COMMISSION FOR THE STUDY OF ALTERNATIVES
TO THE PANAMA CANAL

THE STUDY OF ALTERNATIVES TO THE PANAMA CANAL

(COMPONENT STUDY : ENGINEERING AND COST ESTIMATES)

PHASE 1 : PRELIMINARY ENGINEERING AND COST ESTIMATES

FINAL REPORT

Feb. 1992

YACHIYO ENGINEERING CO., LTD.

under the contract with

JAPAN INTERNATIONAL COOPERATION AGENCY

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SUMMARY REPORT

SUMMARY REPORT

1. General

This Summary Report of the Study of Alternatives to the Panama Canal is a summary of the Final Report for Phase 1 of the Panama Canal Alternative Study. Presented herein are the study results for the four basic study groups which have been considered in Phase 1 for the prescreening of alternatives.

The Final Report itself consists of Part I Engineering for Prescreening and Part II, Cost Estimation for Prescreening and Annex.

Each historic alternative is classified into one of the following four groups.

- Group A High rise lock canal (Water level 90' - 85')
- Group B Low rise lock canal (Water level 55' - 30')
- Group C Sea level canal (Route 10)
- Group D Sea level canal (Route 14S)

Each group is further classified into 9-study cases according to the size of ships, the highest water level in the lake (lock type only), number of lifts (lock type only), number of lanes, and route centerline location. The existing canal with announced culebra cut widening is included as the Status Quo to serve as a basis for comparison.

The Final Report describes the results of the study of all 36 study cases. The interim findings for the Group A and Group C which were included in the Interim Report have been amended as necessary before inclusion in this Final Report.

The main features of the study cases are shown on the Comparative Summation Tables for Lock Type Canal and Sea Level Canal at the end of this Summary Report.

2. Group A - High Rise Lock (W.L.=90'- 85')

2.1 Routes

For the High Rise Lock system, there are two routes. On the first route a ship from the Pacific coast side follows the existing canal route, and changes direction to the west at a point 2 km north of the present port of Balboa where the ship diverts to the new 2-lift locks. The ship passes from the new locks into a new channel excavated 2.5 km west of Cerro Aguadulce, then joins the existing canal about 2.5 km north-west of the present Pedro Miguel locks.

After joining the existing canal, the ship transits the Culebra Cut section and then proceeds on Route-I through Gatun Lake (Fig. S.1), following the existing route. The ship turns right about 3 km before Gatun dam and proceeds via the new Gatun Locks to the new canal which extends 1.5 km east from Gatun Locks and is parallel to the existing canal. The ship then rejoins the existing route at Limon Bay. For this route, the characteristics of each of the 6 study cases are shown on Fig. S.1 as L-1, L-2, L-4, L-5, L-7 and L-8.

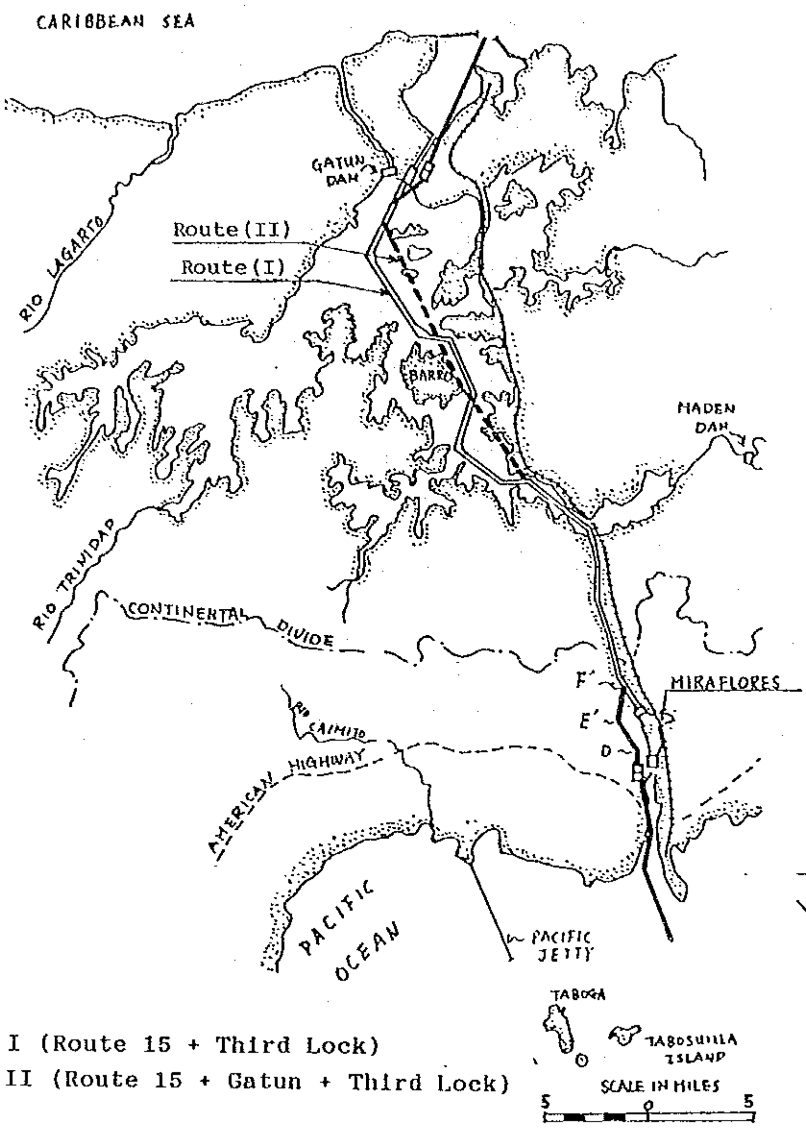
The 2nd route for the high rise lock system takes the same route from the Pacific coast side to reach Gatun Lake, then proceeds to take a modified route through Gatun Lake as shown by Route II in Fig S.1 as a dotted line. Three study cases, L-10, L-13 and L-16 adopt Route II.

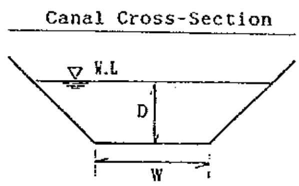
2.2 Water Level

For the High Rise Lock system, the water level of Gatun Lake could be at the present water level (85'), but for the purpose of reducing the excavation volume, 90' water level cases (5' above the existing water level) have also been studied for study cases L-1, L-4 and L-7, as shown in Fig. S.1

From the studies, it is considered that the 90' water level cases require no major reconstructions of existing facilities at Miraflores Locks, Gatun Locks and Gatun Dam, or of the railways and roads around the lake.

Further studies and surveys shall be need and confirmed their safety in the future.





Note:
Route I (Route 15 + Third Lock)
Route II (Route 15 + Gatun + Third Lock)

Study Case	Route	W. Level	No. of Lifts	No. of Lanes	Ship Size (1000 DWT)	Canal Size W (m) D
L-1	I	90'	2	2	100	301 x 18.7
2	I	85'	2	2	100	301 x 18.7
4	I	90'	2	2	150	343 x 20.9
5	I	85'	2	2	150	343 x 20.9
7	I	90'	2	2	250	399 x 24.2
8	I	85'	2	2	250	399 x 24.2
2'	I	85'	1	2	100	301 x 18.7
10	II	85'	2	2	100	301 x 18.7
13	II	85'	2	2	150	343 x 20.9
16	II	85'	2	2	250	399 x 24.2

Fig. S.1 Layout of High Rise Lock System for Group A Study Cases

2.3 New Locks

The new locks at the Pacific coast side would be located in the area already excavated for the Third Lock plan to the West of Cerro Aquadulce and Cerro Cocoli.

The new locks at the Atlantic coast side would be located in the existing excavated area running parallel to the existing Gatun Locks. The new locks have been designed for ship sizes of 100,000, 150,000 and 250,000 DWT in accordance with each study case as shown in Fig. S.1. For the High Rise Lock system, all locks would have 2 lifts, but a single lift system has been especially studied for the L-2' study case.

Gravity type lock structures have been generally adopted. The wall heights are about 50 meters maximum. As one example, Fig. S.2 shows the length and width of 250,000 DWT lock chambers, and the overall length. The size of the water supply culvert allows the filling or draining of lock water within 10 minutes for each lock chamber.

A single miter gate has been adopted for the new lock gates. Separate from the main gate, emergency gates and maintenance gates have also been proposed. For dimensions and number of gate leaves refer to the Summation Table for Lock Type Study Cases at the end of this Summary.

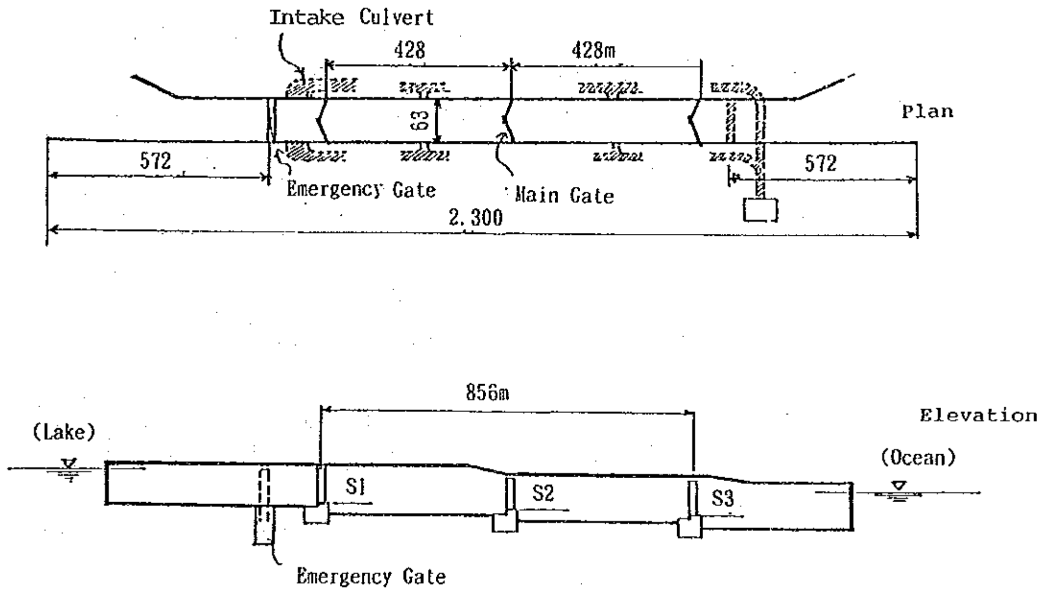


Fig. S.2 Lock Layout for 250,000 DWT Ships

2.4 Ancillary Facilities

(1) Anchorage Area

For the mooring of ships waiting for lock transit, anchorage and mooring areas are proposed above the new locks on the Pacific coast side. In Gatun Lake, no such anchorage area is required above the new locks on the Atlantic coast side because suitable areas are available in Gatun Lake.

(2) Surge Basin

The locks proposed at the Pacific coast side are directly connected by the open bypass channel to the existing canal, and surging may occur in the bypass channel as water pours from the bypass channel into the lock chambers.

To reduce the effects of surging, a surge basin is proposed in the area of the Rio Cocoli Valley. The surge basin utilizes natural terrain as much as possible. A closure dam is required at the south-east side of the basin.

(3) Recycling Pond

At the Pacific coast side, a recycling pond is proposed in the flat land on the northern part of San Juan Hill in order to hold discharged lockage water (mainly fresh water) as a source of supply for pumping operations during lock operation. The area of the pond is approximately 1.5 km2. The effective water level would be +0.6 m - 1.6 m. A discharging channel for returning water from the recycling pond to the surge basin extends 800 meter. The width and depth of the channel have been chosen according to the number of pump stations required.

A similar recycling pond is proposed beside the approach channel on the Atlantic coast side.

(4) Pump Stations
(Recycling Pond to Surge Basin or Gatun Lake)

Approximate locations for pump stations have been proposed and the size of pump stations for each study case are shown on the Summation Table according to the number of transits.

2.5 Water Management

(1) Lockage Water

The sources of water for lock operation come from Madden Lake and Gatun Lake. The water volume of both lakes changes in wet and dry seasons. Therefore, the available lockage water volume has been calculated for each month according to the record of average discharge volume measured at several points over the last 50 years. Lockage water necessary for new lock systems are shown below Fig. S.3. (The lockage water for existing canal is excluded)

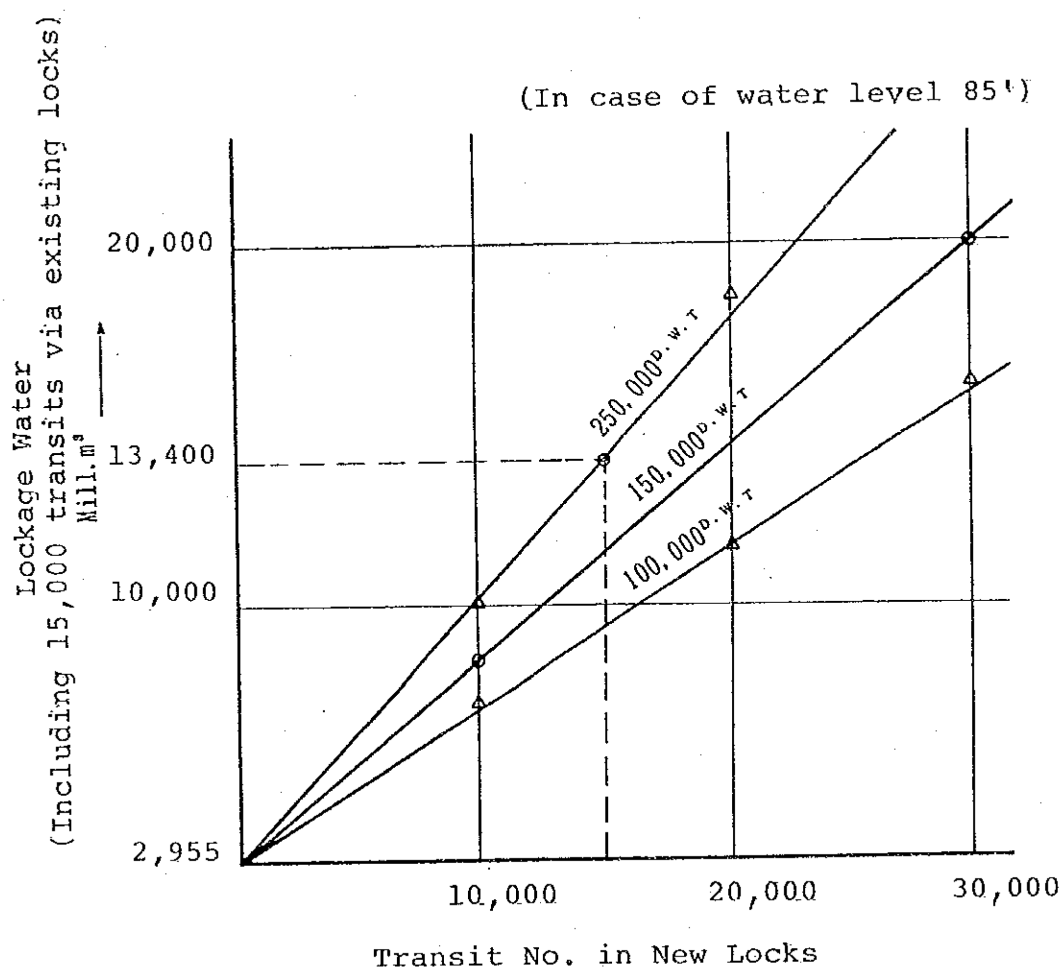


Fig. S.3 Lockage Water Volume by Transits
(Including allowance for 15,000 transits via existing locks)

For example:

a) When 15,000 ships with maximum ship size 250,000 DWT transit the new locks (85' water level) a year, the necessary lockage water volume is 13.4 billion m3 (refer to Fig. S.3).

b) The total required lockage water for passing 10,000 ships of 100,000 DWT a year in the new Locks (85') plus 15,000 transit per year in the existing locks is 6.83 billion m3, comprising 3.88 billion m3 for the new locks and 2.95 billion m3 for the existing locks.

c) For 250,000 DWT, the water volume required is 9.92 billion m3 for 10,000 transits in the new locks plus 15,000 transits in the existing canal locks (10,000 + 15,000 transits).

The water volume in Gatun Lake and Madden Lake is not sufficient for lockage water requirements. The necessary water volume for each study case, assuming transits of 10,000, 20,000 and 30,000 ships per year, are shown on the Comparative Summation Table for Lock Type Study Cases.

(2) New Dams to Increase Water Storage Capacity

To overcome the shortage of lockage water, Trinidado Dam and Ciri Dam have been proposed above Gatun Lake. Other dam sites were also considered but the two sites mentioned can most effectively provide the additional storage capacity which can effectively be used given the limited catchment yield. These dams would reduce spillage losses at Gatun dam but the overall catchment annual yield is not sufficient for the required volume of lockage water.

In the Summation Table, a solution to the shortage of water volume is studied by considering the increase in lockage water supply from the new dams.

(3) New Pump Stations for Solution of Water Shortage

Despite the added capacity of the possible new dams above Gatun Lake, the total annual supply of water is not sufficient in most cases to provide the required water volume for the lock systems proposed.

Therefore, the use of new pump stations to supply lockage water from a recycling pond has been considered.

A pump station comprising two pumps, with an estimated capacity of 30 m3/sec per pump, would have a total capacity of 60 m3/sec. This total capacity becomes 1,829 million m3 of additional available water supply per year. The Summation Table shows necessary numbers of pump stations for each study case.

(4) Transit Capacity

For calculation of lockage water, 10,000, 20,000 and 30,000 transits per year are assumed in the new locks. Assuming also that the new locks have 2 lanes, the allowable relay time (time difference between successive ships passing the same point) between consecutive ships in the same lock would be as follows.

Transits/Year	Average Relay Time (min)
10,000	105
20,000	53
30,000	35

The actual relay time for 100,000-250,000 DWT ships would be at least 80 minutes considering the operation of locks and ship maneuvering. Hence, 13,000 transits would be the limit for 2 lane locks, and if more transits are required, then the number of lock lanes should be increased to 4 lanes or more.

Assuming that sufficient lanes of locks were available, the number of pump stations required for 10,000, 20,000 and 30,000 transits in the new locks, in addition to 15,000 transits in the existing locks, would be as shown in Table S.1.

Table S.1 No. of Pump Stations by Transits

Ship size (DWT)	Transits per year	No. of P.S's (with New Dams)	No. of P.S's (without New Dams)	Note
100,000	10,000	1-set	1-set	W.Level 85'
100,000	20,000	3-sets	4-sets	2-lift
100,000	30,000	5-sets	6-sets	locks
150,000	10,000	2-sets	2-sets	
150,000	20,000	4-sets	5-sets	
150,000	30,000	7-sets	7-sets	
250,000	10,000	2-sets	3-sets	
250,000	20,000	6-sets	7-sets	
250,000	30,000	10-sets	10-sets	

Note: P.S. = pumping station

3. Group B - Low Rise Lock Canal (W.L.≈55'- 30')

In comparison with the High Rise Lock system, the feature of the Low Rise Lock System is the reduction in water level in Gatun lake from 85' to 55' and 30'.

The location of construction of new Low Rise Locks would be the same as for the High Rise Locks. The new locks are designed as single lift. Ships from the Pacific side passing the new locks would take the direction of the existing canal route after detouring Pedro Miguel Locks (demolished) and part of Miraflores Lake. An increase of water depth is required both in the canal and in the lake waterway.

3.1 Layout for 55' Water Level

The layout for the 55' water level is shown in Fig. S.4. The following new facilities are required to reduce the water level to 55'.

(1) In order to keep the water level in other parts of Gatun Lake at the existing 85', barrier dams are required in Gatun Lake.

(2) Spillways/diversion channels are required to discharge major floods from the catchments retained by the barrier dams.

(3) At the existing Gatun dam, spillway modification or reconstruction is required to suit the 55' water level.

(4) One lift of Gatun locks would be demolished and it would also be necessary to demolish Pedro Miguel Locks.

3.2 Layout for 30' Water Level

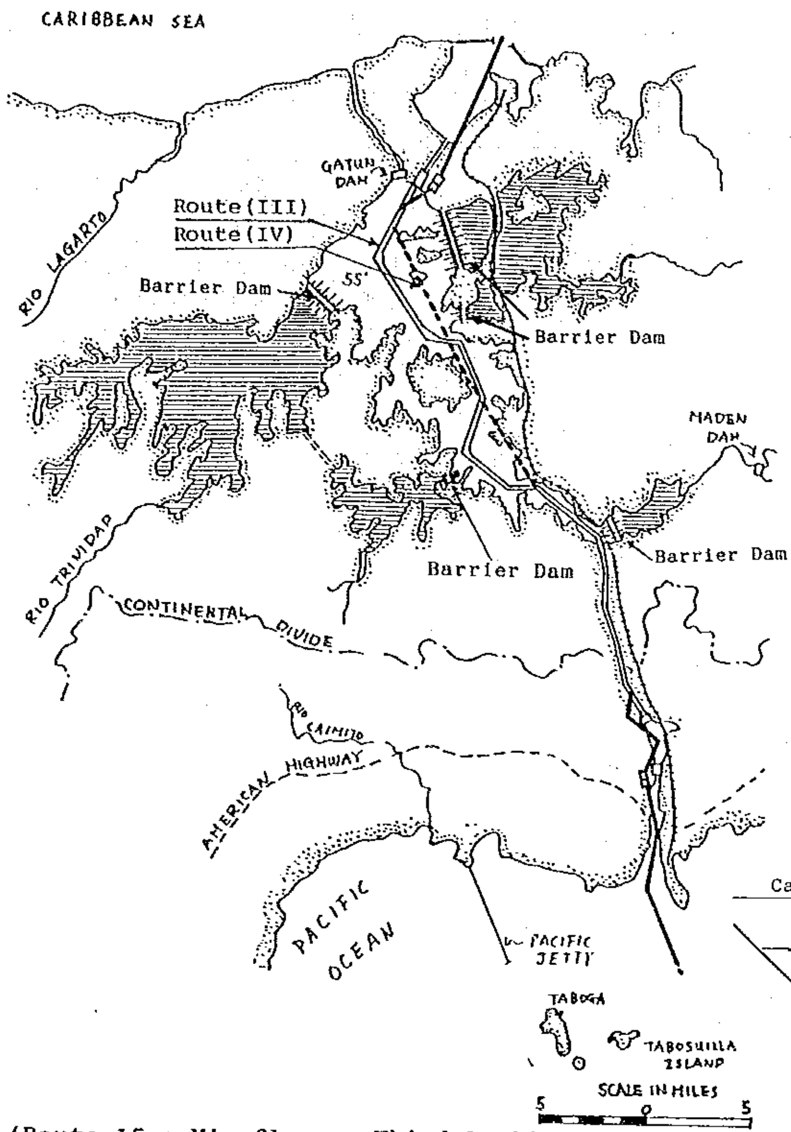
The layout for 30' water level is shown in Fig. S.5. In this case, the following further points should be considered.

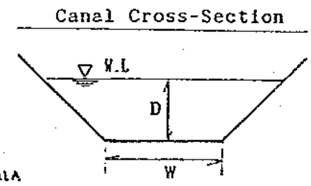
(1) Reconstruction including some demolition is required at the existing Miraflores Locks.

(2) Demolition of Pedro Miguel Locks would be required.

(3) Ships passing the new Low Rise lock proceed along a new canal, partly along the Continental Divide after detouring Miraflores Lake and Pedro Miguel Locks.

(4) Spillways/diversion channels are required to discharge major floods from the catchment retained by the barrier dams.

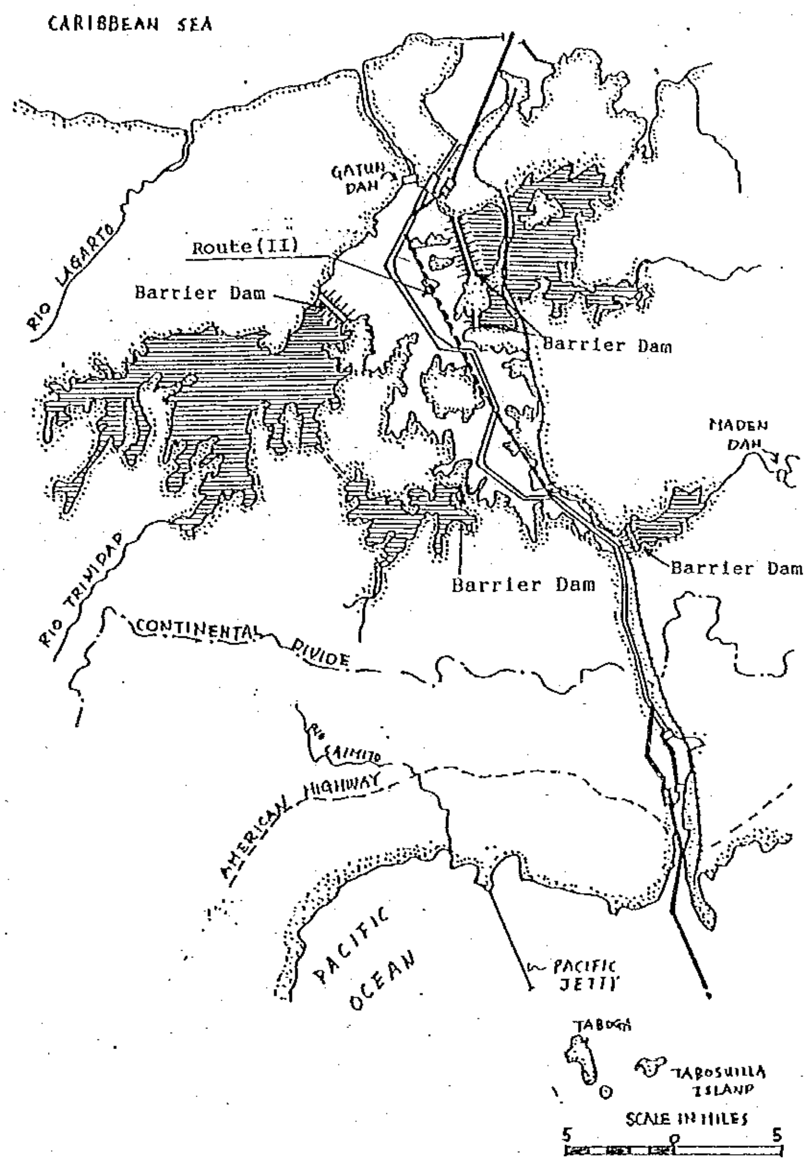


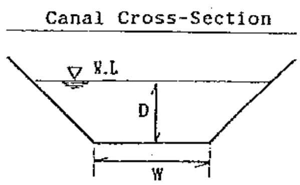


Note:
Route III (Route 15 + Miraflores +Third Lock)
Route IV (Route 15 + Gatun + Miraflores + Third Lock)

Study Case	Route	W. Level	No. of Lifts	No. of Lanes	Ship Size (1000 DWT)	Canal Size W (m) D
L-3	III	55'	1	2	100	301 x 18.7
6	III	55'	1	2	150	301 x 20.9
9	III	55'	1	2	250	399 x 24.2
11	IV	55'	1	2	100	301 x 18.7
14	IV	55'	1	2	150	343 x 20.9
17	IV	55'	1	2	250	399 x 24.2

Fig. S.4 Layout of Low Rise Lock System for Group B Study Cases (55')





Study Case	Route	W. Level	No. of Lifts	No. of Lanes	Ship Size (1000 DWT)	Canal Size W (m) D
L-12	II	30'	1	2	100	301 x 18.7
15	II	30'	1	2	150	343 x 20.9
18	II	30'	1	2	250	399 x 24.2

Fig. S.5 Layout of Low Rise Lock System for Group B Study Cases (30')

4. Group C - Sea-Level Canal (Route 10)

The Group C study cases all follow Route 10 which is located 16 km west of and parallel to the existing canal and is shown in Fig. S.6.

The Pacific terminal of the route is at the town of Puerto Caimito at the mouth of Caimito River. The route follows the river north-westward for 8 km, crossing the Pan American Highway about 4.8 km north-east of La Chorrera. It continues to the north through generally open and rolling terrain; crosses the Continental Divide through the Chorrera Gap; and parallels the Pescado River until it reaches an arm of Gatun Lake at La Laguna. Turning in a more westerly direction, the route continues over relatively flat terrain and crosses the Trinidad arm of Gatun Lake, to Escobal. From there it runs north-westerly through low ridges which become more open toward the coast. It enters the Atlantic at the town of Lagarto. The Atlantic approach channel would be only 3.2 km long; however, that on the Pacific would require 24.1 km of underwater excavation, extending past Taboga Island.

A special feature of this group of study cases is the current stream in the new canal caused by tidal differences between the two ocean levels. For example, the tidal current in a sea level canal was estimated in "Isthmian Canal Studies-1947" (Annex 7, part IV) to be 4.5 knots. This velocity computation was supported by model tests at a scale of 1:100 conducted by the Panama Canal Company during the Isthmian Canal Studies. The results of the model test and the velocity computation were similar. The IOCS study also estimated tidal currents for various canal configurations and concluded that currents would exceed 3 knots for most tide cycles.

Therefore, some form of control of tidal currents should be provided and two methods have been considered. Firstly, currents could be controlled by the construction of tidal gates (concrete structures with steel gates). In this report, various type of tidal gate are studied and a rolling gate of triangular section is recommended.

Another method of tide control was presented in the Vergara plan "El canal nivel" in 1982. The Vergara plan intended to provide tidal control and also safe anchorage and mooring of ships by proposing the construction of large embankments of 20 km in length outside each canal entrance and completely enclosed with the exception of a small opening to allow for ship passage.

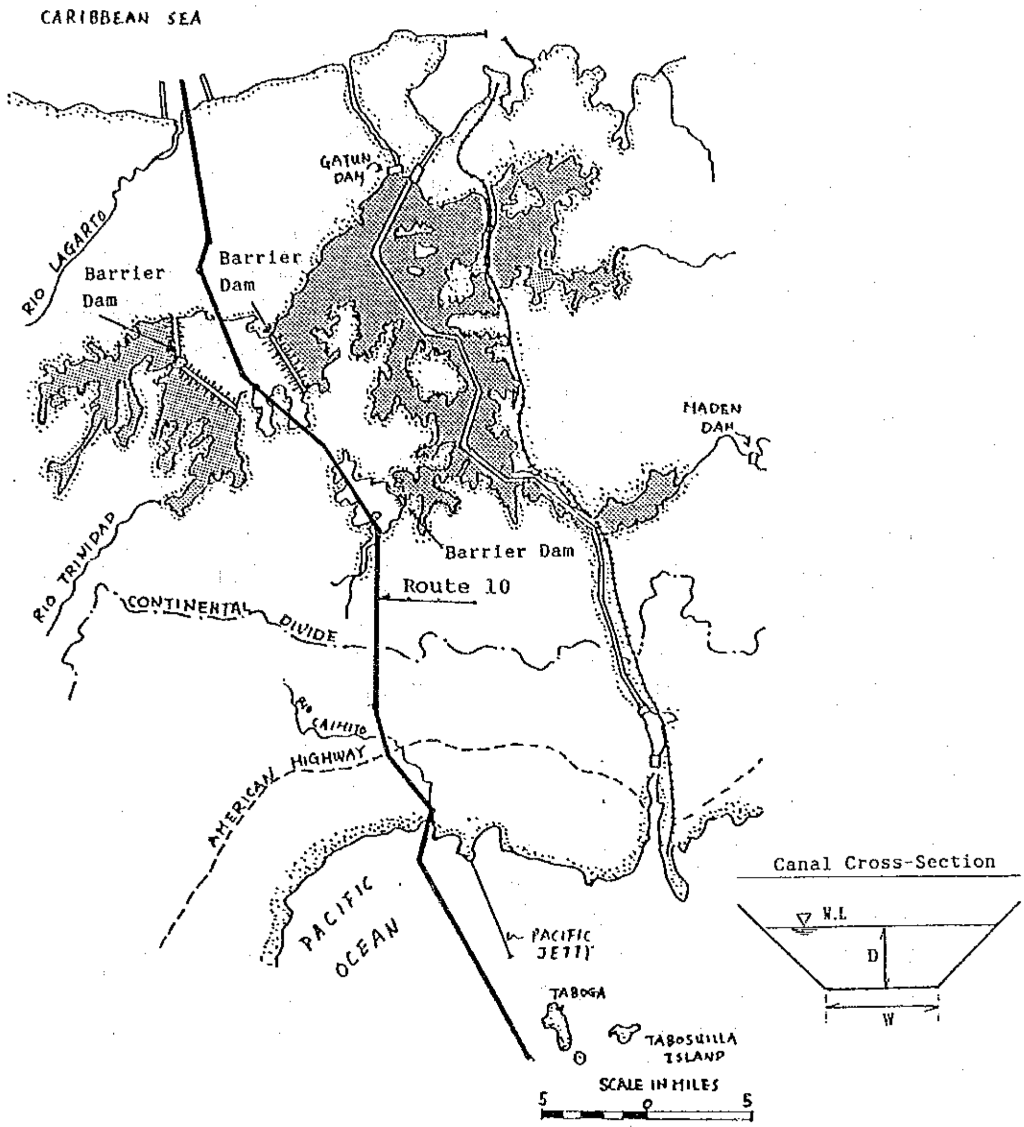
Facilities required for this sea level canal (Route 10) are as follows;

(1) Tidal gates and breakwaters are required at the Pacific Ocean side and Atlantic Ocean side except in the Vergara plan.

(2) Tidal basins are proposed according to the Vergara plan.

(3) Barrier dams and spillways are required to retain the water level of Gatun Lake from the canal route.

The layout of this study case has been shown on Fig. S.6. This group of study cases is classified into 9 study cases; S-1 - 6, and S-13 - 15 in accordance with the conditions such as numbers of lanes and size of ships.

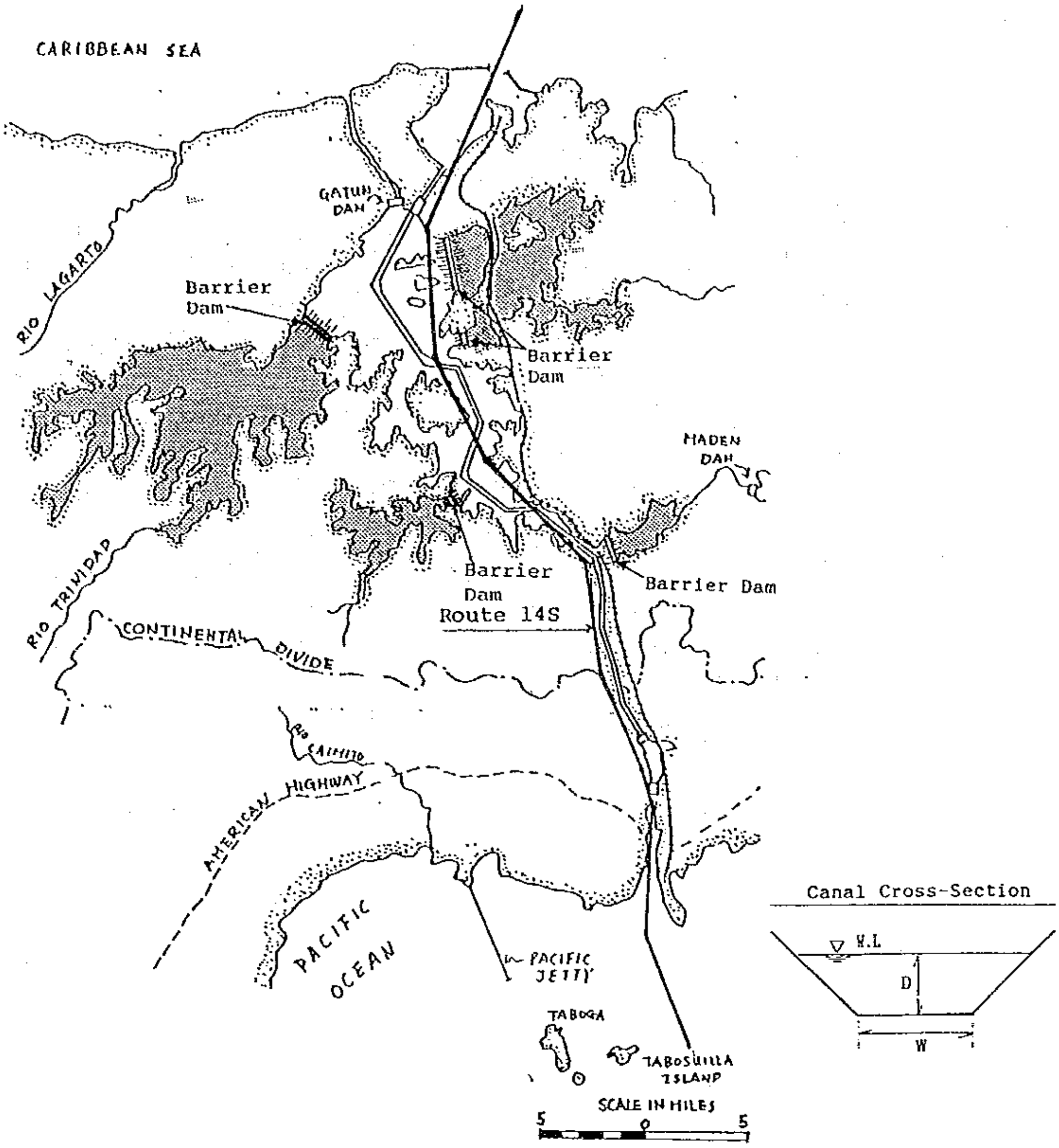


Study Case	Route	W. Level	No. of Lifts	No. of Lanes	Ship Size (1000 DWT)	Canal Size W (m) D
S-1	10	0	-	1	150	147 x 20.9
2	10	0	-	2	150	343 x 20.9
3	10	0	-	1	250	171 x 24.2
4	10	0	-	2	250	399 x 24.2
5	10	0	-	1	300	183 x 25.3
6	10	0	-	2	300	424 x 25.3
13	10	0	-	50%-1	150	147 x 20.9
				50%-2		343 x 20.9
14	10	0	-	50%-1	250	171 x 24.2
				50%-2		399 x 24.2
15	10	0	-	50%-1	300	183 x 25.3
				50%-2		424 x 25.3

Fig. S.6 Layout of Sea Level Canal for Group C Study Cases (Route 10)

5. **Group D - Sea-Level Canal (Route 14S)**

5.1 The Route alignment of this group of study cases is shown in Fig. S.7. On the Pacific side Route 14S coincides with the approaches to the present lock canal until it reaches the Pacific Third Locks cut where it follows a 12.9 km bypass through the divide. The route then generally follows the alignment of the existing canal northeast of Cerro Gord and continuing toward Gatun Lake, keeping southwest of the present canal until it reaches the Darien peninsula. Turning slightly northward, it then passes Barro Colorado on the east, touching the end of Bohio Peninsula. The route then turns north across Gatun Lake and follows the present canal route to the Caribbean. The Pacific approach channel is about 20.9 km long; that on the Atlantic is 12.9 km.



Study Case	Route	W. Level	No. of Lifts	No. of Lanes	Ship Size (1000 DWT)	Canal Size W (m) D
S-7	14S	0	-	1	150	147 x 20.9
8	14S	0	-	2	150	343 x 20.9
9	14S	0	-	1	250	171 x 24.2
10	14S	0	-	2	250	399 x 24.2
11	14S	0	-	1	300	183 x 25.3
12	14S	0	-	2	300	424 x 25.3
16	14S	0	-	50%-1	150	147 x 20.9
				50%-2		343 x 20.9
17	14S	0	-	50%-1	250	171 x 24.2
				50%-2		399 x 24.2
18	14S	0	-	50%-1	300	183 x 25.3
				50%-2		424 x 25.3

Fig. S.7 Layout of Sea Level Canal for Group D Study Cases (Route 14S)

6. Excavation Volume

Excavation volumes have been calculated separately for the areas of sea, land and lake. Volumes include associated excavation volumes for locks, mooring areas, recycling ponds, etc.

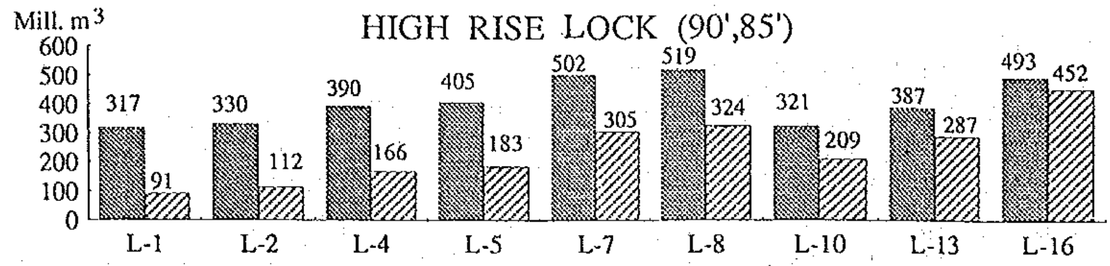
The volume of excavation in each area is classified into two categories, dry and dredging, and each category is further separated into 5 sub-categories, hard rock, soft rock, soil, hard clay and soft clay.

The total maximum and minimum dry and dredging excavation volumes for the Group A, B, C and D Study Cases are summarized in Table S.2.

Table S.2 Excavation Volume (Million m3)

Group	Max. V Min. V	Case
A. High rise lock	945	L-16
	408	L-1
B. Low rise lock	1510	L-18
	594	L-3
C. Sea level (R-10)	2190	S-6
	937	S-1
D. Sea level (R-14S)	2057	S-12
	899	S-7

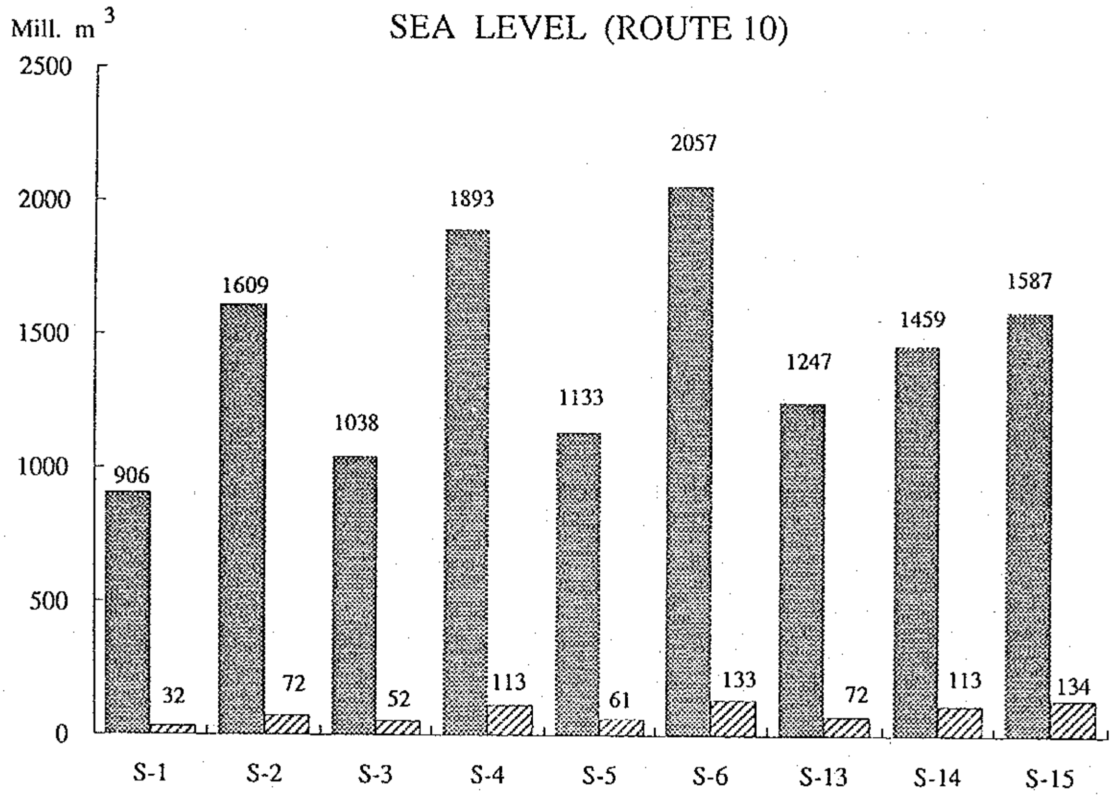
The excavation volumes for each study case are graphed in Figs. S.8 - S.11.



W. Level	90'	85'	90'	85'	90'	85'	85'	85'	85'
Ship Size(1000DWT)	100	100	150	150	250	250	100	150	250
Lane No.	2	2	2	2	2	2	2	2	2
Lift No.	2	2	2	2	2	2	2	2	2

▨ Dry Excavation Volume ▨ Dredging Excavation Volume

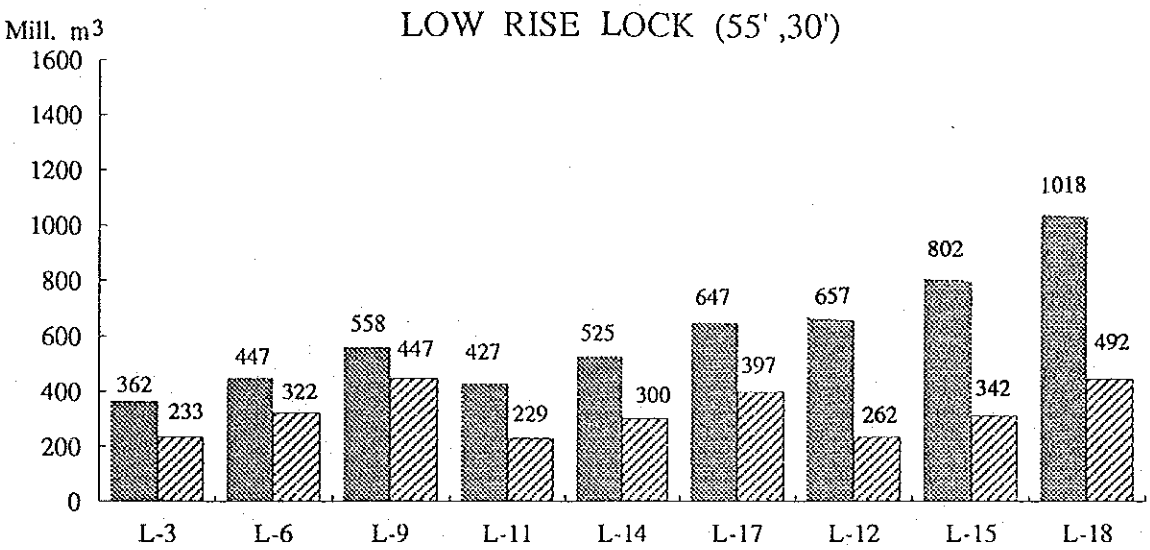
Fig. S.8 Excavation Volume (L1 - L16)



W. Level	0'	0'	0'	0'	0'	0'	0'	0'	0'
Ship Size(1000DWT)	150	150	250	250	300	300	150	250	300
Lane No.	1	2	1	2	1	2	1, 2	1, 2	1, 2

▨ Dry Excavation Volume ▨ Dredging Excavation Volume

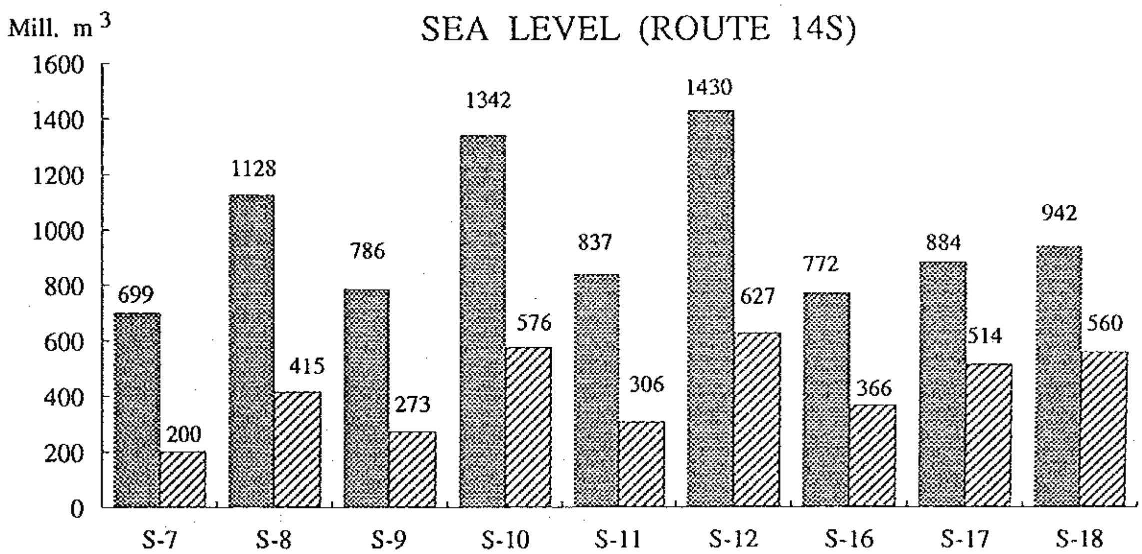
Fig. S.9 Excavation Volume (S1 - S15)



W.Level	55'	55'	55'	55'	55'	55'	30'	30'	30'
Ship Size(1000DWT)	100	150	250	100	150	250	100	150	250
Lane No.	2	2	2	2	2	2	2	2	2
Lift No.	1	1	1	1	1	1	1	1	1

▩ Dry Excavation Volume ▨ Dredging Excavation Volume

Fig. S.10 Excavation Volume (L3 - L18)



W.Level	0'	0'	0'	0'	0'	0'	0'	0'	0'
Ship Size(1000DWT)	150	150	250	250	300	300	150	250	300
Lane No.	1	2	1	2	1	2	1, 2	1, 2	1, 2

▩ Dry Excavation Volume ▨ Dredging Excavation Volume

Fig. S.11 Excavation Volume (S7 - S18)

7. Estimation of Operation and Maintenance Cost

Estimation of Operation and Maintenance cost are shown in APPENDIX 4.

A. LOCK TYPE STUDY CASES COMPARATIVE SUMMATION TABLE(1)

ITEMS	Unit	L-1	L-2	L-2'	L-3	L-4	L-5	L-6	L-7	L-8	L-9	L-10	L-11	L-12	L-13	L-14	L-15	L-16	L-17	L-18
A - FEATURES OF CANAL ALTERNATIVES																				
(1) Design Ship	1000DWT	100	100	100	100	150	150	150	250	250	250	100	100	100	150	150	150	250	250	250
(2) Route	I~IV	I	I	I	III	I	I	III	I	I	III	II	IV	II	II	IV	II	II	IV	II
(3) Water level (El. ft.)	ft.	90	85	85	55	90	85	55	90	85	55	85	55	30	85	55	30	85	55	30
(4) Number of lifts	no.	2	2	1	1	2	2	1	2	2	1	2	1	1	2	1	1	2	1	1
(5) Number of lanes	no.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
(6) Route length; a. Atrantic Approach	km	11.8	11.8	11.8	11.8	12.1	12.1	12.1	12.5	12.5	12.5	11.8	11.8	11.8	12.1	12.1	12.1	21.9	12.5	12.5
b. Channel	km	60.8	60.8	60.8	61.0	60.8	60.8	61.0	60.8	60.8	61.0	54.8	55.0	54.8	54.8	55.0	54.8	52.6	55.0	54.8
c. Pacific Approach	km	14.3	14.3	14.3	14.3	17.5	17.5	17.5	21.9	21.9	21.9	14.3	14.3	14.3	17.5	17.5	17.5	14.5	21.9	21.9
Total Route Length	km	86.9	86.9	86.9	87.1	90.4	90.4	90.6	95.2	95.2	95.4	80.9	81.1	80.9	84.4	84.6	84.4	89.0	89.4	89.2
(7) Channel cross-section (w x d)	m	301x18.7	301x18.7	301x18.7	301x18.7	343x20.9	343x20.9	301x20.9	399x24.2	399x24.2	399x24.2	301x18.7	301x18.7	301x18.7	343x20.9	343x20.9	343x20.9	399x24.2	399x24.2	399x24.2
B - WATER MANAGEMENT PLAN (3 CASES)																				
(1) Annual 15,000 transits in existing locks																				
a. Water volume required	bil.m3	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95
b. Available water capacity	bil.m3	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55
(2) Case 1: 10,000 transits/year in new locks																				
a. Water volume required	bil.m3	4.09	3.87	7.74	5.01	5.35	5.06	6.55	7.36	6.96	9.01	3.87	5.01	2.70	5.06	6.55	3.53	6.96	9.01	4.85
b. Total water required ((1)a + (2)a)	bil.m3	7.04	6.82	10.69	7.96	8.30	8.01	9.50	10.31	9.91	11.96	6.82	7.96	5.65	8.01	9.50	6.48	9.91	11.96	7.80
c. Countermeasures to be taken																				
- Water pumping with new dam	bil.m3	1.30	1.05	4.90	2.47	2.57	2.29	4.01	4.54	4.04	6.47	1.05	2.47	1.55	2.29	4.01	0.99	4.04	6.47	2.31
- Water pumping without new dam	bil.m3	1.55	1.33	5.20	2.47	2.81	2.52	4.01	4.82	4.42	6.47	1.33	2.47	1.55	2.52	4.01	0.99	4.42	6.47	2.31
d. - Sets of pump stations (with new dam)	set	1	1	3	2	2	2	2	3	2	4	1	2	1	2	2	1	2	4	2
- Sets of pump stations (without new dam)	set	1	1	3	2	2	2	2	3	3	4	2	2	1	2	2	1	3	4	2
(3) Case 2: 20,000 transits/year in new locks																				
a. Water volume required	bil.m3	8.18	7.74	15.48	10.02	10.70	10.12	13.10	14.72	13.92	18.02	7.74	10.02	5.40	10.12	13.10	7.06	13.92	18.02	9.70
b. Total water required ((1)a + (3)a)	bil.m3	11.13	10.69	18.43	12.97	13.65	13.07	16.05	17.67	16.87	20.97	10.69	12.97	8.35	13.07	16.05	10.01	16.87	20.97	12.65
c. Countermeasures to be taken																				
- Water pumping with new dam	bil.m3	5.64	4.84	12.63	7.48	7.87	7.28	10.56	11.92	11.07	15.48	4.84	7.48	2.86	7.28	10.56	4.52	11.07	15.48	7.16
- Water pumping without new dam	bil.m3	5.35	5.20	12.94	7.48	8.16	7.58	10.56	12.18	11.38	15.48	5.20	7.48	2.86	7.58	10.56	4.52	11.38	15.48	7.16
d. - Sets of pump stations (with new dam)	set	3	3	7	4	5	4	6	7	6	9	3	4	2	4	6	3	6	9	4
- Sets of pump stations (without new dam)	set	4	3	8	4	5	5	6	7	7	9	3	4	2	5	6	3	7	9	5
(4) Case 3: 30,000 transits/year in new locks																				
a. Water volume required	bil.m3	12.27	11.61	23.22	15.03	16.05	15.18	19.65	22.08	20.88	27.03	11.61	15.03	8.10	15.18	19.65	10.59	20.88	27.03	14.55
b. Total water required ((1)a + (4)a)	bil.m3	15.22	14.56	26.17	17.98	19.00	18.13	22.60	25.03	23.83	29.98	14.56	17.98	11.05	18.13	22.60	13.54	23.83	29.98	17.50
c. Countermeasures to be taken																				
- Water pumping with new dam	bil.m3	9.47	8.69	20.34	12.49	13.26	12.37	17.11	19.28	18.07	24.49	8.69	12.49	5.55	12.37	17.11	8.05	18.07	24.49	12.01
- Water pumping without new dam	bil.m3	9.73	9.07	20.68	12.49	13.51	12.64	17.11	19.54	18.34	24.49	9.07	12.49	5.55	12.64	17.11	8.05	18.34	24.49	12.01
d. - Sets of pump stations (with new dam)	set	5	5	11	7	7	7	9	11	10	13	5	7	3	7	9	5	10	13	7
- Sets of pump stations (without new dam)	set	6	6	12	7	8	7	9	11	10	13	5	7	3	7	9	5	10	13	7
C - MAIN ELEMENTS OF THE STUDY CASES																				
(1) Lock																				
a. Lock chamber dimensions ((LxWxD)& No.)	note*1	(A)-2	(A)-2	(A)-1	(A)-1	(B)-2	(B)-2	(B)-1	(C)-2	(C)-2	(C)-1	(A)-2	(A)-1	(A)-1	(B)-2	(B)-1	(B)-1	(C)-2	(C)-1	(C)-1
b. Gates																				
- Max. lock gate dimensions (BxH)	m	47x36	47x35	47x48	47x39	54x37	54x37	54x41	63x41	63x40	63x44	47x35	47x39	47x32	54x37	54x41	54x34	63x40	63x44	63x37
- Lock gate total number (in pair)	no.	12	12	8	8	12	12	8	12	12	8	12	8	8	12	8	8	12	8	8
- Lock gates total weight	1000 ton	32.7	31.8	27.9	21.4	43.2	41.9	27.9	61.9	59.9	39.2	31.8	21.4	16.9	41.9	27.9	21.6	59.9	39.2	29.4
- Main culvert number	no.	32	32	24	24	32	32	24	32	32	24	32	24	24	32	24	24	32	24	24
- Main culvert dimensions (BxH)	m	7x8	7x8	8x9	8x8	8x9	8x9	9x9	10x10	9x10	10x11	7x8	8x8	6x7	8x9	8x9	7x8	9x10	10x11	9x9
- Emergency gate number	no.	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
- Maintenance gate number	no.	1	1	1	2	1	1	2	2	2	2	1	2	2	1	2	2	2	2	2

Note*1: Lock dimensions; (A) 319x47x19, (B) 363x54x21, (C) 428x63x24

ITEMS	Unit	L-1	L-2	L-2'	L-3	L-4	L-5	L-6	L-7	L-8	L-9	L-10	L-11	L-12	L-13	L-14	L-15	L-16	L-17	L-18
c. Mule towing system																				
- Size	L, M, S	M	M	M	M	L	L	L	L	L	L	M	M	M	L	L	L	L	L	L
- Number	no.	72	72	48	48	72	72	48	72	72	48	72	48	48	72	48	48	72	48	48
(2) Barrier Dams																				
a. Site A, B, C, D :Total Volume	mill. m3	0	0	20.3	20.3	0	0	20.3	0	0	20.3	0	20.3	20.3	0	20.3	20.3	0	20.3	20.3
(3) New Dams																				
a. Site Ciri and Trinidad:Total Volume	mill. m3	4	5.5	5.5	-	4	4	-	4	5.5	-	5.5	-	-	4	-	-	5.5	-	-
(4) Excavation																				
a. Dry excavation	mill. m3	317	330	330	362	390	405	447	502	519	558	321	427	657	387	525	802	493	647	1,018
b. Dredging	mill. m3	97	112	112	233	166	183	322	305	324	447	209	229	262	287	300	342	452	397	492
Total excavation volume	mill. m3	414	442	442	595	556	588	769	807	843	1,005	530	656	919	674	825	1,144	945	1,044	1,510
(5) Power Requirement																				
a. Lock operation total requirement	1000 kW	57.7	55.5	51.6	37.0	93.4	88.9	58.7	113	108.4	69.7	56.2	37.0	25.5	89.4	58.7	38.7	108.4	71.4	46.2
- Lock gate operation	1000 kW	32.3	31.5	27.6	21.4	42.6	40.9	27.7	62.2	60.4	38.7	32.2	21.4	17.1	41.4	27.7	21.7	60.4	40.4	29.2
- Mule operation	1000 kW	25.4	24.0	24.0	15.6	50.8	48.0	31.0	50.8	48.0	31.0	24.0	15.6	8.4	48.0	31.0	17.0	48.0	31.0	17.0
b. Pump stations total requirement																				
- Case 1: 10,000 transits (with dam)	1000 kW	18.4	18.4	55.2	36.8	36.8	18.4	36.8	55.2	36.8	73.6	18.4	36.8	18.4	36.8	36.8	18.4	36.8	73.6	36.8
- Case 2: 20,000 transits (with dam)	1000 kW	55.2	55.2	129.0	73.6	92.0	73.6	110.0	129.0	110.0	166.0	55.2	73.6	36.8	73.6	110.0	55.2	110.0	166.0	73.6
- Case 3: 30,000 transits (with dam)	1000 kW	92.0	92.0	202.0	129.0	129.0	129.0	166.0	202.4	184.0	239.0	92.0	129.0	55.2	129.0	166.0	92.0	184.0	239.0	129.0
c. Total power requirement																				
- Case 1 (Lock oper. + Case 1 pump sta.)	1000 kW	76	74	107	74	130	107	96	168	145	143	75	74	44	126	96	57	145	145	83
- Case 2 (Lock oper. + Case 2 pump sta.)	1000 kW	113	111	181	111	185	163	169	242	218	236	111	111	62	163	169	94	218	237	120
- Case 3 (Lock oper. + Case 3 pump sta.)	1000 kW	150	148	254	166	222	218	225	315	292	309	148	166	81	218	224	131	292	310	175
D - CONSTRUCTION COSTS																				
(1) Channel excavation																				
a. Dry excavation	mill. US$	1,055	1,683	1,683	2,053	1,955	2,042	2,528	2,494	2,589	3,154	1,645	2,402	3,622	1,955	2,944	4,495	2,465	3,632	5,580
b. Dredging	mill. US$	1,555	1,209	1,209	2,776	1,731	1,994	4,024	4,042	4,423	6,069	2,978	3,134	4,097	4,010	4,161	5,380	7,044	5,712	8,189
Total channel excavation	mill. US$	2,610	2,892	2,892	4,829	3,686	4,036	6,552	6,536	7,012	9,223	4,623	5,536	7,719	5,965	7,105	9,875	9,509	9,344	13,769
(2) Lock concrete structure	mill. US$	692	692	692	575	875	875	658	1,212	1,212	822	692	575	560	875	658	631	1,212	822	789
(3) Gate leaves and related items	mill. US$	1,265	1,239	1,159	1,065	1,668	1,632	1,393	2,556	2,496	1,951	1,239	1,065	936	1,632	1,393	1,208	2,496	1,951	1,657
(4) New dams	mill. US$	68	85	85	-	68	68	-	68	85	-	85	-	-	68	-	-	85	-	-
(5) Barrier dams	mill. US$	-	-	-	346	-	-	346	-	-	346	-	346	346	-	346	346	-	346	346
(6) Pumping stations (20,000 transits)	mill. US$	255	255	595	340	425	340	510	595	510	765	255	340	170	340	510	255	510	765	340
(7) Indirect Cost	mill. US$	896	940	982	1,259	1,189	1,226	1,627	1,868	1,924	2,211	1,217	1,372	1,670	1,535	1,716	2,084	2,324	2,230	2,817
(8) Total Project Cost	mill. US$	5,786	6,103	6,405	8,414	7,911	8,177	11,086	12,835	13,239	15,318	8,111	9,234	11,401	10,415	11,728	14,399	16,136	15,458	19,718
E - OPERATION AND MAINTENANCE COSTS																				
(1) Electrical power (energy)	mill. US$	40	40	64	40	64	58	58	86	77	85	40	40	22	58	58	33	77	85	42
(2) Manpower and other O&M costs	mill. US$	479	479	358	358	491	491	375	514	514	393	479	358	358	491	375	375	514	393	393
(3) Total O&M costs	mill. US$	519	519	422	398	555	549	433	600	591	478	519	398	380	549	433	408	591	478	435
F - CONSTRUCTION ASPECTS																				
(1) Comparative ease of construction	grade	B	B	B	B	B	B	B	B	B	B	A	A	C	A	A	C	A	A	C
(2) Technical soundness	grade	A	A	C	B	B	B	B	C	B	C	A	B	A	B	B	A	C	C	B
(3) Construction period	year	10	10	10	10	10	10	10	11	11	13	10	10	14	10	11	16	16	14	18
G - IMPACT AS REFLECTED IN COST ESTIMATES																				
(1) Impact on existing Panama Canal																				
a. Shutdown period during construction	month	0.5	0.5	0.5	2.0	0.5	0.5	2.0	0.5	0.5	2.0	0.5	2.0	2.0	0.5	2.0	2.0	0.5	2.0	2.0
b. Modification works to Panama Canal	grade	S	S	S	M	S	S	M	S	S	M	S	M	L	S	M	L	S	S	L
(2) Potential environmental impact																				
a. Gatun Lake salinity danger	grade	S	S	L	M	M	S	M	L	M	L	S	M	S	M	M	S	M	L	M
b. Placement of excavated materials	grade	S	S	S	S	S	S	M	M	M	M	S	M	M	M	M	L	M	L	L
(3) Socioeconomic impact																				
a. Relocation of residents	grade	Few	Few	Few	Few	Few	Few	Few	Few	Few	Few	Few	Few	Few	Few	Few	Few	Few	Few	Few
b. Increase work opportunities	grade	M	M	M	M	M	M	L	L	L	L	M	L	L	L	L	L	L	L	L

Notes:

1) Comparative ease of construction.
A=Dredging works will be easy.
B=Dredging works will be difficult.
C=Dredging works will be very difficult.

2) Technical soundness (Especially water recycling).
A=Pumping volume will be small.
B=Pumping volume will be medium.
C=Pumping volume will be large.

3) IMPACT
S=To be small.
M=To be medium.
L=To be large.

4) Project costs of lock canal are estimated based on the 35,000 transits / year case.
(15,000 transits at exsisting locks and 20,000 transits at new locks.)

5) Refer to Appendix 4 for Operation and Maintenance costs.

B. SEA LEVEL CANALS COMPARATIVE SUMMATION TABLE (1)

ITEMS	unit	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	S-11	S-12	S-13	S-14	S-15	S-16	S-17	S-18
A FEATURES OF ALTERNATIVES																			
(1) Design Ship	1000 DWT	150	150	250	250	300	300	150	150	250	250	300	300	150	250	300	150	250	300
(2) Route	10, 14S	10	10	10	10	10	10	14S	14S	14S	14S	14S	14S	10	10	10	14S	14S	14S
(3) Number of lane	No.	1	2	1	2	1	2	1	2	1	2	1	2	50%-1	50%-1	50%-1	50%-1	50%-1	50%-1
(4) Route Length; a. Atlantic Approach	km	3.5	3.5	3.85	3.85	3.9	3.9	12.1	12.1	12.5	12.5	12.6	12.6	3.5	3.85	3.9	12.1	12.5	12.6
b. Channel	km	57.0	57.0	57.0	57.0	57.0	57.0	53.0	53.0	53.0	53.0	53.0	53.0	57.0	57.0	57.0	53.0	53.0	53.0
c. Pacific Approach	km	25.7	25.7	27.7	27.7	28.7	28.7	17.5	17.5	21.9	21.9	23.2	23.2	25.7	27.7	28.7	17.5	21.9	23.2
Total Route Length	km	86.2	86.2	88.55	88.55	89.55	89.55	82.6	82.6	87.4	87.4	88.8	88.8	86.2	88.55	89.6	82.6	87.4	88.8
(5) Channel cross-section (Wxd)	m	147X21	343X21	171X24.5	399X24.5	183X25.5	427X25.5	147X27	147X27	171X30.3	171X30.3	183X25.5	427x25.5	147x21	171x24.5	183x25.5	147x21	171x24.5	183x25.5
B MAIN ELEMENTS OF THE STUDY CASES																			
(1) Tidal Gates Structure																			
a. Dimention	Note*1	A	A'	B	B'	C	C'	A	A'	B	B'	C	C'	A	B	C	A	B	C
b. Canal Partition Wall, length	km	-	26	-	26	-	27	-	27	-	27	-	27	-	-	-	-	-	-
(2) Tidal Gate																			
a. Tidal Gate dimension	m	147X27	147X27	171X30.3	171X30.3	183X31.4	183X31.4	147X27	147X27	171X30.3	171X30.3	183X31.4	183X31.4	147X27	171X30.3	183X31.4	147X27	171X30.3	183X31.4
b. Gate weight	ton	6,830	6,830	9,520	9,520	10,780	10,780	6,830	6,830	9,520	9,520	10,780	10,780	6,830	9,520	10,780	6,830	9,520	10,780
(3) Tidal Basin																			
a. Pacific: Basin area	Mill.m2	73	73	73	73	73	73	-	-	-	-	-	-	73	73	73	-	-	-
Embankment Volume	Mill.m3	18.5	18.5	18.5	18.5	18.5	18.5	-	-	-	-	-	-	18.5	18.5	18.5	-	-	-
b. Atlantic: Basin area	Mill.m2	62	62	62	62	62	62	-	-	-	-	-	-	62	62	62	-	-	-
Embankment Volume	Mill.m3	53.8	53.8	53.8	53.8	53.8	53.8	-	-	-	-	-	-	53.8	53.8	53.8	-	-	-
(4) Breakwater																			
a. Pacific : length	km	14.9	14.9	14.9	14.9	14.9	14.9	-	-	-	-	-	-	14.9	14.9	14.9	-	-	-
b. Atlantic: length	km	7.4	7.4	7.4	7.4	7.4	7.4	-	-	-	-	-	-	7.4	7.4	7.4	-	-	-
(5) Barrier Dams																			
a. Site A, B, C, D: Total Volume	Mill.m3	-	-	-	-	-	-	20.3	20.3	20.3	20.3	20.3	20.3	-	-	-	20.3	20.3	20.3
b. Site E, F, G : Total Volume	Mill.m3	10.7	10.7	10.7	10.7	10.7	10.7	-	-	-	-	-	-	10.7	10.7	10.7	-	-	-
(6) Flood Control																			
a. Diversion Culvert: Number	No.	2	2	2	2	2	2	-	-	-	-	-	-	2	2	2	-	-	-
b. Total length	km	18	18	18	18	18	18	-	-	-	-	-	-	18	18	18	-	-	-
(7) Excavation																			
a. Dry Exc.	Mill.m3	906	1,609	1,038	1,893	1,133	2,057	699	1,128	786	1,342	837	1,439	1,247	1,459	1,587	772	884	942
b. Dredging	Mill.m3	32	72	52	113	61	133	200	415	273	576	306	626	72	113	134	366	514	560
Total Excavation Volume	Mill.m3	938	1,681	1,090	2,006	1,194	2,190	899	1,543	1,059	1,918	1,143	2,065	1,319	1,572	1,721	1,138	1,398	1,502

Note*1: A = 147(B) X 27.0(H), 1LANE
A' = 147(B) X 27.0(H), 2LANES
B = 171(B) X 30.3(H), 1LANE
B' = 171(B) X 30.3(H), 2LANES
C = 183(B) X 31.4(H), 1LANE

B. SEA LEVEL CANALS COMPARATIVE SUMMATION TABLE (2)

ITEMS	unit	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	S-11	S-12	S-13	S-14	S-15	S-16	S-17	S-18
A FEATURES OF ALTERNATIVES																			
(1) Design Ship	1000 DWT	150	150	250	250	300	300	150	150	250	250	300	300	150	250	300	150	250	300
(2) Route	10, 14S	10	10	10	10	10	10	14S	14S	14S	14S	14S	14S	10	10	10	14S	14S	14S
(3) Number of lane	No.	1	2	1	2	1	2	1	2	1	2	1	2	50%-1, 2	50%-1, 2	50%-1, 2	50%-1, 2	50%-1, 2	50%-1, 2
(4) Route Length; a. Atlantic Approach	km	3.5	3.5	3.85	3.85	3.9	3.9	12.1	12.1	12.5	12.5	12.6	12.6	3.5	3.85	3.9	12.1	12.5	12.6
b. Channel	km	57.0	57.0	57.0	57.0	57.0	57.0	53.0	53.0	53.0	53.0	53.0	53.0	57.0	57.0	57.0	53.0	53.0	53.0
c. Pacific Approach	km	25.7	25.7	27.7	27.7	28.7	28.7	17.5	17.5	21.9	21.9	23.2	23.2	25.7	27.7	28.7	17.5	21.9	23.2
Total Route Length	km	86.2	86.2	88.55	88.55	89.55	89.55	82.6	82.6	87.4	87.4	88.8	88.8	86.2	88.55	89.6	82.6	87.4	88.8
(5) Channel cross-section (Wxd)	m	147X21	343X21	171X24.5	399X24.5	183X25.5	427X25.5	147X27	147X27	171X30.3	171X30.3	183X25.5	427x25.5	147x21	171x24.5	183x25.5	147x21	171x24.5	183x25.5
C CONSTRUCTION COST																			
(1) Channel Excavation																			
a. Dry Excavation	Mill.US$	4,917	8,247	5,190	9,072	5,947	10,665	4,438	6,957	4,946	8,234	5,251	8,817	6,600	7,269	8,193	4,844	5,507	5,852
b. Dredging	Mill.US$	179	400	311	657	375	830	8,582	17,956	11,960	25,539	13,463	27,898	400	657	830	15,544	22,447	24,546
Total Channel Excavation	Mill.US$	5,096	8,647	5,501	9,729	6,322	11,495	13,020	24,913	16,906	33,773	18,714	36,715	7,000	7,926	9,023	20,388	27,954	30,398
(2) Taidal Gate Structure	Mill.US$	216	257	254	302	292	348	216	257	254	302	292	348	216	254	292	216	254	292
(3) Canal Partition Wall	Mill.US$	-	556	-	650	-	743	-	578	-	675	-	771	-	-	-	-	-	-
(4) Tidal Gate	Mill.US$	207	240	290	335	328	379	208	240	290	335	328	379	208	290	328	208	290	328
(5) Breakwater	Mill.US$	45	45	45	45	45	45							45	45	45			
(6) Barrier Dam	Mill.US$	182	182	182	182	182	182	346	346	346	346	346	346	182	182	182	346	346	346
(7) Flood Control System	Mill.US$	13	13	13	13	13	13							13	13	13			
(8) Indirect Cost	Mill.US$	1,044	1,713	1,128	1,923	1,271	2,235	2,320	4,327	2,863	5,783	3,263	6,283	1,348	1,516	1,703	3,499	4,729	5,132
(9) Total Project Cost	Mill.US$	6,803	11,653	7,413	13,179	8,453	15,440	16,110	30,661	20,659	41,214	22,943	44,842	9,012	10,226	11,586	24,657	33,573	36,496
D OPERATION AND MAINTENANCE COST																			
(1) Man Power and Others O&M Cost	Mill.US$	540	540	553	553	553	553	353	353	366	366	366	366	540	540	553	366	366	366
E Construction Aspect																			
(1) Comparative Ease of Construction	Grade	A	A	A	A	A	A	B	B	B	B	B	B	A	A	A	B	B	B
(2) Technical Soundness	Grade	A	A	A	A	A	A	B	B	B	B	B	B	A	A	A	B	B	B
(3) Construction Period	Year	11	11	12	17	14	19	10	13	10	15	14	18	15	16	17	13	12	14
F IMPACT AS REFLECTED IN COST ESTIMATES																			
(1) Impact on Existing Panama Canal																			
a. Shutdown Period During Construction	Month	-	-	-	-	-	-	6	6	6	6	6	6	-	-	-	6	6	6
b. Modification Warks to Panama Canal	Grade	-	-	-	-	-	-	L	L	L	L	L	L	-	-	-	L	L	L
(2) Potential Enviromental Impact																			
a. Gatun Lake Salinity Danger	Grade	S	S	S	S	S	S	L	L	L	L	L	L	S	S	S	L	L	L
b. Placement of Excurvated Materials	Grade	M	L	M	L	M	L	S	M	S	M	S	M	L	L	L	S	S	M
(3) Socio Economic Impact																			
a. Relocation of Residents	Grade	L	L	L	L	L	L	S	S	S	S	S	S	L	L	L	S	S	S
b. Increase Works Opportunities	Grade	M	M	M	M	M	M	M	L	M	L	M	L	M	M	M	M	L	L

Notes:

1) Comparative ease of construction
   A=Excavation works will be easy
   B=Excavation works will be difficult

2) IMPACT
   S=To be small
   M=To be medium
   L=To be large

I

PART I : ENGINEERING FOR PRESCREENING

CHAPTER 1 - GENERAL

1.1 Description of Existing Canal

The existing situation of Panama Canal route, facilities concerned, lockage water usage and traffic situation are understood as follows.

1.1.1 Route

The Panama Canal is an 81 km long water link connecting the Atlantic and Pacific Oceans. The lock canal consists of short sea-level sections at either end and a long elevated intermediate section including Gatun Lake. The elevated section is separated from the end sections by twin locks 33.5m wide, 304.8m long, and providing 12.5m of water over lock sill under normal conditions. Gatun Locks at the Atlantic end have three lifts from sea level to the Gatun Lake level which is regulated between 25 and 26.5m above Precise Level Datum (PLD). The Pacific end of the canal has two sets of locks: the Miraflores Locks which raise ships in two lifts from sea level to Miraflores Lake at an elevation of about 16.5m, and the Pedro Miguel Locks which raise vessels in one lift from Miraflores Lake to the Gatun Lake level. All locks provide two parallel lanes which can accommodate traffic in either direction independently. The elevated intermediate section between Gatun and Pedro Miguel Locks is 51.5km long. The reach from Gatun to Gamboa through Gatun Lake is 38.6km long and has channel widths varying from 152.4 to 304.8m. The 12.9km Culebra Cut reach of the canal through the Continental divide (Gamboa to Pedro Miguel Locks) has a 152.4m width.

1.1.2 Dams and Lakes

Gatun Dam is an earth dam which forms the Gatun Lake, with an area of about 430 km2 (165 sq. miles). The lake is an integral part of the waterway, as well as the principal source of water supply for canal operations. Pedro Miguel Locks and Dam, which also retain Gatun Lake, consist of the locks and short earth embankments on either end. The waterway between Pedro Miguel Locks and Miraflores Locks passes through Miraflores Lake. Miraflores Dam is an earth structure west of Miraflores

Locks, and controls the level of Miraflores Lake. Madden Dam, a concrete gravity dam across the Chagres River upstream from Gatun Lake, forms Madden Lake which stores additional water for dry season lockages and controls floods in the upper Chagres River. A hydroelectric generating station (197 and 87 GIGA WATT-HOUR at Maden and Gatun respectively in 1990) at the dam is a source of power for the Canal Zone.

1.1.3 Water Supply

The availability of water supply needed for the operation of the Panama Canal locks has become the subject of concern in recent years, and it is expected to be an important factor in considering suitability of the various improvement alternatives. The existing water supply as described in the IOCS reports is summarized hereafter. In the last section recent data taken from the Panama Canal Commission 1989 annual report is introduced in order to form a comparison between the present water supply conditions and those prevailing in the late 1960's at the time of the IOCS study.

(1) Tributary Drainage

The water supply for the operation of the canal is provided by the 3,339 km2 (1,289 sq.miles) drainage area of Gatun Lake. This manmade lake was created in 1912 with the construction of Gatun Dam. The need for additional water supply and flood storage necessitated the construction of Madden Dam in the early 1930's, with a tributary drainage of 1,018 km2 (393 sq. miles). All water discharged from Madden Dam flows into Gatun Lake. Hydroelectric power is generated at both Madden and Gatun Dams. The main rivers contributing to the water supply of Gatun Lake are the Chagres, Pequeni, Boqueron, and Gatun on the east side of the canal, and the Ciri, Trinidad, and Cano Quebrado on the west side.

(2) Rainfall

On the basis of hydro-meteorological records, the climate of Panama can be categorized into two seasons. January through April is usually considered as dry season and May through December the wet season. Most of the rainfall occurs during the wet season, which is about 90% of the total annual rainfall. The annual average rainfall in the Panama Canal Watershed amounts to approximately 2,500 mm. The rainfall isohyetals are presented in Fig. 2.1.1.

(3) Watershed Yield

The study identified the average annual yield for 51 years record by Institute De Recursos HIDRAULICOS Y ELECTRIFICATION, PANAMA (1933-1983) about 6.6 billion m3. A frequency analysis of the records at that time indicated that a maximum yield of 10.7 billion m3 or a minimum yield of 3.7 billion m3 would be equaled or exceeded once per 100 years. Annual evaporation amounted to approximately 673 million m3. The net average annual yield from the watershed was 5.9 billion m3.

(4) Storage

The storage available in Gatun Lake to supplement the runoff during dry periods was about 659 million m3, between elevations 25m and 26.5m. Madden Lake provided an additional volume of 539 million m3 from elevation 61m and 76.2m, bringing the maximum usable storage to 1.2 billion m3.

(5) Water Use

The figures of total yield and percentage of water use vary according to the time and reports. IOCS report (1970) calculated Gatun lake water yield as 5.8 billion m3 and percentage of water utilization was as follows: lockage water 31%, municipal 1%, power 35%, evaporation loss 10% and spillage 23%. According to PCC annual report (1989) net yield of Gatun lake was 4.8 billion m3, a decrease of 0.5 billion m3 from the previous year. In 1989 water use percentage was as follows: lockage water 51%, municipal 5%, power 25%, evaporation loss 13% and spillage 6%.

In this study total yield has been found (Gatun and Madden) 6.6 billion m3. Taking into account the increased municipal and power water requirement, water use percentages considered are as follows: lockage 45%, municipal 4%, evaporation loss 10 % and power plus spillage 41%. Assuming 0.197 million m3 per lockage 15,000 transit can be supported with the present yield.

1.1.4 Traffic

The Panama Canal Commission annual statistics show that during the past ten years the number of commercial transits declined from a peak of 14,000 in 1982 by 20% to a lowest value in 1984. This drop has been related to the opening of the Panamanian pipeline in some reports. The number of transits annually increased thereafter, however this growth trend was reversed in 1989. Details are shown in Table 1.1.1.

Table 1.1.1 - Panama Canal Traffic

Year	Commercial Transits	Tonnage Long Tons (Mill)	Commercial Tolls (Mill. $)
1980	13,507	167.2	291.8
1981	13,884	171.2	301.8
1982	14,009	185.5	323.9
1983	11,707	145.6	286.0
1984	11,230	140.5	286.7
1985	11,515	138.6	298.5
1986	11,925	139.9	321.0
1987	12,230	148.7	328.4
1988	12,234	156.5	337.9
1989	11,989	151.6	327.9

Source : by P.C.C. Report

1.1.5 Operation and Maintenance

(1) Operations

The Panama Canal is operated by the Panama Canal Commission (PCC), an agency of the United States Government. The PCC, established under the Panama Canal Treaty of 1977, is charged with the management, operation, and maintenance of the Canal. Under the terms of the Treaty, PCC will perform these functions until the last day of the year 1999 when the Canal shall be turned over to the Government of the Republic of Panama.

The operation of the Canal is conducted on a self-financing basis. PCC is expected to recover through tolls and other revenues all costs of operating and maintaining the waterway. At the end of fiscal year 1989, PCC had a total staff of 8,577 employees, of which 7,584 employees were Panamanian nationals. The total payroll in that year was $200.5 million.

Daily average transits by oceangoing ships averaged 33.1 per day during fiscal year 1989. Average time to complete the Canal crossing decreased from 21.9 hours in fiscal year 1988 to 17.4 hours in fiscal year 1989. In terms of ship dimensions; ships of 183m length and over were 33.8% of total oceangoing transits, those of 24.5m beam and over were 44.7%, and ships transiting at more than 11m draft were approximately 12%.

(2) Maintenance and Improvements

The Engineering and Construction Bureau of PCC is responsible for the overall physical maintenance and improvement works. Dredging works are done annually with the dual purposes of maintenance and improvement. In fiscal year 1989 a total of 2.56 million m3 of dredging work was accomplished, representing the largest work volume undertaken in any one year since the start of this decade. Volumes of dredging works during the past few years are shown below;

1980:	1.42 million m3
1981:	1.28 million m3
1982:	1.27 million m3
1983:	1.83 million m3
1984:	2.32 million m3
1985:	1.02 million m3
1986:	0.58 million m3

Canal facilities such as locks, dams and spillways, and floating equipment are regularly maintained and improved upon. In fiscal year 1989 the total operating expenses were US$443,119,486, and the amount spent on maintenance and engineering works was US$58,511,706, ie. 13.2%.

1.1.6 Panama Canal Constraints

(1) General

Several factors limit the number and size of ships which can transit the waterway. First, the dimensions of the locks and channel determine the maximum size ship that can use the canal. With normal Gatun Lake regulation level vessels up to an average size of 65,000 DWT can transit. Second, the optimum rate at which vessels can navigate the locks restricts the number of ships that can transit in a given period of time. At present approximately 34 ships can be accommodated daily. Also, the natural supply of water available to operate the locks may restrict the number of transits possible during dry years as well as permissible draft. The decline in the water supply has been discussed above.

(2) Size Limitations

Criteria for size - width and length - and draft limitations are established by the Panama Canal Commission. The development of improved procedures through the years has enabled the criteria to be progressively modified to include larger ships with greater draft. However, the physical dimensions of the locks and channel place an upper limit on the size of ships that can transit.

The width of the existing locks is 33.5m. PCC regulations provide that 32.3m is the widest beam commercial ships acceptable for regular transit. A report prepared in 1990 (Transisthmian Alternatives for Increasing the Throughput Across Panama) showed that an analysis of the annual reports of PCC from 1983 to 1988 reveals that the percentage of ships whose beams equaled or exceeded 30.5m had increased from 20 to 23 percent.
The usable lock chamber length is 305m, thereby restricting transit to ships of lesser lengths.
The allowable draft of ships using the canal depends upon Gatun and Miraflores Lakes elevations. The lower lock sill at the south end of Pedro Miguel Locks (elevation of 3.96m) provides a depth of water of 12.5m with Miraflores Lake at its minimum elevation of 16.4m. This is a more restrictive condition than that imposed by the upper sills at Gatun and Pedro Miguel Locks. These sills, at an elevation of 11.4m, provide a depth of 13.6m with Gatun Lake at the minimum regulation stage of 25m. The maximum draft allowable for transit is 12m in tropical fresh water.

(3) Transit Time

PCC documents define the Canal water time as the sum of queuing and transit time and show that it increased annually from 20.1 hours in fiscal 1983 to 24 hours in fiscal 1987.

1.2 FA/FR Study

By exchange of notes on September 1982, the Governments of the Republic of Panama and the United States of America agreed to establish a Preparatory Committee for the study of alternatives to the Panama Canal, including a sea-level canal. In September 1985, the Government of Japan was invited by both signatories of the exchange of notes to participate in the Commission for the Study of Alternatives to the Panama Canal. The commission consists of commissioners from each of the member nations (Panama, United States, and Japan) and a Secretariat composed of technical staff from the member nations.

After a selection process, the Commission chose a consortium of consultant firms representing the three countries (SINBOL) was chosen to carry out a Feasibility Analysis/Final Report (FA/FR) Study. The objectives of the FA/FR Study as set forth by the Study Commission were as follows;

- to identify potential alternatives to the Panama Canal in the Republic of Panama;
- to study these alternatives in accordance with the Final Report of the Preparatory Committee for the study, prepared in June 1985, in order to develop the information necessary to evaluate the feasibility of each alternative;
- to select the best alternative and study it in detail;
- and then to develop conceptual plans for said alternative for the consideration of the member governments of the Study Commission.

The FA/FR Study produced a Detailed Plan of the Study (DPS) which included an overall work flow plan (Fig. 1.2.1) identifying the various study components. The work flow plan also identified and described a number of Component Studies to be carried out by other consultants and prepared terms of reference for each. The component studies included the Engineering and Cost Estimates Study, identified in Fig. 1.2.1 as work items B.2.1, B.2.2, B.3.2 and B.3.3. Proposals to carry out this study were called for and following the selection procedure the Component Study Contractor for Engineering and Cost Estimates was appointed.

The Engineering and Cost Estimates Study was divided into two main Phases. Phase 1 relates to prescreening and corresponds to work items B.2.1 and B.2.2 in Fig. 1.2.1. In this phase a broad range of study cases are being collated and developed to comparable detail so that the engineering feasibility and cost of each can be assessed. The thirty-seven study cases were developed by the Secretariat as described in Section 1.3 below.

The results of Phase 1 will be reviewed by the Commission and approximately three alternatives will be chosen for further study to be carried out in Phase II corresponding to work items B.3.2 and B.3.3. of Fig. 1.2.1. In Phase 2 the selected alternatives will be developed and costed in further detail so that the Commission will have sufficient engineering detail available for a cost-benefit comparison to be made.

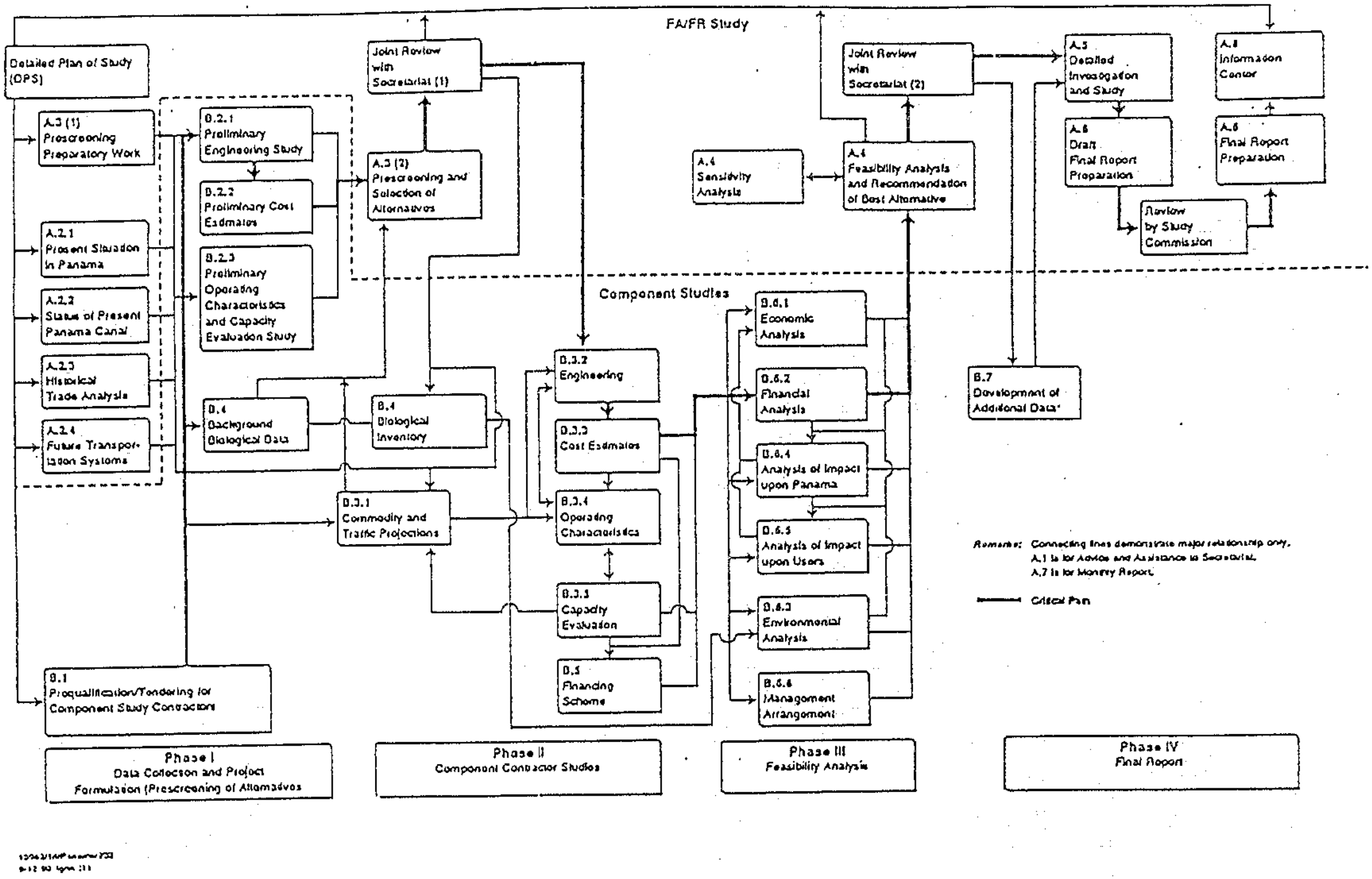


Fig. 1.2.1 Overall Work Plan Flow

1.3 Review of Historical Alternatives

1.3.1 Study Cases and Complementary Systems

Following the appointment by the Commission and subsequent commencement of the FA/FR Study the following existing alternatives which had previously been developed were reviewed by the Secretariat in order to categorize the various concepts for easier comparison:

A. Improvements to the Existing Canal
- (1) Culebra Cut Widening
- (2) Non-lock improvements
- (3) Third Locks Plan
- (4) Terminal Lake plan
- (5) Deep Draft Lock Plan
- (6) Lopez-Moreno Plan (Panamanian Alternative)

B. Sea-Level Canal Alternatives
- (7) Route 10 of the IOCS Study
- (8) Route 14S of the IOCS Study
- (9) Vergara Plan
- (10) Nagano Plan

C. Non-Canal Complementary Transportation Systems
- (11) Oil pipeline
- (12) Landbridge systems
- (13) Centerport Plan

By reviewing the details of the existing alternatives listed above, the Commission prepared a list of study cases for study in Phase 1 which encompassed the concepts inherent in the previous schemes but in a way which would allow the broad range of concepts to be studied and compared on an equal basis. This was achieved by first identifying the concepts on which each existing alternative was based:

1) Substantial Concepts

The main concepts on which the schemes were based were described as substantial concepts and include:
a) Widening and deepening
b) Raising canal water level
c) Method of Water control (for lock canal)
d) Method of Tidal control (for sea level canal)

2) Partial Concepts

Concepts which are supplementary to the substantial concepts since they involve relatively minor improvements compared to those described in 1) above. These include:
a) Improving ship navigation
b) Improving navigation aids
c) Improving locks

3) Complementary Systems

Concepts which relate to non-ship based means of transporting cargo across the Isthmus of Panama. These include supplementing road, rail or pipelines and upgrading of harbors as necessary.

1.3.2 Conceptual Alternatives

From the substantial concepts described in 1) above, four different conceptual alternatives were formulated and these four are the base from which all of the alternatives to be studied in Phase 1 were developed. The four conceptual alternatives are:

Group A. High Rise Lock Canal
(85'-90' water level, 1 and 2 lifts, 2 lanes)
Group B. Low Rise Lock Canal
(30'-55' water level, 1 lift, 2 lanes)
Group C. Route 10 Sea Level Canal
(sea-level, 0 lift, 1, 2, or 50% of 1&2 lane)
Group D. Route 14S Sea Level Canal
(sea-level, 0 lift, 1, 2, or 50% of 1&2 lane)
Group E. Status Quo

Alternatives A and B were broken down into 9 study cases each according to the route through Gatun Lake, the maximum size of ship (100,000, 150,000 and 250,000 DWT) and the level of Gatun Lake (85' and 90' for the high rise and 55' and 30' for the low rise). Alternatives C and D have also been broken down into 9 study cases each according to the maximum size of ship (150,000, 250,000 and 300,000 DWT) and the number of lanes in the canal (1, 2 or 50% 1 lane and 50% 2 lane). The conceptual alternatives and the 36 preliminary screening study cases derived from them are shown in Table 1.3.1 and each study case is further detailed in Table 1.3.2 of the same appendix. The existing canal is shown in the tables as a baseline study case (status quo). The Culebra Cut Widening Project is described in a Panama Canal Commission 1985 Report as a 14.5km long section of the waterway carved mostly through rock and shale. Coming from the Atlantic Ocean, ships enter the Cut at Gamboa where the Chagres River flows into the Canal channel. A short distance before reaching Pedro Miguel Locks, the ships pass Gold Hill on the left, which rises 202m above sea level. The original excavated channel width at Culebra Cut was 92m. During the 1930's and 1940's, the straight section immediately north of Gold Hill was widened to 153m to provide a passing section for large ships, and during the period 1957-1971, the remaining portions of the Cut were also widened to 153m.

In July 1991, the Panama Canal Commission announced that a US$200 million project to widen the Culebra Cut will commence in 1992 using the resources available at PCC for the dredging excavation work while employing outside contractors to implement the dry land work.
The project calls for the excavation of 26 million m3 of earth and rock to widen the Cut section from 153m to 192m along tangents and 223m with transitions from and to 192m, in curve sections. The widening objective is to permit two-way traffic through the divide, and thereby the entire Canal. It is reviewed for comparison with the other study cases but will not be studied for engineering feasibility.

The following schemes fall into the category of partial concepts as described in 2) above and will not be studied as part of Phase 1:

A. Non-Lock Improvements
B. Terminal Lake (except for the 100,000 DWT locks and the waterway route which will be considered in conceptual alternatives A)
C. Lock Consolidation

As appropriate, these schemes will be studied in Phase 2 as supplementary options to the alternatives chosen for further consideration during secondary screening.

Table 1.3.1 Conceptual Alternatives (For Prescreening)

June 12, 1991

Conceptual Alternative	Corresponding Alternative/Plan	Route	Size (10^3 DWT)	Rise (WL - ft)	No. of lift	No. of lane	Corresp. Case	Remarks
A. High Rise Lock Canal	I - d Third Locks I - e Terminal Lake plan except terminal lake I - f *Deep Draft*	15 + Third Locks Route and *15 (part)* + Gatun Lake Modified Route + Third Locks Route	100 150 250	90 85	2	2	L - 1 L - 2* L - 4 L - 5 L - 7 L - 8 L - 10 L - 13 L - 16	
B. Low Rise Lock Canal	I - g Panamanian Alternative	15 + Third Locks Route and 15 (part) Gatun Lake Modified Route + Third Locks Route	100 150 250	55 30	1	2	L - 3 L - 6 L - 9 L - 11 L - 12 L - 14 L - 15 L - 17 L - 18	
C. Route 10 Sea Level Canal	II - a IOCS Route 10 II - c Vergara II - d New Panama Canal	10	150 250 300	0	0	1 2 50% - 1 50% - 2	S - 1 S - 2 S - 3 S - 4 S - 5 S - 6 S - 13 S - 14 S - 15	
D. Route 14S Sea Level Canal	II - b IOCS Route 14 S	14S	150 250 300	0	0	1 2 50% - 1 50% - 2	S - 7 S - 8 S - 9 S - 10 S - 11 S - 12 S - 16 S - 17 S - 18	
E. Status Quo (Baseline)	I - a Status Quo	15	65	85	3	1 and 2	SQ	

* *Also perform a Major Feasibility Check for a single Lift Gate Design for Case L-2*

June 12, 1991
Rev. 1 July 18, 1991

Table 1.3.2 Study Cases (For Prescreening)

CASE	ROUTE	SIZE (10^3 DWT)	RISE (El. ft.)	No. OF lift	No. OF lane	REMARKS
	(Lock Canal)					
L-1	15 + Third L.	100	90	2	2	
L-2	15 + Third L.	100	85	2	2	*
L-3	15 + Third L.	100	55	1	2	
L-4	15 + Third L.	150	90	2	2	
L-5	15 + Third L.	150	85	2	2	
L-6	15 + Third L.	150	55	1	2	
L-7	15 + Third L.	250	90	2	2	
L-8	15 + Third L.	250	85	2	2	
L-9	15 + Third L.	250	55	1	2	
L-10	15 + Gatun + Third L.	100	85	2	2	
L-11	15 + Gatun + Third L.	100	55	1	2	
L-12	15 + Gatun + Third L.	100	30	1	2	
L-13	15 + Gatun + Third L.	150	85	2	2	
L-14	15 + Gatun + Third L.	150	55	1	2	
L-15	15 + Gatun + Third L.	150	30	1	2	
L-16	15 + Gatun + Third L.	250	85	2	2	
L-17	15 + Gatun + Third L.	250	55	1	2	
L-18	15 + Gatun + Third L.	250	30	1	2	
	(Sea Level Canal)					
S-1	10	150	0	0	1	
S-2	10	150	0	0	2	
S-3	10	250	0	0	1	
S-4	10	250	0	0	2	
S-5	10	300	0	0	1	
S-6	10	300	0	0	2	
S-7	14S	150	0	0	1	
S-8	14S	150	0	0	2	
S-9	14S	250	0	0	1	
S-10	14S	250	0	0	2	
S-11	14S	300	0	0	1	
S-12	14S	300	0	0	2	
S-13	10	150	0	0	50% - 1 50% - 2	
S-14	10	250	0	0	50% - 1 50% - 2	
S-15	10	300	0	0	50% - 1 50% - 2	
S-16	14S	150	0	0	50% - 1 50% - 2	
S-17	14S	250	0	0	50% - 1 50% - 2	
S-18	14S	300	0	0	50% - 1 50% - 2	
SQ	15	65	85	3	1 or 2	

* Also perform a Major Feasibility Check
for a single Lift Gate Design for Case L-2

The following schemes fall into the category of complementary systems as described in c) above:

A. Oil Pipeline and associated mooring facility
B. Landbridge, Railway and associated port and terminal facilities
C. Landbridge, Road and associated port and terminal facilities

The complementary systems will be approximately costed as part of Phase 1 so that at the end of that phase they can be combined with any of the 36 case studies or the status quo as necessary to increase their capacity and/or competitiveness. Details of the complementary systems and the corresponding capacities to be studied are shown in Table 1.3.3.

June 12, 1991
Rev.1 July 18, 1991

Table 1.3.3 Complementary Systems (For Detailed Analysis)

Complementary Systems	Route	Capacity
F. Oil Pipeline & Associated Mooring Facilities	Western Panama Near Existing Petro Terminales Location	(mil. b./day) 0.5 1.0 1.5 2.0
G. Landbridge, Railway & Associated Port and Terminal Facilities using Centerport Concepts	Central Panama; Panama City to Colon	(mil. ton/yr) 10 20 30 40
H. Landbridge, Road & Associated Port and Terminal Facilities using Centerport Concepts	Central Panama	(mil. ton/yr) 10 20 30 40

mil.b/day = million barrels/day

1.3.3 Prescribed Criteria for the Study Cases

The principal features of the 37 study cases are broadly described in Section 1.3.1 above. Specific details of the features and design criteria to be adopted were provided by the Secretariat and are described below:

(1) Design Ships

The dimensions of the design ships as provided by the Secretariat are shown in Table 1.3.4 below.

Table 1.3.4 Dimensions of Design Ships

Ship Size (DWT)	L (m)	B (m)	D (m)	Remarks
65,000	295	32	12	Max. Passable Size
100,000	277	43	17	in existing canal
150,000	316	49	19	
250,000	372	57	22	
300.000	394	61	23	

(2) Lock Chamber Dimensions

The Secretariat also provided the required dimensions of the lock chambers as shown in Table 1.3.5 below.

Table 1.3.5 Dimensions of the Lock Chambers

Ship Size (DWT)	L (m)	B (m)	D (m)	Remarks
65,000	304.8 (1,000ft)	33.5 (110ft)	12.8 (42ft)	Existing canal lock dimension
100,000	319	47	19	
150,000	363	54	21	
250,000	428	63	24	

Notes:

(1) The dimensions shown are the inside wetted surface of the lock chamber in the condition of lowest vessel position.

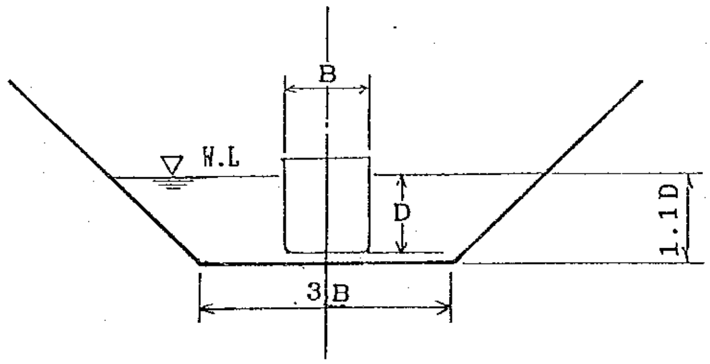
(2) Since lock chambers are considered for design ships having DWT up to 250,000 only, the dimensions for 300,000 DWT ships are not given in this Table.

(3) Canal Sections

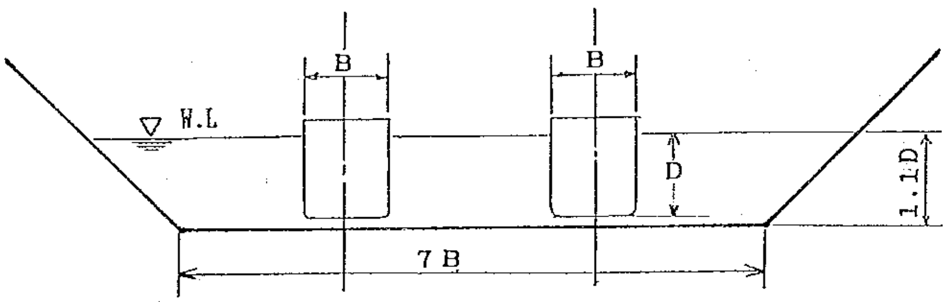
The required cross-section dimensions for the canal in one-way and two-way sections are shown in Fig. 1.3.1.

(4) Routes

The route co-ordinates to be adopted have been supplied by the Secretariat and are shown in the following Tables 1.3.6, 1.3.7 and 1.3.8.



One Way



Two Way

Fig. 1.3.1 Typical Canal Sections

Table 1.3.6 Sea Level Canal Route 14S (IOCS Route 14S)

POINT	STATION	COORDINATES (Km) NORTH	EAST
A	Pacific Channel	982.60	662.60
B	West of Balboa	982.40	657.30
C	Northeast Aceite	990.55	656.90
D	Esclusas de Miraflores	994.55	654.30
E	North of Rio Grande Reserve	999.00	647.95
F	Earthen dam	1,002.60	645.00
G	Gorgona Islands	1,007.50	639.70
H	East of Zaino Island	1,010.30	632.35
I	Southwest Juan Gallegos Island in Gatun Lake	1,017.30	624.20
J	West of Fort Davis	1,022.90	619.75
K	Causeway	1,028.25	618.90
L	Southwest of Ruins	1,029.10	618.65
M	Breakwater Entrance	1,038.00	618.65

Note: These coordinates apply for the Group D study cases.

Table 1.3.7 Sea Level Canal Route 10 (IOCS Route 10)

POINT	STATION	COORDINATES (Km) NORTH	EAST
A	Pacific Approach	977.65	643.65
B	Rio Caimito 1	982.20	641.65
C	Rio Caimito 2	985.30	636.95
D	Route 88	988.00	634.70
E	Rio Pescado	996.75	630.95
F	Gatun Lake	999.40	628.65
G	Gatun Lake	1,001.45	617.45
H	South Cerro Gigante	1,003.55	622.45
I	Cano Gignta Maria Islands	1,004.95	617.45
J	West Santa Maria Islands	1,007.85	611.62
K	Quebranda Brazito	1,011.35	607.75
L	Rio Cano Quebrando	1,014.30	606.55
M	Atlantic at La Paya de Anibal	1,022.10	600.70

Note: These coordinates apply for the Group C study cases.

Table 1.3.8 Third Lock, Terminal Lake and Variations
Deep Draft, The Panamanian Plan - Route II

POINT	STATION	COORDINATES (Km) NORTH	EAST
A	Pacific Channel	982.60	662.60
B	West of Balboa	989.40	657.30
C	Northeast Aceite	990.55	656.90
D	Esclusas de Miraflores	994.55	647.95
(D')	(Existing Canal just South of Pedro Miguel)	(996.00)	(653.35) (for lift 55')
E	West of Cerro Paraiso	997.10	650.70
F	Existing Canal West of Cerro Nitro	998.55	645.90
From F to X the route follows the existing canal (Route I)			
X	Just West of Jaguar and Vigilante Islands	1,020.20	618.20
J	West of Fort Davis (same as V)	1,022.90	619.75
From Point 'J' to end at Atlantic Breakwater, it follows Route V (Route 14S)			

Note: These coordinates apply for the Group A and B study cases although study cases L-10 to L-18 inclusive follow a modified route through Gatun Lake.

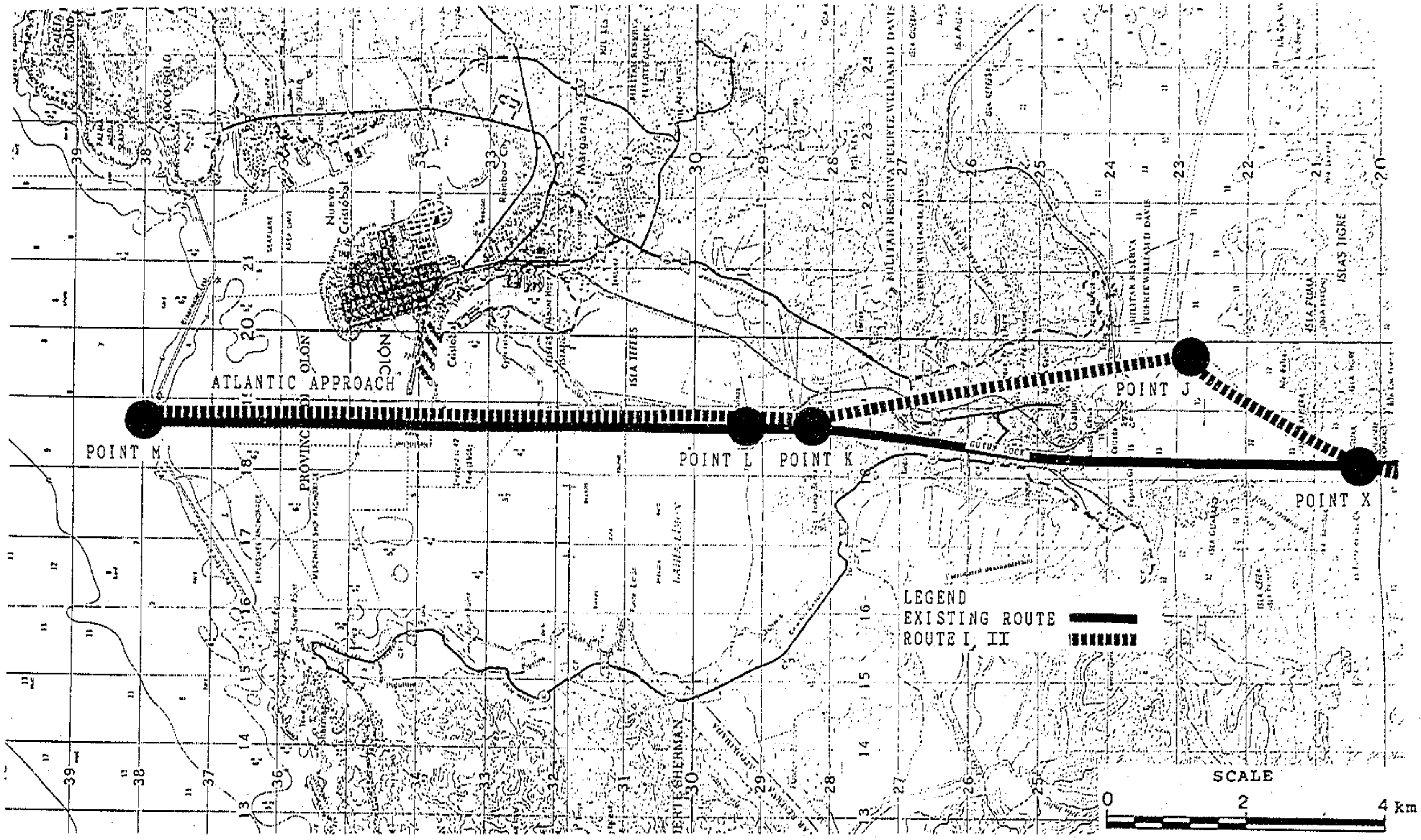


Fig. 1.3.2 Route Location (Atlantic Approach to Gatun Lake)

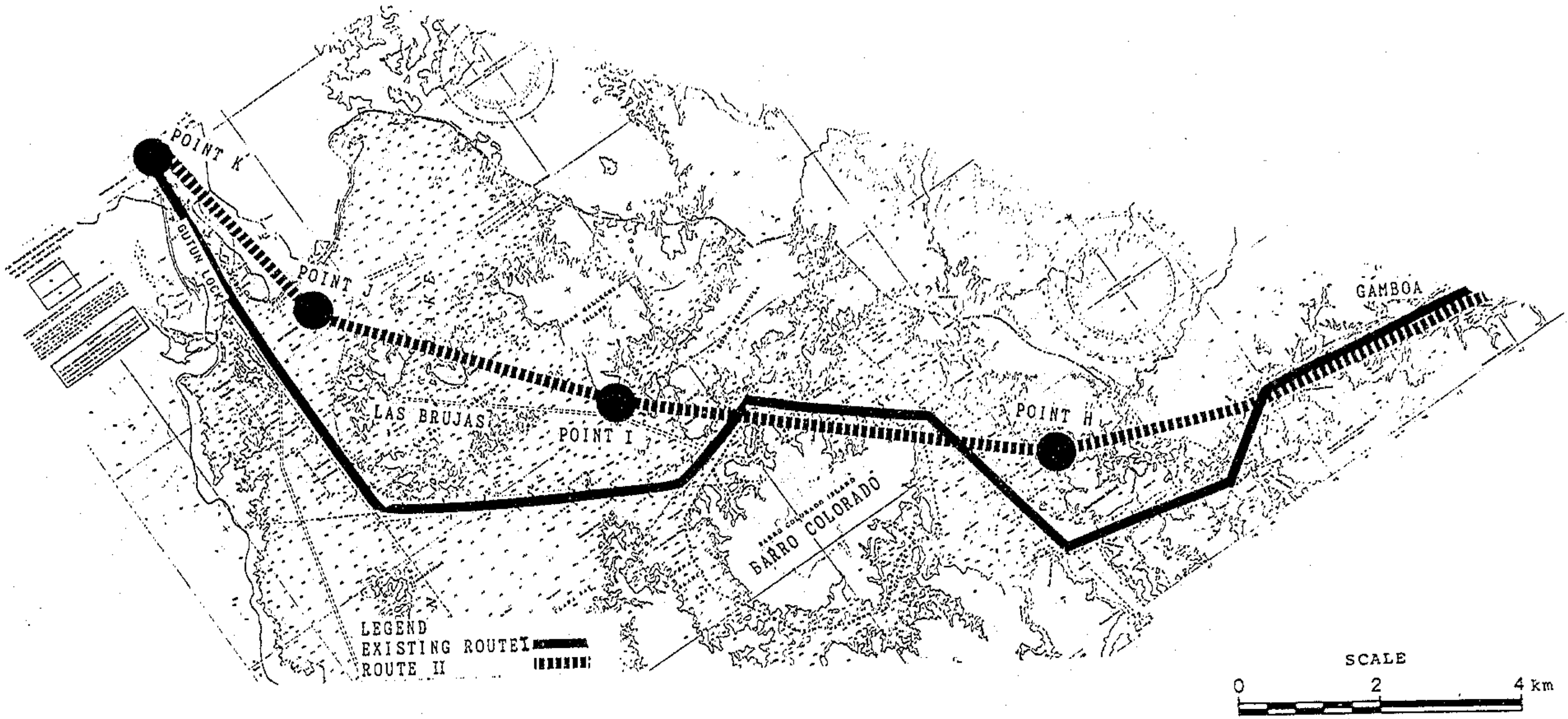


Fig. 1.3.3 Route Location (Gatun Lake)

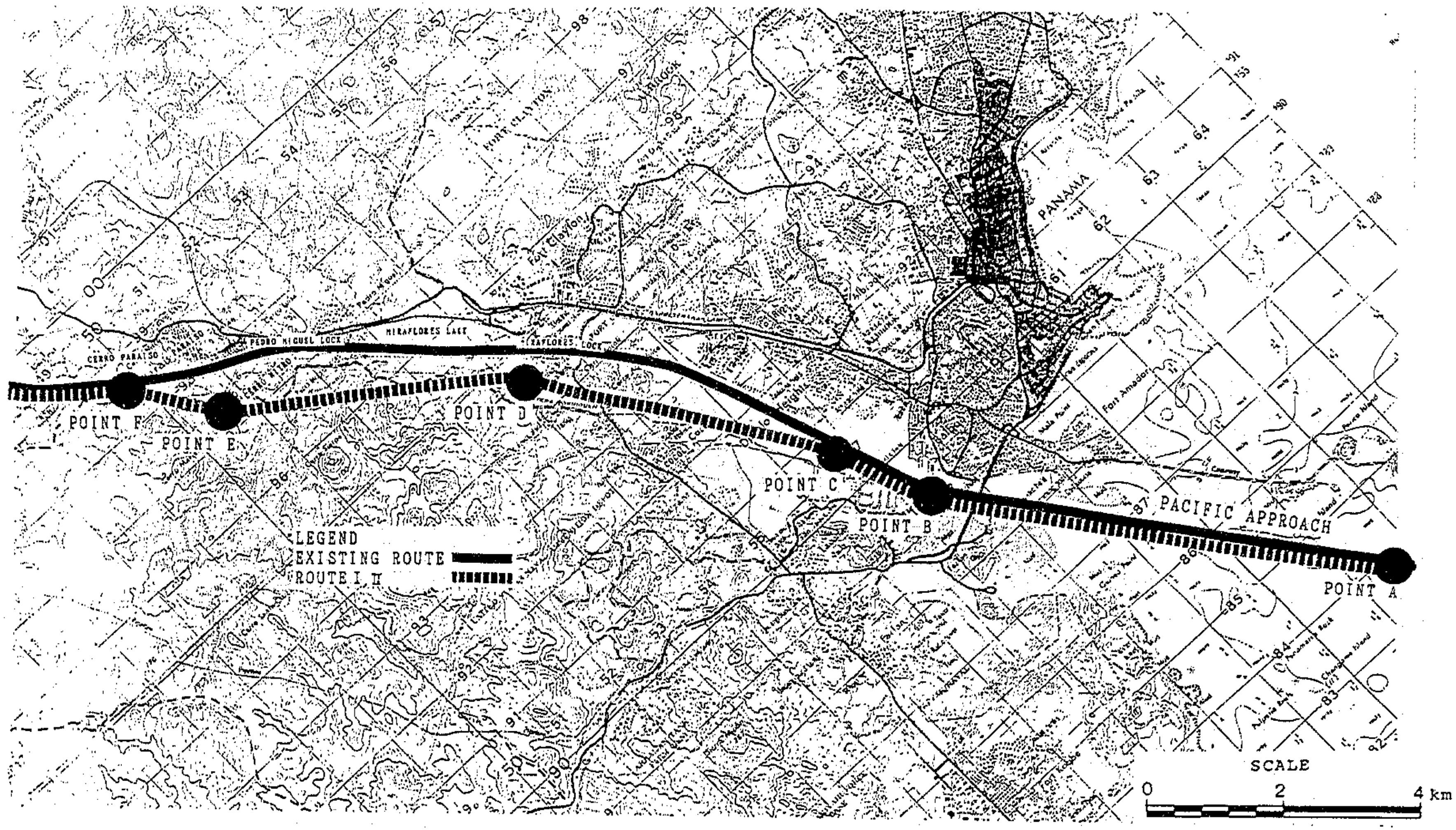


Fig. 1.3.4 Route Location (Paraiso to Pacific Approach)

(5) Planned Water Levels

Water levels are given by the Secretariat for each study case and are 90', 85', 55', 30' and 0'. These basic water levels for each study case have been defined further into high water levels and low water levels considering the variation in lake and sea levels and are summarized below in metric units.

Table 1.3.9 Canal Water Levels (P.L.D. Datum)

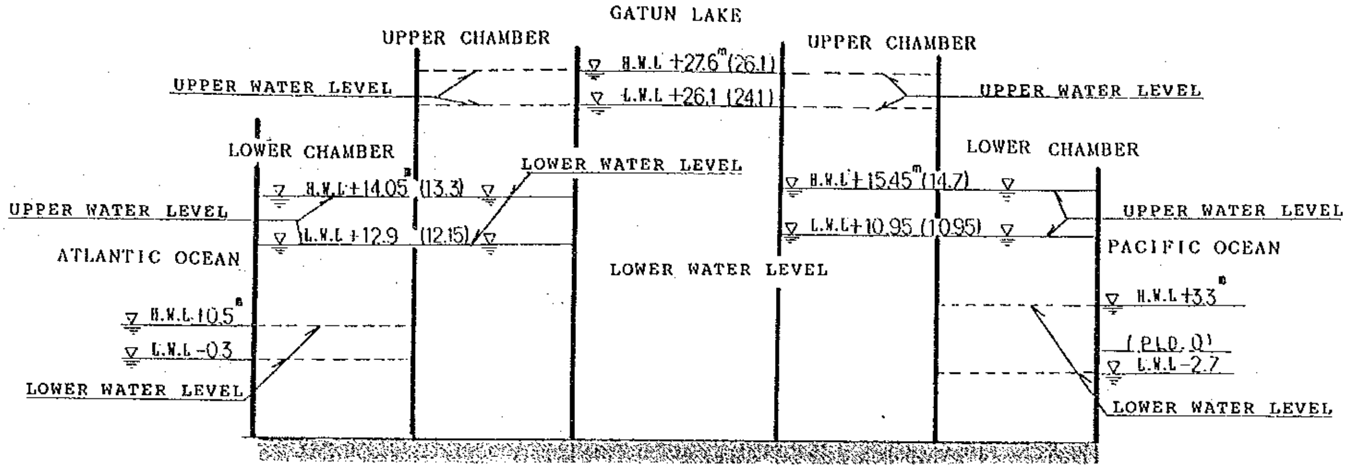
	Rise 90'	85'	55'	30'	Pacific	Atlantic
H.W.L	27.6	26.1	17.1	9.6	+3.3	+0.5
Design Level	90' (27.4)	85' (25.9)	55' (16.8)	30' (9.1)	+0.3	+0.5
L.W.L	26.1	24.6	15.6	8.1	-2.7	-0.3

These fundamental water levels have been defined further for the design of the lock gate leaves, and are shown in Table 1.3.10, Fig. 1.3.5 below.

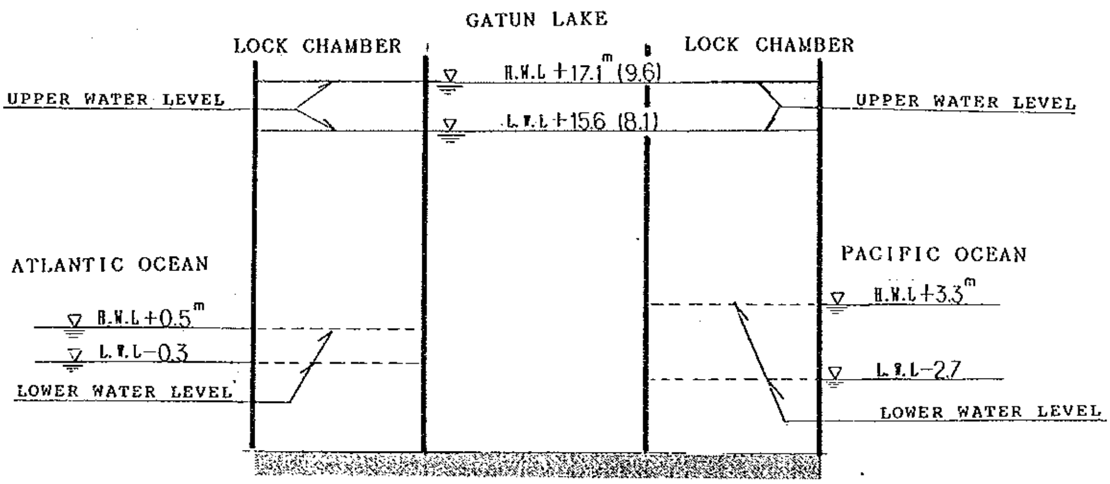
Table 1.3.10 Water Levels for Lock Gate Design

Case	Lower W.L of Lower Chamber - Atlantic	Lower W.L of Upper Chamber - Upper W.L of Lower Chamber	Gatun Lake - Upper W.L of Upper Chamber	Lower W.L of Upper Chamber - Upper W.L of Lower Chamber	Lower W.L of Lower Chamber - Pacific
	H.W.L - L.W.L (m)	H.W.L - L.W.L (m)	H.W.L - L.W.L (m)	H.W.L - L.W.L (m)	H.W.L - L.W.L (m)
L-1, L-3, L-7 2Lift, 90' Rise	0.5 - -0.3	14.05 - 12.90	27.60 - 26.10	15.45 - 11.70	3.3 - -2.7
L-2, L-5, L-8 L-10, L-13, L-16 2Lift, 85' Rise	0.5 - -0.3	13.30 - 12.15	26.10 - 24.60	14.70 - 10.95	3.3 - -2.7
L-2' 1Lift, 85' Rise	0.5 - -0.3	26.1 - 24.6			3.3 - -2.7
L-3, L-6, L-9 L-11, L-14, L-17 1Lift, 55' Rise	0.5 - -0.3	17.1 - 15.6			3.3 - -2.7
L-12, L-15, L-18 1Lift, 30' Rise	0.5 - -0.3	9.6 - 8.1			3.3 - -2.7
S-1 - S-18	0.5 - -0.3				3.3 - -2.7

Note : The numbers in the above table are illustrated in Fig. 1.3.5.



Note: The values above show 90'water level case, and the values in the ( ) show 85'Case.



Note: The values above show 55'water level Case, and values in the ( ) show 30'Case.

Fig. 1.3.5 Water Levels for Lake Gate Design

(6) Tidal Levels

Tidal levels on the Pacific and the Atlantic coasts are summarized as follows.

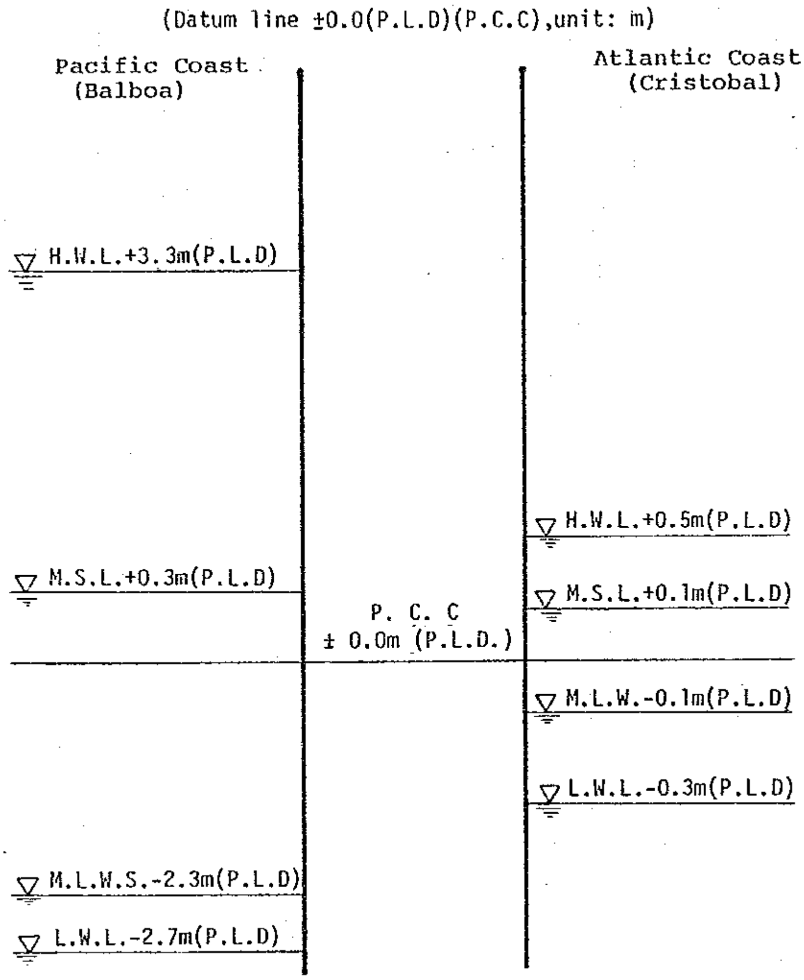


Fig. 1.3.6 Tidal Levels on the Pacific and Atlantic Coasts

(7) Relation between Water Level Chart and P.L.D.

Various water levels at lakes and both Ocean Coasts are indicated below showing the relation between P.L.D (Precise Level Datum) and each level.

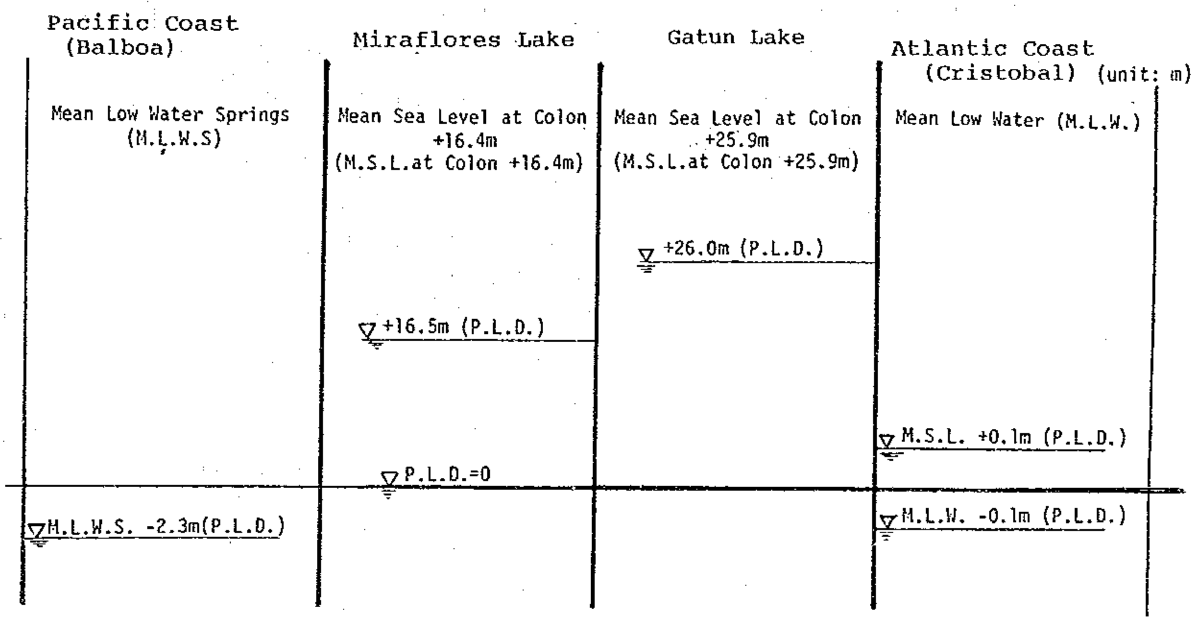


Fig. 1.3.7 P.L.D Datum Line

1.3.4 Review of Prescribed Criteria

The criteria suggested by the Secretariat have been reviewed by the component contractor in the process of carrying out the study. In general the criteria seem reasonable and have been adopted by the contractor. There are however some suggestions on the criteria and these are summarized below for consideration by the Commission. While these comments are presented, the criteria nominated by the Secretariat have been adopted by the contractor in all cases for presentation, comparison and costing of the study cases.

(1) Design Ships

The ship dimensions given by the Secretariat (above) are envelope dimensions and should not be taken to represent actual ships. For example the figures given for a 250,000 DWT ship imply a displacement of about 380,000 tones which is approximately 100,000 tones greater than the actual displacement of a typical tanker of that size.

The figures provided are appropriate for the sizing of the canal and locks but the proposed designs should be checked for typical actual figures.

(2) Canal Sections

Assuming that the ship dimensions in Table 1.3.4 are applicable to the canal sections given in Fig. 1.3.1 then the single lane section would be satisfactory for a 250,000 DWT ship if the side slope is not less than 1:1.5. For a 300,000 DWT ship the side slope would need to be reduced to 1:2. With steeper slopes the area ratios would be too small.

Lane widths would, in every case, be generous (for single lane canal).

In most cases the depths proposed would provide sufficient clearance between ship bottom and channel bottom. With the exception of the 150,000 DWT case, there would be a 2m deep siltation allowance which is probably excessive. In the case of the 150,000 DWT class (which contains a few very deep ships) the depth would be deficient and there would be no siltation allowance. In double lane sections of the canal, squat and trim would be less and the depths, with the one exception, would be even more generous.

There is much less information available about the size of two lane canals but what there is suggests that the cross-section proposed by the Secretariat is too narrow. The publication "International Commission for the reception of very large ships. Report of Working Group IV. Optimal layout and dimensions for the adjustment to large ships of maritime fairways in shallow seas, seastraits and maritime waterways, Supplement to Bulletin No. 35, PIANC", recommends a channel width of 12-13 times the beam of the largest ship. Work done for the Suez Canal development showed that a moored large ship experienced large forces when passed by another large ship with a separation clearance of 2B. If a maximum lane width of 2.8B is assumed, the minimum separation between passing ships could be as little as 0.7B in the cross-section proposed by the Secretariat. This would be equivalent to 0.76B of a typical 300,000 DWT ship. The Suez results suggested a minimum separation of 6.5B which, if applied to a canal would lead to a minimum width of 9.3B plus an additional width necessary because the passing speed would be double the convoy speed. The PIANC proposal would seem reasonable in the light of the Suez data. Further studies for the width of the canal might be necessary in Phase 2 studies.

PIANC: Permanent International Association of Navigation Congresses

1.4 Phase 1 Study

1.4.1 Description

The broad objective of Phase 1 of the component study of Engineering and Cost Estimates is to investigate the engineering feasibility and costs of the study cases so that the Commission can compare the alternatives and select approximately three which will be evaluated in more detail in Phase 2 of the component study.

The actual prescreening selection process will be carried out by the Commission using the results of Phase 1 of this component study as well as the results of the other component studies, operating characteristics and capacity evaluation, and commodity and traffic projections including preliminary environmental and socioeconomic data.

The results of all studies, when combined and collated by the Commission will allow it to eliminate prior to further detailed study in Phase 2 those study cases which:

- are clearly unsound;
- do not meet demand projections even when complementary systems to increase capacity are added;
- are not competitive on the basis of capital costs;
- would generate revenue shortfalls which could not reasonably be overcome by higher tolls or other sources of funding; and/or
- have adverse impacts the severity of which is obviously much greater than other alternatives.

In order to provide the Commission with the information necessary for them to carry out this prescreening process the detailed objectives of Phase 1 are to investigate the study cases identified by the Secretariat in a consistent and equitable manner and supply the following:

- An assessment of the engineering feasibility of the four conceptual alternatives (High rise lock canal, Low rise lock canal, Route 10 sea level canal, Route 14S sea-level canal) for the range of variations listed in Table 1.3.2, giving particular emphasis to the major feasibility check items identified by the Secretariat in the following Table 1.4.1 that are related to the engineering and cost estimates. The exclusion or modification of a study case may be proposed as a result of the check of the major feasibility items.

- Cost estimates for each study case including the status quo. The Status Quo is to include the announced plan by the PCC (July 1991) for the Gaillard Cut widening. Existing cost data will be validated and adjusted as necessary to ensure that all estimates are prepared on an equitable basis. Costs of complementary systems will also be estimated.

- Project summary schedules and annual distribution of costs for each study case.

- An estimate of the impact the construction of each study case would have on continuity of operation of the existing canal.

- An estimate of areas affected by the construction and operation of each study case, including areas likely to be affected by environmental or socioeconomic impacts.

Table 1.4.1 (1) Major Feasibility Check Items For Study Cases (For Prescreening)

Study Case	Engineering Feasibility Check Items	Route	Ship Size (10^3 DWT)	Rise (El - ft)	No. of lift	No. of lane	Remarks
L - 1 to L - 18	1. Ship guidance in lock chamber including mule operation or other innovative systems *	- - -	All cases	- - -	- - -	- - -	
	2. Lock gate concept design: gate type, structural system, alloy, allowable stress, buoyancy provisions, size limitation, corresion protection, drive mechanism, bearings, seals and failures modes. *	- - - - - - - -	All cases	- - - - - - - -	All cases	- - - - - - - -	
	3. Water saving plan including new water sources, development, and reservoir operation. *	-	All cases	All cases	All cases	-	
	4. Sea water pumping *	-	All cases	All cases	All cases	-	
	5. Deep water dredging operation, *	-	All cases	All cases	All cases	-	
S - 1 to S - 18	6. Tidal current analysis with gate **	10 and 14S	All cases	-	-	All cases	
	7. Ship maneuvering in canal under tidal current with gate. **	10 and 14S	All cases	-	-	All cases	
	8. Tidal gate design (including items in 2 above) *	10 and 14S	All cases	-	-	1 and 2	

* To be done by Engineering and Cost Estimates Component Contractor

** To be done by Operating Characteristics and Capacity Evaluation Component Contractor

Table 1.4.1 (2) Major Feasibility Check Items For Study Cases (For Prescreening)

Study Case	Engineering Feasibility Check Items	Route	Ship Size (10^3 DWT)	Rise (El - ft)	No. of lift	No. of lane	Remarks
S - 1 to S - 18	9. Tidal current analysis with tidal basin **	10	All cases	-	-	All cases	
	10. Ship maneuvering in canal under current with tidal basin **	10	All cases	-	-	All cases	
	11. Tidal basin design *	10	All cases	-	-	All cases	
	12. Tidal current analysis under no control condition **	10	All cases	-	-	All cases	
	13. Ship maneuvering in canal under no tidal current control **	10	All cases	-	-	All cases	
Study Case	II. Major Socioeconomic Impacts	Route	Size	Rise	No. of lift	No. of lane	
L - 1 to S - 18	1. Possible major socioeconomic impacts from various view points, both favourable and adverse	All cases	All cases	All cases	-	-	
Study Case	III. Ability to be financed	Route	Size	Rise	No. of lift	No. of lane	
L - 1 to S - 18	1. Ability to be financed under present and near future financial market including governments subsidy	By size of investment: 1) US$ 1 billion size 2) US$ 5 billion size 3) US$ 10 billion size 4) US$ 50 billion size 5) US$ 100 billion size					
Study Case	IV. Major Impacts on Existing Canal	Route	Size	Rise	No. of lift	No. of lane	
L - 1 to S - 18	1. Possible major impacts on the existing canal from various viewpoints, both favourable and adverse *	All cases	All cases	All cases	-	-	

* To be done by Engineering and Cost Estimates Component Contractor

** To be done by Operating Characteristics and Capacity Evaluation Component Contractor

The Study Process Flow Chart is shown in Fig. 1.4.1. A description of each study item was included in the Inception Report. The flow chart was based on the following broad principles for implementation of the project:

- The Study work will be executed in Japan, while periodic visits to Panama will provide opportunities for discussions with the Secretariat and various concerned parties to confirm the study course, submit reports, obtain data and hold hearings (receive information).

- Group A study cases and some study cases from Group C will be studied in the first half of Phase 1, while the remaining study cases will be reviewed in the second half of Phase 1.

- Costs of the complementary systems may be derived using an approximate basis in Phase 1. Engineering studies and revised cost estimates of complementary systems will be carried out in Phase 2.

1.4.2 Inception Report

The Inception Report for Phase 1 was the first report produced by this Component Contractor and the purpose was to define the scope of works, implementation plan and schedule for Phase 1 of the Study. A separate Inception Report for Phase 2 will be produced prior to commencement of Phase 2.

The Phase 1 Inception Report was submitted in July 1991 and included the following:

- Study objectives and implementation policy
- Study framework
- Scope of Study, including work content and procedures
- Study schedule
- Outline of reports to be submitted

The Phase 1 study is being carried out in accordance with the final contents of the Inception Report as revised following the Inception Visit to Panama in July 1991.

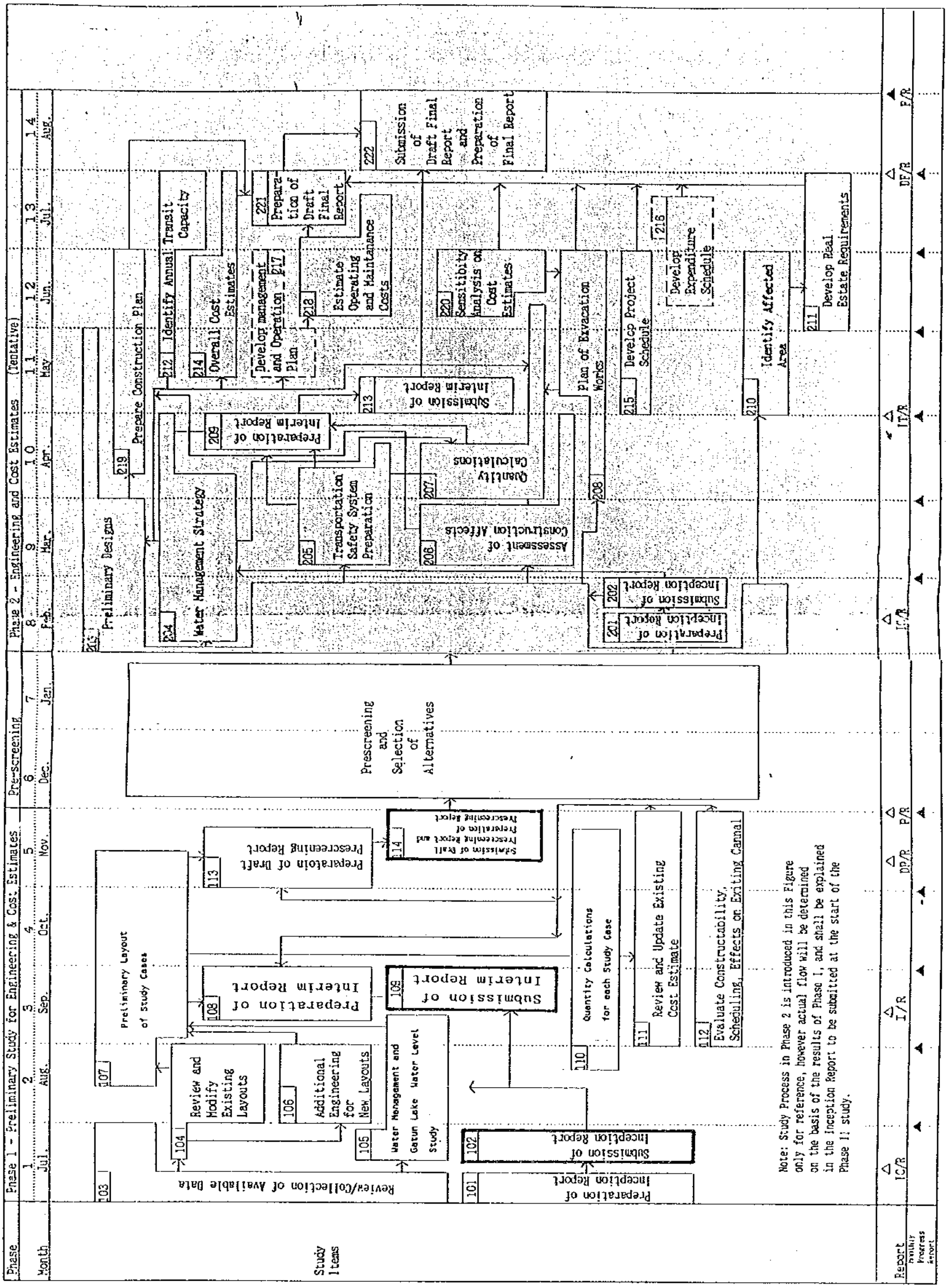


Fig. 1.4.1 Study Process Flowchart

1.4.3 Prescreening Reports

The final results of the Phase 1 study will be presented in the Prescreening Report which will be divided into two sections:

Part I - Engineering for Prescreening
Part II - Cost Estimates for Prescreening

A report summarizing the findings in the main reports above will also be provided.

(1) Interim Prescreening Report

In accordance with the Study Process Flowchart, an Interim Report was submitted to the Secretariat for review and discussion part way through Phase 1. The Interim Report had basically the same format and contents as this Prescreening Report but was not complete. It gave the Secretariat an opportunity to review the methods of presentation, costing and evaluation and allowed procedures to be discussed and confirmed for the remaining study cases to be considered in the second half of Phase 1.

Of the 37 study cases, the results for the 9 study cases included in Group A, High-Rise Lock Canal as well as the Status Quo baseline alternative were studied in the first part of Phase 1 and the results were presented in the Interim Report. The review of the 9 study cases included in Group C, Route 10 Sea-level Canal commenced during the first part of Phase 1 and partial results for these study cases were also included in the Interim Report.

The Interim Report included the review of the following major feasibility check items:

- Ship guidance system within lock chambers using mules' operation
- Proposals for various sizes of lock chambers and lock gate models based on designs in existing alternatives
- Water saving plan including new water sources development and reservoir operation
- Sea water pumping

(2) Prescreening Report

This final report of Phase 1 includes the Interim Report contents, modified as necessary to take into account any comments, as well as the results for the remaining study cases (Groups B and D, and remainder of C) which were reviewed during the latter half of the five-month period allocated for the Phase 1 Study. Cost estimates for the complementary systems were also derived during this period. Engineering studies of the complementary systems will be carried out during Phase 2 of the Study.

A draft of the Prescreening Report will be submitted to the Secretariat at the site visit in November 1991 for review and discussion. Following this the final Prescreening Report will be submitted in December 1991.

CHAPTER 2 - WATER MANAGEMENT PLAN

2.1 Existing Water Supply

2.1.1 Rainfall

On the basis of hydro-meteorological records, the climate of Panama can be categorized into two seasons. January through April is usually considered as dry season and May through December the wet season. Most of the rainfall occurs during the wet season, which is about 90% of the total annual rainfall. The annual average rainfall in the Panama Canal Watershed amounts to approximately 2,500mm. The rainfall isohyetals are presented in Fig. 2.1.1 and Appendix AP 1-2.

2.1.2 Drainage Area

The water supply for operation of the Panama Canal is provided by the 3,339 sq.km drainage area of Gatun and Madden dams. Gatun dam was constructed across the lower Charges river in 1912 and the Madden was constructed in the early 1930's across the upper Charges river. The main rivers contributing to the Gatun lake are the Charges, Pequeni, Boqueron and the Gatun from the east side of the canal, and the Ciri, Trini dad,and Cano Quebrado from the west side. With the excep tion of the Cano Quebrado, all of these rivers have been gauged and discharge records are available. In addition, records from numerous rain gauge stations are also available to supplement the stream flow data. These hydrologic records provide an adequate basis for determining the yield that can be expected from the Gatun lake drainage area. The active rain gauge and discharge measurement stations with period of records are shown in Table 2.1.1 and Appendix AP 1-2.

2.1.3 Watershed Yield

Average annual yield for 51 years of record(1933-1983) by IRHE(Instituto de Recursos Hidraulicos y Electrification) isoo about 6,593 million m3. Maximum and minimum yields of 10,653 and 3,557 million m3 occurred in the years 1981 and 1965 respectively. Annual evaporation is about 673million m3. Therefore, net annual average yield of the watershed would be about 5,920 million m3. The amount of monthly evaporation in the watershed is given in the Table below (See Appendix AP 1-3 to 1-6).

MONTHLY EVAPORATION

(UNIT: mm)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Gatun	140	149	166	156	109	93	89	95	90	94	89	114	1,384
Madden	137	145	162	153	107	91	87	93	88	92	87	112	1,354

Data Source: IOCS MEMORANDUM JAX-50

2.1.4 Storage

The available storage in Gatun lake is about 659 million m3 between elevations 24.6m and 26.1m. On the other hand Madden lake provides an additional volume of 539 million m3 between elevations 61m and 76.2m and increases the total usable storage to 1,198 million m3. Details are presented in Section 2.3.3.

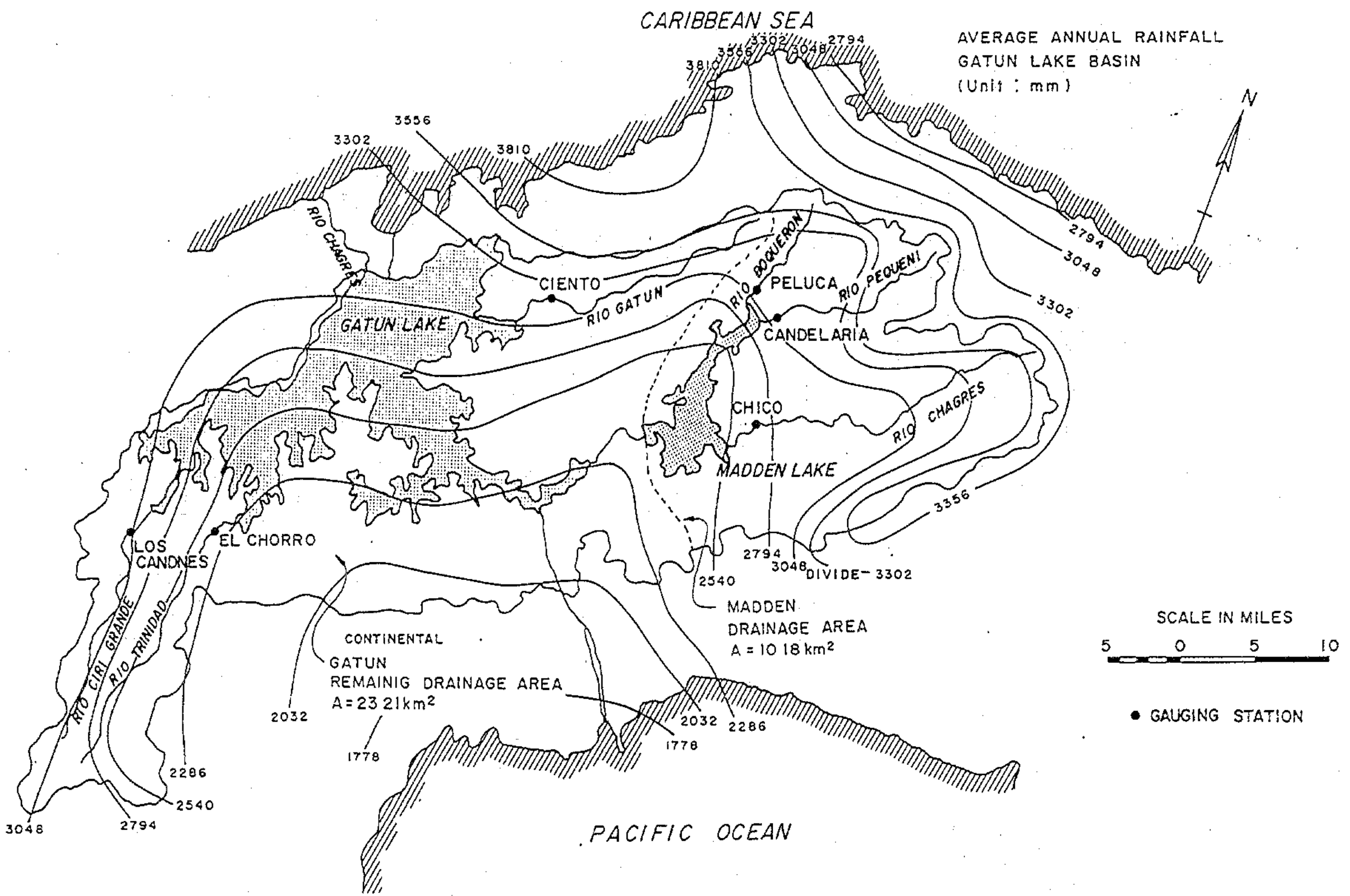
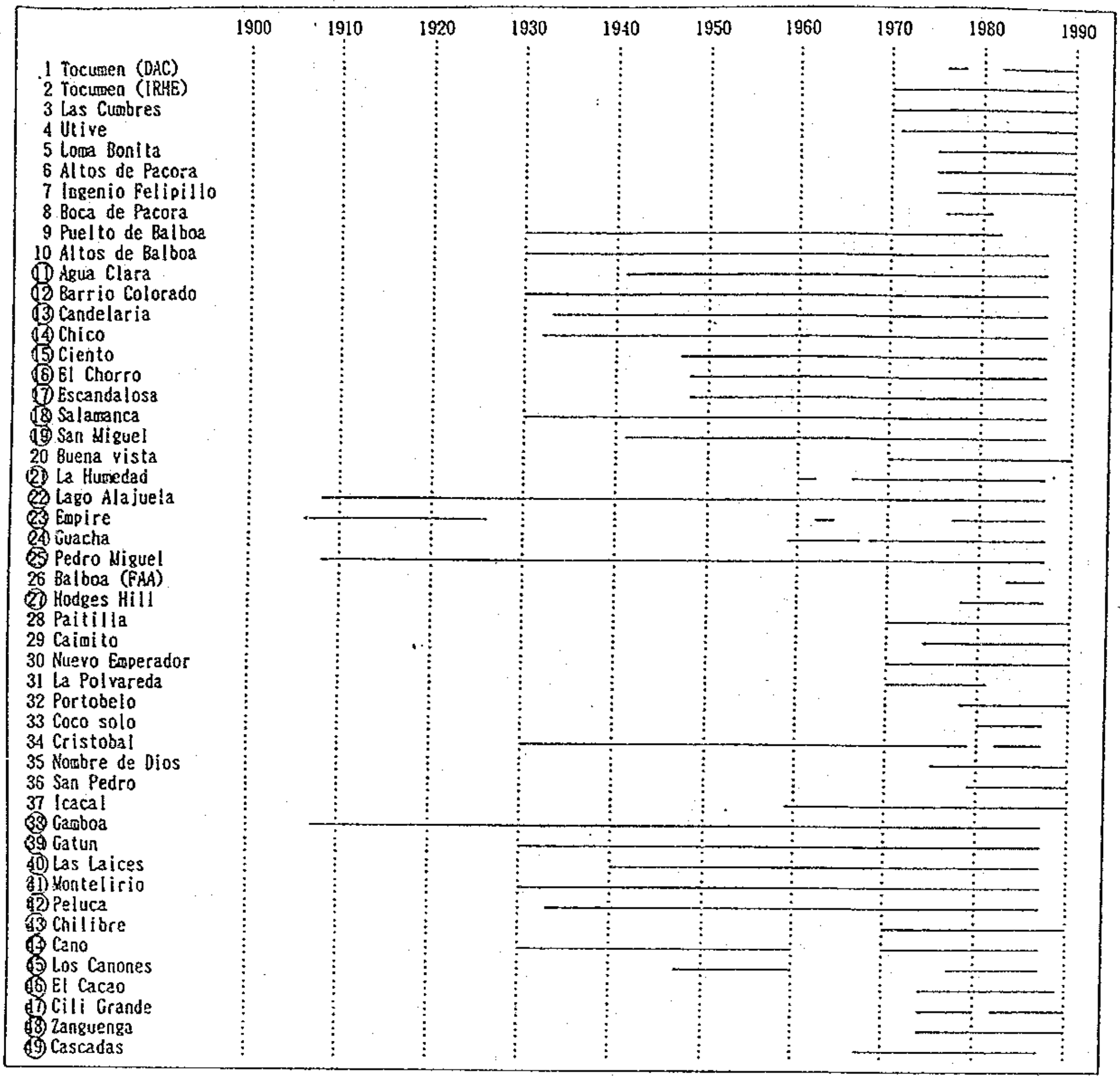


Fig. 2.1.1 Isohyetal Map of Canal Area

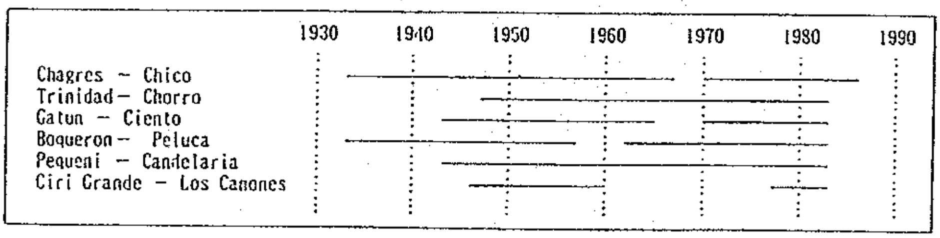
Table 2.1.1 Station and Period of Hydrological Data

(RAINFALL)



O shows rainfall gages in the GATUN watershed

(DISCHARGE)



2.1.5 Water Use

Gatun and Madden lake water is utilized for lockage water; municipal water supply for Panama city and Canal Zone, and Balboa; and to generate power. There are significant losses due to evaporation and spillage when run-off exceeds storage capacities. Percentage wise, water use from the Gatun lake is as follows:

Item	Percent (%)
Lockages	45
Municipal	4
Evaporation	10
Power+Spillage	41
	100

It is assumed that one lockage would require 0.197 million m3 of water. Deducting other losses, a total of 15,000 transit can be supported annually with the present storage volume. Municipal water use has increased significantly since 1968 and amounts to about 270 million m3 in 1989. If transits exceed the present level with a change in ship mix, an increase in available water supply would be necessary.

2.2 Canal Facilities and Water Management Related Restrictions

The existing canal consists of two short sea-level sections at either end and a long elevated intermediate section including Gatun lake. Between the sections there are 110 ft wide and 1,000 ft long twin locks. These locks can provide 41 ft of water over lock sill under normal conditions. The Atlantic end locks i.e. Gatun locks have three lifts from sea level to Gatun lake level which is regulated at between 82 and 87 ft above P.L.D. The Pacific end has two sets of locks; the Miraflores locks which raise ships from sea level to Miraflores lake in two lifts to an elevation of 54 ft, and the Pedro Miguel locks which raise vessels in one lift from Miraflores lake to Gatun lake level. The channel reaches have widths varying from 500 ft to 1,000 ft.

There are several factors which limit the transit capacity of the Panama Canal. The dimensions of the locks, Gatun Lake regulation levels and natural water availability effectively limit the transition capacity of the Panama Canal. The Panama Canal Commission allows ships with maximum widths of 106 ft for regular transit. The 14.5km long and 153m wide Culebra cut has also imposed restrictions on ship's length. At present ships with 950 ft length can transit routinely.

2.3 Water Management Plan

2.3.1 Basic concepts

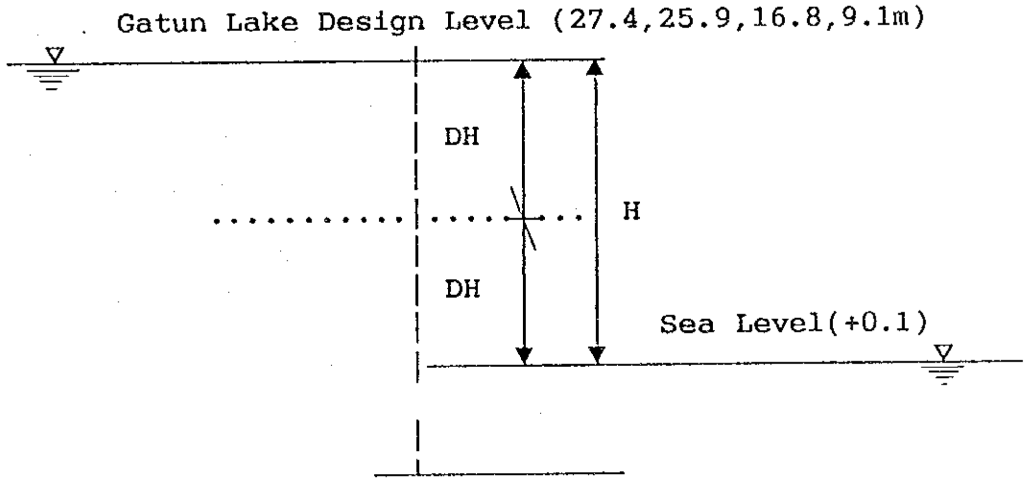
(1) Lockage Water

The volume of water that will be required for one transit through the canal is calculated by the formula given below:

V= BxLx(H/N)x2

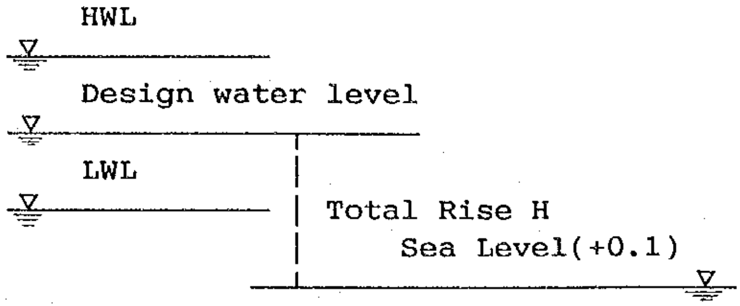
where, V= volume of water required
B= width of lock in meters
L= length " " " "
H= total rise " "
DH= height of one lift "
N= number of lifts (N=H/DH)

A sketch of this concept is presented below for better understanding.



(2) Operational Water Level

The existing operational water level at Gatun lake is between 87 ft(HWL) and 82 ft(LWL). In this study three more cases have been considered. These cases are when Gatun lake operates between 90-87 ft, 57-52 ft and 32-27 ft and are tabulated below.



HWL(m)	27.6	26.1	17.1	9.6
Design(m)	27.4 (90')	25.9 (85')	16.8 (55')	9.1 (30')
LWL(m)	26.1	24.6	15.6	8.1

(3) Simulation Model and Assumptions

In order to evaluate the lockage capability of present usable storage capacity a model for computer simulation has been developed and schematized in the Fig. 2.3.1 and Appendix AP 1-7.

The assumptions that are made for the simulation are listed below:

1. Monthly discharge is calculated by using average discharge of 51 years of record(1933-1983).
2. Gatun lake operates at a design water level of 90, 85, 55 and 30 ft PLD.
3. Madden operates between 200 and 252 ft.
4. Miraflores lake is not taken into consideration.
5. Evaporation loss and municipal water usages are considered.
6. Water for lane reversal, hydraulic assists, solo lockages and water required for floating deep draft ships over the middle sill at Gatun locks are not considered.
7. Water usage for Gatun hydropower generation is not considered.
8. Total usable storage includes the sum of Gatun and Madden lakes.

2.3.2 Study Cases

A mathematical simulation has been performed for 19 different cases. In the simulation the total rise, ship size, width and length of the lock chamber and number of lift were considered as the variables. Applicable combinations of the above mentioned variables were formed and required water per lockage were calculated. The result of the simulation are presented in Table 2.3.1.

Based on the above table, 13 cases were selected and annual water requirements for additional transits with different ship size and water levels were calculated. The result of these calculations are shown in Table 2.3.2.

From the annual water requirement for existing plus additional transits, additional water requirements were calculated. The possible ways to supply this large volume of additional water are by construction of new dams and simultaneous use of pumps for recycling water back into the lake or by using pumps only. Fig. 2.3.2(1) and (2) are presented for easier understanding of this aspect. Fig. (1) shows the case of simultaneous use of new dams and pumps for different increased number of annual transits. The dotted line designates the average discharge of Gatun watershed. The solid lines designate the water requirements for 10,000, 20,000 and 30,000 annual additional transits. The gaps between the dotted line and the solid lines are the amount of water that has to be supplied by pumping for respective number of transits. Fig. (2) is the case of required pump capacities when no new dams are considered. The explanation is the same as for (1). The simulation results of required pump capacities for these cases are presented in Table 2.3.3 and Appendix AP 1-8 – 1-9. It is noteworthy to mention that in the simulation pump capacity has been calculated without putting any limitation on the dam capacity and cumulative spill was counted as water shortage. A different simulation is required in order to know the exact pump capacity with fixed dam capacity and without spill. This case study may be done in the next phase.

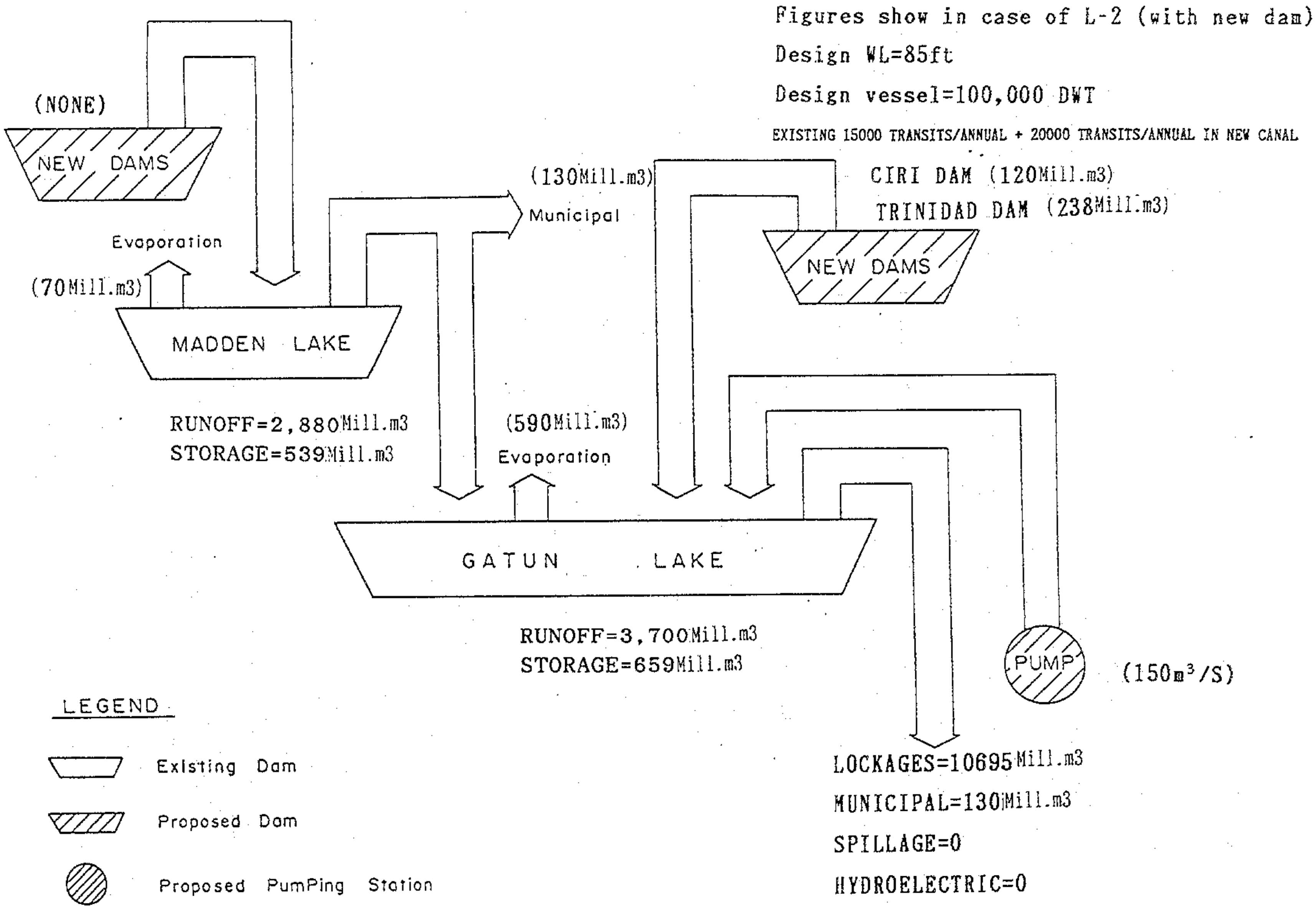
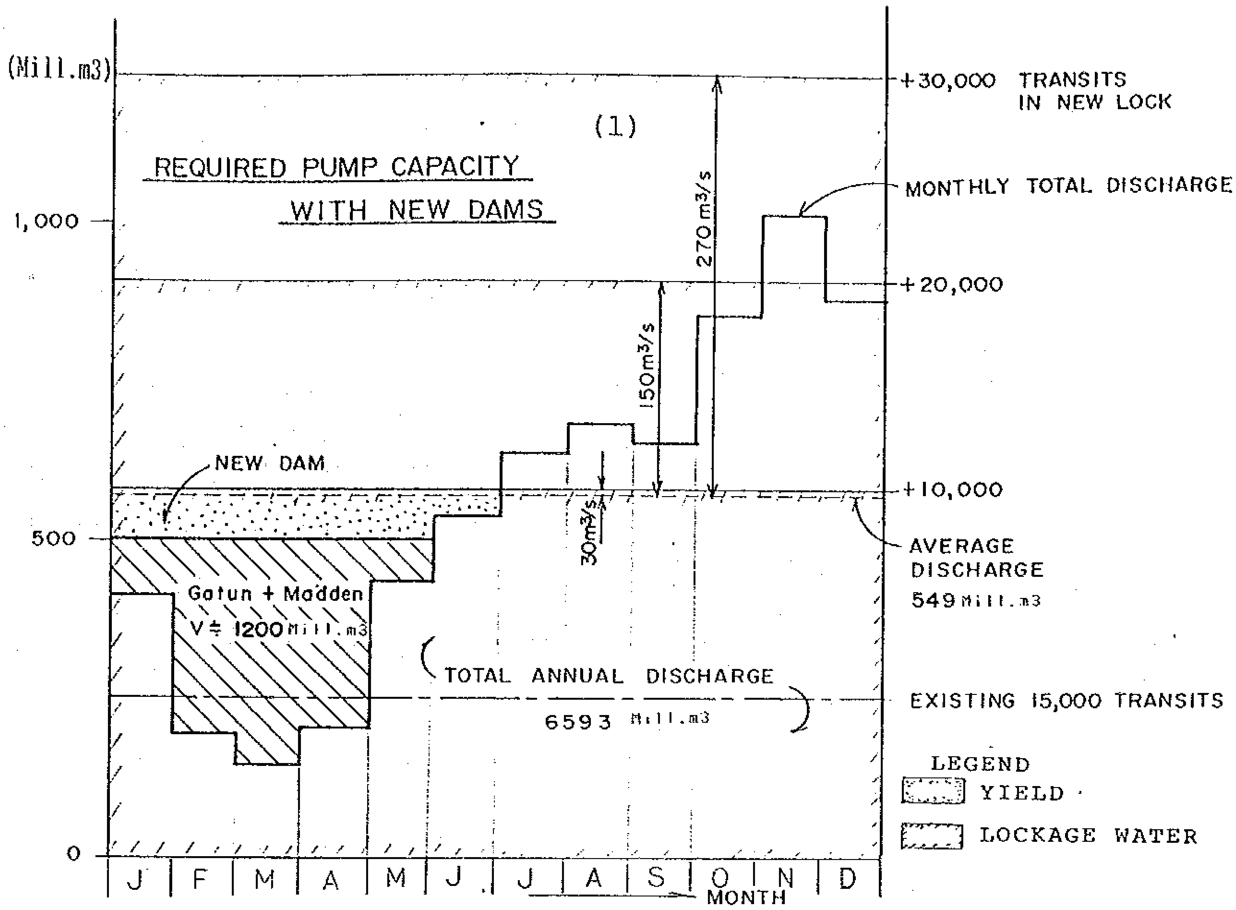
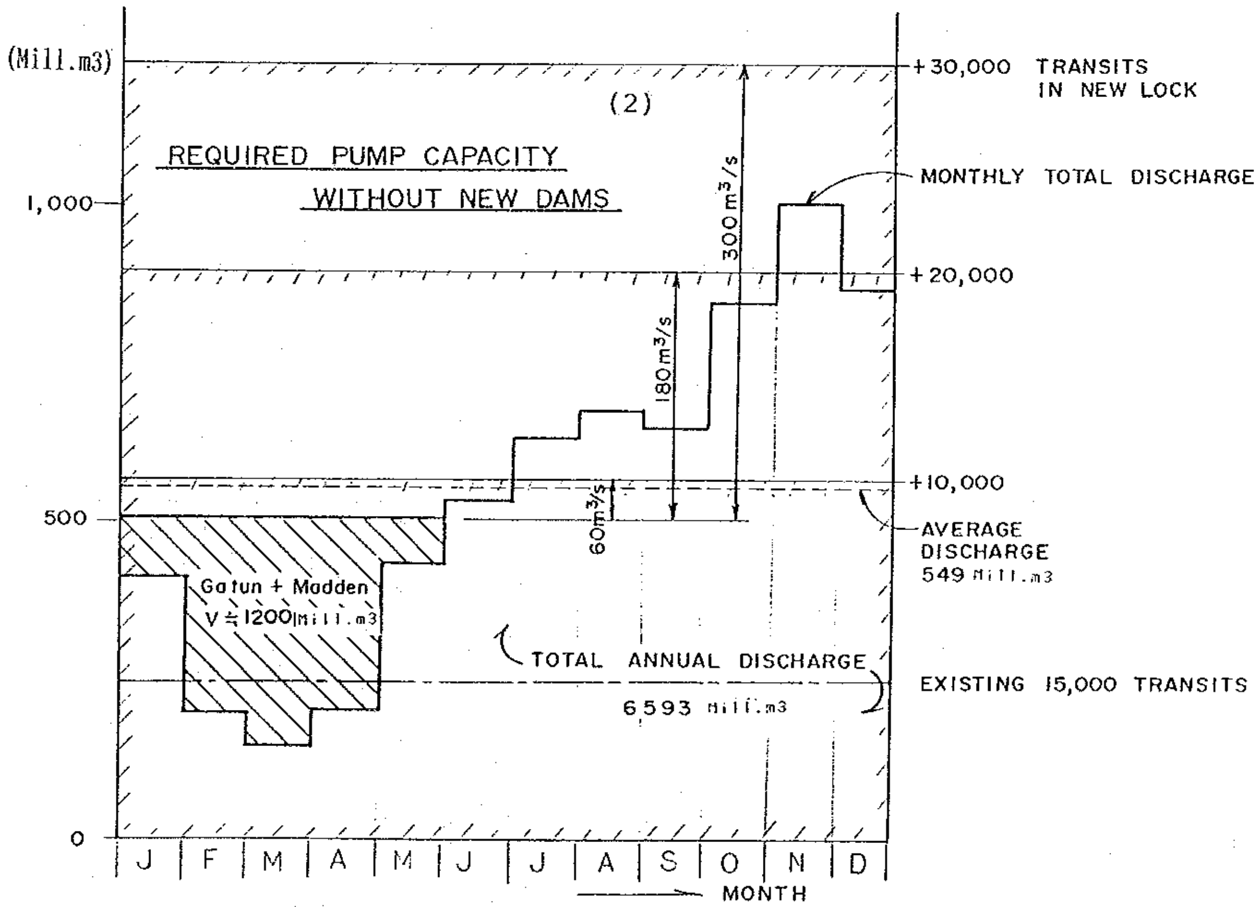


Fig. 2.3.1 Diagram for Water Supply and Usage





Note: NEW DAMS WITHIN GATUN WATERSHED

Fig. 2.3.2 Diagram for Required Pump Capacity
(Case: 85FT 100,000DWT)

Table 2.3.1 Lockage Water for One Transit

CASE	RISE (ft)	SIZE × 10^3 DWT	WIDTH (m)	LENGTH (m)	No. of Lift	Lockage Water (× 10^3 m3)
L-1	90	100	47	319	2	409
L-2	85	100	47		2	387
L-2'	85	100	47		1	774
L-3	55	100	47		1	501
L-4	90	150	54	363	2	535
L-5	85	150	54		2	506
L-6	55	150	54		1	655
L-7	90	250	63	428	2	736
L-8	85	250	63		2	696
L-9	55	250	63		1	901
L-10	85	100	47	319	2	387
L-11	55	100	47		1	501
L-12	30	100	47		1	270
L-13	85	150	54	363	2	506
L-14	55	150	54		1	655
L-15	30	150	54		1	353
L-16	85	250	63	428	2	696
L-17	55	250	63		1	901
L-18	30	250	63		1	485

Note : Existing lockage water per one transit is 197 × 10^3 m^3
(Data Source : PCC Annual Report)

Table 2.3.2 Annual Lockage Water

(UNIT: MCM)

Case No.	L-12	L-15	L-18	L-3,11	L-6,14	L-9,17	L-2,10	L-2'	L-5,13	L-8,16	L-1	L-4	L-7
Water Level (Feet)	30	30	30	55	55	55	85	85*	85	85	90	90	90
Design Vessel ($\times 10^3$ DWT)	100	150	250	100	150	250	100	100	150	250	100	150	250
Existing Lock 15,000 Transits New Lock 0 Transits	2,955	2,955	2,955	2,955	2,955	2,955	2,955	2,955	2,955	2,955	2,955	2,955	2,955
Existing Lock 15,000 Transits New Lock 10,000 Transits	5,655	6,485	7,805	7,965	9,505	11,965	6,825	10,695	8,015	9,915	7,045	8,305	10,315
Existing Lock 15,000 Transits New Lock 20,000 Transits	8,355	10,015	12,655	12,975	16,055	20,975	10,695	18,435	13,075	16,875	11,135	13,655	17,675
Existing Lock 15,000 Transits New Lock 30,000 Transits	11,055	13,545	17,505	17,985	22,605	29,985	14,565	26,175	18,135	23,835	15,225	19,005	25,035

Note : *shows one lift case

Table 2.3.3 Water Balance Table

Case No.		L-12	L-15	L-18	L-3,11	L-6,14	L-9,17	L-2,10	L-2'	L-5,13	L-8,16	L-1	L-4	L-7
Design water level (FT)		30	30	30	55	55	55	85	85	85	85	90	90	90
Design vessel (1,000DWT)		100	150	250	100	150	250	100	100	150	250	100	150	250
Available water for lockage (MCM)		5,500	5,500	5,500	5,500	5,500	5,500	5,500	5,500	5,500	5,500	5,500	5,500	5,500
+ 10,000	Transits lockage water (MCM)	5,655	6,485	7,805	7,965	9,505	11,965	6,825	10,695	8,015	9,915	7,045	8,305	10,315
	Water shortage (MCM)	155	985	2,305	2,465	4,005	6,465	1,325	5,195	2,515	4,415	1,545	2,805	4,815
	Water release from new dam(MCM)	0	0	0	0	0	0	273	297	229	376	245	235	279
	Water pumping (MCM)	155	985	2,305	2,465	4,005	6,465	1,052	4,898	2,286	4,039	1,300	2,570	4,536
	Pump capacity(CU.M/SEC)Without new dam	10	30	70	70	120	200	30	150	70	120	40	80	140
	sets of pump stations	1	1	2	2	2	4	1	3	2	2	1	2	3
	Pump capacity (CU.M/SEC) with new dam	10	30	70	70	120	200	60	180	90	150	60	100	170
	sets of pump stations	1	1	2	2	2	4	1	3	2	3	1	2	3
+ 20,000	Transits lockage water (MCM)	8,355	10,015	12,655	12,975	16,055	20,975	10,695	18,435	13,075	16,875	11,135	13,655	17,675
	Water shortage (MCM)	2,855	4,515	7,155	7,475	10,555	15,475	5,195	12,935	7,575	11,375	5,635	8,155	12,175
	Water release from new dam (MCM)	0	0	0	0	0	0	358	310	292	307	285	288	256
	Water Pumping (MCM)	2,855	4,515	7,155	7,475	10,555	15,475	4,837	12,625	7,283	11,068	5,350	7,867	11,919
	Pump capacity (CU.M/SEC) with new dam	90	140	230	240	340	490	150	400	230	350	170	250	380
	sets of pump stations	2	3	4	4	6	9	3	7	4	6	3	5	7
	Pump capacity (CU.M/SEC) with new dam	90	140	230	240	340	490	180	430	260	380	200	280	400
	sets of pump stations	2	3	4	4	6	9	3	8	5	7	4	5	7
+ 30,000	Transits lockage water (MCM)	11,055	13,545	17,505	17,985	22,605	29,985	14,565	26,175	18,135	23,835	15,225	19,005	25,035
	Water shortage (MCM)	5,555	8,045	12,005	12,485	17,105	24,485	9,065	20,675	12,635	18,335	9,725	13,505	19,535
	Water release form new dam (MCM)	0	0	0	0	0	0	373	339	262	268	251	247	259
	Water pumping (MCM)	5,555	8,045	12,005	12,485	17,105	24,485	8,692	20,336	12,373	18,067	9,474	13,258	19,276
	Pump capacity (CU.M/SEC) without dam sets	180	250	380	390	540	770	270	640	390	570	300	420	610
	of pump stations	3	5	7	7	9	13	5	11	7	10	5	7	11
	Pump capacity (CU.M/SEC) with new dam	180	250	380	390	540	770	300	670	410	600	320	440	630
	sets of pump stations	3	5	7	7	9	13	6	12	7	10	6	8	11
Actual pump head (meter)		(9.0)			(16.7)			(25.8)				(27.3)		

Note :

1) Lockage water includes the water for existing 15,000 transits.
2) Design water level 30'~55' cases have barrier dams.
3) New dam capacity is shown in AP1-9(Water balance simulation).
4) Pump capacity (1 set) = 60 cu.m/sec

2.3.3 Storage Capacity of Gatun and Madden Dam

(1) Gatun Lake

The usable storage depends upon the maximum elevation to which the lake can be filled and the minimum elevation to which the lake can be depleted. The former depends on flood control considerations and the latter on minimum draft restrictions and dam outlets. At present Gatun lake is operated between 26.1 meter and 24.6 meter, the usable capacity is 659 million m3 (see Fig. 2.3.3).

If Gatun lake is operated in its maximum elevation i.e. at 90 ft, reservoir capacity would be increased to 794MCM. Taking the advantage of this surplus amount, the lowest water level can be maintained to a higher level, which will decrease the amount of earth work at the canal bottom.

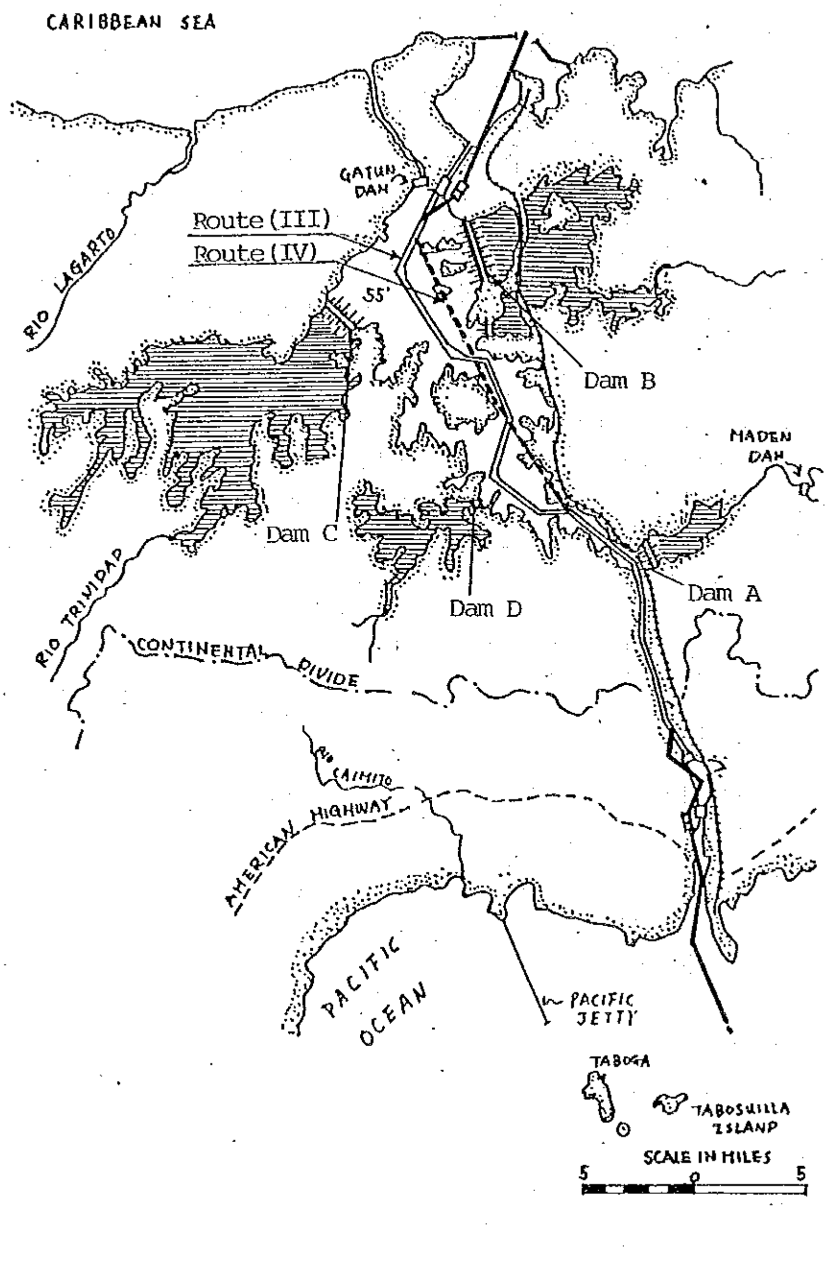
In this study, three more cases have been considered. In the case of 17.1 meter and 9.6 meter Gatun lake HWL levels, barrier dams will be needed to maintain the Gatun lake water level behind the barrier dams at around 25.9 meter(see Fig. 2.3.4).

Table 2.3.4 Storage Capacity at Different Rises

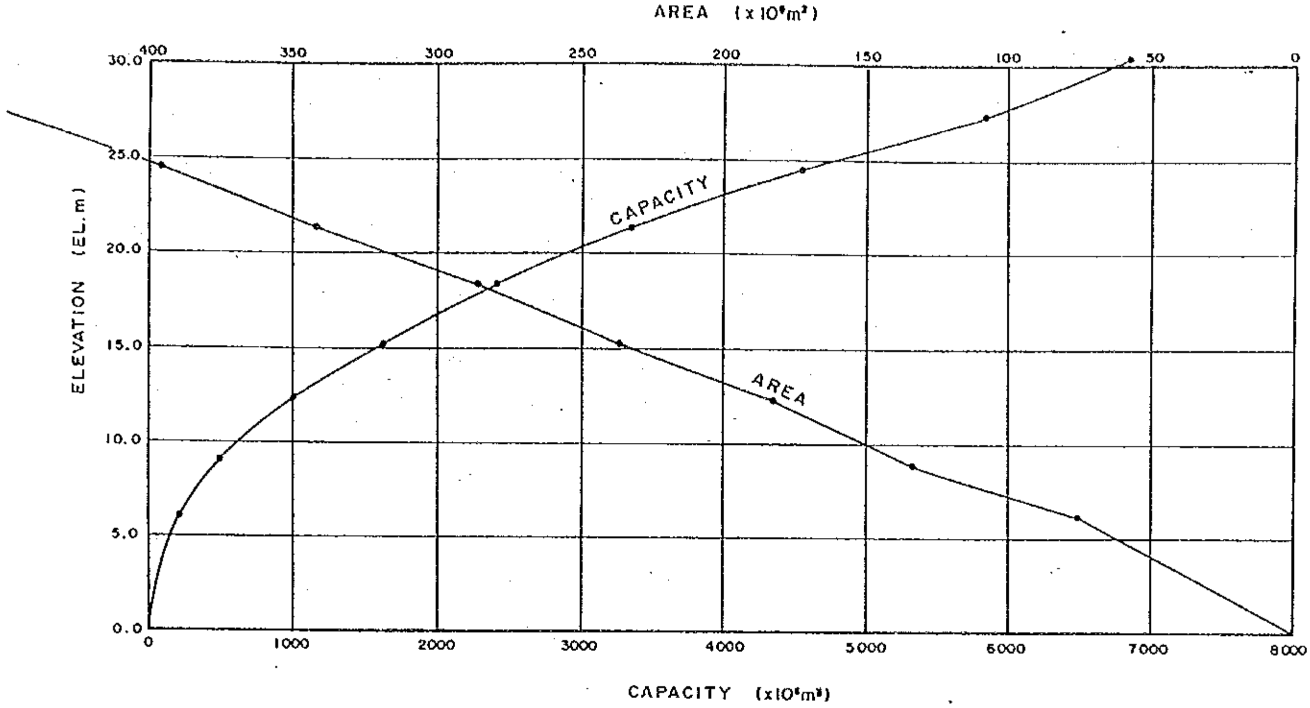
Rise (ft)	L.W.L (m)	H.W.L (m)	Capacity (mil. m3)	Note
90	26.1	27.6	664	
85	24.6	26.1	659	
55	15.6	17.1(26.1)	2,199	Barrier Dam
30	8.1	9.6(26.1)	2,314	ditto

( ) shows Gatun lake water level behind Barrier Dams

Sketches are presented below for locations of barrier dams in Gatun Lake. Details are presented in Chapter 5.



GATUN LAKE AREA CAPACITY CURVE



MADDEN LAKE AREA CAPACITY CURVE

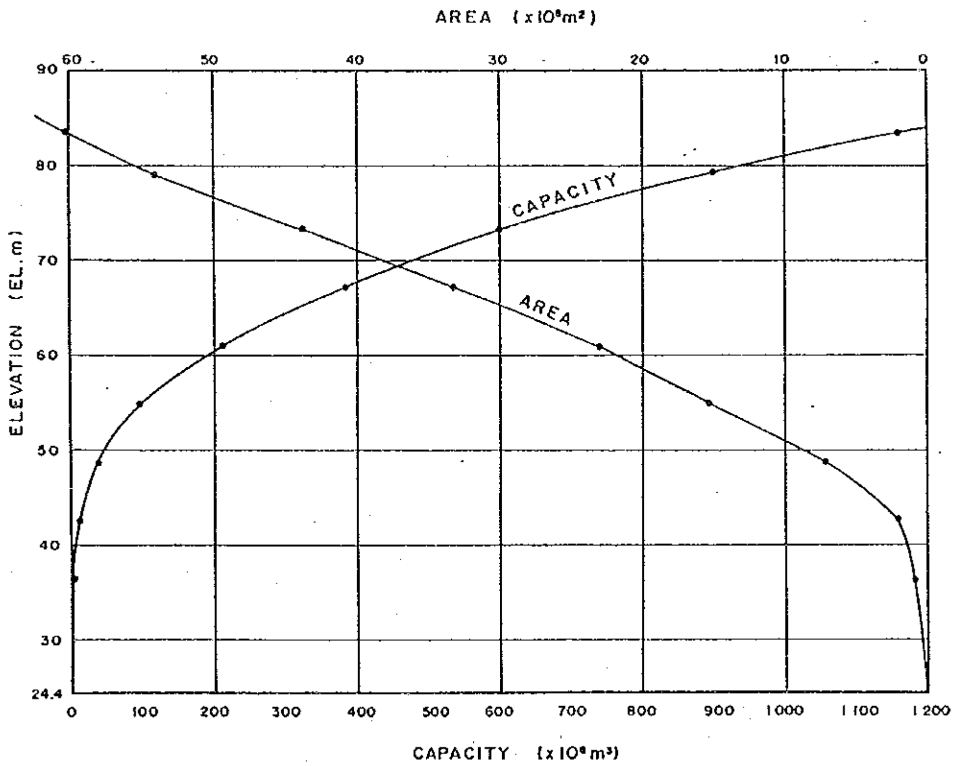


Fig. 2.3.3 Gatun Lake and Madden Lake Area Capacity Curve

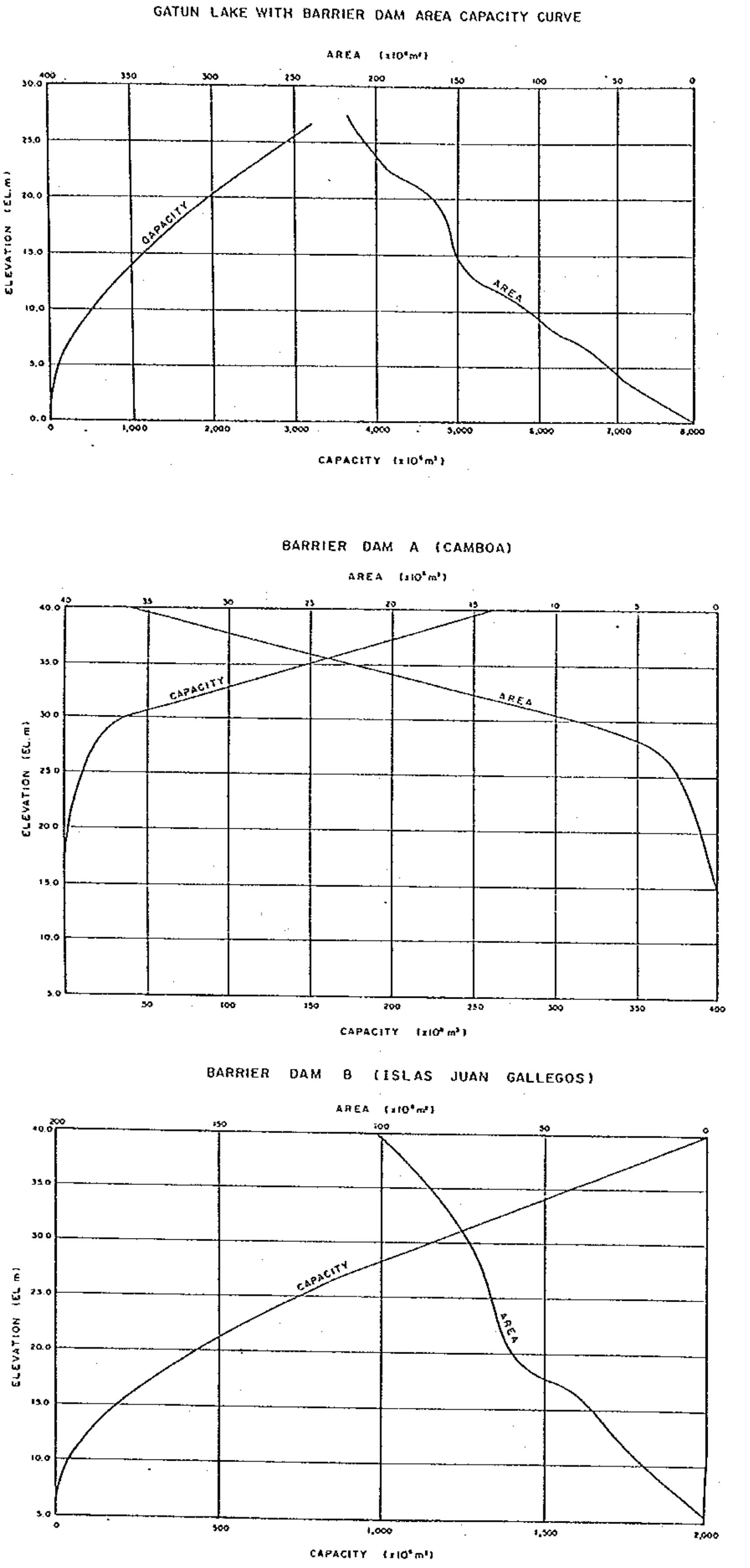
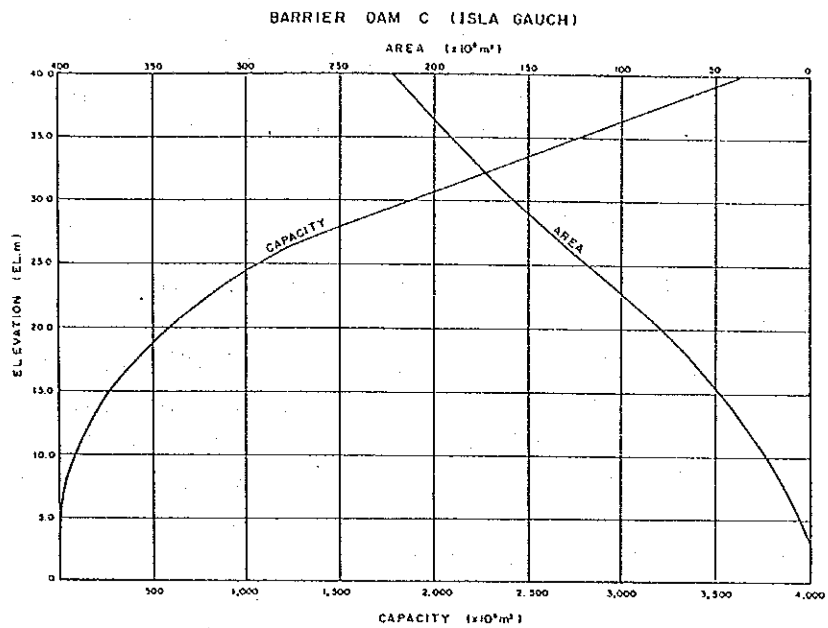


Fig. 2.3.4 (1) Barrier Dam Area Capacity Curve



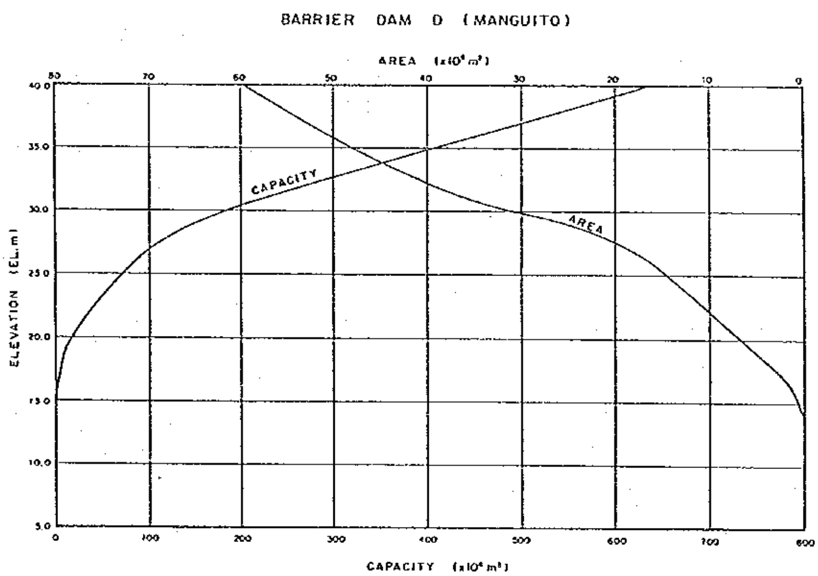


Fig. 2.3.4 (2) Barrier Dam Area Capacity Curve

(2) Madden Lake

The usable storage between elevations 76.2 meter and 61.0 meter is 539 million m3 (see Fig. 2.3.3). Water below elevation 61 meter is reserved for future municipal use in Panama.

2.3.4 Storage Capacity of New Dams

Present usable capacity of the two existing dams (Gatun and Madden) is about 1,200 million m3. From the runoff-data analysis it is found that about 2,700 million m3 of water which is wasted as spill in an average year could be used more efficiently. A calculation has been made of the possible number of additional transits which could be provided by utilization of the wasted water and result of the calculation is presented below.

POSSIBLE TRANSITS BY REMAINING WATER

Design WL(ft)	30	30	30	55	55	55	85	85*	85	90	90	90	90
design Vessel($\times 10^3$)	100	150	250	100	150	250	100	100	150	250	100	150	250
Possible transits	9966	7623	5548	5371	4108	2986	6953	3476	5318	3866	6579	5029	3656

* shows one lift case

Using topographic maps and field survey data it is apparent that there are possibilities for new dam construction within and outside the Gatun watershed. Promising new dam sites within the Gatun watershed are at Pequeni, Trancado, Boqueron, Gatun and Ciri.

However, considering the huge amount of lockage water requirement and watershed yield, total available capacity of these new dams would be limited. The facts are shown in the Fig. 2.3.5(1). From the hydrograph, the average discharge line is drawn and storage capacity to average the hydrograph is calculated to be about 1,363 million m3 (A1+A2). The capacities of Gatun and Madden reservoirs are 1,200 million m3, which means that if new dams are constructed their maximum capacity should be 163 million m3 (1,363-1,200) as shown in the figure. Therefore, new dams of capacity smaller or bigger than the volume of A1 would cause spill or inefficient use of the reservoirs (Fig. 2.3.5(2) and (3)). The simulation results of 13 cases for required new dam capacity with pump are presented in Table 2.3.3. In addition, Low rise cases show no necessity for new dams because the barrier dams capacity is about 2,000 million m3.

A new dam could also be constructed at Indio Dam, outside the Gatun watershed. Due to the long distance, a 10 km diversion tunnel would be necessary to carry the water to the Gatun lake.

Judging from economical conditions, new dam sites are limited. The proposed dam sites, tributaries and capacities are shown in Fig. 2.3.6. and details are presented in Chapter 5.

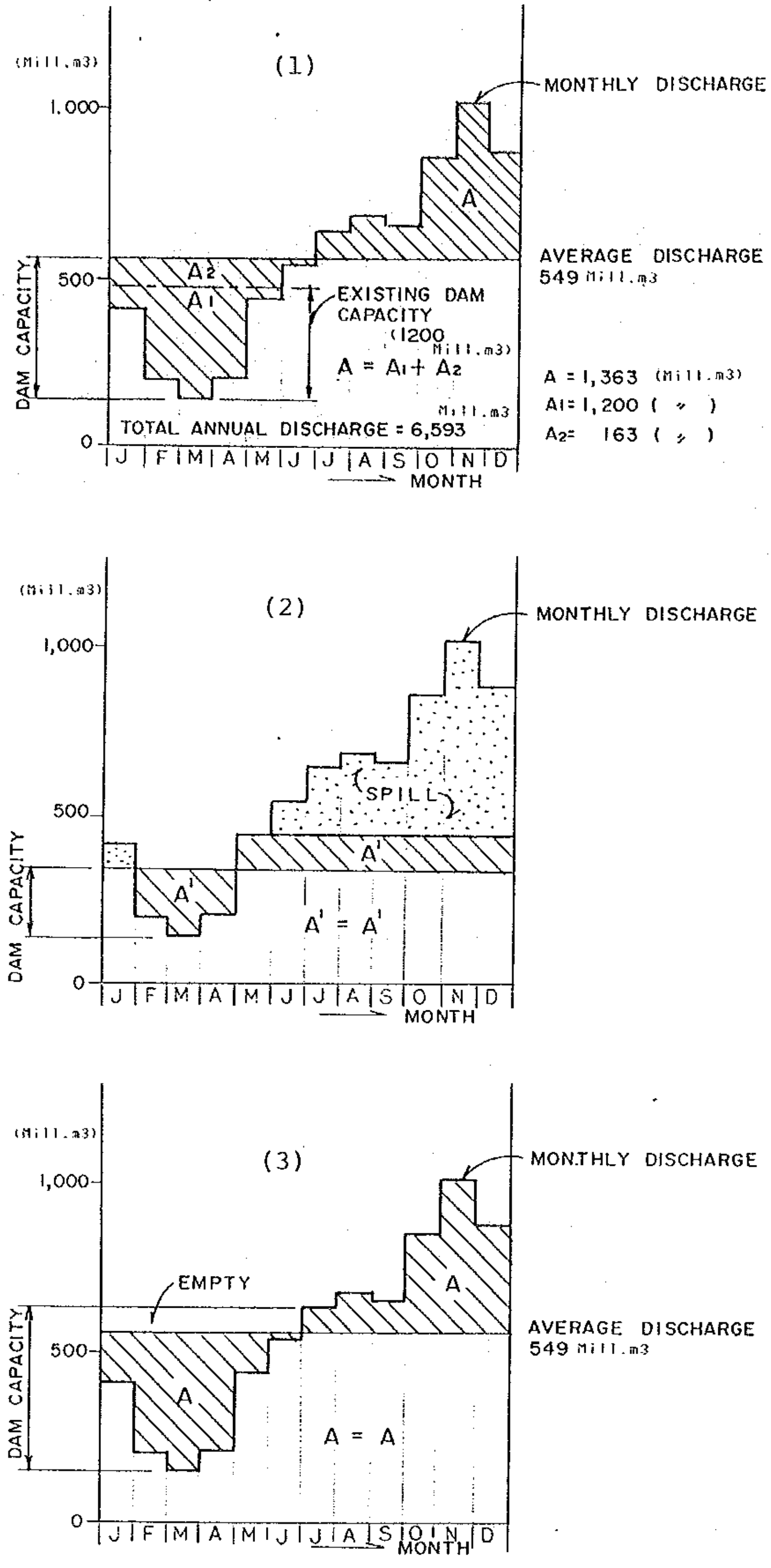
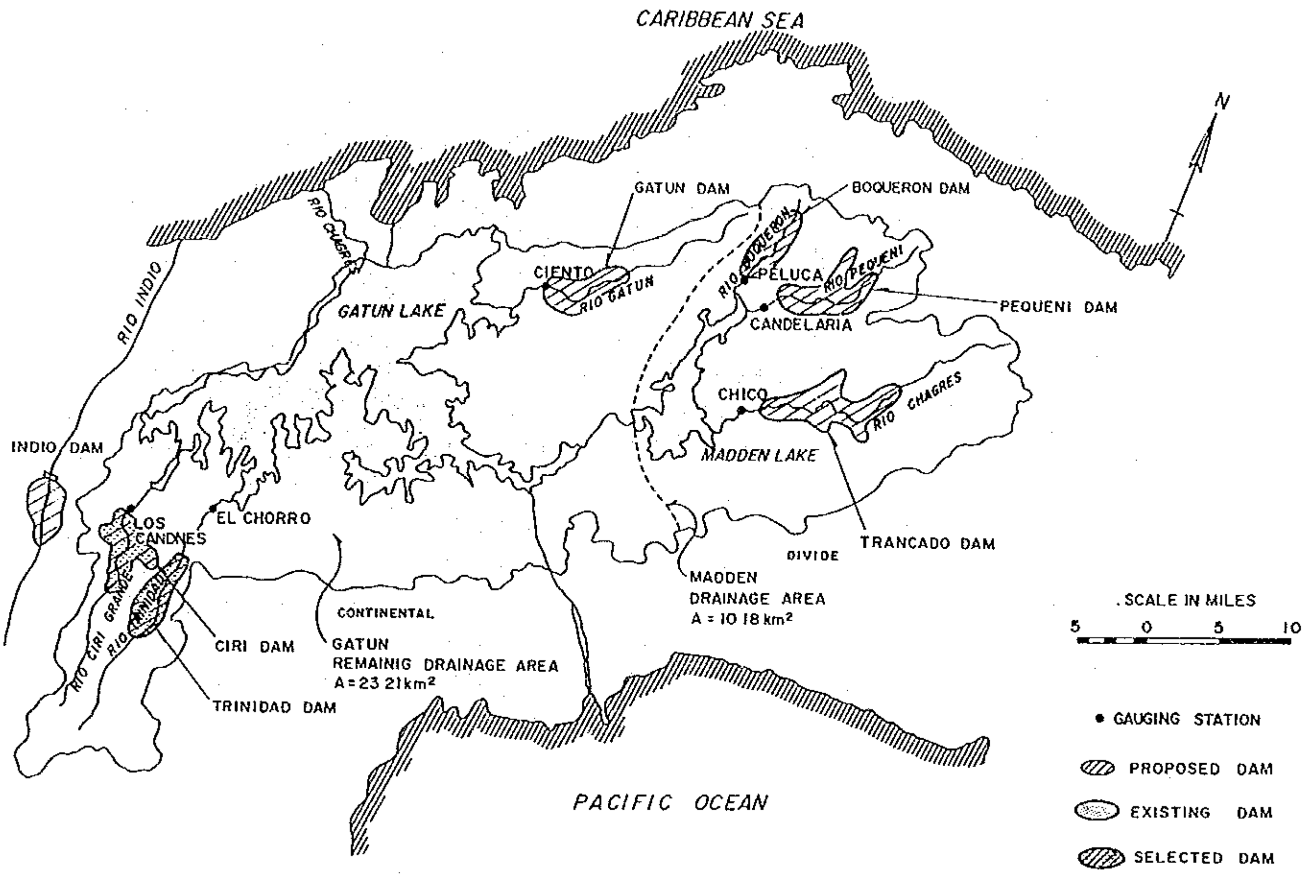


Fig. 2.3.5 Relationship between Discharge and Dam Capacity

LOCATION MAP OF EXISTING DAM AND PROPOSED DAM



Maximum Storage Capacities at Proposed Dam Sites

Dam Name	Tributary Name	Drainage Area(Km²)	Capacity (mill.m³)	Dam Height(m)	Note
Trancado	Chagres	425	---	---	
Pequeni	Pequeni	135	700	130	
Boqueron	Boqueron	95	600	110	
Gatun	Gatun	125	300	100	
Trinidad	Trinidad	165	700	90	Selected
Ciri	Ciri Grande	190	250	70	ditto
Indio	Indio	380	700	90	

Note:

1)Storage capacities(maximum) have been estimated considering topographical condition only.

2)Storage capacity of Trancado dam have not been estimated due to lack of topographical maps.

Fig. 2.3.6 Proposed Dam Sites and Storage Capacity