JUNE, 1962 to Panama Canal Company

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STUDY AND REPORT

ON

Increasing The Water Supply Of The Panama Canal

FOR

PANAMA CANAL COMPANY

BALBOA HEIGHTS, CANAL ZONE

TUDOR ENGINEERING COMPANY • San Francisco

APR 16 1999

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June 1, 1962

Panama Canal Company
Balboa Heights, Canal Zone

ATTN: Colonel M. C. Harrison, C.E., U.S.A.
Engineering and Construction Director

Gentlemen:

We are pleased to submit herewith our study and report on "Increasing the Water Supply of the Panama Canal." This report is submitted in accordance with the provisions of a Contract for Engineering Services, No. PC-2-780 dated 10 July 1961, Modification No. 1 dated 31 October 1961 and Modification No. 2 dated 6 April 1962.

This study and report particularly considers the construction of a Dam across Trinidad Arm of Gatun Lake, Canal Deepening by five feet, and Pumping Sea Water into Gatun Lake. To a lesser extent it also considers construction of a dam on the Chagres River above the existing Madden Dam, raising Gatun Lake by one foot and by five feet, and constructing a Cano Quebrado Dam. All of the latter projects are unattractive either because they do not produce sufficient water storage or are too costly for the results obtained.

A Dam across Trinidad Arm of Gatun Lake, the Canal Deepening or Pumping Sea Water into Gatun Lake are feasible projects and any one of them would provide the necessary additional water for navigation for a reasonable time into the future even in low water years. Initially in these studies, only a preliminary investigation was made of the Pumping Sea Water into Gatun Lake as it was presumed this would not be attractive. However, this preliminary consideration indicated that such a proposal does have considerable merit and a more complete study was authorized by Contract Modification No. 2.

The more complete study of Pumping Sea Water into Gatun Lake shows this method of providing an increased water supply for the Panama Canal involves the least initial capital cost and the facilities can be built in increments generally as required to meet any traffic growth up to the ultimate lockage capacity of the Canal. However, the operating and maintenance costs are high and thus make the overall economy of the plan less attractive than a Dam across Trinidad Arm of Gatun Lake.

The Canal Deepening will provide for more additional lockages than a Dam across Trinidad Arm of Gatun Lake but the capital cost of the deepening is considerably greater than the dam.

Because a Dam across Trinidad Arm of Gatun Lake has the greatest overall economic attractiveness, providing it is built in conjunction with the current Canal Widening project, and for other reasons which are covered in the report, we recommend that it be selected for construction.

As a corollary to this study it is indicated that there may be a substantial advantage in adding to the generating capacity of the Madden Dam power plant and we recommend that this possibility be more completely explored.

We desire to avail ourselves of this opportunity to express our sincere appreciation for the unstinted cooperation and assistance rendered by all departments and personnel of the Canal Company in the conduct of this study.

Very truly yours,

Ralph A. Tudor

Study and Report on

INCREASING THE WATER SUPPLY OF THE PANAMA CANAL

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I. AUTHORIZATION

This report is submitted in accordance with the terms and provisions of a Contract for Engineering Services, No. PC-2-780 between the Panama Canal Company and Tudor Engineering Company dated 10 July 1961, including Modification No. 1 dated 21 October 1961 and Modification No. 2 dated 6 April 1962.

II. PURPOSE AND EXTENT OF REPORT

The basic purpose of this report is to provide results of studies of schemes for increasing the water supply and navigational depths of the Panama Canal. As corollaries to this basic purpose the matters of flood control and power generation have been considered.

The contract provides that the extent of the work shall include the following:

1. A feasibility study of the construction of a Dam across the Trinidad Arm of Gatun Lake using spoil material from the widening project at Las Cascadas-Bas Obispo Reaches. The study will include preliminary designs, estimates and construction procedures for the construction of embankments, spillways, control gates and other necessary facilities.

2. Review of the presently approved program for Cut Deepening with reference to the cost estimate and the feasibility or difficulties inherent in the project, based upon various methods of accomplishment in the face of increasing marine traffic.

3. Comparison of the advantages and disadvantages of the Cut Deepening and Dam across Trinidad Arm of Gatun Lake projects from the point of view of water supply, navigation depths, flood control, power generation and other benefits.

4. Review of other methods of providing additional water storage for lockage purposes and brief description of their advantages or disadvantages.

5. A brief review of the power generation potential at Gatun and the feasibility of developing additional power by means of low head turbines in connection with a Dam across Trinidad Arm of Gatun Lake or by pump storage elsewhere.

6. The necessary reconnaissance and on-site examination of field conditions for the purposes of the study recommend a minimum core boring program for obtaining foundation data at the site of a Dam across Trinidad Arm of Gatun Lake.

Modification No. 1 authorizes geophysical explorations in Gatun Lake by refraction seismograph and electrical resistivity methods to determine the depth to bedrock and to delineate overburden strata of proposed locations for a Dam across Trinidad Arm of Gatun Lake.

Modification No. 2 authorizes additional work to make a more detailed analysis of the installation and operation of pumping facilities for providing additional water required for lockage purposes, and comparison of the advantages and disadvantages of this pumping and a Dam across Trinidad Arm of Gatun Lake.

III. DAM ACROSS TRINIDAD ARM OF GATUN LAKE

1. General

It is proposed to construct a Dam across Trinidad Arm of Gatun lake near Escobal on the Atlantic side of the Isthmus. It will extend from Punta Mala on the west shore of Gatun Lake to Gaucha Island thence to Tern and Booby Islands in turn and finally to the east shore. See Figure 1.

By retaining and storing water behind a Dam across Trinidad Arm of Gatun Lake during the wet season up to eleven feet higher than the normal maximum water surface of Gatun Lake, the water available for operation of the Canal will be increased by 430,000 acre feet. The usuable storage now available in Gatun and Madden Lakes is 519,600 and 445,150 acre feet respectively, for a total of 964,750 acre feet. The increase will thus be 44-1/2%.

The proposed Dam across Trinidad Arm of Gatun Lake will be approximately 14,400 feet long of which some 8500 feet will be constructed in water up to 77 feet in depth. It will be a unique construction project but one with many similarities to a project constructed in 1955-1960 across Great Salt Lake where 31,000,000 cubic yards of material was placed for a railroad causeway. The foundations of the two projects are similar in that both are soft lake bottom mud, high in water content and having no shear strength. The two foundation conditions are dissimilar in that the mud thickness at the Greater Salt Lake site is about 25 feet and that at the dam site across Trinidad Arm of Gatun Lake is as much as 75 feet. The fill at the Greater Salt Lake site was not placed on the mud but the mud was removed so that the fill could be placed on a salt layer. The fill material had to be quarried and it was found to be more economical to remove the soft material over the salt layer rather than spread the load over an extended base width with a resulting increase in the fill quantity.

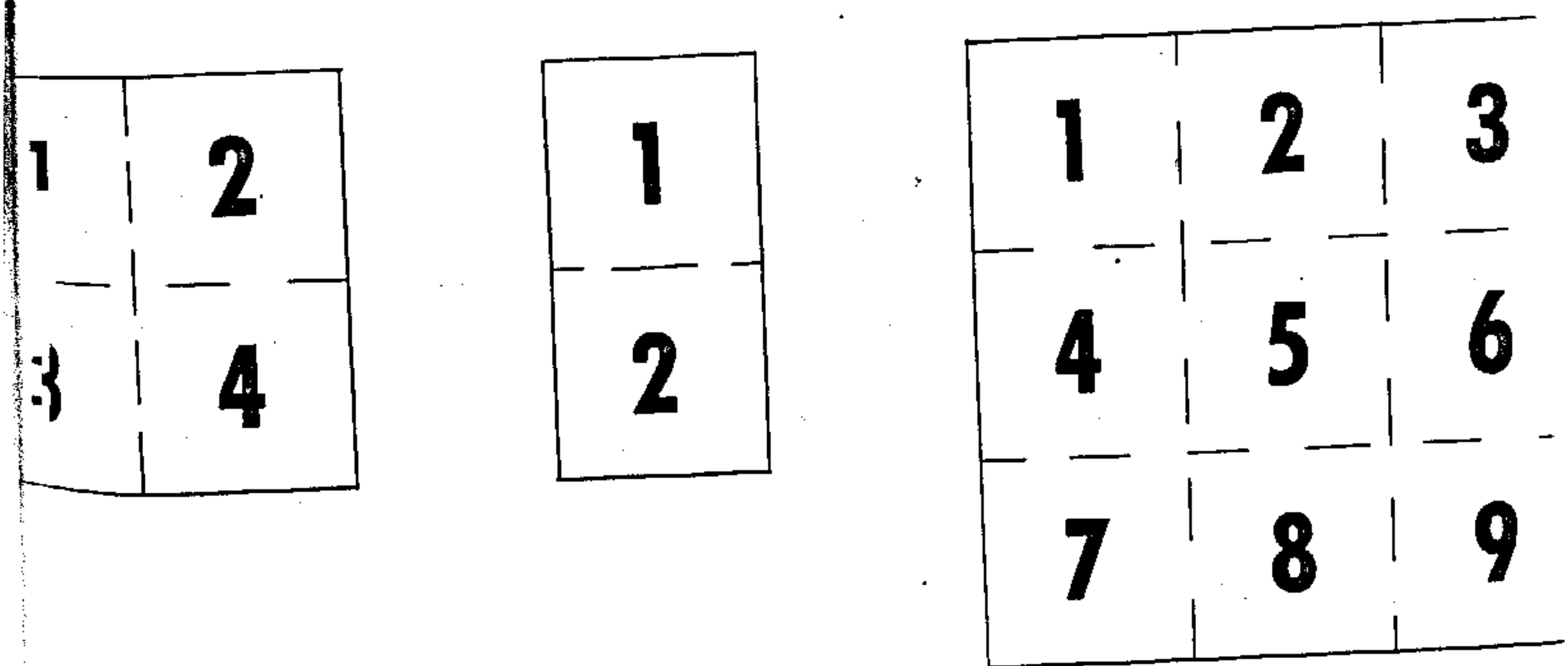
2. Geological Conditions

The geology of the site of the dam was explored by geophysical methods and for this the firm of Geo-Recon, Inc. of Seattle, Washington was retained. There report is in Appendix A.

In order to provide controls for the geophysical observations, the Canal Company made three cored borings along the line of the dam between the west shore and Gaucha Island and a forth boring between this island and Tern Island.

These investigations disclosed that overburden material found in the water areas include recent lake deposits, Atlantic Muck Formation, alluvial deposits, and residual overburden. Between the west shore and Gaucha Island (see Figure 10) these deposits consist of soft to very soft clay, silt, sand and peat (Atlantic Muck Formation) overlying soft to hard deposits of clay, silt, sand and gravel derived both from alluvial deposition and the weathering of bedrock. The Atlantic Muck Formation has an average thickness of about

Maps on this order too large to be entirely included in one exposure are filmed clockwise beginning in the upper left hand corner, left to right and top to bottom as many frames as required. The following diagrams illustrate the method:



60 feet and a maximum thickness of 75 feet. In the lengths between Gaucha Island and Booby Island (see Figure 11), the Atlantic Muck Formation was not found and the overburden material is composed of soft silt and clay with thin zones of organic material over weathered rock.

Virtually all overburden is characterized by high water content and low plasticity, and it is moderately to highly compressible. It is unstable and will be compressed and displaced by the fill material and the dam.

The three islands which are on the axis of the dam, all have an overlying stratum of soft overburdened weathered rock of variable thickness. In general, bedrock is available below elevation +75. The islands offer suitable foundation condition for control structures.

The results of the geophysical surveys and test borings indicate that the site for a Dam across Trinidad Arm of Gatun Lake is underlain by sedimentary bedrock composed primarily of sandstone and siltstone. Recorded seismic velocities are substantially lower than those recorded over a known section of Gatun Formation in the vicinity of Coco Solo Hospital, indicating a softer formation at the side for the Dam across Trinidad Arm of Gatun Lake.

3. Hydrology

The hydrology of the Panama Canal area is characterized by a dry season that normally extends from about mid-December to the first of May. The lowest recorded net inflow into the Canal reservoirs for the dry season was 3 cfs in 1920.

Following the dry season there is normally a period of approximately five months of local thunder showers that will last from a few minutes to several hours. Over the drainage area these storms are neither general nor uniform.

During the remaining two and a half to three months of the fall season, flood producing storms of prolonged heavy rains often covering the entire drainage area are common. This is a particularly difficult situation as these storms come when it would be most desirable, from a water conservation viewpoint, to fill all reservoirs but it is necessary to reserve space for flood control.

The design storm for watersheds in the Canal Zone covers a six-day period and rainfall reaches a maximum during the sixth day. The average amount of rainfall for the period is estimated to be 39.5 inches on the 1285 square mile area above Gatun Dam. The percentages of the total design storm rainfall increase daily and amount to 7, 8, 12, 16, 24 and 33 percent for each 24-hour period. The peak inflow of the resulting design flood occurs on the sixth day and exceeds 1,000,000 cfs for the Gatun watershed.

The minimum annual runoff from the Gatun Lake drainage basin after deducting evaporation losses occurred in 1905 and was 2,710,000 acre feet. The most critical pair of years was 1929 and 1930, with net runoffs of

3,240,000 and 2,720,000 acre feet respectively. The records of annual runoff show that at several times there were two successive dry years but never three in succession that produced a water supply more critical than these.

4. Dam Design and Construction

It is proposed to build most of the underwater portions of the Dam across Trinidad Arm of Gatun Lake by barge dumping of material excavated in connection with the Canal Cut Widening program. This widening program extends for approximately 8-1/2 miles along the canal from Pedro Miguel Locks to the vicinity of Gamboa. Through this length the canal is being widened from 300 feet to 500 feet. Some of the widened portion is also being deepened by 5 feet. A typical cross section is shown in Figure 2. The widened portions of Paraiso and Cucaracha Reaches have been deepened and the widened portion of Empire Reach is being deepened under an existing contract. It is not contemplated to deepen the Las Cascadas-Bas Obispo Reaches, or the previously widened Culebra Reach.

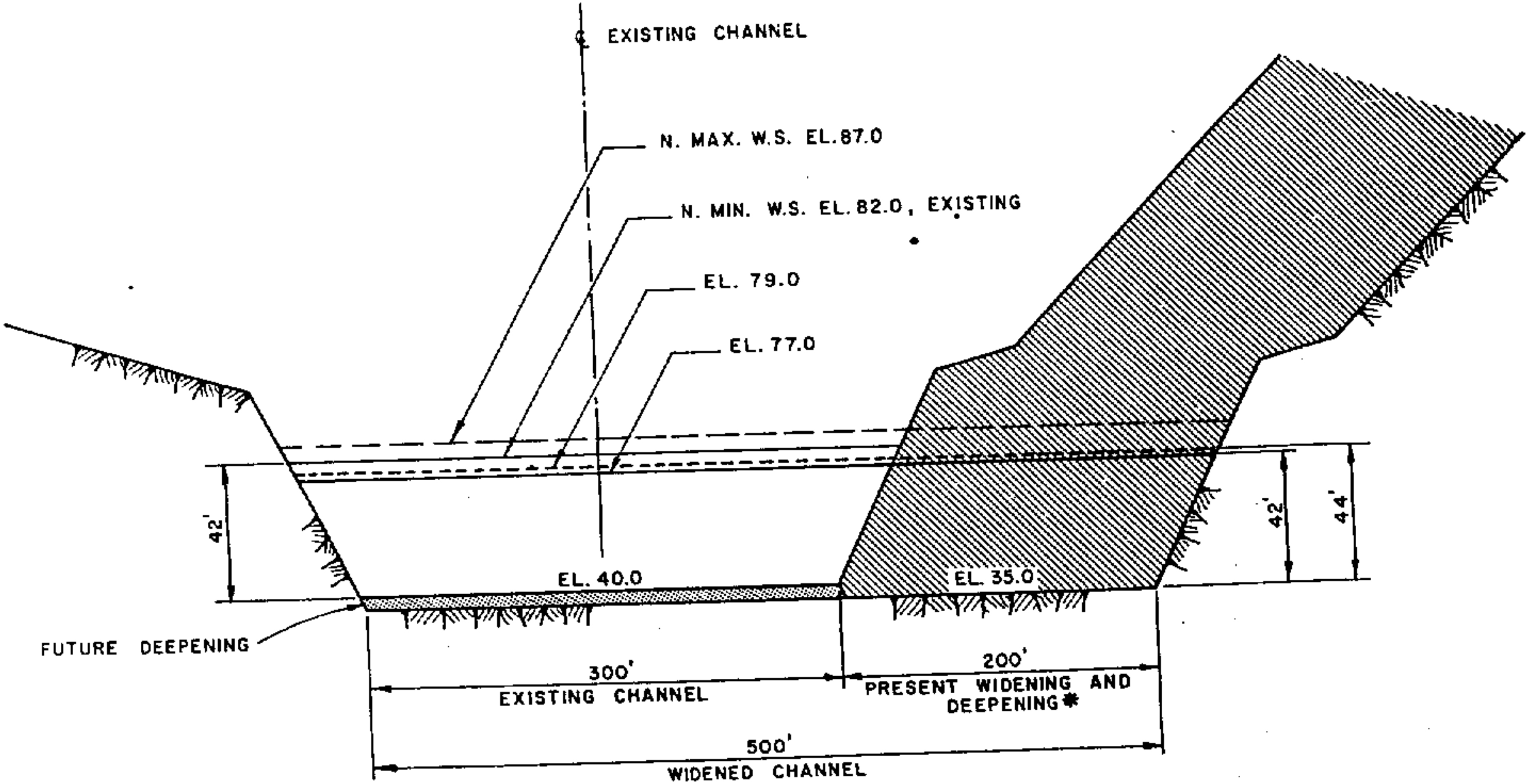
In the widening operation, the procedure until recently, has been to remove the material above elevation about +95 by contract and dispose of it on the high ground back of the canal. The material below elevation +95 was broken up by contract and then removed by Canal Company dipper dredges and bottom dump barges to disposal areas in flooded sections outside the navigation channel. Consideration is being given to changing this procedure whereby the contractor would excavate all material and be responsible for disposing of it either by truck haul to the waste areas away from the canal or to lake dumps, as determined by economics.

To construct a Dam across Trinidad Arm of Gatun Lake, material excavated from the Cut Widening would be loaded on bottom dump barges, transported to the site and dumped along the axis of the structure up to elevation +75. The cost of this material charged against the Dam across Trinidad Arm of Gatun Lake, which comprises over 90% of the required fill for the dam project, will only be the extra cost in handling and hauling.

The Cut Widening program that will remain to be accomplished after the current fiscal year will be the Las Cascadas-Bas Obispo Reaches. This is a canal length of about 3-1/4 miles, estimated to produce 5,860,000 cubic yards of overburden, 5,660,000 cubic yards of soft rock and 5,000,000 cubic yards of hard rock for use in the dam. This will probably bulk not less than 15%, giving a total placed volume of some 19,000,000 cubic yards.

A cross section of the dam between Punta Mala and Gaucha Island is shown on Figure 9. Due to the poor quality of the underlying material, it will be necessary to have a wide-based dam for most of this length. Preliminary designs fix this width at approximately 1000 feet. Based upon test data from the Monte Lirio Railroad Fill, it is assumed that the compression and displacement of the soft underlying material will amount to 30% of the cross section of the dam.

For the dam between Gaucha Island and Tern Island it is estimated that the base width will be about 750 feet.



TYPICAL CROSS SECTION
IN GAILLARD CUT

* NO DEEPENING TO BE DONE WITH WIDENING PROJECT IN BAS OBISPO - LAS CASCADAS REACH

FIGURE NO. 2

The Swedish Slip Circle method of analysis was employed to develop a stable cross section for the dam. For each of the various depths of soft underlying materials several trial circles ranging from shallow to deep depths were computed and for each section the circle exhibiting the minimum factor of safety was accepted as critical and controlling. The minimum factor of safety used was 1.25.

For these calculations the characteristics of the materials were assumed as follows:

Weight of embankment material above El. +79	120 lbs. per cu. ft.
Submerged weight of embankment material below El. +79	57.3 lbs. per cu. ft.
Submerged weight of foundation material	43.0 lbs. per cu. ft.
Cohesion strength of fill material	0.0 lbs. per sq. ft.
Angle of internal friction of fill material	17 degrees
Strength of foundation material*	See report "Stability Analysis, Monte Lirio Railroad Fill" Panama Canal, Special Engineering Division

* Since the Dam across Trinidad Arm of Gatun Lake will be built over a five-year period, it is assumed that most of the consolidation of the foundation material due to the superimposed embankment load will have occurred during construction and that the shear strength of this foundation material will be comparable to that found for the Monte Lirio Railroad Fill foundation.

The design analysis made for this report must be recognized as preliminary. For a final design, extensive soils test data and detailed design studies will be necessary. However, the preliminary design studies made to date show the feasibility of the plan and give quantities sufficiently accurate for purposes of general cost estimates and comparison with other methods of providing an increased water supply for the Panama Canal.

Further tests on Atlantic Muck may show a requirement for considerably larger quantities of fill material than those estimated from the comparison with Monte Lirio data.

In constructing the Dam across Trinidad Arm of Gatun Lake, it is proposed to first bring all underwater sections up to about elevation +45 with material from the cut widening. This would be a first pass along the length of the dam. A second pass would follow to bring the level up to about elevation +75. Barged material cannot be bottom-dumped above this level. The operations to this point will cover a period of about three years and during this time most of the settlement should occur. It is estimated that these operations will require some 11,500,000 cubic yards of material. It thus appears that there will be some 7,500,000 cubic yards of cut widening spoil that will be surplus to the needs of this work.

The portion of the dam above elevation +75 will be built of suitable material excavated from the spillway and borrowed from nearby sources as required. This will be accomplished by end dumping from trucks. If suitable material is available from the cut widening, about 600,000 cubic yards could be placed economically by the use of platform barges or by dumping below elevation +75 and rehandling by dragline or clamshell. The crest of the dam will be carried to elevation +105 and both faces above elevation +75 will be protected from wave damage by selected riprap and filter material 5 feet thick.

Raising the water level behind the Dam across Trinidad Arm of Gatun Lake will necessitate making the low saddles along the ridge line between the lake and the Atlantic Ocean secure against spillage and seepage. The existing Cano Saddle Dam will have to be raised from 2 to 5 feet and it is believed that additional compacted material and a filter drain will have to be added to the section on the face away from the lake. This will insure against failure and keep the seepage line within the section of the dam. See Figure 15.

Two additional low dams will have to be built in the Cano Saddle and another in the Lagarto Saddle. The Escobal and Arroyo saddles appear to be adequately high without dams. All of these points will have to be more fully studied but no serious problems are anticipated.

5. Spillway and Control Gates

A gated spillway is proposed to be built on Gaucha Island where foundation conditions are suitable. This will have a total length of 1200 feet. The individual gates will be of the bascule or leaf type 200 feet long by 8 feet high, each operated by four hydraulic cylinders. There will be six such gates and the control will be from a central station. See Figures 10, 12 and 13.

The gated type of spillway was selected since it provides an additional 120,000 acre feet of storage over that which would be provided by an ungated spillway. It should be noted that no calculations have been made to determine the elevations of the backwater curve during floods. In the final analysis this must be done to avoid infringing on the 100 foot contour (outside the Canal Zone) upstream from the dam. It is believed that proper operating procedures based on data supplied by the telemetering reporting system will avoid this difficulty.

The level of Trinidad Lake above elevation +90 will be controlled by the spillway gates. Below this elevation the lake level will be controlled by operation of the lock or lock control gates.

The spillway design flood for Trinidad Lake is based upon the design storm for Madden Dam in the Third Locks study. A comparison of U. S. Weather Bureau data for the two watersheds indicates that a storm in the Trinidad watershed would have approximately 93% of the rainfal in the Madden watershed. Synthetic unit hydrographs for sub-areas of the Trinidad Lake watershed were developed by Snyder's method. These and an inflow unit hydrograph for the entire watershed are shown on Figures 3 and 4. This hydrograph was applied to a six-day storm, with an average rainfall of 42.9 inches on the 286 square mile area to develop the design flood. In keeping with practice adopted by the Panama Canal Company, this flood was increased 30 percent for use as the design flood for the Dam across Trinidad Arm of Gatun Lake spillway. The six-day storm hydrograph with the increase is shown on Figure 4. Peak inflow on the sixth day is 300,000 cfs. By making full use of the telemetering service and assuming the water in Trinidad Arm Lake at elevation +98 when the storm inflow starts, the outflow peak will be 134,000 cfs on the sixth day. The maximum elevation of Trinidad Arm Lake at the dam will then be 99.1 feet.

6. Navigation Lock

A navigation lock must be included to provide passage for vessels between Gatun and Trinidad Arm lakes. The present plans show this to be located on Gaucha Island. Further investigations may reveal navigation hazards from the spillway currents which would require location of the navigation lock at the Punta Mala end of the dam. Either site would require considerable relocation of the existing navigation channel but it cannot be avoided due to the need for good foundation conditions for the lock structure.

The proposed lock will be 65 feet long by 25 feet wide and the minimum draft over the sills will be 10 feet with both lake levels at a minimum elevation of +82 feet. See Figure 14.

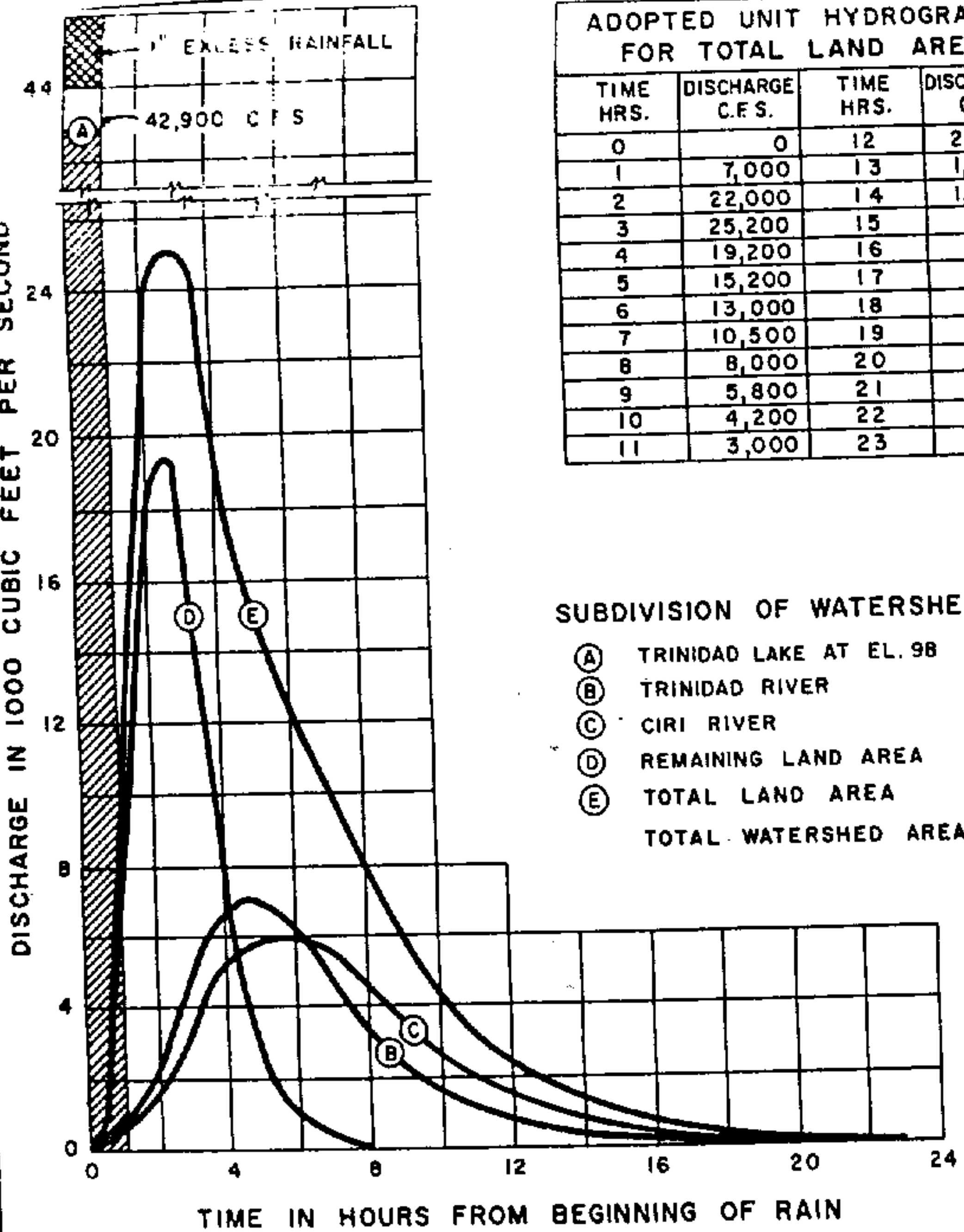
7. Navigation Benefits

Within the limits imposed for safe operation, such as control of floods, the navigational needs of Canal traffic have first claim on the use of all available water. This dictates that tests must be made of water storage plans against conditions of lockage water requirements for maximum estimated future traffic and minimum water supplies.

The Stanford Research Institute made an estimate of Canal traffic and lockages (1.15 transits per lockage) to the year 2000. This estimate ranged from conditions of prosperity to conditions of depression and is summarized below:

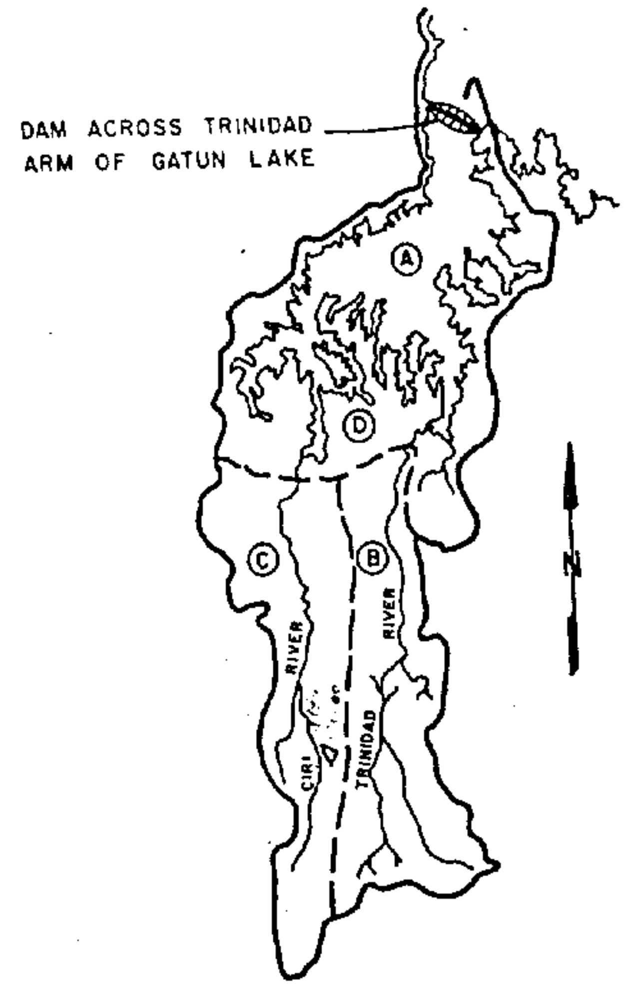
Lockages

Year	Prosperity Cycle	Average	Depression Cycle
1965	32.6	28.5	24.1
1970	35.8	31.1	26.2
1980	41.5	36.1	30.4
1990	46.8	40.7	34.3
2000	52.1	45.3	38.1



ADOPTED UNIT HYDROGRAPH FOR TOTAL LAND AREA			
TIME HRS.	DISCHARGE C.F.S.	TIME HRS.	DISCHARGE C.F.S.
0	0	12	2,200
1	7,000	13	1,600
2	22,000	14	1,200
3	25,200	15	900
4	19,200	16	650
5	15,200	17	500
6	13,000	18	350
7	10,500	19	250
8	8,000	20	150
9	5,800	21	100
10	4,200	22	50
11	3,000	23	0

	SUBDIVISION OF WATERSHED	SQ. MI.
(A)	TRINIDAD LAKE AT EL. 98	67
(B)	TRINIDAD RIVER	67
(C)	CIRI RIVER	72
(D)	REMAINING LAND AREA	80
(E)	TOTAL LAND AREA	219
	TOTAL WATERSHED AREA	286



MAP OF WATERSHED

TRINIDAD DAM
INFLOW UNIT HYDROGRAPH

FIGURE NO. 3

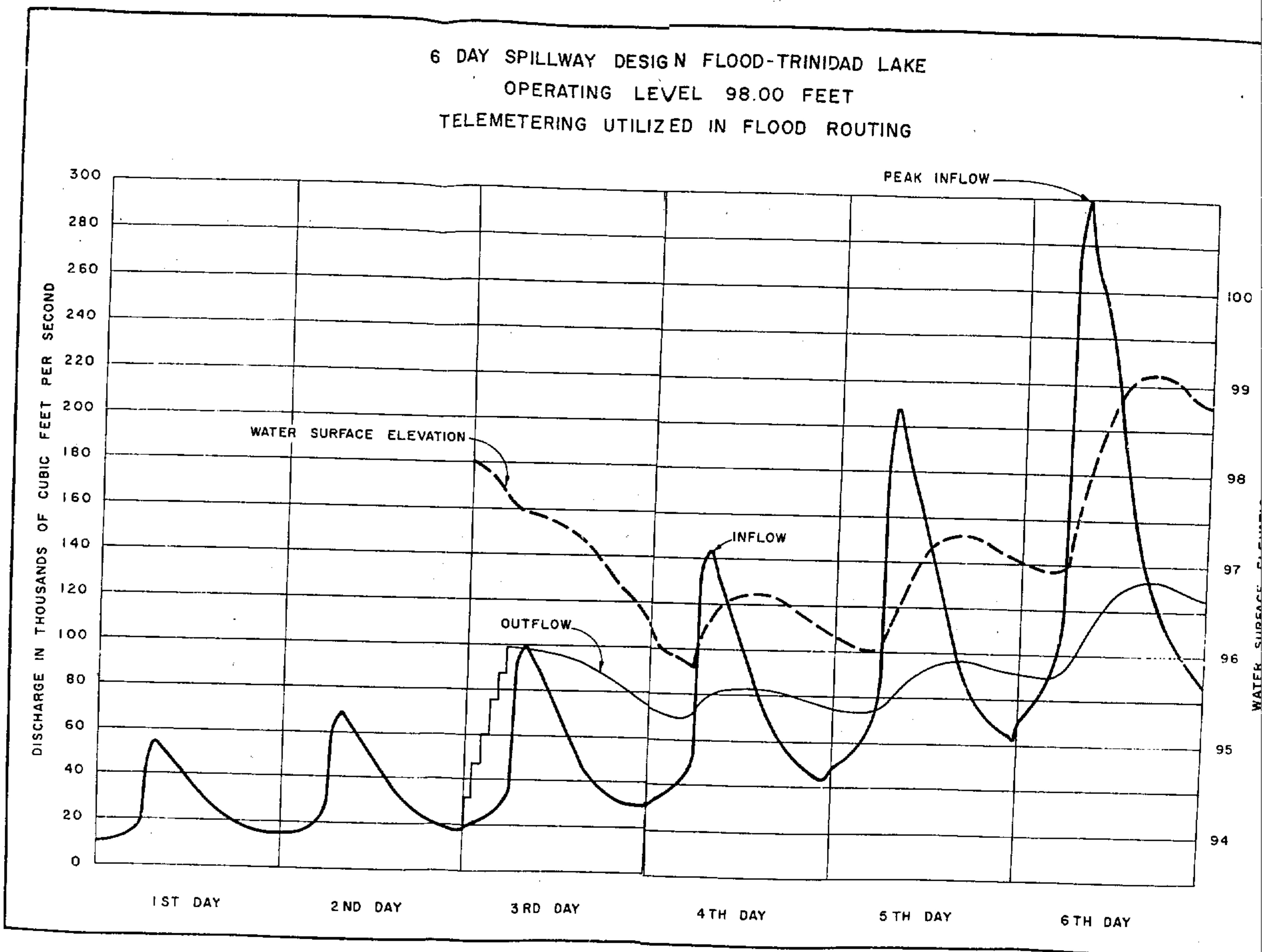

6 DAY SPILLWAY DESIGN FLOOD-TRINIDAD LAKE
OPERATING LEVEL 98.00 FEET
TELEMETERING UTILIZED IN FLOOD ROUTING
PEAK INFLOW
WATER SURFACE ELEVATION
INFLOW
OUTFLOW
DISCHARGE IN THOUSANDS OF CUBIC FEET PER SECOND
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
100
99
98
97
96
95
94
1ST DAY
2ND DAY
3RD DAY
4TH DAY
5TH DAY
6TH DAY

FIGURE NO.

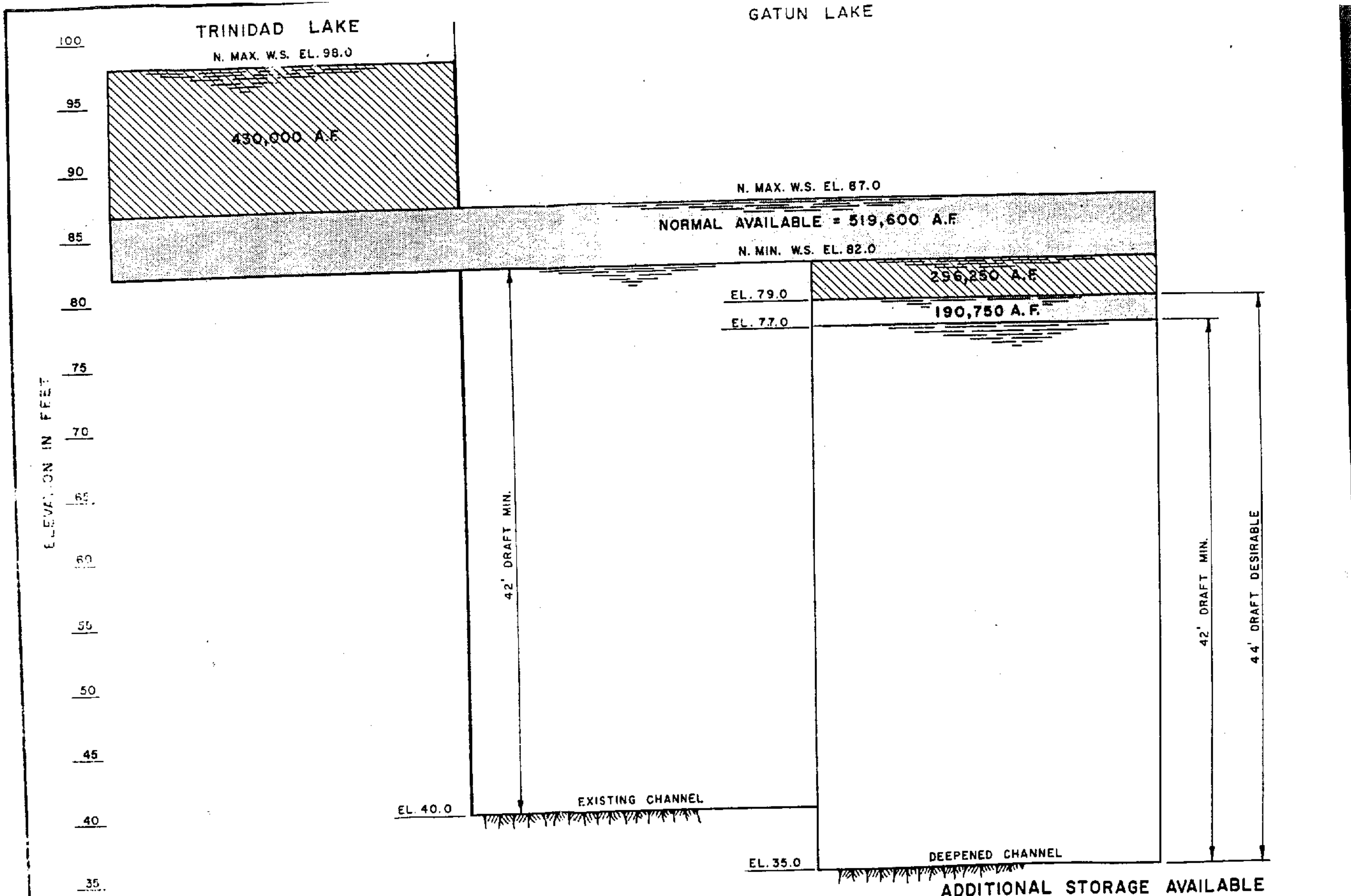
A test was made to determine what maximum traffic could be handled during the most critical dry season under three combinations of water storage facilities. These conditions are (1) with the existing storage in Gatun Lake and Madden Reservoir, (2) with a Dam across Trinidad Arm of Gatun Lake added to the existing facilities, and (3) with Canal Deepening added to the existing facilities. The test assumed that Gatun Lake water surface can be drawn down to elevation +82.0 without Canal Deepening and to elevation +77.0 with Canal Deepening. These conditions are shown in Figure 5.

Usable storage available with existing facilities is 965,000 acre feet; with a Dam across Trinidad Arm of Gatun Lake it would be 1,395,000 acre feet; and with Canal Deepening it would be 1,452,000 acre feet. Each plan includes the 445,000 acre feet of usable storage in Madden Lake.

All subsequent discussions and operation studies are based upon the following storages:

Unit	Between Elevations	Storage (acre feet)
Gatun Lake with Trinidad Arm	77-79	191,000
"	79-82	296,000
"	82-87	520,000
"	82-84	210,000
"	84-87	310,000
Gatun Lake without Trinidad Arm	82-87	345,000
"	82-84	140,000
"	84-87	205,000
Trinidad Reservoir	82-84	70,000
"	84-87	105,000
"	87-98	430,000
Madden Lake	200-250	445,000

The most critical dry season of record occurred in the five months from January through May of 1920. The test for this period is summarized in Table A. It has been assumed that the additional evaporation loss which can be anticipated from the formation of Trinidad Lake would be 7% greater than now experienced on Gatun Lake, including Trinidad Arm. Water requirements for lockage are assumed to vary with the surface elevation of Gatun Lake and, during the dry season, to average 161.5, 160.3, and 155.0 acre feet per lockage respectively for conditions with existing facilities, with the Dam across Trinidad Arm of Gatun Lake and with Canal Deepening.



ADDITIONAL STORAGE AVAILABLE
DUE TO CONSTRUCTION OF
TRINIDAD DAM OR DEEPENING CHANNEL 5'

FIGURE NO. 5

TABLE A

LOCKAGE CAPACITY WITH EXISTING FACILITIES
WITH A DAM ACROSS TRINIDAD ARM OF GATUN LAKE
AND WITH CANAL DEEPENING Critical Dry Season (1920)
(Gatun Lake drawdown to Elevation +82.0 with Trinidad,
+ 77.0 with Canal Deepening)
(Quantities of water are tabulated in acre feet)

	Existing	With Trinidad w/o Deepening	With Deepening w/o Trinidad
DRY SEASON (JAN-MAY Incl.)			
Water in storage at beginning	965,000	1,395,000	1,452,000
Net inflow	+ 1,000	+ 1,000	+ 1,000
Municipal water used @ 110 cfs	- 33,000	- 33,000	- 33,000
Additional evaporation loss @ 7% of recorded evaporation	0	- 20,000	0
Available for lockages and power	933,000	1,343,000	1,420,000
Average number of lockages per day	38.3	55.1	60.7
Water used for lockages:			
@ 161.5 af/lockage	-933,000		
@ 160.3 af/lockage		-1,343,000	
@ 155.0 af/lockage			-1,420,000
Water in storage on June 1st	0	0	0

Note: These are theoretical considerations but are reasonable for purposes of comparison. In actual operations some usable storage must be left on June 1st.

8. Power Benefits

The generating plants now or shortly to be available to the Canal Company are as follows:

Plant	Type	No. of Units	Installed Capacity	Notes
Madden Dam	Hydro	3	24,000 KW	(1)
Gatun Dam	Hydro	6	22,500 KW	(2)
Thermal Plant	Gas Turbine	2	21,600 KW	(3)
Total except stand-by			68,100 KW	
Stand-by diesel plants			14,000 KW	(4)
Total			82,100 KW	

(1) Two units installed in 1934 and a third unit in 1942. All units converted from 25 to 60 cycles in 1958-59.

(2) Three new generators of 3000 KW each installed in 1958-59 to replace older smaller units. A fourth new generator of 4500 KW installed at same time to replace older unit. Fifth and sixth generators of 4500 KW were originally installed in 1946 and 1947. One of these was converted from 25 to 60 cycles in 1958-59 and the other is yet to be converted. Turbines are those originally installed in each case.

(3) This plant now under construction.

(4) These are old units that are costly to operate and cannot be depended upon for sustained operation at their installed capacity.

With the increasing demand for water because of the increase in number of lockages, there is a decreasing supply for hydro generation. As a result, the two hydro plants are becoming less and less dependable. In fact, the Gatun Dam plant is, for all practical purposes, only available for energy and can no longer be depended upon for much capacity in dry years. As traffic increases, the capability of the plant to help meet peak requirements will further decrease.

The company has estimated future annual electrical loads as follows:

Fiscal Year	Gross Energy in kwh	Peak Demand in KW
1961 (actual)	301,927,270	50,100
1962	332,600,000	52,900
1965	466,900,000	72,000
1970	558,000,000	84,900

It is presumed that the hydroelectric plants will be used to their maximum capabilities consistent with the primary claim for water for navigation needs and operation of the reservoirs for necessary flood control. The more expensive thermal plants will be used to provide capacity and energy required beyond the capabilities of the hydro plants.

Reservoir operation studies were made to determine the power production available on a predictable basis from the hydro plants. These studies utilized stream flow records for the period 1905 through 1948. This period includes the driest period of record which was the basis for determining the maximum dependable power that could be produced.

The power studies were made for various levels of canal traffic as estimated for the future and for combinations of (1) the existing facilities, (2) existing facilities plus the Dam across Trinidad Arm of Gatun Lake as described in this report, and (3) existing facilities plus deepening the canal by 5 feet. Operation studies to determine energy production were made on a shortened period believed to represent "average" water conditions. It has been assumed that the Madden Power Plant will be operated as a base load unit with a minimum capacity of 16,000 KW. All operation studies were made by an electronic computer.

A summary of "Power Production and Requirements" for the years 1965 and 1970 is given in Table B. Corresponding data for other years may also be tabulated but it has been found that the resulting difference between the hydro power produced by the two projects is nearly the same regardless of the year.

The termal units presently under construction have a dependable capacity of 21,600 KW and can produce 189,200,000 kwh per year. If the standby diesel plants are added, the capacity is increased to 35,600 KW. However, age and condition of the diesel units is such that they cannot be depended upon except in emergency. Thus, by operating Madden as a base load plant and operating the gas turbine plant 100% of the time, the planned facilities will be deficient in meeting the estimated energy requirements in 1965 by nearly 20,000,000 kwh and will be deficient in peaking capacity by 31,900 KW. Even the old diesel plants cannot meet this capacity requirement. If the Dam across Trinidad Arm of Gatun Lake or the Canal Deepening could be completed by 1965 there would still be a deficiency in capacity. However, it must be recognized that neither of these improvements can be completed by 1965. By 1970 the deficiency in both energy and capacity becomes more pronounced.

TABLE B

POWER PRODUCTION AND REQUIREMENTS
"Average Water Conditions"

For 1965 - Prosperity Cycle Canal Traffic at 33 Lockages Per Day

Installation	Hydro Power Produced o Energy * (kwh)	Hydro Power Produced o Capacity ** (kw)	Total Power Required *** Energy (kwh)	Total Power Required *** Capacity (kw)	Thermal Power Required Energy (kwh)	Thermal Power Required Capacity (kw)
(1) Existing Facilities	258,230,000	18,500	466,900,000	72,000	208,670,000	53,500
(2) Dam across Trinidad Arm of Gatun Lake plus (1)	269,904,000	25,500	466,900,000	72,000	196,696,000	46,500
(3) Canal Deepening plus (1)	260,537,000	24,500	466,900,000	72,000	206,363,000	47,500

For 1970 - Prosperity Cycle Canal Traffic at 36 Lockages Per Day

Installation	Hydro Power Produced o Energy * (kwh)	Hydro Power Produced o Capacity ** (kw)	Total Power Required *** Energy (kwh)	Total Power Required *** Capacity (kw)	Thermal Power Required Energy (kwh)	Thermal Power Required Capacity (kw)
(1) Existing Facilities	212,579,000	16,000	558,000,000	84,900	345,421,000	68,900
(2) Dam across Trinidad Arm of Gatun Lake plus (1)	262,208,000	23,000	558,000,000	84,900	295,792,000	61,900
(3) Canal Deepening plus (1)	252,788,000	21,700	558,000,000	84,900	305,212,000	63,200

* Average annual kwh for period of study
** Dependable in low water year
*** Estimates furnished by Panama Canal Company
o No direct relation exists between capacity and energy because operation studies provided for increases in capacity during months of large inflow.
oo Difference in power produced between a Dam across Trinidad Arm of Gatun Lake and Canal Deepening is the difference in minimum water surface of Gatun Lake for the two conditions.

In fiscal year 1965 an approximate 22,000 KW thermal generating unit will be installed adjacent to the two new gas turbines. This unit will be a steam turbine and will make use of the waste heat from the gas turbines, with provision for oil firing when the gas turbines are not in operation.

If canal traffic does not come up to the prosperity cycle estimate or if there is better than an average water year, the deficiencies, if any, will not be as great as indicated. On the other hand if a water deficient year occurs or canal traffic is in a high cycle the deficiencies would be greater.

More detailed studies with various combinations of operating procedures for the various plants under adverse water conditions should be made in order to determine the true hazard of power deficiencies. Until this is done the foregoing estimates should be accepted only as indicative of the problem. However, the figures do give a good measure of the comparative contributions which the various improvements studied will make toward meeting the future power requirements, and this is the true purpose of the study.

Table C, "Comparison of Power Production," shows the additional power and its value creditable to a Dam across Trinidad Arm of Gatun Lake and the Canal Deepening. The figure of 21.7 mils per kilowatt hour used to compute the value of energy represents the average difference between the total costs of generating diesel power and hydro power in the Canal Zone during the past three years. These costs were:

	1959	1960	1961	Average
Hydro cost at generator/kwh	0.001977	0.002079	0.001716	.001924
Diesel cost at generator/kwh	0.020645	0.028793	0.021357	.023598
			Difference	.021674

A part of the diesel cost is the fuel oil at $0.0085 per kwh. Hydro power available to meet the power demand will effect a saving in annual expenditures for this item. The difference favoring a Dam across Trinidad Arm of Gatun Lake over the Canal Deepening from the saving in this item above would amount to approximately $80,000 annually. Total costs are operation, maintenance, depreciation and supervision.

The advantage of a Dam across Trinidad Arm of Gatun Lake as compared to the Canal Deepening project is valued at approximately $203,000 per year. With interest at 2-5/8% over 20 years, this represents a capitalized value of approximately $3,127,000, or to the year 2000 a capitalized value of approximately $4,319,000.

9. Flood Control Benefits

As discussed heretofore concerning the spillway and control gates, a Dam across Trinidad Arm of Gatun Lake will have the effect of reducing the peak flow into Gatun Lake on the sixth day of the design flood by 166,000 cfs. This is the difference between the inflow to the Trinidad drainage basin and the design discharge of the spillway in a Dam across Trinidad Arm of Gatun Lake. Other than this, Trinidad Reservoir will not improve the flood control conditions over that provided by Gatun Lake with or without Canal Deepening.

TABLE C

COMPARISON OF POWER PRODUCTION WITH
DAM ACROSS TRINIDAD ARM OF GATUN LAKE
AND WITH CANAL DEEPENING

	1965			1970		
	Energy (KWH)	Capacity (KW)	Value/yr	Energy (KWH)	Capacity (KW)	Value/yr
Dam across Trinidad Arm of Gatun Lake	11,674,000*	7,000 *	$253,300 **	49,619,000*	7,000 *	$1,076,700 **
Canal Deepening	2,307,000*	6,000 *	$ 50,100 **	40,209,000*	5,700 *	$ 872,500 **
Difference favoring Dam across Trinidad Arm of Gatun Lake	9,367,000	1,000	$203,200	9,420,000	1,300	$ 204,200

* Excess over that provided by existing facilities--See Table B.
** Assumed at 21.7 mils per KWH. No credit shown for additional firm power at Madden since both plans would provide nearly equal benefit.

10. Timing of Construction

If a Dam across Trinidad Arm of Gatun Lake is to be built, there is a compelling reason why it should be done concurrently with the present Cut Widening program. By such concurrent construction, the cost of the fill material for the estimated 11,500,000 cubic yards placed below elevation +75 will be about 18 cents per cubic yard. If the work is not done concurrently and this fill material must be obtained from quarries in the vicinity of the dam, the cost is estimated at not less than 67 cents per yard. This would increase the cost of the Trinidad project by an estimated $5,635,000, exclusive of a contingent allowance on this amount.

The Canal Deepening program would produce material that could be used in a Dam across Trinidad Arm of Gatun Lake but the total suitable for the purpose would probably be less than the amount required.

11. Incorporation with Other Canal Improvements

If, at some future date a third set of locks is added, a Dam across Trinidad Arm of Gatun Lake will produce the same results as shown in the study for this report. If, at some future date the existing canal is converted to a sea level canal, Trinidad Lake will provide flood control in accordance with plans presently developed. However, for this purpose, the dam need not be as high as required in the study for this report.

If a new canal should be built in a location outside the present Canal Zone and the existing canal facilities converted to power generation, Trinidad Lake would be more effective in producing power than a Canal Deepening project. This is due to the greater effective head resulting from the higher water surface maintained because of the added storage at the higher elevation.

12. Time and Cost Estimates

a. Time

The Canal Company estimates that the Canal Widening through the Las Cascadas-Bas Obispo Reaches will continue through approximately three years beginning about October 1962. This corresponds to the time for placing the dumped fill of the dam below elevation +75. Very little other work on a Dam across Trinidad Arm of Gatun Lake can go on concurrently, primarily because the materials to be excavated for the lock and the spillway will be used to top out the dam. This topping out operation and the completion of the lock and spillway will require an estimated additional thirty months. Thus the estimated completion date will be about mid-1968. See Figure 6 for the construction schedule.

Since the last section of the Cut Widening program is to be let for contract during 1962, it is essential that an early decision be reached concerning the Dam across Trinidad Arm of Gatun Lake project.

b. Costs

The estimated cost of construction of a Dam across Trinidad Arm of Gatun Lake is shown on Table D.

In the estimated cost of construction, particular attention is called to the item for the dam fill below elevation +75.0. This is the material that will come from the Cut Widening program and 18 cents per cubic yard charged against the Dam across Trinidad Arm of Gatun Lake is the difference between the cost of wasting this material in the vicinity of the excavation and the cost of hauling it to the dam. The Panama Canal Company engineers have estimated this difference at the figure used. It is the low cost of this material that makes a Dam across Trinidad Arm of Gatun Lake so attractive economically.

The item for contingencies is taken as 20% of construction costs. This is comparatively high but until more detailed information is available on sub-surface conditions and the designs have been carried to greater refinement, this is considered to be reasonable.

The estimated cost of a Dam across Trinidad Arm of Gatun Lake including allowances for contingencies, administrative and engineering is $10,078,000. If this is amortized over a period of 50 years with interest at 2-5/8% the annual amortization cost would be $364,000. The estimated average annual cost of maintenance and operation until the year 2000 is $106,000. Thus for the period from the completion of a Dam across Trinidad Arm of Gatun Lake to 2000 the total cost of maintenance and operation and amortization of debt is estimated at $15,275,000.

TABLE D

CONSTRUCTION COST ESTIMATE
FOR A DAM ACROSS TRINIDAD ARM OF GATUN LAKE

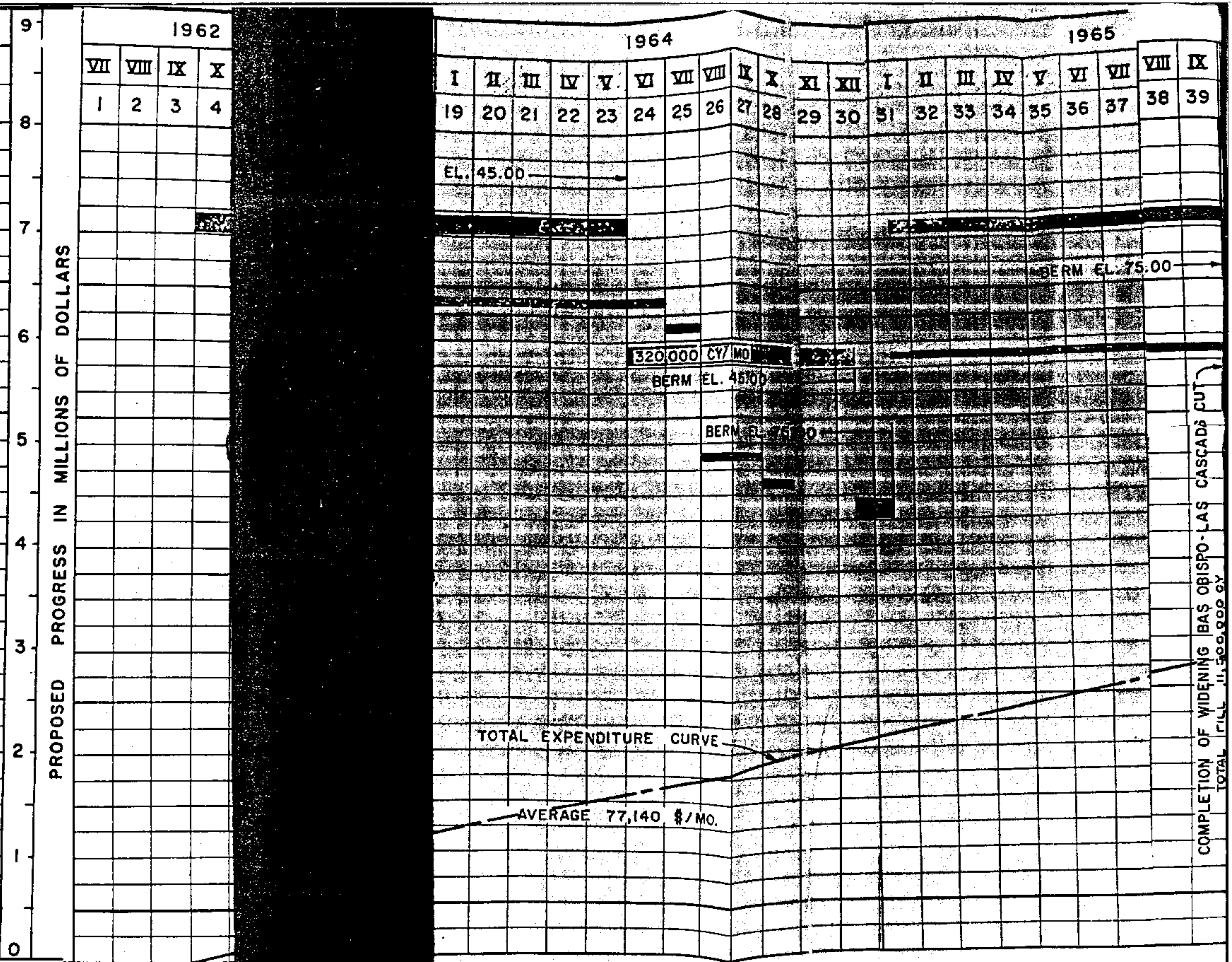
Dam Section	Quantity	Unit	Unit Price $	Amount $	
ta Mala - Gaucha Island					
Access Road to Punta Mala from S 10	2,800	l. ft.	35	98,000	
2. Clearing the abutments under water	14.3	acres	3,700	53,000	
Clearing above water surface	4.1	acres	2,400	10,000	
Dam fill below El.+75.0	8,150,000	cy	.18	1,467,000	
Dam fill above El.+75.0	547,500	cy	.67	366,000	
Riprap including bedding 5 feet thick	139,400	cy	2.50	348,000	
Total					$2,342,000
aucha Island - Tern Island					
Clearing the abutment under water	35.8	acres	3,700	132,500	
8. Clearing above water surface	0.6	acres	2,400	1,500	
9. Dam fill below El.+75.0	3,029,000	cy	.18	546,000	
10. Dam fill above El.+75.0	339,000	cy	.67	227,500	
1. Riprap including bedding 5 feet thick	86,000	cy	2.50	214,500	
Total					1,122,000
ern Island - Booby Island					
12. Access Road on Tern Island	1,110	l. ft.	35	39,000	
13. Clearing the abutment under water	3.8	acres	3,700	14,000	
14. Clearing above water surface	0.4	acres	2,400	1,000	
15. Dam fill below El.+75.0	142,000	cy	.18	25,500	
16. Dam fill above El.+75.0	53,000	cy	.67	35,500	
17. Riprap including bedding 5 feet thick	14,000	cy	2.50	35,000	
Total					150,000

Dam Section	Quantity	Unit	Unit Price $	Amount $	
Booby Island - Main Land					
18. Access Road on Booby Island	460	l.ft.	35	16,000	
19. Clearing the abutments under water	7.7	acres	3,700	28,500	
20. Clearing above water surface	.85	acres	2,400	2,000	
21. Dam fill below El.+75.0	185,000	cy	.18	33,500	
22. Dam fill above El.+75.0	109,000	cy	.67	73,000	
23. Riprap including bedding 5 feet thick	30,000	cy	2.50	75,000	
Total					$228,000
Spillway on Gaucha Island					
24. Clearing above water surface	9.6	acres	2,400	23,000	
25. Excavation	570,000	cy	.25	142,000	
26. Excavation for cut off wall	3,310	cy	5.00	16,500	
27. Concrete for cut off wall ogee, retaining walls and pavement	17,300	cy	70	1,210,000	
28. Reinforcing steel	970,000	lbs.	.15	145,000	
29. Care of water	L.S.	---	---	30,000	
30. Bascule gates 6 8'x200'	L.S.	---	---	1,300,000	
31. Control House	L.S.	---	---	8,000	
32. Steel Sheet Piling MP 110	500,000	lbs.	.20	100,000	
Total					2,975,000
Navigation Lock on Gaucha Island					
33. Clearing above water surface	2.2	acres	2,400	5,200	
34. Excavation above water surface	71,200	cy	.25	17,800	
35. Excavation below water surface	15,000	cy	3.00	45,000	
36. Relocation of navigation channel	6,200	l.ft.	14.00	87,000	

Dam Section		Quantity	Unit	Unit Price $	Amount $	
Navigation Lock on Gaucha Island (Continued)						
37.	Care of water	L.S.	---	---	12,000	
38.	Concrete	2,700	cy	100.	270,000	
39.	Reinforcing steel	270,000	lbs	.15	40,500	
40.	Lock gates: 4 lock gates	80,000	lbs	.40	32,000	
41.	4E motors @ 20 hp and gear reducer	L.S.	---	---	16,000	
42.	Operator House 11'x17' h=12'	4	each	4,000	16,000	
43.	Control gates 60"x60"	2	each	1,750	3,500	
44.	Service bridge	L.S.	---	---	9,500	
45.	Diesel generator 50 KW	L.S.	---	---	4,000	
46.	Generator house	L.S.	---	---	2,000	
47.	Trash rack and miscellaneous steel	5,300	lbs	.35	2,000	
48.	Stop logs	53,000	lbs	.35	18,500	
49.	Electrical & telephone installation	L.S.	---	---	3,000	
	Total					$ 584,000
50.	Enlarge existing Cano Saddle Dam			155,000		
51.	Cano Saddle Dam No. 1			26,000		
52.	Cano Saddle Dam No. 3			43,000		224,000
	Sub total					$ 7,625,000
	Administration & Contingencies @ 20%					1,525,000
	* Engineering including foundation explorations, surveys, designs and supervision of construction					928,000
	Total estimated cost					$10,078,000

* Computed @ 7% of estimated construction cost without applying potential savings from concurrent Cut Widening Project

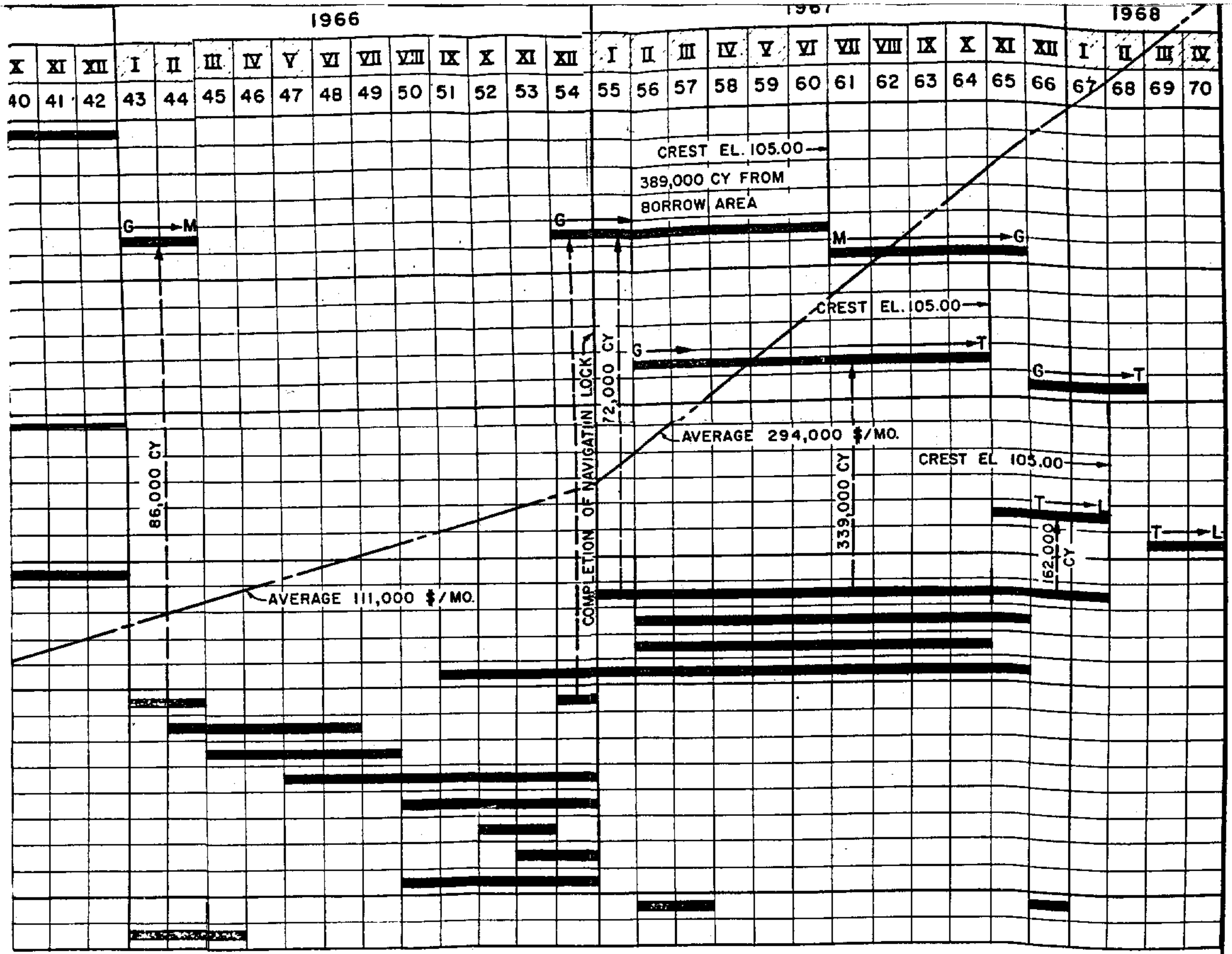
		YEAR
		CALENDAR MONTH
		MONTH SEQUENCE
DAM SECTION A	1	ACCESS ROAD TO PUNTA MALA FROM SIO
	2	CLEARING THE BASE UNDER WATER
	3	CLEARING THE BASE ABOVE WATER
	4	DAM FILL BELOW EL. 75
	5	DAM FILL ABOVE EL. 75
	6	RIPRAP INCLUDING BEDDING
DAM SECTION B	7	CLEARING THE BASE UNDER WATER
	8	CLEARING THE BASE ABOVE WATER
	9	DAM FILL BELOW EL. 75
	10	DAM FILL ABOVE EL. 75
	11	RIPRAP
DAM SECTION C + D	12	ACCESS ROAD TERN ISLAND AND BOOBY ISLAND
	13	CLEARING THE BASE UNDER WATER
	14	CLEARING THE BASE ABOVE WATER
	15	DAM FILL BELOW EL. 75
	16	DAM FILL ABOVE EL. 75
	17	RIPRAP
ISLA GAUCHA SPILLWAY	18	CLEARING ISLA GAUCHA ABOVE WATER SURFACE
	19	EXCAVATION
	20	CONCRETE FOR CUTOFF WALL, OGEE, PAVEMENT, PIPING
	21	CARE OF WATER
	22	BASCULE GATES INCLUDING CONTROLL STATION
ISLA GAUCHA NAVIGATION LOCK	23	EXCAVATION
	24	CARE OF WATER
	25	CONCRETE
	26	STOP LOGS, LOCK GATES, CONTROLL GATES, TRASH RACKS
	27	OPERATOR HOUSES, MACHINERY, DIESEL GENERATOR
	28	SERVICE BRIDGE
	29	ELECTRICAL AND TELEPHONE INSTALLATION
	30	RELOCATION OF NAVIGATION CHANNEL
SP	31	STEEL SHEET PILING
	32	CANO SADDLES



LEGEND

DAM A = PUNTA MALA - ISLA GAUCHA
DAM B = ISLA GAUCHA - TERN ISLAND
DAM C = TERN ISLAND - BOOBY ISLAND
DAM D = BOOBY ISLAND - MAIN LAND

M = PUNTA MALA
G = ISLA GAUCHA
T = TERN ISLAND AND BOOBY ISLAND
L = MAIN LAND



DAM ACROSS TRINIDAD
ARM OF GATUN LAKE
CONSTRUCTION SCHEDULE

FIGURE NO. 6

IV. CANAL DEEPENING

1. Plan

The canal channel bottom is now being maintained at elevation +40 feet. The elevation of the upper sills of the Gatun and Pedro Miguel Locks are at elevation +37.3 feet. Under existing operating conditions, the minimum water level in Gatun Lake is +82.0 which assures not less than a 42-foot depth of navigable water in the cut. Ships drawing up to 37 feet in fresh water are regularly accepted for passage but any greater draft can only be permitted as an emergency and such ships would probably have to be handled by tugs. A 37-foot draft gives 5 feet of clearance under the bottom which is considered a minimum for ships moving under their own power. This minimum can be decreased over the lock sills where large ships are normally towed.

If the channel bottom is lowered 5 feet to elevation +35, Gatun Lake could be drawn down to elevation +77 and still preserve a 5.0-foot clearance for 37-foot draft ships in the canal and a 2.7-foot clearance over the lock sills. However, there is some feeling that the 5-foot margin is inadequate and should be increased to not less than 7 feet. In this event, with the channel bottom at elevation +35, Gatun Lake could only be drawn down to elevation +79 feet. See Figure 2.

If the channel is deepened 5 feet and a drawdown to elevation +77 feet is permitted, the additional storage that may be drawn on for lockages amounts to 487,000 acre feet. If a drawdown only to elevation +79 feet is permitted, the additional available storage for lockages will be 296,000 acre feet. See Figure 5.

In this section of this report the comparative effectiveness of the alternative methods for improving the water supply is based on the assumption that whether a Dam across Trinidad Arm of Gatun Lake is built or the canal deepened, the minimum depth of water will be 42 feet.

2. Navigation Benefits

The deepening of the canal by 5 feet will permit drawing Gatun Lake down to elevation +77.0 and still maintain the present 42-foot minimum depth of water except over the lock sills where it will be 39.7 feet. This drawdown will produce an additional usable storage of 487,000 acre feet, which can be used for lockage purposes. The availability of this storage reduces the probability of imposing navigation restrictions during periods of low runoff.

A distinct advantage of Canal Deepening will be to decrease the average lift of ships through the locks. This in turn requires less water per lockage and thus increases the number of lockages possible with the water in storage.

The quantitative effect on navigation of additional storage from Canal Deepening has already been reviewed in Paragraph III-7 of this report. It shows that the average number of lockages per day during the critical dry season of 1920 could theoretically be increased from the present 38.3 to 60.7. This increase in lockage capacity will take care of estimated traffic growth beyond the year 2000.

3. Power Benefits

The additional power that can be produced if the canal is deepened as been discussed in Paragraph III-8. It was shown that the value in 1970 of this additional power from the Canal Deepening project will be approximately ^872,500 per year. This is approximately $204,000 less than the value of dditional power from a Dam across Trinidad Arm of Gatun Lake will produce.

4. Flood Control Benefits

The deepening of the canal will not improve the control of floods over that which can now be provided by Gatun Lake.

5. Incorporation with Other Canal Improvements

If the existing canal is altered at some future date to provide a third set of locks, the deepening of the canal would be fully effective. If a sea level canal is built in the Canal Zone, approximately 38% of the deepening would be creditable to the sea level project. Excavation in the remaining 62% is outside the proposed alignment of a sea level canal.

If a new canal should be built in a location outside the present Canal Zone and the existing canal facilities converted to power generation, the Canal Deepening would contribute to the extent of more water storage. However, it would be substantially less effective than a Dam across Trinidad Arm of Gatun Lake in the production of power due to a lesser effective height for the water to fall.

6. Navigation Interference

For most of the portion of the Cut Widening program which has been completed, the widened portion of the channel will be 5 feet deeper than the original channel. For the 3-1/4 mile length of canal through the Las Cascadas-Bas Obispo Reaches to be contracted next, this extra depth is not being included. The original 300-foot width of canal will have to be deepened along approximately 5-1/4 miles of initial widening. For the remaining length through the Las Cascadas-Bas Obispo Reaches and through Gatún Lake the deepening would change for the full width of channel.

The deepening operation can be carried out so that never less than 200 feet of channel will be available for ships to pass the dredges, barges and other equipment. The channel will undoubtedly be restricted in width at several points and this will continue for an estimated period of six years. Each restriction will constitute a hazard to navigation and particular care will have to be taken to avoid accidents. During periods of adverse weather, some restrictions may have to be placed on operations either of transiting ships or of the deepening work.

It is not possible to assess the hazard of interference with navigation, but it must be accepted as a detrimental factor that will extend over a period of six years.

7. Time and Cost Estimates

a. Time

The Canal Company has estimated that it will require six years construction time to complete the Canal Deepening project. Assuming that no dredging or barge equipment will be employed in the widening of the Las Cascadas-Bas Obispo Reaches, there will be no operational reason for delaying the Canal Deepening. On this basis the Canal Deepening could be carried out simultaneously with the Cut Widening, and completed by the end of 1968. However, since improvements are being financed from current revenues and the program of Cut Widening and lock gate overhaul procedures is expected to consume most of the available funds through fiscal year 1964-65, it is probable that a more realistic completion date for the deepening would be 1971.

b. Cost

The Canal Company has estimated the cost of Canal Deepening through Gaillard Cut and Gatun Lake to elevation +35 as follows:

Gaillard Cut	Dipper Dredge - 3,800,000 cubic yards of excavation @ $1.52	$5,776,000
	Drilling & Blasting - 1,000,000 cubic yards @ $2.34	2,340,000
	Gaillard Cut Construction Cost	$8,116,000
Gatun Lake	Dipper Dredge - 2,000,000 cubic yards @ $1.52	$3,040,000
	Drilling & Blasting - 300,000 cubic yards @ $1.98	594,000
	Suction Dredge - 10,400,000 cubic yards @ $0.50	5,200,000
	Gatun Lake Construction Cost	$8,834,000
	Canal Deepening Project Construction Cost	$16,950,000
	Engineering @ 5%	850,000
	Total Cost Canal Deepening Project	$17,800,000

Allowances for contingencies are included in the unit prices.

V. PUMPING SEA WATER INTO GATUN LAKE

1. General

A study was made of the costs involved and the resulting benefits of providing an additional water supply by pumping sea water into Gatun Lake. This study is based upon providing sufficient water at all times for an average of 50 lockages per day and the maintenance of not less than a 44-foot depth of water in the cut for navigation. The minimum water level in Gatun Lake for this purpose would be elevation +84.0.

It was assumed that the pumping plant would be located immediately west of Gatun Dam. The deep pool below the spill raceway could serve as the supply since it has a sea level connection to the Atlantic side. However, dredging might be required to assure adequate flow from the ocean. Discharge into Gatun Lake would be made through penstocks approximately 1,000 feet long. See Figures 1 and 16 for the facility location and details.

2. Capacity

A most critical year of record was 1920, and this year was used as a basis for determining pump capacity. Restricting drawdown on Gatun Lake to elevation +84.0 changes the lockage capacity from that presented in previous sections of this report. The effect of this change may be seen in Table E, "Lockage Capacity With Existing Facilities, With a Dam across Trinidad Arm of Gatun Lake and With Pumping Plant." Comparing data in Table E with Table A it will be noted that lockages with a Dam across Trinidad Arm of Gatun Lake decrease from 55.1 to 45.7 per day. However, based upon the water records for the 57-year period from 1905 through 1961, and assuming a 44-foot navigable depth, there were only three years (1920, 1926 and 1957) when lockage capacity with a Dam across Trinidad Arm of Gatun Lake would have been less than 50 per day. Even under these conditions, 50 lockages per day could be accommodated with the lake level reduced below elevation +84.0 between the last week of April and first week in August as shown on the "Chart of Water Surface Elevations," Figure 7. The minimum water surface elevation in 1920 would be close to +82.0.

Under 1920 water conditions and assuming 167 acre feet per lockage, 1,262,000 acre feet of water must be available from storage or storage and pumping during the five-month period January through May to provide 50 lockages per day. After allowing for natural inflow, evaporation and storage existing on January 1, the pumping plan would theoretically require 539,000 acre feet of supplementary water to be pumped during the minimum water year. Under practical operating conditions the amount of pumped water would be more.

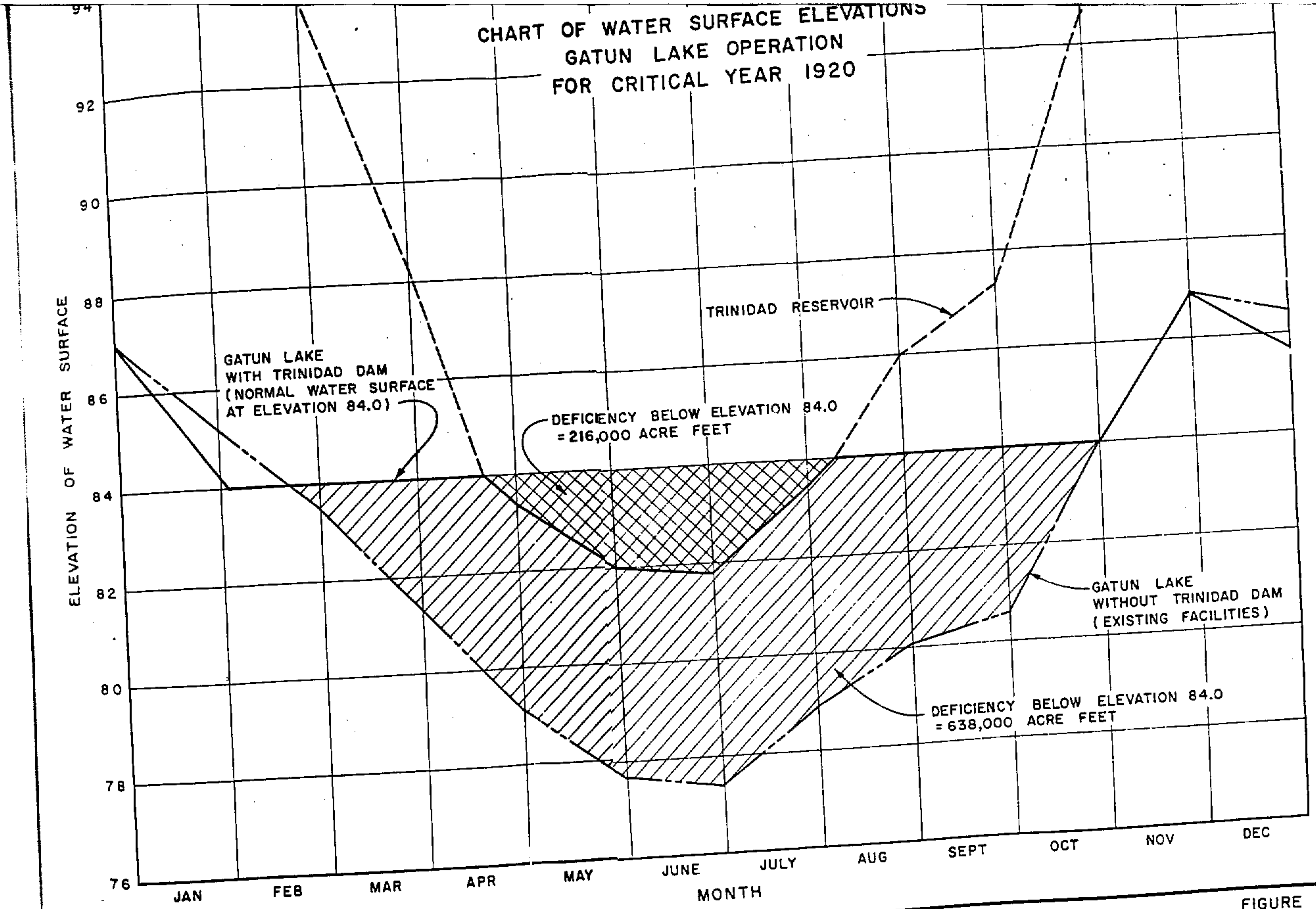


CHART OF WATER SURFACE ELEVATIONS
GATUN LAKE OPERATION
FOR CRITICAL YEAR 1920
ELEVATION OF WATER SURFACE
94
92
90
88
86
84
82
80
78
76
TRINIDAD RESERVOIR
GATUN LAKE
WITH TRINIDAD DAM
(NORMAL WATER SURFACE
AT ELEVATION 84.0)
DEFICIENCY BELOW ELEVATION 84.0
=216,000 ACRE FEET
GATUN LAKE
WITHOUT TRINIDAD DAM
(EXISTING FACILITIES)
DEFICIENCY BELOW ELEVATION 84.0
=638,000 ACRE FEET
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
MONTH

FIGURE NO. 7

TABLE E

LOCKAGE CAPACITY WITH EXISTING FACILITIES, WITH A DAM ACROSS TRINIDAD ARM OF GATUN LAKE AND WITH PUMPING PLANT

Critical Dry Season (1920)
(Gatun Lake drawdown to Elevation +84.0)
(Quantities of water are tabulated in acre feet)

DRY SEASON (JAN-MAY Incl.)	Existing	With Trinidad	With Pumping
Water in storage at beginning	755,000	1,185,000	755,000
Net natural inflow	+ 1,000	+ 1,000	+ 1,000
Net pumped inflow	0	0	+ 539,000
Municipal water used @110 cfs	- 33,000	- 33,000	- 33,000
Additional evaporation loss @ 7% of recorded evaporation	0	- 20,000	0
Available for lockages and power	723,000	1,133,000	1,262,000
Average number of lockages per day	29.1	45.7	50.0
Water used for lockages:			
@ 164.9 af/lockage	- 723,000		
@ 164.1 af/lockage		-1,133,000	
@ 167.0 af/lockage			-1,262,000
Water in storage on June 1st	0	0	0

Note: These are theoretical considerations. In actual operations some usable storage must be left on June 1st.

Table F, "Gatun Lake Operation With Pumping," is a tabulation by months of water supply and demand in a dry year with an average of 50 lockages per day and Gatun Lake level maintained at not lower than elevation +84.0. The assumptions upon which this tabulation is based are as follows:

a. Gatun and Madden Lakes are full on January 1st with usuable capacities of 310,000 and 445,000 acre feet respectively.

b. Water used for normal lockages varies with the surface elevation of Gatun Lake as follows:

Elev. 87.0	173.6 acre feet/lockage
Elev. 86.0	169.0 acre feet/lockage
Elev. 85.0	166.2 acre feet/lockage
Elev. 84.0	162.4 acre feet/lockage

c. Releases from Maden Dam are those necessary to maintain 16,000 KW of firm capacity.

It will be noted that the accumulated deficiency through the months from February through June is 638,000 acre feet. This would have to be made up by pumping.

Although there is a peak monthly deficiency of 210,000 acre feet in April, it is not considered necessary to provide a pumping plant with 3,550 cubic feet per second capacity to meet such a demand within one month. An operating procedure should be established for anticipating the water requirements in advance, with the size of the pumping plant based on conditions set up in the operating procedure. Presumably this would be based upon inflow records of some previous period such that, with decreasing inflow, pumping would increase to meet the needs of a "dry" dry season. The criteria would vary with lockage activity. For purposes of this study, it has been assumed that the rate of pumping in any one month would be determined by the inflow of the previous month, as shown in Table G, "Criteria for Pump Operation." It provides for pumping in the early months to help overcome possible deficiencies in later months. The criteria have been tested and found to satisfy the 1920 needs. The test of these criteria for 1920 is shown in Table H, "Gatun Lake Operation, 1920, with Pumping Plant."

Refinements may be found desirable to meet conditions in other years. The criteria are considered satisfactory for the purpose of this study, which is to determine the relative merits of a Pumping Plant as compared to a Dam across Trinidad Arm of Gatun Lake.

A plant with a capacity of 2,400 cfs can adequately handle the water needs for 50 lockages per day with the water supply as low as that recorded for 1920. Assuming pump efficiency at 80% and total dynamic head at 105 feet, pump capacity to supply 2,400 cfs would require approximately 36,000 horsepower or 27,000 kilowatts.

TABLE F

GATUN LAKE OPERATION
With Pumping
(Gatun Lake drawdown to Elevation +84.0)
50 Lockages per day
(Low Water Year)

	MADDEN LAKE					GATUN LAKE							
Month	Storage at Beginning (Elev.200-250)	Elev.	*Net Inflow	**Total Outflow	Change in Storage	Storage at Beginning (Elev.84-87)	Elev.	Net Inflow Downstream from Madden	Total Net Inflow	Lockage Water	Municipal Water @ 110 cfs	Change in Storage	Theoreti Pumping Require or (Spil
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Jan.	445	250	55	102	- 47	310	87.0	- 14	88	-264	-7	-183	---
Feb.	398	247	25	96	- 71	127	85.3	- 46	50	-231	-6	-127	50
Mar.	327	240	19	99	- 80	0	84.0	- 49	50	-252	-7	--	209
Apr.	247	232	14	100	- 86	0	84.0	- 60	40	-244	-6	--	210
May	161	222	28	111	- 83	0	84.0	6	117	-252	-7	--	142
June	78	212	127	110	+ 17	0	84.0	113	223	-244	-6	--	27
July	95	214	187	110	+ 77	0	84.0	289	399	-255	-7	+137	---
Aug.	172	224	219	102	+117	144	85.4	292	394	-264	-7	+123	---
Sept.	289	236	142	94	+ 48	274	86.65	211	305	-259	-6	+ 49	---
Oct.	337	241	295	185	+108	310	87.0	670	855	-269	-7	--	(579)
Nov.	445	250	226	226	---	310	87.0	400	626	-261	-7	--	(358)
Dec.	445	250	132	132	---	310	87.0	91	223	-268	-7	- 52	---

Note: All figures except elevations (Columns (3) and (8)) are in thousands of acre feet
* Evaporation losses have been subtracted from figures published in tables, since in 1920 net inflow and total runoff were the same at the site of Madden Dam, which was constructed subsequently.
** From 3-unit Power Operation Study by electronic computer, Madden firm power 16,000 KW

TABLE G

CRITERIA FOR PUMP OPERATION

January

Previous Month's Inflow to Gatun Lk. Watershed (cfs)	Average Number Lockages per day	Pumping Rate (cfs)
greater than 10,000	45 50	600 600
between 10,000 and 5,000	40 45 50	600 1200
less than 5,000	35 40 45 50	600 1200 1800 1800

February

Previous Month's Inflow to Gatun Lk. Watershed (cfs)	Average Number Lockages per day	Pumping Rate (cfs)
greater than 4,000		none
between 4,000 and 2,500	45 50	600 600
between 2,500 and 1,500	35 40 45 50	600 600 1200 1200
between 1,500 and 1,000	35 40 45 50	1200 1200 1800 1800
less than 1,000	35 40 45 50	1800 1800 2400 2400

March

Previous Month's Inflow to Gatun Lk. Watershed (cfs)	Average Number Lockages per day	Pumping Rate (cfs)
greater than 4,000	50	600
between 4,000 and 1,500	45 50	600 1200
between 1,500 and 750	35 40 45 50	600 600 1200 1800
less than 750	35 40 45 50	1200 1200 1800 2400

April

Previous Month's Inflow to Gatun Lk. Watershed (cfs)	Average Number Lockages per day	Pumping Rate (cfs)
greater than 1,000		none
between 1,000 and 500	50	600
between 500 and 0	40 45 50	600 600 1200
between 0 and -200	35 40 45 50	600 1200 1200 1800
less than -200	35 40 45 50	1200 1800 1800 2400

May

Previous Month's Inflow to Gatun Lk. Watershed (cfs)	Average Number Lockages per day	Pumping Rate (cfs)
greater than 2,000		none
between 2,000 and 0	45 50	600 600
between 0 and -200	40 45 50	600 1200 1800
less than -200	35 40 45 50	600 1200 1800 2400

June

Previous Month's Inflow to Gatun Lk. Watershed (cfs)	Average Number Lockages per day	Pumping Rate (cfs)
greater than 1,500		none
less than 1,500	40 45 50	600 600 600

Exple: If the average inflow in January is 2,000 cfs and there are 45 lockages per day, pumping rate in February should be 1,200 cfs.

TABLE G

CRITERIA FOR PUMP OPERATION

...ry

Pumping Rate (cfs)
600
600
600
1200
600
1200
1800
1800

February

Previous Month's Inflow to Gatun Lk. Watershed (cfs)	Average Number Lockages per day	Pumping Rate (cfs)
greater than 4,000		none
between 4,000 and 2,500	45	600
	50	600
between 2,500 and 1,500	35	600
	40	600
	45	1200
	50	1200
between 1,500 and 1,000	35	1200
	40	1200
	45	1800
	50	1800
less than 1,000	35	1800
	40	1800
	45	2400
	50	2400

March

Previous Month's Inflow to Gatun Lk. Watershed (cfs)	Average Number Lockages per day	Pumping Rate (cfs)
greater than 4,000	50	600
between 4,000 and 1,500	45	600
	50	1200
between 1,500 and 750	35	600
	40	600
	45	1200
	50	1800
less than 750	35	1200
	40	1200
	45	1800
	50	2400

April

Previous Month's Inflow to Gatun Lk. Watershed (cfs)	Average Number Lockages per day	Pumping Rate (cfs)
greater than 1,000		none
between 1,000 and 500	50	600
between 500 and 0	40	600
	45	600
	50	1200
between 0 and -200	35	600
	40	1200
	45	1200
	50	1800
less than -200	35	1200
	40	1800
	45	1800
	50	2400

May

Previous Month's Inflow to Gatun Lk. Watershed (cfs)	Average Number Lockages per day	Pumping Rate (cfs)
greater than 2,000		none
between 2,000 and 0	45	600
	50	600
between 0 and -200	40	600
	45	1200
	50	1800
less than -200	35	600
	40	1200
	45	1800
	50	2400

June

Previous Month's Inflow to Gatun Lk. Watershed (cfs)	Average Number Lockages per day	Pumping Rate (cfs)
greater than 1,500		none
less than 1,500	40	600
	45	600
	50	600

July & August

Previous Month's Inflow to Gatun Lk. Watershed (cfs)	Average Number Lockages per day	Pumping Rate (cfs)
greater than 4,000		none
less than 4,000	45	600
	50	600

: If the average inflow in January is 2,000 cfs and there are 45 lockages per day, pumping rate in February should be 1,200 cfs.

TABLE H

GATUN LAKE OPERATION, 1920
With Pumping Plant
(Gatun Lake drawdown to Elevation +84.0)

50 Lockages Per Day

GATUN LAKE

Month	*Total Net Inflow	Storage at Beginning (Elev. 84-87)	Elev.	Lockage Water	Municipal Water @ 110 cfs	Change in Storage	Pumped Water or (Spill)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Jan.	+ 88	310	87.0	-268	-7	- 77	110
Feb.	+ 50	233	86.4	-239	-6	- 62	133
Mar.	+ 50	171	85.7	-259	-7	- 69	147
Apr.	+ 40	102	85.0	-247	-6	- 71	142
May	+117	31	84.3	-253	-7	+ 4	147
June	+223	35	84.3	-245	-6	+ 7	35
July	+399	42	84.4	-261	-7	+131	---
Aug.	+394	173	85.7	-267	-7	+120	---
Sept.	+305	293	87.0	-261	-6	+ 17	(21)
Oct.	+855	310	87.0	-269	-7	---	(579)
Nov.	+626	310	87.0	-261	-7	---	(358)
Dec.	+223	265	86.6	-268	-7	- 52	---

Note: All figures except elevations (Column (4)) are in thousands of acre fe
o See "Criteria for Pump Operation." Table G
* See Column (10), Table F

Before concluding the subject of pumping for increasing the water supply of the Panama Canal, it should be noted that if a Dam across Trinidad Arm of Gatun Lake is constructed, a smaller pumping plant may be installed later to increase the capabilities of the Canal to a full 50 lockages per day under all conditions of record. In this case, to accommodate 50 lockages per day with Gatun Lake water surface at or above elevation +84.0, 216,000 acre feet during a 1920-type water year will be required by pumping, or about one-third the pumping requirements without a Dam across Trinidad Arm of Gatun Lake. Accordingly, if a pumping plant were located immediately west of Gatun Dam, pumping capacity to supply 800 cfs would be sufficient and would require approximately 12,000 horsepower or 9,000 kilowatts.

Further savings in both capital and operating costs could be attained by installing a pumping plant in conjunction with a Dam across Trinidad Arm of Gatun Lake because the total dynamic head would be considerably less by pumping into Gatun Lake from Trinidad Lake than from the ocean at sea level. Pumping 216,000 acre feet from Trinidad Lake would lower the water surface elevation behind a Dam across Trinidad Arm of Gatun Lake from +84.0 to approximately +77.0. Assuming total dynamic head at 30 feet and pump efficiency at 80%, pump capacity to supply 800 cfs would require approximately 3,400 horsepower or 2,500 kilowatts. This plan would add to the initial costs of a Dam across Trinidad Arm of Gatun Lake, primarily for providing lock sills below elevation 72.0 and for a suitable pump plant foundation and piping. Further studies would be required on the effects to small boat navigation and adequacy of the water supply. There may also be advantages in providing for reversible pumping in any pumping plant at a Dam across Trinidad Arm of Gatun Lake. A plant pumping fresh water from Trinidad Lake would of course preclude any possibility of salt water contamination in Gatun Lake which is a condition that must be faced when pumping sea water.

3. Pumping Plant Designs and Cost Estimates

Any plant for pumping sea water into Gatun Lake must include its own power production equipment because the present electrical generating plants in the Canal Zone will be utilized to capacity for other needs when the water supply is short. Comparative investigations were made of radial diesel engine direct-drive pumps and electric motor-driven pumps with power supplied by gas turbine-driven generators.

Items which are common to both the diesel and electric plants include access road, dredging, fuel handling and storage facility, penstocks and outlet structure. Fuel storage requirements are based upon one month's supply, or nearly 40,000 barrels at full load. It is assumed that a suitable barge docking facility would be constructed on Gatun Lake, with a pipeline leading to four 10,000 barrel above-ground tanks in the vicinity of the outlet structure. Cost estimates for the penstocks are based upon constructing twin 9-foot diameter pipes, lined with coal tar and installed underground.

Experience to date on radial diesel engines is limited to units of 2,100 horsepower. Seventeen units would be required to provide the capacity for 50 lockages in a critical year, and at least two spare units should be provided in a plant of this size. These diesel-drive units could be installed incrementally with growth in canal traffic and thereby reduce the initial capital requirements.

Construction cost of all elements of a diesel direct-drive pumping plant including allowances for contingencies and engineering is estimated at $11,926,000. Refer to Table I for the estimated construction cost details. If built in two nearly equal increments, the initial capital investment could be reduced to approximately $6,662,000. This initial capacity would suffice until the number of lockages per day reaches 40, or to about 1988 with an average growth of traffic and 1977 with prosperity cycle traffic.

Operating costs are relatively high. Assuming that diesel oil costs 1-1/2 cents per pound (approximately $4.50 per barrel) in Panama and that diesel engines require 0.38 pounds fuel per brake horsepower, fuel costs for pumping water into Gatun Lake will be $1.03 per acre foot. This has been increased to $1.05 in the economic analyses to include lubricating oil and operating supplies.

Cost estimates have also been prepared for a plant having five electric motor-driven pumps, each with a capacity of 600 cubic feet per second. One pump would thereby be available as a spare when full capacity is required. To provide power for these pumps, gas turbine-driven generators were selected so that this generating plant would be similar to the thermal plant now being constructed. Two generators, each with a capacity of 13,700 kva, are capable of providing power for pumping 2,400 cubic feet per second. No emergency generator capacity has been included in the pumping plant, but the cost estimate includes interconnection with the Canal Zone power system which, it is assumed, could supply some power in an emergency. It is thereby also possible to use the pumping plant generators for general power supply when not in use to full capacity for pumping water.

Capital expenditure for a gas turbine-driven generator and electric motor-driven pumping plant is greater than for a direct-drive diesel pumping plant.

The construction cost estimate for the plant with gas turbine-driven generators and electric motor-driven pumps totals $13,354,000, including allowances for contingencies and engineering. Two nearly equal increments of construction could bring the initial investment down to $8,197,000 and provide sufficient capacity for approximately 40 lockages per day. Refer to Table J for the estimated construction cost details.

Operating costs for the gas turbine-driven generators and electric motor-driven pumping plant have been estimated on the basis of burning Navy special fuel oil delivered in Panama for $2.85 per barrel. It is estimated that fuel, lubricating oil and operating supplies for the gas turbines would cost 6.0 mils per kilowatt hour produced. On this basis operating cost for fuel, lubricating oil and operating supplies would amount to $0.81 per acre foot of water pumped into Gatun Lake. This is $0.24 less than the estimate for the direct-drive diesel plant.

TABLE I

CONSTRUCTION COST ESTIMATE FOR PUMPING PLANT
(With Direct Drive Diesel Pumps)

	Quantity	Unit	Unit Price	Amount
Outlet				
Excavation	1,000	CY	$ 2.00	$ 2,000
Concrete	550	CY	70.00	38,500
Cement	825	Bbl.	5.00	4,150
Re-Steel	55,000	#	0.15	8,250
Miscellaneous Steel, trash racks	30,000	#	0.50	15,000
Dewatering	---	L.S.	---	50,000
Sub total				$ 117,900
Penstocks				
Excavation Struct.	13,900	CY	5.00	70,000
Common	4,700	CY	0.50	2,350
Backfill Compact.	9,200	CY	0.50	4,600
Loose	4,700	CY	0.25	1,175
Concrete	300	CY	70.00	21,000
Cement	450	Bbl.	5.00	2,250
Re-Steel	45,000	#	0.15	6,750
Structural Steel	1,154,000	#	0.50	577,000
Sub total				$ 685,125
Pump Plant				
Excavation	19,000		2.00	38,000
Concrete	10,000		70.00	700,000
Cement	15,000		5.00	75,000
Re-Steel	1,500,000		0.15	225,000
Structural Steel	---	L.S.	---	100,000
Dewatering	---	L.S.	---	75,000
Pumps	19	each	100,000	1,910,000
Direct Drive Vertical Diesels	19	each	190,000	3,600,000
Valves and Controls	19	each	55,000	1,045,000
Intake Channel	300,000	CY	1.00	300,000
Tank Farm	---	L.S.	---	500,000
Access Road	---	L.S.	---	20,000
Sub total				$ 8,588,000
Sub total Construction Cost				9,391,000
Contingencies @ 20%				1,878,000
Engineering @ 7%				657,000
Total				$11,926,000

TABLE J

CONSTRUCTION COST ESTIMATE FOR PUMPING PLANT
(With Gas Turbine Generators and Electric Motor Driven Pumps)

	Quantity	Unit	Unit Price	Amount
Outlet				
Excavation	1,000	CY	$ 2.00	$ 2,000
Concrete	500	CY	70.00	38,500
Cement	825	Bbl.	5.00	4,250
Re-Steel	55,000	#	0.15	8,250
Misc. Steel: Trash racks, etc.	30,000	#	0.50	15,000
Dewatering	---	L.S.	---	50,000
Sub total				$ 117,900
Penstocks				
Excavation: Struct.	13,900	CY	5.00	70,000
Excavation: Common	4,500	CY	0.50	2,250
Backfill: Compacted	9,200	CY	0.50	4,600
Backfill: Loose	4,600	CY	0.25	1,150
Concrete	300	CY	70.00	21,000
Cement	450	Bbl.	5.00	2,250
Re-steel	45,000	#	0.15	6,750
Struct. steel A-285B 1/2" plate	1,154,000	#	0.50	577,000
Sub total				$ 685,000
Pump Plant				
Excavation	8,330	CY	2.00	7,000
Concrete	5,000	CY	70.00	350,000
Cement	7,500	Bbl.	5.00	37,500
Re-steel	750,000	#	0.15	112,500
Struct. steel	L.S.		L.S.	50,000
Dewatering	L.S.		L.S.	50,000
Pump	5	ea.	393,000	1,965,000
Motor	5	ea.	230,000	1,150,000
Valves & Controls	5	ea.	150,000	750,000
Electrical equipment	---	L.S.	---	740,000
Turbine Generators	2	ea.	1,835,000	3,670,000
Intake Channel	300,000	CY	1.00	300,000
Tank Farm		L.S.		500,000
Access Road		L.S.		30,000
Sub total				$ 9,712,000
Sub total				$10,515,000
Contingencies @ 20%				2,103,000
Engineering @ 7%				736,000
Total				$13,354,000

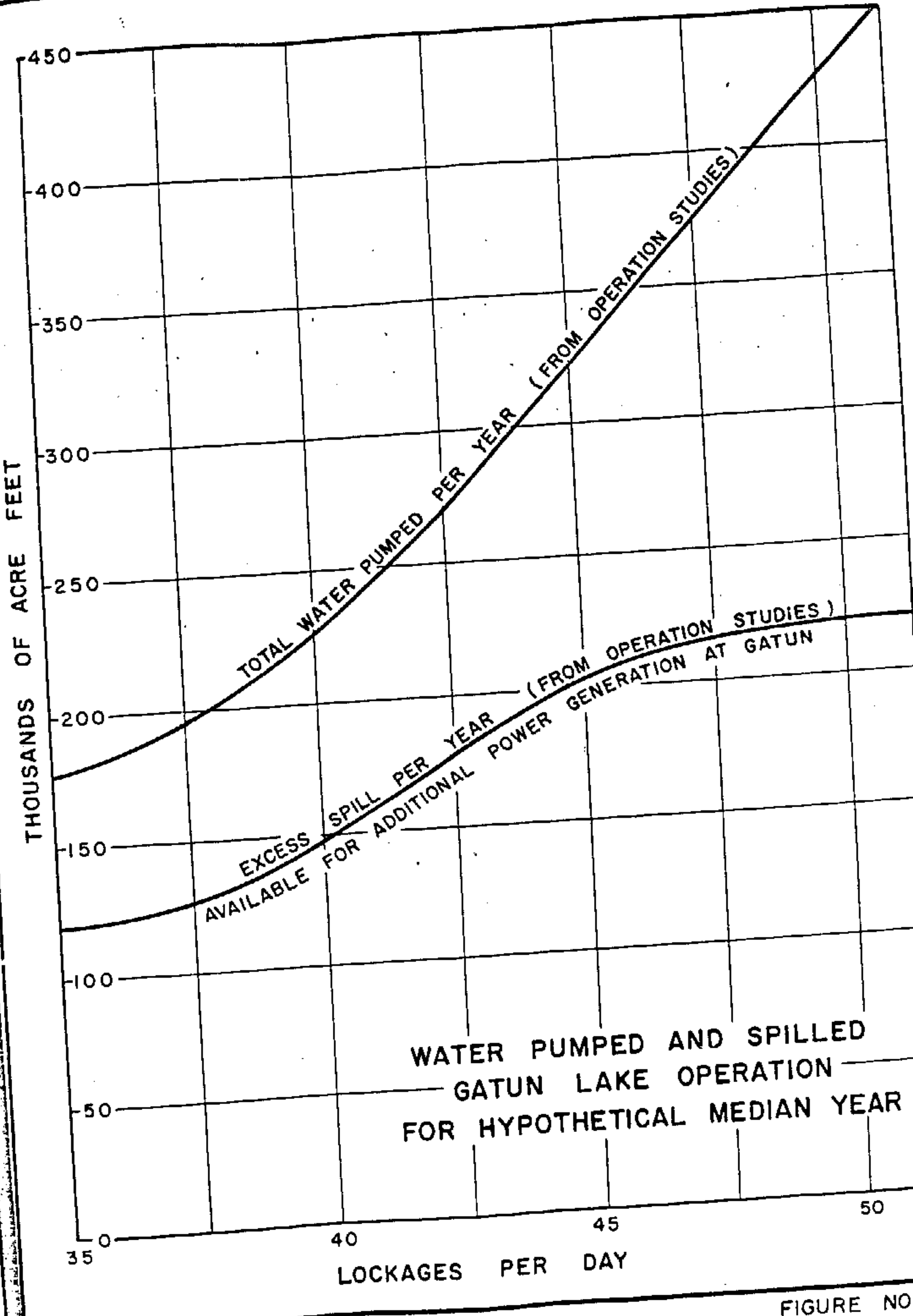
An analysis of the operating and maintenance costs to the year 2000 was made for the direct-drive diesel plant and for the gas turbine generated electric motor plant. The analysis was based upon water records for the peri from 1905 through 1961. The median month in this period for each of the twel months was selected and arranged to produce a hypothetical median year as shown in Table K. The inflows of this hypothetical median year are considere to represent the most probable occurrence of conditions which can be anticipa over an extended period. Using these inflows, operation studies (similar to Tables F and H) for 35, 40, 45 and 50 lockages per day were made and used as a basis for developing the curves of water pumped and spilled shown in Figure No. 8. The previously presented criteria for pump operation were used.

These curves for water pumped and spilled were used as a basis for estimating operating costs and possible power benefits. The number of lockage for each period is an average figure based upon the prosperity cycle. In Table L there is tabulated the total net cost to the year 2000 of a pumping plant with direct-drive diesel pumps and in Table M there is a similar tabulation for a plant with gas turbine driven generators and electric motor drive pumps. It has been assumed that either plant would be constructed in an initi increment during the 1963-1965 period and second increment during the 1981-198 period. It has also been assumed that the necessary capital could be borrowed at an interest rate of 2-5/8% and would be amortized to the year 2000.

Total operating and maintenance costs to the year 2000 for the direct-drive diesel plant are estimated at $14,005,000, whereas these same costs for the gas turbine generated electric motor plant are estimated at $10,795,000. Although some additional maintenance and personnel expenses are anticipated for the diesel plant due to the greater number of units and inherent characteristics of internal combustion engines, the largest part of the $3,210,000 difference is caused by higher fuel costs per unit of water pumped. Operating costs for the direct-drive diesel pump plant more than offset the savings in initial capital investment.

Manufacturer's information indicates that individual radial diesel engines for direct-drive pumping may be increased in size up to 3,000 horsepower by supercharging. No actual operating experience has been obtained for units of this size. If they could be proven suitable for the Panama operation, initial capital costs would be less than shown on Table I because fewer units would be required. Fuel consumption, however, would be more. An analysis to the year 2000 indicates that, including operation, maintenance and amortization, total costs for a plant with 3,000 horsepower direct-drive diesel pumps is nearly the same as the total costs for a plant with gas turbine driven generators and electric motor driven pumps. The latter plant has been chosen for subsequent discussions in this report.

Tables L and M indicate that possible benefits might be obtained from power generated by excess spill. Excess spill is water pumped into Gatun Lake but not required for lockages and, therefore, could generate hydro power at the Gatun Plant. The amount of this water is a function of established operating procedure and actual runoff. It would be available with any type of pumping plant. This excess spill, however, is available



450
400
350
300
250
200
150
100
50
0
THOUSANDS OF ACRE FEET
TOTAL WATER PUMPED PER YEAR (FROM OPERATION STUDIES)
EXCESS SPILL PER YEAR (FROM OPERATION STUDIES)
AVAILABLE FOR ADDITIONAL POWER GENERATION AT GATUN
35
40
45
50
LOCKAGES PER DAY
WATER PUMPED AND SPILLED
GATUN LAKE OPERATION
FOR HYPOTHETICAL MEDIAN YEAR

FIGURE NO

only during the early months of the wet season and may be of doubtful value to the overall power system of the Canal Zone. Its value in Tables L and M has been computed at 21.7 mils per kilowatt hour, a figure which represents the average difference between the cost of generating diesel power and hydro power in the Canal Zone during the past three years. If this energy can be utilized during the early months of the wet season, its value to the year 2000 would exceed $8,000,000.

4. Effects of Salt Water in Gatun Lake

The introduction of salt water into Gatun Lake would present a possible hazard which would not exist with any of the alternate plans for increasing the water supply of the Panama Canal.

Units in direct contact with the sea water would be exposed to corrosive action. Since the pumping plant would be new construction, preventive measures can be provided in the design. These include use of corrosion-resistant metals and coating with inert substances. The pumping plant cost estimate includes provision for such protection against the action of the salt water.

With the outlet structure located near Gatun Dam, most of the salt water can be expected to remain in that immediate vicinity and be discharged through the Gatun Locks. For the impurities to travel in any other direction would require a reversal of the assumed currents in Gatun Lake. Under the pumping criteria assumed in this report, the water surface of Gatun Lake is nearly always being lowered during the pumping operations, indicating a general flow from Gamboa to Gatun Locks. In the unlikely situation of all the pumped sea water replacing a like amount of fresh water in Gatun Lake during a critical dry season, the average concentration of impurities, assuming an even distribution, would be less than one-fifth that found in salt water. This approaches a brackish water quality.

It is very doubtful that any salt water contamination would reach the municipal water source near Gamboa. It is unlikely that the other intake near the Atlantic side would be affected since considerable protection is provided by the Monte Lirio railroad fill. The possibility, however, should not be dismissed.

Investigations should be made on the exposure of metal parts and machinery in Gatun Locks. Some deloterious effect must be anticipated in these works.

5. Time Estimate

A significant advantage of the plan for increasing the water supply by Pumping Sea Water into Gatun Lake is that construction could commence as soon as the design is completed. The construction itself could be done in three years or less. Also, the plant could be constructed incrementally and capacity added as needed. As mentioned previously, however, improvements are being financed from current revenues and the program of Cut Widening and lock gate overhaul procedures is expected to consume most of the available funds through fiscal years 1963-65. A realistic completion date for the initial increment of any pumping plant would probably be 1967 or 1968.

TABLE K

THE HYPOTHETICAL MEDIAN YEAR

Year	Month	*Net Inflow Madden Watershed	Net Inflow Watershed Area Below Madden Dam
1913	January	104	25
1954	February	65	-29
1936	March	29	-35
1935	April	37	-15
1905	May	124	118
1942	June	191	148
1921	July	154	240
1941	August	205	239
1951	September	190	290
1925	October	195	421
1943	November	215	518
1921	December	219	247

* Figures for months in years prior to 1934 are corrected for evaporation and do not agree with those published in tables.

Note: Inflow figures are in thousands of acre feet.

TABLE L

TOTAL NET COST TO YEAR 2000 OF PUMPING PLANT
(Direct Drive Diesel Pumps)

	1963-1965	1966-1970	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	TOTAL
Average number of lockages per day	---	34.35	37.30	40.15	42.80	45.50	48.10	50.80	---
Water pumped (based on hypothetical median year) (af)	---	865	965	1,140	1,385	1,675	1,935	2,215	10,1
Operating cost for fuel, oil and supplies @ $1.05/af ($)	---	910	1,015	1,200	1,455	1,760	2,030	2,375	10,69
Operating cost for personnel ($)	---	230	270	310	355	400	440	480	2,48
Total Cost of Operation ($)	---	1,140	1,285	1,510	1,810	2,160	2,470	2,805	13,18
Maintenance Costs ($)	---	30	60	90	120	150	175	200	82
Total O&M Cost ($)	---	1,170	1,345	1,600	1,930	2,310	2,645	3,005	14,00
Capital Expenditures	6,662				5,264				11,92
Amortization to year 2000 with interest @ 2-5/8% ($)	---	1,492	1,492	1,492	1,492	3,637	3,637	3,637	16,87
TOTAL O&M AND AMORTIZATION COSTS	---	2,662	2,837	3,092	3,422	5,947	6,282	6,642	30,88
Estimated Power Benefits									
Excess Spill (af)	---	590	625	745	905	1,035	1,090	1,100	6,09
Power generated by excess spill (kwh)	---	36,400	38,500	45,900	55,800	63,800	67,200	67,800	375,40
Value of power @ 21.7 mils/kwh ($)	---	790	835	995	1,210	1,385	1,460	1,470	8,145

Note: All figures except number of lockages are in thousands.

TABLE M

TOTAL NET COST TO YEAR 2000 OF PUMPING PLANT
(Gas Turbine Generators & Electric Motor Driven Pumps)

	1963-1965	1966-1970	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	TO[illegible]
Average number of lockages per day	---	34.35	37.30	40.15	42.80	45.50	48.10	50.80	--
Water pumped (based on hypothetical median year) (af)	---	865	965	1,140	1,385	1,675	1,935	2,215	10[illegible]
Operating cost for fuel, oil and supplies @ $0.81/af ($)	---	700	780	925	1,120	1,360	1,565	1,795	8[illegible]
Operating cost for personnel ($)	---	185	215	250	285	320	350	385	1[illegible]
Total Cost of Operation ($)	---	885	995	1,175	1,405	1,680	1,915	2,180	10[illegible]
Maintenance Costs ($)	---	20	40	60	80	100	120	140	
Total O&M Cost ($)	---	905	1,035	1,235	1,485	1,780	2,035	2,320	10[illegible]
Capital Expenditures ($)	8,197				5,157				13[illegible]
Amortization to year 2000 with interest @ 2-5/8% ($)	---	1,805	1,805	1,805	1,805	3,905	3,905	3,905	18[illegible]
TOTAL O&M AND AMORTIZATION COSTS	---	2,710	2,840	3,040	3,290	5,685	5,940	6,225	29[illegible]
Estimated Power Benefits									
Excess Spill (af)	---	590	625	745	905	1,035	1,090	1,100	6[illegible]
Power generated by excess spill (kwh)	---	36,400	38,500	45,900	55,800	63,800	67,200	67,800	375[illegible]
Value of power @ 21.7 mils/kwh ($)	---	790	835	995	1,210	1,385	1,460	1,470	8[illegible]

Note: All figures except number of lockages are in thousands.

the water required per lockage would be appreciably greater. Furthermore, the work involved to permit this would be very extensive and would include increasing the height of the miter gates at the upper levels of both Pedro Miguel and Gatun Locks, raising 15 miles of the Panama Railroad, raising the Dredging Division shore facilities, relocating cables, raising lock walls and other miscellaneous items estimated to cost some $35,000,000.

The cost of raising the lake level to elevation + 92.0 is not justifi and is not comparable with either the Dam across Trinidad Arm of Gatun Lake project or the Canal Deepening project.

Raising the lake level to elevation + 88.0 is economical and can be accomplished at any time in the future. However, it does not by itself produce sufficient additional lockages to suffice over many years and would mean loss of flood control storage. Therefore, it should be considered as an improvement to be made in addition to either a Dam across Trinidad Arm of Gatun Lake or the Canal Deepening.

3. <u>Cano Quebrado Dam</u>

The Cano Quebrado drainage area is adjacent to and along the east side of the Trinidad Basin. A relatively inexpensive dam could be built in the vicinity of the point where this drainage now discharges into Gatun Lake and 50,400 acre feet of usable storage thus provided. This stored water could be discharged into Trinidad Lake through a connecting channel approximately one mile long. This storage would provide an additional 2 lockages per day.

It appears that any location of the connecting channel would be outside the Canal Zone. In that event, an arrangement to discharge directly into Gatun Lake would be necessary or treaty authority worked out with the Republic of Panama.

In any event, this project in itself is not adequate to meet increased water needs for the Canal and must therefore be considered as an addition to either the Dam across Trinidad Arm of Gatun Lake or Canal Deepening projects.

VII. POWER GENERATION INCREASES

1. Addition of a Dam across Trinidad Arm of Gatun Lake or Canal Deepening

The growing power requirements and impending deficiencies of supply both in energy and capacity have been covered in Paragraph III-8 of this report. This particularly points out that as early as 1965 there will be a deficiency in both capacity and energy in an average water year even if either the Dam across Trinidad Arm of Gatun Lake or Canal Deepening projects could be completed. By operating the Madden plant for peaking purposes rather than base load some of the capacity deficit can probably be overcome. Nonetheless some new power generation will have to be provided.

2. Pumped Storage

Consideration has been given to developing power by pumped storage in Gatun Lake. The feasibility of this is predicated on the availability of a large block of inexpensive off-peak power to be used to pump water to an upper pool for later release through a hydroelectric plant during peak load hours. Off-peak power for this pumping is not now available to the Company. It is possible that at some future time when substantially more thermal generating capacity is available than is now the case, a pumped storage installation might be justified.

3. Fourth Unit at Madden Plant

A second possibility for increasing the power production facilities of the Company is the adding of a fourth generator to the Madden power plant. This would make the Madden plant much more suitable for peaking purposes which, in the light of predictable future trends, appears to be the best way to integrate this plant into the overall operation. During the critical low water periods of the future the Gatun power plant will be of decreasing value both to produce energy and to provide dependable capacity. At the same time more thermal capacity will have to be made available to care for increased demands and replace decreased hydro. To provide peaking capacity by thermal plants will involve high plant and operating costs. The Madden plant, if expanded, would be particularly well suited to operate at a low load factor to produce peaking power since the water flow can be re-regulated downstream by Gatun Lake. On the other hand, during the rainy season when runoff is heavy, it is likely that an economic study would disclose that the Madden plant could best be operated for base load and the thermal facilities used for peaking. This would conserve fuel costs.

It is felt that the possible advantages of another unit in the Madden plant are sufficiently attractive to justify further study. This could best be accomplished after a decision is reached as to which method is to be used to increase Canal water supply. Electronic computer analysis of the operation of the existing power plants together with various sizes of an additional Madden unit and additional thermal capacity and various conditions of future water supply including the wet and dry seasons for minimum and average water years would readily determine the benefits of this proposal. In addition, the cost and construction problem involved in the installation of the additional unit and attendant plant facilities should be ascertained.

VIII. SUMMARY

The estimated future continued increase in Canal traffic makes it imperative that the supply of stored water be increased to carry through the dry season of each year and particularly years of low rainfall. Unless this is accomplished in the reasonably near future, there is serious hazard that even the minimum channel depth of 42 feet cannot be maintained at all times.

The construction of a dam on the Chagres above Madden is not attractive because of the high costs, the relatively few additional lockages per day it will add to the present capacity, and the necessity of negotiating a new treaty arrangement with the Republic of Panama to permit its construction. It is not recommended for further consideration at this time.

Raising Gatun Lake by one foot is a possibility because of the low estimated cost of $600,000 to provide approximately 4 additional lockages per day. However, part of this storage is already used occasionally, and the additional lockage capacity is not sufficient to meet estimated increases of traffic for very far into the future. Furthermore, it would decrease the safety factor in flood control. Since this development can be deferred without harm, whereas the Dam across Trinidad Arm of Gatun Lake project must proceed soon or be abandoned, it is recommended that raising the lake not be undertaken.

Raising Gatun Lake by five feet would involve some very extensive alterations to the Canal and bring the estimated costs to such a level - $35,000,000 - that it is not justifiable when compared to other methods of achieving comparable ends.

The Cano Quebrado Dam project would not produce enough additional water to meet long term needs and it is therefore not suitable by itself. It can and should be deferred at present but should be kept in mind if 2 lockages per day should appear important.

The Dam across Trinidad Arm of Gatun Lake, the Canal Deepening, and Pumping Sea Water into Gatun Lake each can provide substantial benefits. The Dam across Trinidad Arm of Gatun Lake project is compared with Canal Deepening in Table N and with Pumping Sea Water into Gatun Lake in Table O following.

TABLE N

COMPARISON OF CANAL DEEPENING AND DAM ACROSS TRINIDAD ARM OF GATUN LAKE (Minimum 42-Foot Channel Depth Provided)

	Canal Deepening	Dam across Trinidad Arm of Gatun Lake	Preferred
1. Capital Cost	$17,800,000	$10,078,000	Trinidad
2. Lockage capacity during critical year (1920) with 42-foot channel depth (average number per day)	61.5	55.1*	Deepening
3. Provides additional flood control	No	Minor	Comparable
4. Advantages of Trinidad in power production:			
KWH per year - average water		9,400,000	Trinidad
Value of power per year		203,000	Trinidad
5. Time of completion of construction	1971	Mid-1968	Trinidad
6. Interference with navigation	Yes	Minor	Trinidad
7. Incorporation with sea-level canal	Partial	Partial	Comparable
8. Conversion of Canal to power production	Yes	Yes	Trinidad**
9. Can be deferred	Yes	No	Trinidad

* If a 44-foot navigation depth is maintained, this would be reduced to 45.7 lockages per day for a low water year but would be 50 or more lockages for all but 3 years during last 57 years of record.

** Trinidad has the advantage of storing water at a higher elevation and thus enabling the production of more power.

In the above tabulation, a Dam across Trinidad Arm of Gatun Lake has substantial advantages in Items 1, 4 and 5, all of which are important. It has a lesser advantage in Items 6 and 8. The Canal Deepening has a substantial advantage in Item 2.

Item 9 is particularly significant. In Paragraph III-10 it was brought out that if a Dam across Trinidad Arm of Gatun Lake is to realize the economy of using the material available from the cut widening work which is now proceeding, the dam must be built simultaneously with the Cut Widening. To build a Dam across Trinidad Arm of Gatun Lake at any other time will increase the cost an estimated $5,635,000, without any allowance for contingencies on this increase.

TABLE O

COMPARISON OF
PUMPING PLANT AND DAM ACROSS TRINIDAD ARM OF GATUN LAKE PROJECTS
(Minimum 44-Foot Channel Depth Provided)

	Pumping Plant	Dam across Trinidad Arm of Gatun Lake	Preferre[d]
1. Capital cost Initial installation	$ 8,197,000	$10,078,000	Pumping
2. Capital cost Total installation	$13,354,000	$10,078,000	Trinidad
3. Average annual cost of maintenance and operation *	$ 308,000	$ 106,000	Trinidad
4. Total cost to year 2000*	$26,500,000	$15,275,000	Trinidad
5. Lockage capacity during critical year (1920) with 44-foot channel depth (average number per day)	50	45.7**	Pumping
6. Provides additional flood control	No	Minor	Comparab[le]
7. When facility can be usable	1967	Mid-1968	Pumping
8. Incorporation with sea-level canal	None	Partial	Trinidad
9. Usable with conversion of Canal to power production	No	Yes	Trinidad
10. Adverse effect on municipal water supply	Possible	None	Trinidad

* Does not include possible power benefits.
** Capacity would be 50 lockages per day average in all years except 3 during the last 57 years of record.

In this tabulation the Dam across Trinidad Arm of Gatun Lake project has very substantial advantages in Items 2, 3 and 4, all of which are important. It has advantages in Items 8, 9 and 10 which are significant.

The pumping plant project can be built in increments to fit the demand and this shows to advantage in Item 1. It also provides an assured capacity of 50 lockages per day whereas it can be anticipated that a Dam across Trinidad Arm of Gatun Lake will fall short of this figure in about 3 years in 57. In such years there will be a restricted draft. This is shown in Item 5. Also, the initial increment of a pumping plant can be placed in operation somewhat earlier than a Dam across Trinidad Arm of Gatun Lake.

A comparison of these three possible solutions to providing additional water supply for the Canal discloses that the Dam across Trinidad Arm of Gatun Lake project has a substantial advantage in the overall costs and, while it provides somewhat less additional lockages than the other projects, it does meet estimated normal requirements through the year 2000. In the unlikely possibility that a high prosperity cycle of lockage demands coincides with a very low rainfall year during the last decade of the century, some restriction on navigable depths would have to be imposed but this would be not less than the 42 feet now provided.

With regard to power generation, it is evident that some additions will have to be made to the power generating facilities of the Company in order to meet increasing loads.

It would appear that there may be substantial economic advantages to installing more generating capacity in the Madden power plant and operating this plant for peaking purposes during the dry season. In the wet season, it would probably be best to operate the plant for base load. Studies were not carried far enough to reach a conclusion in this matter.

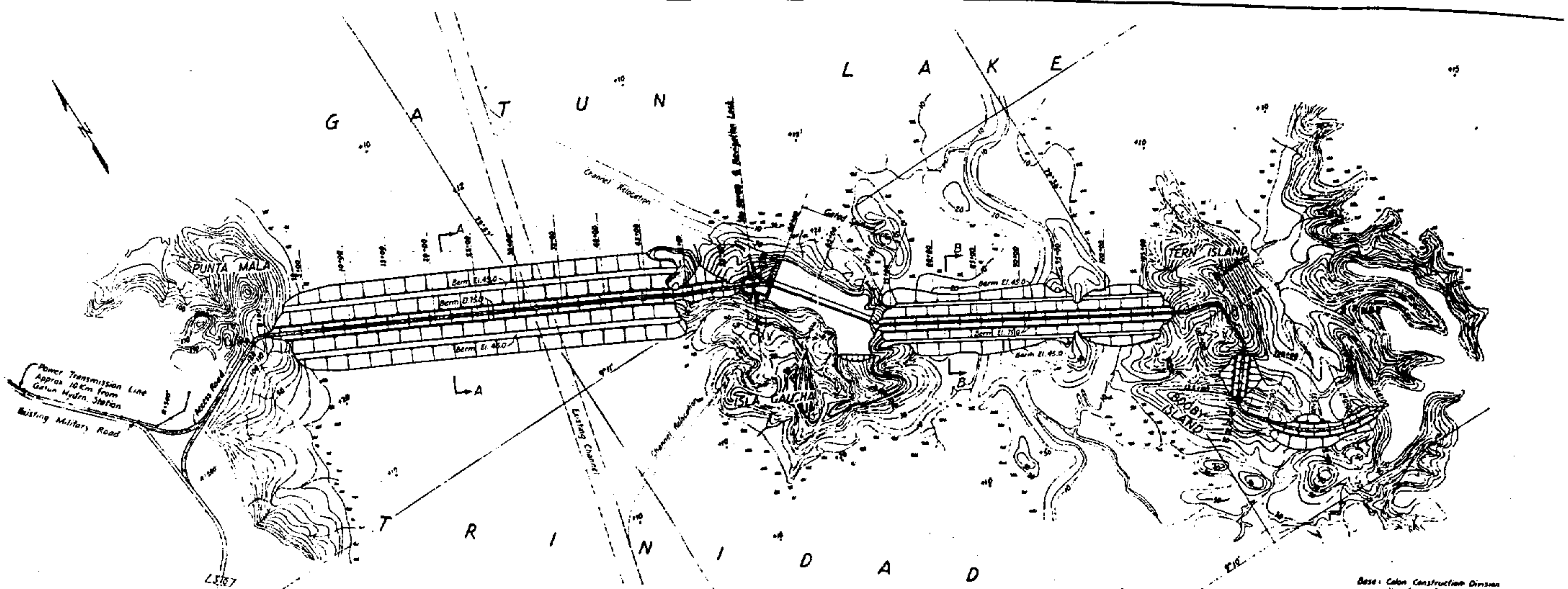
IX. CONCLUSIONS AND RECOMMENDATIONS

It is concluded that of the projects studied, only a Dam across Trinidad Arm of Gatun Lake, the Canal Deepening and Pumping Sea Water into Gatun Lake can adequately meet requirements for lockage water until the end of this century. The pumping of sea water has disadvantages that make it less attractive than either a Dam across Trinidad Arm of Gatun Lake or the Canal Deepening. Of the latter two projects, a Dam across Trinidad Arm of Gatun Lake has significant advantages over the Canal Deepening. Furthermore, to realize a large capital cost saving it must proceed simultaneously with the current Cut Widening program. A pumping plant of any suitable capacity can be added later.

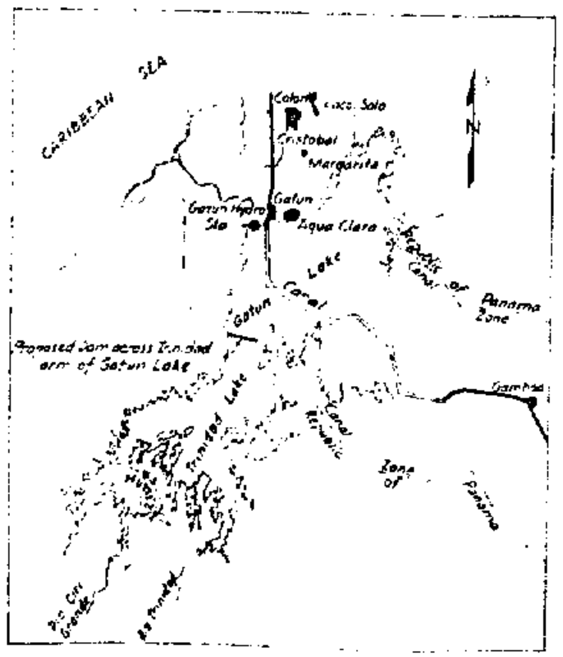
In view of the comparisons made in this study, it is recommended that the Dam across Trinidad Arm of Gatun Lake project be adopted and that construction be initiated concurrently with the balance of the Cut Widening project.

It is also recommended that further studies be made of installing more generating capacity in the Madden power plant.

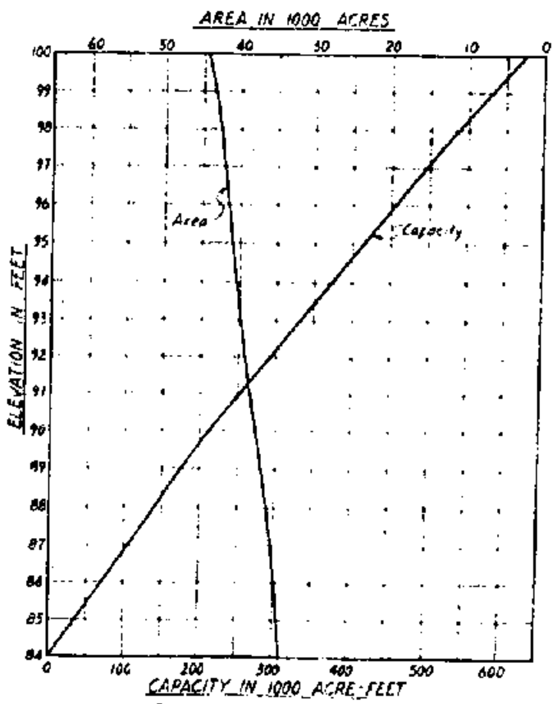
* * * * * * * * * *



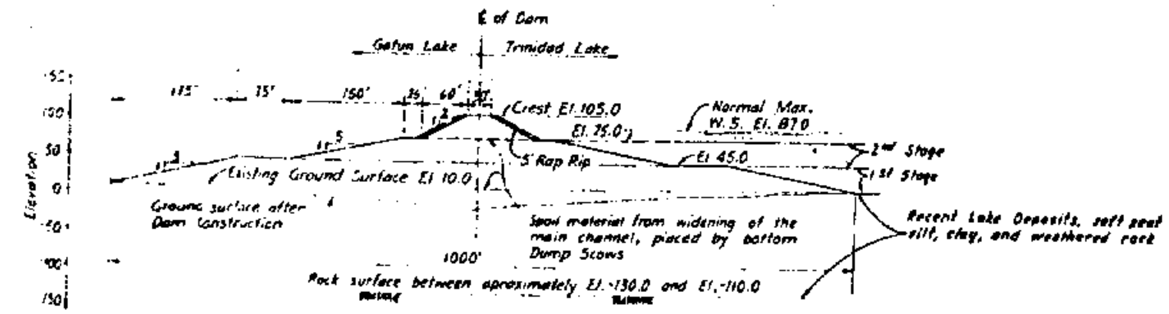
GENERAL PLAN
DAM ACROSS TRINIDAD ARM OF GATUN LAKE
WITH NAVIGATION LOCK AND GATED SPILLWAY
Contour Interval 10'



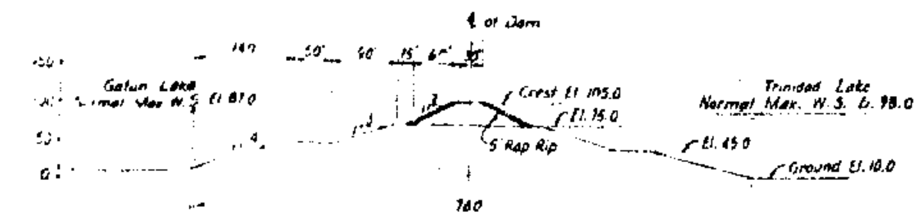
LOCATION MAP



AREA-CAPACITY CURVES
FOR TRINIDAD LAKE

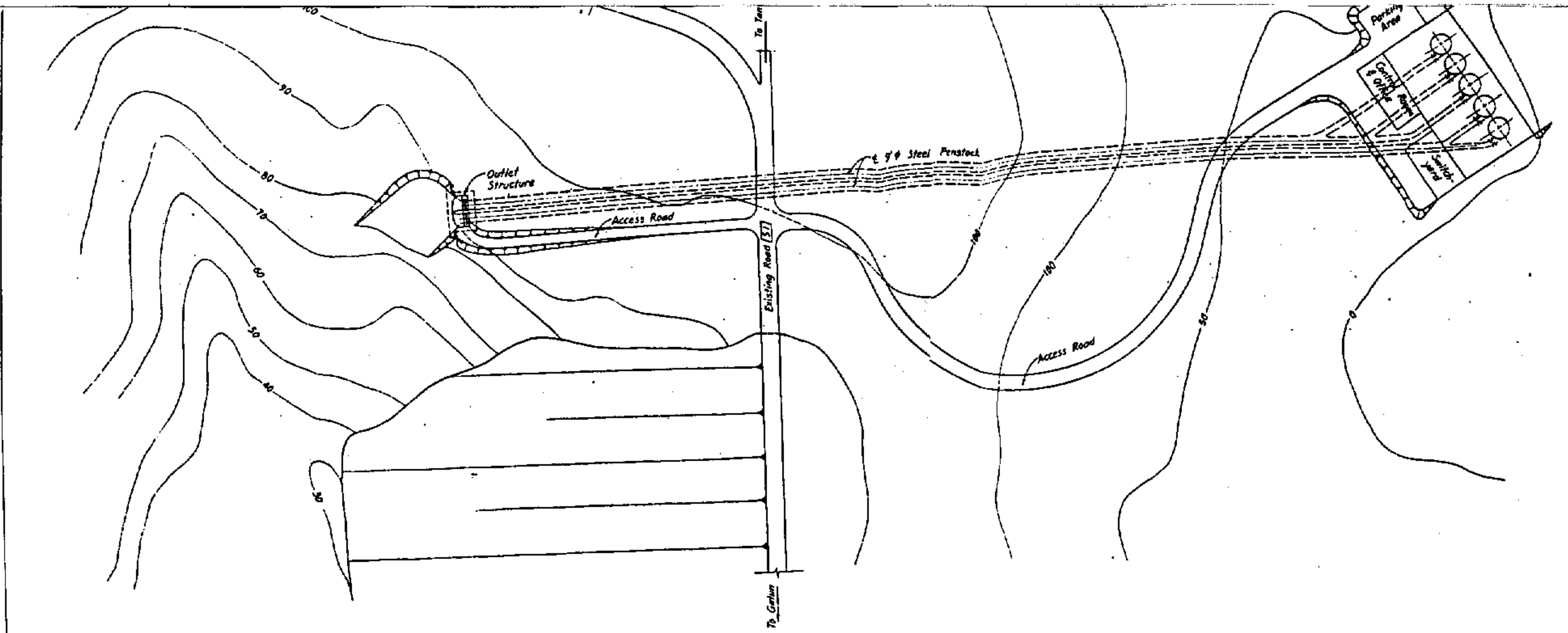


TYPICAL DAM SECTION "A" PUNTA MALA - ISLA GAUCHA
Scale 1" = 100'



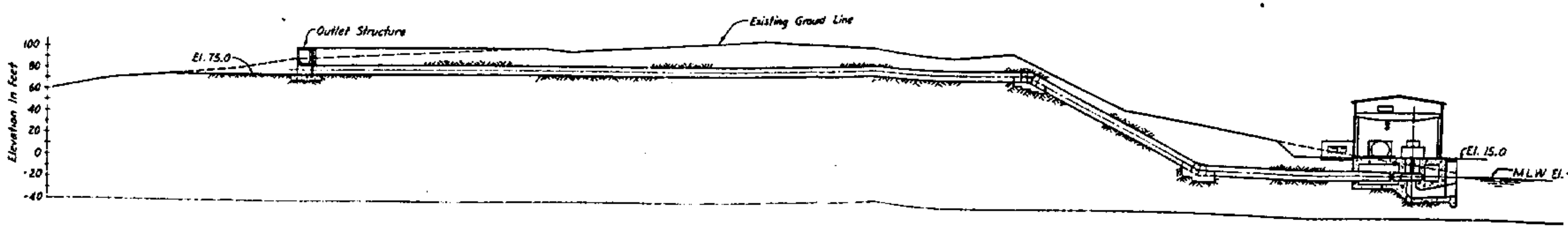
TYPICAL DAM SECTION "B" ISLA GAUCHA - TERN ISLAND
Scale 1" = 100'

THE PANAMA CANAL COMPANY
BALBOA HEIGHTS, CANAL ZONE
WATER SUPPLY AND NAVIGATIONAL DEPTH STUDIES
GENERAL PLAN, DAM ACROSS TRINIDAD ARM OF GATUN LAKE



PLAN
Scale: 1"=50'

Note:
For location of pumping plant see Figure 1
General Map of Panama Canal



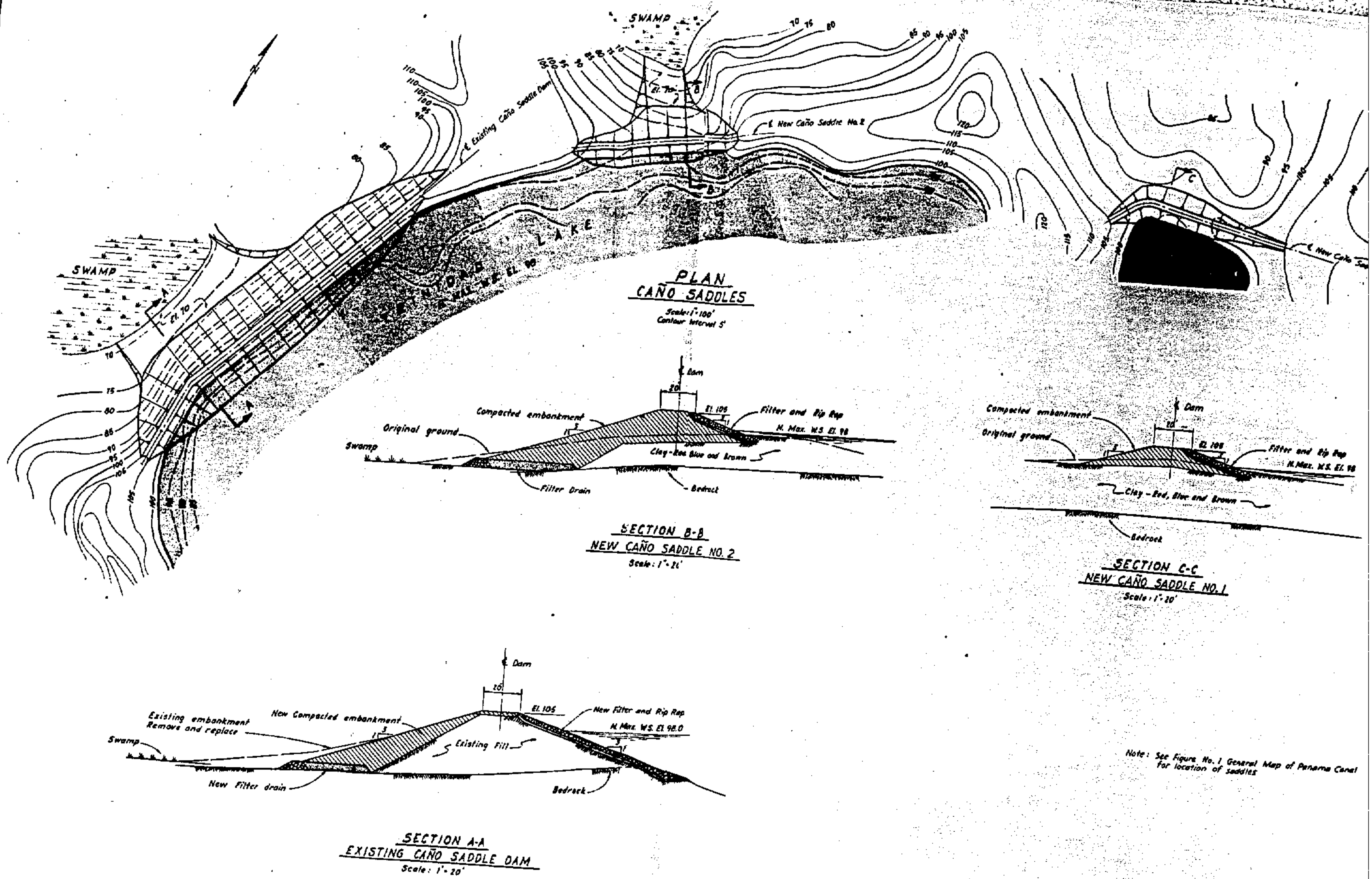
℄ PROFILE
Scale: 1"=50'

THE PANAMA CANAL COMPANY
BALBOA HEIGHTS, CANAL ZONE

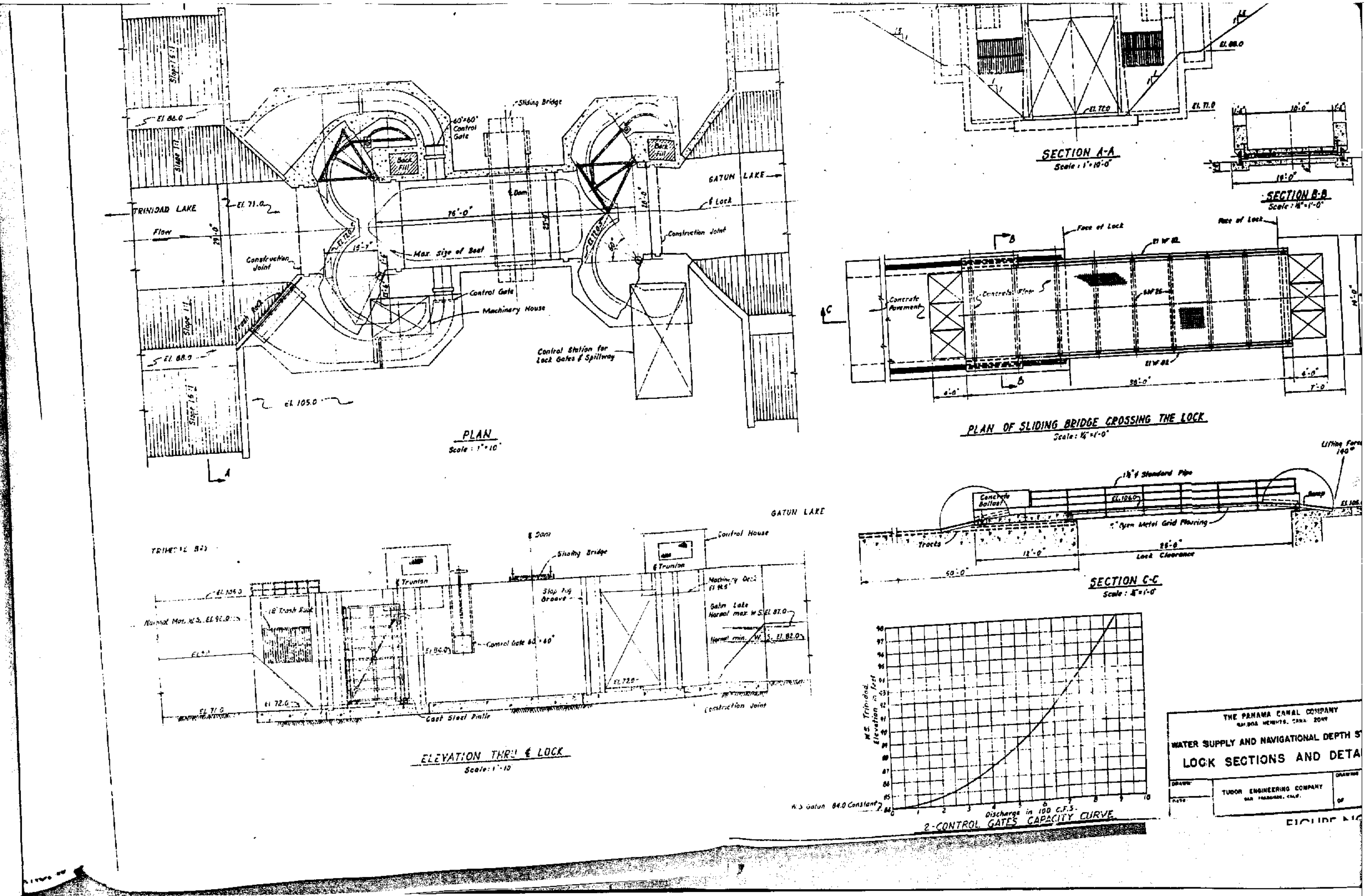
WATER SUPPLY AND NAVIGATIONAL DEPTH STUDIES

PLAN AND PROFILE, PUMPING PLANT

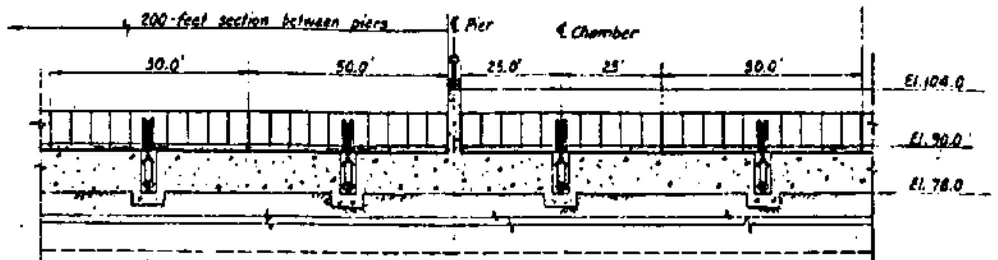
DRAWN:



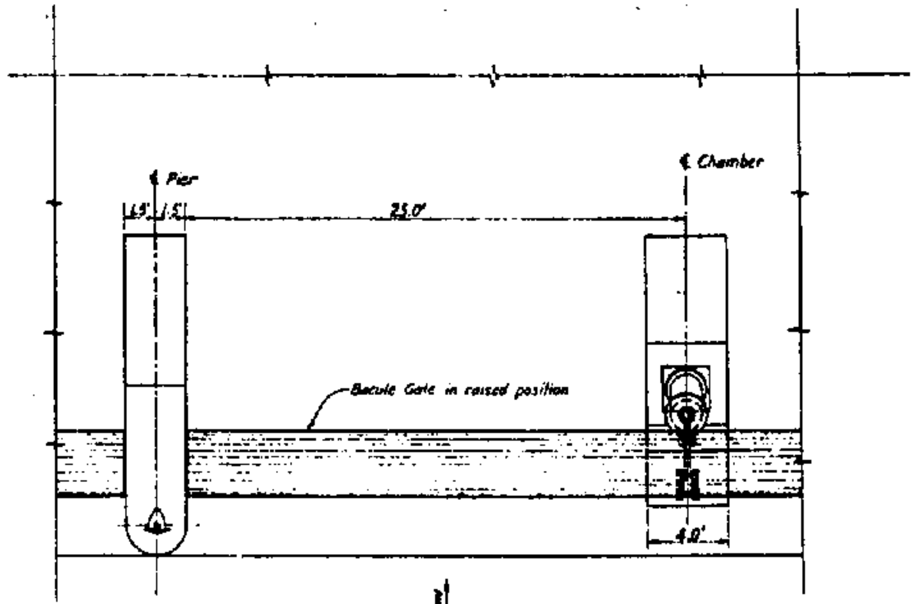
THE PANAMA CANAL COMPANY
BALBOA HEIGHTS, CANAL ZONE
WATER SUPPLY AND ...



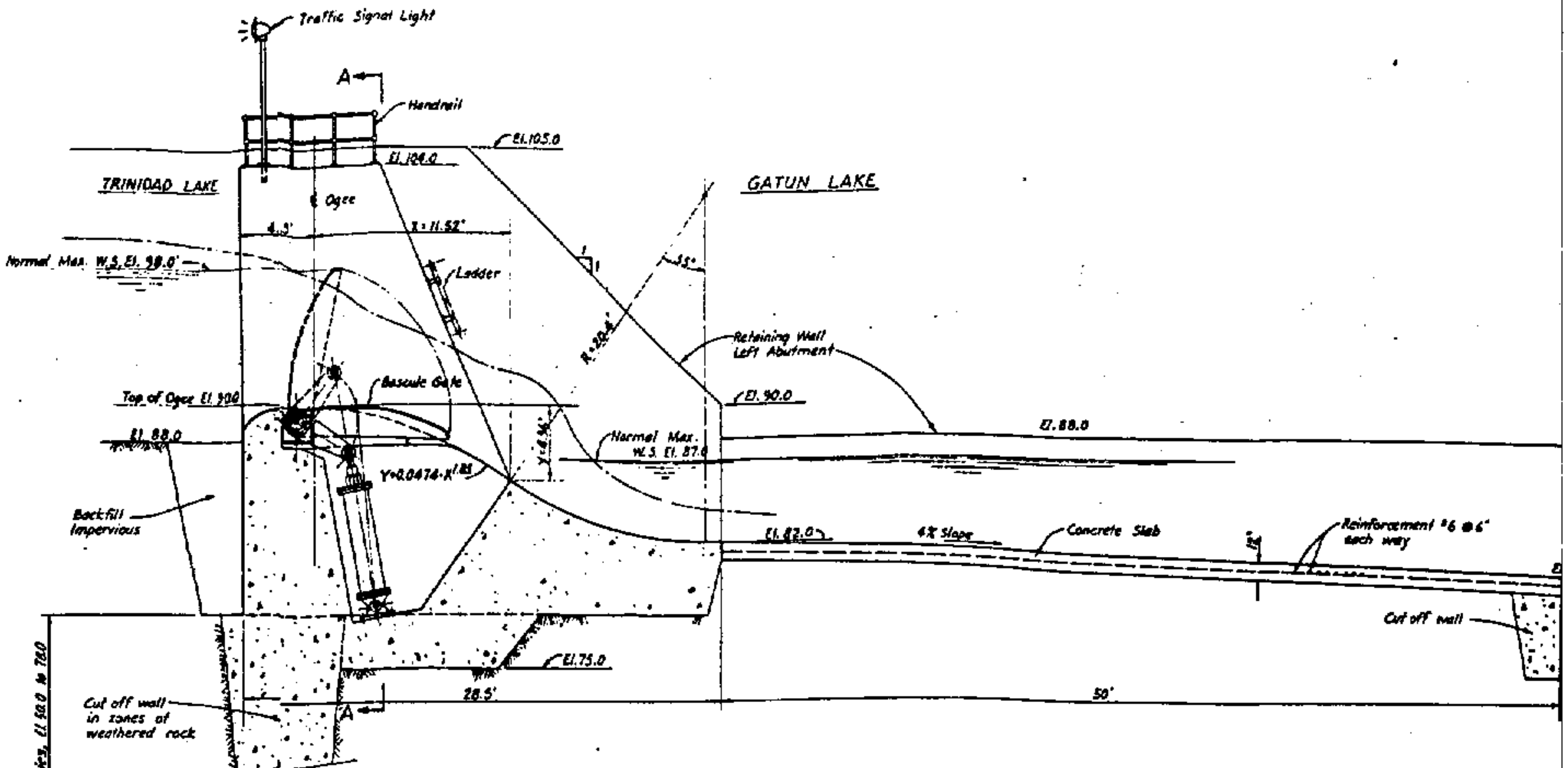
PLAN
Scale: 1" = 10'
TRINIDAD LAKE
GATUN LAKE
Flow
EL 88.0
EL 71.0
EL 105.0
Slope 1:1
Sliding Bridge
60"x60" Control Gate
Back Fill
¢ Dam
¢ Lock
76'-0"
Max. Size of Boat
Construction Joint
Trash Rack
Control Gate
Machinery House
Control Station for Lock Gates & Spillway
SECTION A-A
Scale: 1" = 10'-0"
SECTION B-B
Face of Lock
Concrete Pavement
Concrete Floor
PLAN OF SLIDING BRIDGE CROSSING THE LOCK
1½" ¢ Standard Pipe
Concrete Ballast
Tracks
Open Metal Grid Flooring
Lock Clearance
50'-0"
SECTION C-C
ELEVATION THRU ¢ LOCK
Scale: 1" = 10'
Control House
¢ Trunion
Stop Log Groove
Machinery Deck
Gatun Lake Normal max. W.S. EL 87.0
Normal min. W.S. EL 82.0
Control Gate 60" x 60"
Cast Steel Pintle
Construction Joint
W.S. Trinidad Elevation in feet
Discharge in 100 C.F.S.
W.S. Gatun 84.0 Constant
2-CONTROL GATES CAPACITY CURVE
THE PANAMA CANAL COMPANY
BALBOA HEIGHTS, CANAL ZONE
WATER SUPPLY AND NAVIGATIONAL DEPTH ST
LOCK SECTIONS AND DETA
TUDOR ENGINEERING COMPANY
SAN FRANCISCO, CALIF.



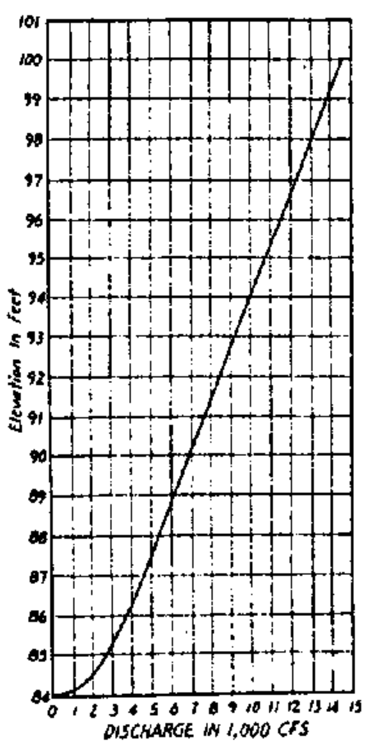
SECTION A-A
Scale: 1"=20'



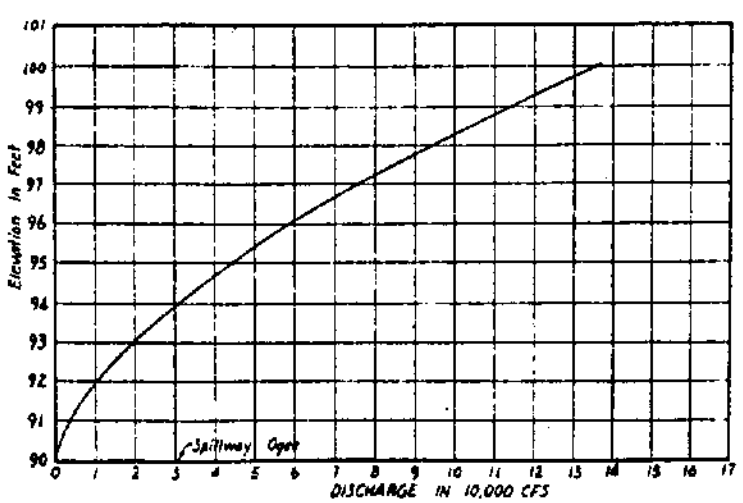
PLAN
Scale: 1/8"=1'-0"



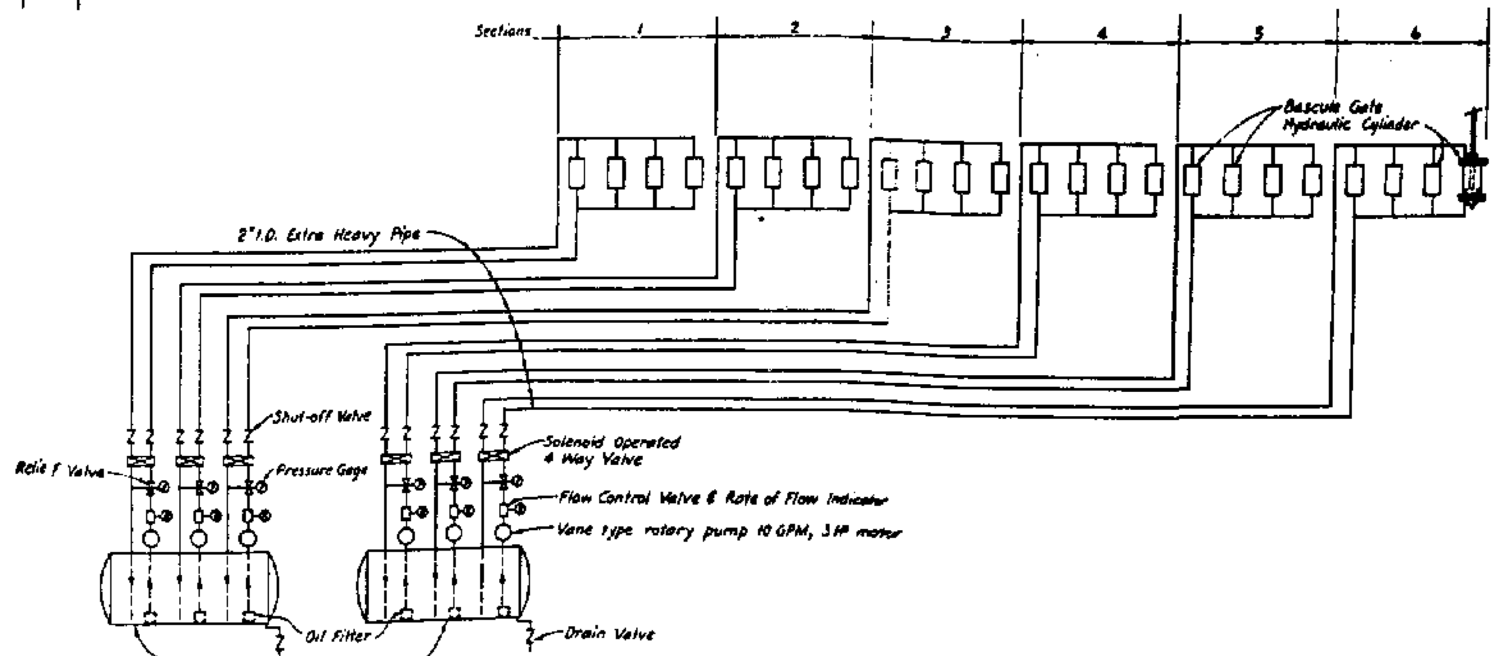
TYPICAL SECTION THRU HYDRAULIC CYLINDER CHAMBER
Scale: 1/4"=1'-0"



LOCK CAPACITY CURVE



SPILLWAY CAPACITY CURVE



HYDRAULIC CONTROL
PIPING SCHEMATIC DIAGRAM
Not To Scale

THE PANAMA CANAL COMPANY
BALBOA HEIGHTS, CANAL ZONE

WATER SUPPLY AND NAVIGATIONAL DEPTH STUDI

SPILLWAY SECTION AND DETAILS

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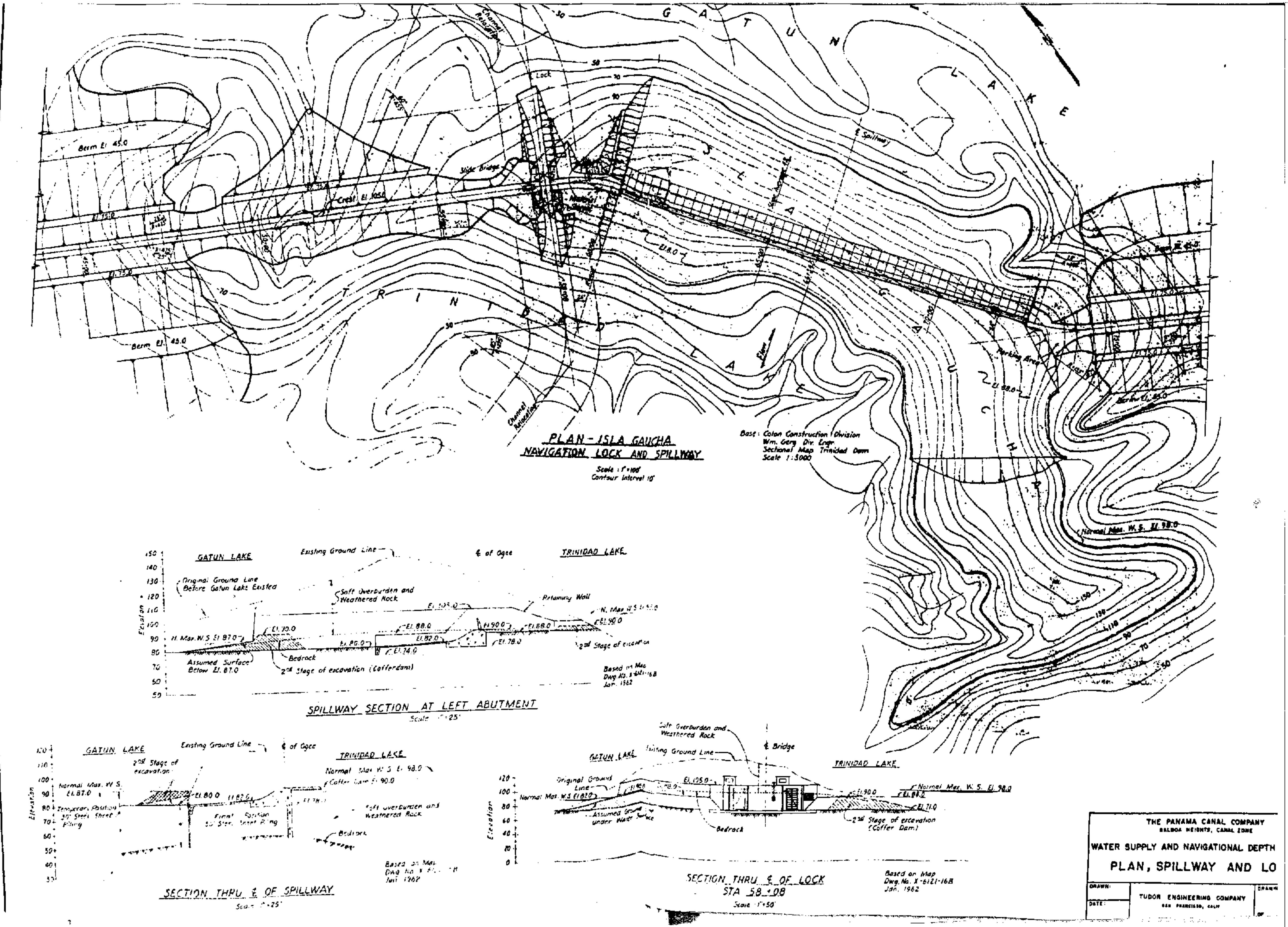
GATUN LAKE
TRINIDAD LAKE
GATUN CHAP
Berm El. 45.0
Crest El. 105.0
Slide Bridge
Lock
Spillway
Channel Relocation
Parking Area
Normal Max. W.S. El. 98.0
PLAN - ISLA GAUCHA
NAVIGATION LOCK AND SPILLWAY
Scale: 1" = 100'
Contour Interval 10'
Base: Colon Construction Division
Wm. Gerg Div. Engr.
Sectional Map Trinidad Dam
Scale 1:5000
GATUN LAKE
Existing Ground Line
℄ of Ogee
TRINIDAD LAKE
Original Ground Line Before Gatun Lake Existed
Soft Overburden and Weathered Rock
Retaining Wall
Bedrock
Assumed Surface Below El. 87.0
2nd Stage of excavation (Cofferdam)
SPILLWAY SECTION AT LEFT ABUTMENT
Scale 1" = 25'
GATUN LAKE
TRINIDAD LAKE
Normal Max. W.S. El. 98.0
Soft Overburden and Weathered Rock
Bedrock
SECTION THRU ℄ OF SPILLWAY
Scale 1" = 25'
GATUN LAKE
Existing Ground Line
℄ Bridge
TRINIDAD LAKE
Soft Overburden and Weathered Rock
Original Ground Line
Assumed Ground under Water Surface
Bedrock
2nd Stage of excavation (Coffer Dam)
Based on Map
Dwg. No. X-6121-168
Jan. 1962
SECTION THRU ℄ OF LOCK
STA 58+08
Scale 1" = 50'
THE PANAMA CANAL COMPANY
BALBOA HEIGHTS, CANAL ZONE
WATER SUPPLY AND NAVIGATIONAL DEPTH
PLAN, SPILLWAY AND LO
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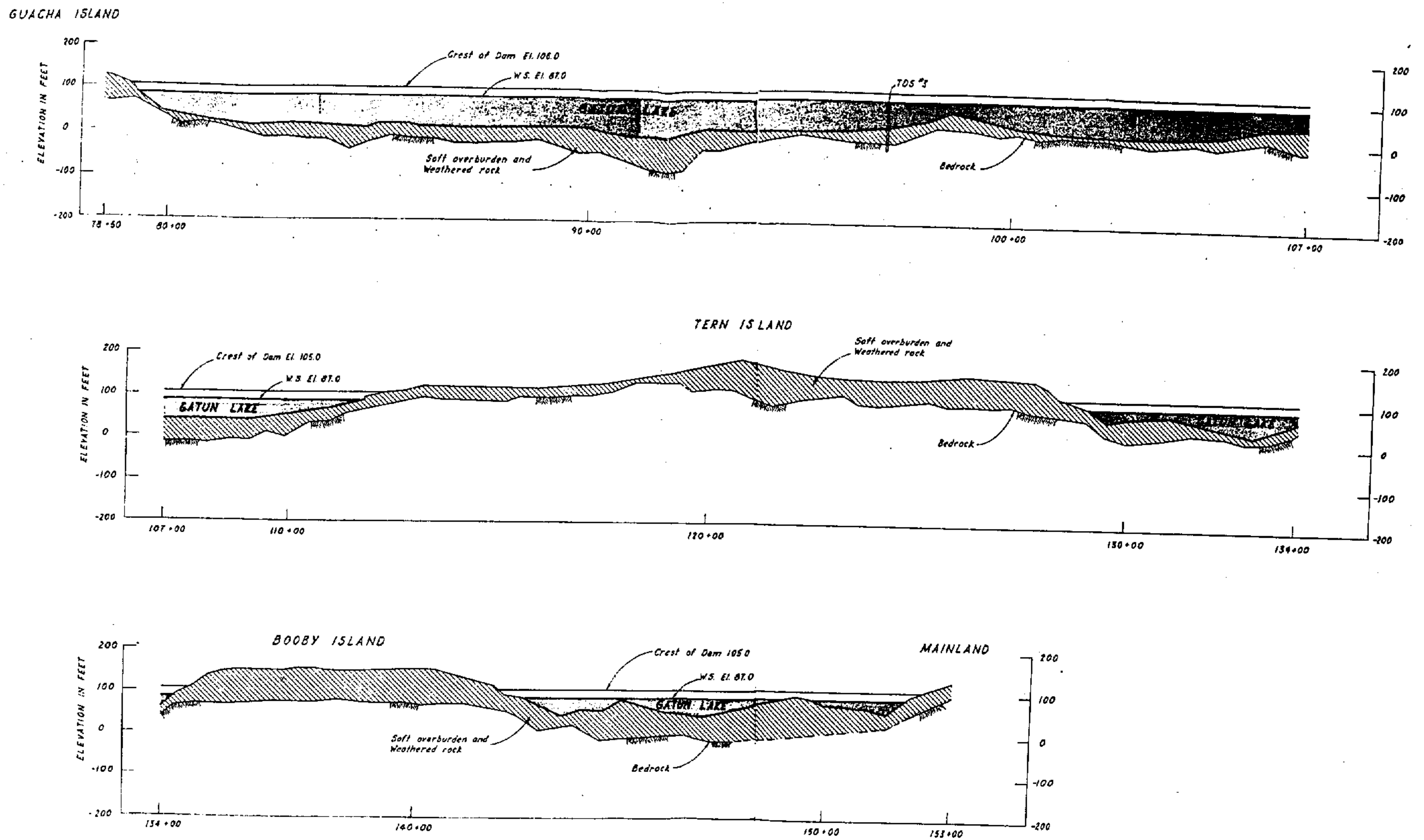
TUDOR ENGINEERING COMPANY
SAN FRANCISCO, CALIF



LEGEND

Dam A Punta Mala to Guacha Island.
Dam B Guacha Island to Tern Island
Dam C Tern Island to Booby Island.
Dam D Booby Island to Mainland.

100 0 100 200 300 400 500

SCALE IN FEET

THE PANAMA CANAL COMPANY
BALBOA HEIGHTS, CANAL ZONE

WATER SUPPLY AND NAVIGATIONAL DEPTH STUDIE

PROFILE, DAMS B, C AND D

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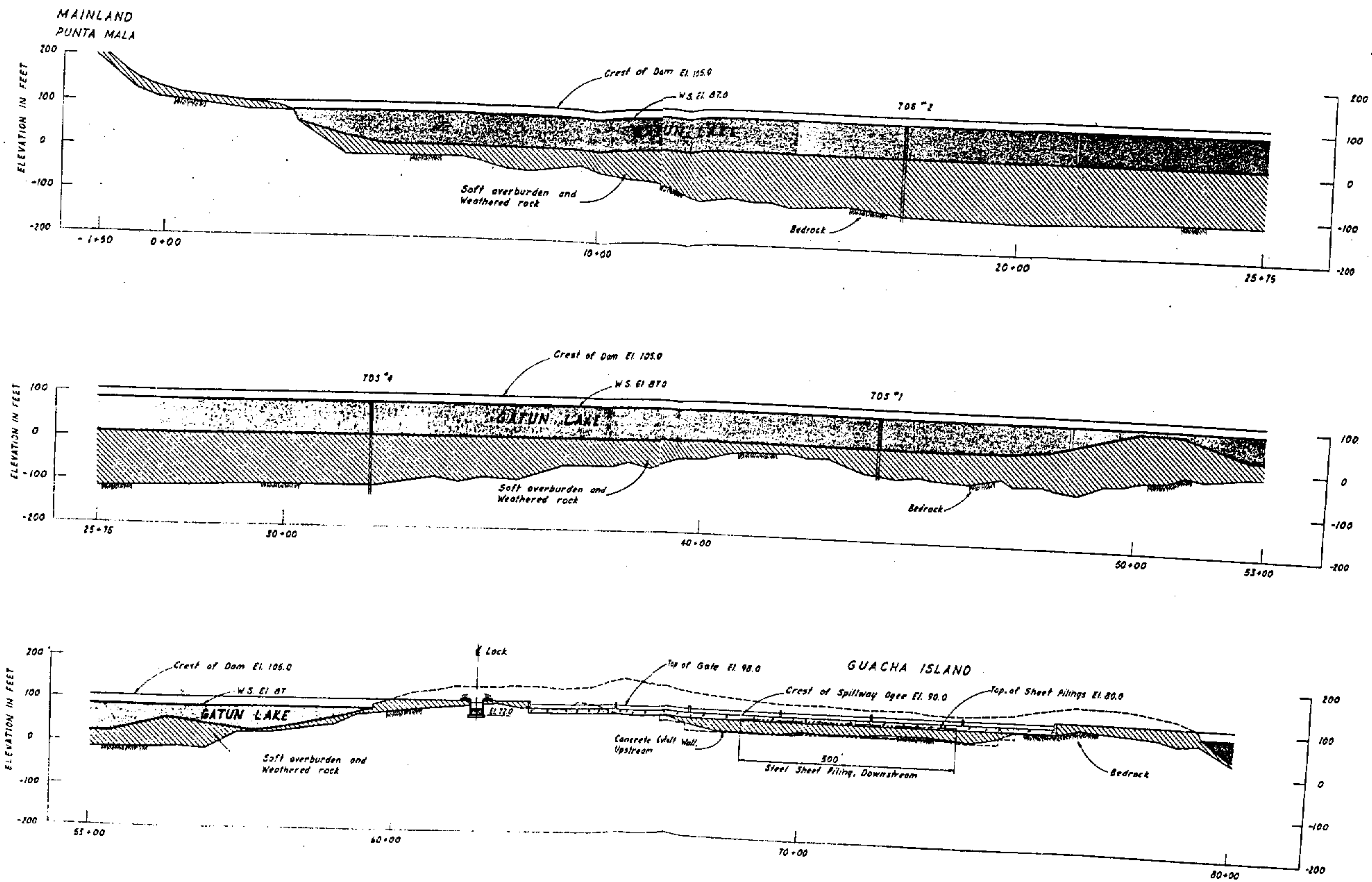
FIGURE NO. 1C



LEGEND

Dam A : Punta Mala to Guacha Island
Dam B : Guacha Island to Tern Island
Dam C : Tern Island to Booby Island
Dam D : Booby Island to Mainland.

TDS #1 Test borings

100 0 100 200 300 400 500
SCALE IN FEET

THE PANAMA CANAL COMPANY
BALBOA HEIGHTS, CANAL ZONE

WATER SUPPLY AND NAVIGATIONAL DEPTH S

PROFILE, DAM A, LOCK AND SPIL

DRAWN:
DATE
TUDOR ENGINEERING COMPANY
SAN FRANCISCO, CALIF.
DRAWING

APPENDIX A

REPORT OF GEOPHYSICAL EXPLORATIONS
TRINIDAD DAM PROJECT
CANAL ZONE

TO

TUDOR ENGINEERING COMPANY
SAN FRANCISCO, CALIFORNIA

BY

GEO-RECON, INC.
SEATTLE, WASHINGTON
FEBRUARY 19, 1962

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REPORT OF GEOPHYSICAL EXPLORATIONS
TRINIDAD DAM PROJECT
CANAL ZONE

I. INTRODUCTION

Geophysical surveys have been completed in connection with preliminary engineering studies for Trinidad Dam Project located in Gatun Lake, Canal Zone.

The axis of two proposed dams cross the Trinidad Arm of Gatun Lake, an artificial lake, which occupies a broad valley. In the vicinity of Trinidad Dam Site Number One, several hilltops extend above the lake surface forming Guacha, Tern and Booby Islands. The reservoir created by this dam site will extend to the southwest for a distance of nearly fifteen miles.

The purpose of this investigation was to obtain seismic velocity and electrical resistivity profiles for use in determining the thickness and nature of overburden materials and the continuity and general condition of bedrock. Explorations were carried out along the axis of the proposed Trinidad Dam Site No. 1, at the Caño Saddles and in the vicinity of Coco Solo Hospital for the purpose of obtaining seismic velocity data of known geologic formations. A very brief overwater electrical resistivity survey was also made along the axis of Trinidad Dam Site No. 2 for the purpose of furnishing general comparative data, although this site is not being considered in the present feasibility study.

Preliminary interpretation of geophysical data was made in the field as the explorations progressed. After study of the preliminary results, locations were selected for four test borings along the axis of Trinidad Dam Site No. 1.

The logs of these test borings were used to correlate depths to various materials located and differentiated by the geophysical survey.

These explorations were completed under contract to the Tudor Engineering Company of San Francisco.

II. PERSONNEL AND EQUIPMENT

Key personnel and all geophysical instruments were furnished by Geo-Recon, Incorporated. Labor, transportation, land surveys, hydrographic surveys, base camp and support for field operations were furnished by the Panama Canal Company.

Our personnel and equipment included a geophysicist, field assistant, twelve channel refraction seismograph with accessories for both land and overwater surveys and a special overwater electrical resistivity apparatus designed and constructed at our office specifically for this investigation.

Personnel furnished by the Panama Canal Company included a powderman, three laborers, and boat operators. A base camp was established on Guacha Island for field personnel and transportation on the site was furnished by three power boats.

III. FIELD EXPLORATION

A. General

Approximately 20,000 feet of land and overwater refraction seismic profile and 4,500 feet of overwater electrical resistivity profile were made for the explorations of Trinidad Dam Site No. 1, Caño Saddles and velocity tests near Coco Solo Hospital. An additional 6,000 feet of overwater resistivity traverse was recorded on the axis of Trinidad Dam Site No. 2.

The field investigation was completed in sixteen working days starting on January 2, 1962 and finishing on January 19. Little difficulty was experienced from brief, but heavy rainstorms which occurred almost daily, but the trade winds which were particularly strong the last week of the field exploration, made overwater explorations in Gatun Lake difficult and sometimes hazardous due to rough water. This was particularly true in areas of relatively shallow water where numerous underwater obstructions, consisting primarily of inundated trees, were present.

B. Methods and Equipment

1. Refraction Seismic

A twelve channel Electro Tech refraction seismograph was used for this investigation. This recording equipment included a PRA-1-12 refraction amplifier, ER-64 oscillograph camera and FS-3 high cut filter for use in overwater recordings. These instruments were operated from a government furnished power launch for both land and overwater explorations except for the velocity tests near Coco Solo Hospital where the instruments were truck-mounted.

Accessory equipment included EVS-5-4 refraction geophones for land exploration and EVP-3 submersible pressure detectors for overwater exploration. Portable brest reel cables were used for the land surveys and a heavy duty twelve pair marine cable with a 4,000 lb. test stainless steel strain core was used for the overwater exploration. The marine cable was floated five feet below the surface of the lake rather than laid on the bottom because of numerous submerged obstructions and the risk of tangling the underwater equipment.

All shots on land were buried in the ground at depths of two to six feet and water shots were floated approximately five feet below the lake surface. Explosive charges varied in weight from 1/4 to 5 pounds of 60% gelatin dynamite.

Seismic recordings were developed immediately after each shot to permit inspection of the record quality and determine that adequate data were being obtained.

2. Electrical Resistivity

A DC type continuous recording overwater resistivity system was designed and constructed for this investigation. This unit employed a two channel strip chart recorder for displaying and recording current and potential. A transistorized power unit capable of furnishing 600 volts DC at 200 milliamperes was used as a power source.

This instrument was mounted in a twenty foot inboard power boat. Two coaxial cables varying in length from 100 to 1,000 feet in length were trailed behind the boat with floats attached to the ends for bouyancy and drag. The shield and center conductor of each coaxial cable was exposed at selected locations to provide electrical contact with the water.

Various electrode spacings were used varying from ... A separate set of recordings was made over the same path for each setting of the electrodes. Several bouys were anchored in the lake to provide markers for distance and alignment. These recordings were made at a uniform boat speed of approximately 250 feet per minute.

Because of the length of trailing cables required for the electrical resistivity exploration, these measurements could only be made in areas of open water exceeding 2,000 feet in length where no underwater obstructions were present. For this reason resistivity measurements could only be made from Sta. 10 + 00 to 43+ 00 and diagonally at station 47 + 00 of Trinidad Dam Site No. 1.

A single set of resistivity measurements was taken at Trinidad Dam Site No. 2 using an electrode separation of 900 feet in order to furnish some basic data for comparing the two sites. These measurements were made for a distance of approximately 5000 feet across the dam axis and excluded the inshore areas for a distance of 1,000 feet from each abutment.

IV. INTERPRETATION AND RESULTS

A. Trinidad Dam Site No. 1

The location and results of this investigation are shown on the enclosed Geophysical Exploration Plan, Fig. A I and Geophysical Profile, Figs. A II and AIII.

The entire site area is underlain by soft sedimentary rocks which are mantled by a relatively thick weathered zone and soft residual overburden. The lower elevation of Trinidad Valley was filled with soft organic and alluvi deposits prior to the raising of the lake. These deposits are called the Atlantic Muck Formation.

1. Overburden Materials

For the purpose of this report all materials overlying firm bedrock and having a seismic velocity of less than 5,000 ft/sec. are called overbu materials. These materials include weathered bedrock, soil overburden, alluvial deposits and all phases of the Atlantic Muck Formation.

These materials are described in detail on the bore logs, Table I, sheets 1 through 14 and because they are quite different in the land and water areas, are discussed separately in this report.

a) Land Areas

Overburden materials encountered in the exposed surface areas of the abutments and on Guacha, Tern and Booby Islands, consist of residual soils and weathered rock having a velocity range of 1,000 to 3,400 feet per second.

These materials are differentiated on the basis of their seismic velocities as shown on the Geophysical Profile, Figs. AII and AIII. Because no test pits or test borings have been made in the land areas, our classification of these materials is based upon the logs of test borings completed in the lake, on the observation of limited local outcrops and on our estimate of the normal geologic sequence of residual overburden materials which would be derived from bedrock weathering in a tropical climate.

Materials having a velocity range of 1,000 to 1,500 ft/sec are classified as soft overburden consisting of unconsolidated, or semi-consolidated surficial deposits or highly weathered rock.

Materials in the velocity range of 1,500 to 3,400 ft/sec are identified as weathered rock. We are of the opinion that variations of velocity within this range reflect changes in the degree of weathering and differences in the type of bedrock from which the weathering products are derived. Exposures of the weathered rock are limited to the shoreline of Guacha Island in the vicinity of Station 79 + 60 where the soft overburden deposits have been eroded away by wave action.

b) Water Areas

Overburden materials found in the water areas include recent lake deposits, Atlantic Muck Formation, alluvial deposits, and residual overburden. These deposits consist of soft to very soft clay, silt, sand and peat (Atlantic Muck Formation) overlying soft to hard deposits of clay, silt, sand and gravel derived from both alluvial deposition and the weathering of bedrock.

These various overburden materials could not be differentiated on the basis of seismic velocities due to the lack of velocity contrast between the overburden deposits and the fresh water of Gatun Lake. However, in areas where electrical resistivity measurements could be made, it was found that the overburden deposits could be separated into two groups on the basis of their electrical properties. The first group is composed of recent lake deposits underlain by thick zones of very soft peat interbedded with thin zones of soft silt and clay (peaty phase of the Atlantic Muck Formation.) The second group underlies the first group and is composed of soft silt and clay with thin zones of organic material over weathered rock. The location and thickness of these deposits is shown on the Geophysical Profiles, Figs. AII and AIII.

The thick zones of soft peat detected by the electrical resistivity survey extend from approximately Sta 16 + 00 to Sta. 35 + 00 and have a maximum thickness of approximately 75 feet. It is possible that the peat deposits could not be detected by the electrical resistivity survey where they are less than 25 feet thick and therefore they may extend beyond the area described.

2. Bedrock Materials

Bedrock within the site area has been identified by the logs of the test borings as rather soft sedimentary rocks consisting of tuffaceous sandstones and siltstones which probably belong to the Gatun Formation.

A rather broad range of seismic velocities, 5140 to 7400 ft/sec, was recorded in the firm bedrock indicating that it may be somewhat more variable in composition and, or condition than is presently indicated by the core samples. Lower velocities indicate the presence of softer sedimentary rocks.

At two locations in the water areas the velocity of the bedrock is below 5,400 ft/sec. At these locations the bedrock does not have sufficient contrast with the overlying water to permit accurate interpretation of depth to rock by the seismic method. These areas extend from Stations 16 + 00 to 32 + 00 and from Stations 147 + 80 to 152 + 00.

The bedrock profile from Station 16 + 00 to 32 + 00 was constructed from electrical resistivity data alone. This method could not be used however,

between stations 147 + 80 and 152 + 00 because of the limited water area in
which to work and the existance of numerous underwater obstructions. Useab
geophysical data is therefore lacking in this area and the bedrock profile
shown on the Geophysical Profile, Fig. AIII is inferred.

B. Caño Saddles

Four seismic lines were completed in the Caño Saddles area, three
at Saddle four and one at Saddle five. The location and results of these sur-
veys are shown on the attached Geophysical Exploration Plan, Fig. A IV and
Geophysical Profiles, Fig. V.

An overburden velocity of 1250 ft/sec was detected throughout the area
explored. Materials in this velocity range include the fill material of the
existing dam and, or soft overburden.

Bedrock velocities measured in this area range from 5,000 to 5,700
ft/sec. This velocity range is low and indicates that the bedrock materials
are relatively soft. These materials are classified by the logs of old test
borings as sandstone and conglomerate interbedded with soft materials whi
are not described in the logs.

C. Coco Solo Hospital

Two seismic velocity tests were completed in the vicinity of Co
Solo Hospital to furnish seismic data on known geologic formations which
expected to be similar to those encountered at Trinidad Dam Site No. 1.

The first test was made on the Gatun Formation at a borrow area
across the road from the entrance to Coco Solo Hospital. The results of th
test indicated that the velocity of weathered Gatun Formation was 1900 ft/
and that of the firm bedrock 7800 ft/sec.

The second test was made along a drainage ditch in a bog area
located a few hundred feet east of the highway intersection approximately
mile south west of the entrance to Coco Solo Hospital. At this location a
velocity of 7700 ft/sec was recorded in Gatun Formation and a velocity of
4500 ft/sec in material which is either Atlantic Muck or weathered Gatun
Formation.

D. Trinidad Dam Site No. 2

A single pass was made over the water area of this site with th electrical resistivity equipment using an elec

feet. These data are not sufficient to construct a geophysical profile of over-burden and bedrock materials, but do furnish values of total resistivity of all materials from the surface of the lake to a depth of approximately three hun-dred feet. These data may be used to make a general comparison to site number one.

It was found that the values of resistivity measured at this site were consistently one or two ohms per foot less than those measured at the same electrode spacing along the axis of site one.

V. CONCLUSIONS

A. Trinidad Dam Site No. 1

The results of the geophysical surveys and test borings indicate that this site is underlain by low velocity sedimentary bedrock composed primarily of sandstone and siltstone. These rocks have been tentatively classified by Robert H. Stewart, geologist for the Panama Canal Company, belonging to the Gatun Formation. Seismic velocities measured in the bedr at this site are substantially lower than velocities recorded over a known section of Gatun Formation in the vicinity of Coco Solo Hospital.

A rather broad range of bedrock velocities was detected which a mostly gradational and appear to reflect changes in lithology. At two locations, however, abrupt changes in bedrock velocity were detected wh may indicate significant fault contacts or shear zones.

Between Stations 67 + 40 and 67 + 90 on Guacha Island a narro zone of 5,250 ft/sec bedrock was detected which is bounded by rock havi a velocity of 7,200 ft/sec. We interpret this low velocity zone as a pos shear zone in rocks of similar type.

At station 119 + 40 on Tern Island an abrupt change in bedrock velocity was measured with a corresponding change in overburden condit We interpret this as a possible fault contact between two formations or different lithologic units of the same formation.

These rocks are deeply weathered and throughout most of the land area the zone of weathering extends below present lake elevation of 87 feet. Changes in seismic velocity of the firm bedrock and weathered zones indicate that these materials are variable in condition and composition.

In the deep water areas of Gatun Lake a deposit of compressible material called the Atlantic Muck Formation is found. This formation is composed primarily of soft peat, silt and clay which overlies the firm bedrock and associated weathered zone. From the geologic standpoint, it appears unlikely that the Atlantic Muck Formation will be found where the lake bottom extends above elevation 10 or 11 and for this reason it is probably limited to the area between Stations 4 + 00 to 47 + 00 on the axis centerline. The peaty phase of this formation is probably the most compressible and was found to have an average thickness of about 60 feet and a maximum thickness of 75 feet.

The results of the geophysical surveys in this area compare well with the logs of the test borings indicating that the geophysical data probably are reliable within the normal limits for this type of survey. We estimate that the thickness of formations shown on the Geophysical Profiles, Figs. AII and AIII are accurate to within plus or minus ten percent of the true thickness except between Stations 3 + 00 and 15 + 00 and Stations 147 + 80 and 152 + 00 where seismic velocity contrast between the water and firm bedrock was marginal or nonexistent and electrical resistivity surveys could not be made due to limitations of operating space or underwater obstructions. In these two areas we estimate the accuracy of the interpreted depths at plus or minus twenty percent.

It is probable that all seismic velocities measured in this investigation can be correlated more closely with regard to the physical and engineering properties of the various materials if future test pits and borings are made in the individual velocity zones and a careful comparison made between the logs and geophysical data.

B. <u>Caño Saddles</u>

The results of the geophysical surveys and test boring completed in this area indicate the site is underlain by low velocity sedimentary rocks composed primarily of sandstone and conglomerate which are interbed-- zones of soft material that are not identified on the bore logs.

We understand that some degree of settlement has occurred in the dam at Saddle four since it was constructed. In connection with this it is interesting to note the configuration of the bedrock surface shown on Seismic Line 2 and particularly on Seismic Line 3. The concave shape of this surface beneath the fill suggests that either material was excavated to prepare the sit for construction of the dam or that the foundation rocks have subsided under the weight of the structure.

The seismic data compare well with the logs of the test borings. C the basis of this comparison we estimate that the depths to rock as shown or the Geophysical Profiles, Fig. A-V probably are accurate to within plus or minus ten percent. These data also show that no materials of higher velocit than those shown on the profiles are present within a depth of one hundred a twenty five feet of the ground surface.

C. Trinidad Dam Site No. 2.

The lower value of electrical resistivity measured at dam site nu ber two could result from an increase in thickness of the Atlantic Muck Formation, a reduction in resistivity of bedrock due to a change in litholog or both.

Of the two possibilities it would seem that the latter is the more reasonable since the drainage in this area prior to the existence of Gatun was to the north and the Atlantic Muck Formation should therefore become thinner toward site two, which is located approximately 2-1/2 miles south site one.

GEO-RECON, INC.

By [signature]
SIGMUND D. SCHWARZ

ELEVATION in feet	DEPTH in feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL	DRILLING CHARACTERISTICS	[illegible]
+86.7	0.0		WATER, GATUN LAKE.		0
+10.7	76.0		Top of Recent Lake Deposits SILT & CLAY. Hard overburden, high plasticity, high water content, unconsolidated, very carbonaceous with abundant plant debris, contains scattered wood fragments. Color: dark grey-brown	Push drilled dry with NX casing. Core in disturbed condition. Plug formed in barrel, pushed material aside H.P. 150 psi 1.6' 40.0%	
+ 6.7	80.0		Top of Old Land Surface Prior to Flooding of Gatun Lake. CLAY. Soft overburden, high plasticity. high water content, unconsolidated, contains some scattered carbonaceous debris, becomes silty with depth. Color: dark grey-brown.	As above. 3.9' 39.0%	
- 3.3	90.0		SILT & CLAY. Hard overburden, high plasticity, high water content, unconsolidated, very carbonaceous with abundant organic, plant debris contains scattered wood fragments. Color: dark grey-brown.	As above.	
	94.0			H H.P. 50 psi	
	98.0			H.P.200 psi 3.2' 29.1%	
- 14.3	101.0 102.6		CLAY. Soft overburden, high plasticity, high water content, unconsolidated, becomes silty with depth Colors: mottled reds, brown & grey.	As above As above H.P. 400 psi 2.8' 25.5%	
-25.3	112.0 112.6		SAND & SILT. Soft overburden, low plasticity, high water content, unconsolidated; consists of a residual, saprolitic sand & silt derived from siltstone & sandstone by normal weathering processes. Color: light to medium brown, buff & grey.	As above H.P. 25-250 psi	

Hole No. TDS-1

Table I. Sheet 1

ELEVATION in feet	DEPTH in feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL	DRILLING CHARACTERISTICS
	124.0		SAND & SILT. (Continued) As above	As above Push drilled dry with BX casing. Core in disturbed condition. Plug formed in barrel, pushed material aside. H.P. 250-450 psi 5.8' 36.3%
-41.3	128.0 132.0 135.1		Top of Weathered Rock SILTSTONE. Hard overburden to soft rock, moderate jointing with joints highly weathered & containing soil-like material, thin bedding, fine-grained, marine; becomes harder with depth. Color: mottled medium browns & grey.	As above Drilled dry with NX single tube. Core in disturbed condition. H.P. 500-600 psi
-50.3	137.0 137.8		Top of Sound Rock SANDSTONE, Tuffaceous. Soft rock, moderate jointing, thin bedding, variably calcareous, contains a few scattered fossils, somewhat carbonaceous containing scattered organic, plant debris; becomes coarser with depth. Color: mottled medium to dark greys.	Drilled rapidly & easily with NX single tube & water. Core ground up. Material inferred from washings & color of water. 6.1' 67.8%
-55.3	142.0		Bottom of Hole	Drilled rapidly and easily with NX single tube & water. Core in fair condition in 0.1 to 0.6 ft. lengths. 3.8' 76.0%

NOTE:

1.

Elevation	Depth		
+ 86.7 to + 10.7	0.0 - 76.0	WATER, GATUN LAKE	
+ 10.7	76.0	Top of Recent Lake Deposits	
+ 10.7 to + 6.7	76.0 - 80.0	SILT & CLAY - Recent Lake Deposits	
+ 6.7	80.0	Top of Old Land Surface Prior to Flooding of Gatun Lake	
+ 6.7 to - 3.3	80.0 - 90.0	CLAY	ATLANTIC MUCK FORMATION
- 3.3 to - 14.3	90.0 - 101.0	SILT & CLAY	ATLANTIC MUCK FORMATION
- 14.3 to - 25.3	101.0 - 112.0	CLAY	Gatun (?) Formation
- 25.3 to - 41.3	112.0 - 128.0	SAND & SILT	Gatun (?) Formation
- 41.3	128.0	Top of Weathered Rock	Gatun (?) Formation
- 41.3 to - 50.3	128.0 - 137.0	SILTSTONE - Weathered	Gatun (?) Formation
- 50.3	137.0	Top of Sound Rock	Gatun (?) Formation
- 50.3 to - 55.3	137.0 - 142.0	SANDSTONE, Tuffaceous	Gatun (?) Formation
- 55.3	142.0	Bottom of Hole	

2. 90.0' of 4" casing used in hole.
117.2' of NX casing used in hole.

3.

Core Box No.	From	To
1 of 2	76.0	134.0
2 of 2	134.0	142.0

4. H.P. indicates hydraulic pressure, on drill head, necessary to cause core barrel to penetrate soil.

ELEVATION in feet	DEPTH in feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL	DRILLING CHARACTERISTICS
+ 86.7	0.0		WATER, GATUN LAKE	
+ 5.3	81.4		Top of Recent Lake Deposits SILT & CLAY. Hard overburden, high plasticity, & Water content, unconsolidated, very carbonaceous with abundant organic plant debris; contains scattered wood fragments. Color: dark grey-brown	Push drilled dry with NX casing. Core recovered in disturbed condition. 3.0' 100%
+ 3.7	83.0			
+ 2.3	84.4		Top of Old Land Surface Prior to Flooding of Gatun Lake. CLAY. Soft overburden, high plasticity, & water content, unconsolidated; becomes silty with depth, contains some scattered carbonaceous debris. Color: mottled medium greys oxidizing rapidly to grey-brown on exposure to air.	As above. 5.6' 100%
- 3.3	90.0		PEAT. Soft overburden, low plasticity, very high water content, unconsolidated, highly compressible; consists of leaves which appear to have been washed into position. Color: dark brown to black.	As above. 1.0' 33.
- 4.3	91.0			
- 6.3	93.0		SILT, Sandy. Soft overburden, low plasticity, high water content, unconsolidated; consists of an alluvial, sandy silt deposited by the old Trinidad River. Color: grey-brown.	As above. 1.3' 72.
- 8.1	94.8		PEAT. Soft overburden, low plasticity, very high water content, unconsolidated, highly compressible, consists of leaves which appear to have been washed into position. Color: dark brown to black.	As above. 0.7' 35.
- 10.1	96.8		SAND, Silty. Soft overburden, low plasticity, high water content, unconsolidated, contains scattered wood fragments; consists of an alluvial, silty sand deposited by the old Trinidad River. Color: mottled medium browns & grey.	As above. 3.0' 57.
- 15.3	102.0		SILT & CLAY. Soft overburden, low to medium plasticity, unconsolidated; consists of an alluvial silt & clay deposited by the old Trinidad	As above..

Table I Sheet 3 Hole No. TDS-2

ELEVATION in feet	DEPTH in feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL	DRILLING CHARACTERISTICS	[illegible]
			SILT & CLAY. (Continued) River. Color: mottled medium blue-greys oxidizing rapidly to brown on exposure to air.	As above.	
				5.4' 58.1%	
-24.6	111.3		PEAT. Soft overburden, low plasticity, very high water content, unconsolidated, highly compressible; consists of leaves which appear to have been washed into position; contains abundant wood fragments. Color: dark brown to black.	Pushed drilled dry with NX casing. Core recovered in disturbed condition.	
2 -26.3	113.0				
				H.P. 50-200 psi	
3 -31.3	118.0				
	121.3				
4 -37.3	124.0			H.P. 250-450 psi	
5 -38.3	125.0				
6 -39.3	126.0				
7 -41.3	128.0				

ELEVATION	DEPTH in feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL	DRILLING CHARACTERISTICS	Core Recov
[illegible]	130.0		PEAT. (Continued)		
[illegible]	130.8		As above.	As above.	
[illegible]	131.3			10.2' 51.0%	6.
			SILT & CLAY. Soft overburden, unconsolidated, medium to high plasticity, high water content, contains scattered, peaty layers & scattered layers containing oyster shells; consists of silts & clays of alluvial & marine origins deposited in a drowned valley of the Old Trinidad River. Color: mottled dark grey-blues & brown oxidizing rapidly to dark grey & black on exposure to air.	Pushed rilled dry with NX casing. Core recovered in distrubed condition. H.P. 25-75 psi	
	138.0		Note: Oyster shells found from 138.0 ft. to 139.0 ft. depths.		
	139.0				
	141.3				10.
[illegible]	147.5			H.P. 50-125 psi	
[illegible]	150.0				
	151.3			H.P. 150-200 psi	

Table I Sheet 5 Hole No. TDS-2

ELEVATION In feet	DEPTH In feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL	DRILLING CHARACTERISTICS
+ 86.7	0.0		WATER, GATUN LAKE	C
+ 10.7	76.0		Top of Recent Lake Deposits SILT & CLAY. Hard overburden, high plasticity & water content, unconsolidated, very carbonaceous with abundant organic plant debris, contains scattered wood fragments. Color: dark grey-brown.	Push drilled dry with NX casing. Core recovered in disturbed condition. 2.3' 57.5%
+ 6.7	80.0		Top of Old Land Surface Prior to Flooding of Gatun Lake CLAY. Soft overburden, high plasticity & water content, unconsolidated; becomes silty with depth, contains some scattered carbonaceous debris. Color: mottled medium greys & brown.	H.P. 125 psi As above. 3.0' 21.0%
− 7.6	94.3		SILT & SAND. Soft overburden, low plasticity, high water content, unconsolidated, consists of a residual, saprolitic silt & sand derived from siltstone & sandstone by normal weathering processes. Color light to medium brown, buff & grey.	As above. H.P. 300-450 psi 4.3' 100%
−11.9	98.6		Top of Sound Rock SANDSTONE, Tuffaceous. Soft rock, moderate jointing, thin bedding, variably calcareous, contains a few scattered fossils, carbonaceous, contains scattered organic plant debris. Color: mottled medium to dark grey.	Drilled rapidly & easi ly with BX casing & water. Core ground easily because of poo cementation; recovere in poor condition in 0.1-0.2 ft.lengths & as a dry-block plug.
	102.8			Drilled rapidly and easily with NX double tube and water. Core recovered in good con dition in 0.1 to 1.0 ft. lengths.
	108.5			13.6' 75.6
29.9	116.6		Bottom of Hole	

See Sheet 10

Table I Sheet 9

Hole No. TDS-3

ELEVATION in feet	DEPTH in feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL	DRILLING CHARACTERISTICS
	204.6		SANDSTONE, Silty. (Continued) Color: mottled medium browns. Note: Upper 1.0 ft. is mottled bright blue-green & dark grey. because of reduction by humic acids from materials above.	As above. Drilled rapidly and easily with NX single tube and water. Core mostly washed away & recovered in poor, fragmentary condition 2.4' 54.5%
-120.0	206.7		Top of Sound Rock SANDSTONE, Tuffaceous. Soft rock, moderate jointing, thin bedding, variably calcareous, contains a few, scattered fossils, somewhat carbonaceous, contains scattered organic plant debris. Color: mottled medium to dark greys.	As above in good condition in 0.1 to 0.7 ft. lengths.
	208.9			Drilled rapidly and easily with NX double tube and water. Core recovered in good condition in 0.1 to 0.7 ft. lengths. 6.2' 86.1%
-127.2	213.9		Bottom of Hole	

NOTE:

1.

Elevation	Depth		
+86.7 to +5.3	0.0 - 81.4	WATER, Gatun Lake	
+5.3	81.4	Top of Recent Lake Deposits	
+5.3 to +2.3	81.4 - 84.4 -	SILT & CLAY - Recent Lake Deposits	
+2.3	84.4	Top of Old Land Surface Prior to Floodi of Gatun Lake.	
+2.3 to -3.3	84.4 - 90.0	CLAY	Atlantic Formatic
-2.2 to -6.3	90.0 - 93.0	PEAT	
-6.3 to -8.1	93.0 - 94.8	SILT, Sandy	
-8.1 to -10.1	94.8 - 96.8	PEAT	
-10.1 to -15.3	96.8 - 102.0	SAND, Silty	
-15.3 to -24.6	102.0 - 111.3	SILT & CLAY	
-24.6 to -44.6	111.3 - 131.3	PEAT	
-44.6 to -101.3	131.3 - 188.0	SILT & CLAY	
-101.3 to -115.6	188.0 - 202.3	SILT, SAND & GRAVEL	
-115.6	202.3	Top of Weathered Rock	Gatun (Formati
-115.6 to -120.0	202.3 - 206.7	SANDSTONE, Silty-Weathered	
-120.0	206.7	Top of Sound Rock	
-120.0 to -127.2	206.7 - 213.9	SANDSTONE, Tuffaceous	
-127.2	213.9	Bottom of Hole	

2. 131.5' of 4" casing used in hole.
180.2' of NX casing used in hole.

3.

Core Box No.	From	To
1 of 4	81.4	123.0
2 of 4	123.0	151.3
3 of 4	151.3	182.7
4 of 4	182.7	213.9

4. H.P. indicates hydraulic pressure, on drill head, neces to cause core barrel to penetrate soil.

5. Samples indicated were taken for geological studies by Dr. Barghorn of Harvard University.

ELEVATION in feet	DEPTH in feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL		
			SILT & CLAY. (Continued)	As above.	
	180.8			Push drilled dry with BX casing. Core recovered in disturbed condition.	
16 -96.3	182.5 183.0		Note: Oyster shells found from 182.5 ft to 184.0 ft. depths.		
17 -97.3	184.0			H.P. 300-425 psi	
	187.0		Note: Carbonaceous layer from 187.0 ft. to 188.0 ft. depth.	49.6'	87.5%
-101.3	188.0		SILT, SAND & GRAVEL. Soft overburden, unconsolidated, low plasticity; consists of an alluvial deposit in the bottom of the old Trinidad River channel which had been slightly weathered prior to submergence beneath the sea. Color: mottled medium grey	Push drilled dry with BX casing. Core recovered in disturbed condition.	
	191.2			H.P. 450-575 psi	
				4.3'	30.
-115.6	202.3		Top of Weathered Rock SANDSTONE, Silty. Hard overburden to soft rock, moderate jointing, thin bedding, fine-grained, weathered	Push drilled dry wi[th] BX casing. Core re[-] covered in disturbe[d] condition	

Sample	ELEVATION in feet	DEPTH in feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL	[illegible]	
				SILT & CLAY. (Continued)		
				As above	As above.	
12	-72.3	159.0		Note: Carbonaceous layer from 159.0 ft. to 160.0 ft. depth.		
		160.0				5.
		161.3				
		162.0		Note: Oyster shells found from 162.0 ft. to 163.0 ft. depths.		
13		163.0				
		163.5		Note: Carbonaceous layer from 163.5 ft to 164.5 ft. depths.	H.P. 225-375 psi	
		164.5				
14	-78.3	165.0				
15	-83.3	170.0		Note: Carbonaceous layer from 170.0 ft. to 171.0 ft. depths.		
		171.0			Drilled dry with NX single tube. Core recovered in disturbed condition.	
		171.3				
					H.P. 25-50 psi	

ELEVATION in feet	DEPTH in feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL	DRILLING CHARACTERISTICS	Cor Reco

NOTE:

1.

Elevation	Depth	
+86.7 to +10.7	0.0 - 76.0	WATER, GATUN LAKE
+10.7	76.0	Top of Recent Lake Deposits
+10.7 to +6.7	76.0 - 80.0	SILT & CLAY - Recent Lake Deposits
+ 6.7	80.0	Top of Old Land Surface Prior to Flooding of Gatun Lake
+ 6.7 to - 7.6	80.0 - 94.3	CLAY
-7.6 to -11.9	94.3 - 98.6	SILT & SAND — Gatun Formation (?)
-11.9	98.6	Top of Sound Rock
-11.9 to -29.9	98.6 116.6	SANDSTONE, Tuffaceous
-29.9	116.6	Bottom of Hole

2. 90.0 of 4" casing used in hole.

3.

Core Box No.	From	To
1 of 1	76.0	116.6

4. H.P. indicates hydraulic pressure, on drill head, necessary to cause core barrel to penetrate soil.

ELEVATION in feet	DEPTH in feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL		
+86.7	0.0		WATER, GATUN LAKE		0.0
+ 7.7	79.0		Top of Recent Lake Deposits Soft Lake Deposits & Atlantic Muck	Push drilled dry with NX casing. Material so soft that casing pushed thru and pushed material aside. 0.0' 0.0%	
-19.6 -20.1 -21.3 -22.3	106.3 106.8 108.0 109.		PEAT. Soft overburden, low plasticity, very high water content, unconsolidated, highly compressible; consists of leaves which appear to have been washed into position. Color: dark brown to black.	Push drilled dry with NX casing. Core recovered in disturbed condition. 4.5' 100%	
-24.1 -24.3 -25.3	110.8 111.0 112.0		SILT & CLAY. Soft overburden, low to medium plasticity, unconsolidated; consists of an alluvial silt & clay deposited by the old Trinidad River. Color: mottled medium blue-greys oxidizing rapidly to brown on exposure to air.	As above 5.5' 100%	
-29.3 -29.6 -32.3 -34.6 -36.3 -37.3	116.0 116.3 119.0 121.3 122.7 123.0 124.0		PEAT. Soft overburden, low plasticity, very high water content, unconsolidated, high compressible; consists of leaves which appear to have been washed into position. Color: dark brown to black	As above.	16.[illegible]

ELEVATION in feet	DEPTH in feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL	DRILLING CHARACTERISTICS	Core Recovery
-38.3	125.0		PEAT. (Continued)		
-39.3	126.0				
-40.3	127.0		As above.	As above. H.P. 25-50 psi	
-43.3	130.0 131.0 131.3				8.6
				16.2' 89.0%	
-47.8	134.5		SILT & CLAY Soft overburden, unconsolidated, medium to high plasticity, high water content, contains scattered peaty layers; consists of silts & clays of alluvial & marine origins deposited in a drowned valley of the old Trinidad River. Color: mottled dark grey-blues & browns oxidizing rapidly to dark grey & black on exposure to air.	Push drilled dry with Nx casing. Core recovered in disturbed condition.	
					6.2
-54.6	141.3			H.P. 50 psi	
-57.3	143.5 144.0 145.0		Note: Carbonaceous layer from 143.5 ft. to 145.0 ft. depths.		
-63.3	150.0				5.3
	151.3			Push drill dry with BX casing. Core recovered in disturbed condition. H.P. 25 - 50 psi	
-67.3	154.0				
					5.1
	161.0 161.3		Note: Carbonaceous layer from 161.0 ft. to 161.3 ft. depths	H.P. 50 psi	
-77.3	164.0				
					3.5
	173.7				

ELEVATION In feet	DEPTH In feet	COLUMNAR SECTION	DESCRIPTION OF MATERIAL	DRILLING CHARACTERISTICS	Core Recovery
-88.3	175.0 176.0		SILT & CLAY. (Continued) Note: Carbonaceous layer from 175.0 ft to 176 ft. depths.		
-91.3	178.0		As above.	As above.	
-96.3	183.0 183.5 184.0		Note: Carbonaceous layer from 183.0 ft. to 183.5 ft. depths.		5.6
				H.P. 250 - 300 psi	
	190.0				
-104.8	191.5		Note: Carbonaceous layer from 190.0 ft. to 192.0 ft. depth	25.6' 44.5%	
-105.3	192.0 194.0		Top of Weathered Rock SILTSTONE: Hard overburden to soft rock, moderate jointing with joints highly weathered & containing soil-like material, thin bedding, fine-grained, marine; becomes harder with depth. Color: mottled medium browns and grey. Note: Upper 2.0 ft. are blue-grey due to reduction of iron by humic acids from materials above.	As above. Push drilled dry with BX casing. Core recovered in distrubed condition. H.P. 450 - 600 psi 4.5' 41.7%	2.9
-116.1	202.8 203.8 209.3		Top of Sound Rock SANDSTONE, Tuffaceous. Soft rock, moderate strength and jointing, thin bedding, variably calcareous, contains a few scattered fossils, somewhat carbonaceous, contains scattered organic plant debris. Color: mottled medium to dark grey	As above. Drilled rapidly and easily with NX double tube and water. Core recovered in fair condition in 0.1 to 0.6 ft. lengths. 8.4' 67.7%	3.7 4.0 3.4
-128.5	215.2		Bottom of Hole See Sheet 14		

ELEVATION in feet	DEPTH in feet	SECTION	DES…

NOTE:

1.

Elevation	Depth	
+86.7 to + 7.7	0.0 - 79.0	WATER, GATUN LAKE
+ 7.7	79.0	Top of Recent Lake Deposits
+ 7.7 to -19.6	79.0 - 106.3	Soft Lake Deposits & Atlantic Muck
-19.6 to -24.1	106.3 - 110.8	PEAT
-24.1 to -29.6	110.8 - 116.0	SILT & CLAY
-29.6 to -47.8	116.0 - 134.5	PEAT
-47.8 to -105.3	134.5 - 192.0	SILT & CLAY
-105.3	192.0	Top of Weathered Rock
-105.3 to -116.1	192.0 - 202.8	SILTSTONE
-116.1	202.8	Top of Sound Rock
-116.1 to -128.5	202.8 - 215.2	SANDSTONE, Tuffaceous
-128.5	215.2	Bottom of Hole

Atlantic Muck Formation (Soft Lake Deposits & Atlantic Muck through SILT & CLAY)

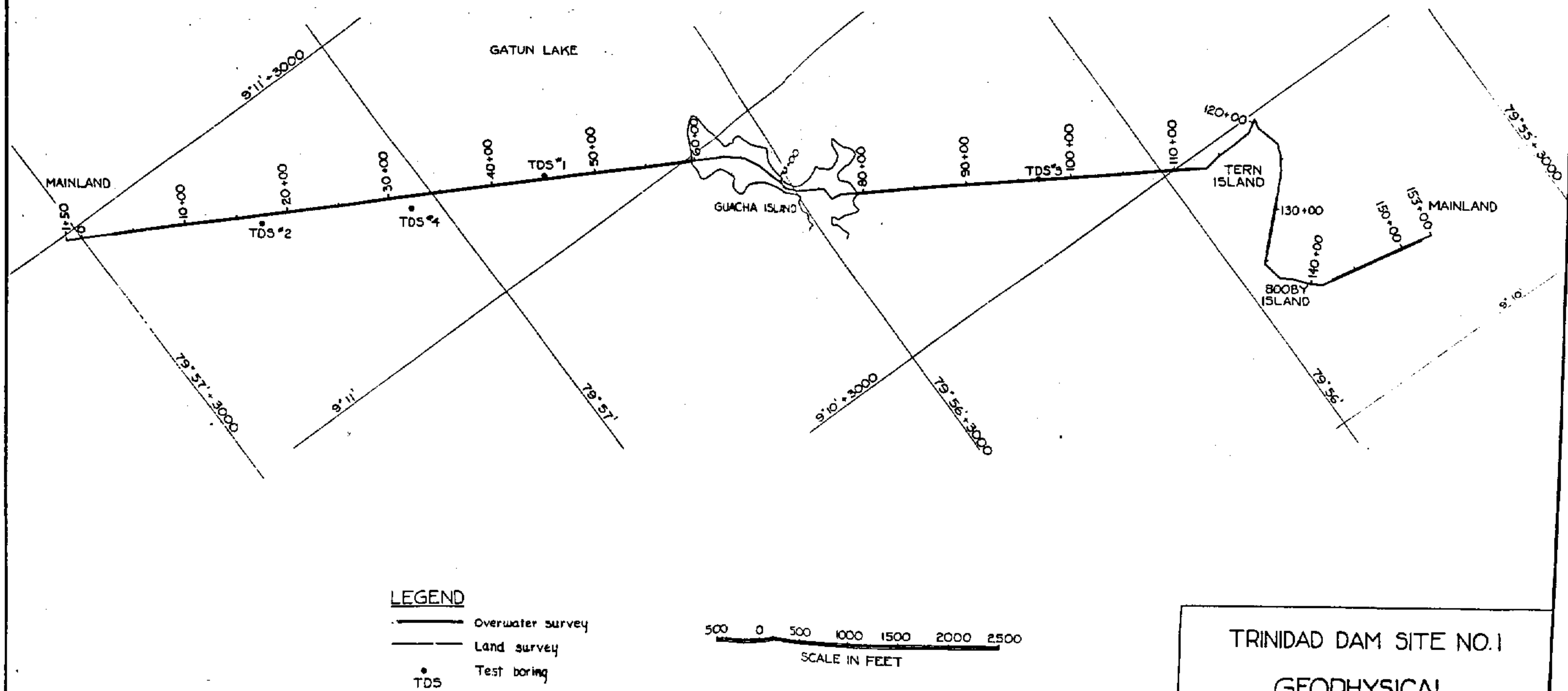
Gatun (?) Forma (Top of Weathered Rock through SANDSTONE, Tuffaceous)

2. 122.1' of 4" casing used in hole.
183.5' of NX casing used in hole.

3.

Core Box No.	From	To
1 of 3	79.0	131.3
2 of 3	131.3	183.0
3 of 3	183.0	215.2

4. H.P. indicates hydraulic pressure, on drill head, necessary to cause core barrel to penetrate soil.



TRINIDAD DAM SITE NO. 1

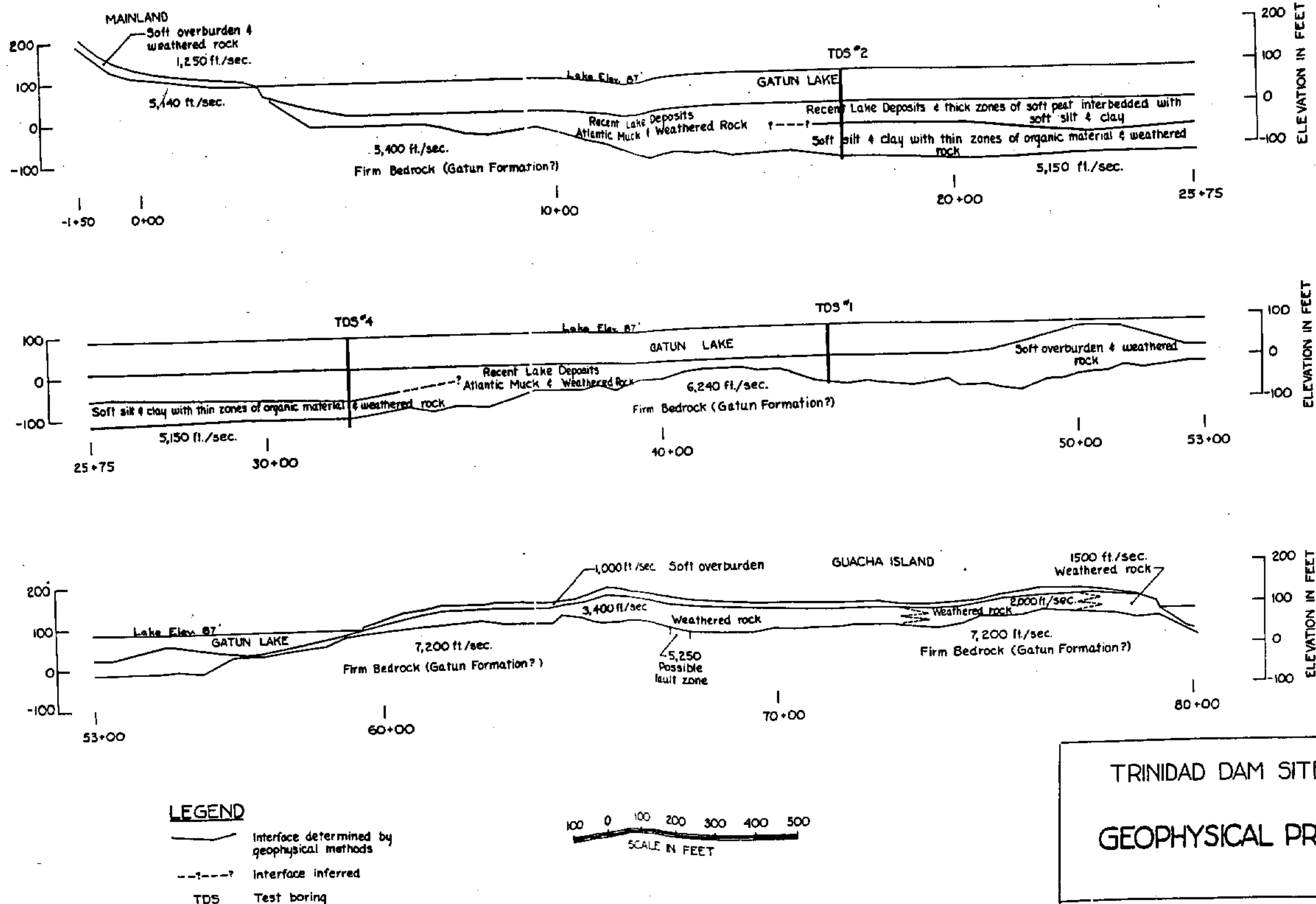
GEOPHYSICAL EXPLORATION PLAN

GEO-RECON INC. SEATTLE

G-60

Feb. 20, 1962

FIG. A1

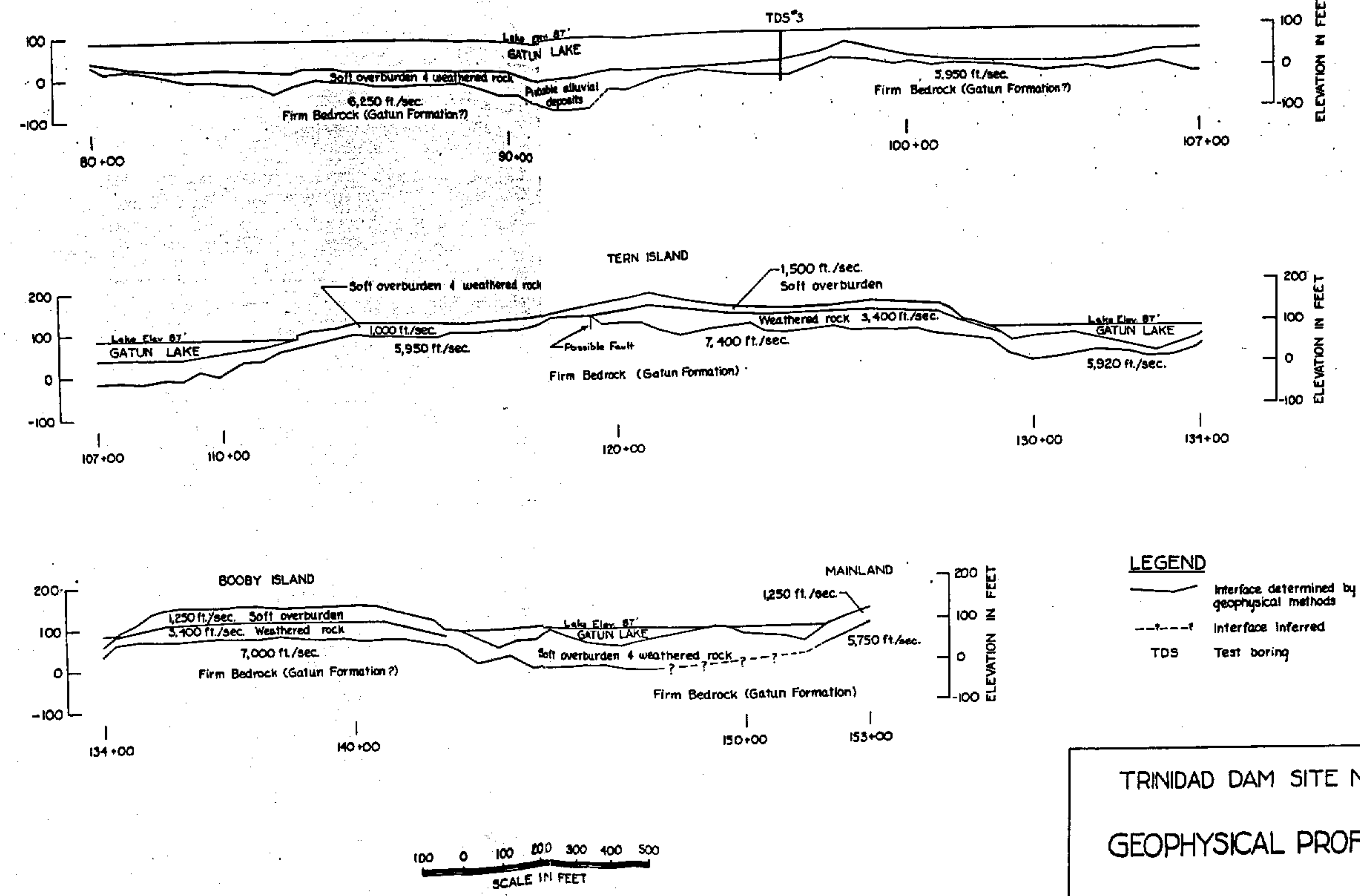


TRINIDAD DAM SITE NO. 1

GEOPHYSICAL PROFILE

GEO RECON INC. G-60 Feb. 20, 1962

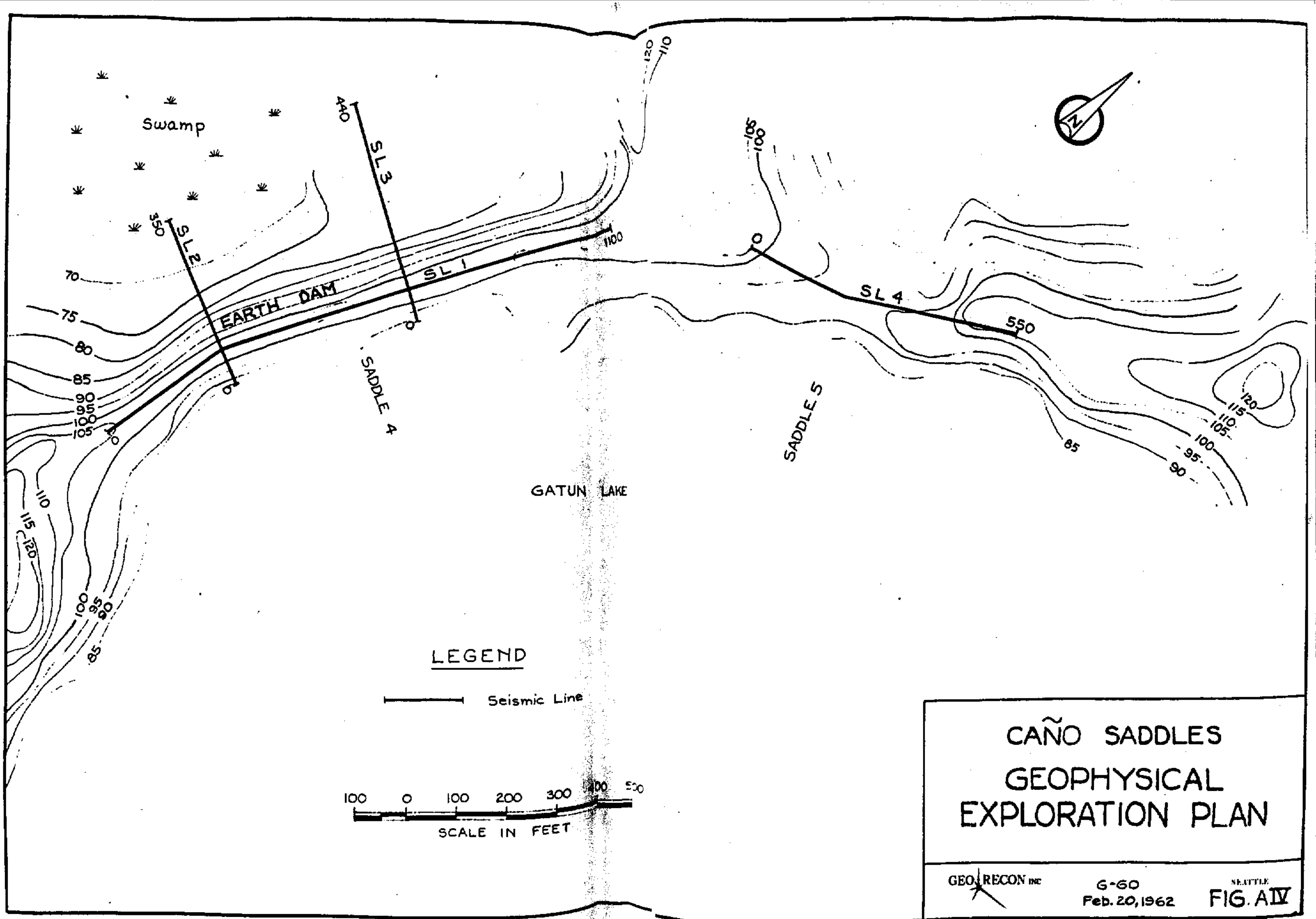
FIG. AII

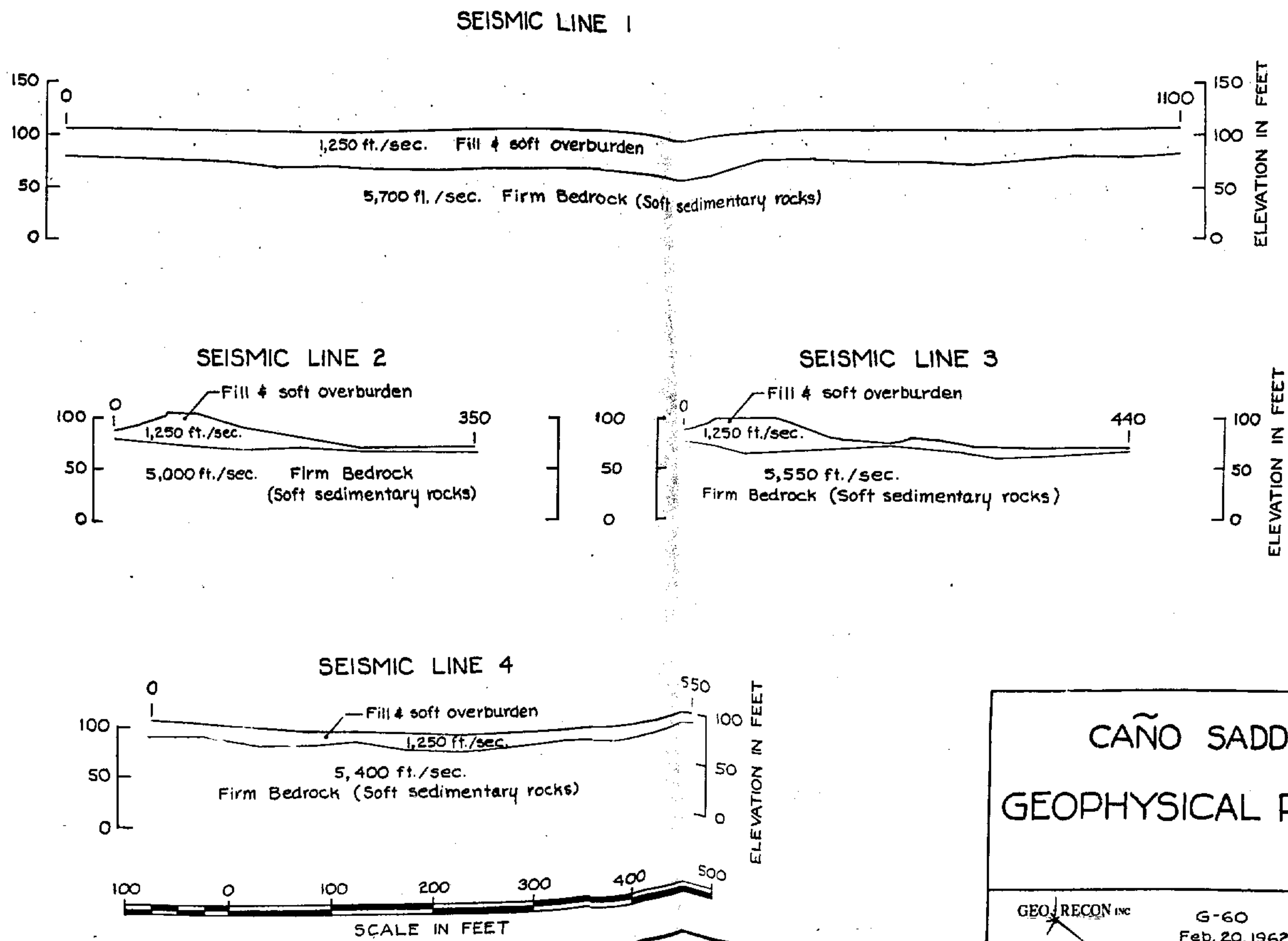


TRINIDAD DAM SITE NO.1

GEOPHYSICAL PROFILE

GEO RECON INC G-60 Feb. 20, 1962 FIG. A


Swamp
SL 3
SL 2
SL 1
SL 4
EARTH DAM
SADDLE 4
SADDLE 5
GATUN LAKE
LEGEND
Seismic Line
SCALE IN FEET
CAÑO SADDLES
GEOPHYSICAL
EXPLORATION PLAN
GEO RECON INC
SEATTLE
G-60
Feb. 20, 1962
FIG. AIV



CAÑO SADDLES

GEOPHYSICAL PROFILES

GEO RECON INC SEATTLE

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Feb. 20, 1962

FIG. AV