eastern end of the Northern Range from about the Arouca

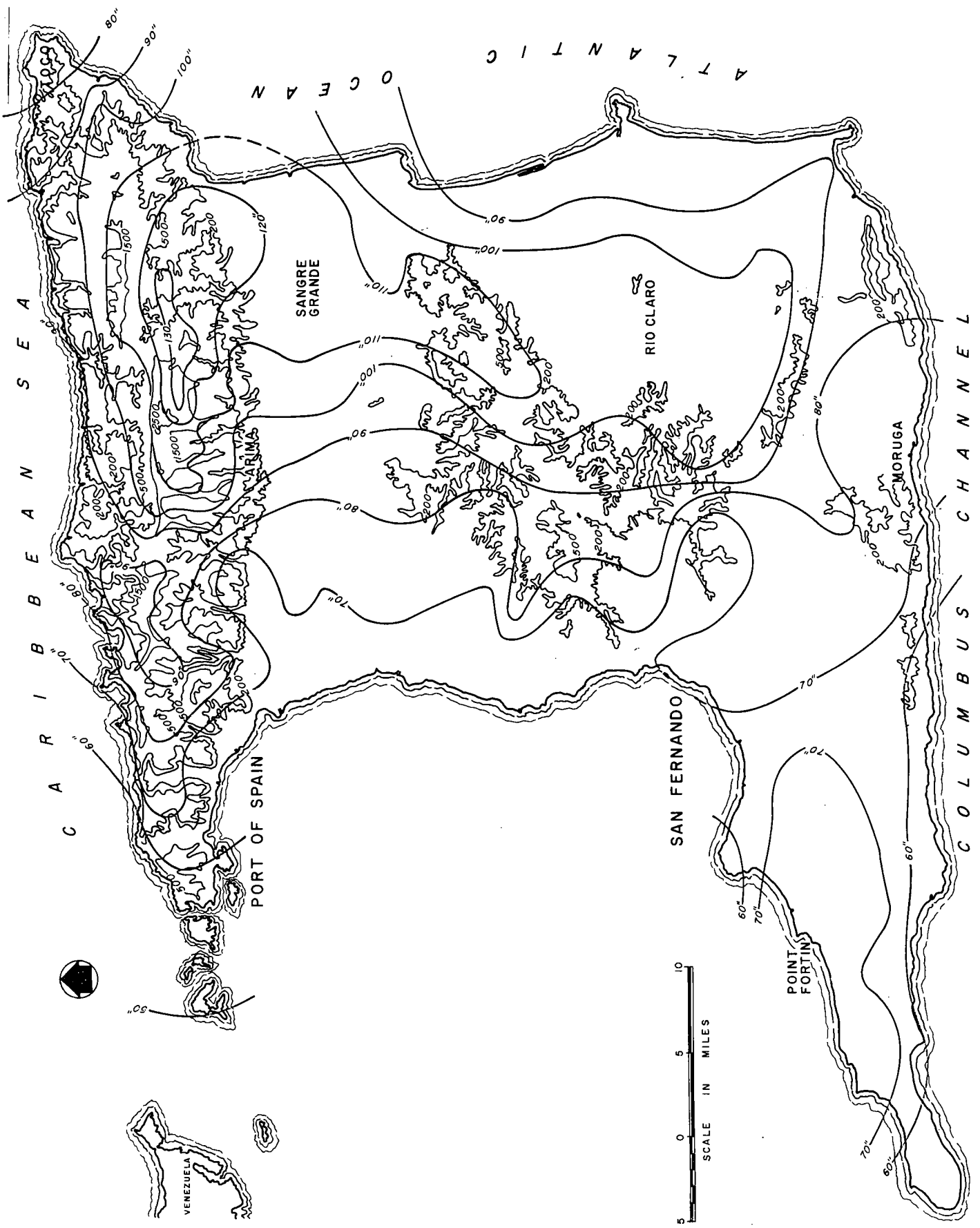


FIG. 9 TRINIDAD MEAN ANNUAL RAINFALL

METCALF & EDDY

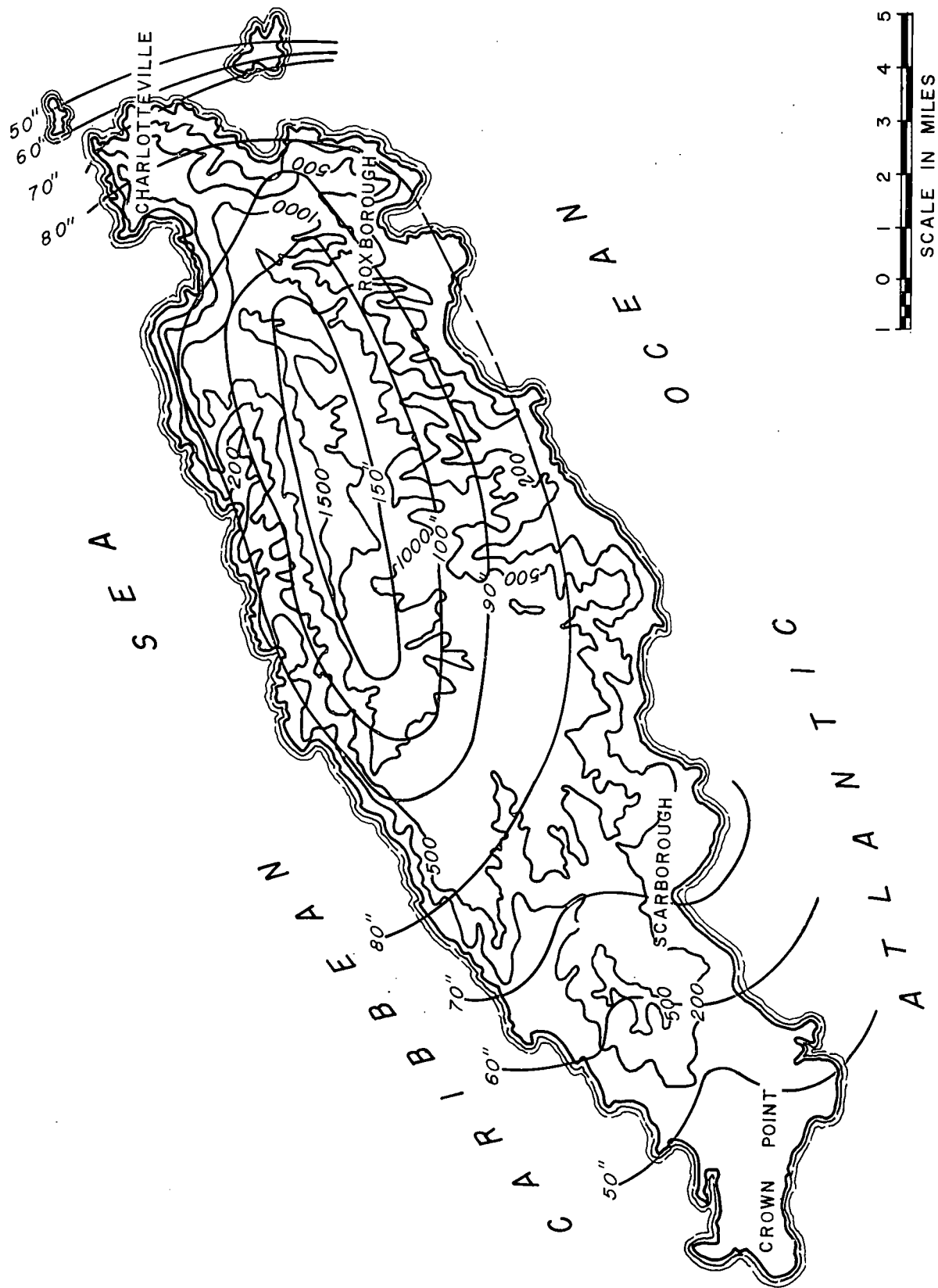


FIG. 10 TOBAGO MEAN ANNUAL RAINFALL

River to the Matura River, and in the central portion of the Central Range. For ease of reference these areas are referred to in this report as zones 1 and 2, respectively. Since zone 1 (the Northern Range area) is closest to the area in which the existing and projected future water demand is highest, the first sites canvassed were in this zone.

Examination of the topography, active land development, and basin geology narrowed the number of potential reservoir sites as indicated in Table 21.

Table 21. Summary of Preliminary Watershed Canvass

Watershed	Zone	Action
<u>Trinidad</u>		
Arima River	1	Eliminate; basin developed and no suitable dam site.
Aripo River	1	Eliminate; catchment too small; and poor dam sites.
Guanapo River	1	Consider for first stage.
North Dropouche River	1	Consider for first stage.
Matura River	1	Consider for first stage.
Salybia River	1	Eliminate; catchment too small; no suitable dam sites.
Tompson River	1	Eliminate; fault down centre of valley.
Grande Riviere	1	Eliminate; fault down centre of valley.
Shark River	1	Eliminate; too steep and small.
Matelot River	1	Eliminate; too small; no suitable dam site.
Madamas River	1	Consider for future supply.
Paria River	1	Eliminate; too small; no suitable dam site.

Table 21 (contd.). Summary of Preliminary Watershed Canvass

Watershed	Zone	Action
Marianne River	1	Consider for future supply.
Yarra River	1	Consider for future supply.
Caroni-Arena River	1 & 2	Consider for first stage.
Caura River	West of 1	Eliminate; poor dam site; low yield.
Tumpuna River	2	Consider for first stage.
Talparo River	2	Consider for first stage.
Cunapo River	2	Consider for future or local development.
Couva-Chickland River	2	Eliminate; low yield.
Pure River	2	Eliminate; no satisfactory reservoir site.
Ortoire River	2	Eliminate; no satisfactory reservoir site.
Navet River	2	Consider for pumped storage project first stage.
Moruga River	South coast	Consider for future supply.
<u>Tobago</u>		
Courland River		Consider for future supply.
Richmond Great Dog River		Consider for future supply.

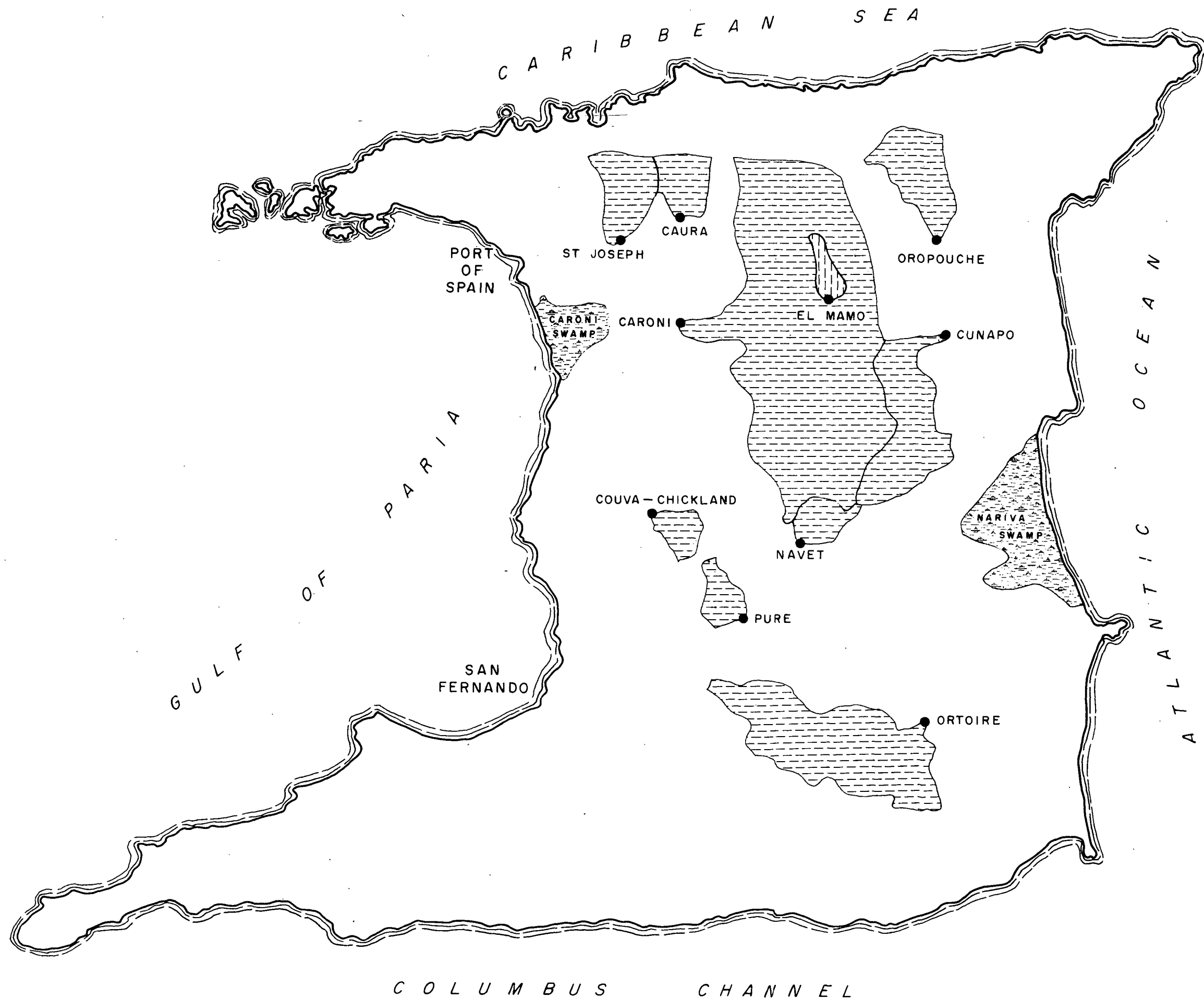
Dependable Yield

The reservoir sites not eliminated in the preliminary canvass were considered to be satisfactory for development. Accordingly, prior to field investigations, studies were made to determine probable yield and cost of development including pipe lines.

Since, as previously indicated, the dry season is about five and one half ($5\frac{1}{2}$) to six (6) months long with eight (8) percent or less of the annual rainfall occurring in that period, water for use then must be stored. In addition, because of lawn and shrub irrigation, more frequent bathing, and other forms of use, water demands reach their peak in the dry season. Accordingly, wherever possible, storage has been sized to allow a dry season draft from 1.25 to 1.5 times the dependable yield of the source together with evaporation losses from the reservoirs. The dependable yield is taken as the yield to be expected in a 95 percent dry year (a year with a five (5) percent chance of occurrence or which may be expected to occur with a frequency of 1 in 20). Rainfall data for Trinidad and Tobago have been recorded for a long enough period of time to allow for most areas a reasonably good determination of the amount of rainfall to be expected in a 95 percent dry year. The limited runoff data available, up to 6 years (Navet Reservoir), are sufficient to indicate probable runoff patterns for specific catchment areas in each rainfall zone, provided some runoff data are available for a catchment area with similar geology, topography and land use or ground cover. The runoff data available in Trinidad cover years with precipitation approximately equal to the mean.

Therefore, seasonal runoff distribution and total runoff should be representative of normal or average conditions, and should allow a fairly accurate estimate of average yield for the watersheds measured and for similar watersheds in the same rainfall zone.

In Table 20 the watersheds listed are grouped according to location and similar catchment conditions. The location of each catchment is shown in Figure 11.



LEGEND



Drainage Area Above
Gauging Station



Stream Gauging Station

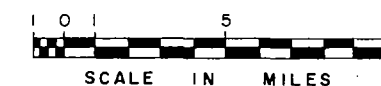


FIG. II KEY WATERSHEDS

After M. M. DILLON

METCALF & EDDY

The variations in percent runoff for the Navet Watershed over the six-year period of record demonstrate that, with the shower type storms which prevail in Trinidad, antecedent moisture conditions and storm frequency during the wet season have a strong influence on annual and seasonal runoff. However, on the basis of rainfall data available for the general area, the 95 percent dry year rainfall should be about 78 inches and total dry year runoff should be 20 to 25 percent of rainfall, or 16 to 20 inches (1615 mg to 2020 mg). Gross runoff for the 95 percent dry year would range between 4.5 and 5.4 mgd for the Navet Reservoir. After reducing yield by the amount of evaporation from the free reservoir surface the dry year watershed yield is around 4.0 mgd.

Navet Reservoir storage capacity is 4,100 million gallons or about 315 million gallons more than the average annual runoff for the 6 years of record. With this reservoir capacity water stored during years of excess runoff can be used during a two- to three-year dry period increasing the 95 percent dry year yield to about 7 mgd. Generally, provision of storage capacity in excess of or even equal to average annual runoff cannot be justified economically. However, the desirable effective storage for optimum watershed development in hydrographic areas like Trinidad and Tobago may approach three-quarters of the average annual runoff, especially where 90 percent or more of the runoff occurs in the wet season. Desirable storage capacity for optimum development of watersheds where the wet season runoff is around 75 percent of annual runoff may range from about 40 to 50 percent of average annual runoff.

Table 23 lists the potential reservoirs, (shown in Figure 12) their catchment areas, effective storage, mean annual rainfall, estimated dependable yield and the dam height. Storage capacity for the northern area reservoirs is, where possible, around 50 percent of estimated average annual runoff. For the central area and Tobago it is about 75 percent of estimated annual runoff.

TABLE 23. POTENTIAL RESERVOIRS

	Potential reservoir	Catchment sq. mi.	Flowage acres	Storage, m.g.		Mean annual rainfall inches	Est. yield, mgd.	Type dam	Dam height feet	Comments
				Total effective	Per square mile					
NORTHERN RANGE AREA	TRINIDAD									
	North Orapouche River	20.5	1140	10,000	500 -	120 to 130	45	Rock-fill	258 ±	All required is Crown lands
	Matura River	13.9	490	5,500	400 ±	120 +	20	" "	180 ±	Same
	Guanapo River	10.0	160	2,200	220 ±	110 +	10	" "	138	Estate and Crown lands
	Yarra River	13.4	520	4,000	300	85 +	9 +	Earth	86 ±	Mostly Estates
	Marianne River (site "A")	13.2	400	4,000	300 +	90 +	10	Rock-fill	98 +	" "
	Madamas River	18.3	300	4,000	220	95 +	18	" "	175	" "
CENTRAL AREA	Caroni-Arena River (1)	150.0	861	3,500	23 +	90 +	33	Earth	63	Most required is Crown lands
	Talparo River (2)	2.9	260	1,400	480	85 +	2	"	99	Crown lands
	Tumpuna River (2)	4.5	350	1,300	290 ±	90 +	3 +	"	52	Crown lands
	Cunapo River	4.4	305	1,300	300 -	100 +	3 +	"	41 ±	90% Crown lands
	Moruga River	31.5	2000	10,000	290 ±	80 +	25	"	56	Oil reserve lands
	TOBAGO									
	Courland River	10.8	804	4,000	370	65 +	6	"	43	Estate lands
	Richmond River	4.4	74	1,350	300 +	80 +	3	"	43	Estate lands

(1) Includes all water-shed above Kelly headworks at Caroni with pumped storage at Arena.

(2) With the Caroni-Arena project, Talparo and Tumpuna reservoirs increase the yield by 9 mgd. or 4 ± mgd. more than if developed separately.

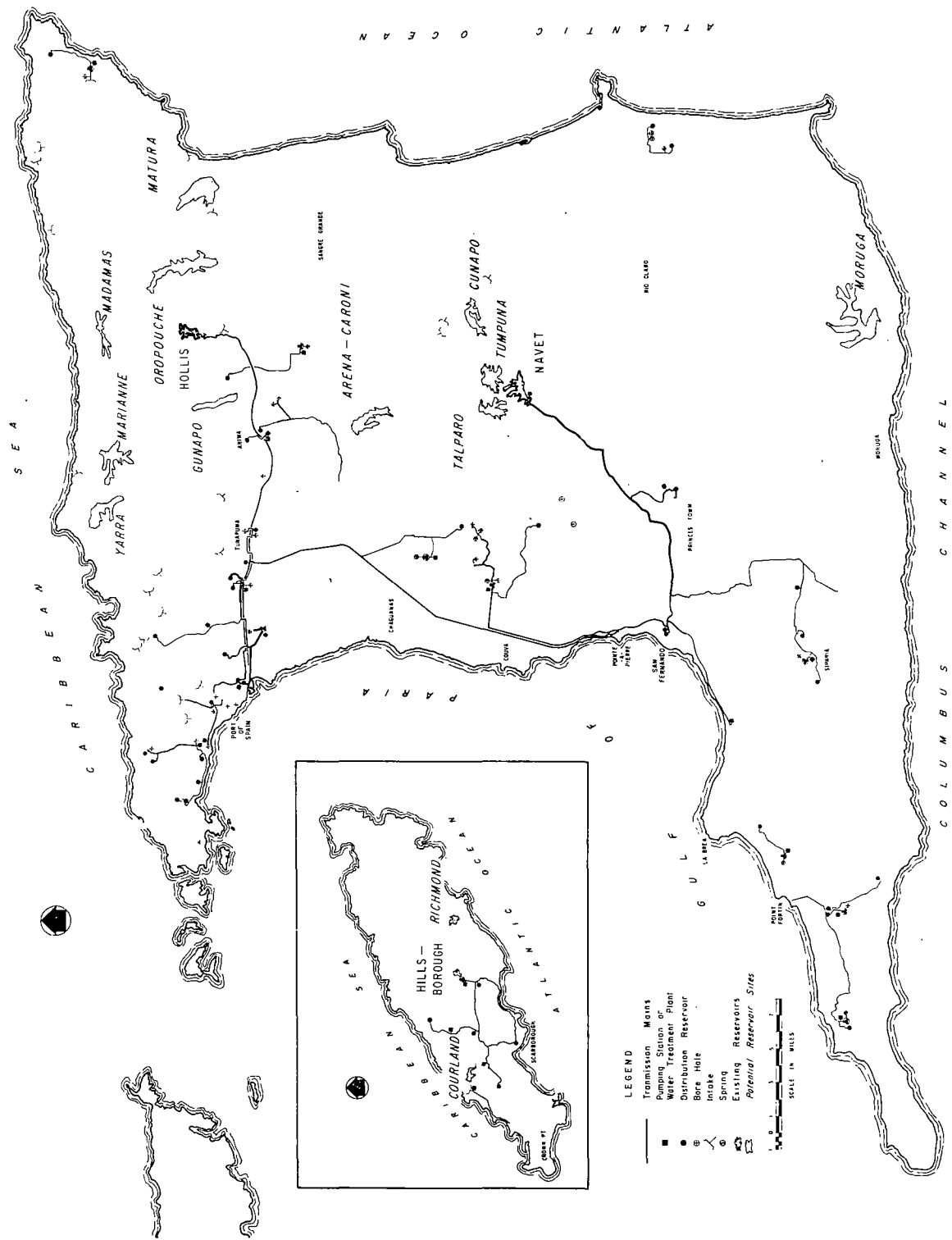


FIG. 12 POTENTIAL RESERVOIRS

Required Treatment

The raw water quality for the watersheds listed in Table 23 is strongly influenced by land use. Generally, those utilized for forests or forest type crops such as cocoa, citrus fruit, etc., will produce a less turbid water than will those used for other forms of agriculture such as truck farming, sugarcane cultivation or dairy farming.

Lands used extensively for sugarcane cultivation may produce water rather heavily contaminated by insecticides and herbicides. Since most of these chemicals are quite stable, they are not naturally removed while the water is in storage. In addition, they are not easily detected in the water supply. Accordingly, catchment areas used extensively for a type of agriculture with heavy dependence upon chemical means of pest and weed control are less attractive for initial watershed development than are those without this potential source of water contamination.

In Trinidad and Tobago the crop most heavily dependent upon chemicals for weed and pest control is sugarcane, although increasing use is being made of chemicals in the citrus industry and on the truck farms.

Treatment for turbidity removal and disinfection would be required for water produced from any of the watersheds investigated. Table 24 indicates the probable raw water quality and the type of treatment required for the potential reservoirs investigated.

The values shown in Table 24 for the potential sources in

Table 24. Raw Water Quality - Required Treatment

Potential reservoir	Turbidity J.T.U.(1)	Hardness PPM CaCO_3	B. Col. MPN (2)	Color	Required treatment
<u>Trinidad</u>					
North Oropouche River	0.5 to 5.0	160 ⁺	1800+	15 ⁺	c,s,d & f ⁽³⁾
Matura River	0.5 to 5.0	150 ⁺	1800+	20 ⁺	c,s,d & f
Guanapo River	0.5 to 5.0	100 ⁺	1800+	25 ⁺	c,s,d & f
Yarra River	0.5 to 5.0	90 ⁺	1800+	20 ⁺	c,s,d & f
Marianne River	0.5 to 5.0	200 ⁺	1800+	25 ⁺	c,s,d & f
Madamas River	0.5 to 5.0	200 ⁺	1800+	20	c,s,d & f
Caroni-Arena	10 to 200+	70 ⁺	1800+	100 ⁺	c,s,d & f
Talparo River	0.5 to 5.0	130 ⁺	1800+	70+	c,s,d & f
Tompire River	0.5 to 5.0	130 ⁺	1800+	70+	c,s,d & f
Cunapo River	0.5 to 5.0	130 ⁺	1800+	70+	c,s,d & f
Moruga River	5 to 10	40 ⁺	1800+	70+	c,s,d & f
<u>Tobago</u>					
Courland River	5 to 10	-	1800+	25 ⁺	c,s,d & f
Richmond	5 to 10	150 ⁺	1800+	25 ⁺	c,s,d & f

1. In a reservoir (lower than the run of stream)
2. Most probable number per ml.
3. c = coagulation; s = sedimentation; d = disinfection; f = filtration.

Trinidad are based on the results of laboratory tests conducted by WASA upon samples of water collected by the Consultant. The values shown for the Tobago sources are based on tests of samples collected by WASA from the present water supply schemes utilizing these sources.

The value of 1800+ for the most probable number of coliform of the B.Coli type represents the maximum number reported, that is, beyond 1800 no attempt is made to determine the probable number of organisms per ml (milliliter). However, the plate counts for the confirmation tests indicate a higher number of organisms for the Caroni by a considerable margin over the other sources checked (30⁺ times as many colonies). This is attributed mainly to the fact that the Caroni watershed is extensive and that raw, domestic, farm, and industrial wastes are discharged directly into the river and its tributaries.

Potable Water Standards

The degree of treatment recommended in Table 24 is that considered necessary to approach the goals adopted by the American Water Works Association and meet the recommended standards of the United States Public Health Service (USPHS).

It is recommended that WASA adopt the potable water quality goals of the AWWA and conform as closely as is possible to the quality limits of the USPHS. These goals and the USPHS limits are summarized in Table 24a.

Table 24a. Potable Water Quality Goals and Limits

Characteristic	Goal AWWA	USPHS limits ⁽¹⁾
<u>PHYSICAL</u>		
	(2)	
Turbidity	Less than 0.1 unit	Less than 5 units
Non-filterable residue	Less than 0.1 unit	-
Macroscopic and nuisance organisms	None	-
Colour	Less than 3 units	Less than 15 units
Odor	None	Threshold odor No.3
Taste	No objectionable	
<u>CHEMICAL</u> in mg/1		
Chloride	-	Less than 250
Aluminum (Al)	Less than 0.05	-
Iron (Fe)	Less than 0.05	Less than 0.30
Manganese (Mn)	Less than 0.01	Less than 0.05
Copper (Cu)	Less than 0.20	Less than 1.00
Zinc (Zn)	Less than 1.00	Less than 5.00
Filterable residue	Less than 200.0	-
Carbon Chloroform extract (CCE)	Less than 0.04	Less than 0.20
Methylene-blue-active substances (MBAS)	Less than 0.20	-
<u>BACTERIOLOGIC FACTORS</u>		
Coliform organisms by (mtf) ⁽³⁾	None	(Allowed in a percentage of samples.
Coliform organisms by (mf) ⁽⁴⁾	None	(See "standard methods".
<u>RADIOLOGIC FACTORS</u>		
Gross beta activity	Less than 100pc/1	1000 pc/1

1. United States Public Health Service.
2. Standard units (See Standard Methods for Examination of Water and Waste Water, AWWA).
3. Multiple tube fermentation techniques.
4. Membrane filter techniques.

GROUNDWATER SOURCES

General

This chapter describes the groundwater resources of the islands of Trinidad and Tobago. Particular emphasis is placed on the ability of known groundwater sources to sustain current withdrawals and the determination of additional quantities of water that might be available. Limitations as to groundwater development are discussed for those aquifers where overdrafts are evident. Additional sources are described although the lack of more complete data precludes really significant evaluation of their potential for development. Recommendations are also made for conserving groundwater supplies by means of artificial recharge, reducing withdrawal rates and relocating well fields in order to maximize the use of the available groundwater.

The study is largely limited to the island of Trinidad. Available geologic data indicate that Tobago's groundwater resources are meager. They are briefly described in this chapter. A fuller evaluation of Tobago's groundwater resources will require the collection of additional hydrologic data including rainfall intensity and distribution, stream flow data, and geologic mapping.

Water Resources Survey work in Tobago and on the North Coast of Trinidad was not included in M.M. Dillon's terms of reference and no data on these districts were available.

Most of this evaluation is based on hydrologic studies made by M.M. Dillon, Consulting Engineers, in cooperation with the

Government of Trinidad and Tobago. Among other available studies is the report by de Verteuil (1968) which describes the major aquifers in Trinidad and makes estimates of quantities of groundwater available from them. These aquifers have been delineated in unpublished maps prepared by K. M. W. Marshall, former geologist in the Ministry of Petroleum and Mines. Additional information on groundwater supplies and related hydrologic data have also been made available by the Trinidad Water Resources Survey, the Water and Sewerage Authority (WASA), the Ministry of Petroleum and Mines, the Ministry of Agriculture, the University of the West Indies and a number of petroleum companies. In addition, numerous individuals from the above-mentioned agencies have generously contributed information for this study.

Groundwater Resources of Trinidad

Groundwater is found throughout most of the island. Its availability is dependent on a number of geologic and hydrologic parameters which will be discussed subsequently. The importance of groundwater supplies is evidenced by the fact that about two-thirds of Trinidad's current water requirements are developed from groundwater aquifers. There are excessive withdrawals from some of these aquifers. Reduction in pumpage will be required to maintain their usefulness as sources of fresh water supply. It is expected that these reductions can be made up by a redistribution of pumping centres or from groundwater sources as yet not fully developed. However, future development, especially in the northern part of Trinidad, will require

greater reliance on surface water sources. Transmission and development costs would preclude the use of potential surpluses from central and southern aquifers. A complete realization of Trinidad's groundwater potential cannot be attained without more detailed hydrologic studies.

Geology

The island of Trinidad is made up of five physiographic provinces all of which roughly parallel each other along an east-west direction. These, in the order of their location, are the Northern Range, Northern Plain, Central Range, Southern Basin and the Southern Range.

The Northern Range is made up of the oldest known rocks on the island. They are of Jurassic and Cretaceous age and include principally metamorphic and sedimentary rocks of schist, phyllite, limestone and shale. The rocks are not believed to be an important source of groundwater and no major well supplies are expected to be developed from them. Of greater importance are the sand and gravel aquifers in alluvial valley fill especially in the southwestern part of the Range where they are relatively thick and widely distributed in the larger valleys. Their importance as groundwater sources in the rest of the Range, however, diminishes with their less widespread occurrence and suspected shallower depth in narrow valleys. Other major sand and gravel aquifers are found in alluvial fans which flank the southern edge of the Range. The fans are mostly made up of sediments deposited by streams at the foot of southerly draining

valleys in the Northern Range. They attain a maximum thickness of over 500 ft. near El Socorro and become progressively thinner toward the east. Generally, the fan deposits are coarsest near the mouth of valleys and become increasingly finer radially outward.

The fans form the northern limits of the Northern Plain where in places they have been modified into a series of marine terraces formed by the progressive lowering of the sea level since Pleistocene times. To the south, the Plain is underlain at varying depths by sediments (mostly clays) which are older in age than the fan deposits. Some extensive artesian aquifers are found in the clays and are an important source of industrial and municipal supplies in west-central Trinidad. These aquifers comprise two distinct sandy horizons, the Sum Sum and the Durham Sands, in the Talparo Formation which is mostly made up of clay and silt. The sands outcrop within a narrow band in the south-central part of the Northern Plain. They become progressively deeper toward the west and north and are overlain by thick sequences of clay and silt which confine water within them. The sands have been segmented by a series of northwesterly trending faults whose principal effect has been to limit groundwater interflow between adjoining sand bodies. Thus, where sands have been significantly offset by faulting, they form distinct aquifers which are not connected hydraulically. Extensive sandstone deposits also occur in formations older than Talparo along the southern limits of the Northern Plain. These deposits may have some potential for groundwater development but at present are not a source of major supplies.

Information on their water bearing character is presently lacking and detailed investigation is needed before valid estimates can be made.

The Central Range is primarily made up of clay, shale and marl with little or no potential for large-scale groundwater development. Scattered areas of permeable reef limestone are reported which may yield moderate supplies. The lack of exposure to recharge from rainfall and the limited area of these deposits probably limit significant withdrawal of groundwater.

A thick sequence of sediments underlies the area just south of the Central Range where it forms the Southern Basin. The sediments are predominantly clayey in the northern half of the Basin, but become progressively sandier to the south. The principal water-bearing materials are sand layers in the Morne L'Enfer, Erin and Mayaro Formations. Other sandy aquifers may occur in the Moruga Formation along the southwestern edge of the Basin and in parts of the Southern Range. Groundwater is developed from the Morne L'Enfer and Erin Formations at the western end of the Basin. The central part is predominantly underlain by non-water-bearing clay and silt deposits although toward the east and southeast the Basin sediments include sandy aquifers in the Mayaro Formation and also in the Moruga Formation whose potential for development is presently unknown. The Authority is currently drawing water from the Mayaro Formation at the extreme eastern end of the Basin.

Hydrology

The principal source of groundwater is rainfall which percolates through the soil mantle to the water table. Most rainfall, however, is lost to the atmosphere by soil evaporation, plant transpiration and direct surface runoff. Under natural conditions that part of the rainfall which reaches the water table sustains an essentially hydrologically balanced groundwater system in which, on the average, recharge equals discharge out of the system. In major aquifers, the effect of seasonal variations in recharge become negligible in relation to the total volume of water stored within them.

Hydrologic imbalances have been created in some aquifers where groundwater withdrawals exceed recharge. Water levels, as a result, are steadily declining. In some coastal areas, pumping is also diverting groundwater flow required to maintain a stabilized fresh-salt water front. The reduction or reversal of groundwater flow toward inland pumping centres has caused salt water to intrude into some coastal aquifers. This condition is evident at the El Socorro well field where average chloride levels have steadily risen from 50 ppm in 1966 to 205 ppm in 1969.

Other imbalances are the result of impermeable man-made structures such as buildings and pavements, which are limiting recharge opportunity to aquifers in urban areas. The magnitudes of such imbalances are unknown, and they may be somewhat offset by infiltration of sewage effluent from on-lot sewage disposal and from

leaking water mains.

Sizeable reductions in annual recharge, especially in the Diego Martin and Port of Spain areas, will severely limit groundwater development from the existing coastal well fields.

In areas of formerly high water table, some beneficial effects can result from lowering water levels by pumping whereby additional aquifer storage is made available for recharge from rainfall and stream flow infiltration. Lowering water levels can also cause an increase in the available groundwater supply through a reduction in losses from evapotranspiration.

Direct recharge from rainfall is the most important source of groundwater in the major aquifers. The average yearly rainfall in Trinidad ranges from 60 to 130 inches of which about 92 percent falls during the wet season which begins in June and ends in December. Because of a potentially high evapotranspiration rate that reaches as high as 64 inches annually (Smith, 1965) little if any of the dry season rainfall during January to May becomes available for recharge. On the basis of studies by Smith (1965 & 1968) actual evapotranspiration during the wet season is estimated at about 30 inches. Available stream flow data in areas with less than 100 inches of annual rainfall, in which most major aquifers are located, similarly indicate that about 30 to 40 inches of the wet season rainfall is lost, mostly by evapotranspiration.

In determining potential groundwater supplies, a value of 30 inches for wet season evapotranspiration was used. The effective

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rainfall during the wet season which contributes to both aquifer recharge and direct surface runoff is the difference of 30 inches from an estimated 80 percent of the annual rainfall. Although little information is available for determining direct runoff, studies by Smith (1965) suggest that it totals about 10 percent of the wet season rainfall in most lowlying aquifer areas but that it can be 20 percent or more in mountainous and developed urban areas. Estimates of recharge using these values for evapotranspiration and direct runoff are more or less in agreement with those determined by a more detailed analysis of pumping and water level relations.

Principal Groundwater Areas

The known major groundwater areas include the Northern Valley Aquifers in alluvial deposits at Chaguaramas, Tucker Valley, Diego Martin and Port of Spain; the Alluvial Fan Deposits at El Socorro, Valsayn, Tacarigua and Arima; the Artesian Aquifers in the Sum Sum and Durham Sands; the reef limestones of the Central Range; and sands in the Erin. Morne L'Enfer and Mayaro Formations of southern Trinidad (See Figure 13). Detailed information on their subsurface distribution and thickness is available in reports prepared by Dillon (1968). Other potential areas for groundwater development are also shown and include predominantly sandy facies of the Manzanilla and Moruga Formations located, respectively, in central and southeastern Trinidad.

Their area of outcrop as shown is based on a geologic map by Kugler (1959). Smaller supplies may be available from alluvial

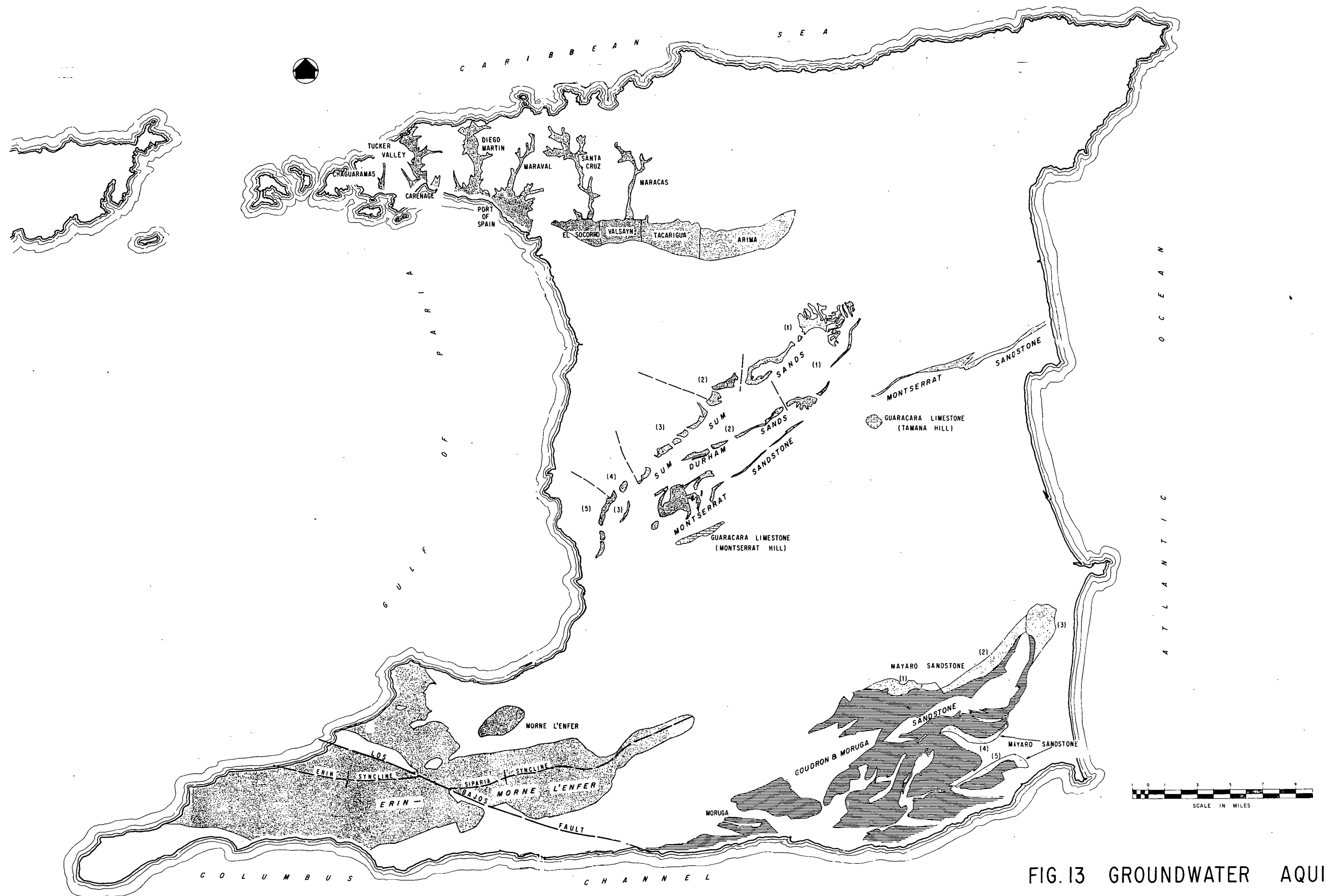


FIG.13 GROUNDWATER AQUIFERS

sediments along numerous streams throughout Trinidad and possibly from limestone deposits in the Northern Range. The most promising areas for development are in the alluvial fill of the southerly draining Santa Cruz and Maracas Valleys in the central part of the Northern Range. The upper part of the Santa Cruz Valley is underlain by as much as 100 ft. of fill, which, if sufficiently permeable, should be capable of yielding 50,000 gpd or more to a well.

Northern Valley Aquifers. The deposits of alluvium lying in bedrock valleys along the northwestern coastal areas of Trinidad are referred to collectively as the Northern Valley Aquifers. The principal aquifers are the Chaguaramas, Tucker Valley, Diego Martin and Port of Spain.

Typically, the aquifers thicken and widen rather abruptly within 2000 to 4000 ft. of the coast. The thickening is caused by a sharp increase in bedrock depth associated with fault zones parallelling the coast.

Numerous wells, both public and private, are at present withdrawing about 14 mgd. A large number of these wells are near the coast. The lowering of water levels by pumping has produced a landward migration of the fresh-salt water interface. The resultant rise in chloride levels has forced some reduction in pumping rates for the purpose of maintaining a stable fresh-salt water front.

Estimated available groundwater supplies which can be developed from each aquifer without causing a serious inland migration of salt water are as follows:

Chaguaramas	1.8 mgd
Tucker Valley	6 mgd
Diego Martin	4.5 mgd
Port of Spain	4 mgd

These quantities are already being exceeded in the Diego Martin and Port of Spain aquifers. Groundwater withdrawals from them average 6 mgd for each source. The difference between pumpage and the available groundwater is made up by secondary recharge originating as leakage from pipeline losses and seepage from sewage disposal systems. A reduction of this leakage will significantly lessen the amount available for pumping. Additional groundwater amounting to 2 mgd is estimated to originate in the inland portions of the Port of Spain aquifer as base flow in the Maraval River. A part of this water is currently diverted by an intake on the river. Any development of well supplies upstream from the intake would therefore decrease the flow component of the river, thereby limiting surface water diversions especially during the dry season when stream flow is at a minimum.

Available groundwater in Chaguaramas and Tucker Valley exceeds present pumpage which totals, respectively, about 0.5 and 1.4 mgd. Additional development is possible although some relocation of coastal wells to inland areas may be required to prevent contamination by salt water.

Alluvial Fan Aquifers. The fans adjoin the southern edge of the Northern Range where they extend from Port of Spain to a point east

of Arima. Their southern limit roughly parallels the Churchill-Roosevelt Highway.

Groundwater withdrawals from these totalled nearly 17 mgd in 1968, all developed from wells tapping sand and gravel in alluvial fan deposits.

Four major groundwater systems are recognized within these deposits. They are the El Socorro, Valsayn, Tacarigua and Arima aquifers (See Figure 13). Very little hydraulic connection is believed to exist between them since the fan deposits tend to become finer and less permeable away from the mouths of streams which formed them.

Groundwater in the fan aquifers is found under water-table and artesian conditions where it is confined by extensive clay and silt layers. It is estimated that recharge to these aquifers annually averages 17 mgd most of which is from rain falling directly on the fans. However, significant amounts of water, estimated at a minimum of 15 percent of the total recharge in the El Socorro and Valsayn aquifers, enter the aquifer by stream flow infiltration (Dillon, 1968).

Recharge also takes place as underflow from the adjoining bedrock and the contiguous alluvial fill in the Northern Range. In the deeper artesian aquifers, recharge is by leakage through the overlying clay and silt layers.

Pumping wells develop the greater portion of the present groundwater discharge out of these aquifers. Prior to major development, discharge probably occurred principally along seepage facies

and from springs in low lying swampy areas along the southern extremities of the fans, and to streams crossing them.

(1) El Socorro Aquifer. Groundwater development from the El Socorro aquifer started in 1959. Since that time withdrawals have increased from 0.4 to 6.8 mgd by 1968. These increases have been accompanied by a steady decline in water levels of about 30 ft. Current water levels are over 20 ft. below sea level and are expected to continue to decline at a rate of up to 5 ft. per year if pumping continues at present rates of 6 to 7 mgd. The extraction of such quantities has effectively intercepted all of the natural groundwater outflow and, starting as early as 1965, has been causing salt water intrusion into the aquifer.

Estimates on recharge indicate that groundwater storage during the past several years is being depleted at a rate of about 2 mgd , with total recharge estimated at 4.5 mgd. A consequence of overpumping has been a continued rise in the salinity of groundwater, which is of primary concern as it limits development at existing rates of withdrawals. It is expected that the salinity will increase as long as water levels in the aquifer remain substantially below sea level.

Available information indicates that saline waters are entering the upper part of the aquifer from tidal bodies in the Caroni Swamp. Chloride levels of up to 1200 ppm are reported in a well located near the swamp toward the southwestern edge of the aquifer. The rate and distribution of the intruding salt water, however,

remains unknown. More detailed information will be required to determine means to limit further encroachment by artificial recharge or by establishing withdrawal rates which can be maintained without causing additional salt water contamination.

(2) Valsayn Aquifer. Excessive groundwater withdrawals since 1952 from the aquifer have caused water levels to decline up to 40 ft., or 25 ft. below sea level. Pumpage reached an average of 6.5 mgd during the period 1957 to 1961, and has since been reduced to about 6 mgd. It is expected that, at present pumping rates, water levels will continue to decline about 2 to 3 ft. per year.

Recharge from rainfall and from infiltration from the St. Joseph River is estimated at 5 mgd. The additional 1 mgd is therefore being mined from the aquifer.

Despite water levels that are well below sea level, there is no evidence of salt water entering the aquifer. This is attributed in part to the aquifer's greater separation from salt water sources than the El Socorro Aquifer, and also because of a high proportion of less permeable sediments toward the edge of the fan deposits which are acting as a partial barrier against salt water movement from coastal areas. There is no assurance, however, that such movement is not taking place since without monitoring water level and quality changes along the seaward margins of the aquifer, it cannot be detected.

(3) Tacarigua Aquifer. The boundaries of the Tacarigua aquifer are not as well defined as those of the other alluvial fan aquifers, and estimates on recharge are less certain. On the basis

of pumping and water level comparisons with those of the Valsayn aquifer, it is estimated that a total recharge of about 5 mgd is reaching the aquifer. An additional potential for development is evident from present withdrawals of about 2.6 mgd which have not significantly lowered the water table from its pre-development position.

It is expected that the aquifer will be the least affected by salt water intrusion because of its inland location, and that water levels could be drawn down below sea level for optimum development. It is not recommended that such development should exceed the average recharge for any prolonged period of pumping. However, temporary mining of groundwater might be feasible to meet critical water demands on a short term basis.

(4) Arima Aquifer. Groundwater production to date has been limited principally by the lack of suitable sites for high capacity wells. Predominantly sand and gravel layers are nevertheless reported in the upper part of the aquifer. The aquifer, which is more fully described by Dillon (1968), reaches a maximum depth of 300 ft. below sea level and rapidly thins out to the south and east. The deeper deposits adjoin a major east-west trending fault along which sediments have been displaced downward relative to those north of the fault.

A tentative estimate of recharge to the Arima aquifer indicates that at least 2 mgd could be developed from it. Current production (1968) totals 0.8 mgd, of which 0.5 mgd is obtained from WASA's Arima well field, the remainder from their Arouca field. Poor

aquifer productivity in the latter field is indicated by a water level decline of over 100 ft. since 1965, while those at the Arima field have remained essentially the same at 120 to 150 ft. above sea level since the start of operations in 1966.

The optimum utilization of this aquifer should be systematically investigated by test drilling for more productive well sites since information does indicate a relatively high sand and gravel content in the fan deposits, even where they thin out to the south and east.

Central Artesian Aquifers. These aquifers are a part of two extensive sand units, the Sum Sum and Durham sands of the Talparo Formation. The sands are generally permeable and capable of yielding 400 gpm or more to a well. They dip relatively uniformly in a west-northwest direction and range from less than 100 to 300 ft. in thickness.

Groundwater withdrawals, which totalled 4.5 mgd in 1968, are mostly developed from aquifers in the Sum Sum Sands with major well fields located at Waller Field, Carlsen Field, Freeport and Pointe-a-Pierre.

Total recharge to them is estimated at nearly 15 mgd of which 11 mgd enters the Sum Sum Sands. Recharge is principally derived from rain falling on outcrop areas to the east. Some recharge might be gained by pumping to induce leakage through the overlying clay and silt deposits. A pumping test at the Carlsen Field, however, indicates that these deposits are relatively tight and very little

recharge by leakage can be expected from them. The aquifers are also believed to pinch out seaward where they are essentially closed off to salt water bodies. Evidence of this is the lack of any salt water contamination in the Pointe-a-Pierre area where water levels have consistently been below sea level since 1945. Because of the relative lack of danger from salt water intrusion, it should be possible to develop the artesian aquifers at rates equalling recharge to them.

(1) Sum Sum Sands. The sands have been divided into five major aquifer units (See Figure 13). This division is based in part on faulting where the sands have been displaced by at least 150 ft. or more. It is also suspected that additional separation by faulting as yet unrecognised, occurs in the sands to the north. As a result of major faulting, each aquifer unit is essentially hydrologically discontinuous and groundwater interflow between units is considered to be small.

Recharge to these aquifer units totals nearly 11 mgd , and is tabulated below:

<u>Aquifer Unit</u>	<u>Recharge,mgd</u>
1	6.4
2	1.1
3	2.0
4	0.6
5	<u>0.8</u>
	10.9

It should be recognized that the recharge originating in

one unit is mostly unavailable to adjoining units, and withdrawal from each aquifer should not exceed the rate of recharge.

A total of 4 mgd is being pumped from the Sum Sum aquifers. The Waller Field, Carlsen Field, and Freeport well fields account for over 80 percent of the total pumpage.

(2) Durham Sands. These sands outcrop east of the Sum Sum Sands and underlie the latter sands to the west and northwest. Limited data from wells indicate that the Durham Sands have hydraulic characteristics similar to the Sum Sum. Well yields comparable to those from the Sum Sum should therefore be available. Although geologic data are lacking, it is probable that the Durham Sands are segmented by faulting into distinct aquifer units. For purposes of this study the sands have been arbitrarily divided into three units which are shown in Figure 13. It is not known to what degree these units are hydrologically connected. More detailed studies are therefore required to establish the quantities of water that can be developed without causing local overdevelopment.

Estimated recharge, derived from rainfall on outcrop areas, totals nearly 4 mgd. Of this quantity, 2 mgd originates in area 1, 1.5 mgd in area 2, and 0.2 mgd in area 3, Figure 13. Present withdrawals of 0.6 mgd are developed from the southern end of area 2 by WASA's Freeport-Todds Road well field.

Central Range Aquifers. In the Central Range, groundwater development is limited to the Guaracara limestone. Supplies totalling 0.3 mgd are obtained from several limestone springs in the Montserrat

Hills area. The limestones of this area and at Tamana Hill are estimated to receive 1 and 0.8 mgd , respectively, from rain falling on their outcrop areas. Groundwater withdrawals approximating recharge might be feasible. However, locating of such supplies will necessitate finding suitable well sites by test drilling since information on the hydraulic character of the limestones is lacking. Any major development of wells in the Montserrat Hills area may be expected to affect spring flow and reduce the amount of water now available from these sources.

Southern Aquifers. The southern aquifers include sands in the Erin, Morne L'Enfer, Mayaro and Moruga Formations. These formations consist of clay, silt and sand layers, the latter making up about 30 percent of the Erin Formation and 50 percent of the Morne L'Enfer. The sands, which are mostly fine grained, are low to moderately permeable and capable of yielding up to 150 gpm or more to a well.

Groundwater withdrawals from the southern aquifers total 3.5 mgd of which over 90 percent is obtained from the Erin and Morne L'Enfer Formations with the remainder from Mayaro. These supplies are developed from aquifers which contain groundwater under both water-table and artesian conditions.

Little information is available on the distribution of these aquifers and groundwater movement within them, but it is believed that the sandy aquifers in each of the formations in close proximity are to some degree hydraulically interconnected, and that

at depth they confine groundwater less effectively than in the central artesian aquifers. Recharge originating at the land surface, therefore, is believed to reach the deeper aquifers through interconnected sand layers and as leakage through the confining clay and silt deposits. The amount of such recharge is estimated to total 46 mgd and does not include quantities originating in the Moruga Formation. Of this amount about one-half, or 23 mgd, is estimated to be available for development without causing excessive salt water intrusion.

The possibility of such intrusion is indicated by the proximity of salt water bodies which both underlie and, in coastal areas, adjoin fresh groundwater in sandy aquifers. It is therefore essential to achieve a balanced program of groundwater development in which sufficient quantities of groundwater are allowed to discharge seaward in order to maintain a relatively stable fresh-salt water interface. Excessive development is likely to cause both an upward and inland migration of salt water.

(1) Erin-Morne L'Enfer Formation. The Erin and Morne L'Enfer Formations are widely distributed in southwestern Trinidad where they are a major source of water supply. They occupy an easterly trending syncline which has been offset by the Los Bajos fault. The Morne L'Enfer, which underlies the Erin Formation, reaches a maximum depth of over 8000 ft. along the axis of the Erin syncline to the east. The groundwater body occupies mostly the overlying Erin Formation in the western half of the area, while occupying principally the Morne L'Enfer in the eastern half. Hydrologically, it is considered

part of a single system in which groundwater flow is mostly controlled by less permeable layers of clay and silt. In inland areas, the groundwater body reaches a maximum depth of about 2000 ft. while toward the coast it generally occurs at depths above 600 ft. Salt water underlies this body throughout the area.

Groundwater flow is believed to be predominantly seaward and a large part of it probably discharges directly to the sea as underflow. This flow is sustained by an estimated 36 mgd of recharge, of which 18 mgd or more is probably recoverable by properly located wells without causing serious salt water encroachment. Present groundwater withdrawals of 3.3 mgd are developed from relatively widespread pumping centres.

(2) Mayaro Aquifers. Groundwater development is limited to sands which make up a high percentage of the Mayaro Formation. The principal aquifer is the Mayaro Sandstone which is found in southeastern Trinidad. Closely associated with it is the Coudron Sandstone, also of the Mayaro Formation, whose potential for groundwater development is unknown.

In this study, the Mayaro Sandstone has been divided into five sub-aquifers on the basis of outcropping areas and faulting (See Figure 13). The estimated recharge, which totals 10 mgd, is listed below for each sub-aquifer:

Sub-aquifers	Recharge, mgd
1	2
2	3.5
3	2.5
4	1
5	1
	<hr/>
	10.0

A potential development amounting to one-quarter of the recharge which originates in each sub-aquifer is estimated to be available without causing serious salt water contamination. Salt water is known to underlie the sub-aquifer area 3 at depths below 500 ft. and presumably is found at similar depths in the other aquifer areas.

Current withdrawals from the Mayaro Sandstone total 0.2 mgd all of which is from wells in the northern half of the sub-aquifer area 3.

Other Groundwater Areas

Moderate well supplies might be available from sandstones as yet undeveloped. These include the Montserrat glauconitic sandstone of the Manzanilla Formation in central Trinidad, the Coudron Sandstone of the Mayaro Formation and a number of sandstone units in the Moruga Formation in the southeastern part of the island. Although presently not a source of groundwater supplies, their potential for development should be investigated.

The Montserrat sandstone outcrops within a narrow easterly

trending belt along the southern edge of the Northern Plain (See Figure 13). It has a general northerly dip which is modified to some extent by folding and faulting. The water bearing character of these sandstones is not known. Consequently test drilling will be required to determine ability to transmit water and to define aquifer units which may be segmented by faulting as are those in the Sum Sum Sands.

The Coudron and Sandstone units of the Moruga Formation outcrop extensively in southeastern Trinidad (See Figure 13). Their large outcrop area indicates a high potential for recharge opportunity. For lack of other information it is assumed that at best the sandstones are about as permeable as the Mayaro Sandstone and are probably as extensively underlain by salt water. The occurrence of salt water at depth is also indicated by two wells about two miles from the coast near the village of Moruga which encountered saline water in sands at depths less than 200 ft.

Water Quality

The major portion of the groundwater found in Trinidad is suitable for use as a public supply. Exceptions occur in areas where over-pumping is causing contamination by salt water, along coastal areas and in some of the deeper aquifers in which saline water is found naturally. Restrictions on groundwater development because of a high salt content are presently limited to the coastal extremities of the Northern Valley Aquifers at Port of Spain, along the southeastern end of the El Socorro Aquifer, and in the deeper and coastal parts of the

southern aquifers. Occasionally, chloride contents exceeding recommended limits of 250 ppm are found in public supplies developed from some wells in Port of Spain and El Socorro. A high iron content is common in groundwater from the central artesian and southern aquifers, and treatment is usually required for its removal. Ranges in the iron content of untreated public supplies are listed in Table 25 and are based on analyses made in 1967.

The groundwater has an overall range in pH of about 6 to 8. Total hardness is commonly less than 180 ppm. Hardness in excess of 180 ppm is found in groundwater contaminated by salt water and water originating from limestone materials.

Table 25. Range in Iron Content of Untreated Public Supplies

Aquifer and well field	Iron ppm
1. Northern Valley Aquifers	0.0 - 0.2
2. Alluvial Fans	
a. El Socorro, Valsayn, Tacarigua and Arouca	0.0 - 0.3
b. Arima	0.0 - 2.9
3. Central Artesian Aquifers	
a. Freeport	5.5- 10.9
b. Carlsen Field	1.0 - 2.4
c. Waller Field	0.0 - 0.1
4. Central Range Aquifers (Guaracara Limestone)	
Morichal Spring	10.9- 19.0
5. Southern Aquifers	
a. Erin-Morne L'Enfer	
(1) Granville	0.5 - 1.7
(2) Cap-de-Ville	0.1 - 0.5
(3) Point Fortin	0.3 - 5.9
(4) Penal	0.0 - 6.1
b. Mayaro	0.0 - 1.1

Groundwater Potential

Groundwater available from the principal aquifers in Trinidad is estimated to total 72 mgd of which about 39 mgd is being developed by public and large private supplies. Additional groundwater might also be available from sandstone aquifers, as yet undeveloped, in central and southeastern Trinidad. Table 26 is a summary of available groundwater from the principal aquifers, the 1968 pumpage from each, and the proposed future development for each.

Table 26. Groundwater Available from Major Aquifers in Trinidad

Aquifer	Water available mgd.	Well Field	Draft mgd.				Comments
			1968		Recommended (1)		
			Field	Aquifer	Field	Aquifer	
<u>NORTHERN VALLEY AQUIFERS</u>							
Chaguaramas	1.8	Chaguaramas	0.5	0.5	1.8	1.8	Develop as needed in Chaguaramas; no export
Tucker Valley	6.0	Tucker Valley	1.4	1.4	6.0	6.0	Develop as needed in Chaguaramas and stop export when major supply is available
Diego Martin	4.5	River Estate	0.5	5.2	0.1	4.5) Reduce production uniformly as reduction in recirculated water results in salt-water intrusion
		Four Roads	2.9				
		Cocorite	2.2				
		Private	0.1				
Port of Spain-Maraval	4.0	Brievies Road	0.1	5.7	1.7	4.0) Cut back of pumping to 4.0 total should be accomplished only as reduction in re-circulated water results in saltwater intrusion
		Wharf	1.0				
		Docksite	1.0				
		St. Clair	0.3				
		Savannah	0.8				
		George V	1.5				
		Private	1.0				
El Socorro	4.5	El Socorro	7.2	7.4	0.3	4.5	Cut back production to reduce saltwater intrusion
	Private	0.2					
Valsayn	5.0	Valsayn	6.0	6.1	0.3	5.0	May be mined on short term Capacity private wells is 0.3 mgd.
	Private	0.1					
Tacarigua	5.0	Tacarigua	2.6	2.7	0.2	5.0	Increase number of wells
	Private	0.1					
Arima	2.0	Arouca	0.2	0.9	0.2	2.0	Increase Arima wells and capacity to 1.6 mgd.
		Arima	0.5				
		Private	0.2				
<u>CENTRAL ARTESIAN AQUIFERS</u>							
Sum Sum Sand							
Area 1	6.5	Miller Field	0.9	0.9	3.0	6.0	New well and treatment works proposed New wells and treatment works proposed
		Las Lunas	-				
Area 2	1.0	Carlson Field	-	-	1.0	1.0	
Area 3	2.0	Carlson Field	1.0	2.0	1.0	2.0) Pumping capacity with Freeport exceeds yield; may be mined temporarily
		Freeport	1.0				

(1) Except as otherwise noted under Comments, this is the maximum sustained pumping rate without mining the aquifer or risking saltwater intrusion.

Table 26 (Continued). Groundwater Available from Major Aquifers in Trinidad

Aquifer	Water available mgd	Well field	Draft mgd				Comments	
			1968		Recommended (1)			
			Field	Aquifer	Field	Aquifer		
Sum Sum Sand								
Area 4	0.6	California	-	-	0.6	0.6	Proposed development	
Area 5	0.8	Texaco	0.6	0.6	0.6	0.6 +	No future WASA development proposed	
Durham Sand								
Area 1	2.0		-	-	-	-	Reserve for future needs	
Area 2	1.5	Freeport (Todds Road)	0.6	0.6	1.5	1.5	Development planned in connection with WTP expansion	
Area 3	0.2		-	-	-	-	Reserve for local supply	
<u>CENTRAL RANGE LIMESTONE</u>								
Montserrat Hill Area	1.0	Springa	0.3	0.3	0.3	0.3	No further development recommended	
Tamana Hill Area	0.8	Los Armadillos	-	-	0.5	0.5	Propose well development if possible	
<u>SOUTHERN AQUIFERS</u>								
Erin-Morne L'Enfer	18.0	Penal	0.7		2.0		Proposed development at Penal with new wells	
		Point Fortin	0.3		1.0		Proposed development with new wells	
		Cap de Ville	0.2		1.0		Proposed development with new inland wells	
		Granville	0.5		0.5		No change proposed	
		Fyzabad	-	-	1.0		New well field and treatment plant proposed	
		Clarke Road	-	-	1.0		" " " " " " " "	
		Palo Seco	-	-	0.5		" " " " " " " "	
		La Brea	-	-	1.0		From new inland wells with new treatment plant	
		Private	2.0	3.7	3.2	11.2	It appears that this is optimum development due to physical limitations on well fields (6 wells/mgd = 10,000 ft.)	
Mayaro Sandstone								
Area 1	1.0	None	-	-	-	-	Reserve for future local demands	
Area 2	1.2	None	-	-	-	-	Reserve for future local demands	
Area 3	1.2	Mayaro	0.2	0.2	1.2	1.2	Provide additional wells	
Area 4	0.5	None	-	-	-	-	Reserve for future local demands	
Area 5	0.5	Guayaguayare				0.5	Proposed future wells for local water demands	
Totals	71.6		38.7	38.7		58.2		

1. Except as otherwise noted under Comments, this is the maximum sustained pumping rate without mining the aquifer or risking saltwater intrusion.

In northern valley aquifers additional groundwater totalling nearly 6 mgd is available from Chaguaramas and Tucker Valley. The development of such supplies is based on existing land use patterns. A reduction in groundwater recharge can be expected as a result of future urbanization. In anticipation of such reductions, plans should be made to balance such eventual losses by artificial means. The full development of Chaguaramas and Tucker Valley will also require wells to be located away from coastal areas to prevent contamination by salt water.

The Diego Martin and Port of Spain aquifers are fully developed at existing rates of withdrawal. Any increase in pumpage is expected to cause an inland migration of salt water which may result in the eventual abandonment of coastal wells. The apparent balance in these aquifers between the fresh and salt water is maintained by secondary recharge from pipe line losses and the infiltration of waste waters. The curtailment of such recharge would result in a substantial overdrought. Some additional groundwater in the Port of Spain aquifer could be developed by a number of small to moderate capacity wells along the Maraval River. Such development, potentially as much as 2 mgd would, however, limit surface diversions from the river which now total 0.7 mgd.

The evident mining of groundwater from the El Socorro and Valsayn aquifer will require a reduction in pumpage in order to stabilize water levels and to prevent further salt water intrusion.

Pumpage from the El Socorro aquifer should initially be cut

back to 4.5 mgd which equals its recharge. There is no certainty, however, that even at such rates salt water encroachment can be curtailed. On the basis of past pumping records, it may become necessary to maintain pumpage at an average 2 mgd before adequate groundwater flow can be established to prevent further salt water intrusion.

Although contamination by salt water is not apparent in the Valsayn aquifer, the mining of groundwater at the present rate of 1 mgd should be stopped. The continued lowering of water levels may ultimately cause saline water to enter the aquifer. A reduction in pumping to 5 mgd, or the rate at which the aquifer is being recharged, will be required to stabilize water levels. Should salt water eventually enter the aquifer, it may become necessary to reduce pumping further, possibly to as little as 3 mgd.

Further increases in pumping are believed possible from the Tacarigua aquifer. Since the aquifer is some distance from salt water sources it should be possible to develop it at a rate equalling recharge. This is estimated to total 5 mgd of which 2.6 mgd. are at present being developed.

Additional groundwater totalling at least 1 mgd is available from the Arima aquifer. Such development should be preceded by a test drilling program to locate wells for optimum yield. Present production is limited by low yielding wells.

Means to supplement existing groundwater deficits and to increase productivity should be investigated for the Alluvial Fan Aquifers. Some possibility for surface water spreading, or the use of recharge

pits, is suggested by the relatively high infiltration rates from streams crossing the fans. Additional infiltration might be made available by increasing infiltration areas along streams for water-spreading purposes, or by river diversions to recharge pits. The suitability of such procedures is principally dependent on land availability and the physical quality and quantity of stream flow divertible.

Similar means to increase recharge might also be used at suitable sites in the Northern Valley Aquifers, where large quantities of storm runoff are currently wasted to the sea.

A large potential for development exists from the Sum Sum Sands north of Carlsen Field. Additional groundwater that can be developed here (Aquifers 1 and 2) total over 6 mgd. An additional 0.5 mgd is also available from aquifer area 4 to the south. The remaining areas are estimated to be fully developed. Groundwater production in the Freeport and Carlsen Field well fields is already exceeding the estimated available groundwater supplies in aquifer area 3 by 0.5 mgd. Such excessive withdrawals will cause a gradual and continued decline in water levels. It is not believed that salt water intrusion will become an immediate problem, but lowering of water levels will cause increased pumping costs.

Other supplies totalling nearly 4 mgd are available from the Durham Sands. Current withdrawals total only 0.5 mgd. Additional geologic data are required to determine hydraulic boundaries which might limit groundwater movement within the sands. This information

will facilitate preparation of plans for proper development.

The feasibility of developing well supplies from the Guaracara limestone depends largely on its capacity to transmit water to wells.

Available supplies from the limestones are estimated at nearly 2 mgd of which about half is available at each of two major outcrop areas. Any major development at the Montserrat Hills area, however, is expected to reduce the flow from limestone springs of which 0.3 mgd. is being used for public supplies.

Major additional supplies can be developed from aquifers in the Erin and Morne L'Enfer Formation. Present production from these sources totals 3.3 mgd. out of a total potential estimated at 18 mgd. Any additional development should be limited to inland areas to minimize any contamination by saline waters. Pumping centres should be spaced widely apart to avoid serious interference by pumping. Depths of wells should be carefully regulated to prevent contamination by the upward migration of brines which underlie the Erin-Morne L'Enfer aquifers. Similar precautions are recommended for development of groundwater from the Mayaro sandstone.

It is estimated that a total of about 5 mgd can be developed from the Mayaro Formation in five separate aquifer areas. The feasibility of such development should first be proven by test drilling in aquifer areas as yet undeveloped. This is needed to determine the location and water yielding character of sand aquifers and the quality and quantity of groundwater that can be expected from them.

Tobago

The northern two-thirds of Tobago is underlain by either metasediments or igneous intrusive rocks. Both rock types are hard and impervious, and offer no potential for groundwater development. The bedrock is overlain by a mantle of residual soils too thin to serve as an aquifer.

The southern third of the island is composed of volcanics and metavolcanics, principally tuffs and tuff breccias. These rocks are highly fractured, and deeply weathered. In areas where sufficient above-sea-level depth can be obtained, the volcanics may produce quantities of water sufficient for domestic use.

On the southwestern tip of Tobago, the volcanics are overlain by deposits of sand, silt, and clay. Near the coast, thicknesses of 400 ft. have been recorded, with some thin sand and gravel zones. However, the bulk of the material is clay, and offers little potential for water supplies. In addition, the material was deposited in sea water, and presently lies predominantly below sea level. Thus, chloride levels would be high, and sea water intrusion likely.

Most of the clastic sediments are overlain by coral limestone. It occurs in a thin layer up to 40 ft. thick, at elevations below 100 ft. The coral is highly fractured and quite "rotten". Where it overlies impermeable clays, water entrapment can occur, providing some groundwater potential. Available information indicates that yields are likely to be less than 50,000 gallons per day.

Deposits of sand and gravel are found in several of the

river valleys near the coast. They are remnants of material deposited in salt or brackish water when sea level was higher. Wells in the deposits can induce recharge from the nearby streams. When good hydraulic connection with the streams does not exist, the water from this source is likely to be high in chlorides.

DEVELOPMENT OF POTENTIAL SOURCES

General

This chapter deals with the development problems and costs for each source identified as feasible in the chapters GROUNDWATER SOURCES and POTENTIAL ADDITIONAL SURFACE SOURCES.

Groundwater development will require less lead time than will surface water development since no major structures are required. However, incremental units of groundwater development are limited to about 1.0 mgd per field. Therefore, the number of facilities required to meet existing average day needs and to provide adequate peaking capacity completely from groundwater are not readily developed. In addition, 20 mgd from groundwater at some 1.0 mgd per facility would require many more operators than 20 mgd from a single surface water source. Accordingly, a combination of groundwater and surface water sources should best meet the needs of Trinidad and Tobago.

Groundwater

The largest undeveloped groundwater supplies are located in the southern area of Trinidad (See Figure 13) generally outside the previously mentioned Tee-shaped area of heaviest water demand. However, some unexploited groundwater does exist in the area of heavy demand.

Within the southern area, not only is there a deficiency in developed supply, but many of the distribution mains are inadequate. Development of strategically located groundwater supplies will reduce

the amount of main reinforcement necessary and delay some major work of a similar nature.

The same distribution and transmission deficiencies exist to a lesser extent in the area of major demand. Development of well fields here will also reduce the supply deficit and delay major distribution reinforcement.

Table 27, Cost of Groundwater Development, lists the well fields proposed for development in the chapter GROUNDWATER SOURCES together with the estimated costs. These costs do not include allowances for engineering and contingencies, nor do they cover the transmission and distribution mains necessary to convey developed water to the users. Transmission and distribution improvement will be discussed later in this chapter.

Table 27. Cost of Groundwater Development

Well Field	No. Wells	Yield mgd	Cost \$1,000 TT			Cost per mgd
			Local	Foreign	Total	
Chaguaramas	16	1.3	493.0	383.0	876.0	\$ 674.0
Tucker Valley	29	4.6	1,092.0	986.0	2,078.0	542.0
Tacarigua	7	2.2	485.0	348.0	833.0	379.0
Arima	7	1.1	381.0	239.0	620.0	564.0
Waller Field	9	2.1	928.0	724.0	1,652.0	787.0
Las Lomas	13	3.0	1,333.0	1,103.0	2,436.0	811.0
Carlsen Field (1)	4	1.0	690.0	666.0	1,356.0	1,356.2
California	3	0.6	369.0	286.0	655.0	1,090.0
Freeport (2)	6	0.9	565.0	443.0	1,008.0	1,120.0
Los Armadillos	2	0.5	141.0	99.0	240.0	480.0
Penal (3)	8	1.3	816.0	689.0	1,605.0	1,235.0
Point Fortin	4	0.7	468.0	369.0	837.0	1,196.0

Table 27 (Continued), Cost of Groundwater Development

Well Field	No. Wells	Yield mgd	Cost \$1,000 TT			Cost per mgd
			Local	Foreign	Total	
Cap-de-Ville (3)	5	0.8	549.0	418.0	967.0	1,209.0
Fyzabad	6	1.0	659.0	507.0	1,166.0	1,166.0
Clarke Road	6	1.0	659.0	507.0	1,166.0	1,166.0
La Brea	6	1.0	659.0	507.0	1,166.0	1,166.0
Palo Seco	3	0.5	412.0	320.0	732.0	1,464.0
Mayaro	12	1.0	597.0	375.0	972.0	972.0

-
1. Sum Sum Sand 2
 2. Durham Sand 2
 3. Includes WTP Expansion

Surface Water Sources

Table 28 lists the surface sources considered for development and the estimated full development construction cost of each, exclusive of the cost of transmission and distribution mains.

Table 28. Cost of Surface Water Development

Source	mgd	Estimated cost \$1,000 TT ⁽¹⁾			
		Local	Foreign	Total	Per mgd
North Oropouche	45	17,636	15,942	33,578	745
Matura	20	7,366	6,930	14,290	715
Guanapo	10	4,677	5,232	9,909	991
Yarra	9+	2,900	4,300	7,200	800
Marianne (Site A)	10	2,750	4,400	7,150	715
Madamas	18	7,140	6,490	13,630	756
Caroni-Arena)	42	12,055	11,437	23,492	560
Taiparo (2))					
Tumpuna (2))					
Cunapo	3	2,172	2,800	4,972	1,657
Moruga	25	5,611	4,795	10,406	417
Navet Pumped Storage ⁽³⁾	10	953	1,450	2,403	240
Courland	6	1,620	3,460	5,080	850
Richmond	3	910	2,140	3,050	1,017

1. Costs do not include engineering or contingencies.
2. Costs not computed separately as these are too small to be economic by themselves.
3. No reservoir storage provided, utilizes Navet excess storage.

The estimated cost of development for the surface water sources requiring a dam and reservoir ranges from \$417,000 per mgd for the Moruga to \$1,657,000 per mgd for the Cunapo. The high yield reservoirs in the Northern Range cost around \$750,000 per mgd to develop, while the lower yield reservoirs in the same area cost from \$800,000 to \$900,000 per mgd.

Comparison of development costs in Tables 27 and 28 show that:

1. The cost of increasing Navet dependable yield from 7 to 17 mgd is the lowest supply development cost at \$240,000 per mgd;
2. The development cost of most groundwater from the northern aquifers is less than the development cost of most surface sources; and
3. The development cost of groundwater from the central and southern aquifers is greater than the cost of development of most surface water sources.

Selection of Alternative Sources

The cost of source development and the cost of transmission and distribution facilities necessary to convey the developed water to users must be considered for the purpose of determining the most economical sources for development. Therefore, a transmission cost allowance for supplying each water service area from each source listed in Tables 27 and 28 was developed. This allowance was based on full utilization of all mains and took into consideration

contiguous service areas supplied from the same source. These allowances were added to the cost of source development shown in the two above-mentioned Tables, and the results compared. Table 29 is a summary of the results of this comparison, showing for each service area the relative economic advantage of supply from each source. The most advantageous source is indicated by the numeral 1, the next by the numeral 2 etc.

Where projected water demands in the area in which the source is located equal or exceed the yield of the fully developed source, that source has not been considered to supply other areas.

Table 29. Summary Comparison of Water Sources

		Service area												
S o u r c e		Chaguaramas	Diego Martin	Port of Spain	Eastern Main Rd.	Caroni	Montserrat	San Fernando	South Trinidad	North Coast	Toco	Sangre Grande	Mayaro	P.O.S.- S.F. Urban Fee
S u r f a c e S o u r c e s	North Oropouche	4	4	5	6	5	-	4	11	-	3	3	-	2
	Matura	5	5	6	7	8	-	5	12	-	1	2	-	3
	Guanapo	6	6	7	8	8	-	6	13	-	-	-	-	5
	Yarra	8	8	9	10	10	-	8	15	2	5	-	-	-
	Marianne	7	7	8	9	9	-	7	14	1	4	-	-	-
	Madamas	9	9	10	11	11	-	9	16	3	2	-	-	-
	Caroni-Arena	3	3	3	5	2	-	3	9	-	-	-	-	4
	Moruga	-	-	11	12	6	-	2	6	-	-	-	3	4
	Navet	-	-	-	-	-	-	1	1	-	-	-	2	1
	Oropouche Intake (1)	-	-	-	-	-	-	-	-	-	-	1	4	-
Hollis (2)	-	-	1	1	-	-	-	-	-	-	-	-	-	
U n d e r g r o u n d w a t e r S o u r c e s	Chaguaramas Well Field	2	2	-	-	-	-	-	-	-	-	-	-	-
	Tucker Valley " "	1	1	-	-	-	-	-	-	-	-	-	-	-
	Tacarigua " "	-	-	2	3	1	-	-	-	-	-	-	-	-
	Arima " "	-	-	-	4	-	-	-	-	-	-	-	-	-
	Waller Field " "	-	-	-	2	-	-	-	-	-	-	5	-	-
	Las Lomas	-	-	4	-	-	-	-	-	-	-	-	-	-
	Carlson Field	-	-	-	-	7	-	-	-	-	-	-	-	-
	California	-	-	-	-	4	-	-	-	-	-	-	-	-
Freeport	-	-	-	-	3	1	-	-	-	-	-	-	-	
	Los Armadillos	-	-	-	-	-	-	-	-	-	-	4	-	-

Table 29. (Continued) Summary Comparison of Water Sources

	Source	Service area										
		Chaguaramas	Diego Martin	Port of Spain	Eastern Main Road	Caroni	Montserrat	San Fernando	South Trinidad	North Coast	Toco	Sangre Grande
Gr o s s p r o d u c e s	Penal	-	-	-	-	-	-	-	8	-	-	-
	Point Fortin	-	-	-	-	-	-	-	4	-	-	-
	Cap de Ville	-	-	-	-	-	-	-	5	-	-	-
	Fyzabad	-	-	-	-	-	-	-	3	-	-	-
	Clarke Road	-	-	-	-	-	-	-	7	-	-	-
	Pluck	-	-	-	-	-	-	-	10	-	-	-
	La Brea	-	-	-	-	-	-	-	3	-	-	-
	Palo Seco	-	-	-	-	-	-	-	8	-	-	-
	Mayaro	-	-	-	-	-	-	-	-	-	-	1

1. Intake at Sangre Grande utilizing flow from Quare and Oropouche Rivers below Hollis Dam and the proposed Oropouche Dam.
2. Increase in yield made possible by pumping to increase flow capacity of main.

Inspection of Table 29 reveals that:

1. Generally, groundwater sources within a service area are the most economically advantageous sources to supply that area;
2. The Caroni-Arena is the most advantageous major source of supply, and the North Dropouche the next, and
3. The Moruga is the most advantageous major source of supply for south Trinidad.

As previously mentioned, development of groundwater in small increments requires less lead time than does development of a major surface water source. WASA is experienced in the design and construction of wells and small treatment works for iron removal. In addition, WASA has completed preliminary planning for many strategically located groundwater sources. The readily developable groundwater resources are estimated to total about 22 mgd. Of this total, an amount of 9.8 mgd is so located as to be desirable for first stage construction. Development by 1974 of this amount of water in conjunction with metering should in most areas eliminate the average day but not the maximum day deficit.

Although 12.2 mgd of developable groundwater would remain after development of the above-mentioned 9.8 mgd this potential supply is well removed from the areas of deficit, and transmission mains would be required to convey it to such areas. The cost of development of this groundwater at the source is generally greater than the cost of developing the northern surface sources, and the

required transmission mains are about the same length. In addition, this water will be needed near the source in the future.

The projected water demand for the year 2000 is 170 mgd. Existing developed dependable yield is 47.1 mgd in Trinidad and 2.3 mgd in Tobago, leaving a total additional water requirement of 120.6 mgd, of which 3.5 mgd are required in Tobago.

The full development of groundwater together with the development of three or more of the surface sources indicated in Table 29 as the most economically advantageous to supply Trinidad and Tobago, will meet this requirement as indicated in Table 30.

Table 30. Alternative Additional Supply at Year 2000

Source	Dependable Yield, mgd
<u>Trinidad</u>	
Navet Pumped Storage	10 ✓
Caroni-Arena	42 ✓
Groundwater and Miscellaneous Intakes	22 ✓
Moruga Reservoir	25 ✓
Dropouche Reservoir	19 ✓ (Partial development)
	<u>118</u>
Navet Pumped Storage	10
Dropouche Reservoir	45
Moruga Reservoir	25
Groundwater and Miscellaneous Intakes	22
Caroni-Arena	16 (Partial development)
	<u>118</u>
Navet Pumped Storage	10
Dropouche Reservoir	45
Groundwater and Miscellaneous Intakes	22
Caroni-Arena	42
	<u>119</u>
Navet Pumped Storage	10
Caroni-Arena	42
Dropouche Reservoir	45
Groundwater and Miscellaneous Intakes	22
	<u>119</u>
<u>Tobago</u>	
Courland Reservoir	1.3 (Partial development)
Richmond Reservoir	1.5 (Partial development)
	<u>2.8</u>
Courland Reservoir	<u>2.8</u> (Partial development)
Richmond Intake	0.5
Courland Reservoir	2.3 (Partial development)
	<u>2.8</u>

Development of Caroni-Arena

Caroni-Arena Yield. - The Caroni River catchment upstream from the proposed intake and treatment works at Kelly Headworks in Kelly Village is about 150 square miles in area (See Figure 16). Flow gauging at Kelly Headworks has been carried on for about two years. Fortunately, total rainfall for the full year of record available approaches the mean annual for the period of record (15 to 30 years for the area gauging station), and the seasonal distribution is normal. Study of the rainfall records for the drainage area indicates that the 95 percent dry year rainfall on this catchment would be about 20 percent lower than the mean annual rainfall of 89.3 inches, or about 71 inches. Table 22 in the chapter POTENTIAL SURFACE SOURCES shows that in 1968 the total runoff was about 37 percent of the mean areal rainfall with 10.5 percent occurring in the dry season. It is estimated that the 95 percent dry year runoff would be about 20 percent less than the mean annual runoff, or about 27 inches. Seasonal distribution should be about the same.

Yield determination for the Caroni-Arena system has been based upon a flow duration curve derived from the 1967-1968 flow records for the Kelly gauging station. Determination of the flow duration curve for the pumped storage intake at San Rafael in the absence of gauging records at this point, was by reduction of Kelly flow in proportion to the reduction in the contributing catchment or watershed. Since the proposed storage reservoirs are located within the Caroni catchment the portion of the area they control was deducted

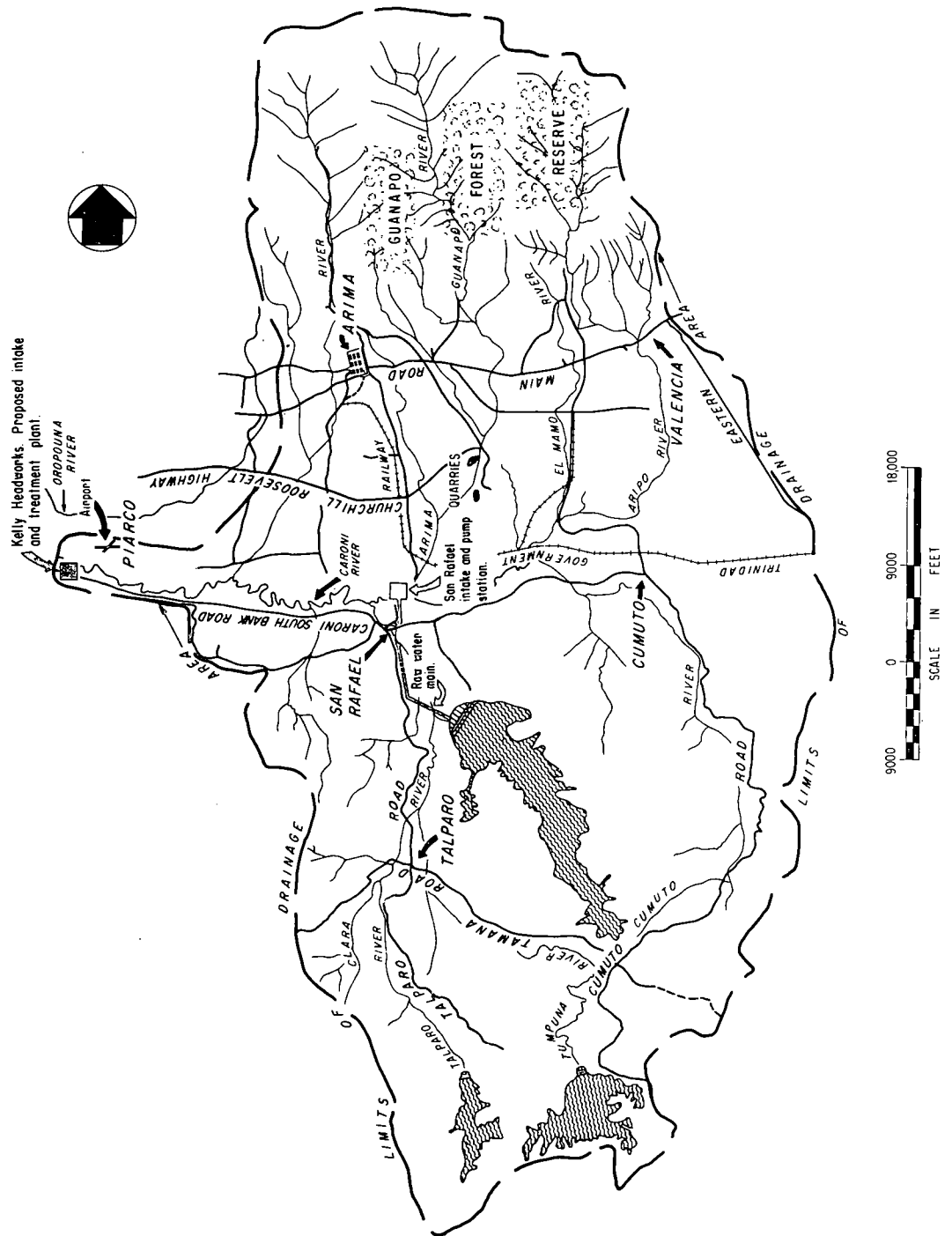


FIG. 16 CARONI-ARENA CATCHMENT

in obtaining the average year and the 95 percent dry year curves. The estimated 95% dry year flow duration curve was taken at 20 percent lower than the average year runoff. The runoff deficit for the Arena reservoir was estimated to be about 1650 million gallons on the 95% dry year, and 400 million gallons on the average. Therefore, the estimated maximum annual pumpage required is 1650 million gallons on the 95% dry year. Since the above estimates are based on one year's runoff data it is recommended that provision be made for pumping at 20 mgd in lieu of the 15 mgd indicated as necessary to fill the Arena reservoir.

Available stored water is estimated to be as shown in Table 31.

Table 31. Caroni-Arena Available Stored Water

Reservoir	Storage Million Gallons		
	Capacity	Ave. year ⁽¹⁾	95% dry year ⁽¹⁾
Tumpuna	1,300	1,300	1,300
Talparo	1,400	1,380	850
Arena	<u>3,500</u>	<u>3,500</u>	<u>3,500</u>
Total	6,200	6,180	5,650

1. In excess of evaporation.

Figure 17 Caroni-Arena yield shows the required flow supplementation, maximum pumpage to Arena Reservoir and the yield, for both the 95 percent dry year and the average year.

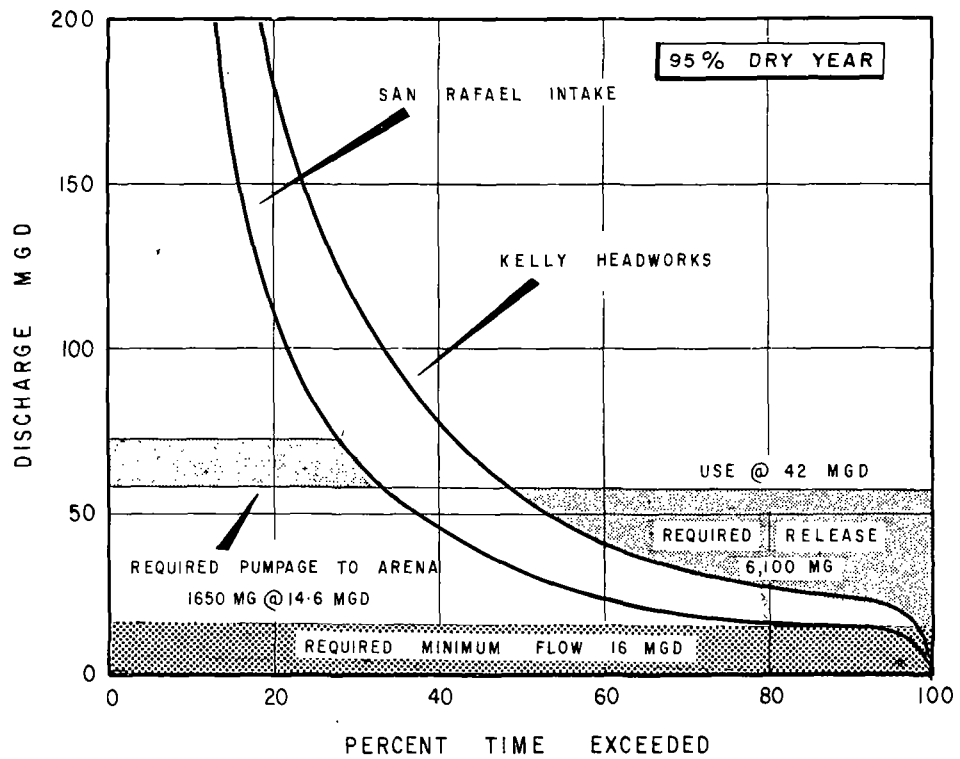
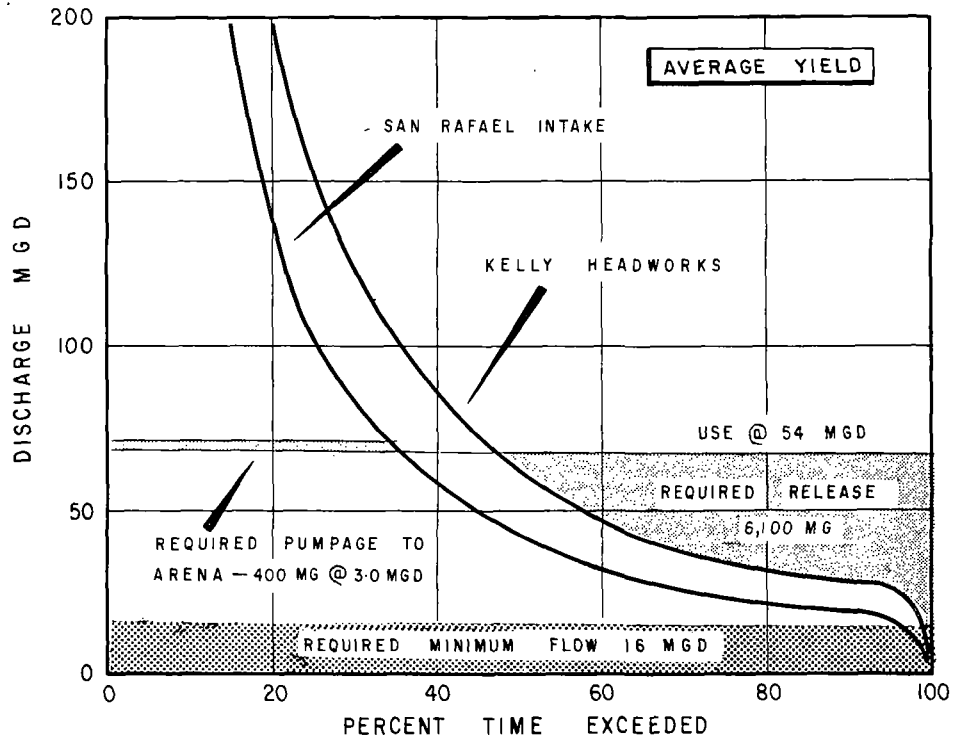


FIG 17 CARONI - ARENA YIELD

Study of the Caroni River as a source of water included two other means of supplementing dry weather flow.

The first was to provide a tertiary treatment plant at the sewage lagoons for filtering lagoon effluent to remove algae and other suspended matter. The chlorinated filter effluent would be pumped to the irrigation canal at Kelly Village via a steel main. This system would allow use of the total flow of the river at Kelly headworks for potable water supply. The net dependable yield from this plan would be about 15 mgd.

The second means investigated included construction of an off-stream reservoir to store water pumped from the Caroni at Kelly headworks in the wet months for release to supplement dry weather yield. The site investigated for the reservoir is southwest of the El Socorro water works. It appears to be too low and wet for agricultural purposes and is presently idle. The reservoir to store 3500 million gallons for dry season release would be diked and would measure about 3,800 feet square by 40 feet deep. The dependable yield would be about 33 mgd.

While facilities necessary to the first plan can be constructed in the areas indicated, the cost of development is too high to be competitive with the Oropouche project or the Caroni-Arena system as a first stage.

A soils boring at the proposed dike location for the second plan indicated that foundation conditions were not satisfactory for construction of the proposed reservoir.

Treatment and Pumping Facilities. The water treatment plant would be located at the Kelly Headworks and would require acquisition of about 19 acres of land, 6 houses and 5 small-frame warehouses. Although no borings have been made at the proposed treatment plant site, borings taken for the sewerage system at nearby Piarco Airport, and observation of excavations at the Airport indicate that subsurface conditions are satisfactory for plant construction. The proposed treatment works area floods periodically to a depth of 2 to 4 feet. Accordingly, the selected layout of the works is such as to minimize uplift and the plant site will be filled to a height above anticipated flood levels.

The San Rafael intake site is located on the south bank of the Caroni River just downstream from the Tumpuna Road Caroni bridge (See Figure 16). The area of the land required at this site is about 1.5 acres.

The pipeline from the Caroni intake to the Arena Reservoir (See Figure 18) follows the roadway through San Rafael, up the Talparo Road to a point opposite the reservoir site, then along a trace to the reservoir. The diameter of the pipeline is 36 inches and the length is about 18,700 feet.

Geology of the Arena, Talparo and Tumpuna Basins

Arena. The proposed Arena Reservoir lies in the northern drainage of the Central Range southeast of the village of San Rafael. The area has moderate relief ($\pm 100'$) and consists of rolling hills formed by an erosional drainage pattern impressed on fine grained

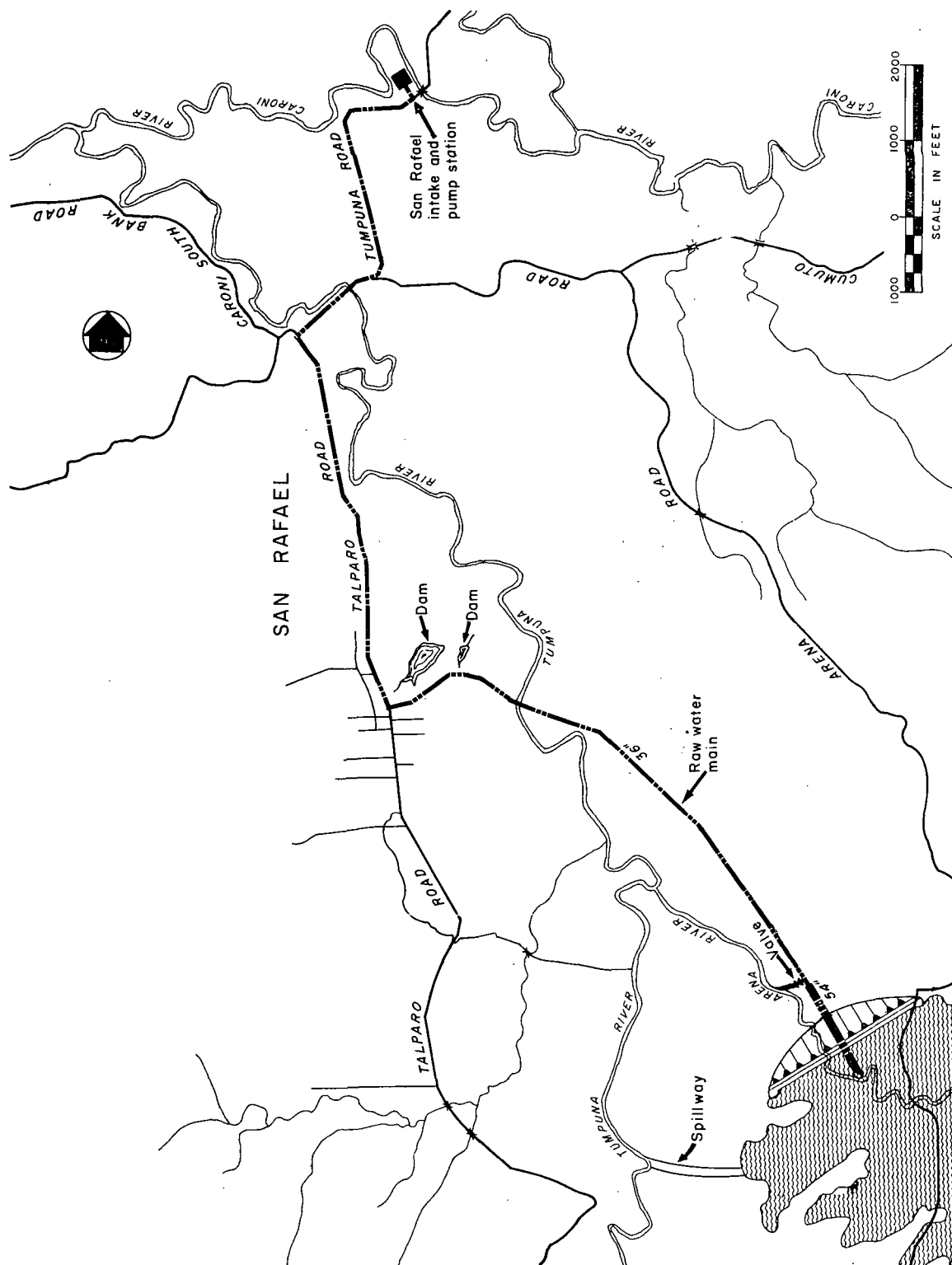


FIG.18 SAN RAFAEL — ARENA MAIN

soils. Geologically it occupies about the center of the Caroni Syncline although a slight upbow in sediments makes the particular area of the dam site an anticline (the Mahaica anticline).

The reservoir lies in the Talparo and Springvale Formations of Pliocene and Oligocene age, respectively. They are both unconsolidated formations consisting in this particular area of silts and clays interbedded with thin sand layers (See Figure 19). The ridges near the dam site and along the northeast side of the reservoir area are reported to be outcrops of the Mahaica sands. In the upper reaches of the reservoir area the Caparo sands are reported to crop out.* These sands are medium to fine-grained and dip beneath the overlying silts and clays in the lower half of the reservoir. The base of the Caparo sands is more than 300 ft. deep at the dam site. The head of the reservoir is underlain by sands and silts of the Manzanilla Formation, of Oligocene age. The drainage-ways on both sides of the Arena have gulleys working headward.

Talparo. The Talparo Reservoir also lies in the northern drainage of the Central Range, about 12 miles south of Arima. It is underlain primarily by northward dipping sands and clays of Miocene age. The proposed dam site lies within the clays of the Springvale and Manzanilla Formations. The head of the reservoir overlies cavernous reef limestones of the Tamana Formation. All of the formations are unconsolidated except the Tamana Limestone. The limestone is moderately weathered.

*Dominion Oil Company

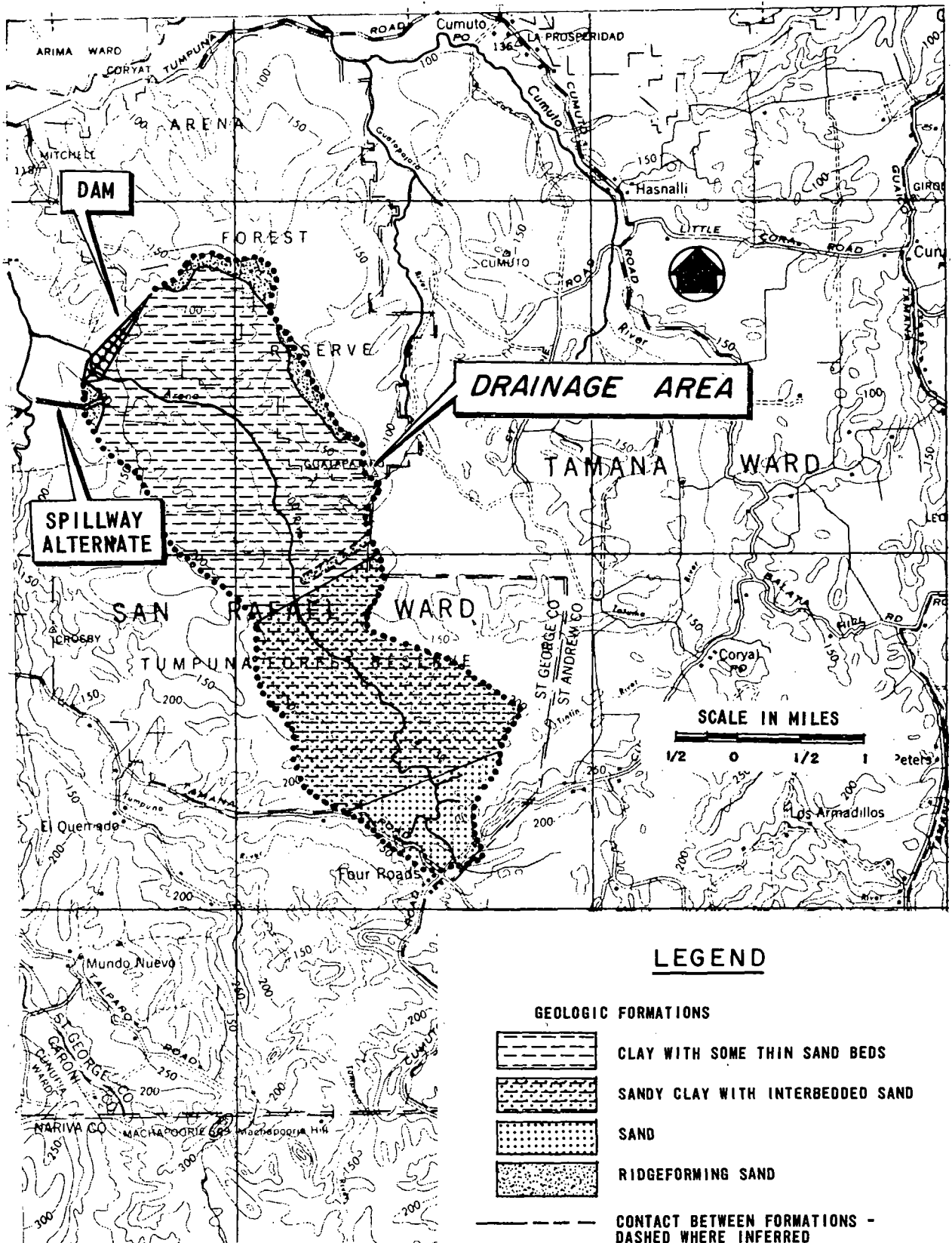


FIG. 19 ARENA RIVER BASIN

No major structural features are reported within the reservoir area.

Tumpuna. The reservoir area is underlain by steeply dipping vertical sands and clays of Oligocene and Miocene age. The geology of the proposed dam site is quite complex. It lies near the crest of an anticlinal structure in the Nariva Formation. The Nariva is folded and faulted into contact with the calcareous sands and marls of the Cipero Formation. At least one major fault is reported near the proposed dam site. The remainder of the strata in the reservoir area belong to the Nariva and Cipero Formations. These two formations are in fault contact near the head of the reservoir.

Evaluation of the Arena Basin as a Reservoir

Tightness. Borings taken during this study as well as test pits dug during the time the area was mapped by Dominion Oil Company indicate that the reservoir is underlain with relatively impermeable silts and clays with minor sand lenses. Only the northeastern ridges and the head of the basin appear to contain granular material. Provided the flow line remains below the bottom of the granular material no appreciable leakage through the reservoir floor or walls is anticipated. Some additional protection may be required to prevent leakage through the sand ridges to the north.

Slope Stability After Impoundment. Slopes in the area of the Arena impoundment are much less steep than slopes in the Northern Range and although much of the terrain is composed of silt and clay there are fewer land slips here.

After impoundment it is expected that there will be several small slips from time to time into the reservoir and that consideration should be given to clearing but not grubbing the area below the flow line. It is anticipated that leakage through some of the thinner ridges separating headward working gulleys and adjacent drainages will be minimal. However, the stability of the thin ridges and gully sides requires thorough investigation during final design. Stability analyses made for preliminary design from a limited number of borings indicate that slopes are stable.

Dam Location. The proposed dam is located between two ridges which enclose the drainage of the Arena River about three miles upstream from the confluence of the Arena and Caroni. The abutment ridges are composed of about 17 ft. of coarse brown sand that overlies the softer silty sand and clay which also make up the foundation of the dam. The proposed dam location gives the greatest impoundment consistent with the topography.

Two problems are apparent with the type of subsurface conditions present at this location. One is the stability of the foundation with a dam on it under static condition and the second is the performance of dam and foundation under the dynamic conditions produced by seismic shock during an earthquake. The stability of the foundation under these two situations has been analysed and the design concept of the proposed dam evolved (See Figure 20).

In the investigation conducted for the preliminary design a more suitable site for a dam could not be located. Foundation

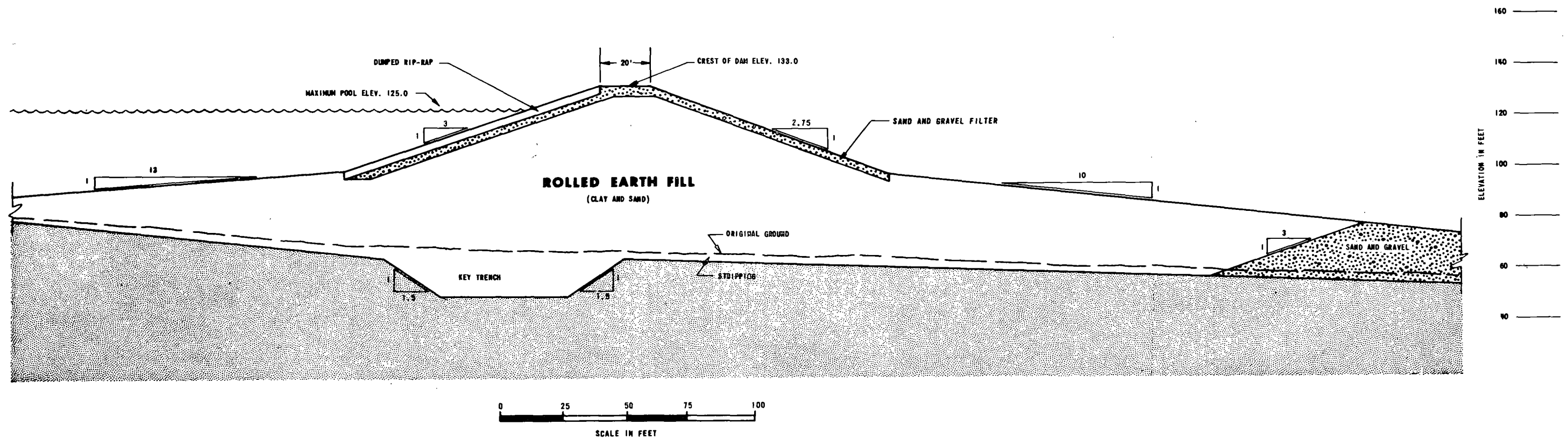


FIG. 20 PROPOSED HOMOGENEOUS
EARTH FILL DAM SECTION

problems will be similar anywhere along the Arena, gradually getting worse as one approaches the Caroni River.

Spillway Locations. There are two satisfactory locations for spillways. One location is through the ridge to the west of the main dam and the other is in the crest of the main dam directly above the present channel of the Arena River.

Both spillway locations route water back into the Arena drainage. Some slope protection will be required in the thin sandy ridge area west of the main dam to combat headward erosion from the adjacent drainage-way. A spillway in this location can incorporate the necessary protection from the thin ridge.

Construction Materials. Sand is available within the catchment area near the upstream end of the reservoir and at other selected locations within $1\frac{1}{2}$ miles of the dam site.

Gravel is not available within the reservoir area. The nearest location is La Horquette where there are privately owned pits and a ready-mix plant. The shortest distance by road to this area is 5.6 miles via San Rafael. Additional gravel sources are to be found along the Arima River in the Waller Field area where both private and Government pits exist. The distance by road to this source is 8 miles.

Rip-rap will be a problem since the nearest source of sound rock comes from the Quarry on the Arima-Blanchisseuse Road about 14 miles from the dam site. During final design, studies of other means of slope protection should be made.

Design Considerations.

1. Stability of the dam under static and dynamic conditions.
2. Loss via leakage into the Caparo sands, i.e., continuous recharge of aquifers.
3. Stability of thin ridges after impoundment.
4. Design of the main dam and spillway for construction giving consideration to the requirements for construction during the various seasons of the year.
5. Instrumentation required for observing settlement and dissipation of pore water pressure to ensure stability during construction.

Recommended Dam Type.

1. It is recommended that a rolled earth-fill dam composed of materials naturally occurring within the reservoir area be constructed at the location shown on Figure 21 with a maximum pool elevation of 125.

Because of subsurface conditions, counterweight berms are required and it is recommended that they be composed of locally excavated silt and clay, buttressed on the downstream side by sand and gravel which will form the toe of the downstream berm. The upstream face of the dam is protected by dumped rip-rap over gravel filters which also extend over to the downstream face for protection against erosion.

All of the material except the sandy gravel and rip-rap can be obtained from within the reservoir area.

This plan uses a minimum of quarried rock and gravel which must be imported from distances of 14 and $5\frac{1}{2}$ miles respectively.

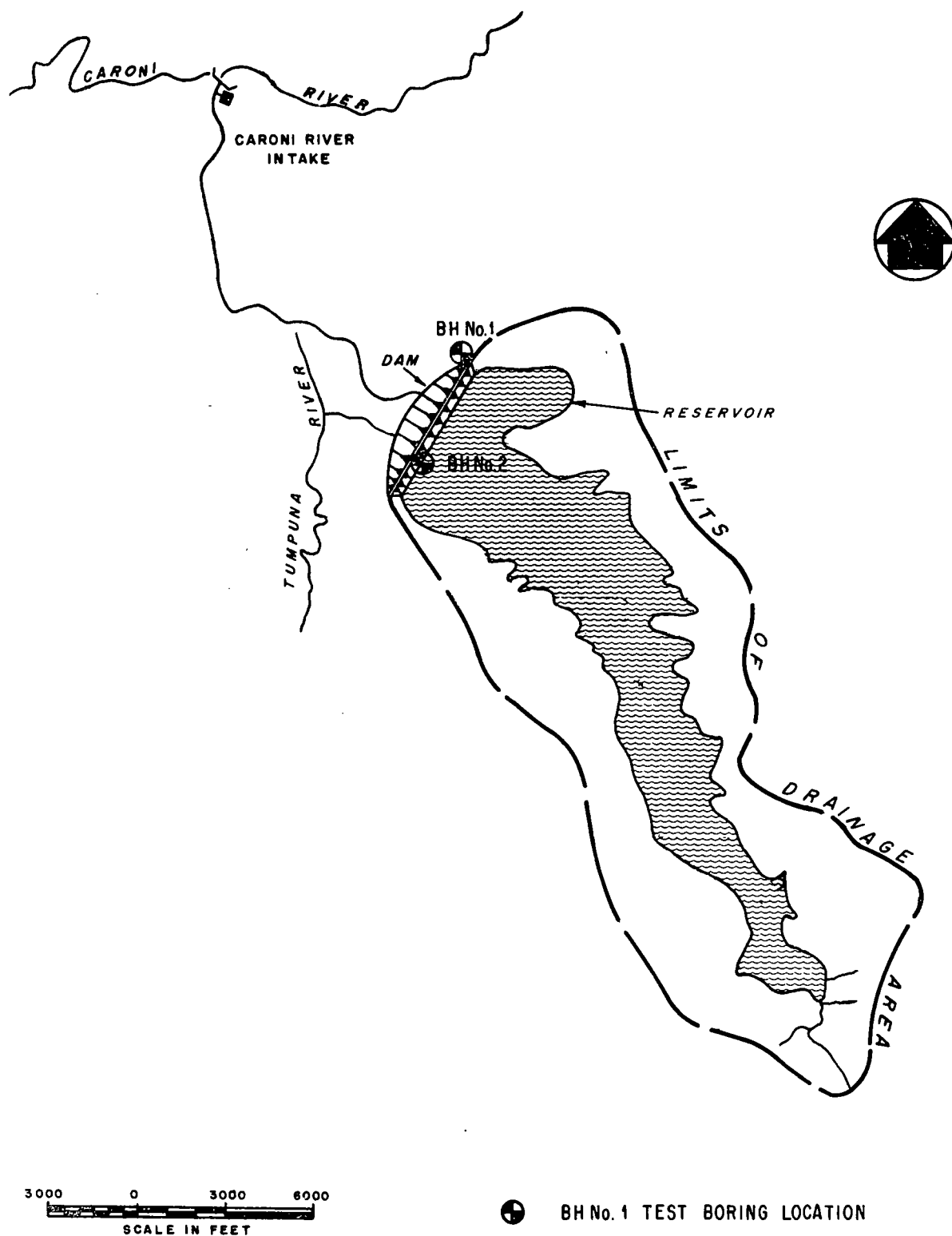


FIG. 21 LOCATION PLAN – ARENA RESERVOIR

The homogeneous rolled earth-fill will be sufficiently flexible to withstand the maximum horizontal acceleration from seismic shock.

2. It is recommended that diversion of the Arena River be made by conduit laid in the floodplain of the Arena River.

It is recommended that either a chute-type spillway be constructed through the thin ridge immediately west of the main dam, or that the spillway be constructed on the crest of the main dam above the channel of the Arena River. Further study during the design stage is required to fix the optimum position for the spillway.

If the chute type spillway is not selected, a small dyke composed of rolled earth with rip-rap protection is recommended to protect the thin ridge.

Development of Dropouche

The proposed Dropouche Reservoir catchment is about 20.5 square miles in area and occupies the southern slope of the Northern Range west of Valencia (See Figure 22). Complete stream gauging records are available for 1966 and 1967. Rainfall records of about 35 years' duration are available for the Hollis Reservoir catchment west of the Dropouche.

Runoff mass diagrams were constructed from these data and gross yield, together with required storage for said yield, was determined. For a gross yield of about 52 mgd the storage required was 6,000 million gallons and for a net yield of 42 mgd the required storage was about 3,000 million gallons. On years with rainfall

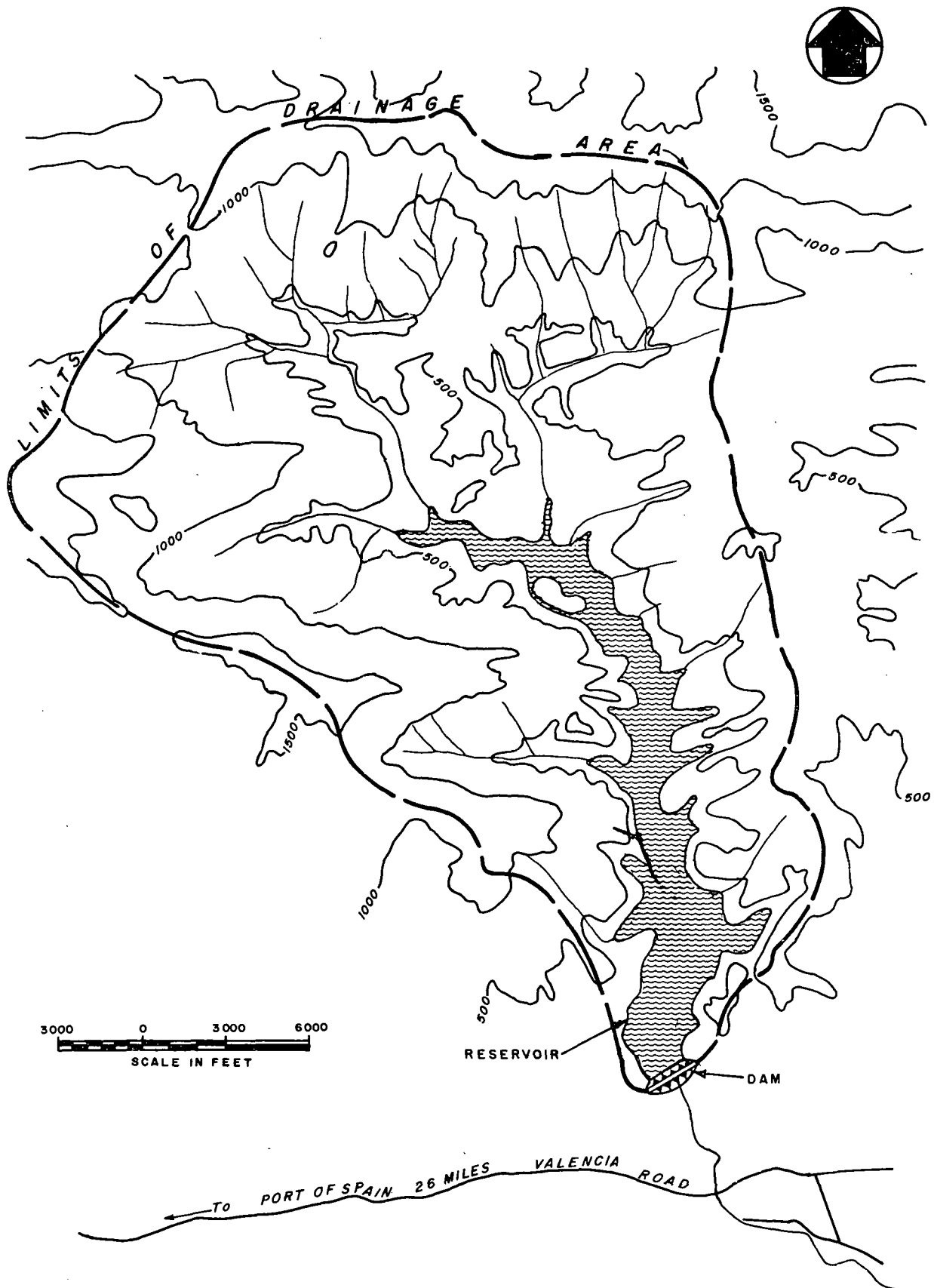


FIG. 22 LOCATION PLAN — OROPOUCHE RESERVOIR

about equal to the mean and with a reservoir capacity of about 10,000 million gallons, approximately 4,000 million gallons of stored water would be carried over. Thus, 3,000 to 4,000 million gallons of stored water should be available to supplement dry year runoff.

It is estimated that the 95 percent dry year runoff would total about 13,000 million gallons for the Oropouche catchment. This estimate is based upon 90+ inches of rainfall with about 50 percent runoff. At 45 mgd the annual draft would be about 15,300 million gallons, or 3,300 million gallons more than the runoff. The carry-over storage of 4,000 million gallons should therefore be ample to ensure about 45 mgd yield on the 95 percent dry year.

Geology of the North Oropouche Basin

The Oropouche Basin is composed of steeply dipping metamorphic rocks of Upper Jurassic and Lower Cretaceous age. The trend of these beds is roughly east-west and the dip is dominantly southward and generally averages more than 45 degrees. The rocks consist of low grade metamorphic non-calcareous phyllites interbedded with calcareous phyllites, thin to moderately thick beds of crystalline limestone and a few grits.

Taken in sequence from north to south and as shown on Figure 23, the younger beds are the first encountered as one enters the Oropouche Basin from the south (Valencia Road).

The basin is broken into roughly five formations from south to north, as follows:-

1. Non-calcareous phyllites - thin bedded; dark grey;

interbedded with light gray quartzite grits and a few thin beds of limestone. The dam occupies most of this section, which is similar in lithology to the shaley phyllite member of the Laventille Formation, as described by Brown.

2. Calcareous phyllites - thin bedded, interbedded with thin to massive beds of limestone, and occasional non-calcareous shaley phyllites. The section is characterized by thick sequences of thin beds of the same rock type. It is similar in lithology to the Belvedere Formation as described by Brown. Several potential quarries for dam construction are located in this section.

3. Massive bedded limestones, occasionally cavernous, makes up the central portion of the basin. The massive beds are occasionally interlayered with calcareous phyllites and thin bedded limestone. This section is similar in lithology to the Aripo Limestone member of the Rio Seco Formation described by Brown.

4. Thin calcareous phyllites, interbedded with thin limestones and non-calcareous phyllites occupy most of the upper reaches of the basin. The three rock types are distributed uniformly through the sequence. This section is similar to the phyllite member of the Rio Seco described by Brown.

5. Thin bedded quartzites interbedded with calcareous phyllites occupy the head of the basin. These rocks are similar in lithology to the Tucuche Formation which forms much

of the main crest of the Northern Range.

Structurally, the rocks occupying the Oropouche River drainage basin have been intensely folded over most of the southern part of the basin resulting in the steep southward dips. Only minor faulting has been noted in the field, however. Several major faults, interpreted from the regional structure are anticipated to cut the basin in several places. These inferred faults are shown on Figure 23.

A major fault, shown locally as the Arima fault, is part of the great fault system known as El Pilar which runs east-west along the southern margin of the Northern Range in Trinidad and the Coast Range of Venezuela at least as far as the Caracas Valley. The fault is inferred as falling downstream of the dam site approximately $2/3$ of a mile. Little activity has been noted along the Trinidad portion of this fault system for many years. More rock in the basin is deeply weathered. The phyllites and grits weather the deepest and the limestone least of all. In places where exploration has been carried out the phyllites are known to weather differently to depths of 100 ft. The stream bottom is the only area, with the exception of road cuts, where fresh rock can be observed. A residual soil has developed on top of the weathered rock and consists of a clayey silt or silty clay. Ridge tops in the southern foothills are covered with a thin cap of terrace gravels unconformably overlying the residual soil.

Evaluation of the North Oropouche Basin as a Reservoir

Tightness. The only threat to tightness in the reservoir

impounding area is the massive limestone of the upper basin in the vicinity of Cumaca. This limestone tends to form solution openings and becomes locally cavernous. However, the impounding level (flow line) is low enough in the limestone section to be below the spring line for this rock in neighbouring valleys. In addition, the steep dip of the hundreds of thousands of thin beds of limestones, phyllites and grits downstream prevent major leakage. Further protection against leakage is provided in the cover of residual soil and the deeply weathered grit and phyllite beds which form an impermeable blanket.

Slope Stability After Impoundment. Saturation of the clay and silt soils covering the exceptionally steep valley walls coupled with the great length of the shore line provide maximum exposure to sliding. Study of laboratory test results indicates that fluctuation of the reservoir level will probably create landslips.

Dam Location. The proposed dam is located in a bedrock valley at the southernmost position in the Oropouche basin. South of the dam site the hills drop sharply away to the Arima flats. The dam is entirely within the Laventille formation of non-calcareous phyllites and thin bedded limestones all dipping steeply south 50-70 degrees and trending perpendicular to the valley. The abutments would be in decomposed grits and phyllites and the dam founded on the fresher rock cleaned by the river.

One problem with the site is the abutment or spillway ridge to the east. This ridge is thin, steep-sided, and capped with

granular material. It has a high permeability in the granular material at the top and insufficient sections to withstand a high level of impoundment.

Spillway Location. The proposed spillway location is through this thin ridge and would be cut down through the granular materials and probably deeply into the weathered rock. Use of a spillway in this location would route water back into the Dropouche River below the proposed dam location. Additional spillway sites were examined particularly the alternate site at the dyke location (See Figure 23). This site would require extensive protection downstream as well as protection around the spillway itself. In addition, it would divert all the spillway water into another drainage therefore requiring new bridges, channel improvements and drainage structures on the running stream. This particular site will require a dyke with cutoff if a high flow line is used.

Construction Materials. Rock is available within the Dropouche basin at approximately the locations shown on Figure 23 and is suitable for rock fill. Crusher run rock should be suitable for filter gravels and sand or concrete aggregate.

Impermeable soil suitable for an earth core is available in the vicinity of the proposed dam site. There does not appear to be sufficient material for a rolled earth dam without extensive stripping of the valley walls and ridge tops. Natural sand is not available within the basin but Melajo sand and gravel can be found south of the Valencia Road in several privately operated pits.

Design Considerations. Reservoir design considerations are:

1. Keep the flow line at a maximum of elevation 350 ft. above mean sea level to prevent the necessity of excessive protection for thin ridges in the vicinity of the dam and within the reservoir area.
2. Design a dam to make use of materials naturally occurring in the basin and considering the length of dry and wet seasons as well as their effect on the construction.
3. Consider clearing trees and brush only up to the normal flow line and not above. Do not permit grubbing except at the dam site in an effort to keep landslips on the steep valley walls to a minimum.
4. Locate the dam wholly within the Laventille series of phyllites and grits for reason of the favourable geology of the formation.
5. Locate the spillway in the thin ridge to the east of the dam to make use of spillway construction to protect the ridge and turn water back into the lower Dropouche.
6. Design for magnitude 7.5 (Richter scale) seismic loading from earthquakes along the northern coast or from adjustments along the nearby Arima fault.

Recommended Dam Type.

1. It is recommended that a rock-fill dam with a maximum pool level of elevation 350 and a rolled earth core as shown in Figure 24 be constructed at the location shown in Figure 25. This type dam can be constructed from natural materials located within the basin.

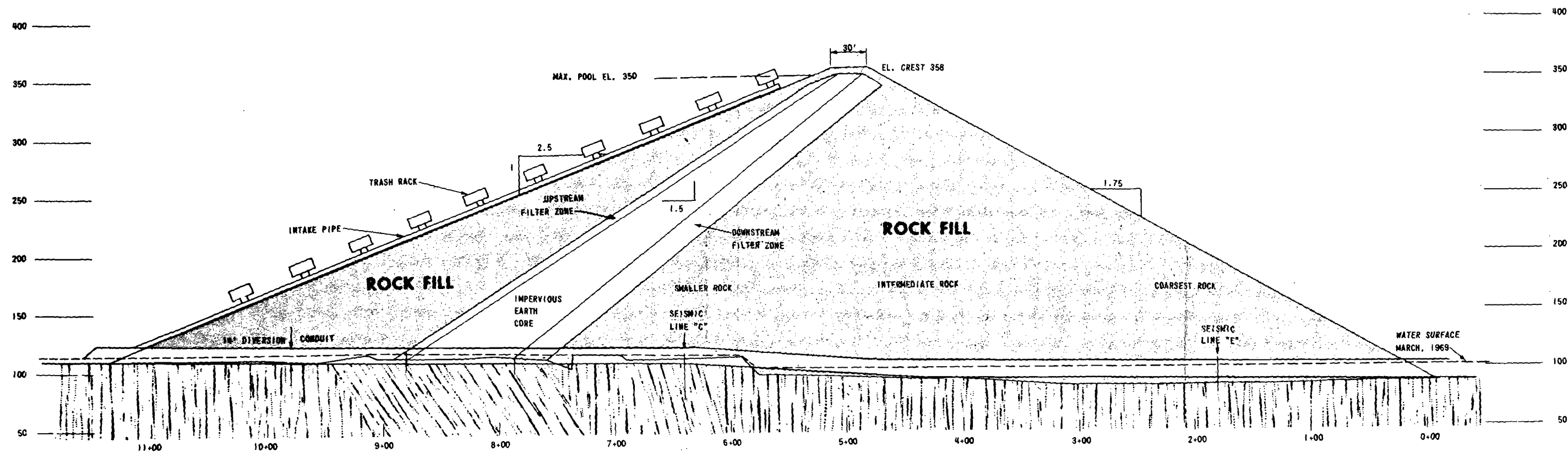


FIG.24 PROPOSED ROCK FILL DAM SECTION

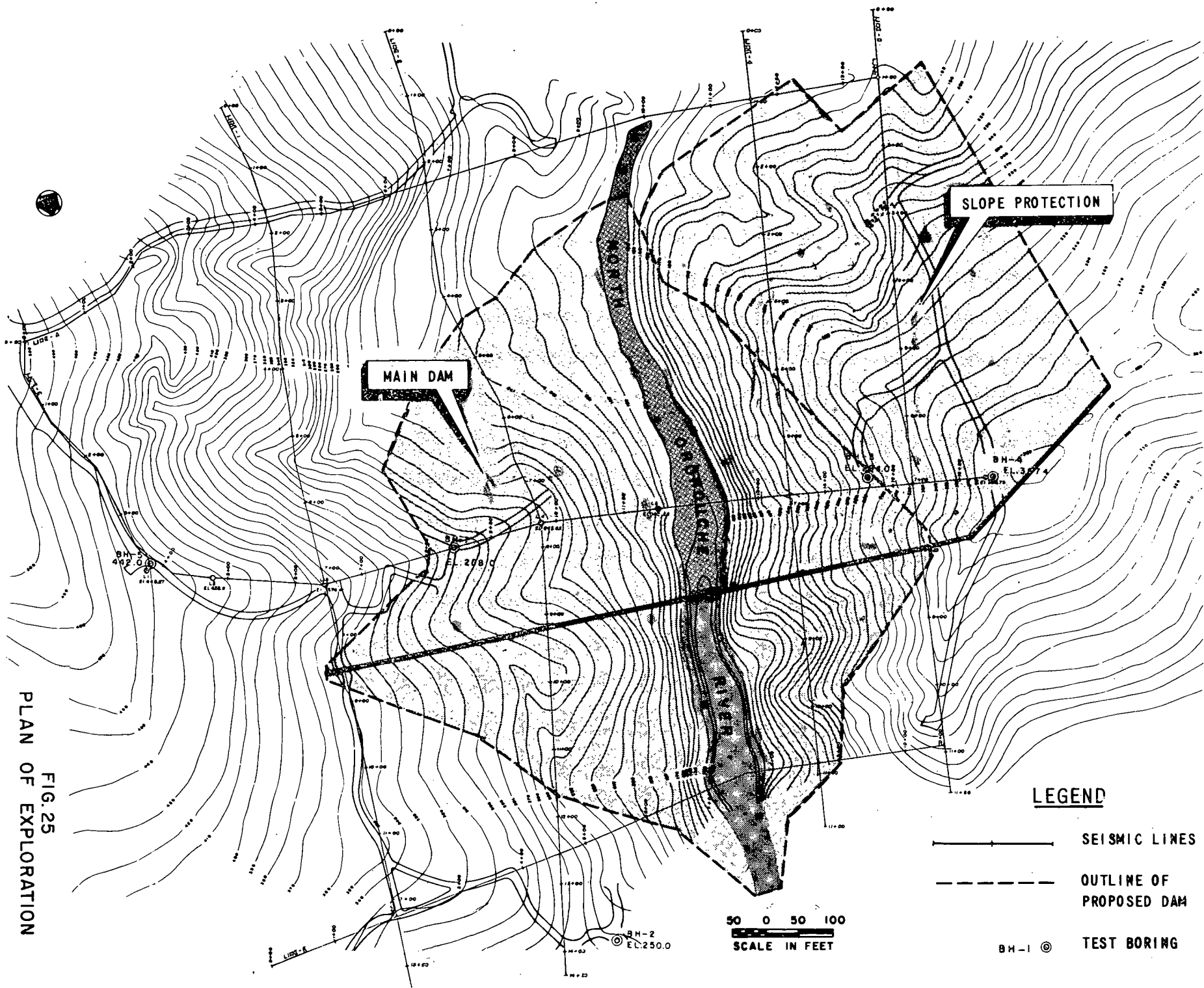


FIG. 25
PLAN OF EXPLORATION

The stable rock-fill portion can be placed during the wet season leaving the dry season for placing the relatively small yardage of the rolled core or blanket and its protection.

The rock-fill dam will be flexible enough to withstand high seismic loading.

2. It is recommended that diversion of the river during construction be by means of a cut and cover tunnel parallel to the river and passing through the base of the dam.

3. A chute-type spillway on the thin ridge immediately east of the main dam is recommended.

4. The recommended intake structure is of the type which lies inclined on the upstream face of the dam and draws water at required elevations through a series of valved openings protected by trash racks. Water would be dropped into the diversion tunnel on the upstream toe so that the intake structure does not penetrate the core. Such a structure eliminates the need for a free standing intake protected against seismic shock wave actions and with the necessary access appurtenances.

Evaluation of Oropouche First Phase

It has been proposed that initial utilization of the Oropouche be accomplished through construction of an intake to harvest run of the stream yield. Dependable yield of such an intake would be no more than 8 million gallons per day, the recorded minimum flow.

Because of construction operations at the proposed dam site and clearing operations in the reservoir area, regardless of intake location, a water treatment works would be required to assure that this

flow could be harvested.

The first phase of the Dropouche would not be economically feasible because the investment in temporary facilities of \$420,000 to \$1,135,000 depending on intake location would be an excessive, non-recoverable capital cost.

Moruga Yield

The proposed Moruga River Reservoir is located primarily on oil reserve lands just east of the Village of Moruga (See Figure 26). The reservoir catchment is about 31 square miles in area and is gently rolling. Mean annual rainfall within the catchment is about 80 inches and it is estimated that runoff is between 35 and 45 percent of rainfall. The estimated mean annual and the 95 percent dry year runoff are listed below:

	Runoff					
	Annual		Wet season		Dry season	
	Inches	mil. gals.	Inches	mil. gals.	Inches	mil. gals.
Mean annual	33	14,800	29	13,000	4	1,800
95 percent dry year	23	10,300	21	9,400	2	900

With available storage capacity between 7,500 to 10,000 million gallons the yield from the proposed reservoir should be:

	Yield mgd	
	Gross	Net
Mean annual	40	36
95 percent dry year	28	25

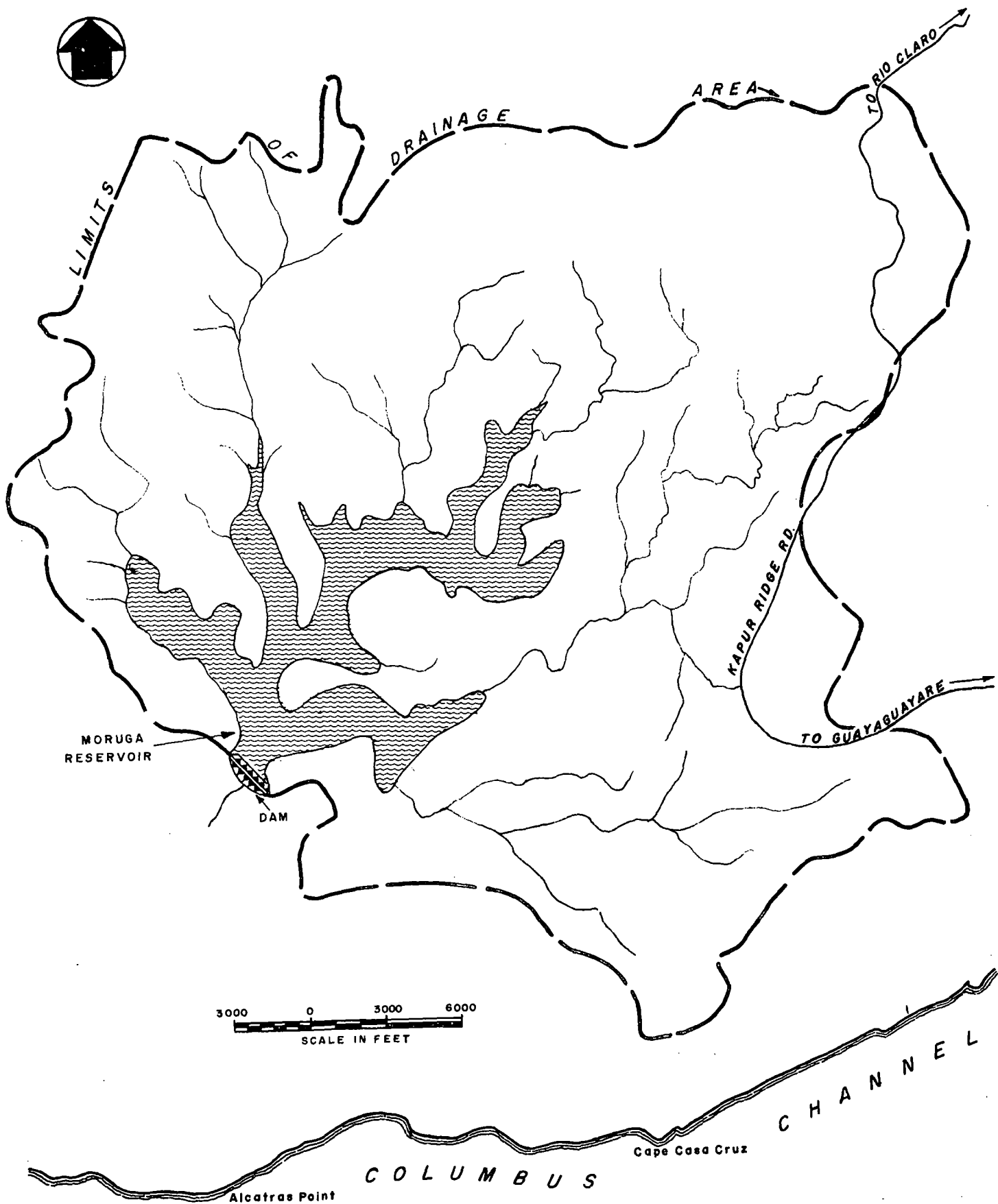


FIG.26 LOCATION PLAN - MORUGA RIVER SUPPLY

METCALF & EDDY

No stream gauging of the Moruga has been carried out. Therefore estimates of runoff and, consequently, yield are based upon the limited information available on streams in the general area.

It is recommended that the Water Resources Survey establish a stream gauging station downstream from the dam site at the earliest possible date to determine more exactly the probable yield of the proposed reservoir.

Geology of Moruga Reservoir Area

The Moruga Reservoir lies within the southern drainage of the Southern Range, about five miles east of Moruga. It is underlain by deltaic sands, silts, and clays of Miocene age. The proposed dam site is underlain by sands of the Cruse Formation, and abuts sandstones of the Moruga and Mayaro Formations on the north and south respectively. The reservoir area is underlain primarily by the Cruse and Moruga Formations, of which the latter is deeply weathered.

The reservoir lies within a block delineated on three sides by fault systems. However, no major faults are reported within the reservoir area. Prior to construction of a reservoir at this site, a comprehensive survey (surface and subsurface) of the basin to determine tightness, and of the dam site to ascertain foundation conditions, is recommended.

EVALUATION OF ALTERNATIVE PROGRAMS

General

In the Chapter DEVELOPMENT OF POTENTIAL SOURCES, potential supplies were selected for development to meet projected system demands through the year 2000. Construction of the Navet pumped storage project for an additional 10 mgd dependable yield and development of groundwater for an additional 18.9 mgd of dependable yield are obvious projects of any first stage development plan. Local conditions in the more remote low-demand areas, where a major transmission main from a large source of supply cannot be justified, will govern the sequence of development of the remaining groundwater.

This chapter is primarily concerned with determining the sequence of development of the major supplies (Dropouche, Caroni-Arena, and Moruga). It appears from the comparison of unit capital costs in the preceding chapter that the Caroni-Arena supply is the logical first stage project. Unit capital costs are useful when comparing similar types of development. However, operating costs for both the Caroni-Arena and the Moruga supplies will be substantially higher than for the Dropouche, which is essentially a gravity supply. Therefore, a valid economic comparison requires consideration of annual operating costs as well as capital costs. Also, a project which may appear as a poor choice for first stage construction may, in later stages of development, prove economical because of a change in conditions.

In this chapter four alternative programs for staged development are described, and a comparison is made to determine the most economic program. This comparison provides a basis for the recommended development program described in succeeding chapters.

Description of Program

Of the three major supplies selected for future development (Oropouche, Caroni-Arena, and Moruga), only two appear suitable as first stage projects. These are the Oropouche and the Caroni-Arena. The Oropouche has long been considered as the next logical source to be developed. However, since it is relatively remote from the principal areas of demand, development will require an extensive transmission system. In comparison, the Caroni-Arena system is relatively close to the areas of demand and will require a much less extensive transmission system. This source, however, is near sea level so that pumping costs will be higher than for the Oropouche supply.

As a first stage project the Moruga would have to supply both the north and the south. Because of its remoteness from the centre of demand, the transmission system costs for first stage development would be prohibitively high. However, after the construction of one of the northern sources, it would become desirable as a second stage project to supply increasing demands in the south, thereby freeing the northern supplies to meet demands in the north.

If the Caroni-Arena and the Oropouche are the only feasible first stage projects, the possible development programs involving

the Oropouche, Caroni-Arena and the Moruga are limited to the four alternatives shown in Figures 27, 28, 29, and 30. Figures 31 and 32 show how they meet projected future demands.

Program A - Oropouche/Caroni-Arena. Initial construction in this program comprises full development of the Oropouche supply for a dependable yield of 45 mgd and a maximum day capacity of 55 mgd; a 48-inch diameter transmission main from the treatment works to Tacarigua; a 36-inch main from Tacarigua to Tunapuna; a 30-inch main from Tunapuna to the existing El Socorro Pumping Station, and a 42-inch main from Tacarigua to a proposed 4-million gallon reservoir at California. Water would be conveyed from El Socorro to Port of Spain via the existing 30-inch El Socorro main.

About 1978, a 36-inch diameter main from California to San Fernando would be required to meet projected demands in the San Fernando area and South Trinidad. The system would operate by gravity until about 1981 when it would be necessary to construct booster pumping stations at California and El Socorro. Around 1982, a third booster pumping station would be required at Caroni to pump to the California Reservoir.

In 1987, an additional supply and more transmission capacity would be required. The Caroni-Arena system designed for a dependable yield and maximum day capacity of 42 mgd; a water treatment plant at Kelly Headworks; a 42-inch diameter main from the water treatment plant to California; a 36-inch main from California to San Fernando; a 36-inch main from Caroni to El Socorro; and a 30-inch main from El

FIG. 27 PROGRAM A CAPITAL IMPROVEMENTS
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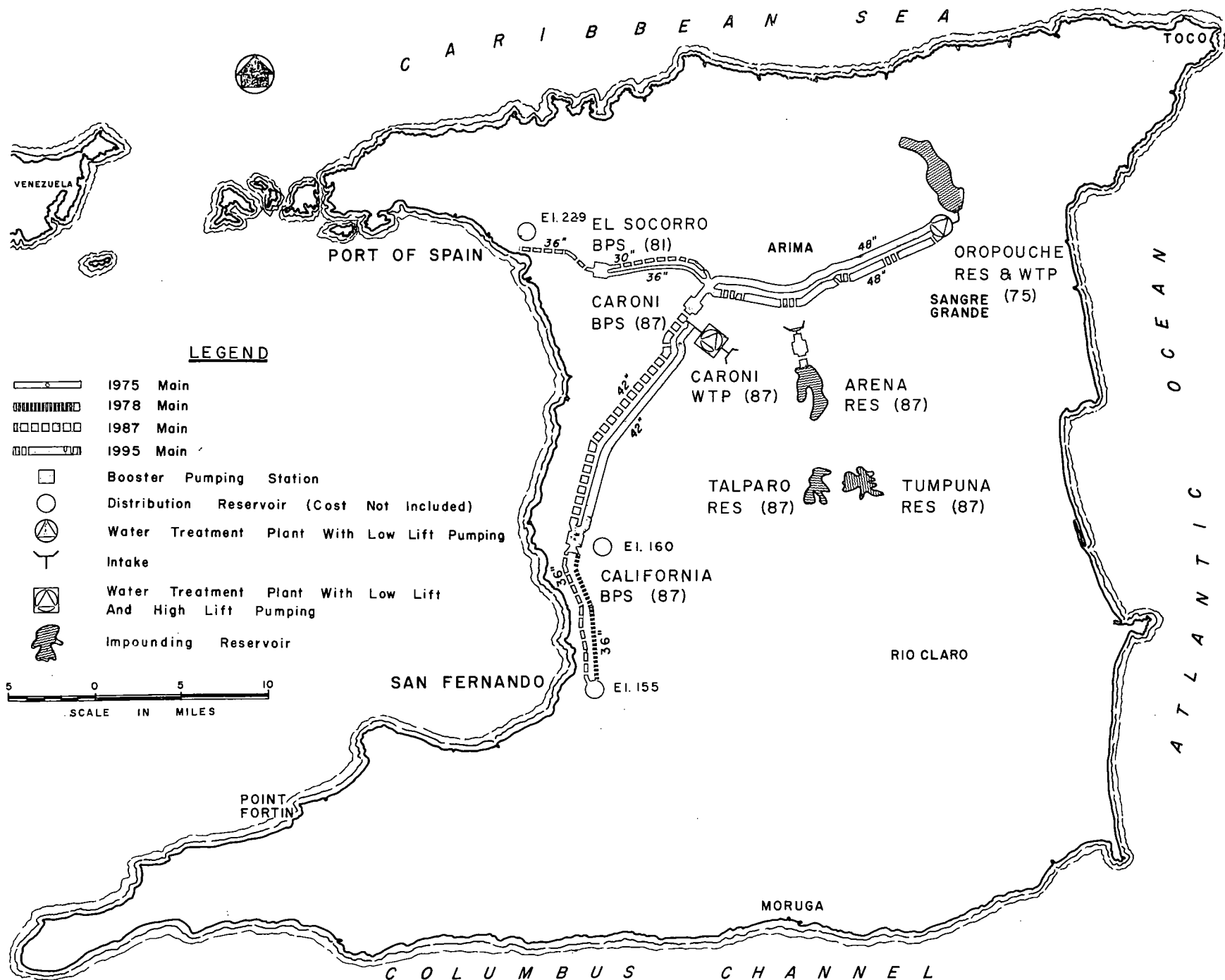


FIG. 28 PROGRAM B CAPITAL IMPROVEMENTS

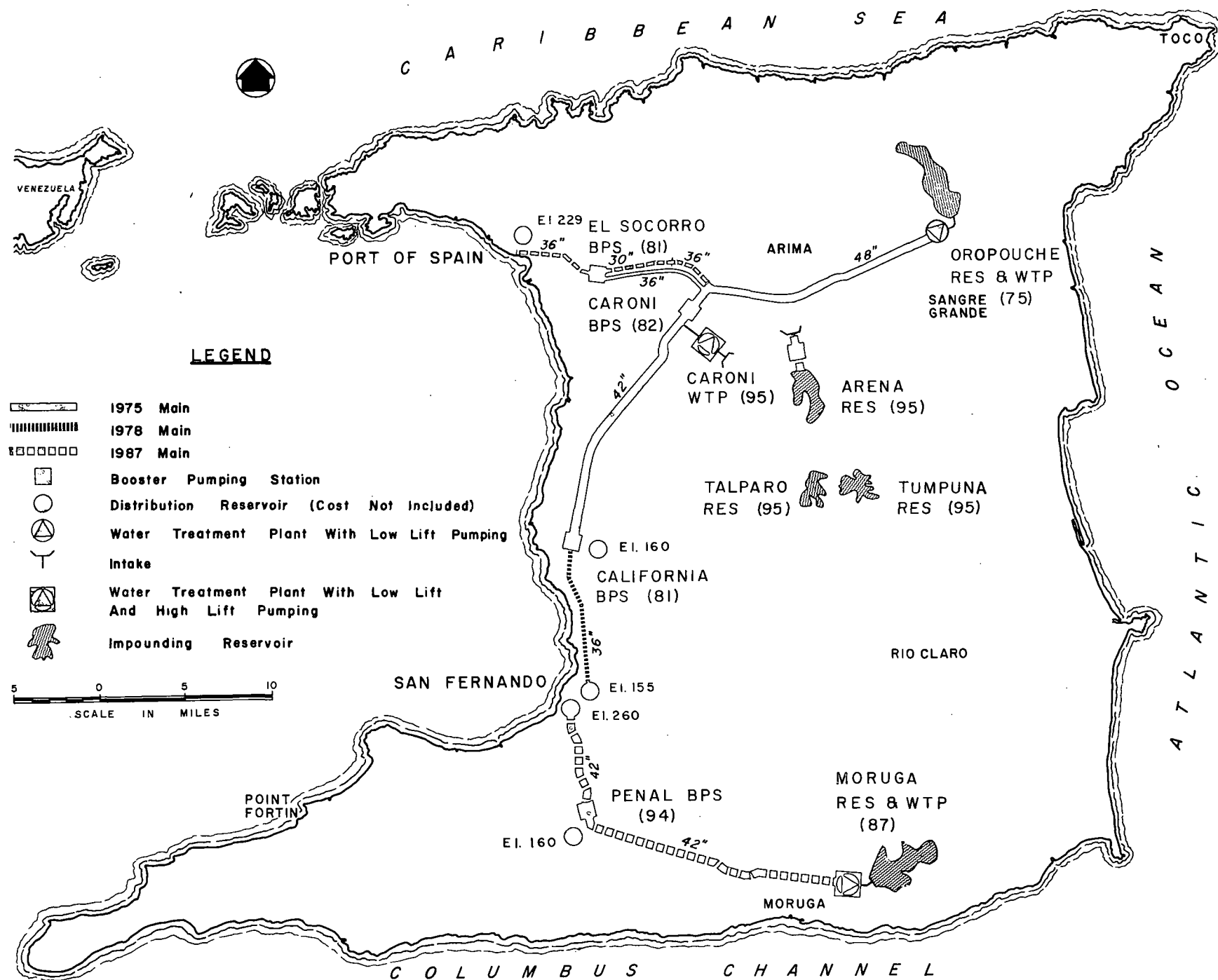


FIG. 29 PROGRAM

C

CAPITAL

IMPROVEMENTS

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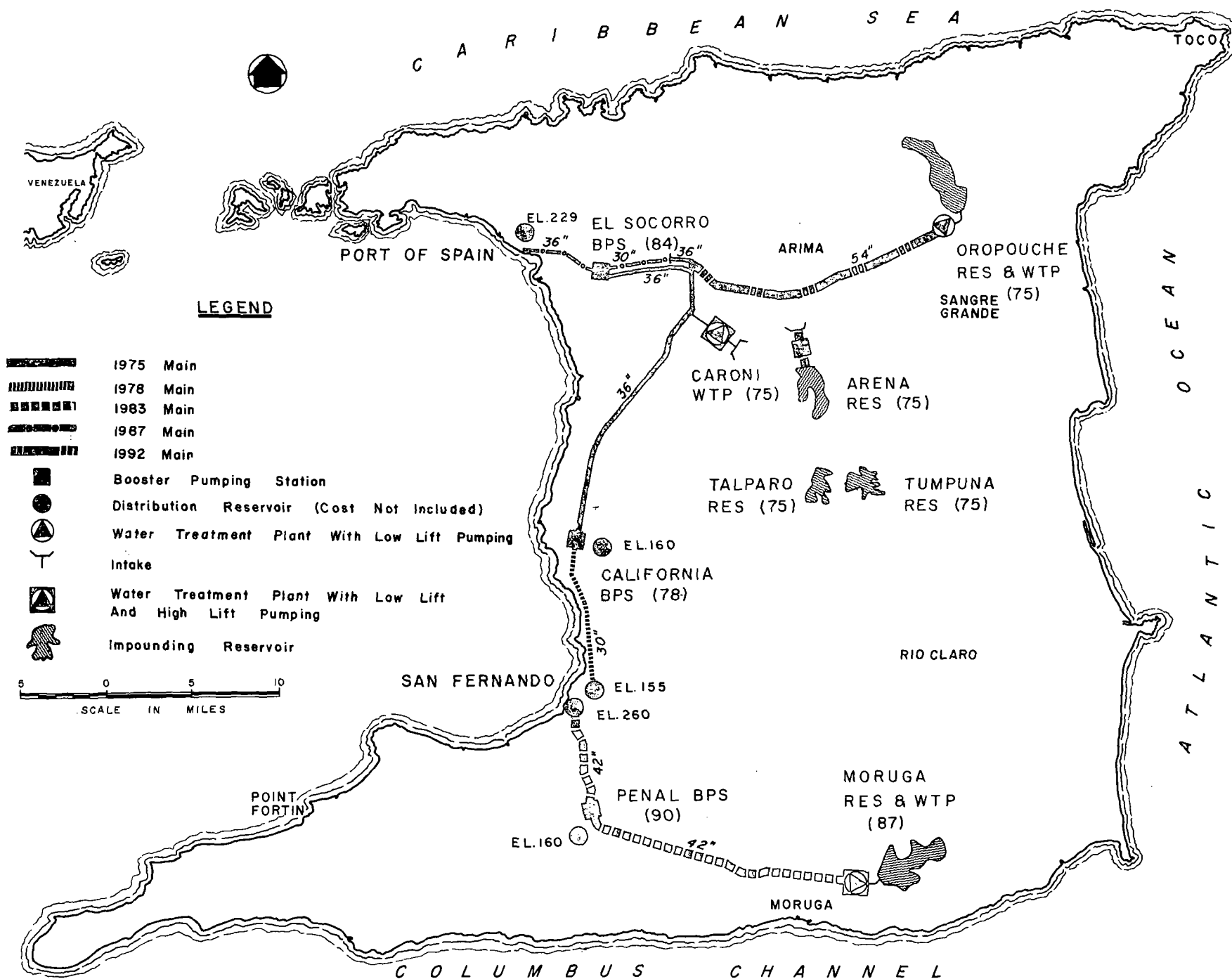


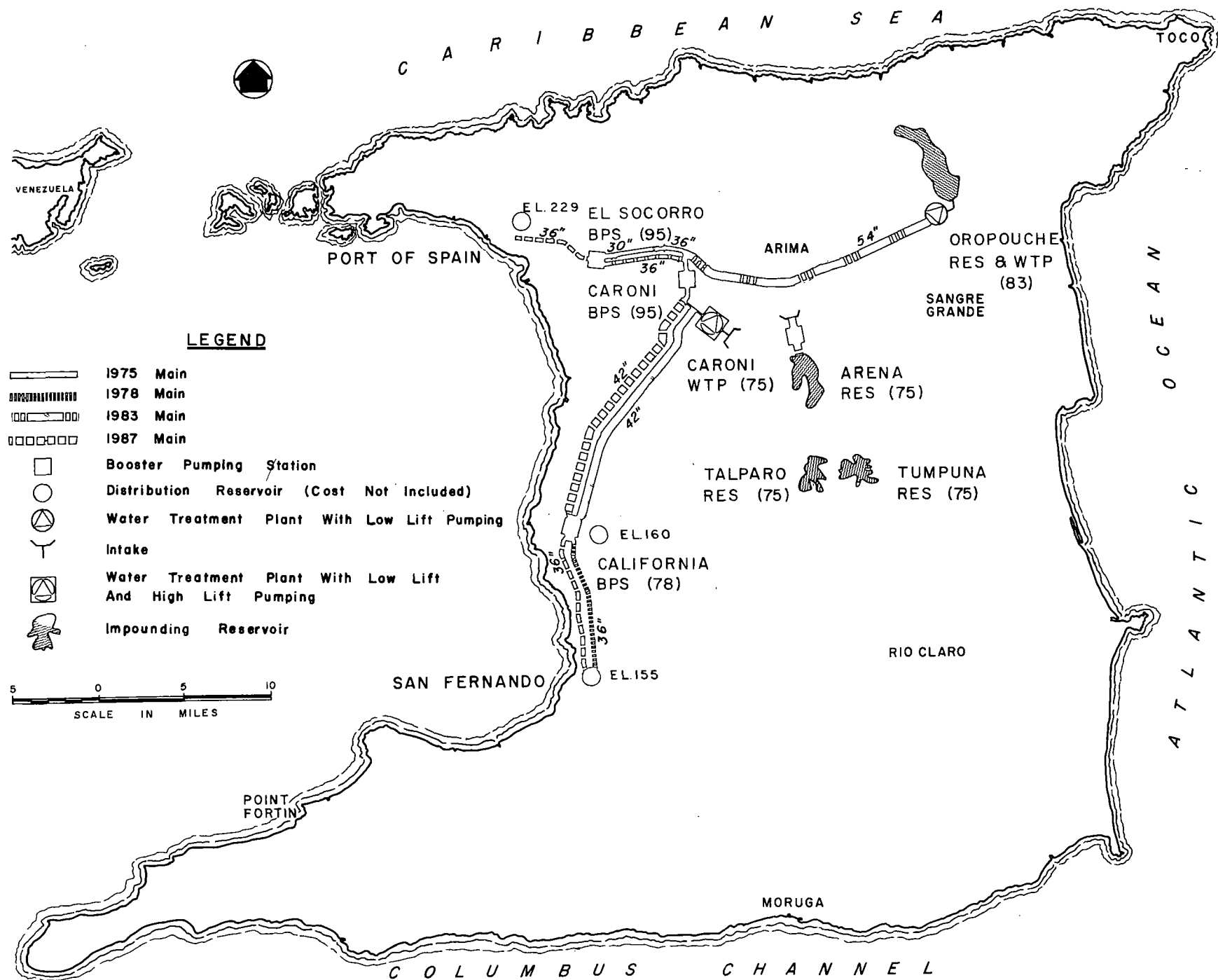
FIG. 30 PROGRAM

D

CAPITAL

IMPROVEMENTS

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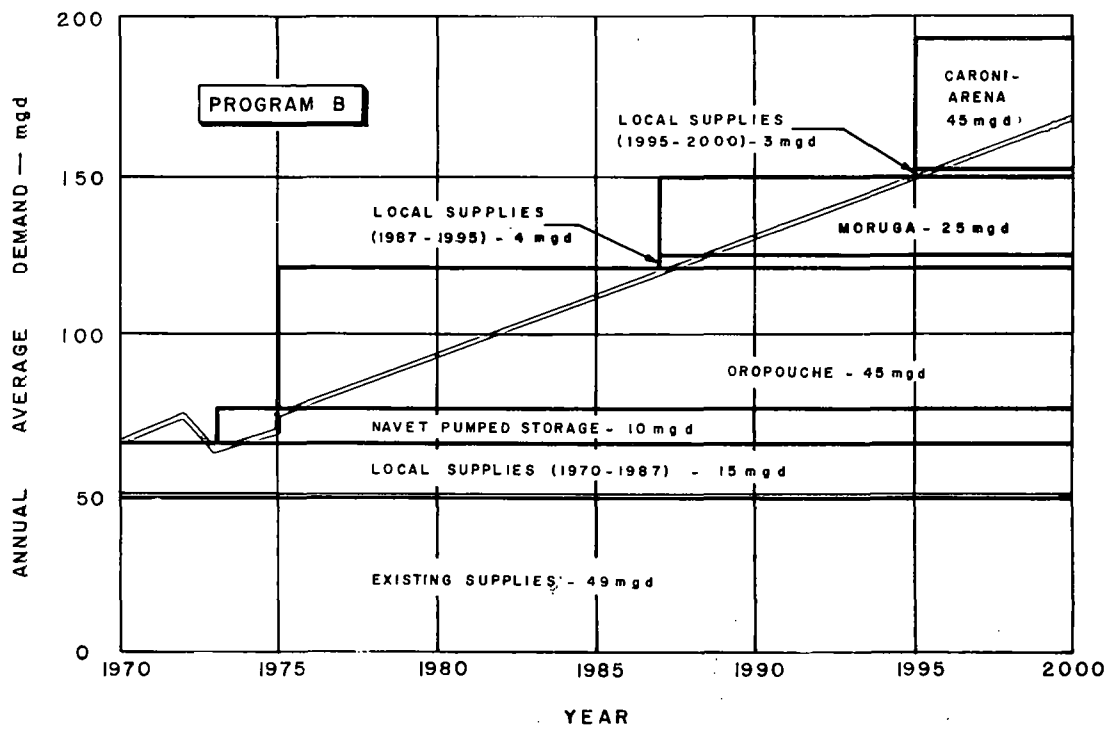
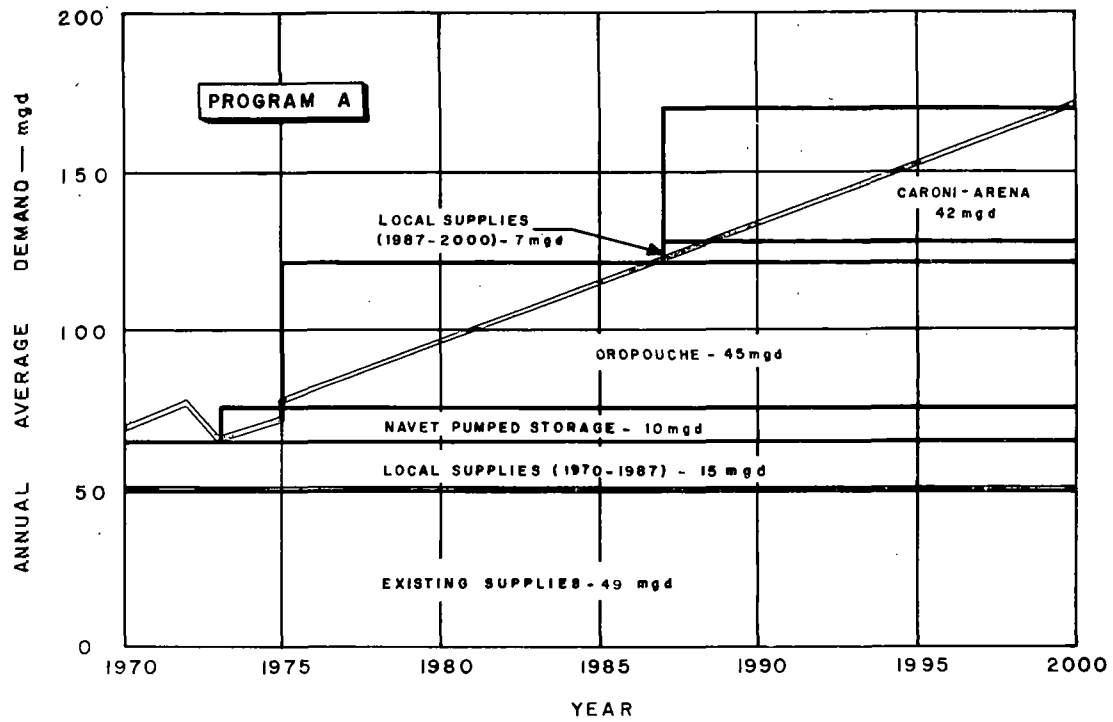


FIG. 31 ALTERNATIVE PROGRAMS 'A' AND 'B'

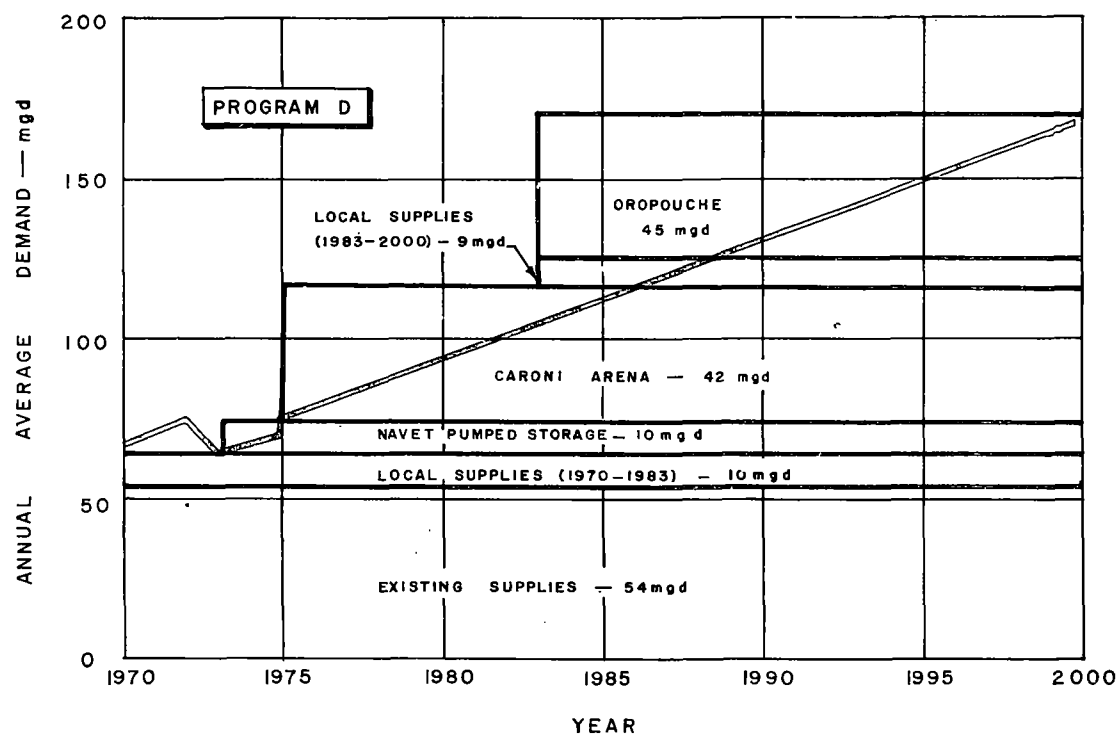
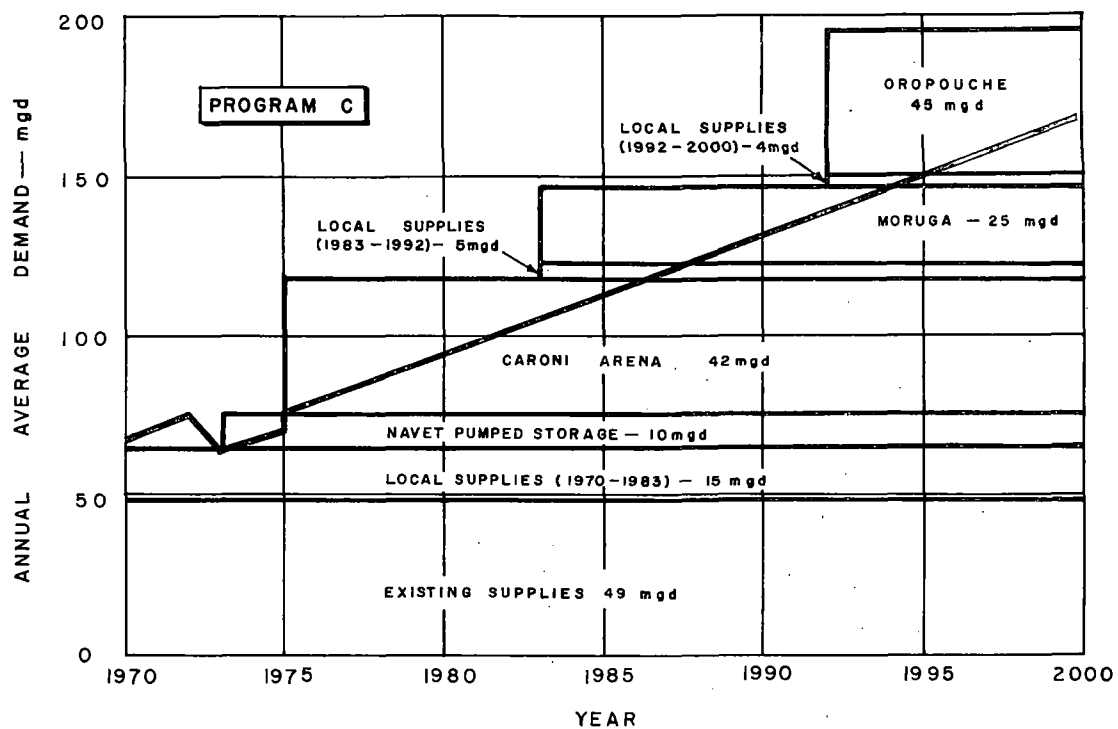


FIG. 32 ALTERNATIVE PROGRAMS 'C' AND 'D'

Socorro to Port of Spain, would meet the needs of Trinidad until 1995. Then a second 48-inch pipeline from the Oropouche water treatment plant to Tacarigua (together with development of local supplies in remote areas) would provide the added capacity required to meet projected demands to the year 2000.

Program B - Oropouche/Moruga. This program is similar to the Oropouche/Caroni program in all respects until the year 1987. At this point, instead of constructing the Caroni-Arena system as a second stage supply, the Moruga supply would be constructed for a dependable yield of 25 mgd and a maximum day capacity of 33 mgd with a 42-inch pipeline from the reservoir to San Fernando. Initially the 42-inch pipeline would be adequate to convey water to San Fernando with a single lift at the reservoir. By 1992, a booster pumping station would be required at Penal. Construction of the Moruga supply would eliminate the need for a second pipeline south from Tacarigua.

Additional supply would again be needed in 1995, at which time the Caroni-Arena system would be constructed. The next improvement would not be required until after the year 2000.

Program C - Caroni/Moruga. Initial construction in this program includes the Caroni-Arena system designed for a dependable yield and maximum day capacity of 42 mgd; a 36-inch transmission main to the proposed California Reservoir; a 36-inch main to Tunapuna, and a 30-inch main from Tacarigua to El Socorro. Two sets of high lift pumps would be provided at the Caroni water treatment plant, one to pump to the El Socorro pumping station sump and the other to the

California reservoir.

By 1978, increasing demands in San Fernando and the south would require laying of a 30-inch main from California to San Fernando and the construction of a booster pumping station at California.

Additional supply would be required in 1983. This would be provided by the construction of the Moruga supply for a dependable yield of 25 mgd and a maximum day capacity of 33 mgd with a 42-inch pipeline from Moruga to San Fernando. An additional 36-inch pipeline from Caroni to Port of Spain would be required in 1987. Around 1989, a booster station would be required at Penal. The Moruga supply would reach its maximum capacity about 1992. The Oropouche supply would then be constructed with a 54-inch main from the reservoir to Tacarigua. Because Oropouche operating costs would be lower, the Oropouche supply would be operated at near design capacity and production from the Caroni-Arena system would be reduced accordingly.

Program D - Caroni/Oropouche. This program is similar to the Oropouche/Moruga program until 1983, except that the transmission main to California from the Caroni water treatment plant would be 42 inches in diameter and from California to San Fernando 36 inches in diameter. In 1983, instead of constructing the Moruga as the second source, the Oropouche supply designed for a dependable yield of 45 mgd and a maximum day capacity of 67 mgd would be constructed with a 54-inch transmission main from the reservoir to Tacarigua. To take advantage of lower power and chemical costs, the Oropouche would be operated at design capacity and production at Caroni would be reduced

accordingly. In 1987, smaller pipelines would be constructed from Tacarigua to Port of Spain and from Caroni to San Fernando. Booster pumping stations at El Socorro and Caroni would be required in 1995. No additional supplies would be required to meet projected demands for the year 2000.

Basis of Comparison

Each year's capital charges and operating expenses for the development programs were determined and then multiplied by the appropriate present worth* factor to refer these expenses to 1971 (the date of initial construction).

The totalling of the present value of expenses year by year for a period of 29 years to the year 2000 indicates the program with the most favourable long term cost.

Capital Charges. The construction cost of each program was based on 1969 prices. The project cost was determined by adding an allowance of 40 percent to cover the cost of engineering, administration, contingencies and other overhead expenses. To determine the annual capital charges, the project cost was multiplied by the appropriate capital recovery factor presented in Table 32. These factors are based on the estimated useful life of the facility and an interest rate of 8 percent.

*Present worth is the value at the present time of a sum of money that would repay a future series of payments at a given interest rate.

Table 32. Capital Recovery Factors

Type of facility	Estimated useful life, yrs.	Capital recovery factor
Dams and reservoirs	50	0.0817
Transmission mains	50	0.0817
Water treatment plants	25	0.0937
Pumping stations	25	0.0937

Annual capital charges are equated to the annual level debt service payment on a serial bond issue having a term of repayment corresponding with the useful life of the project. They are also equivalent to the interest plus depreciation (computed by the sinking fund method).

Operating and Maintenance Expenses. Operating and maintenance expenses were developed for each year beginning at the first year that the facility is in service, and include the cost of power, chemicals, maintenance and salaries.

Power costs were based on the present schedule of rates published by the Trinidad and Tobago Electricity Commission, and, assuming efficient operation, are estimated at \$14 per million gallons per 100 foot of lift.

Chemical costs for each supply were estimated as follows:

<u>Supply</u>	<u>Cost per mg</u>
Oropouche	\$40.00
Caroni-Arena	\$60.00
Moruga	\$40.00

Percentages of construction costs were estimated as approximations of annual maintenance and repair costs, as follows:

<u>Type of Facility</u>	<u>Percentage</u>
Dams and reservoirs	0.5
Water treatment plants	2.0
Transmission mains	0.5
Pumping stations	2.0

Salaries, including benefits, were based on the following wage rates:

<u>Position</u>	<u>Annual Wage</u>
Operator	\$4,000
Supervisor	\$6,000

VS on TT?

Staffing of the various facilities assumed heavy reliance on manual operation of all facilities. Pumping stations were assumed to require four operators and a supervisor. Major supply facilities like the Oropouche were assumed to require a staff of 40 to 80.

Economic Comparison

Annual operating and maintenance expenses were added to the annual capital charges for each year. This sum was multiplied by the appropriate present worth factor (interest rate of 8 percent) to determine the present value of all future expenses at 1971.

The year by year present values (i.e. 1971) were added together and cumulative totals developed for each program. These cumulative totals are the sums of the present values of all expenses for the preceding years.

Figure 33 is a plot of present values for the four programs from 1971 to the year 2000. Cumulative capital costs are plotted in Figure 34. Table 33 is a comparison of the cumulative costs at the year 2000. The present worth figures indicate the economic merits of the alternative programs. A comparison of the figures in Table 33 shows that Program C, with the Caroni-Arena as the first stage project followed by Moruga as the second stage project, has the best overall economic advantage.

Table 33. Comparative Costs of Alternative Programs

Program	Cumulative capital cost at year 2000	Present worth in 1971 of annual capital and operating costs to the year 2000
A	\$150,900,000	\$94,600,000
B	\$154,600,000	\$90,900,000
C	\$159,800,000	\$79,500,000
D	\$138,100,000	\$85,800,000

The most economic program also has the highest capital cost by the year 2000. Both programs B and C cost more than A and D because they include development of all three recommended sources and as a result have excess capacity at the year 2000, whereas programs A

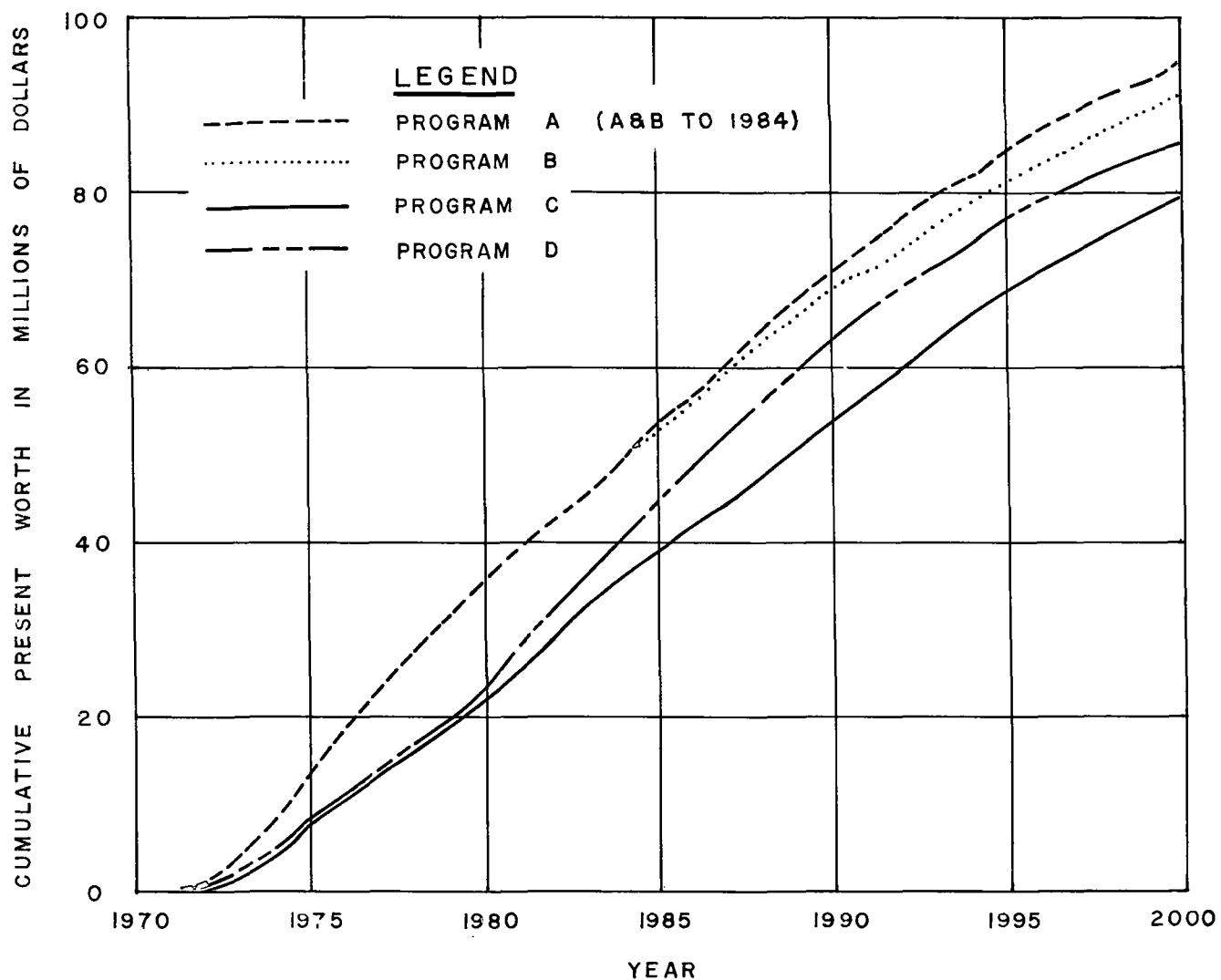


FIG. 33 CUMULATIVE PRESENT WORTH

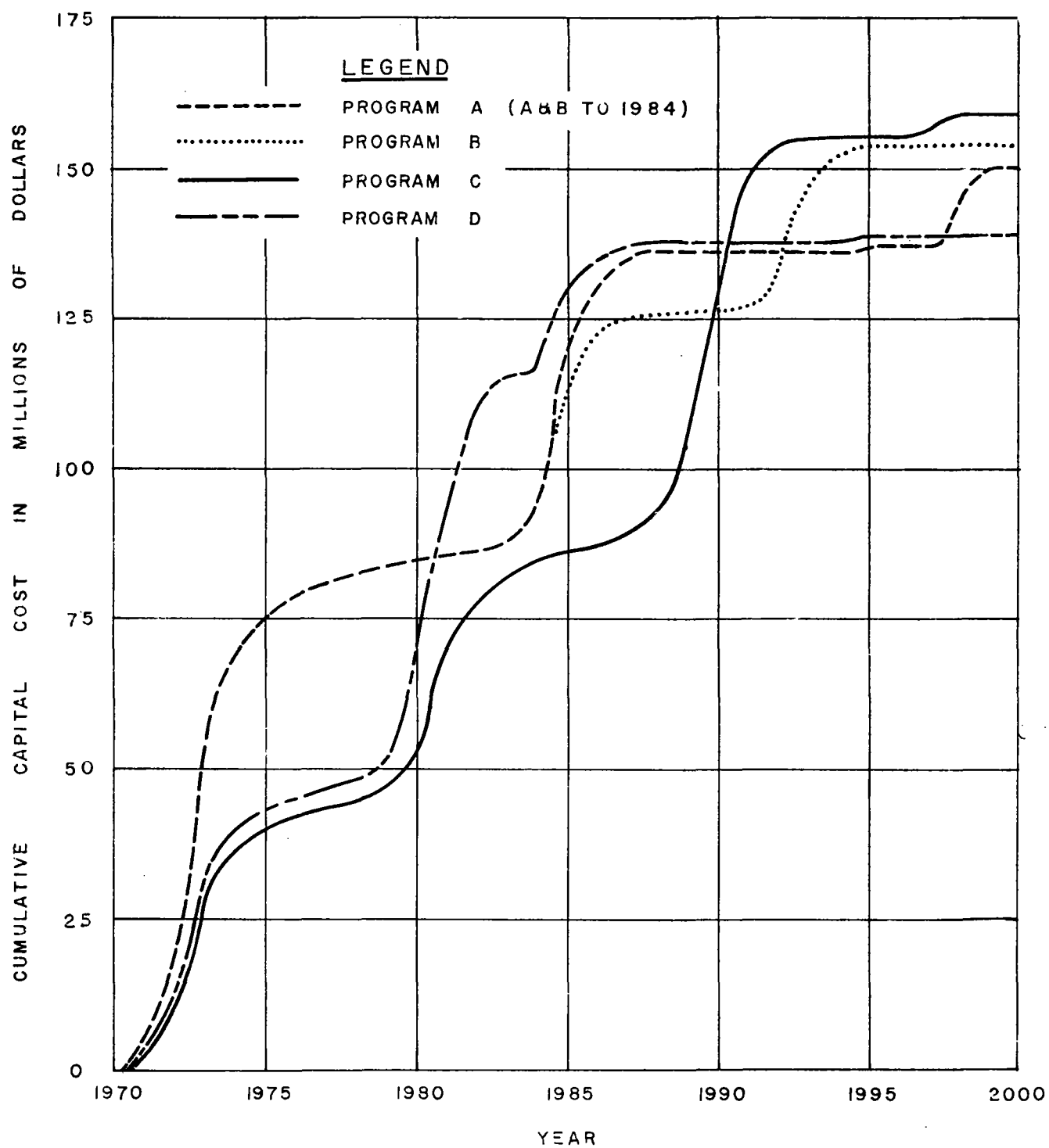


FIG. 34 CUMULATIVE CAPITAL COSTS

and D only develop two sources, and have no excess capacity at the year 2000.

The higher cost of program C over program B is caused by the larger size of the Oropouche transmission main. In program B with the Oropouche constructed as the initial project and a low initial demand, a 48-inch main was determined to be the economic size. The larger 54-inch main in program C is economically justified to permit full utilization of the Oropouche supply initially in order to reduce production from the Caroni-Arena system which has a much higher operating cost.

The higher capital cost of the most economic program is not surprising since it obtains its economic advantage by staging the construction of large capital items thereby increasing total expenditure in order to obtain a more evenly distributed cash flow. This advantage is shown in Figure 34 which compares the capital expenditures for each program. Although the total capital cost of program C is the greatest of the four alternatives up to the year 2000, it is the least up to 1990.

The details of the economic comparison of the alternative development programs are presented in Appendix A.

Recommended Program

It is recommended that WASA adopt Program C with the Caroni-Arena as the first stage project and the Moruga and the Oropouche as the second and third stage projects respectively, as the long term development program. This program is the best from the standpoint of long term economic and initial capital requirements.

Sanitary Recommendations for Caroni Drainage Area

Economic and hydrologic studies indicate that a water supply project developing the Caroni-Arena at Kelly headworks will produce water at substantially lower costs than will any alternative project.

It is obvious that the basin must be made as sanitary as possible. Estimated population of the watershed is 40,000. Some of the required improvements will be needed for general benefit of the country, but even if a more costly alternative were selected it would only be a question of time before the Caroni water would be needed and the required work would thus merely have been deferred to a later date. Costs of such works may approximate \$18,000,000. Figure 35 shows the present sanitary condition of the watershed.

A program to clean up the basin would include, but not necessarily be limited to the following items:

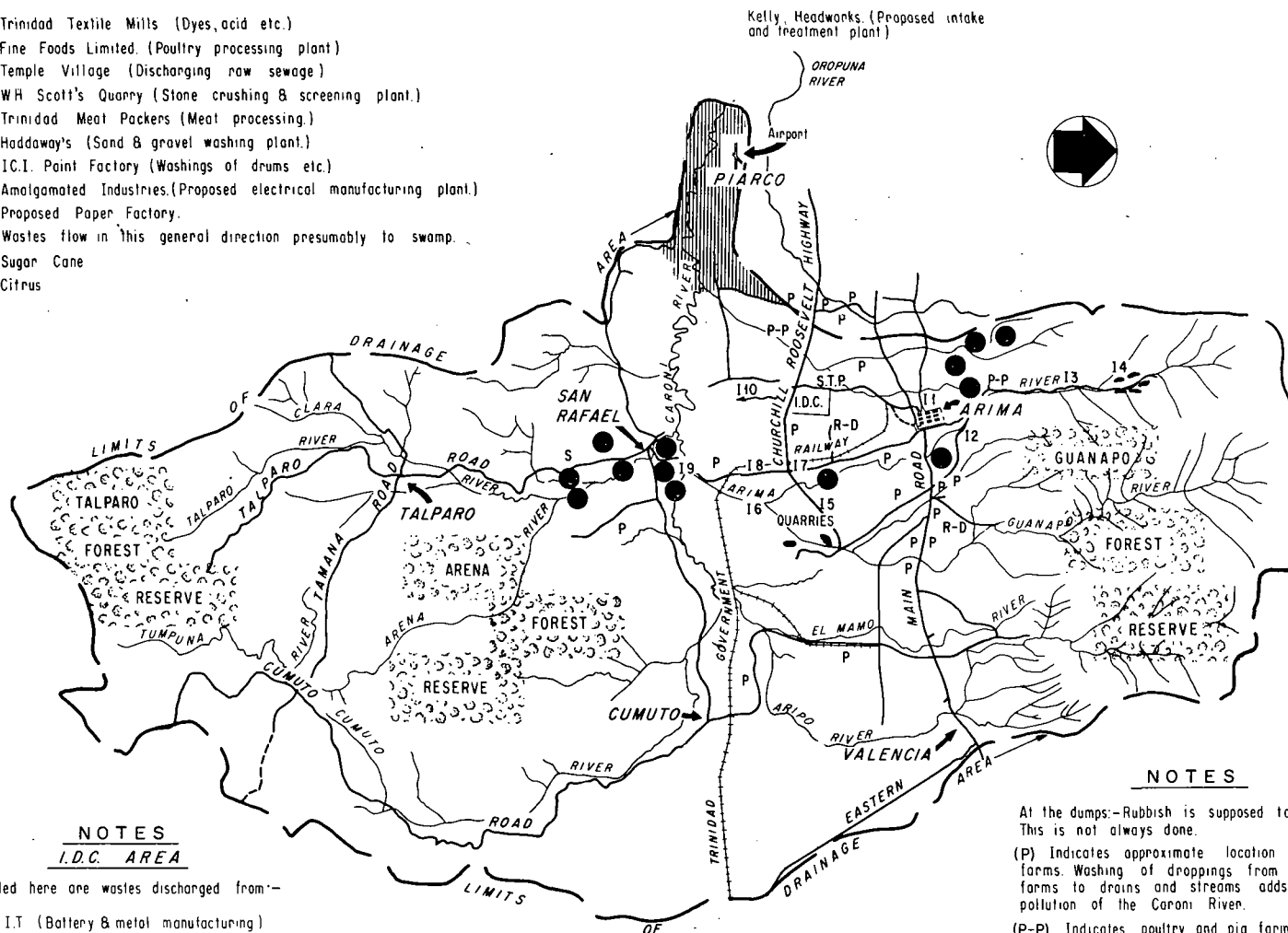
1. Redesign the presently planned treatment plant at Piarco south of the existing terminal as a lift station to pump the raw sewage to treatment works at the proposed new terminal facilities at the north side of the field; or, add chlorination equipment to the presently planned plant. When the north terminal is developed it is recommended that effluent be discharged into the Caroni River downstream from Kelly by use of the Oropuna River.
 2. Chlorinate all sewage disposal plant effluent.
- This would include that from WASA plant at Arima and

FIG. 35 POTENTIAL SOURCES OF POLLUTION

NOTES

- 11 Trinidad Textile Mills (Dyes, acid etc.)
- 12 Fine Foods Limited. (Poultry processing plant)
- 13 Temple Village (Discharging raw sewage)
- 14 WH Scott's Quarry (Stone crushing & screening plant.)
- 15 Trinidad Meat Packers (Meat processing.)
- 16 Haddaway's (Sand & gravel washing plant.)
- 17 I.C.I. Paint Factory (Washings of drums etc.)
- 18 Amalgamated Industries. (Proposed electrical manufacturing plant.)
- 19 Proposed Paper Factory.
- 110 Wastes flow in this general direction presumably to swamp.

- Sugar Cane
- Citrus



NOTES I.D.C. AREA

Included here are wastes discharged from:-

- A.B.M.I.T. (Battery & metal manufacturing)
- Caribbean Printers. (Photo, chemicals)
- Diversy Corp. (Industrial cleaning chemicals).
- Proposed Caribbean Pharmaceutical's Factory (for drug manufacture)

NOTES

At the dumps:-Rubbish is supposed to be buried. This is not always done.

(P) Indicates approximate location of poultry farms. Washing of droppings from these farms to drains and streams adds to the pollution of the Caroni River.

(P-P) Indicates poultry and pig farms, washings flow directly to streams

(R-D) Rubbish dump.

(S.T.P.) Sewage Treatment Plant

(S)

that from the various private industrial waste disposal facilities, existing or to be installed.

3. Connect Textile Mill and other industrial waste products to existing system where feasible. Special waste treatment may be required by the industries before discharge to the public system or to any open drain or stream.
4. Provide for proper lagooning of pig, cattle and poultry wastes and continue insistence of the Public Health Inspectors that all rubbish, feathers and entrails be buried at dumps. Effect strict control of dumping procedures both at dumps and at unauthorized places. Prevent dumping of rubbish and garbage into streams.
5. Extend planned Piarco sewer to collect sewage at Piarco Village, Guest Houses, Police Station, Radio Complex, and other structures in the area.
6. Chlorinate effluent from Mausica Teachers College.
7. Construct new sewage treatment plant south of Churchill Roosevelt Highway near confluence of Arima and Guanapo Rivers. (Refer to Page 59 of Report to WASA upon Sewerage Facilities of September 23, 1968).
8. Construct settling ponds at quarry and gravel washing operations to reduce turbidity in wash water effluent.

9. Clean up village areas by treatment works, by well, designed septic tanks, or by controlled privy program. Temple Village, for example, should either be relocated, or piped water and a water-borne sewerage system should be developed even if only by communal baths and latrines.
10. All chemicals, fertilisers, weedicides, pesticides, etc., used for agricultural purposes or otherwise should have prior approval from WASA.
11. Operation of any water source, surface or ground, requires careful and continuing sanitary inspection of the drainage area or basin so that conditions in the area affecting the water quality will be known at all times.

It is recommended that necessary steps be taken to ensure the most economical development of the Caroni project, so as to benefit from the substantial savings derived from using this project rather than an alternative. It may be reiterated that one day the water from this source will be needed and that clean-up procedures at a later date will assuredly be more expensive.

Sensitivity of Second Stage Development to Changes

Since each program is based on projections of demand, any major change in demand requirements could affect the results of the analysis in the choice of the second stage project. This could easily happen since the difference in present worth between the recommended program with the Moruga as the second stage supply and program D with the Oropouche as the second stage supply is only 8 percent by the year 2000. Should the increase in demand in the south be less than our studies anticipate, the Moruga project may no longer be the most advantageous second stage project. The principal economic advantage of the Moruga over the Oropouche is that it eliminates the need to reinforce the main from Caroni to San Fernando. If the future increase in demand is concentrated in the north and reinforcement of the main from Caroni to San Fernando would not be necessary regardless of source, then the Oropouche becomes the more economical source for second stage development. Accordingly, final selection of the second stage source will require a comparison of future conditions with the projections made in this study and re-analysis if there is a substantial difference.

The importance of the second stage project at this time lies in the sizing of the transmission main from the Caroni water treatment plant south to California. With Moruga as the second stage project, this should be a 36-inch main. Had the Oropouche been an economic second stage project, a 42-inch main would prove a better choice.

COMPARISON OF MAJOR FIRST STAGE PROJECTS

General

In the chapter "EVALUATION OF ALTERNATIVE PROGRAMS" it was established that, provided growth in population, industry and resulting water demands occur as projected in the chapter "WATER REQUIREMENTS", the alternative long term program with the Caroni-Arena as the first stage and the Moruga as the second is the most economical program. Furthermore, in the chapter "DEVELOPMENT OF POTENTIAL SOURCES" it was indicated that the only economical major first stage alternatives are the Oropouche and the Caroni-Arena systems.

In this chapter the recommended first stage projects comprising metering all connections, construction of the Navet Pumped Storage Project and construction of the Caroni-Arena Project is compared with an alternative first stage project substituting the Oropouche for the Caroni-Arena project.

Project Descriptions

Projects making up the recommended program and its alternative are independent. The features of design of each facility making up the recommended and alternative projects are described below.

Metering Program. In order to reduce consumption and water waste and to provide a basis for a new rate structure, domestic meters would be purchased and installed on all direct connections. The program would take three years and would require the purchase and installation of approximately 100,000 meters. Installation should be accomplished by contract.

Navet Pumped Storage Project. The existing Navet reservoir has an estimated dependable yield of 7 mgd. The proposed pumped storage project would expand the capacity of the existing facilities to 17 mgd. The features of design are as follows:

1. A 25-foot high diversion dam, approximately 2 miles downstream of the existing dam and reservoir. The dam would increase the controlled drainage area by 11 square miles and would back water up to the toe of the existing dam.
2. An intake and pumping station at the toe of the existing dam to pump water from the newly created diversion dam through a short length of conduit over the dam and into the existing reservoir.
3. Expansion of the existing water treatment plant from its existing capacity of 12 mgd to 17 mgd maximum day capacity.
4. A booster pumping station at Malgretoute to increase the capacity of the existing transmission main from 11 mgd by gravity flow to 17 mgd.

Caroni-Arena System. The initial construction of the Caroni-Arena system would consist of a pumped storage reservoir, a river intake, a water treatment plant with low-lift and high-lift pumping, and a transmission system to serve areas of demand in the north and south. Dependable yield of the initial construction would be 33 mgd. Treatment plant and pumping capacity would be designed for a maximum day

production rate of 42 mgd. Future construction would add two impounding reservoirs in the Caroni watershed to increase the dependable yield of the system to the 42 mgd maximum day rate.

The features of design are shown on Figure 36 and are as follows:

1. A 63-foot high earth-fill dam and reservoir on the Arena River with useable storage of 3500 million gallons to augment low flows in the Caroni River downstream of San Rafael.
2. A river intake and pumping station on the Caroni River near San Rafael to pump water to the proposed reservoir during periods of high river flow.
3. A 36-inch transmission main from the pumping station and intake near San Rafael to the proposed reservoir.
4. A river intake and water treatment plant with low-lift and high-lift pumping at Kelly Village to extract water from the Caroni River, treat it and pump it to distribution.
5. A 36-inch transmission main from the water treatment plant to Tunapuna with a 24-inch and a 30-inch main to sumps at the Valsayn water works and the El Socorro pumping station, respectively.
6. A booster pumping station to pump water from the 36-inch transmission main at Tunapuna to local distribution.
7. A 36-inch transmission main from the water treatment

12,000,000 gal³

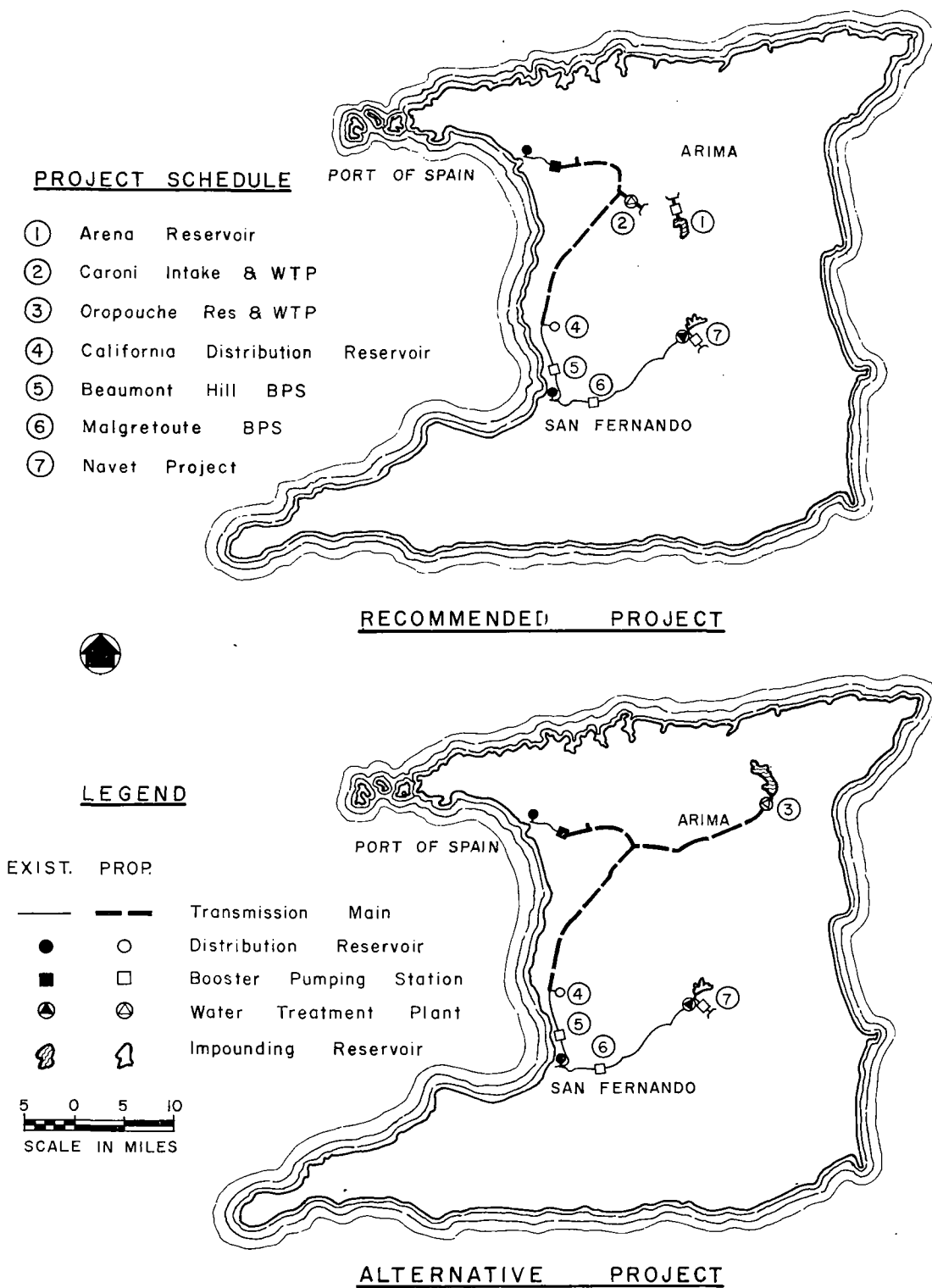


FIG. 36 RECOMMENDED AND ALTERNATIVE PROJECTS

plant southward to California.

8. A 4-million gallon distribution reservoir at California with a 30-inch connecting main from the 36-inch California main.
9. A booster pumping station at Pointe-a-Pierre on the existing 20-inch main from Freeport to San Fernando to pump water from the California reservoir to existing reservoirs in San Fernando.
10. Approximately 10,400^{30 km} feet of 30-inch main and 13,500^{15,000 ft.} feet of 24-inch main to reinforce transmission south of San Fernando. These mains are part of the Point Fortin transmission main scheduled for construction by 1978.

Dropouche System. The initial construction of the Dropouche system would consist of an impounding reservoir on the North Dropouche River, a low-lift pumping station to pump water from the reservoir to a water treatment plant, and gravity flow transmission mains to the major areas of demand. Dependable yield of the reservoir would be 45 mgd. The treatment plant and low-lift pumping station would be sized for a maximum day production rate of 33.5 mgd initially, expandable to 67 mgd in the future. Maximum flow obtainable by gravity through the transmission system would be 35 mgd. Pumping stations proposed for construction at a later date would increase transmission capacity to 55 mgd.

The features of design are shown on Figure 36 and are as follows:

1. A 258-foot high rock-fill dam and a reservoir on the North Oropouche River with a useable storage capacity of 10,000 million gallons.
2. A low-lift pumping station to pump water from the reservoir to a water treatment plant located on a hill approximately 100 feet higher than the high water level in the reservoir.
3. A 33.5 mgd water treatment plant on a hill above the reservoir.
4. A 48-inch transmission main from the clearwell of the water treatment plant to Tacarigua.
5. A 36-inch transmission main from Tacarigua to Tunapuna with 24-inch and 30-inch branch mains from Tunapuna to the discharge headers at the Valsayn water works and the El Socorro pumping station, respectively.
6. A 36-inch transmission main from Tacarigua south to California.
7. A 2-million gallon reservoir at California with a 30-inch connecting main from the end of the 42-inch California main.
8. A booster pumping station at Pointe-a-Pierre on the existing 20-inch main from Freeport to San Fernando to pump water from the California reservoir to San Fernando.
9. Approximately 10,400 feet of 30-inch main and 13,500

38,000,000

feet of 24-inch main to reinforce transmission south of San Fernando. These mains are part of the Point Fortin transmission schedule for construction in 1978.

Capital Cost Comparison

Cost estimates are shown in Tables 34 and 35 for the recommended and alternative projects, respectively. Cost of each item includes land, construction, price escalation and contingencies. *listed separately* Engineering costs are listed separately. Total capital costs for the recommended and the alternative projects are compared in Table 36.

Annual Cost Comparison

Debt service, operation and maintenance costs were estimated for both the recommended and the alternative projects for a period of seven years starting in 1975. The average annual operating costs for each year of the seven-year period are listed in Tables 37 and 38. Operating cost for chemicals and power were based on the estimates of annual production. Salary costs are based on estimates of manpower requirements and current pay scales. Maintenance costs are based on a percentage of the construction cost for each of the proposed facilities. Debt service payments are based on an 8 percent interest rate and a 25-year repayment period.

Table 39 compares total annual costs of the recommended and alternative projects.

Table 34. Capital Cost of Recommended Projects

Item	Estimated Cost in \$ 1,000 TT.			
	Foreign	Local	Total	
Metering program	5,900	500	6,400	3.2.
Navet project	1,470	933	2,403	1.2
C.A. Waterworks and intakes (1)	7,650	4,312	11,962	6.0
Arena dam (includes land)	2,932	4,053	6,985	3.5
Transmission mains and reservoirs	8,852	4,792	13,644	6.8
Contingencies	5,360	3,597	8,957	4.5
Engineering (2)	3,587	3,992	7,579	3.5
	<u>35,751</u>	<u>22,179</u>	<u>57,930</u>	<u>29.0</u>

Int. .8
 Insp. Vig. .2
 1.5
 21.5
 9.0
 30.5

1. Includes highlift and low lift pump stations
2. Includes topographic surveys and surveys for land aquisition, subsurface exploration, soils testing, design, preparation of contract documents, shop drawings review, and monitoring of construction.

Table 35. Capital Cost of Alternative Projects

Item	Estimated Cost in \$ 1,000 TT			
	Foreign	Local	Total	
Metering program	5,900	500	6,400	3.2
Navet project	1,470	933	2,403	1.2
Dropouche WTP and raw water				
pump station	9,485	5,623	15,108	7.6
Dropouche dam	4,138	11,298	15,436	7.7
Transmission	16,298 <small>29 921</small>	9,098 <small>26 019</small>	25,396 <small>55 940</small>	12.7
Contingencies	9,428	6,821	16,249	8.1
Engineering (1)	4,861	5,071	9,932	5.0
Total	51,580	39,344	90,924	vs 48.5

sub 1.1
mp. 3.1
adm 2.5
48.8 ~ 50.5

1. Includes topographic surveys and surveys for land aquisition, subsurface explorations, soils testing design, preparation of contract documents, shop drawing review, and monitoring of construction.

Table 36. Capital Cost Comparison of Recommended and Alternative Projects

Recommended Project

\$ 57,930,000 TT ✓

Alternative Project

\$ 90,924,000 TT ✓

$$\text{Ratio} = \frac{\text{Alternative Project}}{\text{Recommended Project}} = 1.57$$

*fail the in design
and stress is correct
= 1.57*

Table 37. Annual Operating and Maintenance Costs of Recommended Projects

Item	Annual Cost in \$ 1,000 TT							1975-81 Ave
	1975	1976	1977	1978	1979	1980	1981	
Metering Program								
Meter reading	56	59	62	65	68	71	74	65
Test and repair	168	177	186	195	204	213	222	195
Navet Project (1)								
Salaries	62	62	62	62	62	62	62	62
Maintenance	38	38	38	38	38	38	38	38
Power	201	201	201	201	201	201	201	201
Chemicals	88	88	88	88	88	88	88	88
Caroni-Arena Project (2)								
Salaries	368	368	368	368	368	368	368	368
Maintenance	329	329	329	329	329	329	329	329
Power	168	200	244	285	340	407	490	305
Chemicals	209	277	345	414	482	550	617	413
Total	1687	1799	1923	2045	2180	2327	2489	2064

1. Power and chemical costs based on an incremental increase in production of 6.0 mgd. Existing average annual production is 11.0 mgd, 4 mgd in excess of estimated dependable yield.
2. Power and chemical costs based on an annual average production of 9.5 mgd in 1975 increasing at the rate of 3.1 mgd annually to 28.1 mgd in 1981.

Table 38. Annual Operating and Maintenance Costs of Alternative Projects

Item	Annual Cost in \$ 1,000 TT							1975-81 Ave
	1975	1976	1977	1978	1979	1980	1981	
Metering Program								
Meter reading	56	59	62	65	68	71	74	65
Test and repair	168	177	186	195	204	213	222	195
Navet Project (1)								
Salaries	62	62	62	62	62	62	62	62
Maintenance	38	38	38	38	38	38	38	38
Power	201	201	201	201	201	201	201	201
Chemicals	88	88	88	88	88	88	88	88
Dropouche Project (2)								
Salaries	184	184	184	184	184	184	184	184
Maintenance	506	506	506	506	506	506	506	506
Power	57	76	94	113	131	150	168	113
Chemicals	139	184	230	275	320	365	410	274
Total	1499	1575	1651	1727	1802	1878	1953	1726

1. Power and chemical costs based on an incremental increase in production of 6.0 mgd. Existing average annual production is 11.0 mgd, 4 mgd in excess of estimated dependable yield.
2. Power and chemical costs based on an annual average production of 9.5 mgd in 1975 increasing at a rate of 3.1 mgd annually to 28.1 mgd in 1981.

Table 39. Annual Cost Comparison of Recommended and Alternative Projects (1975-81)

Item	Recommended project	Alternative project
Operation and maintenance (1)	\$ 2,060,000 TT	\$ 1,730,000 TT
Debt service (2)	5,140,000	8,500,000
Total	\$ 7,204,000 TT	\$ 10,230,000 TT

$$\text{Ratio} = \frac{\text{Alternative Project}}{\text{Recommended Project}} = 1.42$$

*Factor
to compare
alternatives*

(1) Average annual cost 1975-81

(2) Does not include allowance for interest during construction.

Pollution Control

There are more sources of water pollution on the Caroni catchment than there are on the Oropouche catchment. Before development of the Caroni, or concurrently with development, a pollution control program costing up to \$18,000,000 should be undertaken. However, the cost of this program should not be included in the cost of development since the pollution control facilities will be needed even if the area is not developed as a first stage project.

The potential sources of pollution on the Oropouche catchment are too small and too few to require pollution control facilities of the type necessary on the Caroni.

RECOMMENDED DEVELOPMENT PROGRAM

General

In preceding chapters system demands until year 2000 have been established on the basis of the proposed overall metering of both domestic and industrial supplies.

These demands can only be partly met by the maximum economic development of supplies in local areas. The additional supply required will come from four major projects:

- (1) Navet Pumped Storage
- (2) Caroni-Arena Reservoir
- (3) Moruga Reservoir
- (4) North Oropouche Reservoir

This chapter describes the phased development of these major projects, the local supplies, distribution improvements, the metering program and continuing works required to meet projected demands to the year 2000.

The metering program is scheduled for immediate implementation, with the local supplies and continuing works being developed on a schedule dictated by local requirements and the economics of developing major transmission system extensions. To meet system demands up to the end of 1980 will in general require the full development of all local supplies, and also supplies from two of the major projects, Navet pumped storage and the Caroni-Arena project. The average capacity of these sources is expected to be:

Local sources	15 mgd
Navet pumped storage	10 mgd
Caroni-Arena	33 mgd

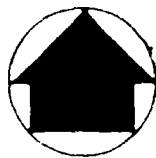
By 1983 it will be necessary to increase the Caroni-Arena supply and construct the Moruga project. By 1992 further system demands will require the supply from the North Oropouche project which will satisfy requirements to the year 2000. The average capacity of these sources is expected to be:

Local Sources	4 mgd
Caroni-Arena (increase)	9 mgd
Moruga	25 mgd
North Oropouche	45 mgd

The recommended program would be constructed in three stages to meet the estimated water requirements for 1980, 1992, and 2000.

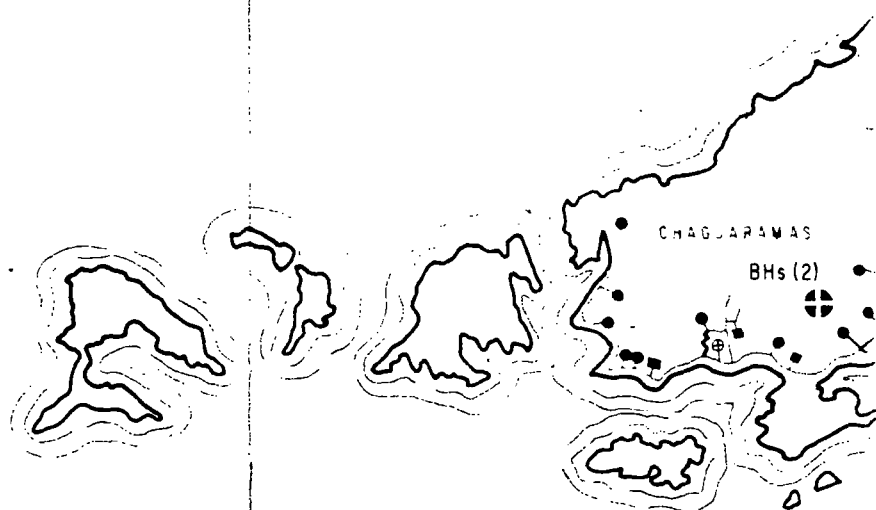
The first stage improvements to 1980 comprise a complete program for meeting supply, transmission, primary distribution and distribution storage needs. The second and third stage improvements are linked to the development of the supply facilities of the major projects and comprise a program to meet mainly supply and major transmission requirements. The recommended improvements are shown on Figure 37 for the three stages of development. How these improvements would meet the supply requirements for each stage is shown graphically on Figure 38 for all Trinidad and Tobago.





PORT OF SPAIN PROJECT

La Platte & Paramin Villag
6" Main at Gonzales (1)
Knaggs Hill BPS & 12" Mai
Knaggs Hill High Service S
Lady Chancellor High Serv
Hololo Road Res 0.1 mg
St Barbs Reinforcing Ma

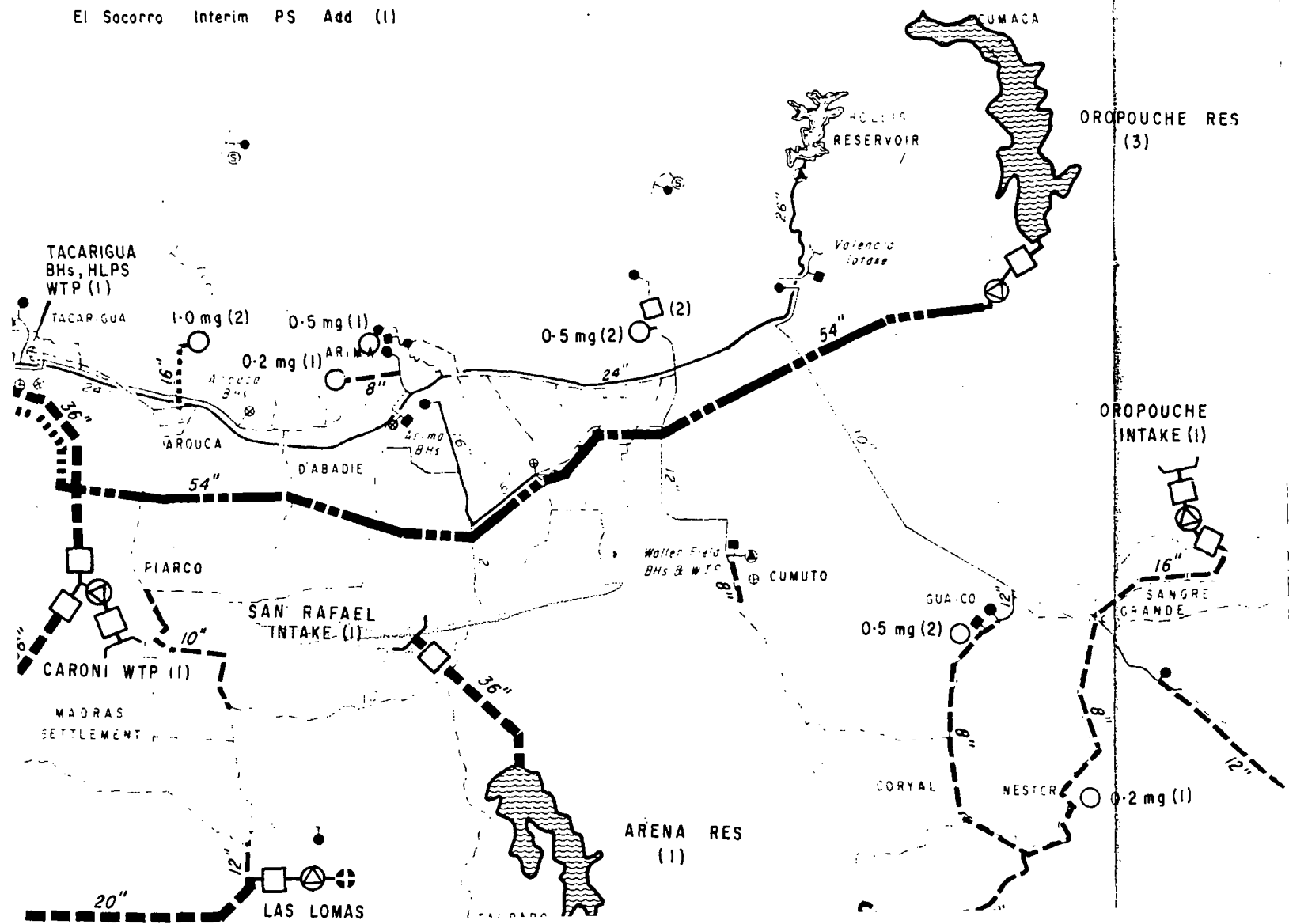


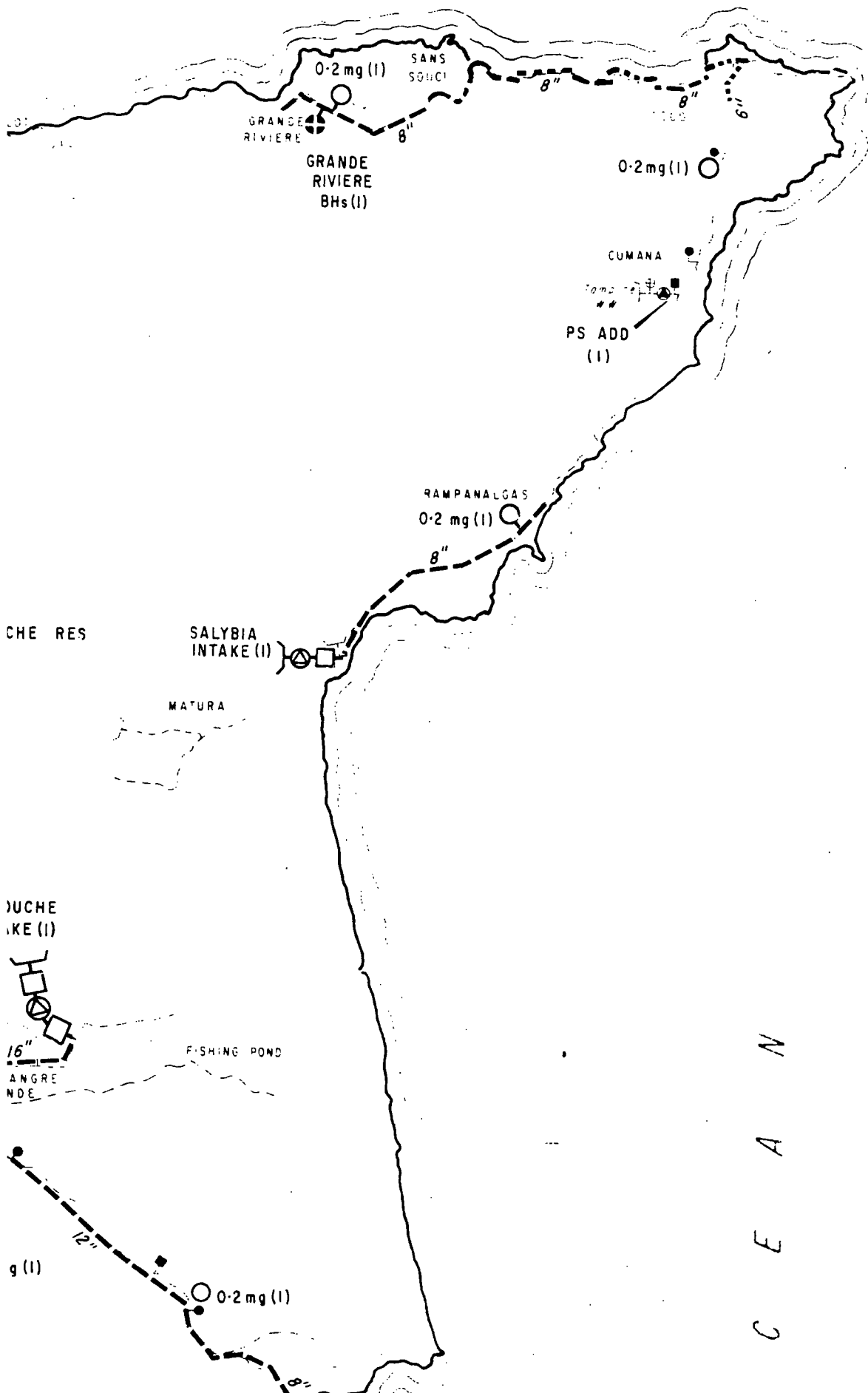
C A R I B B E A N

EAS
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Curepe BPS (1)
 Connection of Hollis 20" Main to Caroni-Arena Main (1)
 Valsayn Water Works PS Add (1)
 El Socorro Interim PS Add (1)

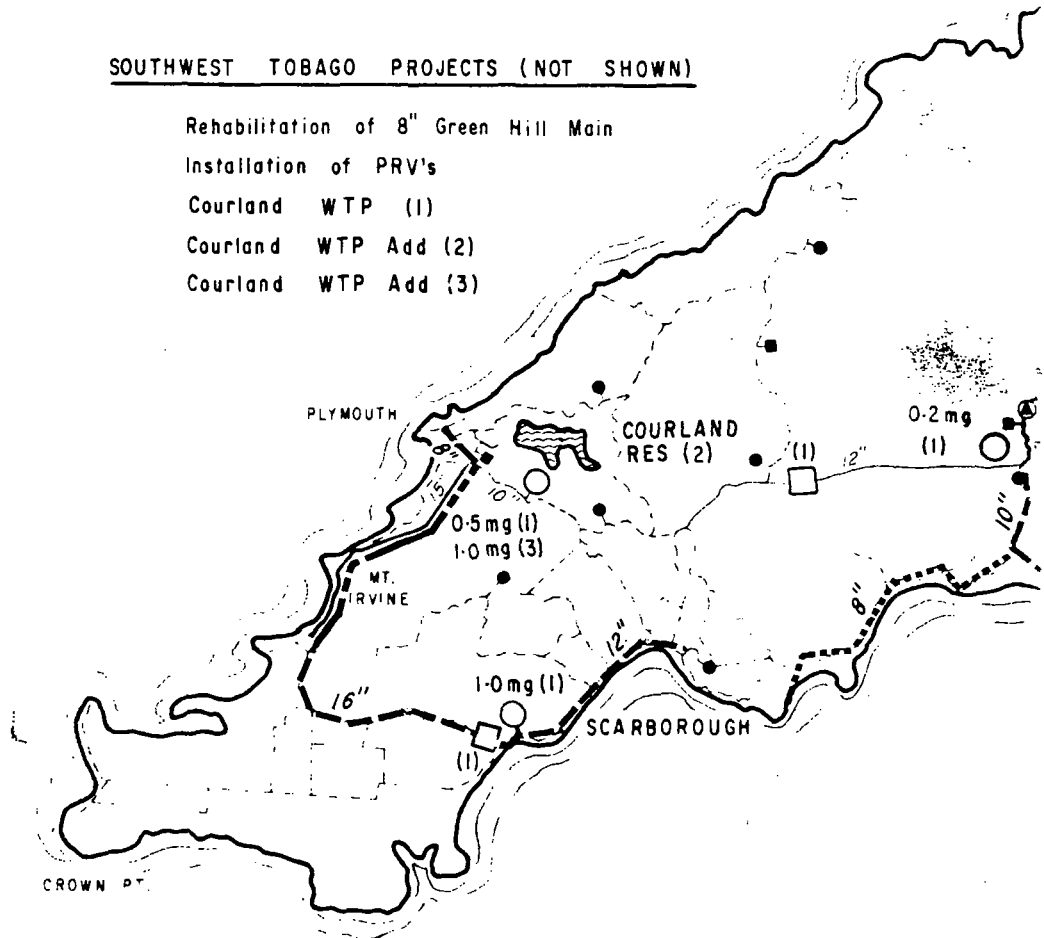






SOUTHWEST TOBAGO PROJECTS (NOT SHOWN)

Rehabilitation of 8" Green Hill Main
 Installation of PRV's
 Courland WTP (1)
 Courland WTP Add (2)
 Courland WTP Add (3)



LEGEND

EXISTING

-----	Mains 8" and smaller
—————	Mains 9" and larger
⊕	Borehole
⊙	Water Treatment Plant
■	Pumping Station
λ	Intake
●	Distribution Reservoir
Ⓢ	Spring

PROPOSED

— — — — —	1st Stage Main
· · · · ·	2nd Stage Main
— — — — —	3rd Stage Mains
⊕	Borehole
⊙	Water Treatment
○	Distributing Rese
□	Pumping Station
λ	Intake



WEST TOBAGO PROJECTS (NOT SHOWN)

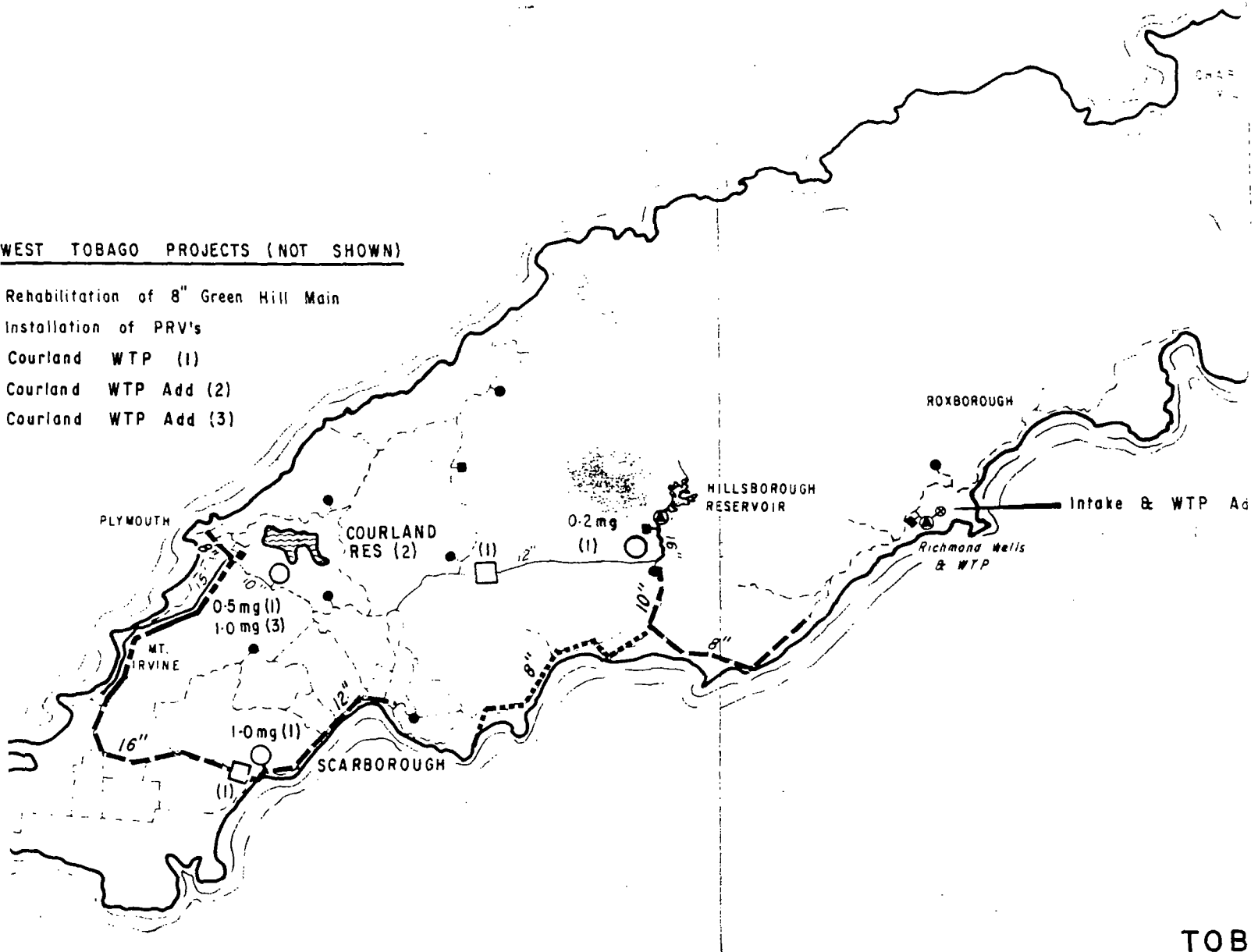
Rehabilitation of 8" Green Hill Main

Installation of PRV's

Courland WTP (1)

Courland WTP Add (2)

Courland WTP Add (3)



TOB

LEGEND

PROPOSED

smaller

larger



1st Stage Mains

2nd Stage Mains

3rd Stage Mains

Water Treatment Plant

Distributing Reservoir

Pumping Station



Borehole

Water Treatment Plant

Distributing Reservoir

Pumping Station

Intake

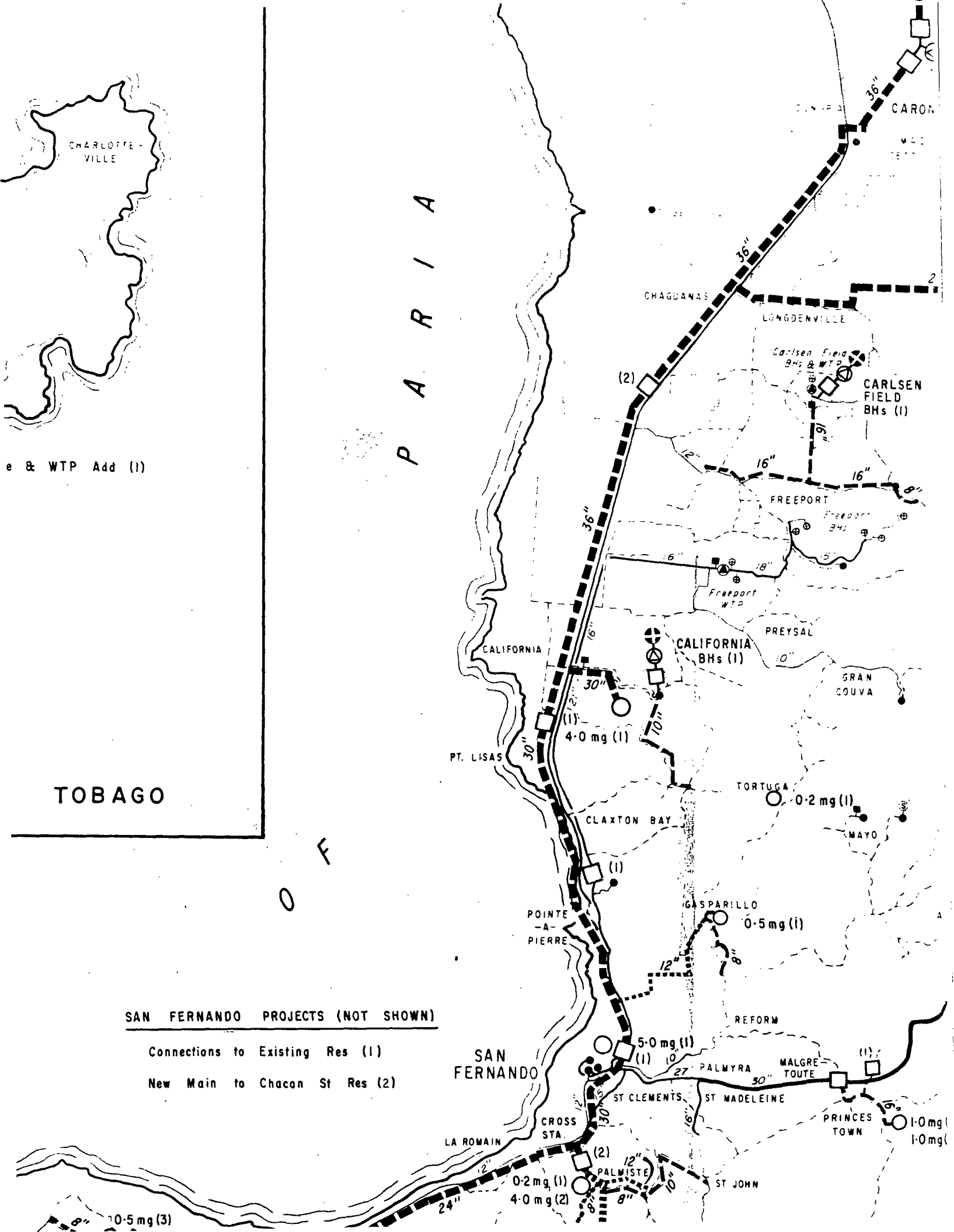
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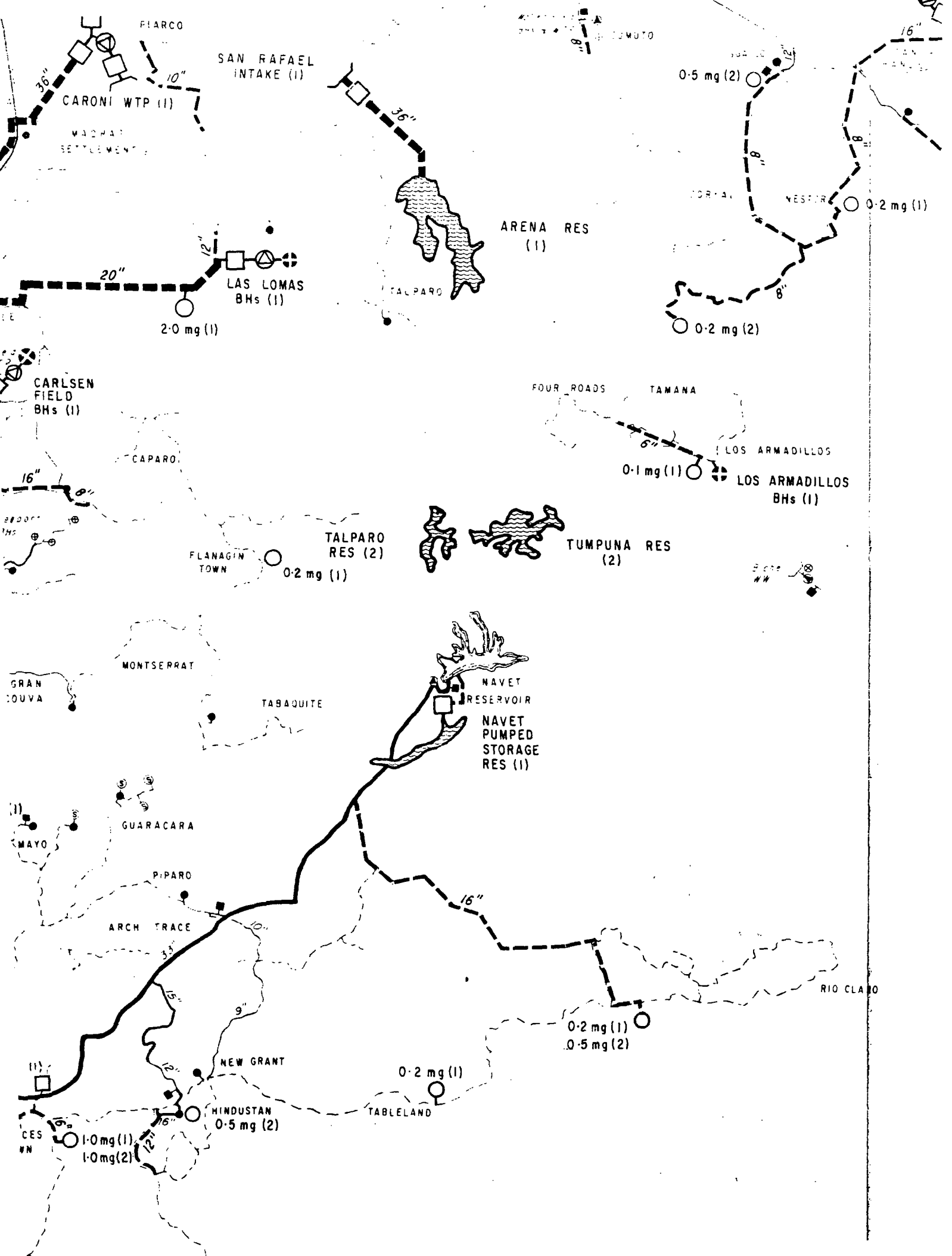
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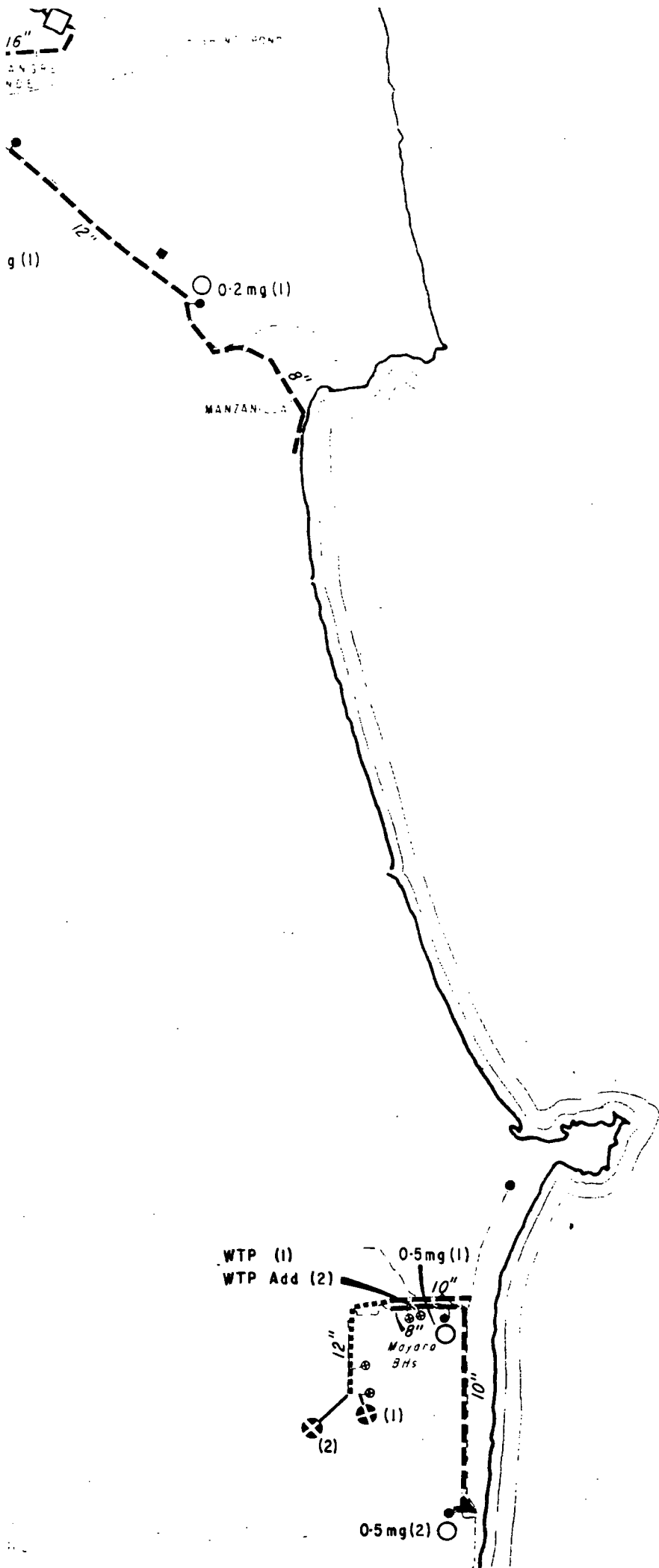
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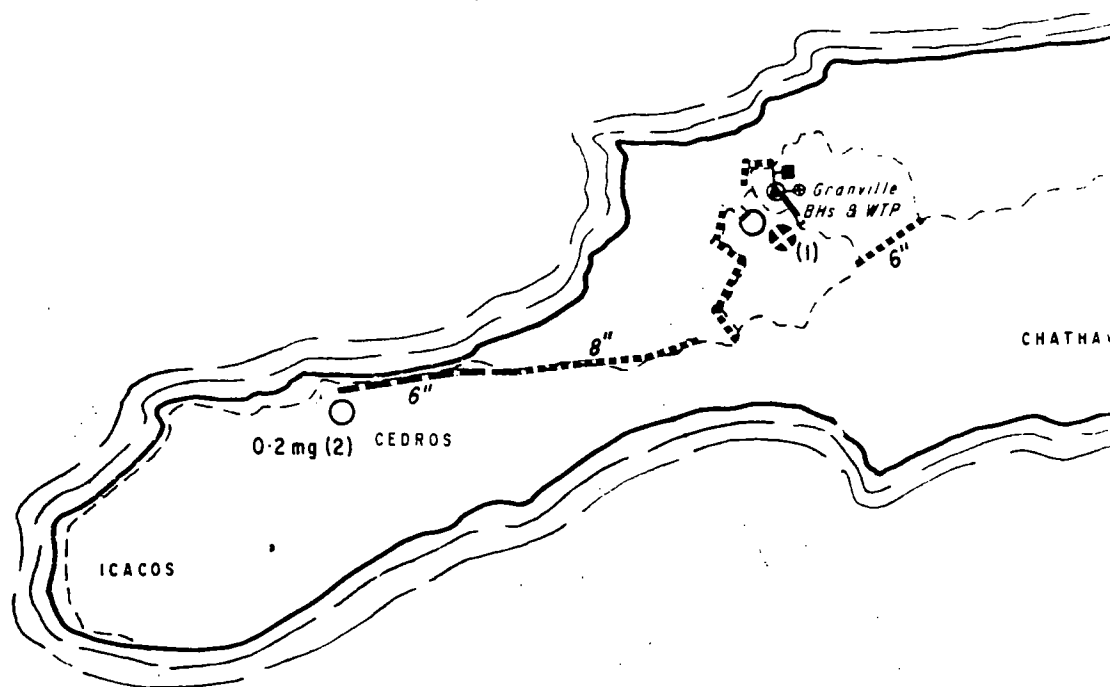
LEGEND

EXISTING

-----	Mains 8" and smaller
—————	Mains 9" and larger
⊕	Borehole
⊗	Water Treatment Plant
■	Pumping Station
∧	Intake
●	Distribution Reservoir
⑤	Spring

PROPOSED

-----	1st Stage Main
.....	2nd Stage Mains
-----	3rd Stage Mains
⊕	Borehole
⊗	Water Treatment
○	Distributing Reser
□	Pumping Station
∧	Intake
⌋	Impounding Reser
(I)	Construction Stag
	1st Stage 1970
	2nd Stage 1981
	3rd Stage 1993



LEGEND

NG

8" and smaller

9" and larger

ole

Treatment Plant

ng Station

bution Reservoir



(I)

PROPOSED

1st Stage Mains

2nd Stage Mains

3rd Stage Mains

Borehole

Water Treatment Plant

Distributing Reservoir

Pumping Station

Intake

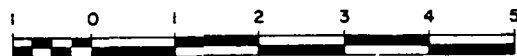
Impounding Reservoir

Construction Stage

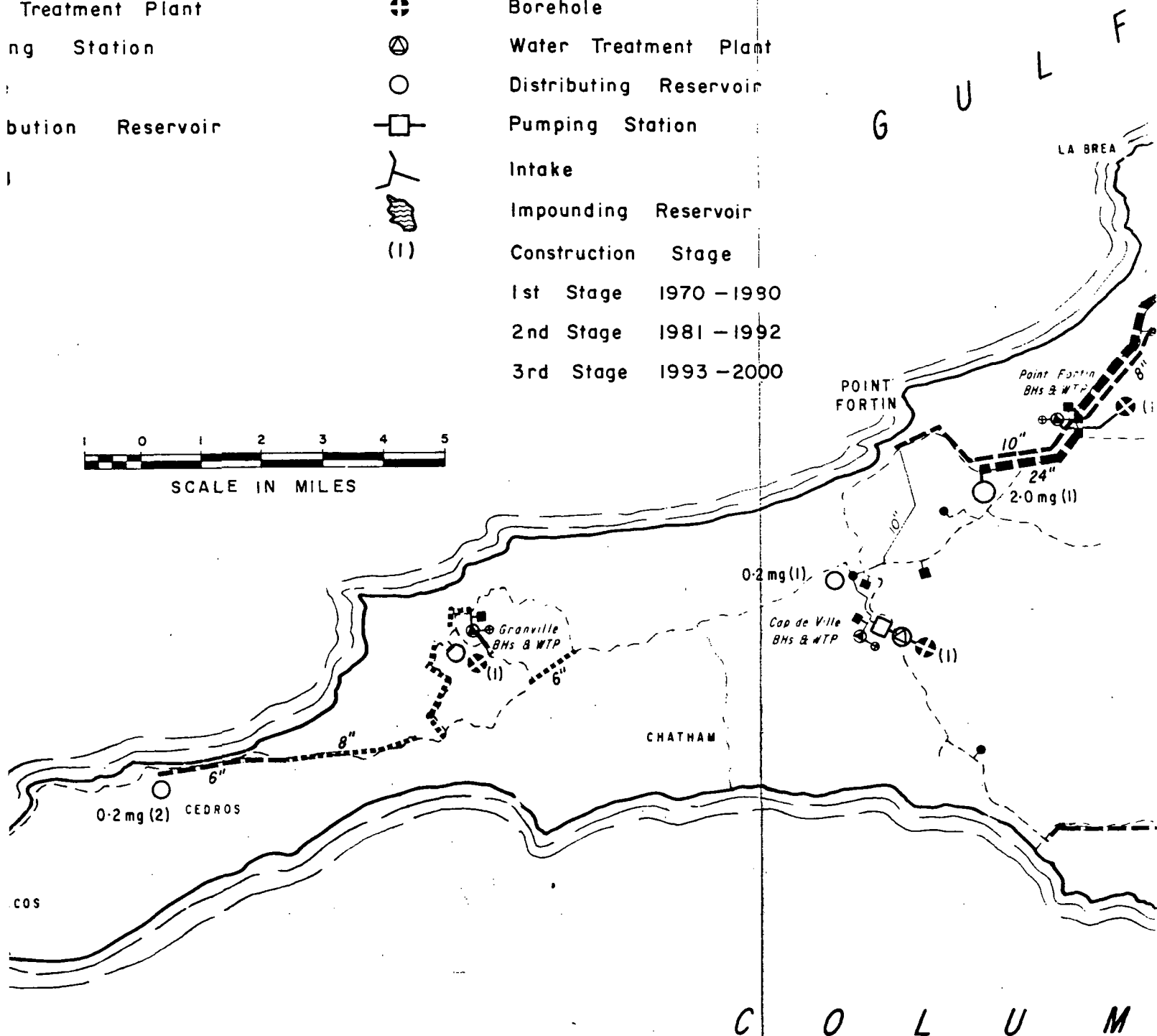
1st Stage 1970 - 1990

2nd Stage 1981 - 1992

3rd Stage 1993 - 2000

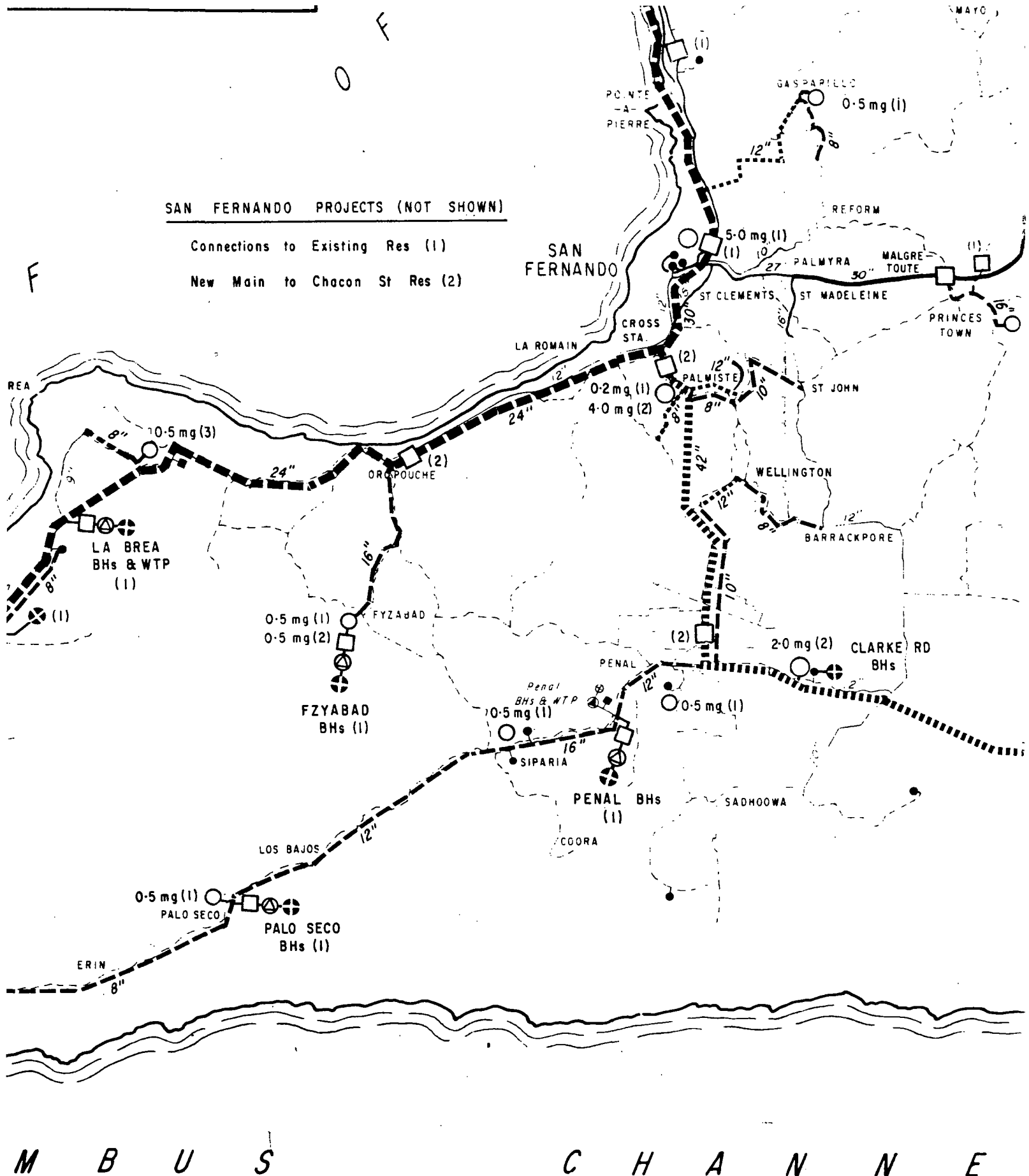


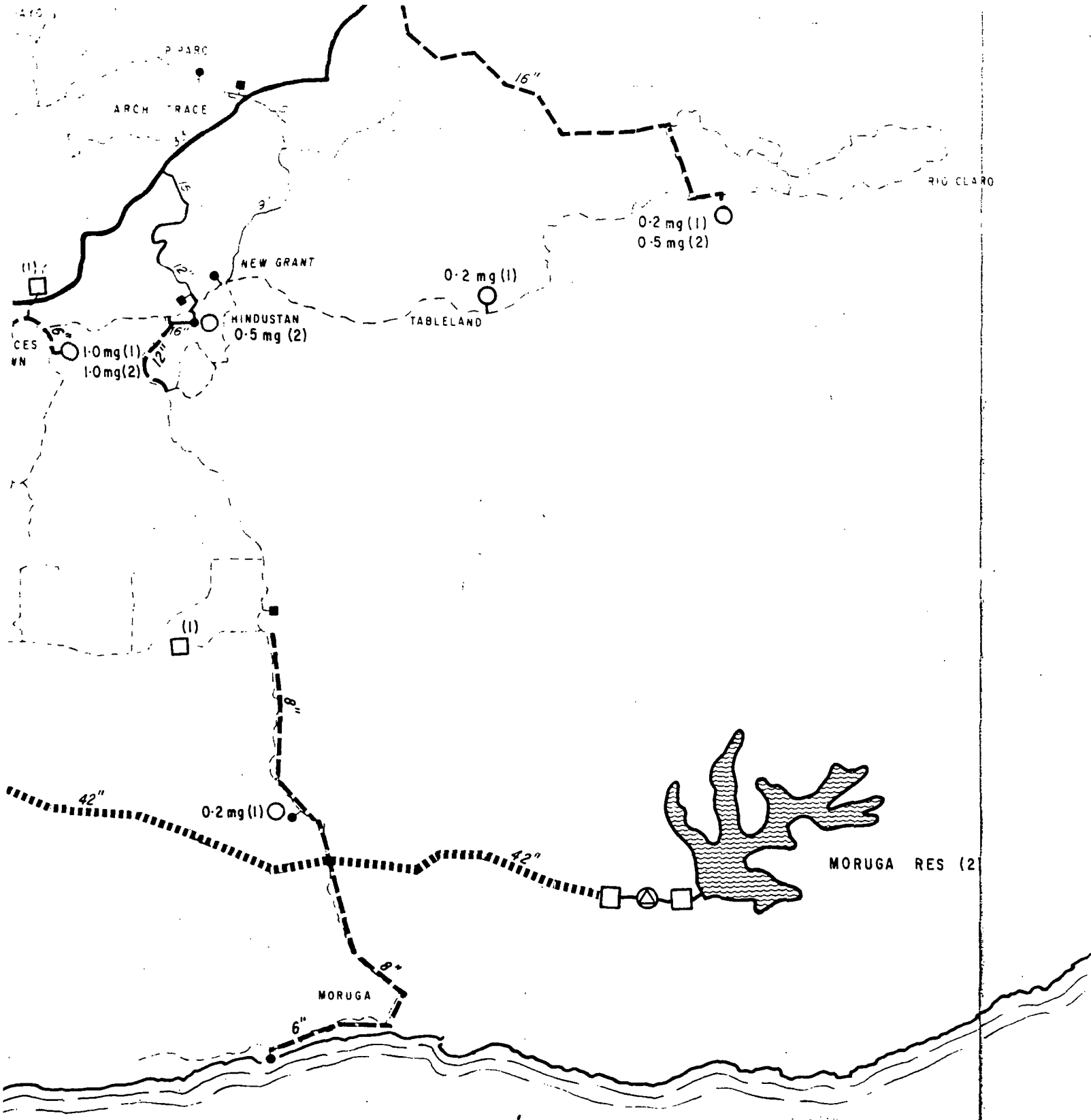
SCALE IN MILES



SAN FERNANDO PROJECTS (NOT SHOWN)

Connections to Existing Res (1)
New Main to Chacon St Res (2)





E L

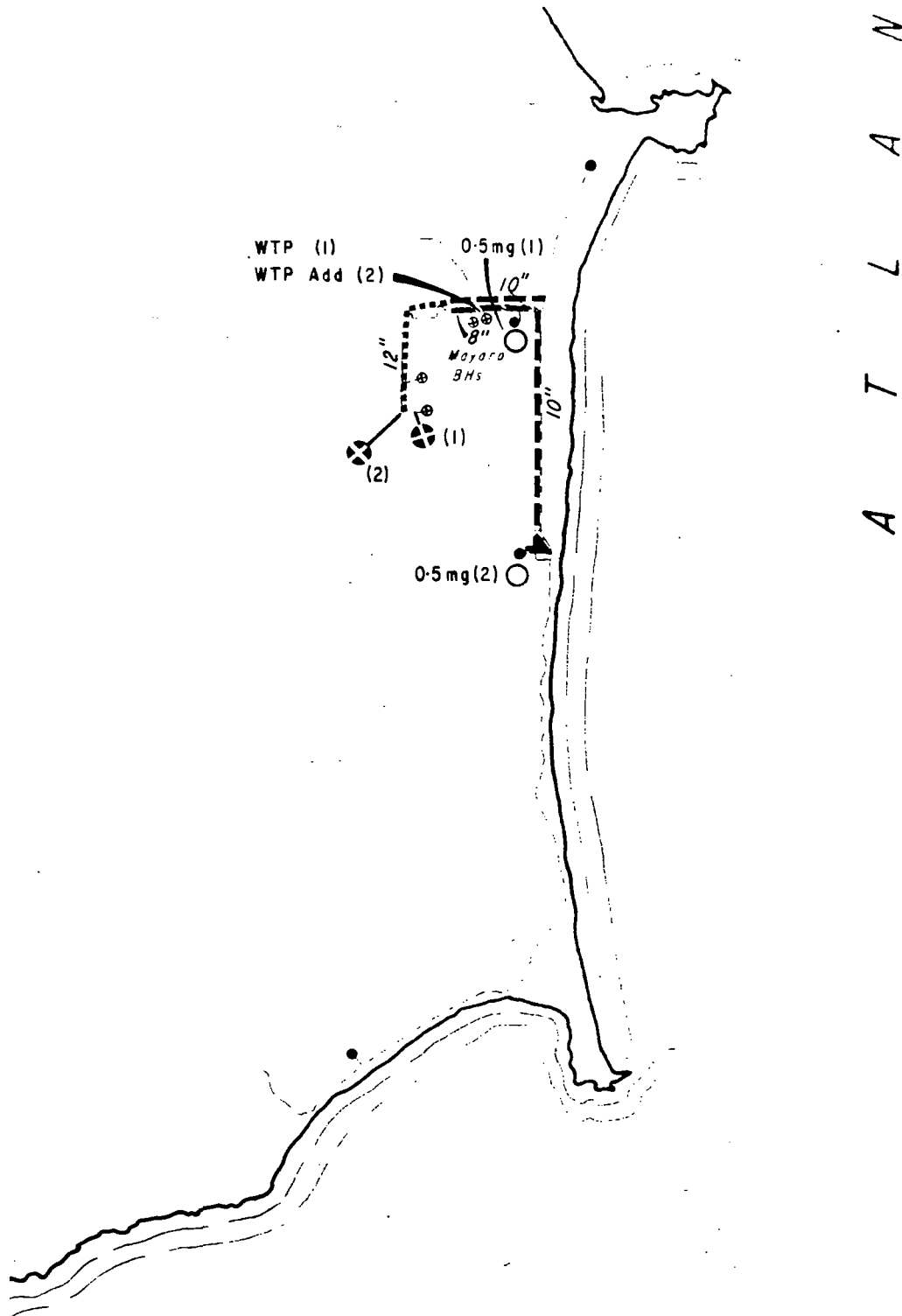


FIG. 37 RECOMMENDED IMPROVEMENTS
TRINIDAD AND TOBAGO

METCALF & EDDY

Date: 1970

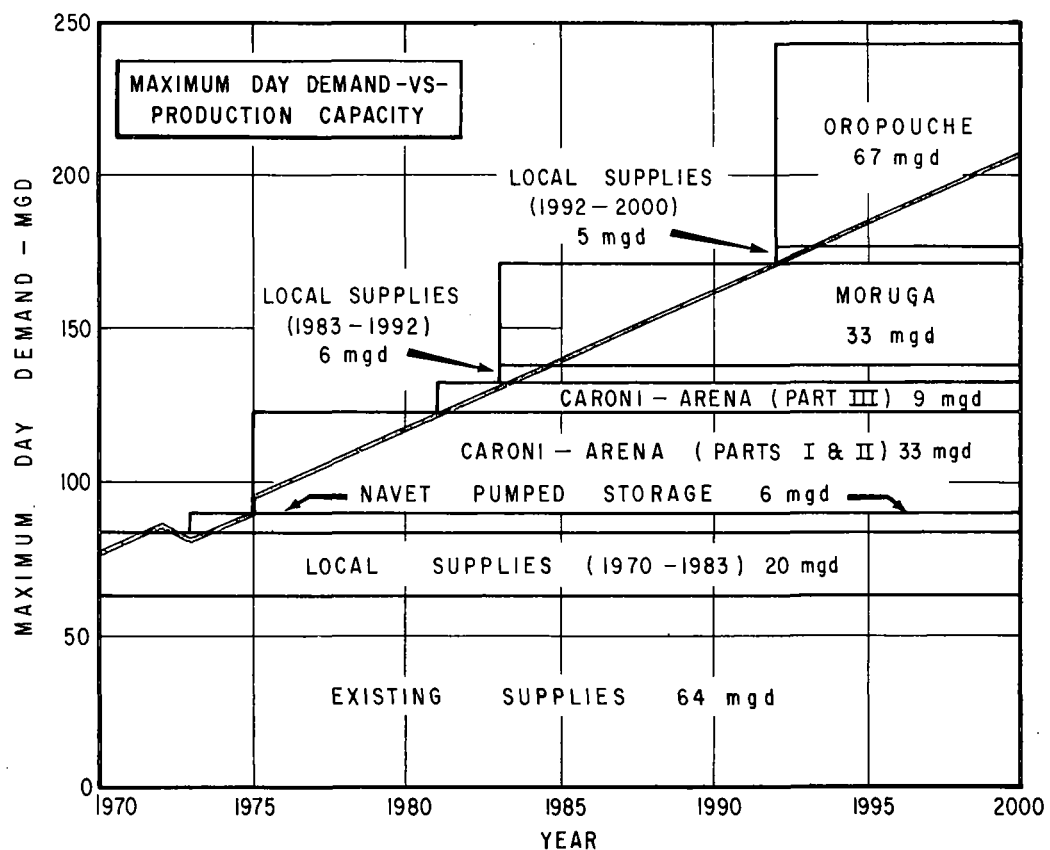
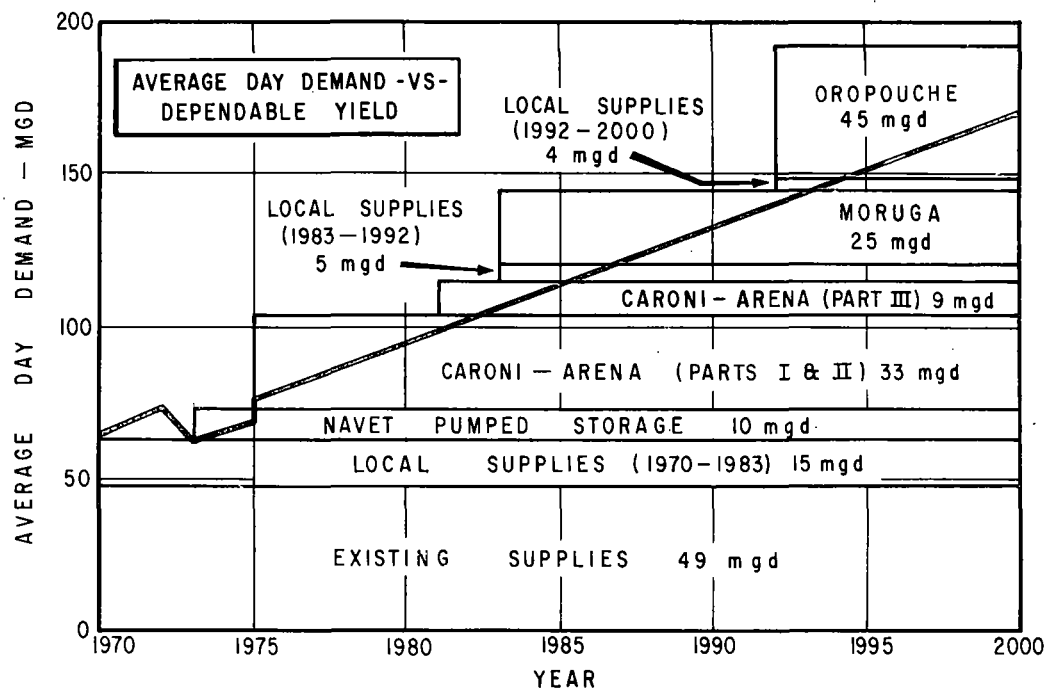


FIG. 38 RECOMMENDED PROGRAM
CAPACITY vs DEMAND

Rev. 24.3.70

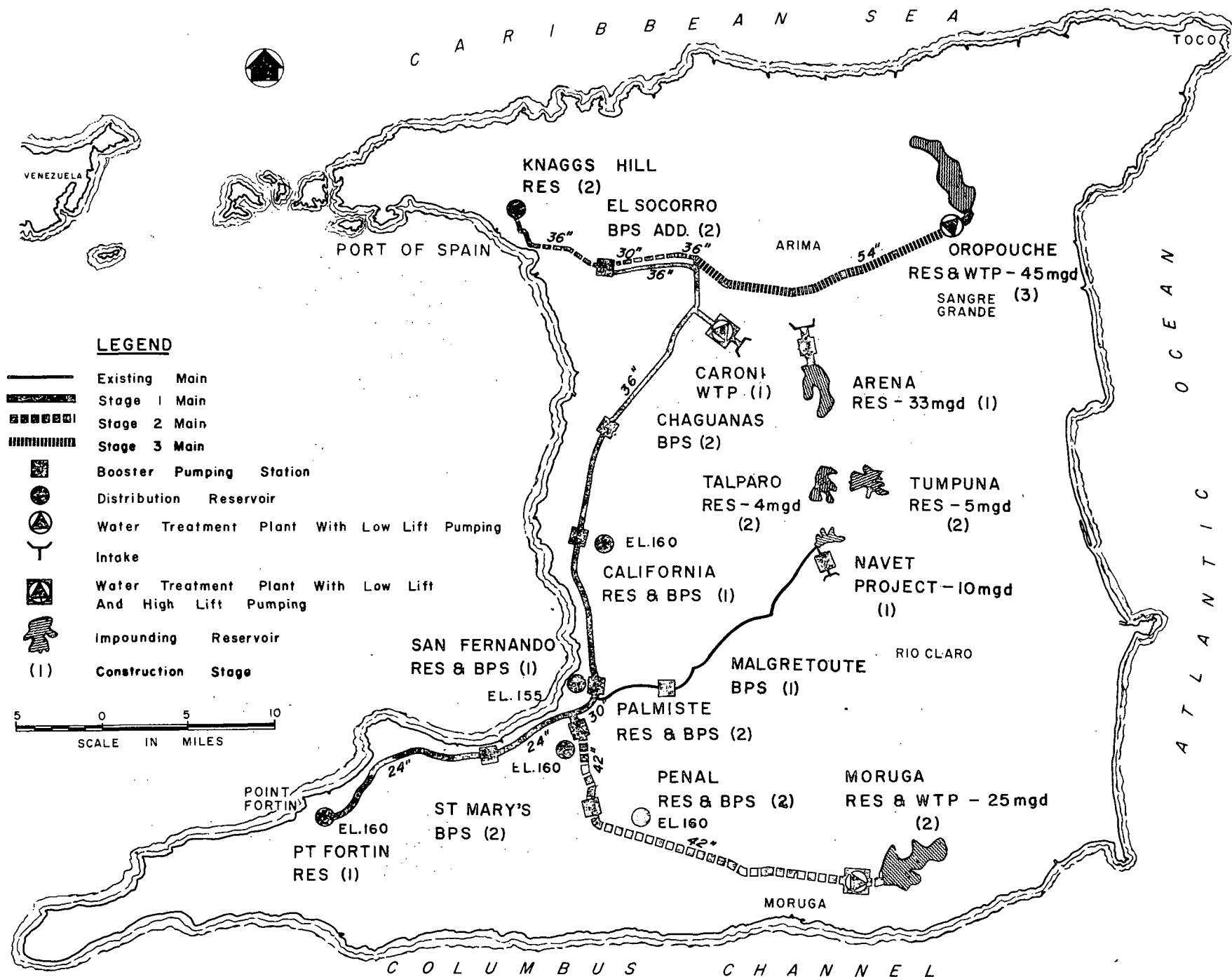
Discussion of these improvements is in three parts. The first part contains a description of the development of major supply and transmission projects and includes a construction schedule of the recommended works with costs. The second part describes local improvements by major water areas and the integration of local improvements, major supplies and existing facilities to meet future demands with each water area. It also provides a schedule of the recommended works and costs for each of the local supplies in order of priority and by construction stage. The third part describes continuing works with cost allowances to meet the estimated requirements to 1980.

Major source of supply

Four major supplies are recommended for development, these are: The Navet Pumped Storage expansion, the Caroni-Arena, the Moruga and the North Dropouche. Supply from these four sources would serve Diego Martin, Port of Spain, the Eastern Main Road communities, Caroni, San Fernando and South Trinidad. The remaining areas of Chaguaramas, Montserrat, the North Coast, Toco, Sangre Grande, Mayaro and the three service areas in Tobago would be supplied from local sources. Development of the major sources at the year 2000 is shown in Figure 39.

First Stage Development. During the First Stage the metering program would be implemented, the existing Navet system would be expanded to a capacity of 17 mgd and the Caroni-Arena system would be developed to a full capacity of 42 mgd with the dependable yield at 33 mgd from the Arena pumped storage facilities. Design and construction of these projects would proceed concurrently.

FIG. 39 MAJOR WATER SUPPLY DEVELOPMENT



Rev. 24.3.70

The domestic metering program would have as its objective the metering of all direct connections so that billing for all except standpipe users could be based on metered consumption. The installation of meters would be accomplished over a three year period with those areas with the highest percapita consumption being metered first. In estimating future demands, we have assumed that metering would result in a 20 percent reduction. The details and justification for this program are given in the Report on Organization and Administration.

The Navet Pumped storage expansion project is the smaller and less expensive of the two supply projects and should be completed by 1973. This project consists of a small dam downstream of the main Navet dam on the Navet River which impounds runoff from the intervening watershed. The dam would be high enough to back water up to the toe of the existing Navet Dam where a new intake and pumping station would pump water into the existing Navet Reservoir. The proposed improvements would add 11 square miles to the Navet drainage area which will increase the dependable yield from 7 mgd to 17 mgd. The capacity of the existing Navet trunk main would be increased to 17 mgd by construction of a booster pumping station at Malgretoute. Additional treatment capacity would also be provided.

The Caroni-Arena System would be constructed in three parts. Part I would be started at the same time as the Navet pumped storage project but would not be completed until 1975. When all three parts are completed, this system would provide water to the Eastern Main Road Communities and Port of Spain in the North and to Central and Southern

Trinidad as far south as Point Fortin at full development.

Part I would consist of an intake on the Caroni River at San Raphael with pumping and transmission facilities for supplying a reservoir on the Arena River. Water from this reservoir would augment the dry season flows in the Caroni River. A second intake on the Caroni at Kelly Village would feed to a water treatment plant at this location with pumping facilities to supply transmission mains to both the north and south.

Transmission to serve the north would consist of a 36-inch main laid as far as Curepe on the Churchill-Roosevelt Highway and a 30-inch main from there to the existing El Socorro pumping station. The section of this main between Tunapuna and El Socorro is scheduled for early completion to facilitate the maximum output from local sources. Part I transmission to serve the south would extend only as far as a new reservoir at California. The transmission main would be 36-inch and would provide sufficient capacity to meet anticipated demands at the Pt. Lisas Industrial complex and also provide limited capacity to the south through the existing Freeport 20-inch main. A temporary booster pumping station at Pointe-a-Pierre on the 20-inch main would provide the necessary lift to the existing Marryat Street reservoir at elevation 260 at San Fernando. A section of the San Fernando to Pt. Fortin transmission main would also be constructed to reinforce local distribution between San Fernando and La Romain. The remainder would be constructed under Part II.

Construction of the Navet pumped storage project together with development of local groundwater supplies in the south and the limited supply available from California are expected to meet demands in south Trinidad and in San Fernando until 1978. About this time it would be necessary to construct Part II of the Caroni-Arena System in which a 30-inch main from California would be extended to San Fernando. It would then be necessary to extend and complete the transmission main from San Fernando to Point Fortin and construct a terminal storage reservoir in Pt. Fortin.

Initially, a high-lift pumping station at the Caroni water treatment plant would meet all pumping requirements. This station could have two separate sets of pumps. One set would pump water to the El Socorro pumping station, and the other set would pump against the head established by the proposed reservoir at California. Additional pumping stations would be required at California, San Fernando, Chaguanas and at St. Mary's as the system is extended southward. The California Booster Pumping Station would pump water to a new reservoir to be constructed in San Fernando at elevation 160. A pumping station at the new reservoir would then lift water to the Marryat Street Reservoir for distribution south. Both stations would be constructed in Part II. The St. Mary's and Chaguanas pumping stations would not be needed until the Second Stage.

Second Stage Development. By 1981, production at Caroni would reach the dependable yield of the Arena pumped storage facility of 33 mgd. At this time the Tumpuna and Talparo reservoirs would be constructed to raise the dependable yield to 42 mgd.

To deliver the increased supply the booster pumping stations at Chaguanas and St. Mary's would be constructed. These projects constituted Part III of the Caroni-Arena system. When the Caroni-Arena system reaches maximum capacity, the Moruga supply would be developed in two parts for an average capacity of 25 mgd and a maximum day production capacity of 33 mgd. Part I would include the dam, water treatment, low-lift and high-lift pumping facilities and a 42-inch transmission main to deliver water to a 4-million gallon reservoir and pumping station at Palmiste. From here a 36-inch main would join the Point Fortin transmission main constructed in the First Stage. Initially, the high-lift pumping station at the Moruga reservoir would pump water the entire distance from the water treatment plant to Palmiste. Part II of the Moruga project would be constructed to consist of a booster pumping station and a 2.0-million gallon reservoir at Penal.

About 1987, transmission capacity from the Caroni water treatment plant to Port of Spain would be exceeded. A new booster pumping station at El Socorro and a parallel 36-inch main from Tacarigua to Port of Spain would then be constructed.

About the same time the main is constructed additional storage would be required in Port of Spain. This would be constructed at the existing Knaggs Hill site and would require demolition of the existing reservoir. The new reservoir would have a capacity of 10 mgd and would be filled via the new 36-inch main from Tacarigua.

Third Stage Development. In the Third Stage the North Dropouche supply would be developed for an average capacity of 45 mgd and a maximum day production capacity of 67 mgd. A 54-inch transmission main would be constructed to deliver water from the water treatment plant to a connection to the Caroni-Arena mains at Tacarigua. Upon completion, the Dropouche supply would serve as the exclusive source for the Eastern Main Road and Port of Spain areas. The pumping stations at El Socorro would be taken out of service since Port of Spain could be supplied by gravity. The Caroni supply would be used to serve only the Southern Area. Production would be cut back to about 20 mgd initially but would increase gradually as demands in the south continue to increase.

Schedule. Table 40 is a summary with costs, of the recommended major supply projects described in the preceding paragraphs. A complete description of each project with a detailed cost estimate is given in Appendix H.

Local Supply Development

This section describes the development of new local supplies and distribution improvements recommended to meet future demands. Table 41 lists sources of supply by area for each stage. Production rates shown for the years just prior to the introduction of a new major source. When both major and local supplies would be operating at maximum capacity, Tables 42 and 43 summarize production by source.

Table 40. Schedule of Recommended Major Supply Projects

Priority No.		Construction period.	Cost (\$1,000 TT)
<u>First Stage Program</u>			
1	Installation of domestic meters.	1970-1973	8,000
2	Navet pumped storage. Low dam, intake pumping station, transmission main and booster pumping station at Malgretoute.	1970-1973	4,084
3	Caroni-Arena Part I. Transmission main from Tunapuna to El Socorro.	1970-1972	1,913
4	Caroni-Arena Part I. Arena dam, intake and pumping station on the Caroni River at San Rafael, transmission main to Arena dam. Intake, low-lift pumping station, water treatment plant, and high-lift pumping station at Kelly Village, north transmission main from water treatment plant with off-take to the Valsayn water works, south transmission main to California, California reservoir, booster pumping station at Pointe-a-Pierre, and a transmission main from San Fernando through Cross Crossing to La Romain.	1970-1975	43,933
5	Caroni-Arena Part II. Transmission main from California to San Fernando, booster pumping station at California, new reservoir at San Fernando, transmission main from La Romain to Point Fortin and a reservoir at Point Fortin.	1976-1978	12,796
First Stage Cost			70,726

Table 40 (Continued). Schedule of Recommended Major Supply Projects

Priority No.	Project description	Construction period	Cost (\$1,000 TT)
<u>Second Stage Program</u>			
6	Caroni-Arena Part III. Tumpuna and Talparo dams and a booster pumping station at each Chaguanas and St. Mary's.	1978-1981	9,950
7	Moruga Part I. Moruga dam, water treatment plant and pumping station. Transmission main through Penal to Palmiste with reservoir and pumping station at Palmiste, and a transmission main to join the San Fernando-Point Fortin main at Cross Crossing.	1977-1983	33,320
8	Tacarigua to Port of Spain transmission main. New main parallel to existing and proposed transmission mains from Tacarigua to Port of Spain, continuing through Port of Spain to a new reservoir at Knaggs Hill, and a new booster pumping station at El Socorro.	1985-1987	10,325
9	Moruga Part II. Booster pumping station and reservoir at Penal.	1984	<u>1,885</u>
	Second Stage Cost		55,480
<u>Third Stage Program</u>			
10	North Oropouche. Oropouche dam, water treatment plant and pumping station. Transmission main to join Caroni-Arena transmission mains at Tacarigua.	1987-1992	<u>62,753</u>
	Third Stage Cost		62,753
	Total Program Cost		188,959

Table 41. Future Production by Major Water Area

Area and Source	Production, mgd							
	1974		1983		1992		2000	
	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.
<u>Trinidad</u>								
<u>Chaguaramas</u>	1.0	1.2	1.9	2.6	3.1	3.8	3.9	4.7
Tucker Valley Boreholes	0.5	0.7	1.4	2.1	2.6	3.3	3.4	4.2
Chaguaramas Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
<u>Diego Martin</u>	3.3	4.1	4.4	5.5	5.9	7.2	6.9	8.6
Carenage Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
River Estate Boreholes	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Four Roads-Cocorite Boreholes	0.7	1.5	1.8	2.9	2.5	3.7	2.5	3.7
Tucker Valley Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Caroni-Arena Reservoir	-	-	-	-	0.8	0.9	-	-
Oropouche Reservoir	-	-	-	-	-	-	1.8	2.3
<u>Port of Spain</u>	15.2	18.6	19.0	23.0	23.0	28.0	26.0	31.8
Four Roads-Cocorite Boreholes	1.8	2.2	0.7	0.8	-	-	-	-
Hollis Reservoir	5.4	5.4	-	-	-	-	-	-
St. Ann's Intake	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cascade Intake	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dibe Intake	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
El Socorro Boreholes	3.0	5.0	1.5	5.0	1.5	5.0	1.5	5.0
Caroni-Arena Reservoir	-	-	11.8	11.2	16.5	17.0	-	-
Oropouche Reservoir	-	-	-	-	-	-	19.5	20.8
Haleland Park Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Maraval Intake	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
St. Clair Borehole	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Savannah Boreholes	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Wharf Boreholes	0.9	1.4	0.9	1.4	0.9	1.4	0.9	1.4
Dockside Boreholes	-	0.5	-	0.5	-	0.5	-	0.5
George V Boreholes	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Table 41 (Continued). Future Production by Major Water Area

Area and Source	Production, mgd							
	1974		1983		1992		2000	
	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.
<u>Eastern Main Road</u>	16.7	20.6	24.0	29.5	32.1	39.4	39.2	48.2
Valseyn Boreholes	5.0	6.2	5.0	6.2	5.0	6.2	5.0	6.2
Tacarigua Boreholes	5.0	6.2	5.0	6.2	5.0	6.2	5.0	6.2
El Socorro Boreholes	1.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Las Lomas Boreholes	0.5	0.2	-	-	-	-	-	-
Hollis Reservoir	2.6	2.6	6.0	6.5	6.0	6.5	6.0	6.5
Arouca Boreholes	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Arima Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Waller Field Boreholes	1.1	1.3	1.7	2.2	2.2	2.8	2.8	3.5
Caroni-Arena Reservoir	-	-	2.3	4.4	9.9	13.7	-	-
Santa Cruz Borehole	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dropouche Reservoir	-	-	-	-	-	-	16.4	21.8
Local Intakes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Deficit	-	0.1	-	-	-	-	-	-
<u>Caroni-Montserrat</u>	5.8	7.3	8.3	10.3	11.7	14.5	14.3	17.8
Carlson Field Boreholes	2.0	2.5	2.0	2.5	2.0	2.5	2.0	2.5
Freeport Boreholes	0.8	0.7	2.5	3.0	2.5	3.0	2.5	3.0
Las Lomas Boreholes	2.5	3.5	3.0	3.7	3.0	3.7	3.0	3.7
Caroni-Arena Reservoir	-	-	0.3	0.5	3.7	4.7	6.3	8.0
California Boreholes	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6
<u>San Fernando</u>	5.6	6.9	7.3	8.9	9.1	11.0	10.5	12.7
Navet Reservoir	5.6	6.9	7.3	8.3	7.6	5.1	5.2	2.4
Caroni-Arena Reservoir	-	-	-	0.6	-	-	5.3	9.6
Dropouche Reservoir	-	-	-	-	-	-	-	-
Moruga Reservoir	-	-	-	-	1.5	5.9	-	0.7

Table 41 (Continued). Future Production by Major Water Area

Area and Source	Production, mgd							
	1974		1983		1992		2000	
	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.
<u>South Trinidad</u>	15.6	19.1	25.8	31.5	36.6	44.0	46.7	57.0
Navet Reservoir	8.2	10.1	9.7	8.7	9.4	11.9	11.8	14.6
Penal Boreholes	2.0	2.5	2.0	2.5	2.0	2.5	2.0	2.5
Point Fortin Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
La Brea Boreholes	-	-	1.0	1.2	1.0	1.2	1.0	1.2
Clarke Road Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
Granville Boreholes	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6
Cap de Ville Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
Morichal Springs	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Guaracara Springs	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Palo Seco Boreholes	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6
Moruga Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Caroni-Arena Reservoir	-	-	7.7	12.7	-	-	1.5	-
Moruga Reservoir	-	-	-	-	18.8	22.0	25.0	32.3
Fyzabad Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
Freeport Boreholes	-	0.1	-	-	-	-	-	-
<u>Mayaro</u>	0.4	0.5	0.8	0.9	1.1	1.3	1.4	1.7
Mayaro Boreholes	0.4	0.5	0.8	0.9	1.1	1.3	1.4	1.7
<u>North Coast</u>	0.3	0.3	0.6	0.7	0.8	0.9	1.0	1.2
Tyrice Bay Intake	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Maracas Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Yarra Boreholes	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Local Intakes	-	-	0.1	0.2	0.3	0.4	0.5	0.7
<u>Toco</u>	0.4	0.5	0.7	0.8	0.8	1.0	1.0	1.2
Tompson Water Works	0.2	0.3	0.4	0.5	0.4	0.5	0.4	0.5
Grande Riviere Boreholes	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2

Area and Source	Production, mgd							
	1974		1983		1992		2000	
	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.
Local Intakes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Salibya Intake	-	-	0.1	0.1	0.2	0.2	0.3	0.4
<u>Sangre Grande</u>	1.7	2.1	2.6	3.2	3.5	4.4	4.2	5.2
Valencia Intake	1.3	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Waller Field Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Los Armadillos Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dropouche Intake	-	-	0.6	1.2	1.5	2.4	2.2	3.2
Biche Water Works	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Coryal Boreholes	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Deficit	-	0.1	-	-	-	-	-	-
<u>Petrochemical Demand</u>	2.0	2.2	7.0	7.7	8.8	9.7	10.0	11.0
Navet Reservoir	0.3	-	-	-	-	-	-	-
Freeport Boreholes	1.7	2.2	-	-	-	-	-	-
Caroni-Arena Reservoir	-	-	7.0	7.7	5.6	5.7	10.0	11.0
Moruga Reservoir	-	-	-	-	3.2	4.0	-	-
<u>Tobago</u>								
<u>Southwest</u>	1.4	1.6	2.0	2.4	2.9	3.5	3.7	4.4
Courland Intake	0.1	0.2	-	-	-	-	-	-
Hillsborough Reservoir	1.3	1.4	1.5	1.5	1.5	1.4	1.4	1.3
Courland Reservoir	-	-	0.5	0.9	1.4	2.1	2.3	3.1
<u>Windward Coast</u>	0.2	0.2	0.3	0.4	0.5	0.6	0.6	0.7
Richmond Intake	0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.5
Hillsborough Reservoir	-	-	-	-	-	0.1	0.1	0.2
<u>Rural</u>	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4
Local Intakes	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4
Total	69.7	85.3	104.8	127.6	140.1	169.6	169.7	206.6

Table 42. Future Surface Water Production by Source

Source	Production, mgd							
	1974		1983		1992		2000	
	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.
<u>Trinidad</u>								
Caroni-Arena Res.	-	-	29.1	37.1	36.5	42.0	23.1	28.6
Dropouche Res.	-	-	-	-	-	-	37.7	44.9
Hollis Res.	8.0	8.0	6.0	6.5	6.0	6.5	6.0	6.5
St. Ann's Intake	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cascade Intake	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dibe Intake	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Maraval Intake	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Navet Res.	14.1	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Tyrico Intake	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Tompson Waterworks	0.2	0.3	0.4	0.5	0.4	0.5	0.4	0.5
Salybia Intake	-	-	0.1	0.1	0.2	0.2	0.3	0.4
Valencia Intake	1.3	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Dropouche Intake	-	-	0.6	1.2	1.5	2.4	2.2	3.2
Biche Waterworks	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Moruga Res.	-	-	-	-	23.5	31.9	25.0	33.0
Local Intakes	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.9
<u>Tobago</u>								
Courland Intake	0.1	0.2	-	-	-	-	-	-
Richmond Intake	0.2	0.2	0.3	0.4	0.5	0.5	0.5	0.5
Courland Res.	-	-	0.5	0.9	1.4	2.1	2.3	3.1
Hillsborough Res.	1.3	1.4	1.5	1.5	1.5	1.5	1.5	1.5
Local Intakes	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4
Total	26.7	30.1	58.7	68.6	92.0	108.3	119.8	143.3

Table 43. Future Groundwater Production by Source

Source	Production, mgd							
	1974		1983		1992		2000	
	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.
Tucker Valley Boreholes	1.0	1.2	1.9	2.6	3.1	3.8	3.9	4.7
Chaguaramas Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
River Estate Boreholes	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Four Roads-Cocorite Boreholes	2.5	3.7	2.5	3.7	2.5	3.7	2.5	3.7
Carenage Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
El Socorro Boreholes	4.5	8.0	4.5	8.0	4.5	8.0	4.5	8.0
Las Lomas Boreholes	3.0	3.7	3.0	3.7	3.0	3.7	3.0	3.7
Haleland Park Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
California Boreholes	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6
Brieves Road Borehole	-	-	-	-	-	-	-	-
St. Clair Borehole	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Savannah Boreholes	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Wharf Boreholes	0.9	1.4	0.9	1.4	0.9	1.4	0.9	1.4
Docksite Boreholes	-	0.5	-	0.5	-	0.5	-	0.5
George V Boreholes	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Valsayn Boreholes	5.0	6.2	5.0	6.2	5.0	6.2	5.0	6.2
Tacarigua Boreholes	5.0	6.2	5.0	6.2	5.0	6.2	5.0	6.2
Arouca Boreholes	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Arima Boreholes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Waller Field Boreholes	1.2	1.4	1.8	2.3	2.3	2.9	2.9	3.6
Santa Cruz Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Carlson Field Boreholes	2.0	2.5	2.0	2.5	2.0	2.5	2.0	2.5

Table 43 (Continued). Future Groundwater Production by Source

Source	Production, mgd							
	1974		1983		1992		2000	
	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.	A.D.	M.D.
Freeport Boreholes	2.5	3.0	2.5	3.0	2.5	3.0	2.5	3.0
Clarke Road Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
Penal Boreholes	2.0	2.5	2.0	2.5	2.0	2.5	2.0	2.5
Point Fortin Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
La Brea Boreholes	-	-	1.0	1.2	1.0	1.2	1.0	1.2
Granville Boreholes	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6
Cap de Ville Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
Morichal Springs	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Guaracara Springs	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Palo Seco Boreholes	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6
Moruga Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Fyzabad Boreholes	1.0	1.2	1.0	1.2	1.0	1.2	1.0	1.2
Coryal Boreholes	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Mayaro Boreholes	0.4	0.5	0.8	0.9	1.1	1.3	1.4	1.7
Maracas Boreholes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Yarra Boreholes	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Grande Riviere Boreholes	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Los Armadillos Borehole	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	43.0	55.0	46.1	59.0	48.1	61.3	49.9	63.3

Chaguaramas. By the year 2000, 4.9 mgd will be required in Chaguaramas on the maximum day. The potential of existing groundwater aquifers in this area is more than adequate to meet this demand; therefore, it is proposed to meet all future demands in this area by locally developed groundwater. The existing rate of 1.5 mgd in Chaguaramas is excessive for the present number of users. It is estimated that most of the production goes to waste and that with effective waste and loss control, production can be reduced considerably. If this is possible, no additional boreholes in the Chaguaramas area would be required for approximately ten more years.

Improvements to the distribution system and location of new boreholes will depend on future development which cannot be projected at this time.

Diego Martin. The demand in Diego Martin will continue to be met from local groundwater supplies. The present groundwater withdrawal is about 6 mgd. Another 0.5 mgd is imported from Tucker Valley, making a total supply to the area almost 7 mgd. However, this rate can only be maintained as long as secondary recharge continues at present levels. We estimate that repair of leaks and the completion of the Sewerage Program in Diego Martin will reduce production from this aquifer to about 4.5 mgd. At this rate importation of water to Diego Martin would be required by 1980. Importation of water would be through the existing 21-inch Cocorite Main which is now used to deliver water to the Knaggs Hill Reservoir from the Cocorite and Four Roads Boreholes.

Major deficiencies in the Diego Martin area are excessively high pressures in the southern end of the valleys, excessive leakage and water waste, and lack of service in high areas above the gradient. Recommended improvements include dividing the service area at Sierra Leone Road into north and south service areas, and constructing a new reservoir in the southern area. The southern service area would be supplied from the Four Roads Boreholes which would pump water to the proposed reservoir. The Cocorite borehole field would eventually be abandoned with new boreholes drilled at Four Roads to replace the loss in capacity at Cocorite. A new high-lift pumping station would be constructed at Four Roads with pumps capable of supplying local demands.

Most of the future increase in demand is anticipated in the northern service area. When demands in this area exceed the capacity of the River Estate boreholes, a booster pumping station would be constructed at Sierra Leone Road to pump water from the southern service area to the northern service area.

Port of Spain. Present withdrawal of water from the Port of Spain aquifer system is about 5 mgd. As leakage is reduced in the water system and the sewer system is expanded to cover new areas, this rate of production will drop back to an estimated yield of 4.0 mgd. For planning purposes it has been assumed that this should not occur before completion of the Caroni-Arena project. To meet demands until the completion of the Caroni-Arena project, and additional 3.9 mgd would be made available from Hollis Reservoir. After construction of

the Caroni-Arena system, additional supplies to Port of Spain would be through the El Socorro system. The new transmission main from the Caroni Water Treatment Plant would be designed to deliver water to the existing sump at El Socorro Pumping Station. With unlimited supply, this pumping station could deliver up to 15 mgd to Port of Spain and the intervening areas. Water would continue to be pumped to the existing reservoirs on Picton Hill and then distributed to Port of Spain. The additional supply available at this location would reduce the draft from the Knaggs Hill Reservoir.

Existing production at Hollis is about 6.5 mgd. At present approximately 1.2 mgd of Hollis water is delivered to Port of Spain. To increase the flow by approximately 3.9 mgd, it is proposed that the production from Hollis be increased by approximately 1.5 mgd and that 2.4 mgd now being used in the Caroni and Eastern Main Road areas be diverted to Port of Spain. The diversion of Hollis water from these areas will be made possible by the completion of the new Las Lomas supply and increasing production from the Tacarigua borehole field.

Increased production from Hollis would be accomplished in two phases. Initially, the standby pump at the Tunapuna Pumping Station would be relocated to a new pumping station at Success. The new pumping station in series with the remaining pump would be thus doubling the pumping head available between Tunapuna and Picton Reservoir No.1. This should increase the flow by an additional one mgd. The remaining 2.9 mgd would be delivered to Port of Spain by a new route which would require early construction of a section of the Caroni-Arena transmission main between Tunapuna and the El Socorro pumping station. With this section of main

in place, Hollis water could be diverted from the 24-inch main at Tunapuna through a connection to the North-South 20-inch Hollis main to the sump of the El Socorro Pumping Station. Once in the sump at El Socorro, Hollis water would be mixed with the supply from the El Socorro boreholes and pumped to Picton reservoir No.2 in Port of Spain. Las Lomas water could be delivered to Port of Spain by the same method in emergencies.

Other improvements in Port of Spain include a proposed pumping station at Knaggs Hill to supplement the present supply to the St. Ann's and Cascade areas, and reinforcements to strengthen distribution in the Dundonald Hill, Fort George and St. Barbs areas and in Maraval.

Eastern Main Road Area. Prior to the completion of the Caroni-Arena project, increased demands in the Eastern Main Road area would be supplied from the Tacarigua borehole field. New boreholes and a high-lift pumping station are proposed at Tacarigua to increase the maximum day production rate from the present 3.2 mgd to 6.2 mgd. The high-lift pumping station would pump water through existing distribution mains with minor reinforcements, to the St. Joseph Reservoir. Excess water that could not be used locally or pumped to storage would be pumped directly to the Hollis transmission main and repumped at either the Tunapuna or El Socorro pumping stations. Eventually the Tacarigua high-lift pumping station would pump through new mains to proposed reservoirs at Tunapuna and Lopinot.

After completion of the Caroni-Arena system, Hollis water would be used exclusively to meet demands within the Eastern Main Road area, and would serve as the principal source of supply for a new low service area south of the Eastern Main Road between St. Augustine and Port of Spain now included in the Valsayn System service area. This new system would consist of the 18-inch Hollis main which would be supplied from the St. Joseph reservoir. The reservoir would be filled initially by gravity from Hollis and in the long term by re-arrangement of the pumping facilities at the Tunapuna booster station. Areas along the Churchill-Roosevelt Highway would be served by a take-off from the Caroni-Arena transmission main through a booster pumping station at Curepe.

The Valsayn system would continue to serve only those areas north of the Eastern Main Road including Morvant. Supply to this area would be supplemented by water from the Caroni-Arena system through a 24-inch connection from the Caroni-Arena Transmission Main to the sump at the existing Valsayn water works. Additional pumps would be installed at this station in the space provided, to deliver this additional water to supply. When the Valsayn System reaches its maximum capacity, supply to San Juan and Morvant would be supplemented through a new main off the existing El Socorro main, or the parallel 36-inch main at Barataria, to a proposed reservoir at Malick.

Mains to the Santa Cruz and Maracas Valleys will require reinforcement in Stages 3 and 2 respectively. The main to Santa Cruz would be a 16-inch. A 12-inch main would be adequate to meet increased

demands in the Maracas Valley. Additional distribution storage would also be provided.

Waller Field would continue to operate as a separate system. Sufficient water is available in this area to meet local demands until Stage 3. Supply to this area would then be supplemented from Hollis.

Caroni. Prior to completion of the Caroni-Arena project, Caroni would continue to be supplied by the Carlsen Field and Freeport systems. The limited supply from Hollis would be replaced by the new boreholes at Las Lomas. The Carlsen Field supply would serve as the exclusive supply for a new service area which would include Caparo, Carlsen Field, Freeport and Flanagan Town. Pressure in this area would be controlled by the level in the existing Freeport Reservoir which would be maintained by pumping from the Carlsen Field supply to the Reservoir through new mains.

The remaining areas in Caroni would be supplied by the Freeport and Las Lomas supplies initially. After completion of the Caroni-Arena project these areas would be supplied by direct connection to the new transmission main to California.

Montserrat. The supply to Montserrat would continue to be from the Freeport water works. By cutting back pumpage to the Caroni area, sufficient supply will be available until the year 2000. Except for additional distribution storage, no improvements are anticipated for this system for both the near and long term.

San Fernando. San Fernando and its suburbs would continue to be served from the reservoirs on Naparima Hill, including the new reservoir

included in the major works program. Initially, these reservoirs would continue to be supplied from Navet. In the future they would be supplied from the Caroni and Moruga projects also.

South Trinidad. Areas close to the Navet Trunk Main would continue to be served from Navet with limited distribution reinforcements. Increased demands in Princes Town that could not be met from the Dunmore Hill reservoir in Hindustan through existing mains would be supplied from pumps at the Malgretoute booster pumping station and a 16-inch main to a new reservoir in Princes Town. Local groundwater supplies at Clarke Road, Penal and Palo Seco and water from Navet through existing mains would be adequate to meet local demands in this area until construction of the Moruga supply in 1983. After this date, a take-off at Penal from the Moruga main would meet increasing demands in these areas. By 1978 demands in La Brea, Point Fortin, and Fyzabad are expected to exceed local supplies, plus the water supplied through an existing transmission main from San Fernando. To meet these increasing demands, a 24-inch transmission main from San Fernando would be constructed under Part II of the Caroni-Arena System. The size of this main may be increased or decreased at the time depending on the potential for industrial development in Point Fortin. The supply to the Granville area would continue to be met from the Granville water works. In the long term additional water would be brought in from the Cap-de-Ville reservoir. Moruga would be served by a limited groundwater development. If groundwater proves unsuccessful, it will be necessary to reinforce existing mains to Moruga to meet demands until 1983 when the Moruga supply

would be constructed. Rio Claro would be served by a take-off from the Navet Main at Tabaquite and a new distribution main to Rio Claro.

Mayaro. Mayaro would continue to be served by local groundwater supplies as long as such supplies can be developed economically. The estimated potential of the Mayaro sandstone aquifers indicates that sufficient water is available; however, this water may prove difficult to develop. Should water from an outside source be required, the logical source would be Navet. Importation of Navet water would require a transmission main from Rio Claro to Mayaro.

Sangre Grande. Completion of the 0.5 mg reservoir at Guaico will solve immediate problems at Sangre Grande by increasing the average flow in the existing mains from Valencia to 1.5 mgd. To overcome deficiencies in both supply and distribution in the Guaico and Four Roads Tamana areas, reservoirs would be constructed at Los Armadillos Nestor and Tamana Hill, and boreholes would be drilled at Los Armadillos. When an additional supply is required it would be obtained from the Oropouche River, just north of Sangre Grande unless other groundwater development is feasible. After development of the Oropouche Reservoir the estimated flow of the river at this point will be 5.0 mgd. This source would be adequate to meet demands in the Sangre Grande area until the year 2000.

Toco. Resort type development in Toco and along the North Coast is expected to increase demands in this area to 1.2 mgd by the year 2000. The existing works on the Tompire River can be expanded

to a capacity of 0.5 mgd by new pumping and treatment facilities. To reduce transmission costs and to supplement the Tompire supply, it is proposed to develop groundwater at Grand Riviere and upgrade the intake at Salybia.

North Coast. The recently completed Tyrico Bay scheme and newly drilled boreholes at Yarra will be adequate to serve future North Coast demands until about 1980. The construction of local intakes similar to the one at Tyrico are proposed to meet demands until the year 2000. Should a large demand develop as a result of intensive resort type development, the construction of the Yarra Dam and Reservoir would be the logical means to develop a large dependable supply of water.

Southwest Tobago. With expected decreases in demand as a result of waste and loss control measures and metering, the existing supply in southwest Tobago would be adequate to meet demands in this area until after 1980. Minor problems that now exist can easily be overcome with the completion of the Courland Project. At the present time this system is functioning inadequately due to the lack of distribution storage. Tenders have already been submitted for the construction of a 0.5 mg reservoir on Bad Hill. Operational difficulties now being experienced should end with the completion of this reservoir. A conventional treatment plant will be required for the Courland supply since the existing roughing filter has not been able to reduce turbidity to acceptable levels.

At the present time the Courland Transmission Main is only half complete. When complete this main will extend to the opposite side of the island to a proposed reservoir on Lambeau Hill. This reservoir would

be used to serve Scarborough by gravity, but would require a pumping station to fill it from the Courland Transmission Main.

A booster pumping station on the Hillsborough transmission main will increase the supply to areas of Patience Hill and Bethel. The additional supply at Hillsborough will be made available by repairing the leaks and lowering pressures in the existing 8-inch main between Greenhill and Bacolet. Eventually, the main should be replaced. Lower pressures will mean that this main will no longer be able to supply Scarborough. This source will be replaced initially by increasing the flow from the Hillsborough transmission main at Harmony Hall and later by an extension to the Courland system.

The Hillsborough supply would continue to serve the high level areas and should be adequate to meet demands in this area to the year 2000 as long as increasing demands in the lower areas are met from the Courland supply. Eventually, a dam and storage reservoir will be required on the Courland River to increase the yield of this source to 4.0 mgd.

Windward Coast. The Richmond Water Supply which is the only supply for this area is at present inadequate to meet demands in the dry season. It is proposed to increase the dependable yield of this source by taking surface water from the Richmond River. This would increase the yield of this source from its present 0.2 mgd dependable yield to 0.6 mgd. The existing treatment plant can be expanded to carry this additional load; however, sedimentation may be required.

Eventually this system would be linked with the Hillsborough system by an 8-inch main from the Greenhill Reservoir.

Rural Tobago. It is doubtful if future growth will justify any major water system construction in areas now served by rural intakes. Improvement in service to areas would consist primarily of providing new local supplies and improving existing intakes by the addition of slow sand filters. Plans for these filters are included in the Chapter PRELIMINARY DESIGN.

Schedule. Table 44 presents a summary with costs of the recommended local supply projects described in the preceding paragraphs. The projects are listed in order of priority and by construction stage. A complete description of each project with a detailed cost estimate is given in Appendix H.

Alternative Projects. Several of the recommended local projects are contingent on developing substantial groundwater yields. In most cases if adequate groundwater cannot be found, it will mean that other projects must be constructed earlier than would otherwise be necessary. However, for three of the recommended projects there are specific alternatives if the yields required cannot be developed. These alternatives are listed in Table 44a.

Table 44. Priority List of Recommended Local Supply Projects

Priority No.	Water area	Project description	Cost (\$1,000 TT)
<u>First Stage Program</u>			
1	Eastern Main Road	Additional boreholes and a new HLPS at Tacarigua. Added capacity 2.0 mgd. New 12-inch distribution mains at St. Augustine and Curepe. Connection to Hollis system at site of HLPS.	1,892
2	Eastern Main Road	New BPS on the Hollis main at Success.	47
3	Eastern Main Road	New BPS on the 12-inch Arima off-take from Hollis main.	116
4	Caroni	New boreholes, WTP and HLPS at Las Lomas. Capacity 3.0 mgd. New 2.0 mg reservoir at Las Lomas. New 20-inch distribution main from Las Lomas to the Hollis system at Chaguanas and a new 12-inch main to Las Lomas.	6,701
5	Caroni	Additional boreholes and a new WTP and HLPS at Carlsen Field. Added capacity 1.0 mgd. New 16-inch transmission and distribution mains to Freeport area and 8-inch distribution reinforcement from Freeport Reservoir.	3,014
6	South Trinidad	New boreholes, WTP and HLPS at Fyzabad. Capacity 1.0 mgd. New 0.5 mg reservoir and 12-inch connecting mains.	2,698
7	South Trinidad	Additional boreholes and a new WTP and HLPS at Cap de Ville. Added capacity 0.8 mgd. A 0.2 mg addition to the Cap de Ville reservoir.	1,976

Table 44 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water area	Project description	Cost (\$1,000 TT)
8	South Trinidad	New boreholes, WTP and HLPS at Palo Seco. Capacity 0.5 mgd. New 0.5 mg reservoir.	1,867
9	South Trinidad	Additional boreholes and a new WTP and HLPS at Clarke Road. Added capacity 0.8 mgd.	1,067
10	South Trinidad	Additional borehole at Granville and a 6-inch reinforcing main from Bonasse to Los Gallos.	606
11	South Trinidad	New BPS at Rochard Douglas Road to augment the supply to Moruga. Capacity 0.1 mgd.	78
12	South Trinidad	New 0.2 mg reservoirs at Tableland and Rio Claro.	284
13	South Trinidad	New temporary BPS at Buen Intento Road. Capacity 0.5 mgd.	110
14	South Trinidad	New 0.2 mg reservoir at Palmiste.	148
15	Caroni	New 10-inch distribution main from California reservoir to Forres Park.	509
16	Caroni	New boreholes, WTP and HLPS at California. Capacity 0.5 mgd.	1,369
17	Toco	New pumping and treatment facilities at existing Tompire waterworks. Added capacity 0.3 mgd. A 0.2 mg addition to the Toco reservoir and 8-inch reinforcements to the main between Toco Village and Sans Souci.	665

Table 44 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water area	Project description	Cost (\$1,000 TT)
18	Eastern Main Road	New 0.2 mg reservoir at Cleaver Road with a new 8-inch main from the Arima system.	283
19	Port of Spain	New 6-inch distribution main at Gonzales.	36
20	Tobago (Southwest)	New 0.5 mg reservoir at Bad Hill.	229
21	North Coast	New water system with boreholes on the Yarra River. Capacity 0.2 mgd. New 8-inch transmission main to new 0.2 mg reservoir in Blanchisseuse.	614
22	Tobago (Southwest)	New 8-inch distribution main from Courland to Plymouth.	96
23	Tobago (Southwest)	Leak survey and rehabilitation of existing 8-inch main between Greenhill and Bacolet.	150
24	Tobago (Southwest)	Pressure regulation valves at Scarborough and Les Coteaux.	8
25	Diego Martin	A new borehole at Four Roads and a new 8-inch transmission main from the borehole to the existing Cocorite HLPS.	105
26	Tobago (Southwest)	Addition to the intake at Courland. New WTP and HLPS. Added capacity 0.6 mgd.	1,933
27	Tobago (Southwest)	New 0.2 mg reservoir at the Hillsborough WTP and a BPS on the Hillsborough transmission main to Harmony Hall. Installation of control valves at the Harmony Hall and Greenhill off-takes.	274
28	Diego Martin	New 16-inch distribution main from Four Roads HLPS to a new 1.0 mg reservoir.	1,135

Table 44 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water area	Project description	Cost (\$1,000 TT)
29	Port of Spain	New BPS at Knaggs Hill Reservoir. Capacity 1.0 mgd. New 12-inch transmission main from BPS to St. Ann's.	299
30	Port of Spain	New BPS at Maraval reservoir.	110
31	Mayaro	Additional boreholes at Mayaro. New aeration and chlorination facilities for new and existing boreholes.	203
32	Mayaro	New 8-inch reinforcing main from existing Mayaro boreholes to reservoir and from reservoir to system.	194
33	South Trinidad	New 0.5 mg reservoir at Gasparillo and 8-inch supply main from Reform to reservoir.	646
34	Eastern Main Road	New 10-inch distribution main from Madras Settlement to Piarco Airport.	493
35	Sangre Grande	New 0.2 mg reservoir at Comparo and an 8-inch distribution reinforcing main between Comparo and Manzanilla.	872
36	Sangre Grande	New 8-inch main from Waller Field WTP to Cumuto.	136
37	Sangre Grande	New boreholes at Los Armadillos. New 0.1 mg reservoir and 6-inch distribution main from Los Armadillos to road junction west of Four Roads intake.	516
38	Sangre Grande	New 8-inch reinforcing main from Guaico reservoir to Coryal.	638
39	South Trinidad	New 10-inch and 8-inch main from the Barrackpore main at St. John to the Palmiste reservoir.	535

Table 44 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water area	Project description	Cost (\$1,000 TT)
40	South Trinidad	New 8-inch distribution main from the Barrackpore main at Barrackpore to Wellington.	317
41	South Trinidad	New 0.2 mg reservoir at Flanagin Town.	141
42	South Trinidad	Additional boreholes and additions to the WTP and HLPS at Point Fortin to bring total capacity to 1.0 mgd. Added capacity 0.7 mgd. New 8-inch transmission main to KTO reservoir. New 10-inch distribution main from existing 10-inch main from Cap de Ville along Point Fortin Road to the Point Fortin WTP.	2,654
43	South Trinidad	Additional boreholes, WTP and HLPS at Penal to bring capacity to 2.5 mgd. New 12-inch main from the WTP to Penal Village. Added capacity 1.2 mgd.	3,188
44	South Trinidad	New boreholes, WTP and HLPS at La Brea. Capacity 1.0 mgd.	2,191
45	Port of Spain	New boosted supply system to serve the north end of Lady Chancellor Road. Capacity 0.1 mgd.	440
46	Port of Spain	New boosted supply system to serve the south end of Lady Chancellor Road and Knaggs Hill. Capacity 0.1 mgd.	303
47	Port of Spain	New BPS at Brieves Road with a new 12-inch main from the existing Maraval 27-inch main. New 6-inch and 8-inch transmission and distribution mains to Dundonald Hill and Fort George area. New 0.2 mg reservoir at Dundonald Hill.	574
48	Port of Spain	Addition to the Picton BPS to increase total capacity to 1.0 mgd. New 12-inch and 8-inch transmission and distribution mains to St. Barbs. A 0.2 mg addition to the St. Barbs reservoir. Added capacity 0.8 mgd.	965

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Table 44 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water area	Project description	Cost (\$1,000 TT)
49	Port of Spain	New boosted supply system to serve La Platte and Paramin Villages.	556
50	South Trinidad	New 8-inch distribution main between Palo Seco and Erin.	800
51	South Trinidad	New 8-inch and 6-inch distribution main from the intersection of the Moruga and Rochard Douglas Roads to La Lune. New 0.2 mg reservoir at site of existing Moruga reservoir.	1,598
52	South Trinidad	New 16-inch distribution main off the Navet main at Tabaquite along the Tabaquite Rio Claro Road to the proposed Rio Claro reservoir.	2,049
53	South Trinidad	New 12-inch distribution main from Hindustan south along Moruga Road.	585
54	South Trinidad	New 16-inch transmission main from Penal WTP to Siparia.	791
55	Toco	New intake, WTP and HLPS at Salybia. Capacity 0.2 mgd. New 8-inch transmission and distribution main to new 0.2 mg reservoir at Balandra.	1,302
56	Eastern Main Road	Additional pumping facilities at the Valsayn HLPS to bring total capacity to 10.0 mgd. Added capacity 3.0 mgd.	132
57	Eastern Main Road	A 0.4 mg addition to Morvant reservoir.	250
58	Port of Spain	A 0.2 addition to Hololo reservoir. New 0.1 mg high-level reservoir with new 8-inch main in Hololo Road. Addition to Hololo BPS to increase capacity to 0.3 mgd.	391

Table 44 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water area	Project description	Cost (\$1,000 TT)
59	Eastern Main Road	New pumping facilities at the El Socorro interim PS to increase capacity to 3.0 mgd. Added capacity 1.0 mgd.	413
60	Tobago (Southwest)	New 16-inch transmission main from Mt. Irvine to Lambeau. New BPS and 1.0 mg reservoir at Lambeau.	1,736
61	Tobago (Southwest)	New 12-inch distribution main from proposed Lambeau reservoir to Scarborough.	653
62	Eastern Main Road	New 16-inch inlet main from Hollis trunk main to the St. Joseph reservoir. New 20-inch outlet main from St. Joseph reservoir to the Hollis trunk main.	384
63	Eastern Main Road	Aeration and chlorination facilities for water quality control at the Tacarigua and the El Socorro interim HLPS.	319
64	Mayaro	Additional boreholes at Mayaro to bring total borehole capacity to 0.8 mgd. New HLPS including aeration and chlorination facilities with a rated capacity of 1.0 mgd. New 0.5 mg reservoir at Pierreville. New 10-inch reinforcing main between Pierreville and Maloney Road.	1,975
65	South Trinidad	New 0.5 mg reservoir at Penal. New 10-inch distribution main between Penal Village and Debe.	826
66	Eastern Main Road	New 2.0 mg reservoir at Tunapuna with new 16-inch connecting main from the Eastern Main Road.	844
67	Eastern Main Road	A 0.5 mg addition to the Arima reservoir.	335

Table 44 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water Area	Project description	Cost (\$1,000 TT)
68	Tobago (Windward Coast)	New intake and WTP addition at Richmond to increase supply capacity to 0.6 mgd. Added capacity 0.4 mgd.	232
69	Sangre Grande	New intake, WTP and HLPS on the lower Oropouche River. Capacity 2.5 mgd. New 16-inch transmission main to Sangre Grande.	3,307
70	Toco	New boreholes at Grande Riviere and a new 0.2 mg reservoir and 8-inch distribution main from boreholes to the reservoir.	806
71	South Trinidad	New 16-inch transmission main from St. Mary's to Fyzabad.	864
72	South Trinidad	New 16-inch transmission main off the Navet trunk main at Malgretoute to a new 1.0 mg reservoir at Sainte Croix. New BPS at Malgretoute.	1,076
73	South Trinidad	A 0.5 mg addition to the Gonzales St. reservoir in Siparia. A new 12-inch distribution main between Siparia and Palo Seco.	1,603
74	Montserrat	New 0.2 mg reservoir at Caratal.	141
75	Sangre Grande	New 12-inch distribution main from Sangre Grande reservoir to Comparo reservoir.	867
76	Sangre Grande	New 8-inch distribution main from Sangre Grande to Tamana Hill reservoir. New 0.2 mg reservoir at Nestor.	1,478
First Stage Cost			69,738

Table 44 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water area	Project description	Cost (\$1,000 TT)
<u>Second Stage Program</u>			
77	Tobago (Southwest)	New 10-inch and 8-inch distribution main between Greenhill, Bacolet and Scarborough.	1,189
78	Chaguaramas	New boreholes at Chaguaramas and Tucker Valley.	542
79	Tobago (Southwest)	Courland dam and expansion of WTP from 1.5 to 3.0 mg.	4,337
80	Toco	New 6-inch distribution main from Toco reservoir to Toco Village and 8-inch reinforcements to the main between Toco Village and Montevideo.	1,070
81	Diego Martin	New boreholes, HLPS and WTP at Four Roads.	814
82	South Trinidad	New 12-inch distribution main from Palmiste reservoir to Esperance, and from Debe to Wellington. New 8-inch distribution main from Palmiste reservoir to Rambert.	678
83	Mayaro	New boreholes in Mayaro to bring total borehole capacity to 1.5 mgd. New 12-inch transmission main along Cedar Grove Road. Additions to HLPS and treatment facilities to bring capacity to 1.5 mgd. Added capacity 0.5 mgd. New 0.5 mg reservoir at Maloney Road.	1,744
84	Eastern Main Road	New 0.5 mg reservoir on Aripo Road in Waller Field and a BPS to the existing reservoir to allow pressure zoning of Waller Field system.	367
85	South Trinidad	New 12-inch distribution main off the California to San Fernando transmission main to the proposed Gasparillo reservoir.	328

Table 44 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water area	Project description	Cost (\$1,000 TT)
86	South Trinidad	New 8-inch distribution main between Granville WTP and Bonasse. A 0.2 mg addition to the reservoir at Los Gallos.	1,093
87	South Trinidad	A 0.5 mg addition to Fyzabad reservoir.	229
88	South Trinidad	A 0.5 mg addition to the Rio Claro reservoir.	229
89	Eastern Main Road	A 12-inch distribution main in the Maracas Valley from St. Joseph reservoir to Loango. New 0.5 mg reservoir at Loango and new BPS at the St. Joseph reservoir.	2,155
90	San Fernando	New 20-inch distribution main to Chacon Street reservoir from proposed 4.0 mg San Fernando reservoir.	278
91	Port of Spain	New 8-inch distribution main from Haleland Park to a new 0.5 mg reservoir at Perseverance.	385
92	Diego Martin	New BPS at Sierra Leone Road. Capacity 1.0 mg.	136
93	Eastern Main Road	New 1.0 mg reservoir at Lopinot with a new 16-inch main to Eastern Main Road.	604
94	Sangre Grande	A 0.5 mg addition to Guaico reservoir and a new 0.2 mg reservoir at Tamana Hill.	369
95	South Trinidad	A 0.5 mg addition to reservoir at Dunmore Hill and a 1.0 mg addition to reservoir at Sainte Croix serving Princes Town.	632
Second Stage Cost			17,179

Table 44 (Continued). Priority List of Recommended Local Supply Projects

Priority No.	Water area	Project description	Cost (\$1,000 TT)
<u>Third Stage Program</u>			
96	Eastern Main Road	New 0.5 mg reservoir at Success and 12-inch connecting main.	314
97	South Trinidad	New 0.5 mg reservoir with 8-inch distribution main to La Brea.	542
98	Port of Spain	New 0.2 mg reservoir at Fort George.	142
99	Mayaro	New boreholes at Mayaro to bring total borehole capacity to 1.8 mgd. Expand HLPS and WTP from 1.5 mgd to 2.0 mgd. Added capacity 0.5 mgd.	587
100	Tobago (Windward Coast)	New 8-inch distribution main from Greenhill reservoir through Studley Park.	734
101	Eastern Main Road	New 16-inch distribution main from Eastern Main Road to La Canoa BPS in Santa Cruz Valley. Increased booster capacity and a new 12-inch main to a new 1.0 mg reservoir at La Pastora. New 8-inch main along La Canoa Road to a new 0.2 mg reservoir at La Canoa.	2,557
102	Port of Spain	New 2.0 mg reservoir at Cocorite.	831
103	Eastern Main Road	New 2.0 mg reservoir at Malick with a 20-inch connection from the El Socorro to Port of Spain transmission mains.	916
104	Tobago (Southwest)	Expansion of Courland WTP to 4.5 mgd. Added capacity 1.5 mgd. A 1.0 mg reservoir addition at Bad Hill with a new 16-inch transmission main from Courland to Mt. Irvine parallel to the existing 15-inch main.	<u>2,874</u>
Third Stage Cost			<u>9,497</u>
Total Program Cost			96,414

Table 44a. Alternatives to Recommended Local Supply Projects

Recommended project no.	Alternative project description	Cost (\$1,000 TT)
9	<p><u>Rochard Douglas BPS.</u> The proposed Clarke Road boreholes are estimated to provide up to 1 mgd. If the yield obtained falls short of the amount estimated, it will be necessary to make up the deficiency from the Barrackpore main by constructing a booster pumping station with a capacity of 1.0 mgd immediately north of the Rochard Douglas Road.</p>	116
37	<p><u>Los Armadillos Supply.</u> The proposed Los Armadillos boreholes are estimated to provide up to 0.5 mgd. However, results that may be obtained in the Guaracara Formation cannot be predicted; if therefore, the yield is unsatisfactory it will be necessary to bring water from the Sangre Grande-Guaico system in order to meet the requirements of the area, by laying a 6-inch main from Coryal to Los Armadillos and constructing a booster pumping station. The estimated cost of this alternate includes the 0.1 mg reservoir scheduled for construction in project 37.</p>	763

Table 44a (Continued). Alternatives to Recommended Local Supply Projects

Recommended project no.	Alternative project description	Cost (\$1,000 TT)
31, 64, 99,	<u>Mayaro Transmission Main.</u> The proposed	
83	<p>Mayaro (Cedar Grove Road) boreholes are estimated to provide up to 1.8 mgd to meet the estimated maximum day demand at year 2000. The 1975 estimated maximum day demand is 0.5 mgd. The yield of the new boreholes proposed for 1975 will indicate whether local demand can be met from this source. If there is a shortfall in production it will be necessary to make up the deficiency by providing the additional water from the Navet system at Rio Claro by laying a 12-inch main from Rio Claro to Pierreville, Mayaro, and constructing a booster pumping station. The estimated cost of this alternate includes two 0.5 mg reservoirs scheduled for construction in projects 64 and 83.</p>	3,606

Continuing Works

Table 45 lists continuing works which comprise items of capital expenditure required annually for the control and improvement of supply systems. Also included is an item for completion of projects in progress at 1970 and which have not been covered under local supply projects. These projects are shown as completed on all maps of the system.

Each item of continuing works is described in detail in Appendix H. Cost estimates are presented only for the first stage since items of this nature are of concern primarily for cash flow studies which for this study are made only for the first stage. Table 45 presents a summary of continuing works with total estimated costs.

Table 45. Continuing Works

List No.	Description	First Stage Cost (\$1,000 TT)
1	Leak detection and systems investigation.	1,000
2	Construction of domestic metering program 1970 to 1980.	3,000
3	Rural water system improvements at existing sources which are either untreated or inadequate.	750
4	A rural well program providing small wells and well joint systems in areas without a pipe borne supply.	500
5	Groundwater exploration of known aquifers related to yield and water quality and investigation of aquifers which have not yet been explored.	750
6	The provision of observation wells for monitoring of existing groundwater aquifers.	300
7	Reinforcement of mains where capacity is deficient.	1,750

Table 45 (Continued). Continuing Works

List No.	Description	First Stage Cost (\$1,000 TT)
8	Extension of mains to areas devoid of a pipe-borne supply.	7,000
9	Installation of master meters at service area boundaries and at major transmission system take-offs.	150
10	Installation of fluoridation equipment at major sources of supply.	150
11	Purchase of specialized equipment for investigations, surveys, research and system operation.	500
12	Surveys and investigations including special studies related to development projects.	1,500
13	Expansion of transport fleet and communication system.	500
14	Refurbishing of area offices and construction of new offices.	2,000
15	WASA 1970 commitments on projects in process of completion and which have not been covered under the local supply development program.	
	These projects include the following:	

Table 45. (Continued) Continuing Works

Description	First Stage Cost (\$1,000 TT)
Dunmore Hill reservoir	
St. Julien Road BPS	
Waller Field WTP	
Maraval WTP	
Tyrice WTP	
Guaico reservoir and BPS	
River Estates HLPS.	
Freeport WTP addition	950
Total First Stage Cost	20,800

RECOMMENDED FIRST STAGE PROGRAM

General

In this chapter cost estimates and a design and construction schedule for the recommended stage I program are presented. For convenience, the stage I projects are divided into two categories, major projects and local supply projects. These categories are subdivided into initial and final construction programs.

The initial construction program comprises a group of stage I facilities which together will meet the projected water demands of Trinidad and Tobago until about 1978 and can be designed and constructed in a four- to five-year period.

The final stage I construction program can be designed and constructed in a similar period of time and will provide water supply and transmission capacity sufficient to meet projected water demands until about 1981.

The recommended facilities listed as major projects are those which supply more than one water area. Those facilities listed as local supply projects serve only the areas in which they are located.

The major projects and the local supply projects are listed in the "RECOMMENDED DEVELOPMENT PROGRAM" in tables 40 and 44 respectively. With the exception of the metering project they are described in the above referenced chapter.

The metering program is recommended as a means of reducing water demand and detecting excessive leakage within the system. It

comprises metering of all unmetered water services in Trinidad and Tobago (about 100,000) whether a yard or building service. The metering project would be accomplished in a two-year period by contract. During the contract period and after the contract is completed, WASA forces would install meters on all new service connections including construction services as a continuing annual operation. Meters installed on construction services would be read and all water used during or after construction billed to the owner. When the new structure is completed the construction service would become the permanent service.

Each meter installation whether made under contract or by WASA forces would be inside a lock-type buried meter box located outside the property line or fence line. The meter box for 1/2 and 5/8 inch meters would be equal to the Inter-America Box, manufactured by the Ford Meter Box Co. Inc., Wabash Indiana, U.S.A. Boxes for 3/4 and 1-inch services would be equal to the appropriate Yoke-box, manufactured by Ford. Large meters would be installed in concrete vaults equipped with a lock type access manhole cover directly over the meter.

Upon completion of each meter installation, the contractor or WASA, depending upon which installed the meter, would complete a report and sketch showing the location of the meter, the street address, the owner's name, the meter size and number, the meter reading and the installation date. Copies of this report and sketch would be forwarded to the appropriate meter reader through the district engineer and to the billing department.

As a part of the metering contract or before letting the

contract, a canvass of the system to determine the actual number of connected premises, the location of each, and the owner's name and legal address would be undertaken. It is estimated that the metering contract would cover installation of approximately 100,000 meters, most of which would be 5/8 inch to 3/4 inch size.

Timetable - Major Supplies

The timetable or time schedule for design, and construction of the stage I major facilities recommended for initial construction, excepting the metering project, has been developed by the critical path method and is presented as critical path diagrams.

The critical path schedule allows rapid and accurate evaluation of the effects of delay in any activity upon the project completion time and identifies those activities where delay is reflected in the completion time of the entire project.

A separate critical path schedule (Figure 41) has been prepared for the Navet Pumped Storage project to allow evaluation of an early start on this portion of the work if WASA deems this advisable. Figure 42 is a critical path schedule for the remaining first stage major projects recommended for initial construction. This schedule is based on building these facilities under six separate construction contracts; four transmission main contracts (including the raw water main San Rafael to Arena dam and the California reservoir); a contract for Arena dam and reservoir; and one including the Caroni intakes and the water treatment plant.

The metering project would require less lead time for design

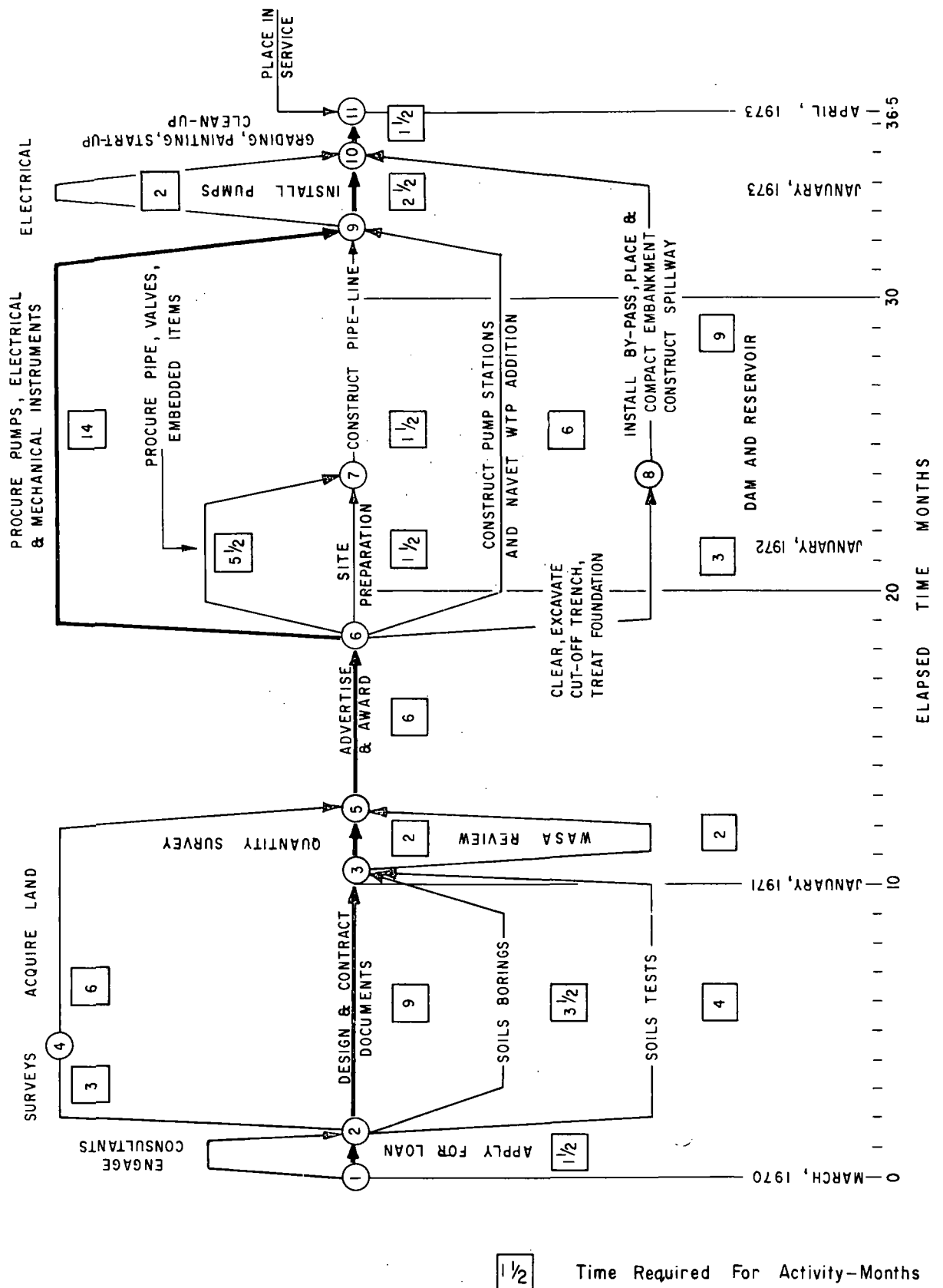
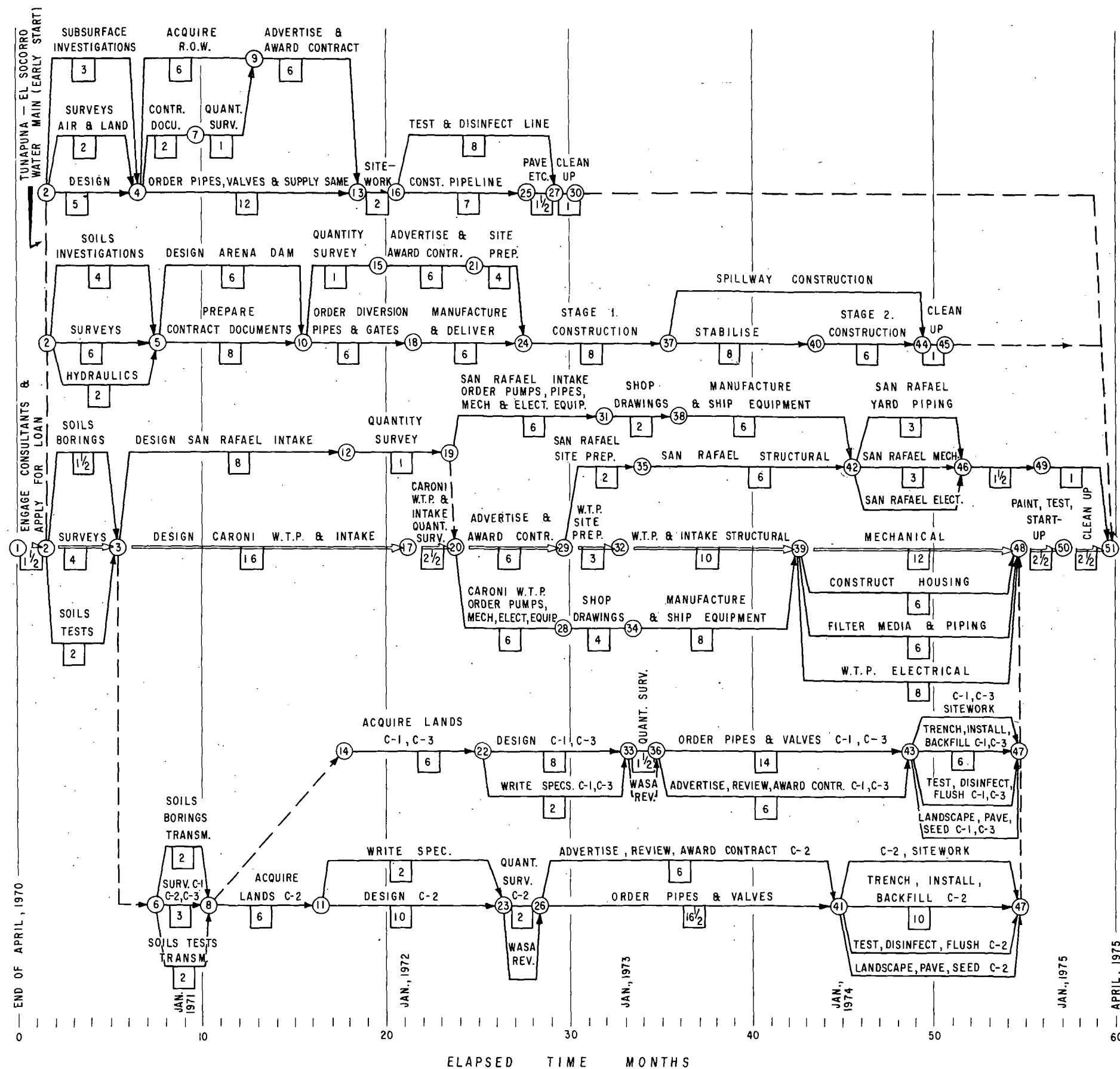


FIG. 41 NAVET PUMPED STORAGE (C.P. Schedule)



- C-1 { 36" Transmission Main from Caroni W.T.P. to Tunapuna.
24" Transmission Main from Tunapuna to Valsayn Sump.
- C-2 { 36" Transmission Main from Caroni W.T.P. to California.
36" Raw Water Main from San Rafael to Arena Dam.
- C-3 { 30" Transmission Main from California to Reservoir.
30" Transmission Main from San Fernando to Cross Station
24" Transmission Main from Cross Station to La Romain.

FIG. 42 FIRST STAGE
MAJOR PROJECTS (C.P. Schedule)

than would the other major projects and is not critical insofar as scheduling of the entire major works program is concerned. It is anticipated that WASA forces would start a canvass of the system in early 1970 completing it before 1971. In 1971 the metering contractor would start installation of meters completing the installation by 1973.

Timetable - Local Supply Projects

Priorities 1 through 59 inclusive in Table 44, comprise the local supply projects recommended for initial construction. WASA has started preliminary planning, design, or construction work on thirty-one (31) of these projects. The estimated total cost of the 59 projects is \$52,292,000. It is apparent that the WASA engineering and construction staff is not large enough to accomplish this amount of work in addition to their normal work load before 1975. Accordingly, it is recommended that WASA accomplish at least a portion of the engineering and construction for these projects by contract.

The schedule of development for the local supply projects is presented as a bar graph indicating design and construction time requirements for 18 groupings of projects which would be designed concurrently and could be constructed under a single contract or separate contracts or as concurrent force account projects. Table 46 shows the adopted grouping of projects and Figure 43 is the bar graph showing a design and construction schedule for each group. Planning, design and construction which WASA has completed or has in process has been taken into account in making time allotments for each group of projects. The design and construction schedule shows the minimum time in which the listed projects

Can be completed assuming that consultants with the requisite design experience are immediately available and that Trinidad and Tobago has enough qualified contractors who are not working to capacity to complete the work.

Table 46. Groupings of Initial Construction (Local Supply Projects)

Group	Priorities (Table 44)	Description
1	1, 2 & 3	Tacarigua boreholes, HLPS & mains, Success BPS & Arima BPS.
2	4, 5 & 6	Las Lomas, Carlsen Field & Fyzabad projects.
3	7, 8 & 9	Cap de Ville addition, Palo Seco boreholes & WTP, & Clarke Road boreholes.
4	10, 11 & 13	Granville boreholes, Rochard Douglas BPS, & Buen Intento BPS.
5	12 & 14	Rio Claro, Tableland & Palmiste Distribution Reservoir.
6	15, 17, 18 & 19	Forres Park main, Cleaver Road main, Gonzales main, & Toco improvements.
7	16, 26 & 31	California boreholes & WTP, Courland WTP, & Mayaro boreholes.
8	20, 22, 23 & 24	Bad Hill Res., Plymouth main, Greenhill main rehab., & Tobago PRV.
9	21, 25 & 28	Blanchisseuse system improvements, Four Roads main, & Diego Martin.
10	27, 29 & 30	Tobago high service improvements, Knaggs Hill PS, & Maraval PS.
11	32, 33, 34, 35, & 36	Mayaro, Piarcó & Cumuto mains, & Gasparillo & Manzanilla mains & Reservoir.
12	37, 38, 39 & 40	Los Armadillos boreholes & mains, & Guaico, Debe and St. John-Palmiste mains.
13	42, 43 & 44	Point Fortin, Penal & La Brea boreholes & treatment works.
14	41, 45, 46 & 47	Brieves Road BPS & mains, Flanagan Town Res., & Lady Chancellor & Knaggs Hill mains and Reservoir.
15	48, 49 & 50	St. Barbs' system, La Platte Village system, & Erin main.
16	51, 52 & 53	Rio Claro & Hindustan mains, & Moruga main & Res.
17	54, 55 & 56	Penal-Siparia main, Balandra water system, & Valsayn PS addition.
18	57, 58 & 59	Morvant Res. addition, Hololo addition & El Socorro interim PS addition.

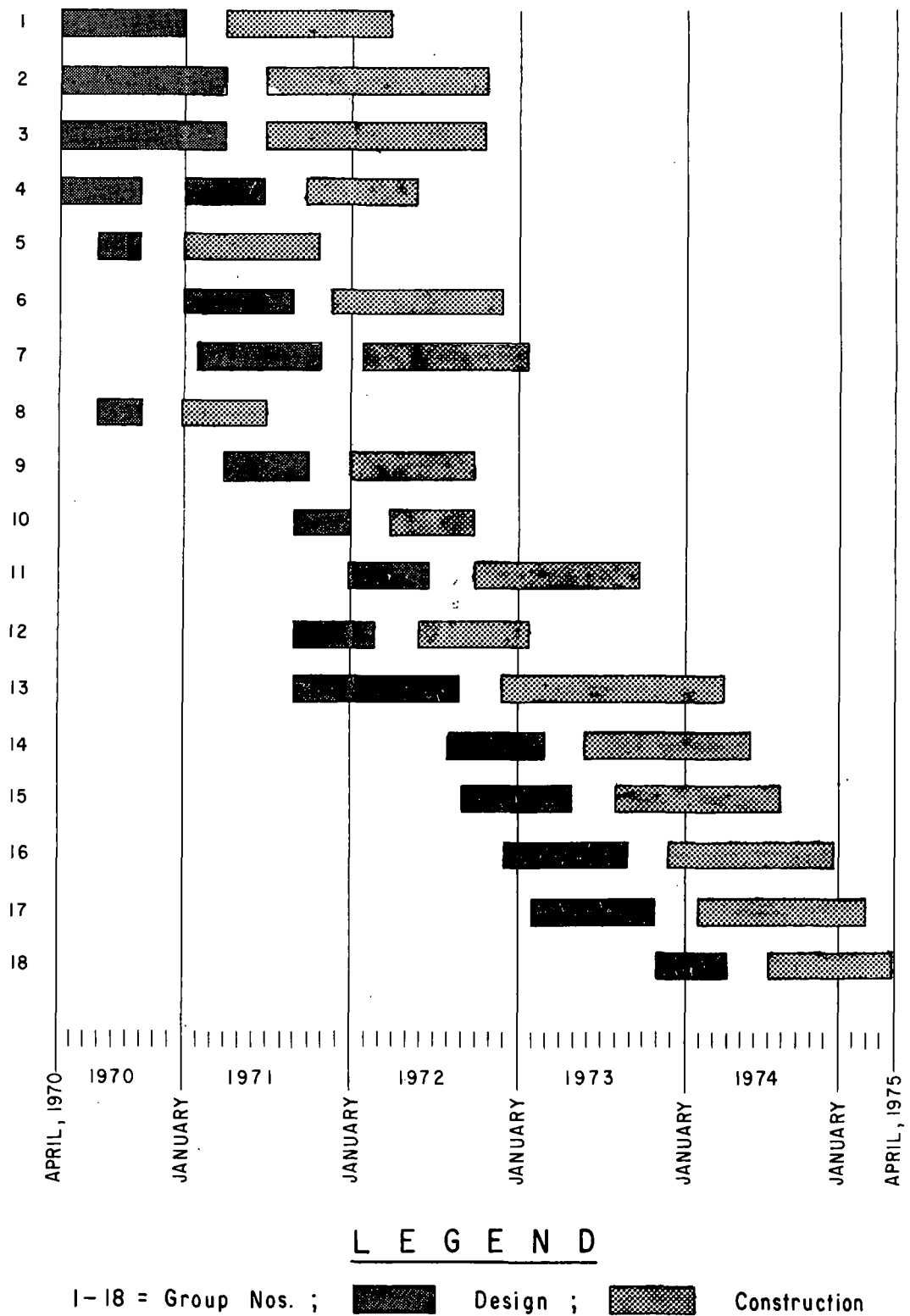


FIG. 43 DESIGN AND CONSTRUCTION SCHEDULE
LOCAL SUPPLY PROJECTS

Should financing or availability of qualified personnel make it impossible for WASA to complete the local supply projects recommended for initial construction prior to 1975, the usefulness of the major projects would not be changed. However, there would be areas of the country which would continue to suffer from low pressure or intermittent service upon completion of the major supply projects.

Costs

Cost summaries for the First Stage facilities recommended for initial construction are presented in this section. Detailed cost estimates are presented in Appendix H, and Appendix K contains the basis for cost estimates such as unit prices etc. All cost estimates are at January 1970 prices and ENR 1310, (Engineering News Record Construction Cost Index). The cost summaries list estimated foreign and local costs of construction, contingencies and engineering for each construction contract or group of projects. Table 47 is the cost summary for the major initial construction projects by contracts, and Table 48 the summary for initial construction local supply projects by groups. The total costs of the initial construction projects, major and local supply, are shown in Table 49.

In these estimates land costs are included in the construction costs. Engineering includes, acquisition and topographic surveys, sub-surface investigations and soils testing, design and preparation of contract documents, review of bids and recommendations upon award of contract, review of shop drawings, and monitoring of construction including full time inspection. A portion of the engineering cost is

shown as foreign cost because it is expected that local engineers cannot complete the designs and construction monitoring of the major and local supply projects in the initial construction period (by 1975) without bringing in foreign personnel.

Table 47. Cost Summary Major Projects - Initial Construction

Contract	\$1,000 TT											
	Construction			Contingencies			Engineering			Totals		
	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total
Metering	5,900	500	6,400	1,180	120	1,300	60	240	300	7,140	860	8,000
Navet Pumped Storage	1,470	933	2,403	294	234	528	559	594	1,153	2,323	1,761	4,084
Caroni Water Treatment Plant and intakes	7,650	4,312	11,962	1,530	1,078	2,608	1,366	1,428	2,794	10,546	6,818	17,364
Arena Dam and Reservoir	2,932	4,053	6,985	586	946	1,532	749	614	1,363	4,267	5,613	9,880
Early Start Transmission	950	408	1,358	190	102	292	108	155	263	1,248	665	1,913
Contract 1 Transmission	1,437	671	2,108	287	143	430	145	218	363	1,869	1,032	2,901
Contract 2 Transmission	5,005	2,256	7,261	1,001	564	1,565	394	486	880	6,400	3,306	9,706
Contract 3 Transmission	1,460	1,383	2,843	292	410	702	206	257	463	1,958	2,050	4,008
Land Acquisition Transmission	-	74	74	-	-	-	-	-	-	-	74	74
Totals	26,804	14,590	41,394	5,360	3,597	8,957	3,587	3,992	7,579	35,751	22,179	57,930

Table 48. Cost Summary Local Supply Projects - Initial Construction

Project	\$1,000 TT											
	Construction			Contingencies			Engineering			Totals		
	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total
Group 1	606	699	1,305	121	174	295	184	271	455	911	1,144	2,055
Group 2	4,036	4,182	8,218	808	1,042	1,850	1,048	1,297	2,345	5,892	6,521	12,413
Group 3	1,178	1,853	3,031	236	458	694	465	720	1,185	1,879	3,031	4,910
Group 4	238	245	483	44	58	102	101	108	209	383	411	794
Group 5	72	240	312	7	35	42	18	60	78	97	335	432
Group 6	256	517	773	82	117	199	152	183	335	490	817	1,307
Group 7	872	1,175	2,047	174	290	464	430	564	994	1,476	2,029	3,505
Group 8	115	209	324	20	40	60	39	60	99	174	309	483
Group 9	454	707	1,161	91	177	268	156	269	425	701	1,153	1,854
Group 10	211	216	427	41	55	96	68	92	160	320	363	683
Group 11	696	789	1,485	139	196	335	220	301	521	1,055	1,286	2,341
Group 12	606	651	1,257	121	163	284	186	279	465	913	1,093	2,006

Table 48 (Continued). Cost Summary Local Supply Projects - Initial Construction

Project	\$1,000 TT											
	Construction			Contingencies			Engineering			Totals		
	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total
Group 13	2,453	2,743	5,196	490	686	1,176	665	996	1,661	3,608	4,425	8,033
Group 14	307	601	908	59	143	202	139	209	348	505	953	1,458
Group 15	662	779	1,441	133	195	328	221	331	552	1,016	1,305	2,321
Group 16	1,540	1,189	2,729	308	300	608	394	501	895	2,242	1,990	4,232
Group 17	632	745	1,377	126	186	312	235	301	536	993	1,232	2,225
Group 18	233	448	681	43	97	140	93	140	233	369	685	1,054
Totals	15,167	17,988	33,155	3,043	4,412	7,455	4,814	6,682	11,496	23,024	29,082	52,106

Table 49. Cost Summary First Stage Initial Construction

Projects	\$1,000 TT		
	Foreign	Local	Total
Major projects	26,804	14,590	41,394
Local supply projects	15,167	17,988	33,155
Contingencies	8,403	8,009	16,412
Engineering	8,401	10,674	19,075
Totals	58,775	51,261	110,036

Final Construction

Major Projects. The final First Stage construction program increases the Caroni River developed dependable yield from 33 mgd to 42 mgd and increases transmission capacity to the south and west. Table 50 lists the recommended projects with the dates they should be started and completed.

Local Supply Projects. The final construction local supply projects in the First Stage of the recommended program are priorities 60 through 76 inclusive in Table 44, Recommended Development Program. The total estimated cost of these facilities is \$17,446,000 TT. It is recommended that these projects be constructed as a continuing program of development financed primarily from revenue. To complete the program by 1980 will require an annual capital expenditure of about \$3,490,000 TT in excess of the annual capital works expenditures for distribution system reinforcement and expansion, and such items as the expansion of the WASA transport fleet and the improvement of the communications system.

The priorities are based on projected demands throughout the country. Should population growth patterns differ from the projected patterns, the order of development may be altered or the rate of development adjusted, hastened or slowed, as is indicated. However, no project should be delayed beyond that time when the average day use reaches the dependable yield of the local supply or when pressure problems begin to occur during peak hours in the dry season. Table 51 lists the recommended projects in order of priority, with the cost of each.

Table 50. Major Projects First Stage Final Construction

Projects	Project dates		\$1,000 TT		
	Start	End	Foreign	Local	Total
Transmission mains					
California-San Fernando & La Romain to Point Fortin	1976	1978	4,199	2,251	6,450
BPS California (Q= 24 mgd h = 150feet)	1976	1978	360	240	600
BPS San Fernando (Q= 24 mgd h = 150feet)	1976	1978	360	240	600
Point Fortin 2 mg reservoir	1977	1978	120	300	420
San Fernando 5 mg reservoir	1977	1978	250	650	900
Construction totals			5,289	3,681	8,970
Land acquisition			-	36	36
Contingencies			1,060	930	1,990
Engineering			720	1,080	1,800
Grand Total			7,069	5,727	12,796

Table 51. Local Supply Projects First Stage Final Construction

Project	Cost \$1,000 TT (1)		
	Foreign	Local	Total
16-inch main Mt. Irvine to Lambeau new BPS and 1.0 mg Lambeau reservoir	684	1,052	1,736
12-inch main Lambeau reservoir to Scarborough	285	368	653
16-inch inlet main from Hollis main to St. Joseph reservoir; 20-inch outlet from St. Joseph reservoir to Hollis main	188	196	384
Aeration and chlorination facilities for the Tacarigua and the El Socorro interim HLPS	170	149	319
Boreholes at Mayaro; new HLPS, aeration and chlorination at 1.0 mgd; 0.5 mg reservoir at Pierreville; and 10-inch reinforcing main Pierreville to Maloney Road	865	1,110	1,975
0.5 mg reservoir at Penal and 10-inch main Penal to Debe	381	445	826
2.0 mg reservoir at Tunapuna and 16-inch connecting main to Eastern Main Road	291	553	844
0.5 mg addition to Arima reservoir	82	253	335
Intake and WTP addition at Richmond (0.4 mgd)	84	148	232
Intake, WTP and HLPS on Dropouche east of Sangre Grande (2.5 mgd) with 16-inch main to Sangre Grande	1,517	1,790	3,307
Boreholes at Grande Riviere, new 0.2 mg reservoir and 8-inch main boreholes to reservoir	308	498	806
16-inch main St. Marys to Fyzabad	479	385	864
16-inch main with BPS from Navet main at Malgre-toute to 1.0 mg reservoir at St. Croix	455	621	1,076
0.5 mg addition Siparia Gonzales St. reservoir and 12-inch main Siparia to Palo Seco	809	794	1,603

Table 51 (Continued). Local Supply Projects First Stage Final Construction.

Project	Cost \$1,000 TT (1)		
	Foreign	Local	Total
0.2 mg reservoir at Caratal	36	105	141
12-inch main Sangre Grande to Comparo reservoir	471	396	867
8-inch main Sangre Grande to Tamana Hill reservoir and 0.2 mg reservoir at Nestor	685	793	1,478
Totals final construction	7,790	9,656	17,446

1. Includes engineering and contingencies.

Table 52 presents a summary of the First Stage and Final Construction costs of the Major and the Local Supply projects:-

Table 52. Summary of Costs, First Stage and Final Construction

Projects	Cost \$ 1,000 TT (1)								
	Initial Construction			Final Construction			Total		
	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total
Major Projects	35,751	22,179	57,930	7,069	5,727	12,976	42,820	27,906	70,726
Local Supply Projects	23,210	29,082	52,292	7,790	9,656	17,446	31,000	38,738	69,738
Total:	58,961	51,261	110,222	14,859	15,383	30,242	73,820	66,644	140.464

PRELIMINARY DESIGN

General

This chapter presents design criteria and preliminary designs for the facilities included in the recommended first stage program and the alternative first stage program.

Design criteria and considerations for each type of facility are listed, and preliminary design drawings for each project are presented.

Design Criteria

Mains. All pipelines are designed for a maximum operating pressure of 150 psi and an external loading consistent with probable truck loads. The minimum recommended cast iron thickness class (USA Standards Institute USAS.21.6) is Class 22 for mains 4 inches to 14 inches inclusive.

The use of welded steel pipe conforming to AWWA C-201 and C-203 is recommended for mains 16 inches and over in diameter. All mains should be cement-lined and coated with coal-tar enamel single-wrap coating conforming to AWWA Standards C-203. The minimum recommended wall thickness for steel pipe is as indicated in Table 53 below.

Table 53 Minimum Recommended Wall Thickness for Steel Pipe

Wall thickness (inches)	Pipe diameter in inches
0.250	16 to 24
0.312	30 to 36
0.375	42 to 48
0.438	54
0.500	60
0.562	66

These recommended thicknesses conform to the BS 534 and AWWA C-201 and C-203 recommendations for minimum thickness.

Manual air release valves are provided at minor high points and automatic release valves at major high points. Minimum recommended pipe cover for pipes 4 to 16-inch diameter is $2\frac{1}{2}$ feet, and for 16- to 66-inch diameter, 3 feet.

Corrosion protection should be provided as indicated necessary by field soils conductivity surveys along the routes of the pipes. Where possible the protection should be of the sacrificial anode type for reliability and ease of maintenance.

Maximum recommended spacing of shut-off valves in large diameter transmission mains (16 inches and larger) is 3,000 feet. Small-main valve spacing should be less. Gate valves are recommended for 4-inch diameter to 14-inch diameter mains. For mains from 16-inch

diameter and larger, direct burial butterfly valves are recommended. The butterfly valve in sizes from 16 inches and larger operate more easily than do gate valves, initial cost is less, and maintenance costs are comparable to those for gate valves.

Pumping Stations. Recommended design criteria for pumping stations include the following:

1. Earthquake Design; For an intensity of 7.5 Richter
2. Super structures; Steel frame with corrugated metal roof and masonry walls.
3. Sub structures; Reinforced concrete
4. Pumps; Vertical turbine type for operation over a wide range of heads and single stage horizontal centrifugal type pumps for constant head or narrow range of head conditions.
5. Surge protection; Installation of controlled closing rate valves, automatic surge relief valves as indicated necessary in final design

Water Treatment Plant Criteria are as follows:

1. Chemical mixing;
 - Number of basins - 2
 - Detention time - 20 seconds
 - Type mixing - mechanical agitation and inlet turbulence
2. Flocculation;
 - Type - Mechanical (Walking beam)
 - Detention time 40 minutes

3. Sedimentation; Type - Horizontal flow
- Detention time - 4 hours
- Surface loading - *500 Gallons/day/s.f.
 (overflow rate)
- Sludge removal - Mechanical on lower deck
 of multideck units and
 manual on all others
- Weir loadings - 16,667 gallons/day/lin.ft

4. Chemical storage; Storage capacity for 6
 months at average demand
 for all chemicals

5. Filters; Type - Rapid sand
- Rate - 3-1/3 gallons per minute per square foot

Media -	<u>Effective size</u>	<u>Uniformity coefficient</u>
Coal or acti- vated carbon	0.9 to 1.0 mm	1.35
Sand	0.5 to 0.6 mm	1.35 to 1.5

Wash - Air and water maximum expansion 50 percent

Buildings - Same as for pumping stations

6. Dams; Design considerations and criteria for dams are
 concerned primarily with the safety of the
 structure under conditions which may reasonably
 be expected to occur. They are:

1. Earthquake conditions - 7.5 Richter
2. Stability under drawdown conditions
3. Spillway - capacity for 100 year storm
4. Foundation - ability to support the dam and low permeability.

*Imperial

Preliminary Design - Recommended Program

Navet Project. Figures 44, 45, 46, 47 and 48 depict the principal features of the Navet Pumped Storage project. The pumping station is designed to deliver 40 mgd against a head of 93 feet. Four 10 mgd and two 5 mgd pumps are provided to allow a wide range of flexibility in pumping rates between 5 and 40 mgd. The raw water main inlet to Navet reservoir is designed to eliminate stratification by promoting lake circulation while pumping to the reservoir is going on. This should reduce the need to scour the reservoir saving stored water.

Arena Dam and Reservoir. The principal features of this design are shown in the Chapter DEVELOPMENT OF POTENTIAL SOURCES, figures 16, 17, 18, 19, 20 and 21. The Arena reservoir area - capacity curve, figure 49, is presented in this section. A drawing showing land aquisition and the results of tests upon soils samples taken at the reservoir site are included in Appendix F.

San Rafael Intake. The San Rafael intake and pumping stations are designed for a maximum pumping rate of 20 mgd. The pumping head is 167 feet. Figures 50, 51 and 52 show the major features of this design. The degritter is sized to remove suspended material with 0.05 mm diameter and greater, to reduce the danger of pump impeller erosion.

Caroni Water Treatment Plant and Intake. The Caroni plant is located at Kelly Village on the south bank of the river, see Figure 16 in the Chapter "DEVELOPMENT OF POTENTIAL SOURCES". Since there are

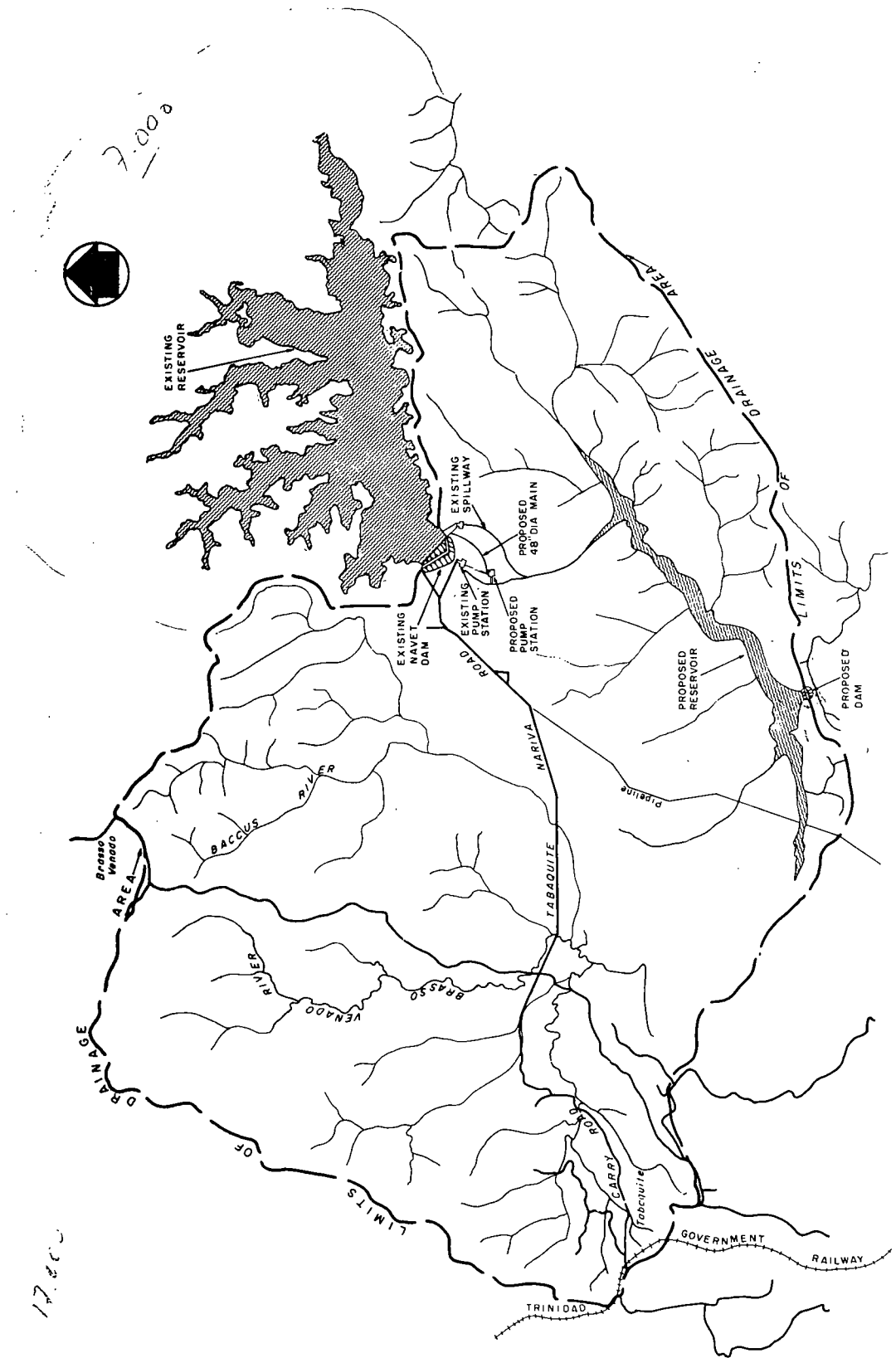


FIG.44 LOCATION PLAN
NAVET PUMPED STORAGE RESERVOIR

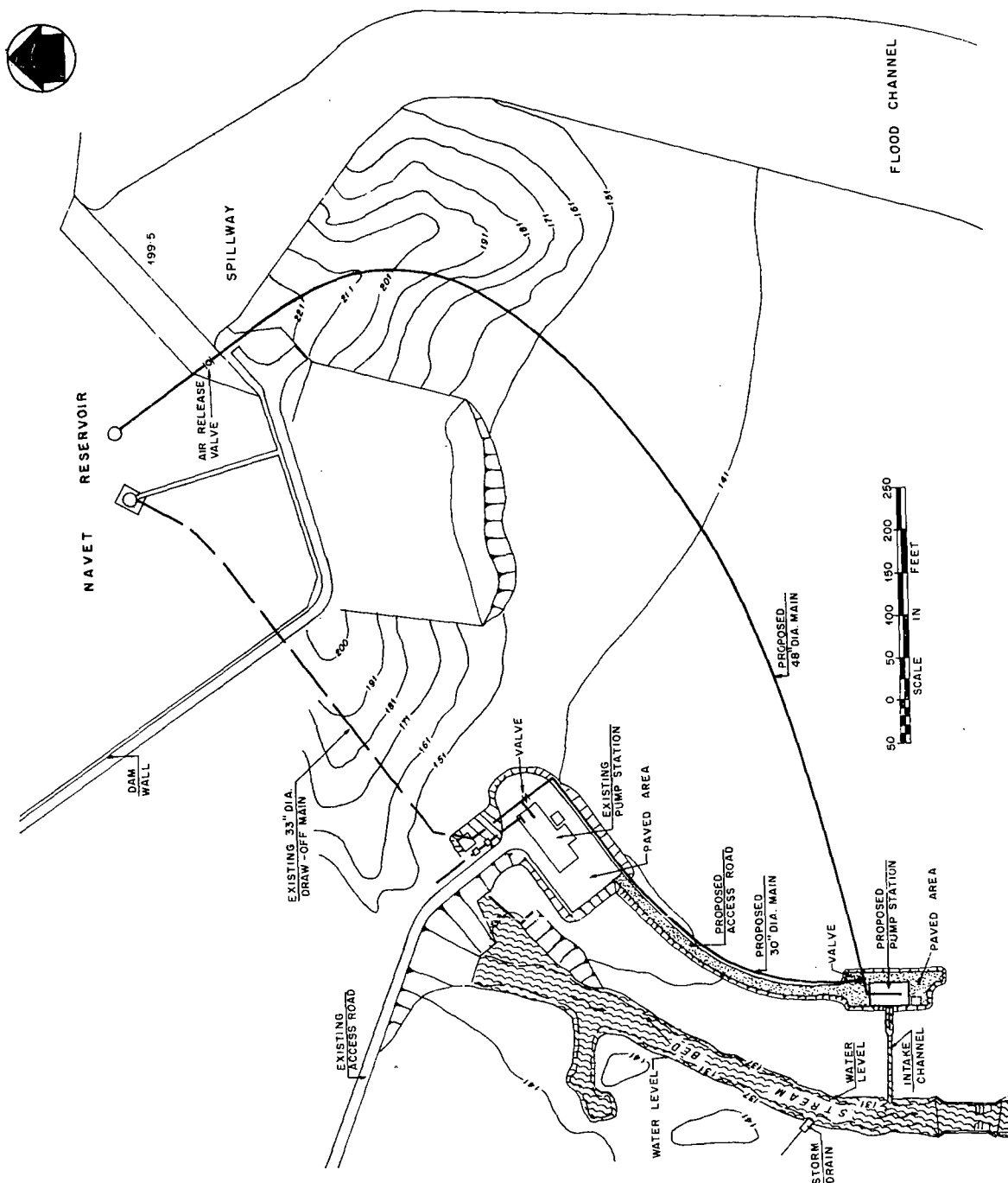


FIG. 45 LOCATION PLAN
PROPOSED NAVET PUMP STATION & INTAKE

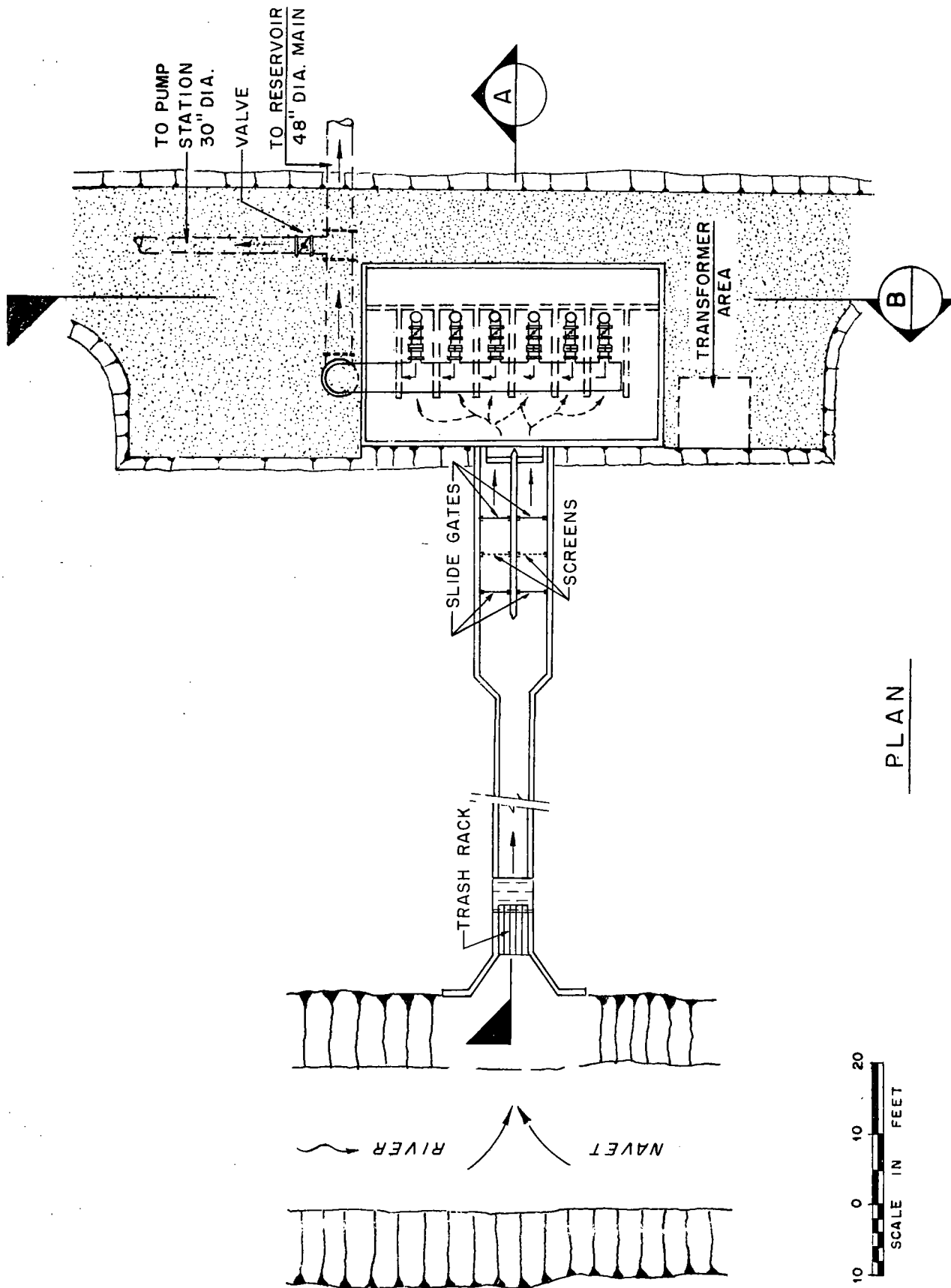
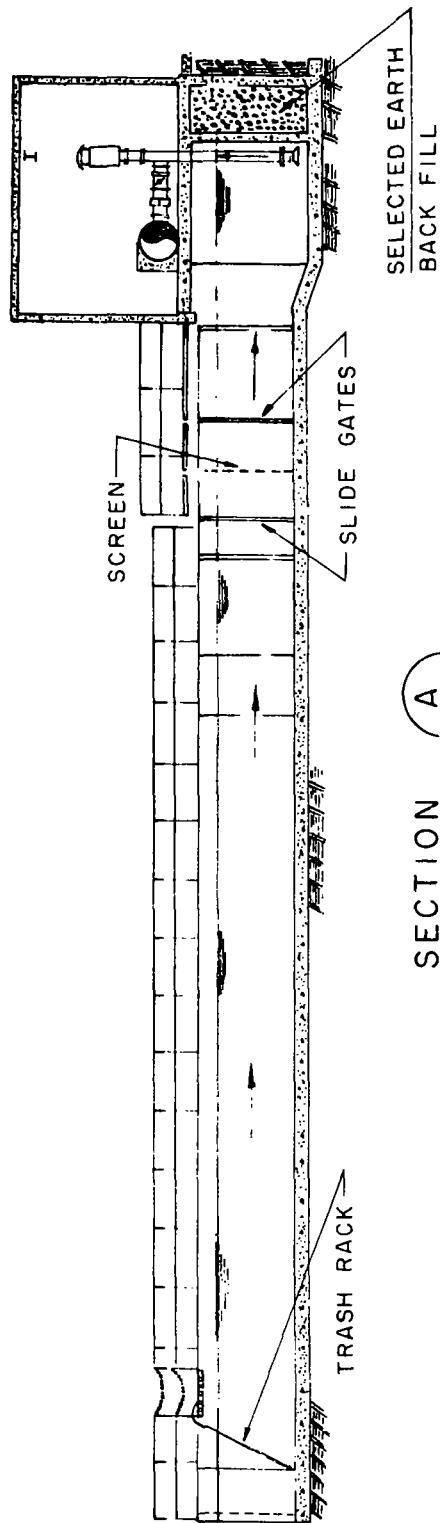
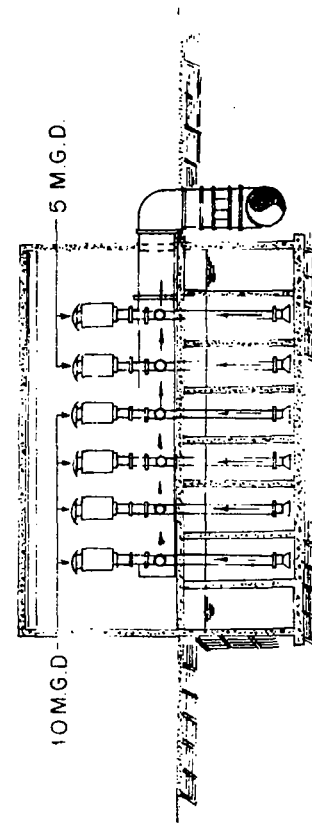


FIG.46 PROPOSED NAVET PUMP STATION



SECTION A



SECTION B

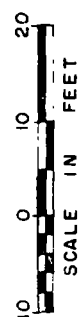


FIG. 47 SECTIONS NAVET INTAKE & PUMP STATION

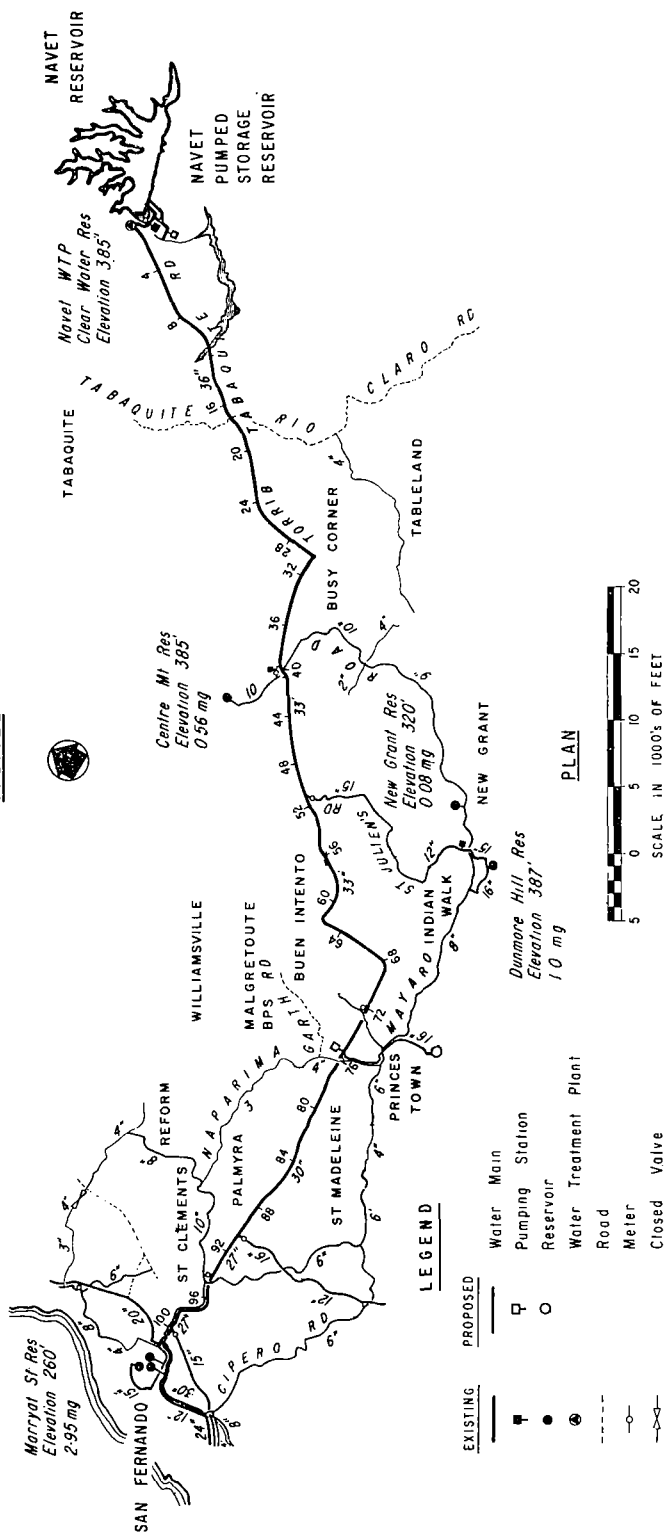
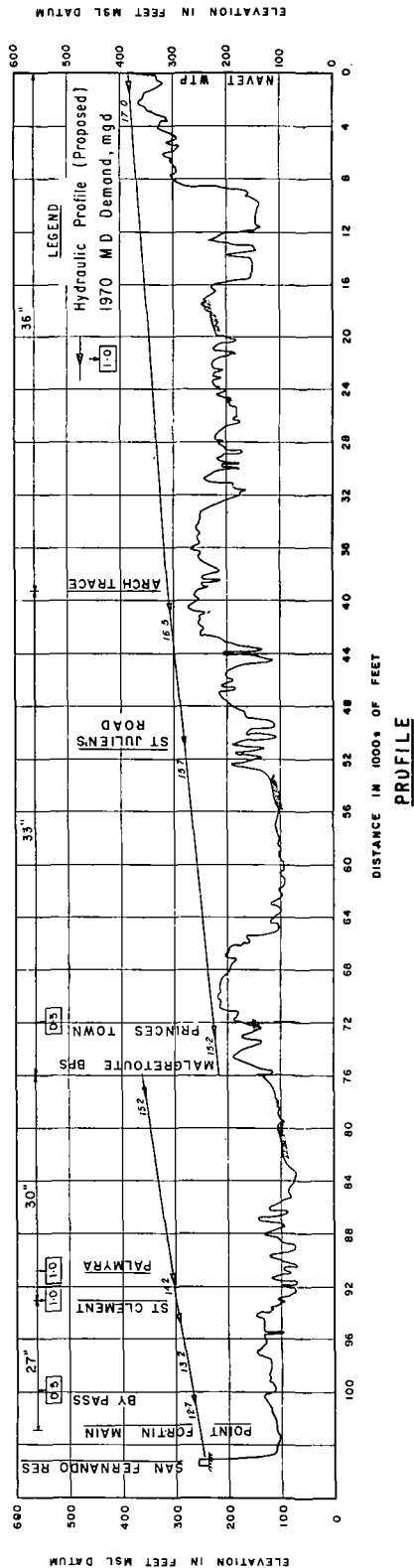
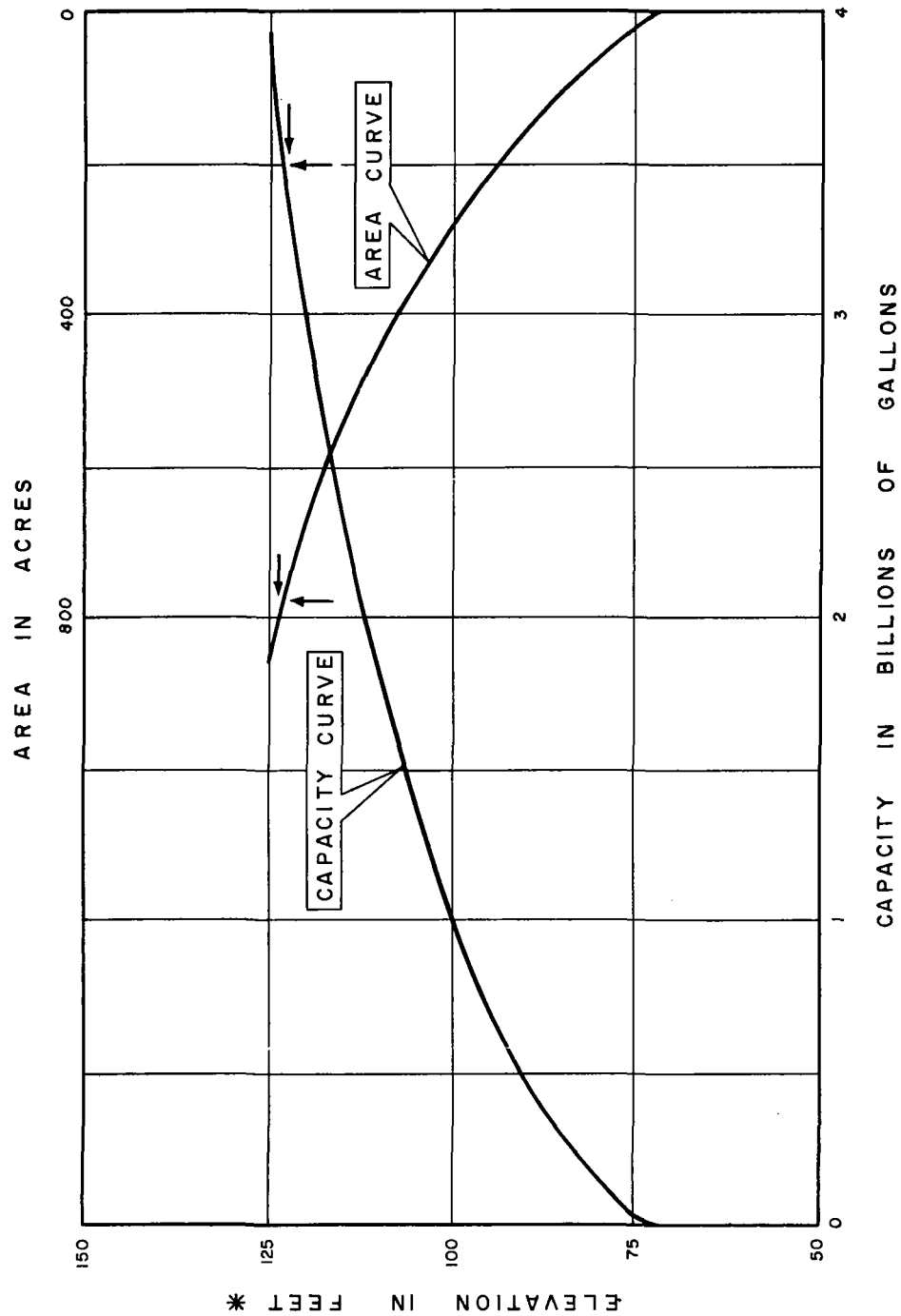


FIG 48 NAVET TRANSMISSION MAIN



* Mean Sea Level Datum

FIG. 49 AREA - CAPACITY CURVES
ARENA RESERVOIR

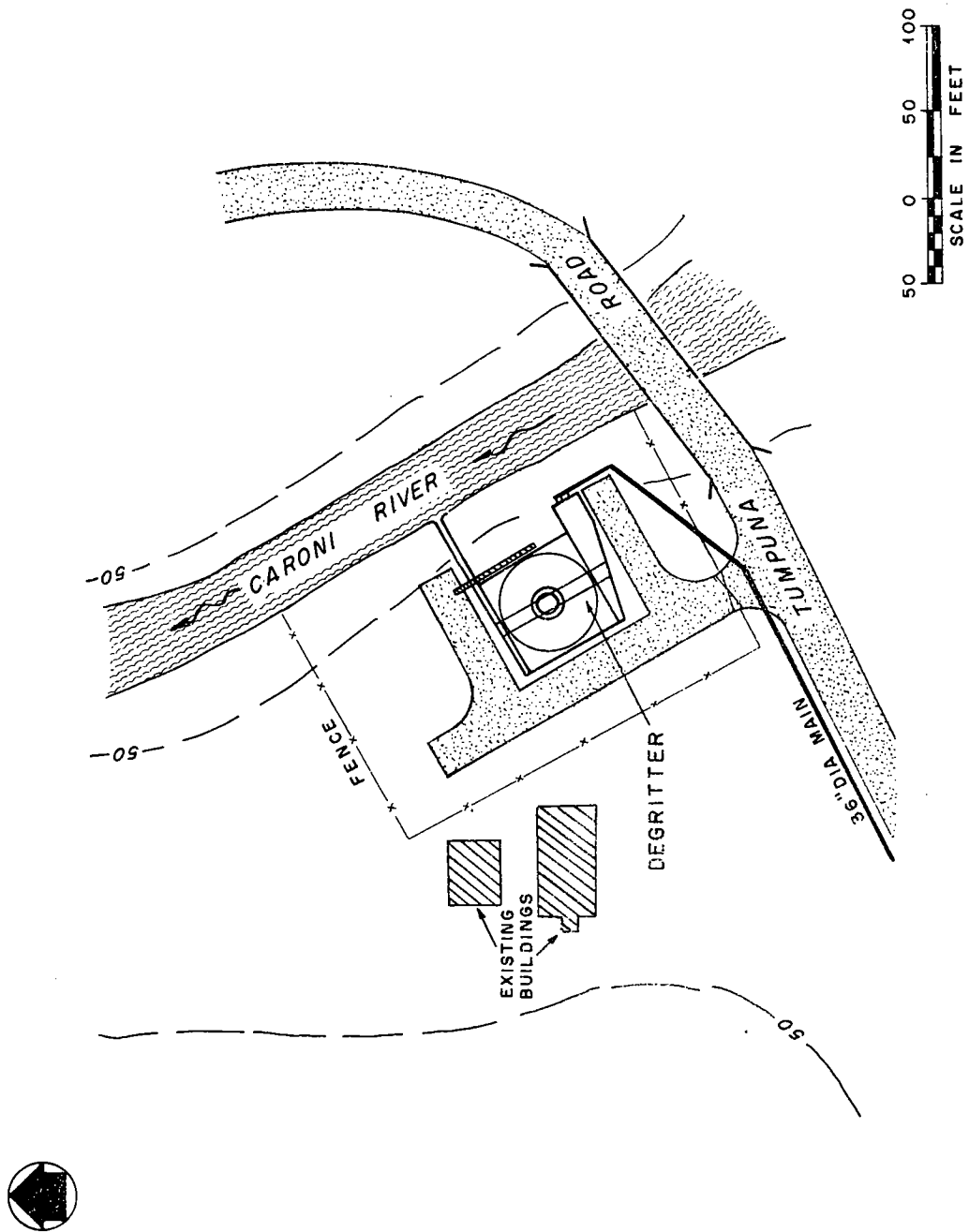


FIG. 50 SITE PLAN SAN RAFAEL INTAKE

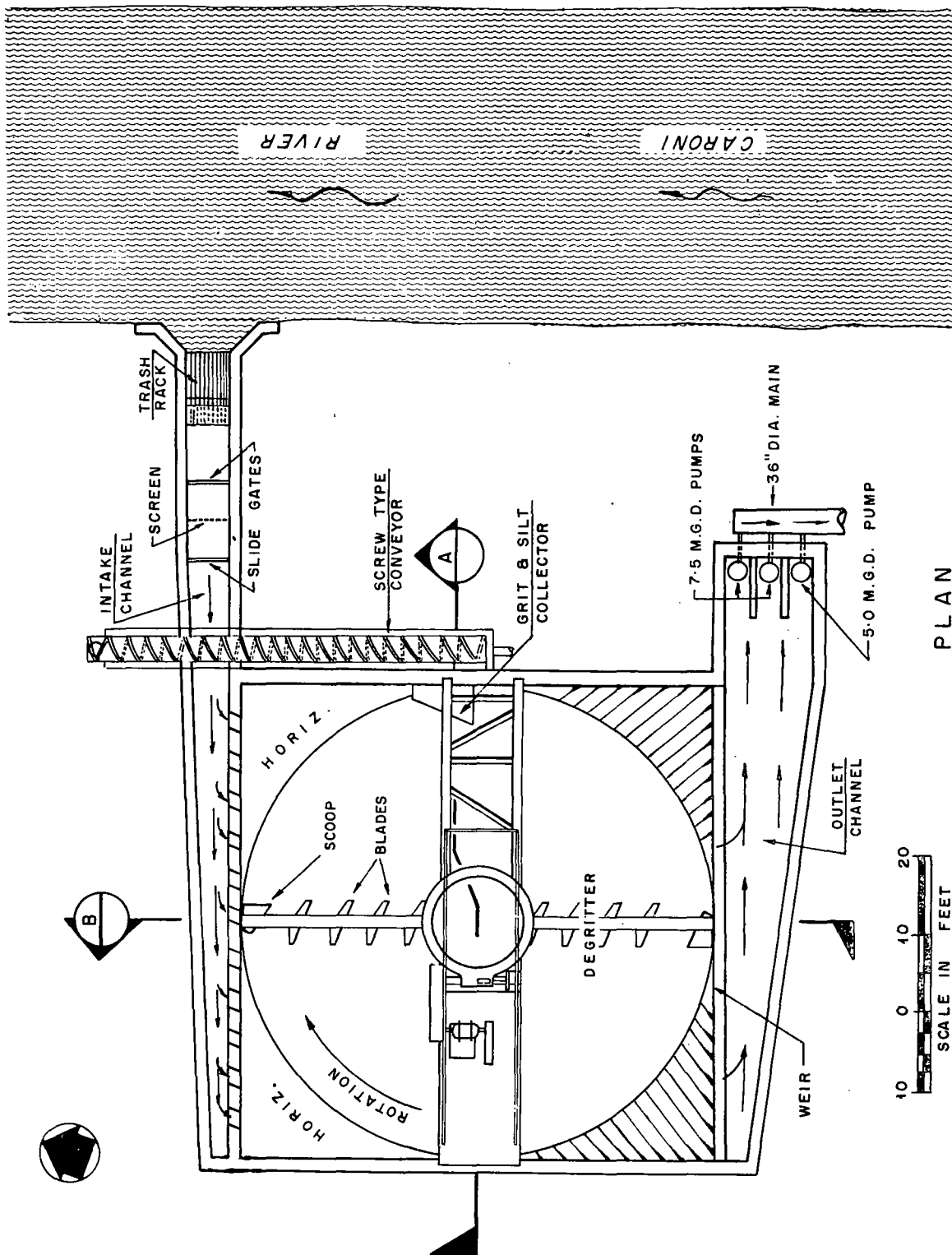


FIG. 51 DETAIL PLAN SAN RAFAEL INTAKE

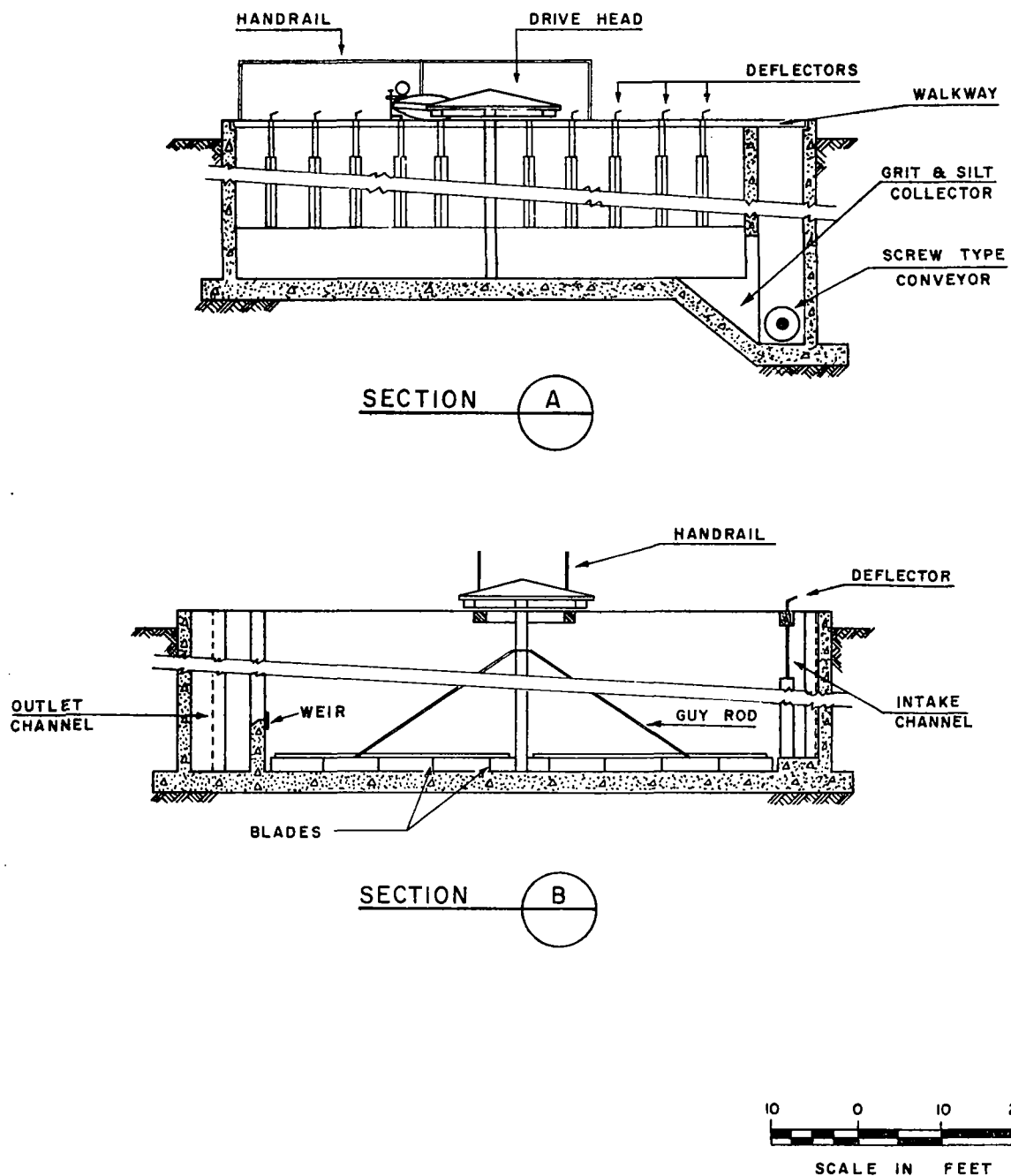


FIG. 52 SECTIONS — SAN RAFAEL DEGRITTER

chances of water contamination by oil spills, agricultural chemicals or industrial wastes, and taste and odor problems due to algae, blooms may occur, thus the dual filter media in this plant is granular activated carbon and silica sand. Provision is made for regeneration of the activated carbon utilizing either oil or natural gas as a fuel depending upon which proves more economical in final design studies.

Figures 53, 54 and 55 show the principal design features of the treatment plant and the high-lift pumping station. The intake degritter and low-lift pumping station design are similar to the San Rafael facility.

The low-lift pumps are sized to supply 42 mgd to the plant at a lift of 40 feet. There are three 18 mgd pumps and two 6 mgd pumps providing one spare for each size.

The high-lift station is designed to deliver water to both the San Fernando area and the Port of Spain area. Accordingly, there are two sets of pumps with a split header and two discharge mains. The maximum pumping rates are 28 mgd to San Fernando and 18 mgd to Port of Spain. The pumping heads at the above rate are 250 feet to San Fernando and 110 feet to Port of Spain. Initially, two of the 14 mgd, 250-foot head pumps would be installed. When the Chaguanas booster pumping station is added, a third 14 mgd pump would be installed. Initially, three 9 mgd pumps at 110-foot head would be provided to pump water to Port of Spain. After the Moruga supply is constructed and the demand in the south is supplied from this source, one of the 14 mgd, 250-foot head pumps and one of the 9 mgd, 110-foot head pumps would be replaced with larger pumps to increase the pumpage rate to the Port of Spain area to about 30 mgd.

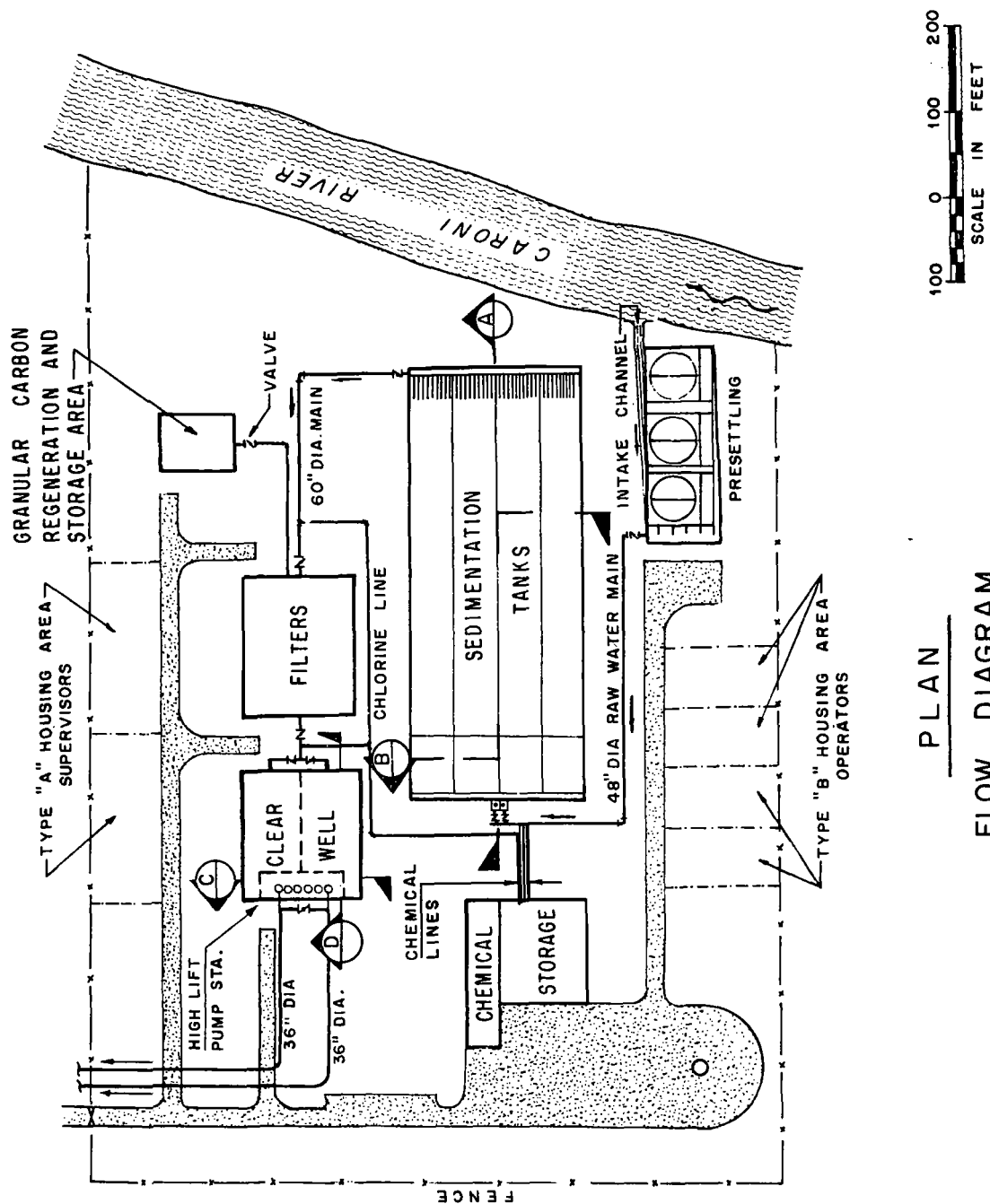
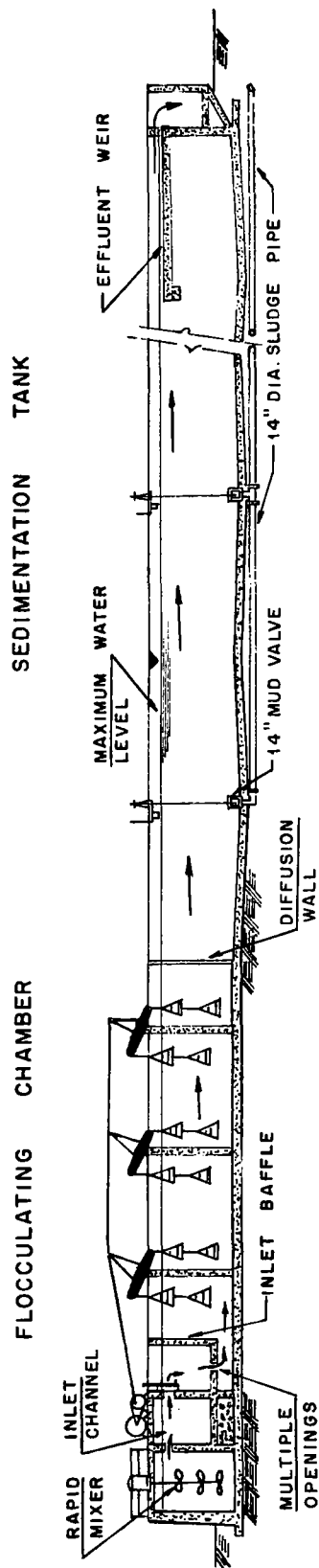
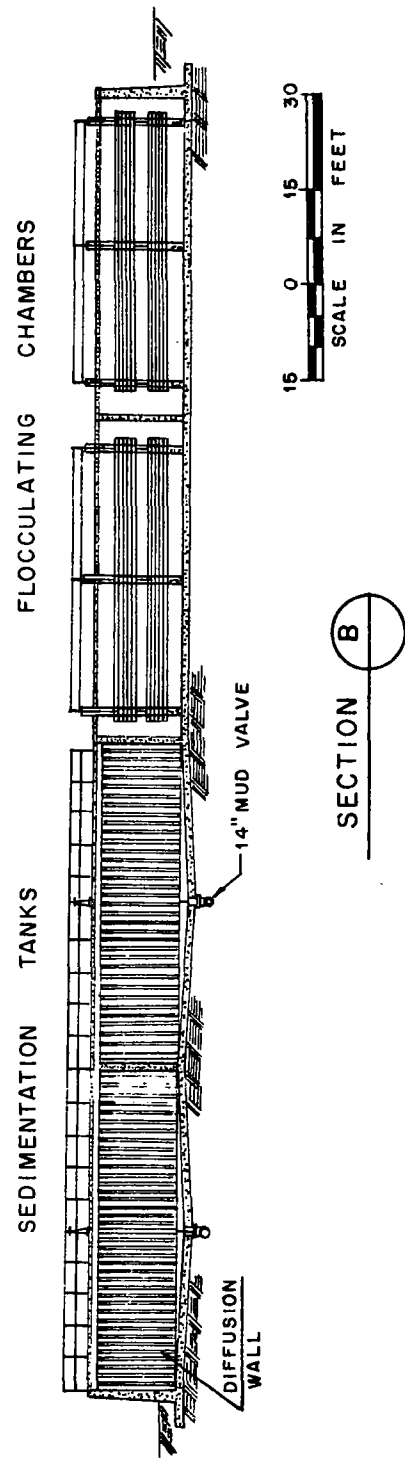


FIG. 53 CARONI - ARENA TREATMENT PLANT



SECTION A



SECTION B



FIG. 54 SECTIONS CARONI — ARENA TREATMENT PLANT

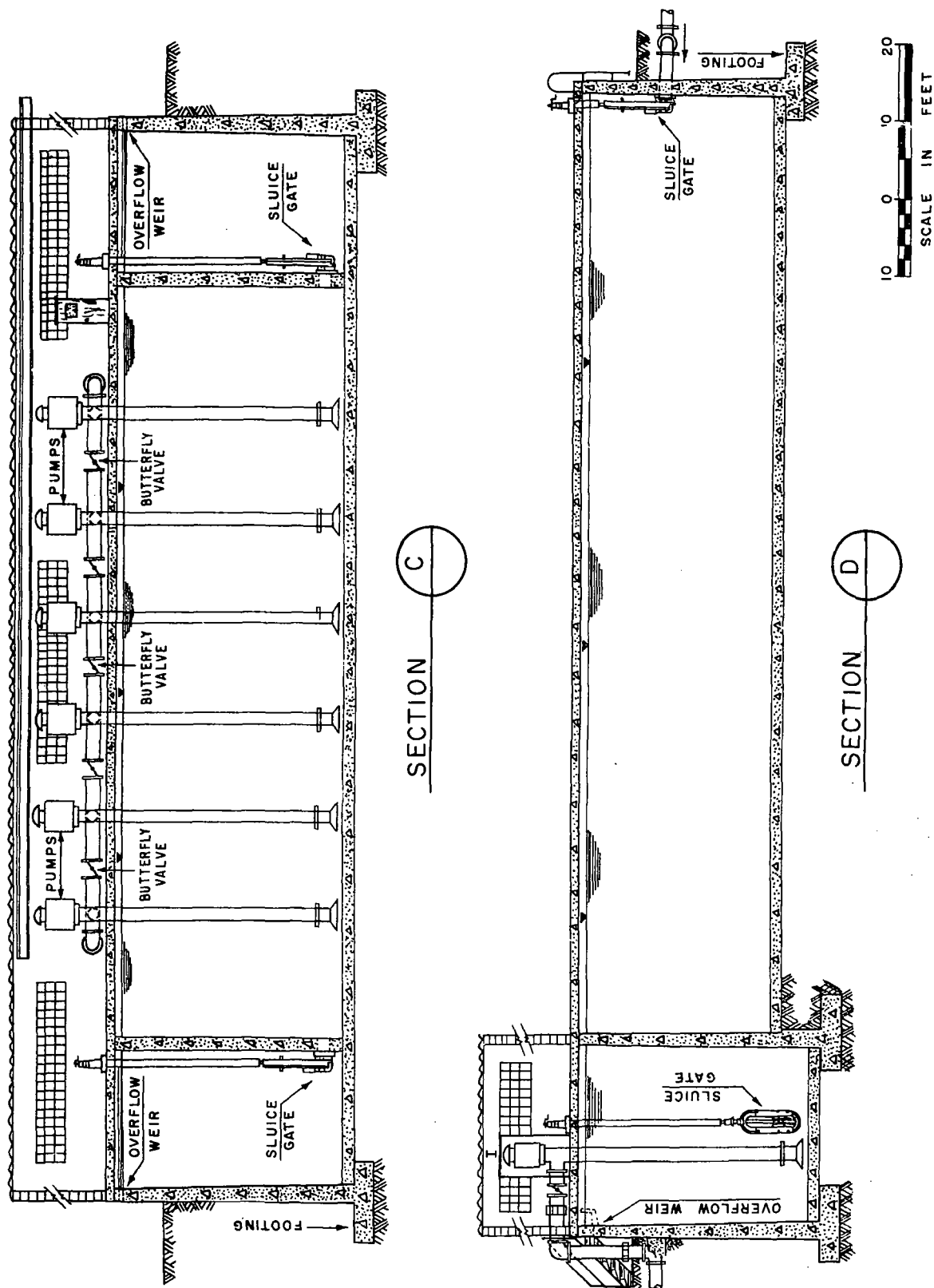


FIG. 55 CARONI — ARENA
HIGH LIFT PUMP STATION & CLEAR WELL

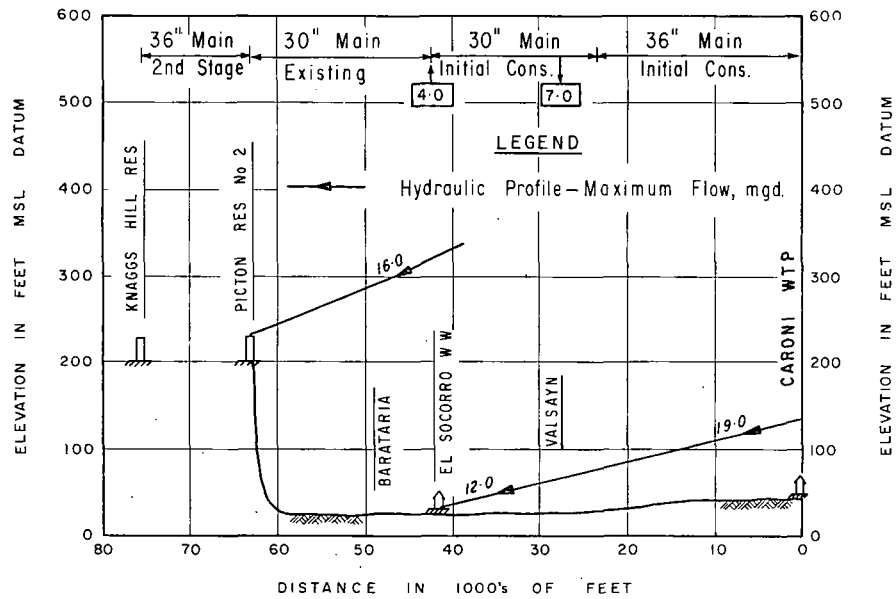
Transmission Mains. The first stage transmission main locations and profiles are shown on Figures 56, 57 and 58. They show the route of each pipeline, its profile and the head characteristics under maximum first stage flow conditions.

Preliminary Design-Alternative Program

Dropouche Dam and Reservoir. The major features of the Dropouche dam and reservoir are shown on Figures 23, 24 and 25 in the Chapter DEVELOPMENT OF POTENTIAL SOURCES. The results of subsurface investigations, surveys and soils tests carried out at the site are contained in Appendices F and J. The Area-Capacity curve for the reservoir, Figure 59 is presented herein.

Dropouche Low-Lift Pumping Station. The Dropouche low-lift pumping station is located immediately downstream from the toe of the proposed dam on the west bank of the river. The wide range of possible water levels make it necessary to install two sets of pumps; one set for operation when the reservoir level is between elevations 190 and 260, and the other when the level is between elevations 260 and 350. The principal features of design are shown on Figures 60, 61, 62, 63 and 64.

Dropouche Water Treatment Plant. This plant is located on a hill above the low-lift pumping station and the proposed reservoir. The principal features of the plant design are shown on Figures 65, 66 and 67. The settling basins are two-deck horizontal flow units as the available site is too small for single-deck units. The lower deck would be equipped with sludge removal rakes and automatic sludge draw-off valves. The upper deck would be cleaned manually by partially draining the basin and



PROFILE

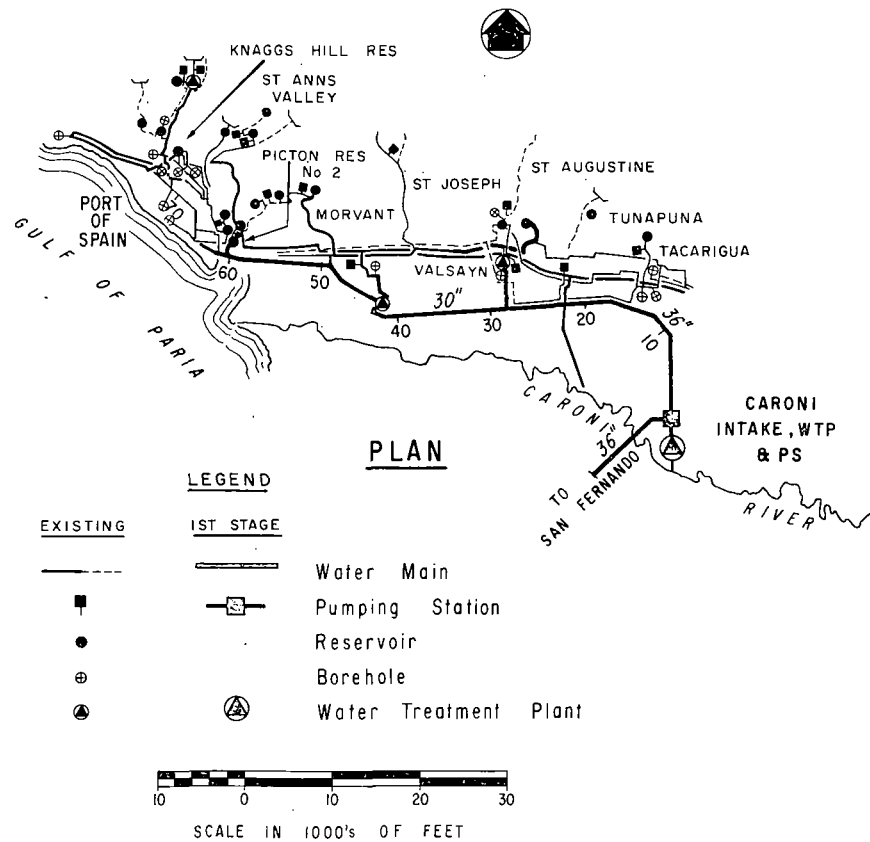


FIG. 56 CARONI TRANSMISSION MAIN
CARONI TO PORT OF SPAIN

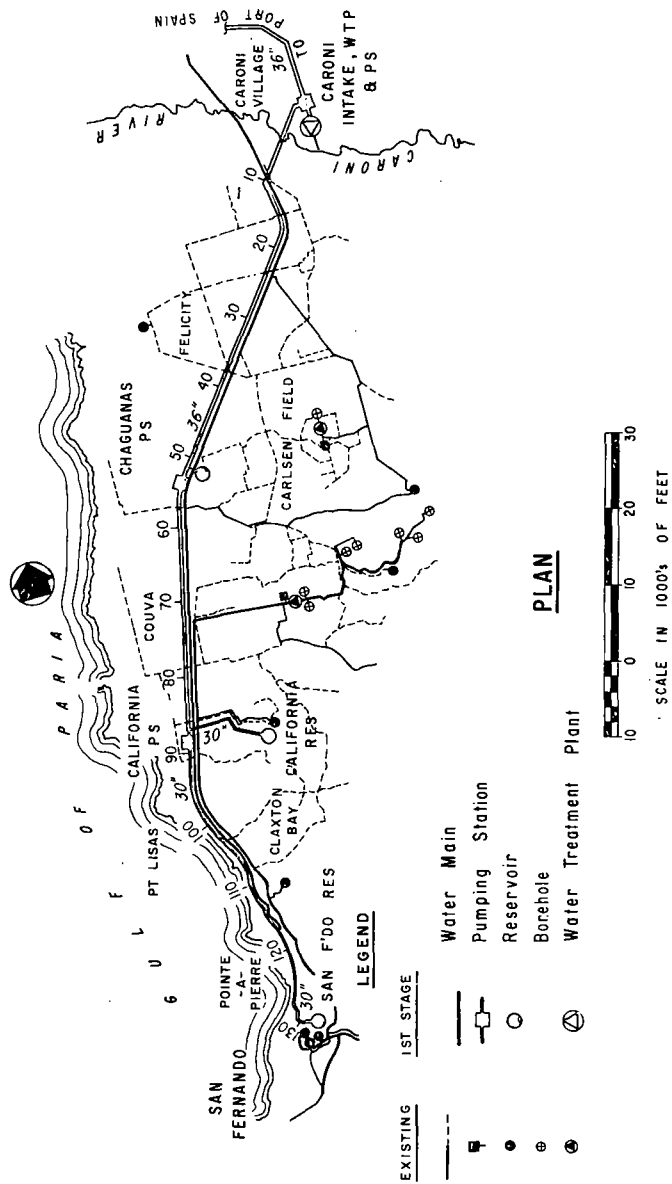
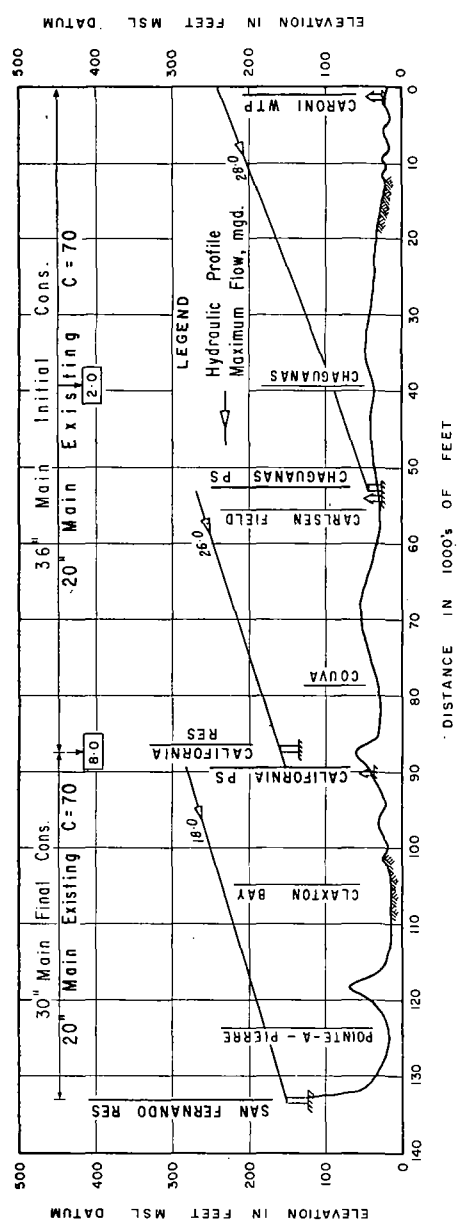
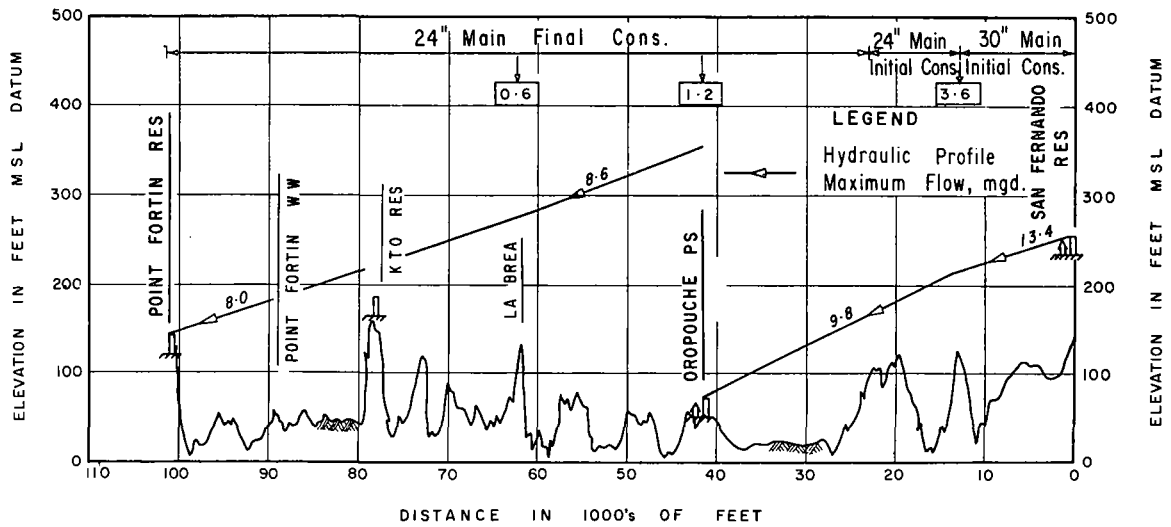
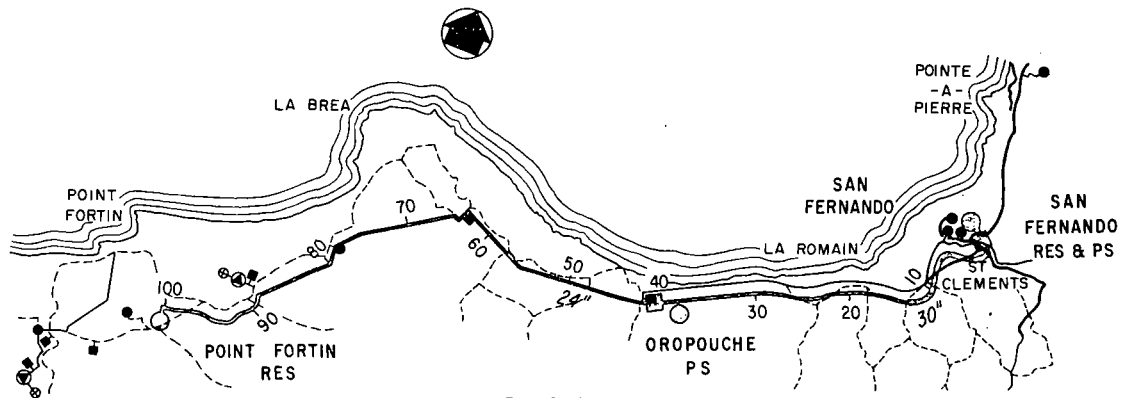


FIG.57 CARONI TRANSMISSION MAIN
CARONI TO SAN FERNANDO



PROFILE



PLAN

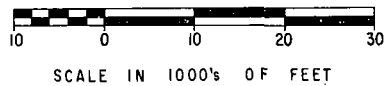
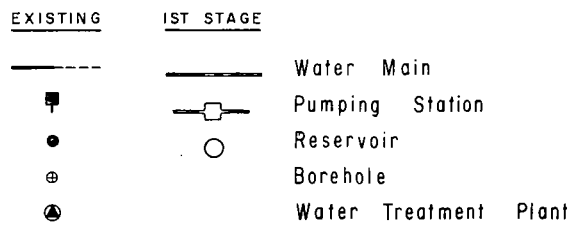
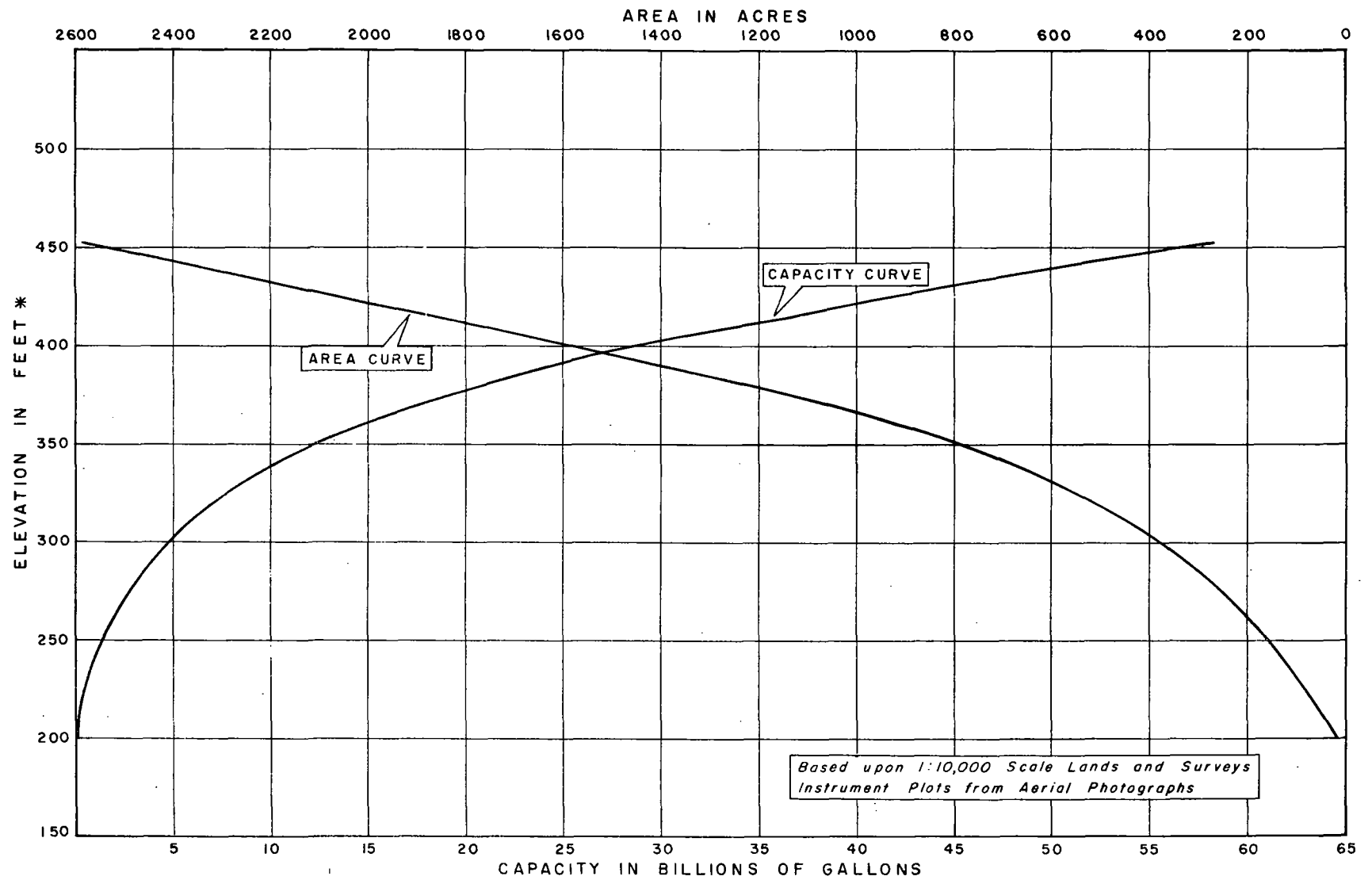


FIG.58 POINT FORTIN TRANSMISSION MAIN

FIG. 59 AREA - CAPACITY CURVES
ORPOUCHE RESERVOIR

* Mean Sea Level Datum

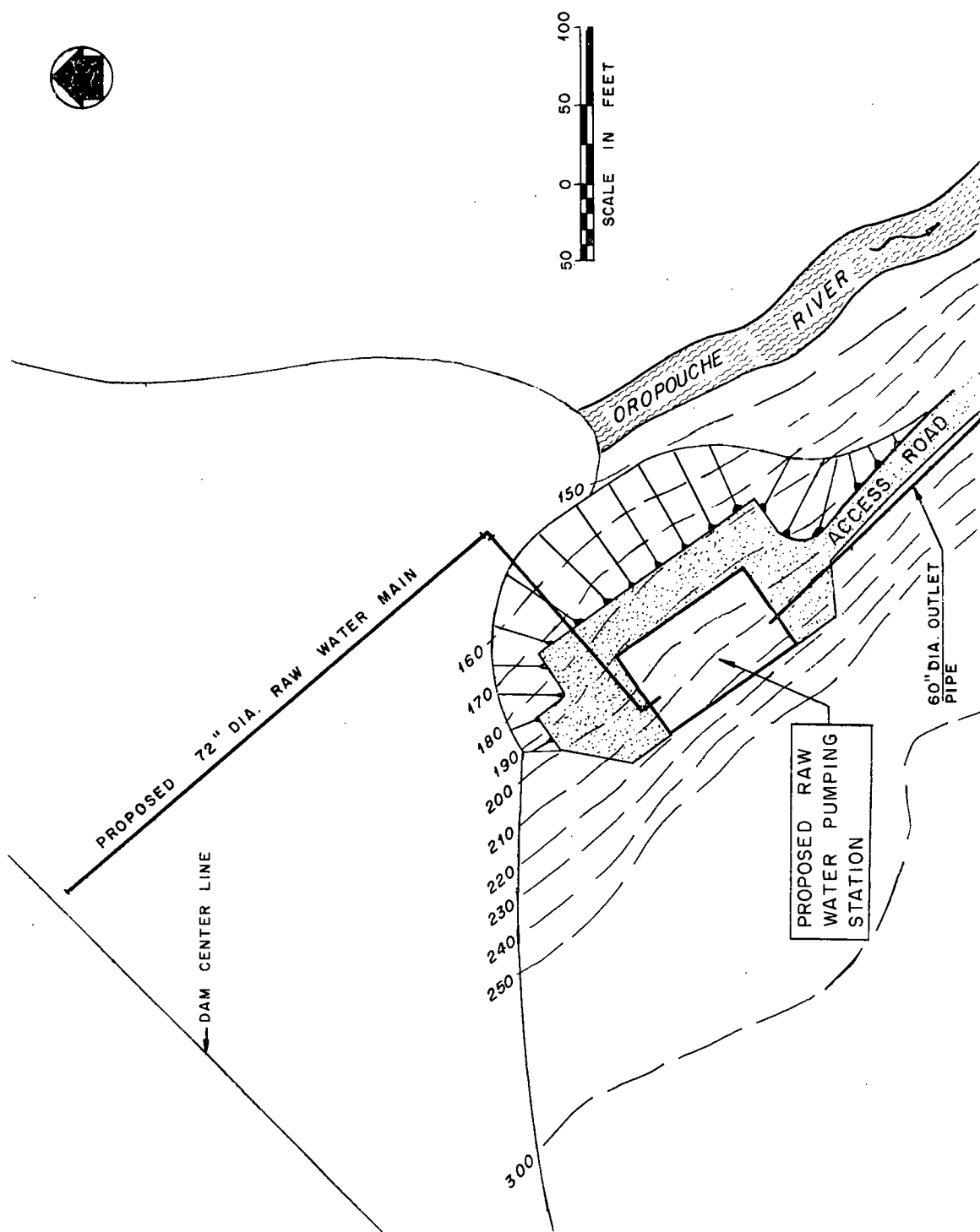


FIG. 60 SITE PLAN
ORPOUCHE RAW WATER PUMP STATION

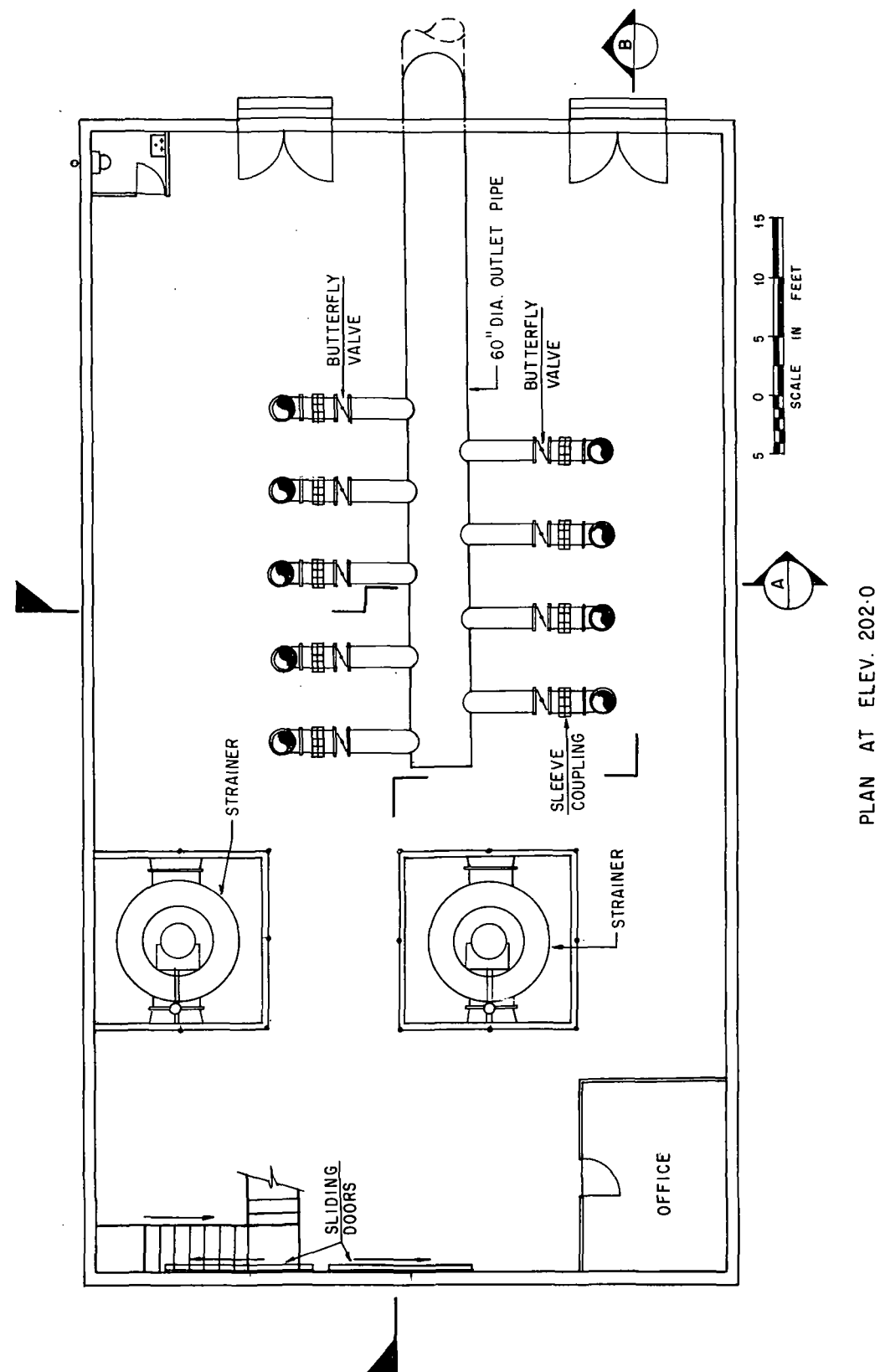


FIG. 61 PLAN AT ELEV. 202.0
OROPOUCHE RAW WATER PUMP STATION

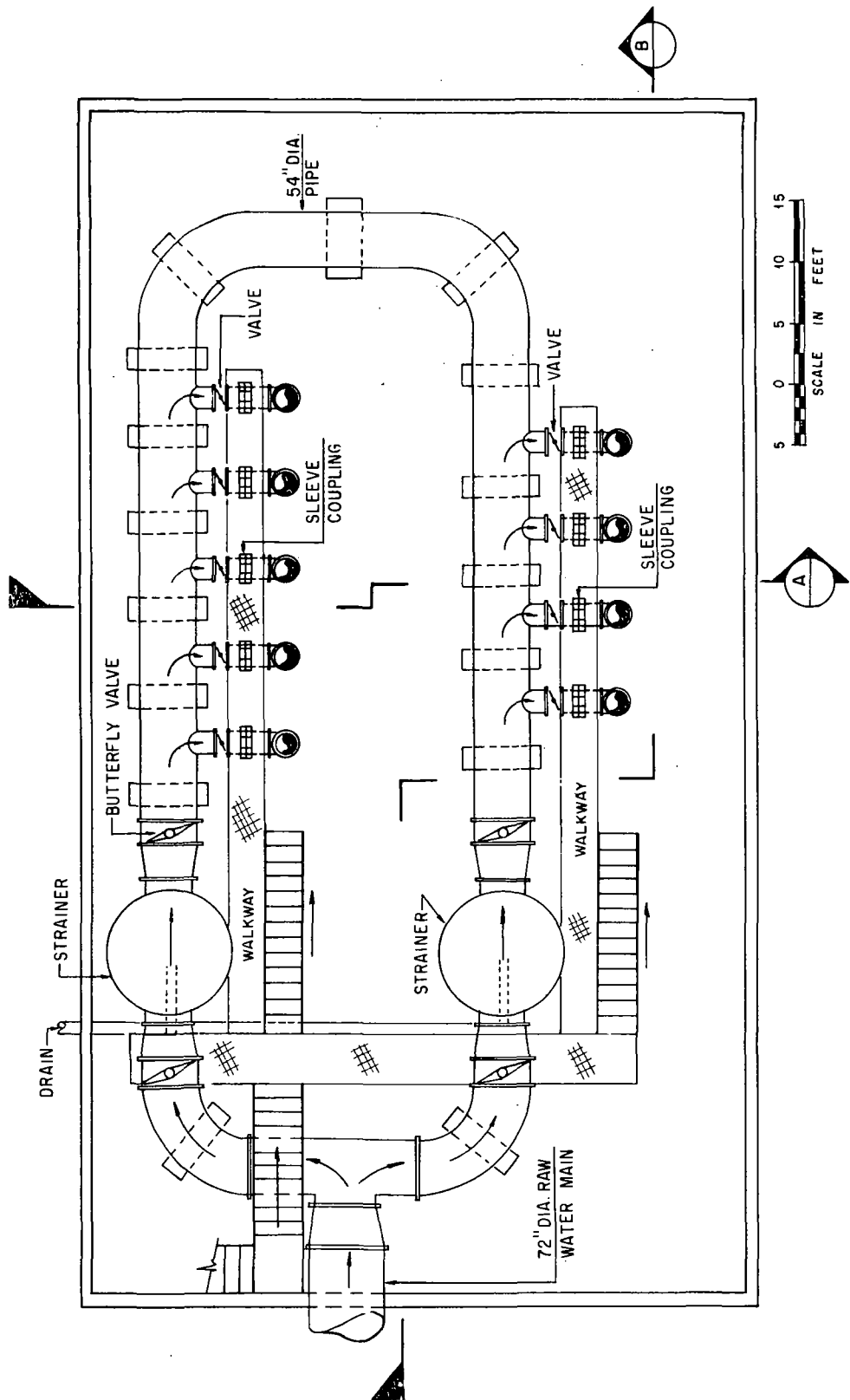


FIG.62 PLAN AT ELEV. 176.0
OROPOUCHE RAW WATER PUMP STATION

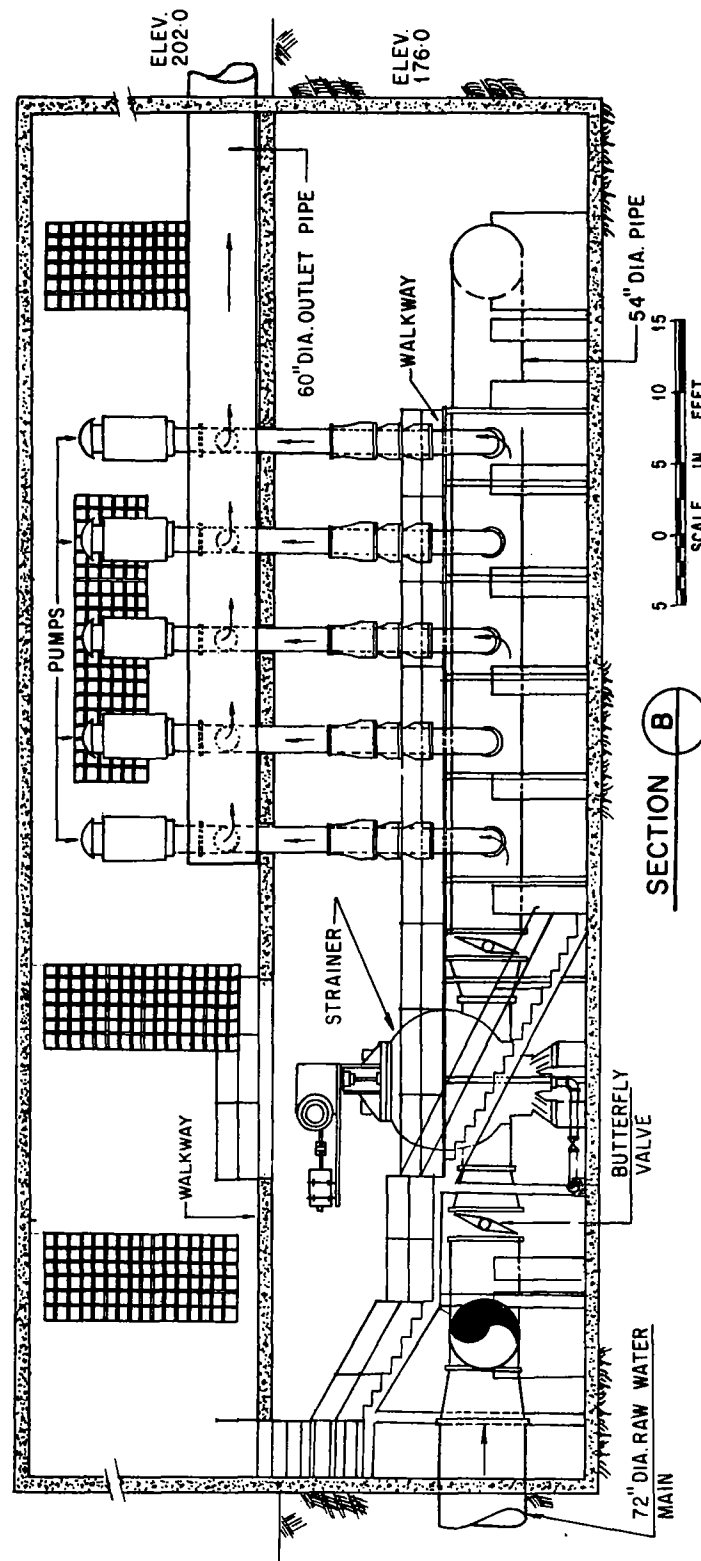


FIG. 63 SECTION OROPOUCHE RAW WATER PUMP STATION

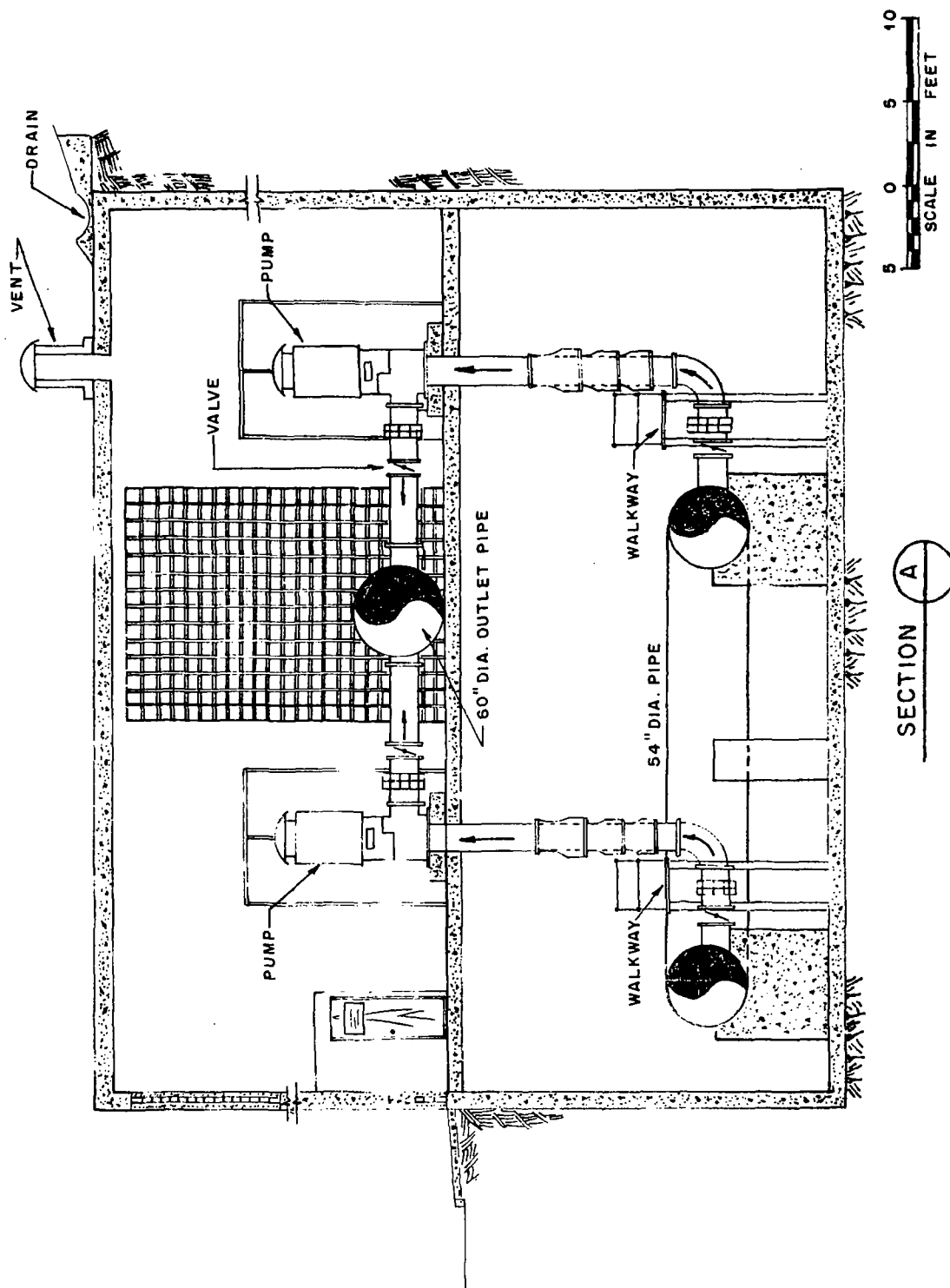


FIG. 64 SECTION - OROPOUCHE RAW WATER PUMP STATION

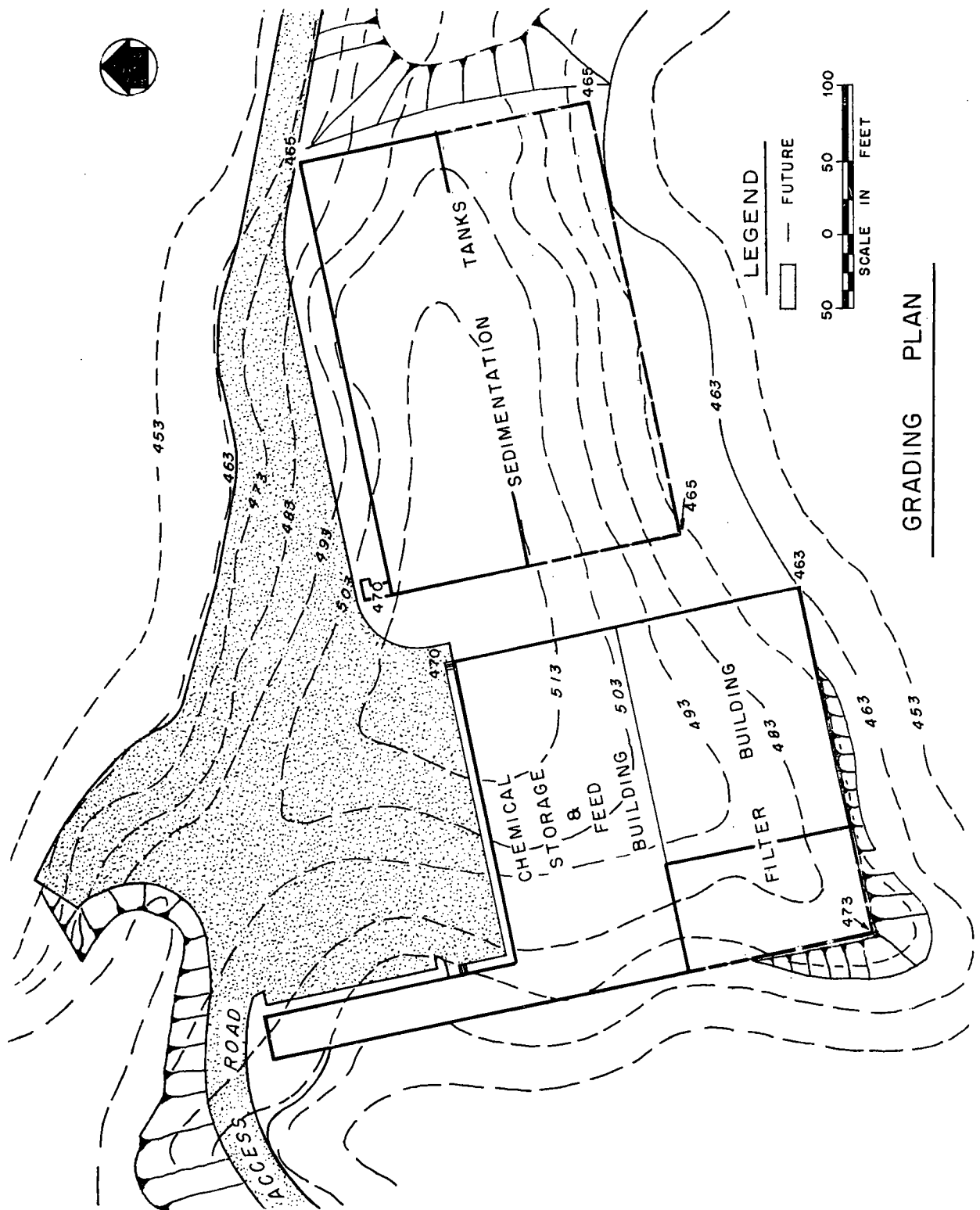


FIG. 65 OROPOUCHE TREATMENT PLANT

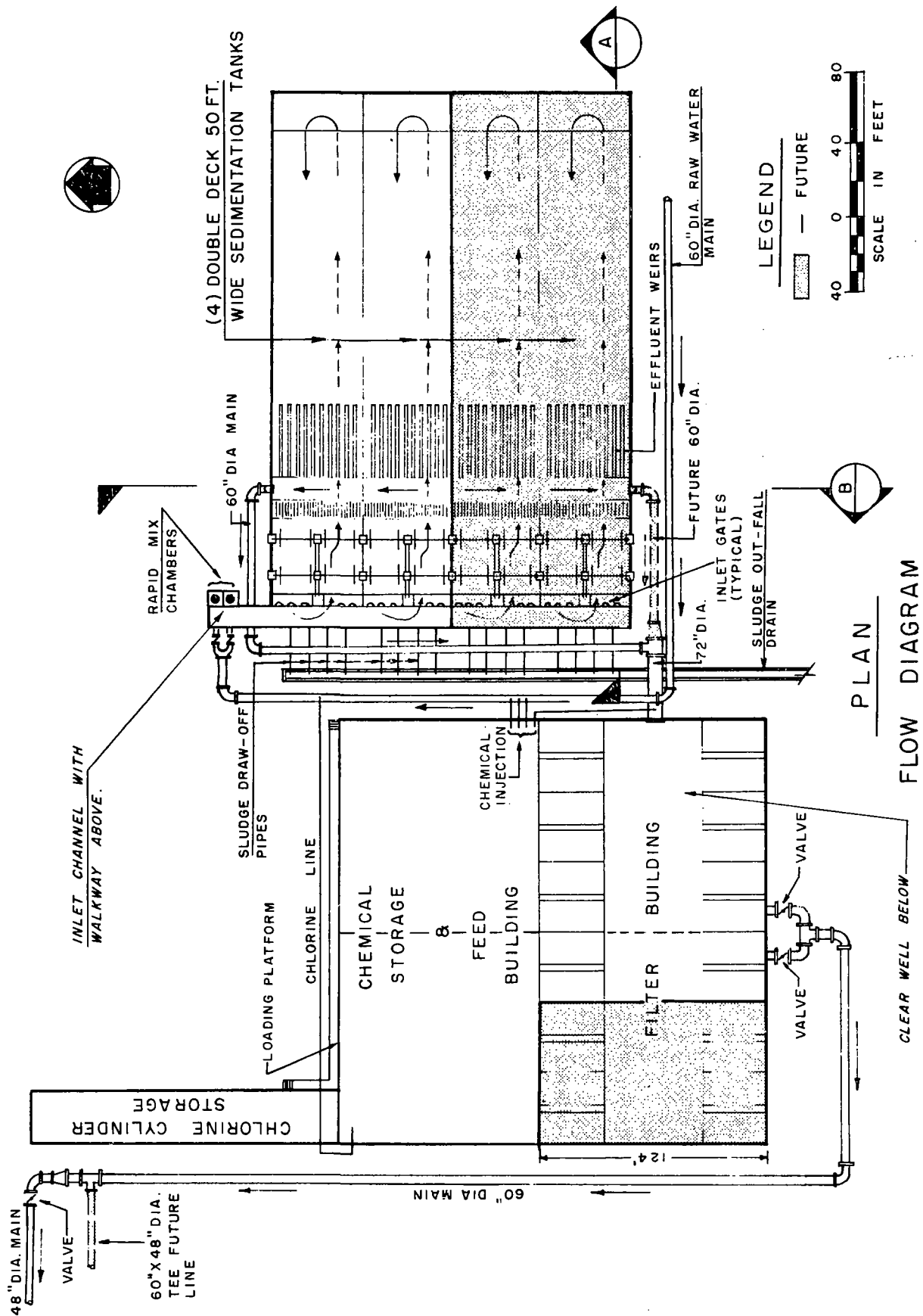
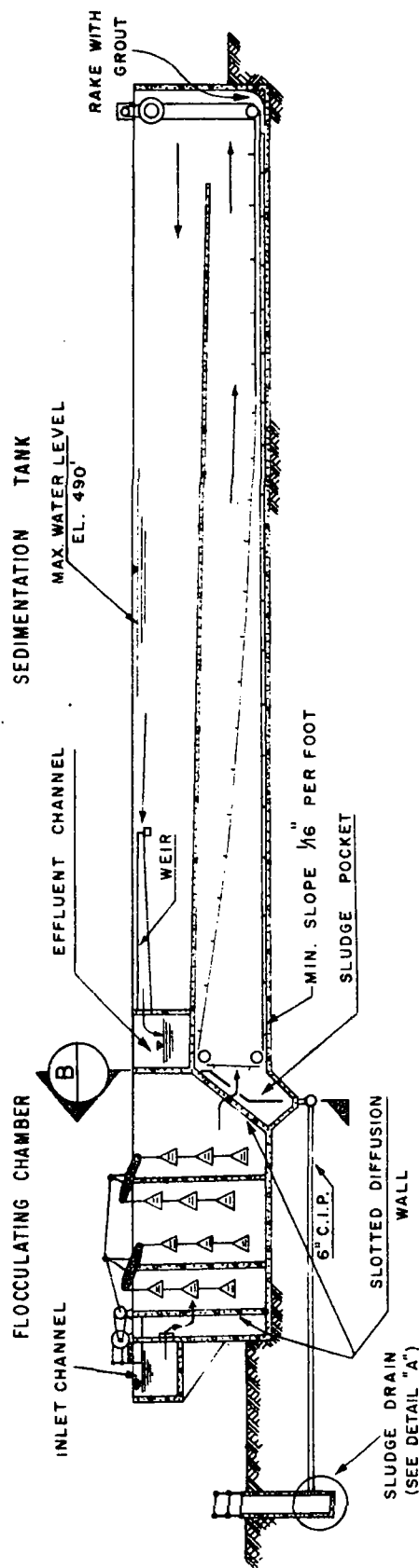
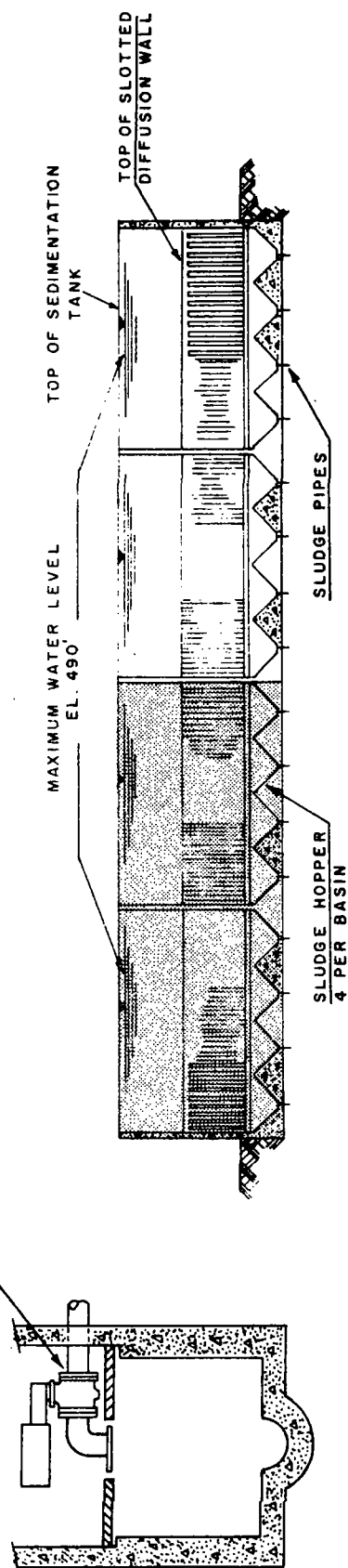


FIG. 66 OROPOUCHE TREATMENT PLANT



SECTION A
SCALE: 1"=40'-0"

6" AUTOMATIC SLUDGE VALVE
WITH ADJUSTABLE TIMER AND
HYDRAULIC OPERATOR



SECTION B
SCALE: 1"=20'-0"

DETAIL A
SCALE: 1/4"=1'-0"

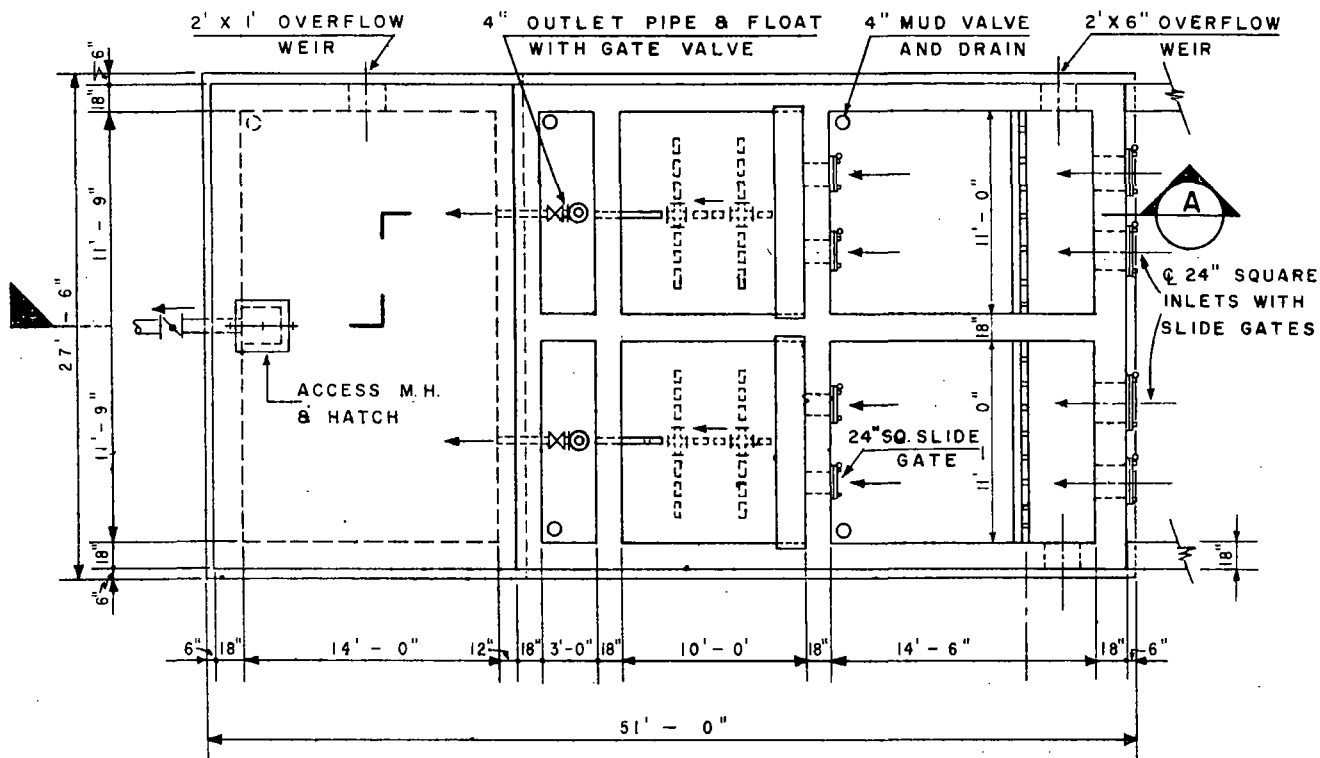
FIG 67 SECTIONS—ORPOUCHE SEDIMENTATION TANKS

scraping the alum sludge into the lower deck or washing it there by hydraulic means. The sludge removal equipment on the lower deck would be operated while cleaning the upper deck.

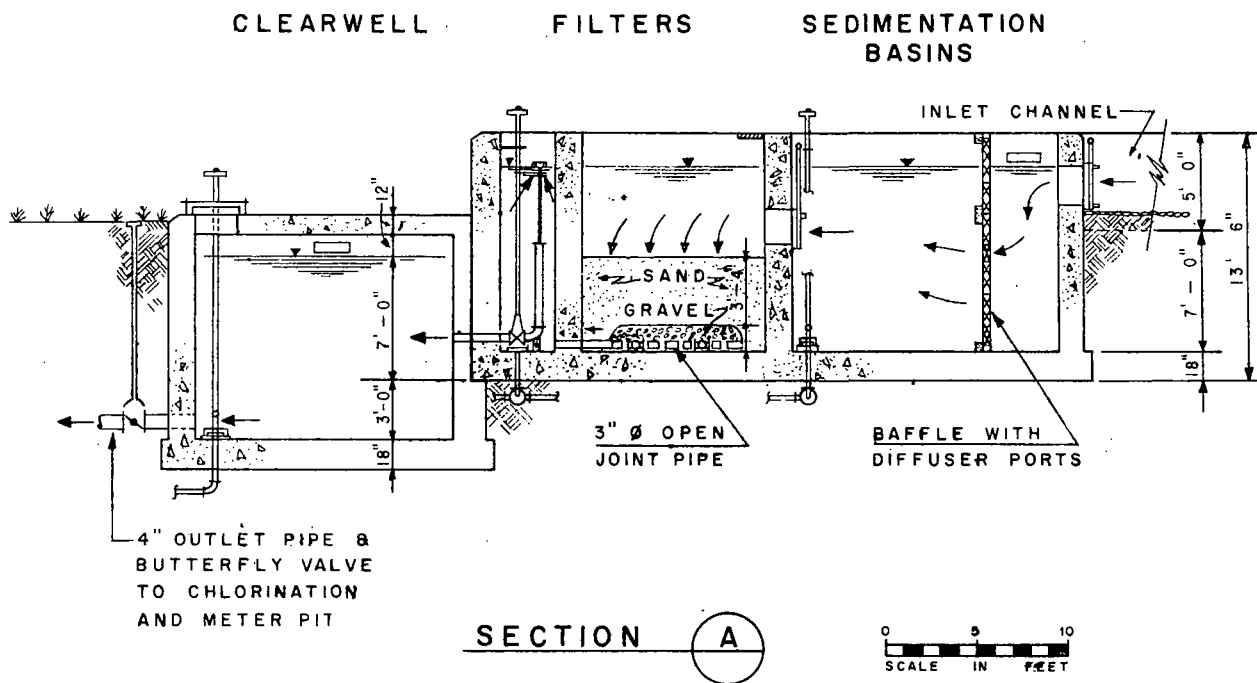
Transmission Mains. Details of the preliminary design for the Dropouche transmission mains are shown in Appendix I. Generally the mains southward from Caroni would follow the same routes as the Caroni-Arena mains, however, they would be larger.

Local Supply Treatment

Slow sand filter plants with presettling tanks and hydraulically operated chlorinators have been recommended to treat water collected from intakes with capacities from 10,000 to 100,000 gpd. This section includes suggested designs for 10,000- 20,000 and 100,000 - gallon per day units (Figures 68, 69 and 70). Figure 71 is a cost curve giving approximate costs of plant per gallon per day of capacity. Figures 68 and 69 show the top of the clearwell lower than the top of the rest of the plant while Figure 70 shows the top of the clearwell at the same elevation as the rest of the plant. The latter is preferable unless the topography is too steep to allow such a configuration.



PLAN



SECTION A

0 5 10
SCALE IN FEET

FIG. 69 TYPICAL 20,000 GPD SLOW SAND FILTER

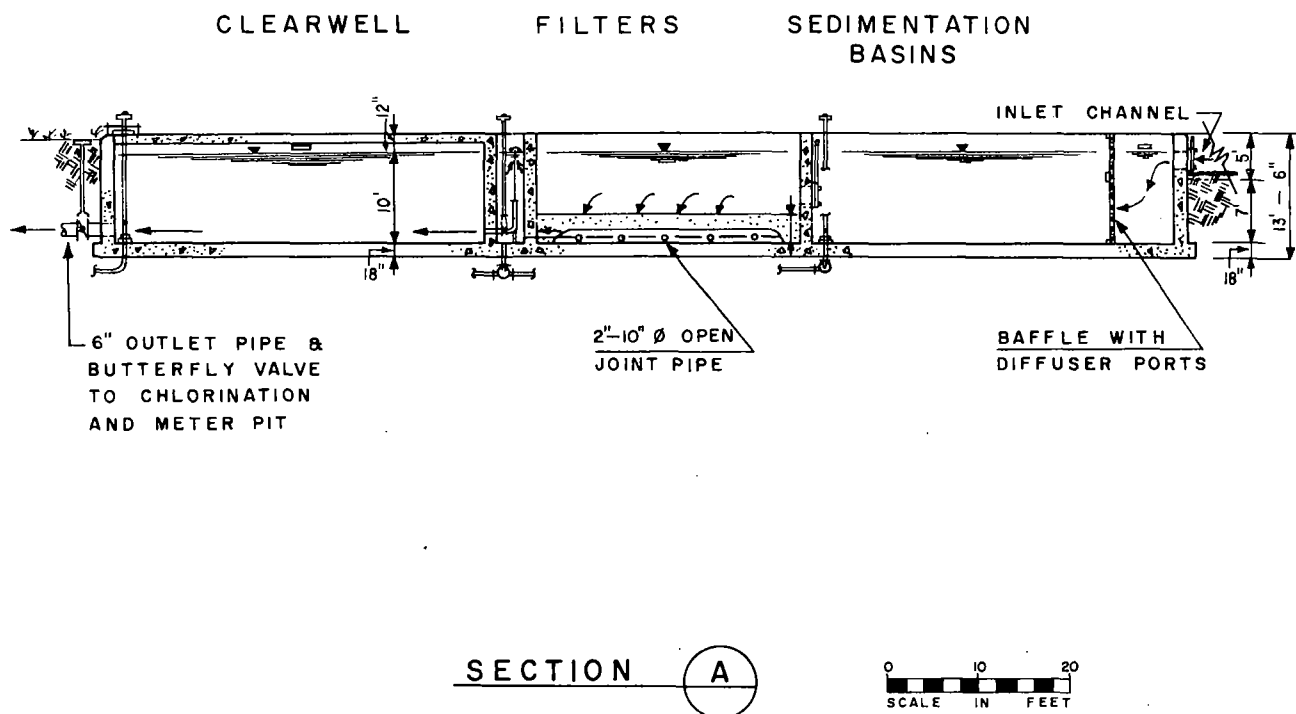
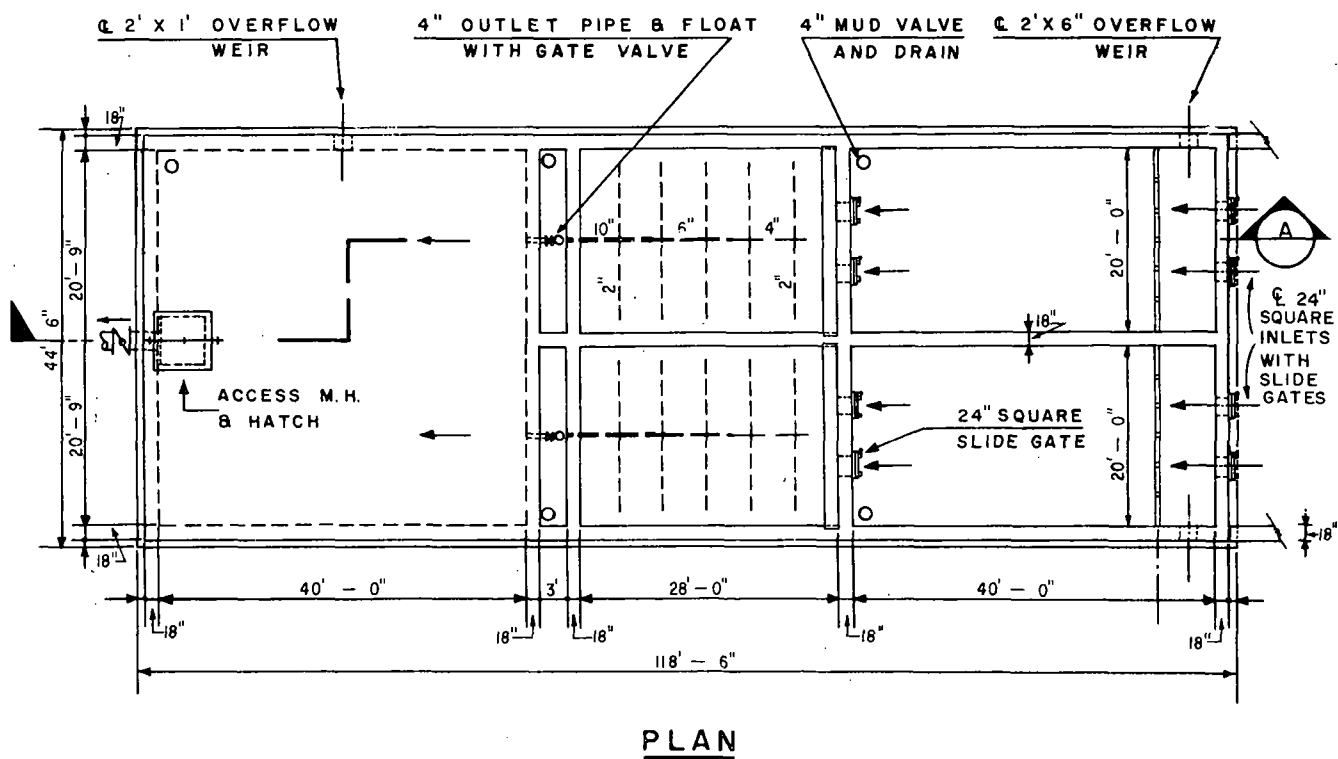


FIG. 70 TYPICAL 100,000 GPD SLOW SAND FILTER

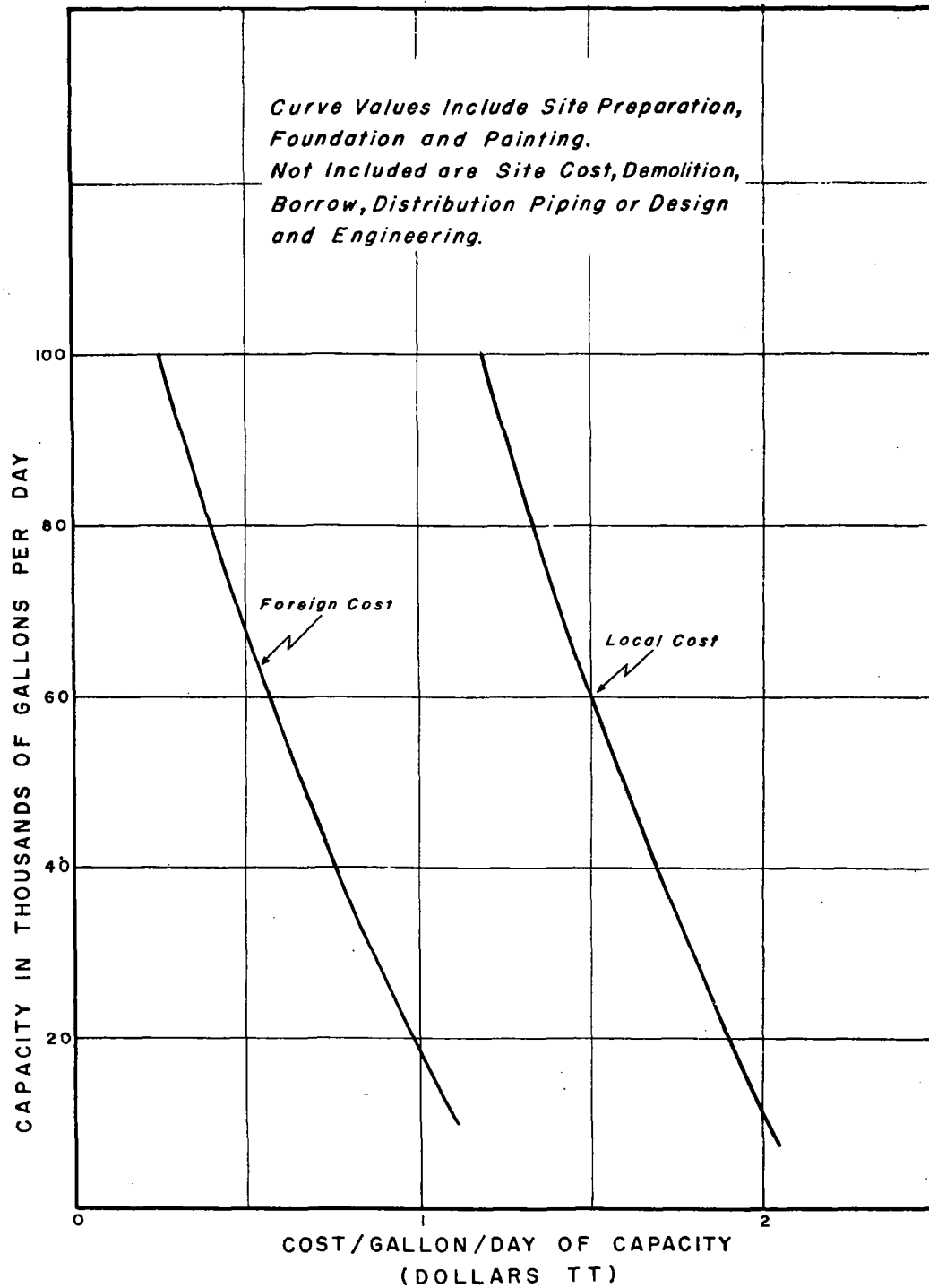


FIG.71 COST OF SLOW SAND FILTER PLANTS

TERMS OF REFERENCE FOR FINAL DESIGN

General

Terms of reference for final design are set forth in accordance with Appendix I, Description of Project, VII. Main Recommendations B. First Stage Program 13. Terms of Reference for the Final Plans. "Terms of reference will be presented for the work necessary for the preparation of the final engineering plans. These terms of reference should specify in detail every piece of field work that will be necessary and all the documents and plans that will comprise the final engineering project".

Two alternate sets of projects have been considered for inclusion in the First Stage Program. The first set includes the Navet Pumped Storage Scheme plus the North Dropouche Dam and pipeline; the second set includes the Navet Pumped Storage plus the Caroni-Arena project (the Recommended Program).

Terms of reference have been developed for each project and are presented in this chapter.

Engineering Services - Dropouche Project

Design Phase.

1. Preparation of contract documents for detailed surveys of sites or routes for:
 - a. Dropouche dam and appurtenances.
 - b. Dropouche reservoir below flow line.
 - c. Dropouche water treatment plant and appurtenances.

- d. Dropouche raw water pumping station and appurtenances.
- e. The transmission mains for construction by 1975 in Figure 27.
- f. California reservoir and appurtenances.

2. Preparation of contract and bidding documents for subsurface explorations for the following facilities:

- a. Dropouche dam and appurtenances.
- b. Dropouche water treatment plant and appurtenances.
- c. Dropouche raw water pumping station and appurtenances.
- d. The transmission mains indicated for initial construction (by 1975) in Figure 27.

3. Preparation of Contract documents for furnishing qualified personnel on site laboratory and off site laboratory for testing of soils samples taken by the subsurface explorations contractors.

4. Monitoring the subsurface explorations and interpretation of the soils test results.

5. Design of, and preparation of contract and bidding documents and construction cost estimates for the following facilities:

- a. Dropouche dam and appurtenances.
- b. Dropouche water treatment plant and appurtenances.
- c. Dropouche raw water pumping station and appurtenances.
- d. California distribution reservoir and appurtenances.
- e. The transmission mains for construction in 1975 in Figure 27.

6. Preparation of bills of materials and equipment and purchase specifications and bidding documents for international tenders to supply the materials of foreign manufacture necessary to

construct the above listed facilities.

7. The Engineer shall give particular attention to the following in connection with Dropouche dam design:

- a. Stability of the proposed structure under earthquake conditions (Intensity 7.5 Richter scale).
- b. Possibility of over topping by waves generated by either landslides or seismic forces.
- c. The type of materials available and the time schedule under which the dam will be constructed.
- d. The Engineer shall retain one or more consultants who are recognized authorities on design and construction of large rock fill dam in deeply weathered rock environments. Such consultants to review exploration, concept and final design, tendering comments and recommendations at each stage.
- e. Hydraulic model tests of the spillway structures with particular emphasis upon erosion problems and capacity.*

8. In connection with the Dropouche Water Treatment Plant design, the Engineer shall give particular attention to the following:

- a. Dependability of power supply to assure continuous operation or minimize shutdowns.
- b. Provision of on site chemicals storage capacity sufficient to meet plant needs for a period of at least 6 months.
- c. Provision of quarters for resident staff.
- d. Provision of adequate access to the plant by large trucks delivering

* The engineer would arrange for the model tests with a reliable hydraulic laboratory and said tests would be performed under direct contract to WASA (Separate contract).

chemicals.

- e. Provision for unloading trucks, including special cranes (for chlorine cylinders) and fork lift trucks (both hand trucks and electric powered).

Bidding Stage.

1. Provision of 100 copies of each set of contract drawings, specifications and bidding documents for each project.
2. Review all written questions during the bidding period and issue addenda answering said questions to all bidders prior to the due date for bids.
3. Review at least the two lowest bids submitted for each project and make a recommendation regarding award of each contract.

Construction Period.

1. Review and approval of shop drawings submitted by the contractors.
2. Provision of main office back-up for resident representatives.
3. Provision of resident representatives to monitor the various contractors' work.
4. Review and approval of the quantity surveyor's progress payment estimates.

Field Work - Dropouche Project

In general, the field work required for the final engineering plans consists of survey and subsurface exploration for the impounding structure, reservoir and treatment facilities. The impounding

structures consist of the main dam, spillway, diversion structure, inlet works, and dikes. The reservoir consists of the watershed area, principally the area below the flow line. The treatment facilities consist of the treatment plant, pumping station, access roads and all interconnecting pipelines.

It is envisioned that several camps would be set up to provide quarters, storage, laboratory and field office spaces to conduct the work more efficiently in the short dry season. The main camp should be located at the site of the present WASA field survey camp adjacent to the Oropouche River just above the proposed dam site. The camp would contain quarters for all survey and drill crews as well as supervisory personnel plus storage for dynamite, spare equipment, soil laboratory for performing the necessary soil tests on samples as they are extracted from the borings, and offices for supervising this work.

The required tasks are outlined as follows.

Survey.

1. Conduct a complete topographic survey of the reservoir area and prepare a topographic plan at 1:2400 scale with a contour interval of 10 feet.

2. Prepare a land acquisition map showing in detail ownership of all land parcels affected by the dam, reservoir, pumping station, treatment plant and interconnecting pipelines at a scale of 1:2500.

3. Establish monumented vertical and horizontal control and layout baseline as required for control of exploration and

preparation of design plans.

4. Prepare complete detailed topography for 1:600 scale plans with 2-foot contours covering the following structures:

- a. Dam site and spillway.
- b. Inlet works.
- c. Diversion structure.
- d. Dike areas.
- e. Treatment plant.
- f. Pumping station.
- g. Access roads.
- h. Quarry sites.

5. Conduct a perimeter survey of the reservoir flow line noting any thin ridges or other detrimental topographic features. Thin ridges or areas which may require design of reservoir wall protection will be surveyed with sufficient coverage to produce 1:600 scale topography for preparation of design drawings.

6. Layout all boreholes and geophysical survey lines prior to subsurface exploration. Prepare plots of the final location of the borings on 1:600 scale topographic base.

7. Additional traverses, topographic survey or field stake out as required to produce the final design drawings shall be conducted.

8. All survey data shall be taken in such a manner that data reduction and plotting can be done by digital computer. In addition all field survey data will be taken in a form suitable for earthwork

design by digital computer.

Subsurface Investigation.

1. Test borings shall be made by an experienced drilling contractor who can demonstrate recent experiences on projects of similar type and size. He should be able to supply at least 2 rigs in good repair with suitably experienced crews to run them.

2. Machines and crews shall be capable of efficient drilling and careful sampling in soft fine grained soil and of maximum recovery of cored rock and decomposed rock. It is anticipated that in addition to Standard Penetration Tests undisturbed samples will have to be taken of a size suitable for laboratory testing.

3. Test borings are anticipated to be not less than $2\frac{1}{2}$ inches in diameter in soil and not less than 3 inches in diameter in rock.

4. The following structures will require test borings for final design:

- a. Main dam and spillway.
- b. Dike.
- c. Inlet structure.
- d. Diversion structure.
- e. Pumping station.
- f. Treatment plant.
- g. Access roads.
- h. Unstable areas around reservoir or dam site.
- i. Quarry.

j. Borrow areas.

5. In addition to the test boring it is recommended that the thin ridge areas in the vicinity of the main dam and any other similar areas as well as the quarry site be explored by geophysical methods. The work should be contracted as professional services to a reliable firm specializing in shallow seismic surveys for civil engineering purposes that can demonstrate recent experience in deeply weathered rock environments.

6. Tests on soils sampled in the boring program are required to determine values for the physical characteristics of the in-place soil to be used in the final design. The laboratory should be located in close proximity to the job site so that samples, particularly undisturbed samples, can be tested soon after extraction with as little disturbance as possible. The laboratory work should be contracted to a firm of recognized standing in the field of soil testing and under the direction of a qualified soil engineer.

Engineering Services - Caroni-Arena Project

Design Phase.

1. Preparation of contract documents for detailed topographic surveys of sites or routes for:
 - a. Arena dam and appurtenances.
 - b. Arena reservoir flow line.
 - c. Caroni-Arena water treatment plant and appurtenances.
 - d. The initial construction transmission mains indicated in Figure 39.
 - e. San Rafael and Kelly raw water pumping stations and appurtenances.

f. California distribution reservoir and appurtenances.

2. Preparation of contract and bidding documents for subsurface explorations for the following facilities:

- a. Arena dam and appurtenances.
- b. Caroni-Arena water treatment plant and appurtenances.
- c. California distribution reservoir and appurtenances.
- d. San Rafael and Kelly water pumping stations and appurtenances.
- e. The initial construction transmission mains indicated in Figure 39.

3. Preparation of contract documents for testing of soil samples taken by the subsurface explorations contracts.

4. Monitoring the subsurface explorations and interpretation of the soil test results.

5. Design of, and preparation of contract and bidding documents and construction cost estimates for the following facilities:

- a. Arena dam and appurtenances.
- b. Caroni-Arena water treatment plant and appurtenances.
- c. San Rafael and Kelly water pumping stations and appurtenances.
- d. California distribution reservoir and appurtenances.
- e. The transmission mains.

6. Preparation of bills of materials and equipment and purchase specifications and bidding documents for international tenders to supply the materials of foreign manufacture necessary to construct the above listed facilities.

7. The Engineer shall give particular attention to the following in connection with Arena dam design:

- a. Stability of the proposed structure under earthquake conditions (Intensity 7.5 Richter scale).
- b. Possibility of over topping by waves generated either by land-slides or seismic forces.
- c. Hydraulic model tests of the spillway structure with particular emphasis upon cantation problems and capacity.*

8. In connection with the Caroni-Arena water treatment plant design the Engineer shall give particular attention to the following:

- a. Dependability of power supply to assure continuous operation or minimize shutdowns.
- b. Provision of on-site chemical storage capacity sufficient to meet plant needs for a period of at least 6 months.
- c. Provision of quarters for resident staff.
- d. Provision of adequate access to the plant by large trucks delivering chemicals.
- e. Provision for unloading trucks, including special cranes (for chlorine cylinders) and fork lift trucks (both hand trucks and electric-powered).

Bidding Phase.

1. Provision of 100 copies of each set of contract drawings, specifications and bidding documents for each project.

2. Review all written questions during the bidding period and issue addenda answering said questions to all bidders prior

*The Engineer would arrange for the model tests with a reliable hydraulic laboratory and said tests would be performed under direct contract to WASA (separate contract).

to the due date for bids.

3. Review of at least the two lowest bids submitted for each project and a recommendation regarding award of each contract.

Construction Period.

1. Review and approval of shop drawings submitted by the contractor.

2. Provision of main office back-up for resident representatives.

3. Provision of resident representatives to monitor the various contractors' work.

4. Review and approval of the quantity surveyor's progress payment estimates.

Field Work - Caroni-Arena Project

The field work required for the final engineering plans consists of survey and subsurface exploration for the impounding structure, reservoir, and treatment facilities. The impounding structures consist of a 70-foot high dam, spillway, diversion structure, and inlet works. The reservoir consists of the watershed area principally below the flow line. The treatment facilities consist of the treatment plant, which will be close to the Kelly Headworks, the San Rafael Pumping Station, access roads and interconnecting pipelines.

In the case of the Arena dam it will not be necessary to establish a camp for survey, exploration and testing activities in view of the proximity of the proposed dam to the main centres of population concentration and the short travel time involved. One

building will, however, be required to provide accommodation for a soils laboratory for performing the necessary soil and materials tests.

In contrast with the North Oropouche dam, considerably more attention to the foundation and abutments of the dam and spillway are required in view of the relatively low strength of the underlying silts and clays.

The required tasks are as follows.

Survey.

1. Conduct a complete topographic survey of the reservoir area and prepare a topographic plan at 1:4800 scale with a contour interval of 5 feet.
2. Prepare a land acquisition map showing in detail ownership of all land parcels affected by the dam, reservoir, treatment plant San Rafael pumping station, and interconnecting pipelines at a scale of 1:2500.
3. Establish monumented vertical and horizontal control and layout baselines as required for control of exploration and preparation of design plans utilizing to the fullest extent possible the Trinidad and Tobago Lands and Surveys control grid.
4. Prepare complete detailed topography for 1:600 scale plans with 2-foot contours covering the following structures:
 - a. Dam site and spillway.
 - b. Inlet works.
 - c. Diversion structure.

- d. Treatment plant.
- e. Pumping station.
- f. Access roads.
- g. Borrow site.

5. Conduct a perimeter survey of the reservoir flow line noting any thin ridges or other detrimental topographic features. Thin ridges or areas which may require design of reservoir wall protection will be surveyed with sufficient coverage to produce 1:600 scale topography for preparation of design drawings.

6. Layout all boreholes test sections and instrument locations prior to subsurface exploration. Prepare plots of the final location of the borings test sections and instrumentation on 1:600 scale topographic base.

7. Additional traverse, topographic survey or field stake cut as required to produce the final design drawings shall be conducted.

8. All survey data shall be taken in such a manner that data reduction and plotting can be done by digital computer. In addition all field survey data will be taken in a form suitable for earthwork design by digital computer.

Subsurface Investigation.

1. Test borings shall be made by an experienced drilling contractor who can demonstrate recent experiences on projects of similar type and size. He should be able to supply at least 3 rigs in good repair with suitably experienced crews to run them.

2. Machines and crews shall be capable of efficient drilling

and careful sampling in soft fine grained soil. It is anticipated that a large number of undisturbed samples will have to be taken of a size suitable for recovery of soil for laboratory testing. In addition test sections of surcharge with installation of piezometers and settlement plates may be required as well as observation wells and slope indicators. The installations of these sections and instrumentation should be performed by the test boring contractor under the direction of a qualified soil engineer.

3. Test borings are anticipated to be not less than $2\frac{1}{2}$ inches in diameter in soil and not less than 3 inches diameter in rock.

4. The following structures will require test borings for final design:

- a. Main dam and spillway.
- b. Inlet structure.
- c. Diversion structure.
- d. Treatment plant and intake at Kelly Village.
- e. Raw water intake and pumping station at San Rafael.
- f. Access roads.
- g. Unstable areas around reservoir or dam site.
- h. Borrow areas.

5. Tests on soils sampled in the boring program are required to determine values for the physical characteristics of the in-place soil to be used in the final design. The laboratory should be located in close proximity to the job site so that samples, particularly undisturbed samples, can be tested soon after extraction with as little

disturbance as possible. The laboratory work should be contracted to a firm of recognized standing in the field of soil testing and under the direction of a qualified soil engineer.

Engineering Services - Navet Pumped Storage Project

Design Phase. Design, prepare plans, specifications, documents for tender, and construction cost estimates for the following facilities:

1. Low dam, spillway, and mudgate.
2. Intake and pumping station.
3. Pipeline and outfall to present reservoir.
4. Slope protection as required.
5. Booster at Malgretoute.

Consider types of dam, probably earth (rock near surface), slope protection; riprap, soil cement or asphalt cement, cut-off trench; grout curtain, type structure; overflow, rockfill or concrete.

Field Work - Navet Pumped Storage Project

The field work required for the final engineering plans consists of survey and subsurface exploration for the impounding structure, reservoir and pumping facilities. The impounding structure consists of the dam, stilling basin, check dam and intake works. The reservoir consists of the watershed below the flow line. The pumping facilities consist of the pumping station, associated pipelines and access roads.

In order to do the work efficiently a field camp should be set up near the Navet Treatment Plant and all survey, exploration and

testing conducted from the plant. The camp would contain quarters for all survey crews, drill crews, supervisory personnel and a soil laboratory to perform the necessary soil tests. Perhaps the conditions would indicate handling this without a camp as at Arena.

The required tasks are outlined as follows.

Survey.

1. Conduct a complete topographic survey of the reservoir area and prepare a topographic plan at 1:4800 scale with a contour interval of 5 feet.
2. Prepare a land acquisition map showing in detail ownership of all land parcels affected by the impounding structures, reservoir, pipeline, and pumping station at a scale of 1:2500.
3. Establish monumented horizontal and vertical control consistent with datum existing at the Navet Treatment Works.
4. Prepare detailed topography, i.e. maps at 1:600 scale with 1-foot contours covering the following structures:
 - a. Dam and spillway.
 - b. Pumping station.
 - c. Inlet and outlet works.
 - d. Access roads.
 - e. Pipeline route.
5. Conduct a careful perimeter survey of the flow line since low relief of basin causes large horizontal movements of flow line with small vertical changes in water surface.
6. Layout all boreholes prior to subsequent exploration,

prepare plots of the final location of borings on 1:600 scale topographic base.

7. Additional traverses, topographic survey or field stake-out as required to produce the final design drawings shall be conducted.

Subsurface Investigation.

1. Test borings shall be made by an experienced drilling contractor. He should be able to supply at least two rigs in good repair with suitable experienced crews to run them.

2. Machines and crews shall be capable of efficient drilling and sampling in soft fine grained soil, decomposed rock and of maximum recovery in cored rock. It is anticipated that undisturbed samples will have to be taken of a size suitable for laboratory testing.

3. Test borings are anticipated to be not less than $2\frac{1}{2}$ inches in diameter in soil and not less than 3 inches in diameter in rock.

4. The following structures will require test borings for final design:

- a. Dam and spillway.
- b. Stilling basin.
- c. Bank protection areas.
- d. Pipeline.
- e. Pumping station.
- f. Access roads.
- g. Borrow areas.
- h. Malgretoute pumping station.

5. The impoundment is in an area of highly erosive soils

which will be subject to rapid movement with only subtle changes in stream regimen. It is felt a careful hydrologic study should be made to determine the effect of the proposed change on the basin soils so that proper final design of the pumped storage system with adequate protection of facilities and basin can be achieved.

6. Tests on soils sampled in the boring program are required to determine values for the physical characteristics of the in-place soil to be used in the final design. The laboratory should be located in close proximity to the job site so that samples, particularly undisturbed samples, can be tested soon after extraction with as little disturbance as possible. The laboratory work should be contracted to a firm of recognized standing in the field of soil testing and under the direction of a qualified soil engineer.

Field Work - Transmission Mains

The field work required for the final engineering plans consists of aerial photographic survey, ground survey and subsurface exploration for the installation of large size water mains from the water source at Oropouche to the distribution centre of Port of Spain and San Fernando.

It is anticipated that the work would be done in the dry season from March through May. Some of the profile work has been done by WASA especially through the forested section from the Treatment Plant area to the Valencia Road. The rest of the route lends itself very nicely to photogrammetric survey.

The required tasks are outlined as follows:

Survey.

1. Contract for aerial photographic survey of the pipeline route from the point of intersection of the treatment plant access road west to the various termini. The contract should include establishment of ground control and to ultimate production of strip topographic coverage of the pipeline route transparent plan and profile drawing sheets at 1:600 scale for congested areas, and 1:1250 for relatively free country. The contract should be made with a survey firm of recognized standing in preparation of topographic maps from aerial photographs.

2. The photogrammetric maps shall be suitable for preparation of land acquisition maps at a scale of 1:2500.

3. Field survey will be required for all stream crossings, locating borings, existing underground utilities, and miscellaneous route study as necessary.

Subsurface Investigation.

1. Test borings shall be made by an experienced drilling contractor who can demonstrate recent experience on projects of similar type and magnitude. Due to the length of the pipeline and the relatively short dry season it will be necessary for the contractor to supply a minimum of 4 rigs and crews.

2. Test borings should consist of two types of borings, auger borings and drive sample borings. Auger borings will be used as a rapid means of determining the nature of the subsurface material along the pipeline route. The drive sample borings will be used for obtaining specific foundation design information at stream crossings and special design sections.

3. In addition, special borings may be required in areas of extremely soft soils where undisturbed samples will be taken and vane shear tests conducted.

4. Tests on soils sampled in the boring program are required to determine values of the physical character of the in-place soil for use in final design. The laboratory work should be contracted to a firm of recognized standing in the field of soil testing and under the direction of a qualified soil engineer.

5. The following type areas will require test borings for final design:

- a. Major stream crossings.
- b. Major highway crossings.
- c. Areas of soft soil such as swamps.
- d. Routine alignment.

Corrosion Control.

1. Final design of the corrosion control of the pipeline will require soil resistance measurements along the route of the pipeline. Since this is a very specialized field the engineer should retain a recognized authority in the field of corrosion control in relation to pipelines.

2. The consultant will conduct the necessary field investigation, make design recommendations, including specifications, and review the final design with respect to the suitability of the overall corrosion protection system.

3. The consultant's recommendations of corrosion protection

will consider such things as the availability of protection and the labour skills required for installation.

Contract Documents

The contract documents shall be sufficiently complete to provide all the information necessary to obtain international tenders for the proposed work. They shall include information normally furnished under the following sections:

Notice to Contractors,
Information for Bidders,
Bids,
Agreement,
Contract Bonds,
Special Conditions,
General Specifications,
Specifications - Detail,
Appendix.

Notice to Contractors. This shall be in the form of an advertisement required for publication inviting bids for the construction work. It shall contain all the information needed by prospective bidders to understand the location and scope of the project. Certain additional details and the location where documents may be procured shall also be included.

Information for Bidders. This section shall give additional information necessary for the bidder to prepare his bid, including the location and date of the bid opening, time for completion of the work,

and other detailed requirements and conditions governing the submission of bids.

Bids. This section of the documents provides a schedule of items with appropriate blanks for insertion of the itemized bid figures by the prospective bidders. It also contains certain conditions governing the basis for bidding, including the time requirements for completion of the work.

Agreement. This section sets forth in detail the legal basis for the agreement between the owner and the contractor and defines the legal and technical commitments of both parties with regard to the execution of the work, and payment therefor.

Contract Bond. This section sets forth the requirements of the bonds for performance and labour and materials.

Special Conditions. This section sets forth in detail the data and conditions peculiar to the contract. These conditions include such items as liquidated damages, basis for progress estimates and money retained, insurance requirements and other special requirements of the project.

General Specifications. This section specifies the general conduct of the work, including specific instructions and operating procedures common to contracts of like character. It includes material sampling and inspection procedures, shop drawing requirements, rules governing contractors' operations, safety and sanitary requirements, provisions for laying out the work and definitions of the basis of payment and other general requirements governing the contractors'

operations.

Detail Specifications. These specifications detail the methods of doing the specific work under the contract. It is subdivided into the various classes of work to be performed and includes identification of acceptable materials to be used, and the basis of payment for the work.

Appendix. This shall include additional reference information such as typical drawings, boring logs and the like.

Contract Drawings

These drawings shall show sufficient detail to enable a contractor to read and understand construction methods and procedures for accomplishing the specific work included in the contract. The designer should produce sheets which will include the following details in conformity with the following standards.

1. Drawings to be size 24-inch by 36-inch with standard title, revision, scale and approval block 12-inch by $\frac{3}{4}$ -inch in lower right hand corner.

2. Cover sheet with name of owner, agency and principal officer, title of project, contract number, index of drawings, and title of engineering firm.

3. Sheet showing vicinity map, general notes and legend. Quarry site and borrow pit locations to be shown on vicinity map if not in reservoir area.

4. Sheets showing topography of reservoir area, scale 1:4800, contour intervals 5 feet, with outline of dam and spillway,

dikes, reservoir rim protection, normal pool line, timber clearing limits, owner's property lines, existing buildings, access roads and coordinate grid indicated thereon. Location of quarries and borrow areas to be indicated if in the reservoir area.

5. Sheets showing detail topography of the following areas (scale 1:600, contour interval 2-foot):

- a. The dam site with plan of dam and spillway, outlet conduit (or tunnel), channels, dikes, gate structure (if applicable).
- b. Treatment plant sites with layout, and grading plan of site, location of buildings, drainage of area and access roads.
- c. Pumping station sites with plan and grading of area, inlet and outlet piping, drainage and access roads.
- d. Service reservoir sites with location and grading plan, location of piping, drainage and access roads.
- e. Housing areas with layout, grading, drainage, access roads and sewer disposal.
- f. Pipeline routes with river, drains and other utility crossings and location.

6. Sheets showing typical cross sections of dams, dikes, channels, treatment plants, pumping stations, service reservoirs, houses, pipelines and access roads together with all pertinent details. Scales as appropriate.

7. Sheets showing longitudinal profile of dams including ground and rock lines. Profile and typical cross section of tunnel

(if applicable) at appropriate scales.

8. Sheets showing structural design and details of treatment plants, pumping stations, houses, service reservoirs, spillways, intake structures, outlet conduits, and gate structures. Scales as appropriate.

9. Sheets showing architectural design and details of treatment plants, pumping stations, houses, gate houses (if applicable) etc., at appropriate scales.

10. Sheets showing all mechanical and electrical details for all the above structures.

11. Sheet or sheets showing plan, profile, and details of any special pipeline crossings or supports. Scales as appropriate.

Other Considerations

The designer shall give careful consideration to covering the possible "surprise" areas in the plans, specifications, bills of quantities and documents for tender.

Dams and Appurtenances - Changed Conditions. It is well known, despite preconstruction boreholes, test pits, seismic studies and geological work, that subsurface conditions may be found which differ from those expected. The designer should do as much as possible to prevent such changed conditions from penalizing the contractor or causing excessive charges to the owner. Bid items for overbreak, extra depth excavation, extra backfill with either concrete or other materials should be well defined and allow for reasonable prices either preset or negotiated.

It does not appear to be indicated from information developed during the investigation that grouting will be required. The designer, from further investigation, will design for cement or chemical grouting if required. The designer should provide for test fills either in the design stage or the construction stage so that such items of compaction and gradation, roller sizes, types, and passes, as well as thickness of lifts and quantity of sluicing water will be clearly defined and may be economically priced.

Instrumentation. It is recommended that the designer clearly define the required instrumentation and set up unit prices in the bill of quantities for such work so that the contractor will install such instrumentation as piezometers, observation wells, inclinometers, vertical cross arms, bench marks, surface reference points, horizontal extensometers, seismoscopes, etc. Description and estimated frequency of compaction, gradation and any other required tests should be such as to enable the contractor to estimate and plan for construction procedures.

Pipelines - Changed Conditions. Subsurface explorations for pipelines should, because of depths involved, more positively define existing conditions. However, the final design must include such items as found necessary to provide maximum protection for both parties to the contract.

Optimum locations for pipelines will be in areas where rock and excessively soft material are at a minimum and in public rights of way or on government property.

Pipelines should be laid in cut, never in fill, or placed on suitable foundations for overhead crossings. Side hill cuts should be avoided if possible. If used, the geology and soil conditions of the area must be studied to determine the type of protection if any is required.

Buildings and Structures. The designer shall ensure that all buildings and structures to be erected will be able to withstand

- (i) Seismic loads of a magnitude of 7.5 (Richter scale) from earthquakes; and
- (ii) Winds of up to 60 miles per hour.

Standards. All plant, machinery, equipment, materials, fittings and furnishings to be used shall conform to the applicable standards and specifications of the following international societies and associations. Materials and equipment conforming to these standards have been successfully utilised in the past in Trinidad and Tobago.

The American National Standards Institute

British Standards Institute

American Water Works Association

American Society for Testing and Materials

National Electrical Manufacturers Association (U.S.).

CONCLUSIONS AND RECOMMENDATIONS

As a result of our investigations we present the following summary of our more important conclusions and recommendations:

1. The existing system operated by the Water and Sewerage Authority serves 90 percent of the total population. The estimated present and future population of Trinidad and Tobago is:

<u>Year</u>	<u>Population</u>
1970	1,130,000
1975	1,268,000
1980	1,400,000
1985	1,546,000
2000	2,020,000

Estimates of future domestic water requirements assumed 100 percent population served.

2. Water production at the start of 1970 (60 mgd) was 10.6 mgd in excess of developed dependable yield. Early 1970 production and presently developed dependable yield by type of source are:

<u>Type Source</u>	<u>Number of sources</u>	<u>Dependable Yield, mgd</u>	<u>1970 Production, mgd</u>
Groundwater	32	30.6	38.0
Surface water (including intakes)	33	18.8	22.0
Total	65	49.4	60.0

3. Per capita demand exclusive of industrial use is estimated at 58 mgd. In 1968 per capita production for domestic use was only 46 gpd. Both figures are considered excessive for the service provided and reflect a large amount of system leakage and water waste.
4. Metering of all direct connections, a substantial increase in metered water rates and a continuing leak control program are recommended to reduce per capita consumption. These steps are essential not only to keep capital and operating costs down, but to secure international financing for proposed projects. Projections of future demands assume that these steps will be taken and become effective no later than 1973.
5. Future water supply requirements of Trinidad and Tobago to be supplied by WASA are estimated as follows:

<u>Year</u>	<u>Annual average demand, mgd</u>	<u>Maximum day demand, mgd</u>
1975	77.4	94.3
1980	94.4	115.0
1985	112.5	136.8
2000	169.7	206.6
6. To meet the anticipated demands listed in 5 will require development of the following additional dependable yield:

3. Per capita demand exclusive of industrial use is estimated at 58 mgd. In 1968 per capita production for domestic use was only 46 gpd. Both figures are considered excessive for the service provided and reflect a large amount of system leakage and water waste.
4. Metering of all direct connections, a substantial increase in metered water rates and a continuing leak control program are recommended to reduce per capita consumption. These steps are essential not only to keep capital and operating costs down, but to secure international financing for proposed projects. Projections of future demands assume that these steps will be taken and become effective no later than 1973.
5. Future water supply requirements of Trinidad and Tobago to be supplied by WASA are estimated as follows:

<u>Year</u>	<u>Annual average demand, mgd</u>	<u>Maximum day demand, mgd</u>
1975	77.4	94.3
1980	94.4	115.0
1985	112.5	136.8
2000	169.7	206.6
6. To meet the anticipated demands listed in 5 will require development of the following additional dependable yield:

<u>Year</u>	<u>Additional dependable yield, mgd</u>
1975	28.0
1980	45.0
1985	63.1
2000	120.3

7. Total groundwater potential of Trinidad and Tobago is estimated at 72 mgd of which 30.6 mgd has already been developed.

8. The potential of surface water sources which were considered for development are:

<u>Source</u>	<u>Potential dependable yield, mgd *</u>
North Dropouche River	45
Matura River	20
Moruga River	25
Yarra River	9+
Caroni River (Arena Reservoir)	33
Marianne River	10
Madamas River	18
Guanapo River	10
Cunapo River	3+
Courland River	6
Talparo River	3
Richmond River	3
Tumpuna River	3+

* Yield based on each source operating independently.

9. The dependable yield of the Navet reservoir is estimated at 7.0 mgd. Construction of a downstream diversion dam and pumping station is recommended to increase the yield of this source to 17 mgd.
10. Development of local supplies consisting of boreholes, intakes and small impounding reservoirs is the most economical means of supplying future demands. We estimate a dependable yield of 19 mgd and a maximum day production capacity of 25 mgd can be economically developed from these sources and be in use by the year 2000.
11. The increased yield from Navet reservoir and the development of small local supplies will add 25 mgd dependable yield to supply by 1975, nearly sufficient to overcome existing deficits and meet the 28 mgd increase in demand projected for 1975.
12. The construction of new large surface water reservoirs will be required to meet the majority of future requirements between 1975 and the year 2000. The following reservoirs are recommended for development in the order listed:

<u>Supply</u>	<u>Potential dependable yield, mcd</u>
Arena reservoir (Caroni River)	33
Talparo reservoir)	9
Tumpuna reservoir)	
Moruga reservoir	25
North Oropouche reservoir	45

The Arena, Talparo and Tumpuna reservoirs will augment low flows in the Caroni River for downstream withdrawal. These three reservoirs form the Caroni-Arena system. The Courland reservoir is recommended for development as a local source.

13. Supply from the Caroni-Arena system, the Moruga and the North Oropouche reservoirs would serve an area including Port of Spain and the Eastern Main Road communities, Central Trinidad west of the Central Range, and South Trinidad west of Rio Claro including San Fernando, Point Fortin, Princes Town, Penal and Siparia.
14. Based on the sequence of reservoir development, a three stage construction program is recommended. The first stage program would include the construction of the Arena reservoir and would meet demands projected for 1980. The second program would include expansion of the Caroni-Arena system by construction of the Talparo and Tumpuna reservoirs, and construction of the Moruga and Courland reservoirs. The third stage program would include

construction of the North Dropouche reservoir and would meet the demands projected for the year 2000. The first stage program anticipates all required primary system improvements. The second and third stage programs include new sources to satisfy projected demands and only those primary distribution improvements which satisfy an obvious future need.

15. The first stage program includes the following improvements in addition to the Arena reservoir:

- (1) Development of 15 mgd dependable yield from groundwater and local supplies;
- (2) metering of all domestic connections;
- (3) increase of 10 mgd in the dependable yield of the Navet storage reservoir;
- (4) the Caroni water treatment plant and intake;
- (5) transmission mains from the Caroni water treatment plant to El Socorro in the north and California in the south;
- (6) reinforcements and improvements to the primary distribution system;
- (7) the Courland water treatment plant;
- (8) extension of the Caroni-Arena transmission system to San Fernando and Point Fortin in the latter part of the first stage program; and
- (9) an intake and water treatment plant on the lower North

Oropouche to serve Sangre Grande.

16. The second stage program includes the following improvements in addition to the Talparo, Tumpuna, Moruga and Courland reservoirs:
 - (1) An addition to the Caroni water treatment plant;
 - (2) Development of 5 mgd capacity from groundwater and local supplies including the Courland reservoir;
 - (3) the Moruga water treatment plant;
 - (4) a transmission main from the Moruga water treatment plant to Palmiste; and
 - (5) reinforcements and additions to the primary distribution system.
17. The third stage program includes the following improvements in addition to the North Oropouche reservoir:
 - (1) The Oropouche water treatment plant;
 - (2) a transmission main from the Oropouche water treatment plant to Tacarigua;
 - (3) reinforcements and additions to the primary distribution system; and
 - (4) development of 4 mgd of capacity from groundwater and local supplies.
18. The three stage development program would be constructed at an estimated cost of \$285,373,000, based on 1970 construction costs. The cost by construction stage for major and local projects is as follows:

Stage	Estimated cost (\$1,000 TT)		
	Major projects	Local projects	Total
First	70,726	69,738	140,464
Second	55,480	17,179	72,659
Third	62,753	9,497	72,250

19. In addition to capital expenditures for the recommended development program, WASA must complete projects already under construction and meet continuing capital requirements for expansion of the secondary system, accommodation, and transportation. These expenses in the first stage program are estimated at \$20,800,000.
20. Certain major projects in the first stage program are needed immediately and are considered suitable for international bank financing. These projects and their estimated foreign and local cost components are:

Project	Estimated cost (\$1,000 TT)		
	Foreign	Local	Total
Metering	7,140	860	8,000
Navet project	2,323	1,761	4,084
Caroni-Arena system (Initial Construction)	26,288	19,558	45,846
Total	35,751	22,179	57,930

21. Several small local supplies are presently untreated.

In order to meet suggested water quality goals it is recommended that presettling basins and slow sand filters be constructed to treat the water supplied from these sources. Suggested designs for 10,000, 30,000 and 100,000 gpd plants are provided.

ACKNOWLEDGEMENT

We wish to acknowledge with thanks the helpful co-operation we have received from the Board of Commissioners and the Management of the Water and Sewerage Authority under the guidance, respectively, of the Chairman, Mr. Wilfred Best, and the Executive Director, Mr. George Davis. We also express our appreciation of the assistance given by the Deputy Executive Director, Mr. R.A.V. Philip; the Technical Director, Mr. Emile B. Warner; the Director of Finance, Mr. Esmond A. Jones, and the many other members of the staff who provided us with much of the basic data required for the preparation of the report and gave us as well of their time and effort.

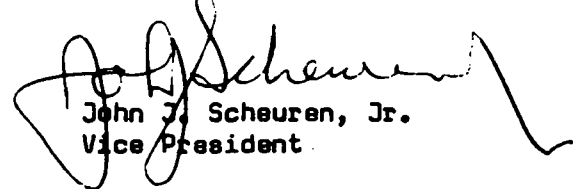
We acknowledge, too, the assistance of the various Ministries and Departments of the Government of Trinidad and Tobago, and Statutory Bodies who contributed significantly to the success of our investigations. We refer specifically those agencies of Government listed in Annex C hereto.

Finally, we express our appreciation of the help given by citizens, businessmen and industrialists throughout Trinidad and Tobago who contributed much useful information.

The surveys, studies and preliminary designs were carried out and the report written by J. J. Scheuren, Jr., A. D. Moody, R.A. Mac Ewen, R.G. Sherman, E.R. Lubke, D.G. Ball, Gordon E. Thomas, W.E. Daniel and

N. Clapp under the direction of H.L. Kinsel, Senior Vice President.
They were assisted by collaborating consultants Weston Geophysical
Associates and Pitometer Associates of the United States of America,
and Ian De Verteuil, Granville Johnston and Emile Sabga & Associates
of Trinidad and Tobago.

Respectfully submitted,
METCALF & EDDY INTERNATIONAL, INC.



John J. Scheuren, Jr.
Vice President

ANNEX A

Preliminary Report on the First Stage of the Long Term Program

Any report on the First Stage of the Long Term Program is necessarily detailed in the Preliminary Report on the Long Term Program.

Sections are developed in this report for both Initial Construction and for Final Construction for a program which will cover the needs of the country for a period not shorter than ten years.

The First Stage Program is elaborated in detail to allow for reasonable cost estimates, to form a basis for final engineering plans, and to support possible negotiation for financing.

The program has been presented in accordance with the sections of the contract described in Appendix I, Descriptions of the Project, Main Recommendations VII B 1) b, VII B 2), and VII B 3).

The first phase of the Oropouche project was reviewed but is not recommended for reasons of inconvenience and of excessive non-recoverable capital costs.

The second phase of the Oropouche project is described and elaborated in detail.

The Chickland project was reviewed and found not to be feasible.

Other sources and alternatives to Oropouche and Chickland were developed.

The Caroni-Arena project has been developed and comparison made with the Oropouche Project in the Chapters on EVALUATION OF

ALTERNATIVE PROGRAMS and on COMPARISON OF MAJOR FIRST STAGE PROJECTS.

The Navet pumped storage project has been developed as an alternative to the Chickland project and is described in the above mentioned chapters.

The remainder of the items under VII B are developed in the Preliminary Report on the Long Term Program with the exception of VII B 15) which refers to loan applications.

The completion of the preparation of a loan application awaits information, selection of projects and authorization from the Water and Sewerage Authority.

Preliminary Report on the Interim Program

Any report on the Interim Program is necessarily detailed in the Preliminary Report on the Long Term Program and in the Report on Organization and Administration.

These reports include scheduling and budgeting requirements for the program.

The capacities of the various assets of the existing system are set forth in the Preliminary Report on the Long Term Program in the chapter on EXISTING SYSTEMS.

The areas of scarcity are identified in Figure 8 of the above report and described in the chapter on ADEQUACY OF THE EXISTING SYSTEM.

Recommended improvements to the existing system are included in the chapter on CONCLUSIONS AND RECOMMENDATIONS.

Recommended additions of sources and systems are listed in the chapter on RECOMMENDED DEVELOPMENT PROGRAM.

The services of the Pitometer Associates were furnished for the period of six months to carry out water waste and hydraulic surveys. The report of Pitometer Associates is included and evaluated in the Appendix. Advance copies of this report have been submitted to WASA.

Consumption and demand in each zone are described in the chapter on WATER REQUIREMENTS.

Specific recommendations as to waste and losses control measures are set forth in the chapters on WATER REQUIREMENTS, RECOMMENDED

DEVELOPMENT PROGRAM, and CONCLUSIONS AND RECOMMENDATIONS of the Preliminary Report on the Long Term Program, and in the chapters on ORGANIZATION AND ADMINISTRATION and METERING of the report on Organization and Administration.

The measures described include a continuing investigation of waste and losses, repair of leaking valves, repair or replacement of leaking pipes and reduction of excessive pressures.

The effect of these measures on the availability of additional water has been considered in the development of the Long Term Program and its First Stage. These programs have been based on a reduction of the percentage of unaccounted for water from a presently estimated 33 percent to a predicted 20 percent.

During the investigation the Consultant has worked with WASA, made suggestions for interim improvements, and helped in the implementation of the recommended projects. The following are some of the improvements achieved to date as a direct result of the Feasibility Study:

1. A recommended connection made to the 12-inch main east of boreholes 1 and 2 at the Tacarigua borehole field increased well production from these two boreholes by 0.10 mgd.
2. A recommended pump change at the Arima borehole high-lift pumping station increased production from this source by 0.17 mgd while reducing power demands by 25 percent. Also a recommendation to supply the

southern half of Arima with a direct connection to the Hollis trunk main was implemented by the construction of a new 12-inch main in Pro Queen Street. The new main and increased borehole supply have increased pressures in Arima appreciably.

3. Field measurements in St. James in Port of Spain resulted in the location and elimination of a substantial amount of waste which increased the average water level in the Knaggs Hill reservoir from 6 to 13 feet.
4. In Diego Martin approximately 161 leaks were located and repaired, resulting in an estimated reduction in demand of 1.0 mgd.

Recommendations for additional waste, loss, and pipe condition investigations were adopted by WASA and further work in these areas was authorized which will continue the water waste and hydraulic surveys until the end of December 1970.

A plan for a metering program is presented in the chapter on METERING in the Report on Organization and Administration. The recommended implementation of this plan is further detailed in the chapter on RECOMMENDED DEVELOPMENT PROGRAM.

The Consultant has been required by both sections 5 and 6 of the Description of the Project for Interim Program to develop an adequate rating system and make recommendations for the establishment of a revenue producing rate structure and rate setting procedure. In this exercise he was required to cooperate with or review the work of

PAHO consultants..

The results of this work are set forth in the report on Organization and Administration. The report of PAHO of September 1968 was reviewed and is discussed in the Report on Organization and Administration. The Consultant cooperated with PAHO consultants on the subject of rates and revenues, accounting procedures, and on operation and maintenance but received no additional documents for review.

The subjects listed in section 6 of the Description of Project, Interim Program, have been studied by the Consultant. Details of these studies together with the Consultant's conclusions and recommendations are presented in the Report on Organization and Administration.

ANNEX C

Following is a list of the Ministries, Departments and other agencies of Government which have contributed time, effort and information to the study:-

MINISTRY OF FINANCE

Permanent Secretary
Valuations Division

MINISTRY OF PLANNING AND DEVELOPMENT

Director of Planning
Town and Country Planning Division

MINISTRY OF PUBLIC UTILITIES AND HOUSING

Permanent Secretary
Trinidad & Tobago Electricity Commission
National Housing Authority
Port Authority
Meteorological Service

MINISTRY OF AGRICULTURE

Permanent Secretary
Chief Technical Officer
Crown Lands Division
Lands and Survey Department
Mapping and Control Section
Central Experimental Station

MINISTRY OF PETROLEUM AND MINES

Permanent Secretary
Geological Section

MINISTRY OF HOME AFFAIRS

Permanent Secretary
Immigration Department
Police Division

MINISTRY OF WORKS

Director of Drainage

MINISTRY OF INDUSTRY AND COMMERCE

Industrial Development Corporation

CENTRAL STATISTICAL ORGANIZATION

In addition, significant contributions were made by the Faculty of Engineering and the Seismic Department of the University of the West Indies.