6. MASTER PLAN FOR CHANNEL IMPROVEMENT

CHAPTER 6. MASTER PLAN FOR CHANNEL IMPROVEMENT

6.1 General

This chapter describes the channel improvement plan for the vessel navigation, in viewpoint of efficient operation and maintenance including minimization of dredging activities. The technical aspects of master planning such as basis of channel improvement, methods of channel improvement, dredging improvement and preliminary cost estimates for the proposed project are discussed in sections from 6.2 to 6.5. The institutional and organizational studies, and environmental impacts are explained in sections 6.6 and 6.7. Moreover, economic and financial evaluation of the project from the standpoint of national economy and selection of priority projects are discussed in sections 6.8 and 6.9.

6.2 Basis of Channel Improvement

Since the Rio Grande was opened for the waterway navigation in 1950s, enormous efforts have been spent to maintain the navigation channel. Due to the heavy sediment discharges from the Orinoco River basin, the certain sections of channels in the river delta are continuously required more than 8 million m^3 of annual dredging works in total. In addition, the long shore current along the coast transports and accumulates the sediment together with sediment discharges of the Orinoco causing 10 million m^3 of dredging work annually in the navigation channel at the river mouth. The operation and maintenance of navigation channel specially dredging works has become a heavy burden to the development of the waterway transportation.

Therefore, sufficient channel improvement is desired to minimize the dredging activities and to guarantee the navigation safety as well. As for the channel improvement defined above, a combination of structural and non-structural measures must be employed along with an efficient method for dredging activity. The concept for the channel improvement discussed in this chapter is given in the Table 6.2.1 below.

Table 6.2.1 Concept for the Channel Improvement

<table>
<tr><td>Present Condition</td><td colspan="3">- Difficulty in huge amount of dredging work required
- Difficulty in provision of target depth for navigation</td></tr>
<tr><td rowspan="2">Issues</td><td>Operation and Maintenance</td><td colspan="2">Navigation channel improvement</td></tr>
<tr><td>Improvement of Dredging methods</td><td>Structural</td><td>Non-structural</td></tr>
<tr><td>Objectives</td><td>Provision of required depth</td><td>Reduction of dredging volume with river structure</td><td>Reduction of dredging volume without river structure</td></tr>
<tr><td>Measures</td><td>- Increase of dredging time
- Acquire a flat bed leveling the uneven channel bottom
- Prevent the return of disposed dredged materials into the channel</td><td>River structures to confine the flow to a narrow width and increase the discharge in the navigation channel.</td><td>Usage of deeper route for navigation</td></tr>
</table>

The Rio Grande channel was selected as the most suitable navigation route among all, such as Manamo and Macareo routes, taking into consideration of present and future cargo demands and efficient shipping systems as well as prevailing channel characteristics, improvement and maintenance costs for navigation as discussed in Chapter 5. Therefore, the channel improvement in this study is focused in Rio Grande route.

In addition, according to the forecast for future requirement, maximum size of the vessel needs to be used, would be 65,000 DWT class of Panamax type same as the present allowable size. Therefore, the depth to be maintained in the channel improvement is adopted to be the same with the present navigation criteria as follows:

- 10.2m (34 feet) below LWL(NAB) in Rio Grande (Inland channel).
- 13.2m (44 feet) below LWL(NAB) in Boca Grande (Outer channel).

In flood seasons, Panamax class vessels can navigate with full load (12.8 m draft) in the above proposed channel. In dry seasons, however, since the waterlevel goes down to LWL the smaller vessel types than Panamax and/or adjusted load method, have to be selected.

6.3 Channel Improvement Measures

In order to reduce the maintenance dredging works for navigation in the Rio Grande, alternatives of channel improvement are discussed and the most effective structural and non-structural measures are proposed in this section.

6.3.1 Dredging Sections

At present, in the Rio Grande channel, it can be identified that there are seven sections where dredging activities are required for the navigation of Panamax type of vessels, as shown in Fig. 6-3-1 and in the Table 6.3.1 below.

Table 6.3.1 Present Dredging Sections

Section Name	Chainage (km)	Dredging Length (km) (Section Length in km)	Annual Dredging Volume (million m^3)
(1) San-Felix	330 - 339	8 (9)	1.61
(2) Aramaya	306 - 322	4 (16)	1.04
(3) Guarguapo-Barrancas-Ya-Ya	246 - 278	19 (32)	3.82
(4) Araguaito	222 - 246	1 (24)	0.10
(5) Sacupana-Guasina	182 - 207	16 (25)	1.51
(6) Curiapo	93 - 115	2 (22)	0.40
(7) Boca Grande	0 - 78	78 (78)	10.00
TOTAL			18.48

Note: The dredging volume represents the average dredging between 1965-1972.

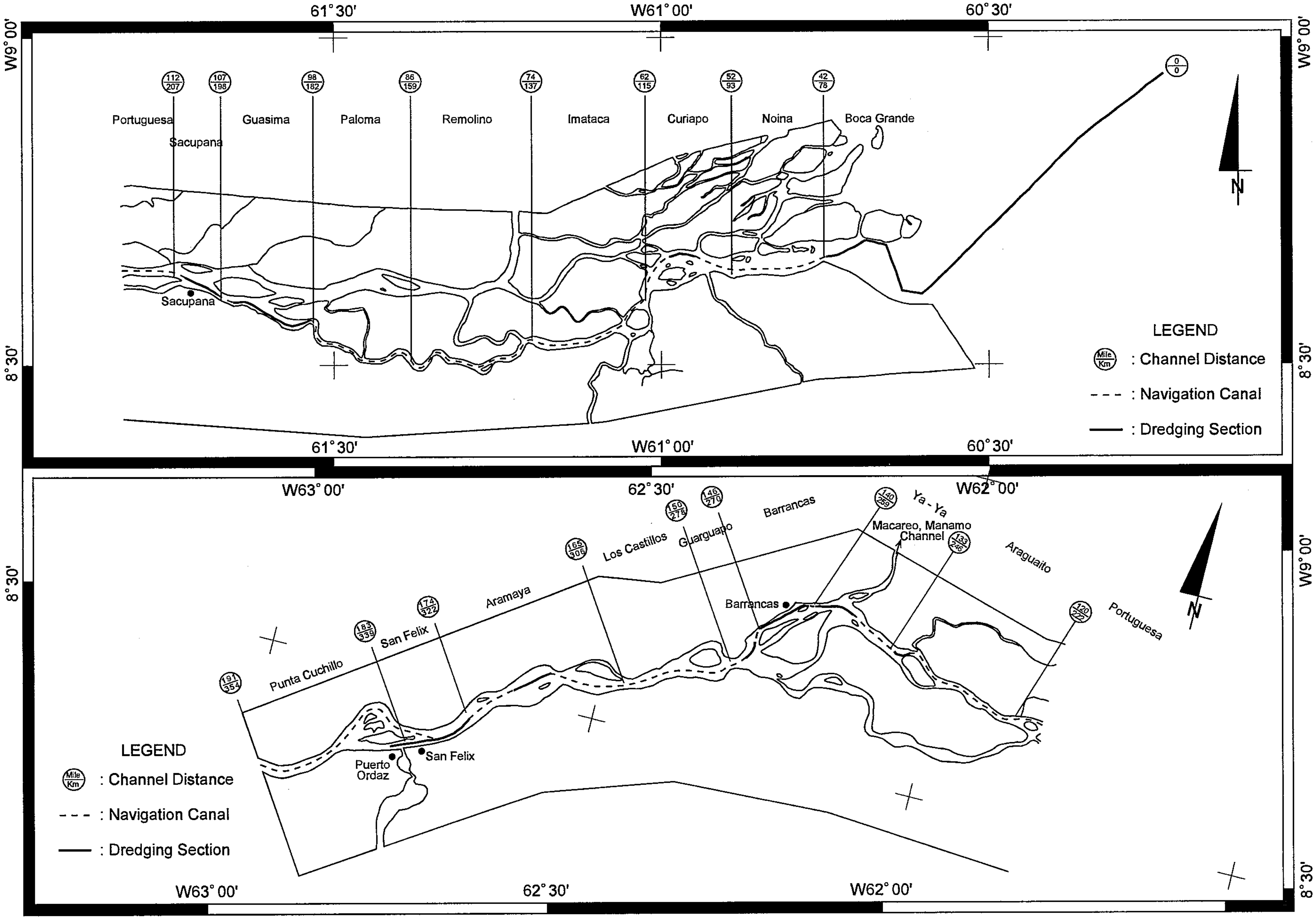


Fig. 6-3-1 Dredging Sections in the Rio Grande Channel

Based on the similar hydraulic characteristics, the dredging sections can be categorized into four groups as follows;

(1) San Felix and Aramaya sections

In these areas, cross sectional width is quite larger than the average river width. Therefore, flow depth is very shallow due to the lower bed-shear-force of flow.

(2) Guarguapo-Barrancas and Sacupana-Guasina sections

In these reaches, river has several diversion branches that have been formed due to the development of large islands in the river channel. Therefore, discharge of the river is divided into all these branches, causing the flow intensity in the navigation channel less significant.

(3) Araguaito and Curiapo sections

These places are located at the transition portion of meandering bends. Outer bank in the meandering bend, that is subjected to concentrate the water flow, has a higher depth. In transition portion, however, the depth becomes remarkably shallow as water flows through a wide area.

(4) Boca Grande section

The bed-shear-force of flow at the river estuary is drastically reduced due to the expanded flow width. Hence, the wash loads from the Orinoco River and sediment with the long shore currents from south coast are accumulated and the depth becomes shallow in this section.

Since huge bed-loads of 15.0 million m^3 per year are discharged in the Orinoco River, the dredged channel in the river section is completely filled at the end of every rainy season. In the Boca Grande, however, it is experienced that annual deposition is only 1.0 m to 1.5 m in the previously dredged channel, although sedimentation occurs throughout the year from the river and the coast. It has also experienced that total annual maintenance dredging volume is almost same in every year.

6. 3. 2 Possible Measures and Selection of Sections for Structural Measures

Specific characteristics of the Rio Grande channel, which are of prime importance prior to take the structural measures, are verified by the one-dimensional (1-D) numerical analysis as shown in the previous chapter 3.2. A prominent inverse relationship between water depth and channel width is given as a remarkable tendency in the channel. The water depth is shallow in the reach where the channel is wide, contrarily deep in the narrow reach. Based on these characteristics of the river flow structural measures are determined to acquire a larger water depth either by confining the flow to a narrow width or increasing flow discharge in the navigation channel.

Two types of measures, "point structural measures" targeting specific places and "longitudinal structural measures" along the channel can be envisaged as given in Table 6.3.2. The schematic diagrams for these measures are also shown in Fig.6-3-2.

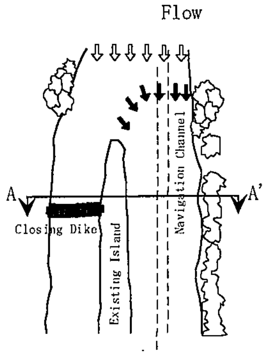
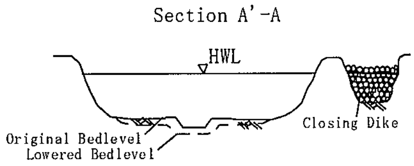
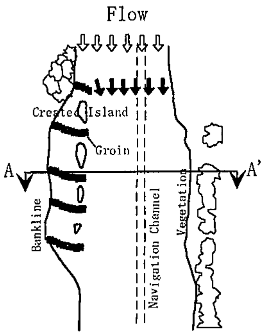
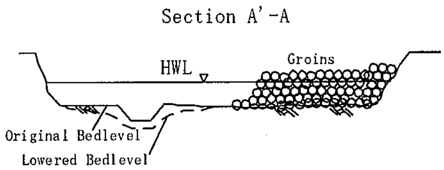
Table 6.3.2 Possible Channel Improvement Measures

Possible Measures		Main Features
Point Structure	1. Closing Dike for secondary channels	A quite effective **point structure** to control the discharge or increase the flow intensity along the main channel.
Longitudinal Structures	2. Groins	**Longitudinal structures (Type-1)** located basically perpendicular to the bank line to confine the channel width and to increase the flow intensity along the navigation channel.
		Longitudinal structures (Type-2) basically perpendicular to the bank line, located at the upstream of a bifurcation, to change the flow direction into the navigation channel. This type of groins is effective only for steep the channel slopes.
	3. Training dikes	**Longitudinal structures** located basically parallel to the bank line to confine the channel width and to increase the flow intensity along the navigation channel where secondary flow is dominant.
	4. Bed load traps	**Longitudinal structures** located along the navigation channel to concentrate sedimentation in to a limited area and avoid sedimentation in the navigation channel. Bed load trap is popular in harbor and port areas.

As the Orinoco river is a huge river in terms of scale and discharge, large scale structural measures along the longitudinal direction of the channel would not be economically feasible as well as unpractical due to the lengthy dredging reaches. Moreover, in a mild slope channel, the longitudinal structures such as groins Type-2 would not sufficiently increase the discharge in the main channel to provide the required navigable depth. Hence, appropriate structural measures should be focused as point measures targeting specific places.

The possible structural measure to reduce the maintenance dredging at the Boca Grande section would be a training dike or diversion channels of approximately 70 km, equivalent to the present dredging length. This type of huge structures and works would obviously cost more than the current expenditure for maintenance dredging. In addition, the impacts of the measures would be less significant since the reduction of major sources of sediment transport by long shore currents and turbulence of wave breaking, could not be expected by the measures.

Fig.6-3-2 Schematic Diagrams of Possible Channel Improvement Measures

<table>
<tr><th>Type</th><th>Plan View</th><th>Cross Section</th></tr>
<tr><td>Closing Dike for secondary channels(Discharge Control Dike)</td><td>
</td><td>
</td></tr>
<tr><td>Groins (Type 1)</td><td>
</td><td>
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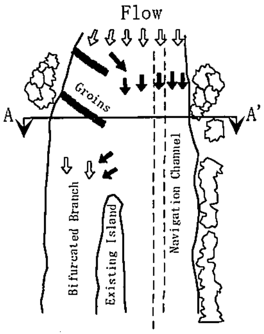
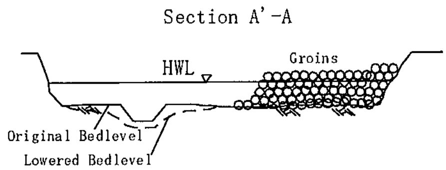
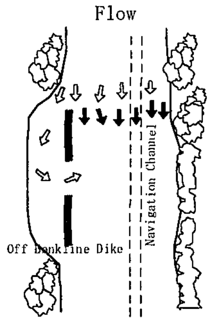
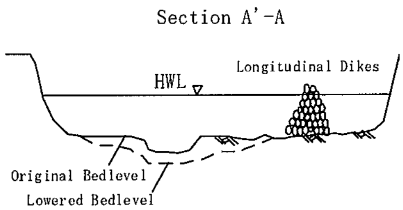
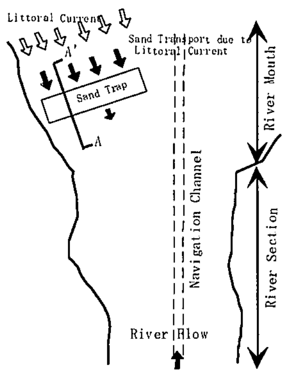
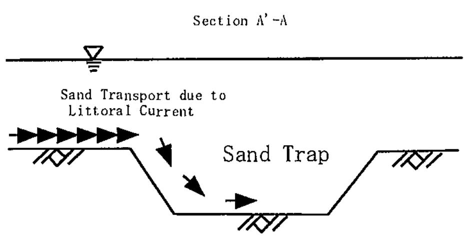
<tr><td>Groins (Type 2)</td><td>
</td><td>
</td></tr>
<tr><td>Training Dikes(Off Bankline Dikes)</td><td>
</td><td>
</td></tr>
<tr><td>Bed Load Traps</td><td>
</td><td>
</td></tr>
</table>

At San Felix section, the river is branched off into two channels and one branch accessing to Puerto Ordaz port requires maintenance dredging, although the other branch is deep enough. As a possible structural measure to lower the channel bed accessing to the port, closing of the branch for navigation route would be envisaged, however, it would require huge construction cost for a long closing dike compared to the maintenance dredging cost.

Similarly, at the other sections of Araguaito and Curiapo, it is not economical to apply the structural measures, as the cost of maintenance dredging activities is less than that of huge works of the measures.

Therefore, it is recommended that maintenance dredging activities should be continued efficiently in these four sections; Boca Grande, San Felix, Araguaito and Curiapo where structural measures will not be proposed.

The remaining 3-sections Aramaya, Guarguapo- Barrancas - Ya-Ya and Sacupana – Guasina are selected for channel improvement by means of possible point structural measures. The environmental impacts and future maintenance requirements are also needed to be assessed.

6.3.3 Alternatives for Structural Measures

Owing to the existence of diversion channels at the 3-sections; Aramaya, Guarguapo-Barrancas-Ya-Ya, and Sacupana-Guasina which are selected for channel improvement, it is envisaged as the possible alternative measures, to close the certain diversion branches by dikes for improving flow intensity and lowering bed elevation in the branch of navigation channel.

The alternatives of structural measures for each of the three sections selected are described below.

(1) Aramaya section:

The river is very wide and shallow in this reach. As Alternative A-1, close the diversion branch by constructing a closing dike was conceived in order to increase the discharge in the navigation channel. (Fig.6-3-3 (1/3))

(2) Guarguapo-Barrancas-Ya-Ya section:

In this section, three islands that exist in the river course, divert the discharge. In order to increase the discharge in the navigation channel, therefore, three alternatives were envisaged as Alternatives B-1, B-2 and B-3 by means of dikes closing diversion channels. However, increasing discharge in the navigation channel by this measure may cause severe river bank erosion. Therefore, together with each alternative of closing dike, the revetment for bank protection is considered at the reach near Barrancas. (Fig.6-3-3 (2/3))

(3) Sacupana-Guasina Sections:

In this area also, the flow intensity in the navigation channel is lowered due to the distribution of discharge to several branches of channel formed by large islands in the river course. In order to increase the flow intensity in the navigation channel, the closing dikes as Alternatives G-1 and G-2 are conceived. (Fig.6-3-3 (3/3))

The alternatives at these three sections are summarized in the Table 6.3.3 below.

Table 6.3.3 Alternatives of Structural Measures

Section	Alternative	Main Facilities
Aramaya	A-0	No Facility (Maintain the present condition)
	A-1	Closing Dike; L=3,000 m
Guarguapo-Barrancas-Ya-Ya	B-0	No Facility (Maintain the present condition)
	B-1	Closing Dike; L=1,000 m and Revetment; L=2,000 m
	B-2	Closing Dike; L=2,200 m and Revetment; L=2,000 m
	B-3	Closing Dike; L=1,000 m and Revetment; L=2,000 m
Sacupana-Guasina	G-0	No Facility (Maintain the present condition)
	G-1	Closing Dike; L=1,700 m

In order to identify the effect of each alternative, the bed elevation change in the dredging section was simulated by utilizing one-dimensional (1-D) numerical model.

As the result of simulation, the Alternative B-2 for Guarguapo - Barrancas - Ya-Ya section is confirmed as the most effective measure to lower the bed elevation of navigation channel, owing to the fact that currently the 40 % of the main stream discharge flowing in the Tortola channel is distributed to the other channels and the discharge of the navigation channel increases almost twice. It can be clearly shown, however, that Alt. B-1 and B-3 are not so effective as most of the diverted discharge will flow into the wider channels such as Tortola channel, not to the navigation channel. Alt.B-1 could increase the depth in the Guarguapo section, however, the downstream sections such as the Barrancas and Ya Ya sections would be shallower than the present condition due to the lower discharge in those sections.

For Aramaya and Sacupana-Guasina sections, A-1 and G-1 require large-scale structures. Hence the construction cost is high and it is not economical.

Table 6.3.4 shows the summary of comparison of all the envisaged alternatives for channel improvement. For the detailed results, refer the Supporting Report to Chapter 6.

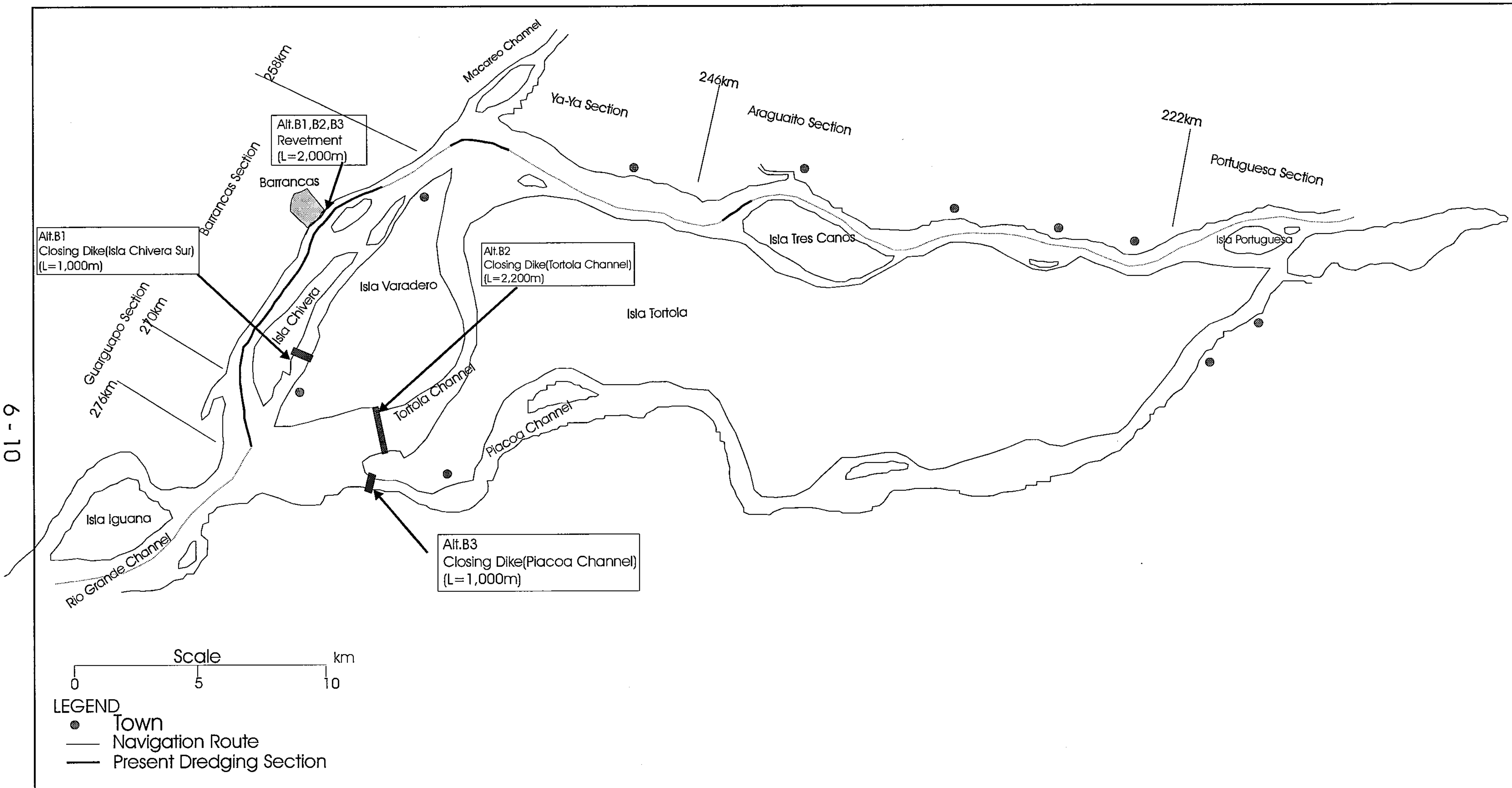


Fig.6-3-3(2/3) LOCATION OF ALTERNATIVES FOR CHANNEL IMPROVEMENT

THE STUDY ON INTEGRATED RIVER IMPROVEMENT OF THE ORINOCO RIVER IN THE REPUBLIC OF VENEZUELA

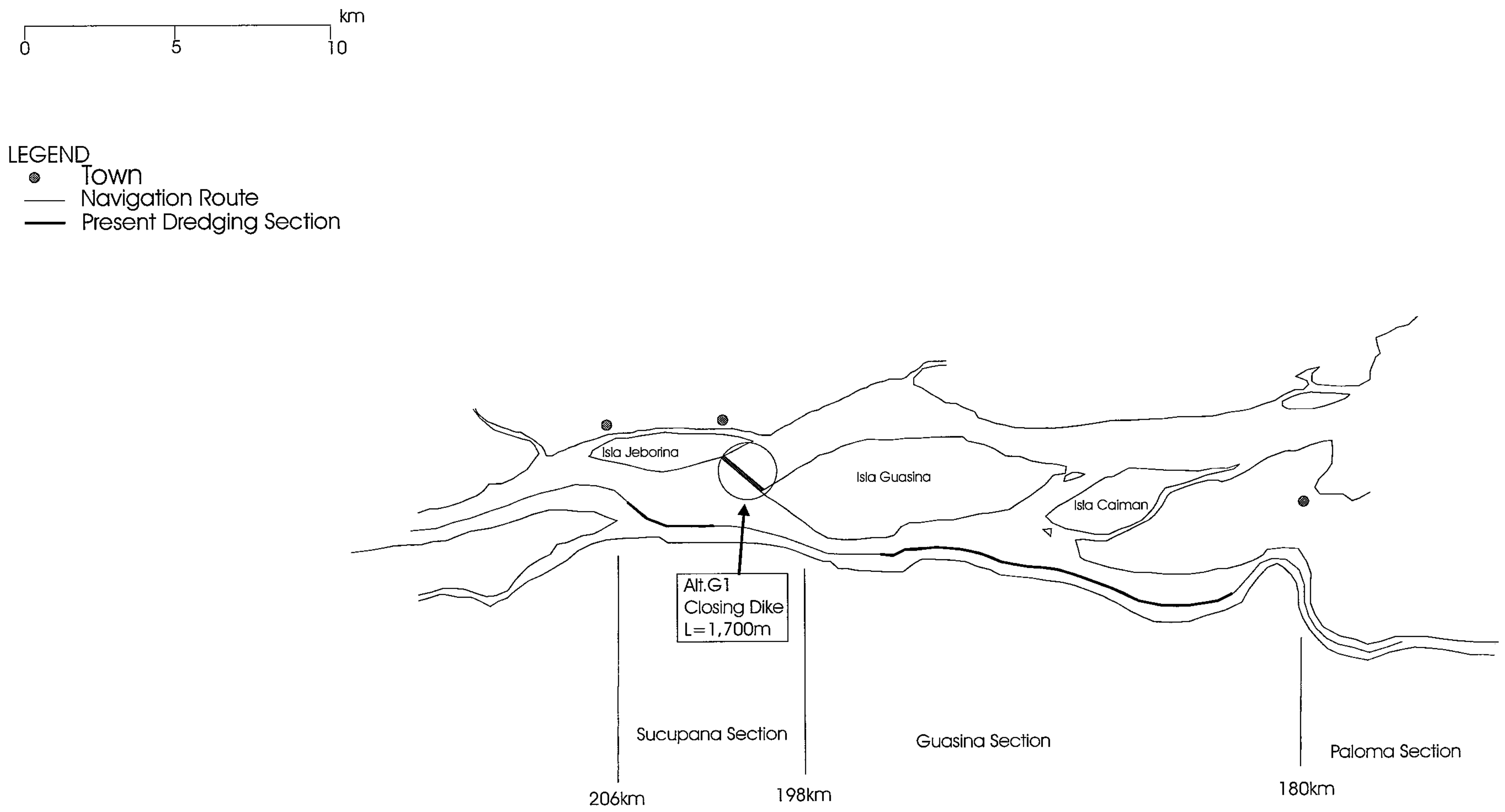


Fig.6-3-3(3/3)	LOCATION OF ALTERNATIVE FOR CHANNEL IMPROVEMENT(GUASINA SECTION)
	THE STUDY ON INTEGRATED RIVER IMPROVEMENT OF THE ORINOCO RIVER IN THE REPUBLIC OF VENEZUELA

Table 6.3.4(1/3) Comparison of Alternatives for Channel Improvement

Section	Present Condition and Reason of Sedimentation	Alternative No.	Alternative Name / Detailed description	Hydraulic Effect: Maintenance Dredging Volume (m3/year)	Hydraulic Effect: Other	Environmental Effect	Cost: Initial	Cost: O/M	Economic Evaluation
Aramaya(306-332km)	Wide width section in the upstream straight reach of Rio Grande Channel. In the right side of the channel, a island is under forming. From the configuration of the upstream and downstream sections, in the near future a deep water path will be formed in the left side resulted from the development of the right side.	A-0	No countermeasure Expecting a deep water path is formed at the left side of channel	1,040,000		Nothing special	0	73	×
		A-1	Non-submerged Closing Dike L=3,000 m from the head of Isla Mucura to the right bank	0		Stagnation in the downstream of the dike(9 km2)	61	15	×

Note: Cost: US$ in million (Rough estimate)

Table 6.3.4(2/3) Comparison of Alternatives for Channel Improvement

Section	Present Condition and Reason of Sedimentation	Alternative No.	Alternative Name Detailed description	Hydraulic Effect		Environmental Effect	Cost		Economic Evaluation
				Dredging Volume (m3/year)	Other		Initial	O/M	
Guarguapo–Barrancas–YaYa (246 km–278km)	Historically these sections was suddenly expanded as the head of the Orinoco Delta. Afterward several islands were formed rigidly, resulting in 3 branches among the islands. The discharge of each branch became small , hence shallow cross sections are formed.	B-0	No Countermeasure -	3,920,000		Nothing special	0	275	×
		B-1	Non–submerged Closing Dike in Isla Chivera Sur L=1,000 m Dike intending to increase the discharge in the canal+Revetment L=2,000m	2,936,000	The closed branch is confluensing the main stream again downstream, so that the discharge will decrease due to the upstream closing.	Closing of the south side of Isla Chivera	39	218	×
		B-2	Non–submerged Closing Dike in Tortola Channel L=700 m Dike intending to increase the discharge in the canal + Revetment L=2,000m	100,000	40 % of the main stream discharge will be distributed into the remaining channels.	Closing of Tortola channel	70	42	
		B–3	Non–submerged Closing Dike in Piacoa Channel L=700 m Dike intending to increase the discharge in the canal + Revetment L=2,000m	2,480,000	The discharge in Piacoa Channel will go to the Tortola, not to the main stream.	Closing of Piacoa Channel, affect the downstream towns	47	190	×

Note: Cost: US$ in million (Rough estimate)

Table 6.3.4(3/3) Comparison of Alternatives for Channel Improvement

Section	Present Condition and Reason of Sedimentation	Alternative No.	Alternative Name / Detailed description	Hydraulic Effect: Dredging Volume (m3/year)	Hydraulic Effect: Other	Environmental Effect	Cost: Initial	Cost: O/M	Economic Evaluation
Sacupana-Guasina(182-208 km)	The basic situation is same as the Guarguapo-YaYa Sections. Different from the Guarguapo-YaYa Sections, the diverted branch is confluensing the main stream near the Boca Grande, so that the closing of a branch does hardly affect the downstream section. Closing is the most effective.	G-0	No countermeasure / -	1,510,000		Nothing special	0	106	×
		G-1	Non-submerged Closing Dike / L=1,700 m connecting between Isla Jeborina and Isla Guasina	0		Nothing special	42	16	×

Note: Cost: US$ in million (Rough estimate)

6.3.4 Structure Types

Three types of closing dike are envisaged for structural alternatives as follows (Fig.6-3-4):

- Upright dike composed of steel pipe piles with sand fill
- Mound dike composed of rubble stone with armor block
- Composite dike with caisson and rubble foundation

As shown below Table 6.3.5 "Comparison of the Structure Types for Closing Dike", the mound dike type is proposed in this study taking into the consideration construction and maintenance easiness, lower cost, etc.

Table 6.3.5 Comparison of Alternatives for Closing Dike Structure

Item	Upright Dike		Mound Dike		Composite Dike	
Construction Method	Slightly difficult	Steel pile of 50m long to be imported	Easy	Local material to be used	Possible	Complicated in construction and manufacturing of caisson
Construction Cost	Medium		Cheap		Expensive	
Operation and Maintenance for Bed Scoring	Possible to maintain	Against scoring, it can be stable by connecting the top of piles	Easy to maintain	It can be added for maintenance of rubble stone and armor block	Difficult to maintain	It is required to reconstruct, in case of scoring failure

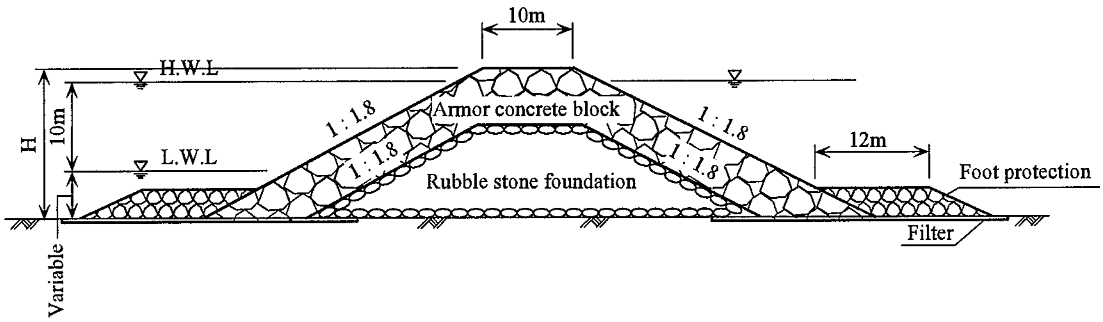
6.3.5 Proposed Structural Measure

The alternative B-2 is only adopted and recommended as the effective structural measure to reduce maintenance dredging works for the section of Guarguapo-Barrancas-Ya-Ya. The work component of proposed channel improvement consists of construction of closing dike and bank protection as shown in Fig. 6-3-5 and Table below.

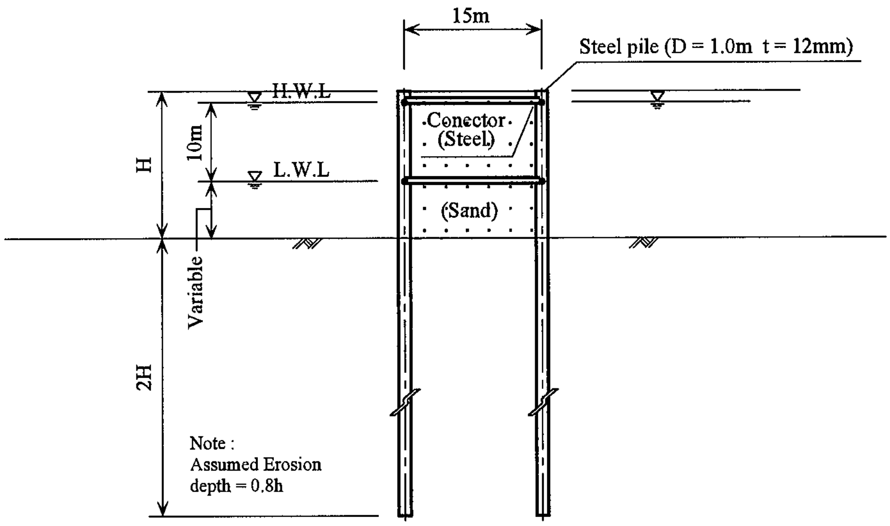
Table 6.3.6 Work Component of Proposed Channel Improvement

Closing Dike	Mound type dike composed of rubble stone or blocks in Tortola channel	L=2,200 m
Bank Protection	Revetment at Barrancas Town to protect bank from erosion, as a consequent of the discharge increase in the navigation channel	L=2,000 m

1. Mound Type Closing Dike



2. Upright Type Closing Dike



3. Composite Type Closing Dike
(Caisson Type Concrete Block)

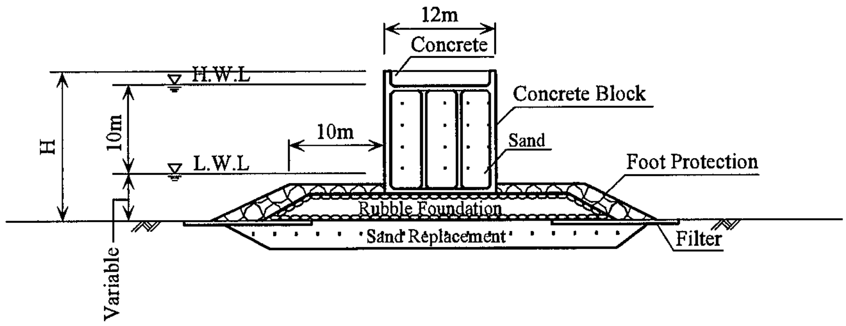


Fig. 6-3-4 Structure Type for Closing Dike

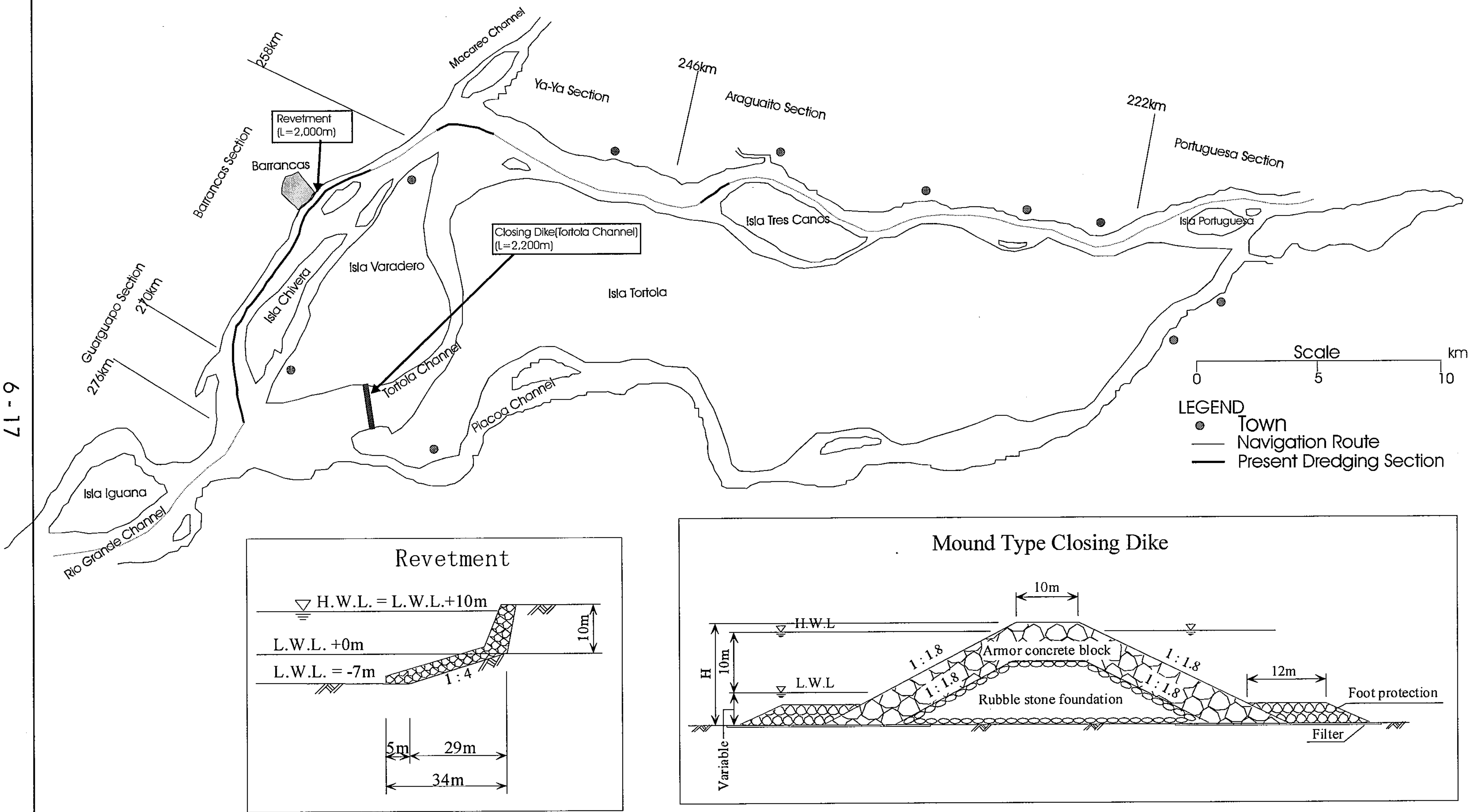


Fig.6-3-5	PROPOSED CHANNEL IMPROVEMENT PLAN

By conducting 1-D hydraulic simulation analysis, the effect of the proposed works of structural measure is evaluated as shown in Fig. 6-3-6 "the changes in bed elevation and discharge distribution". The result shows that it would not be required any maintenance dredging between Guarguapo and Ya-Ya sections after the implementation, as the channel depth in the section would be deeper than the designed draft.

It should be noted, however, that the expected results with implementation of B2 scheme are evaluated hydraulically utilizing purely 1-dimensional numerical analysis. The adverse effects of river bank erosion by increase of discharge in the navigation channel, could not be clearly studied yet, especially in terms of extent and intensity of erosion, due to lack of information in this stage. The risk is still existed due to unclear phenomenon and the estimated construction cost for bank protection structure is also tentative.

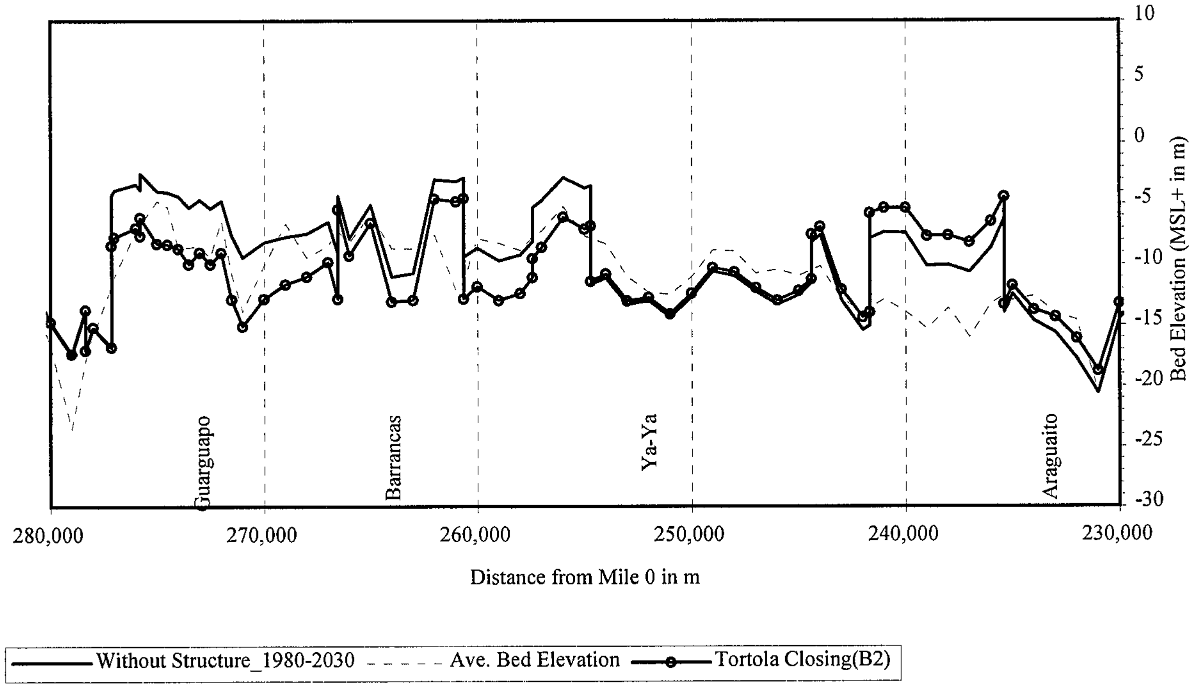
Hence, more detailed analysis including a field survey and 2- dimensional numerical results, is required in the next stage to make a final decision for adopting B2 scheme.

6.3.6 Non-structural Measures

In order to reduce the maintenance dredging volume, the non-structural measures as less expensive measures, can also be applied for channel improvement, ie., specifying the best route for navigation through the deepest area of the channel.

The seasonally deep water path in the channel subjects to move according to the changes in river flow. Therefore, by conducting regular bathymetrical surveys, the deeper area in the channel has to be defined and the navigation route revised in viewpoint of reduction of the dredging volume, after careful evaluation.

LONGITUDINAL PROFILE OF BED ELEVATION IN RIO GRANDE CHANNEL
Alt.B2:Discharge Control at Tortola Channel



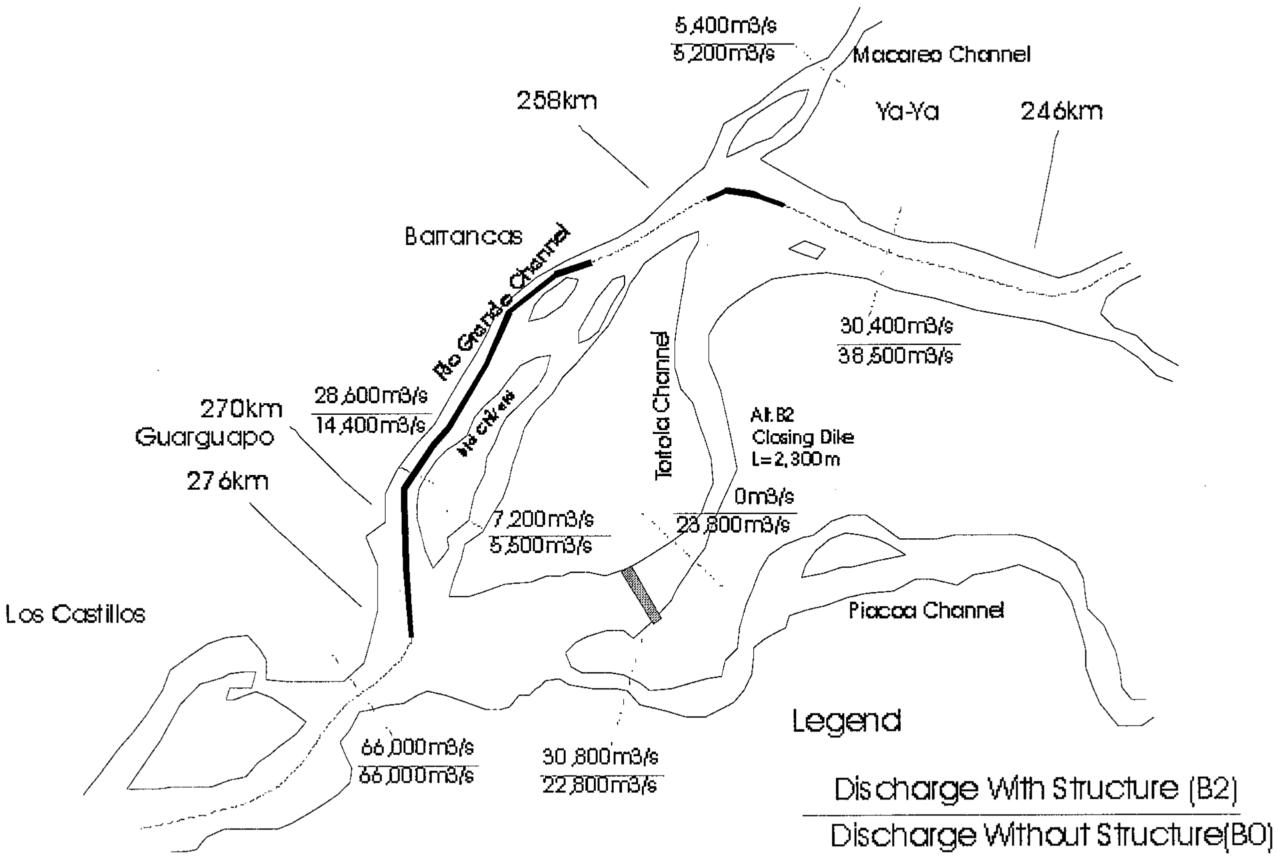


Fig.6-3-6 CHANGE OF BED ELEVATION AND DISCHARGE DISTRIBUTION BY ALT.B2