3.3 Coastal Characteristics

With about 20,000,000 m^3 needed to be dredged annually to assure safe navigation, the impact of dredging on any development plan is essentially vital. About more than half of this amount is said to be from the outer channel at Boca Grande. Hence, understanding the characteristics of the delta coastal areas and the marine processes taking place there, is critical for maintaining and developing the navigation system of the Orinoco Delta. Therefore, in this section coastal related processes will be reviewed, analyzed and assessed.

3.3.1 Wind

The Defense Mapping Agency of the United States has about 50 representative areas/stations in the North Atlantic Ocean where surface weather observations are available. The locations of these stations are outlined and numbered as shown in Fig. 3-3-1. Stations No. 44, 45 and 48 provide information offshore the Atlantic coast of Venezuela that are most relevant to the study area. Annual wind data at these stations are summarized in Tables 3.3.1 through 3.3.3. At each station data is presented on a quarterly base, as shown in Supporting Report section 3.3.

Wind direction histograms at each station, based on these data, are shown in Fig. 3.3.2. From these tables and figure, it can be noticed that prevailing wind directions in front of the Venezuelan Atlantic coast are E, NE and SE respectively, and prevailing wind speed varies between 9 to 14 knots.

Table 3.3.1 Annual Distribution of Wind at St. 44

Direction \ W(kt)	2	5.5	9	14	19.5	25	31	Total
N	0	0	1	0	0	0	0	2
NE	0	2	7	11	5	1	0	28
E	1	4	15	23	11	2	0	56
SE	1	1	4	3	1	0	0	10
S	0	0	1	1	0	0	0	2
SW	0	0	0	0	0	0	0	1
W	0	0	0	0	0	0	0	1
NW	0	0	0	0	0	0	0	1
Calm	1	0	0	0	0	0	0	1
Total	4	9	28	37	18	4	0	100

Table 3.3.2 Annual Distribution of Wind at St. 45

Direction \ W(kt)	2	5.5	9	14	19.5	25	31	Total
N	0	0	0	0	2	0		3
NE	1	2	7	15	8	2		35
E	0	4	13	23	16	3		60
SE	0	2	3	2	1	0		8
S	0	0	0	0	0	0		1
SW	0	0	1	0	0	0		1
W	0	0	0	0	0	0		1
NW	0	0	0	0	0	0		1
Calm	1	0	0	0	0	0		1
Total	3	9	25	40	20	3		100

Table 3.3.3 Annual Distribution of Wind at St. 48

Direction \ W(kt)	2	5.5	9	14	19.5	25	31	Total
N	0	0	0	1	0	0		2
NE	1	2	6	14	8	3		34
E	1	6	10	13	6	1		36
SE	1	4	8	4	2	0		23
S	0	1	1	1	0	0		4
SW	0	0	0	0	0	0		0
W	0	0	0	0	0	0		0
NW	0	0	0	0	0	0		0
Calm	1	0	0	0	0	0		1
Total	4	14	26	36	16	3		100

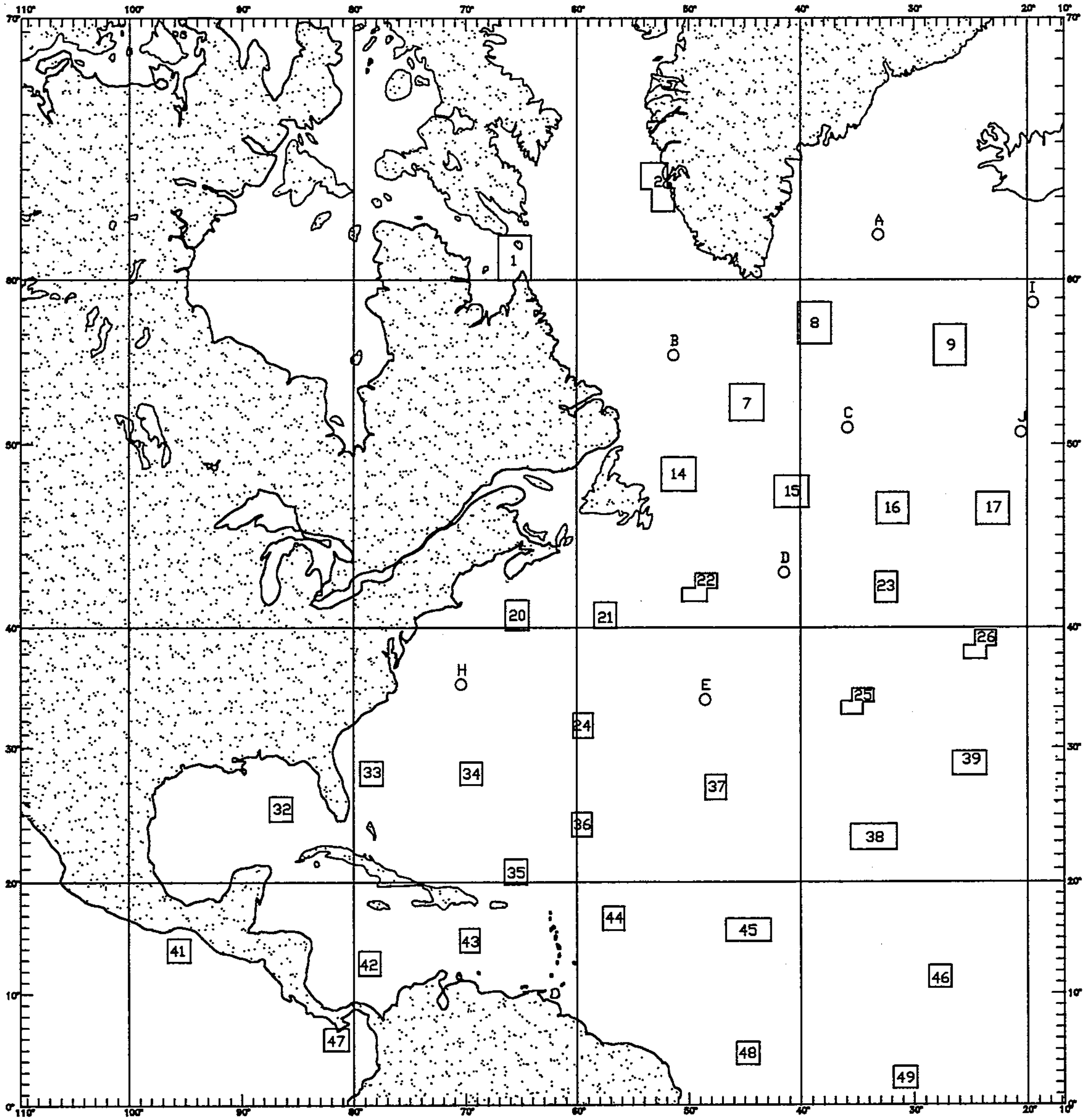


Fig. 3-3-1 Positions of Observation Stations

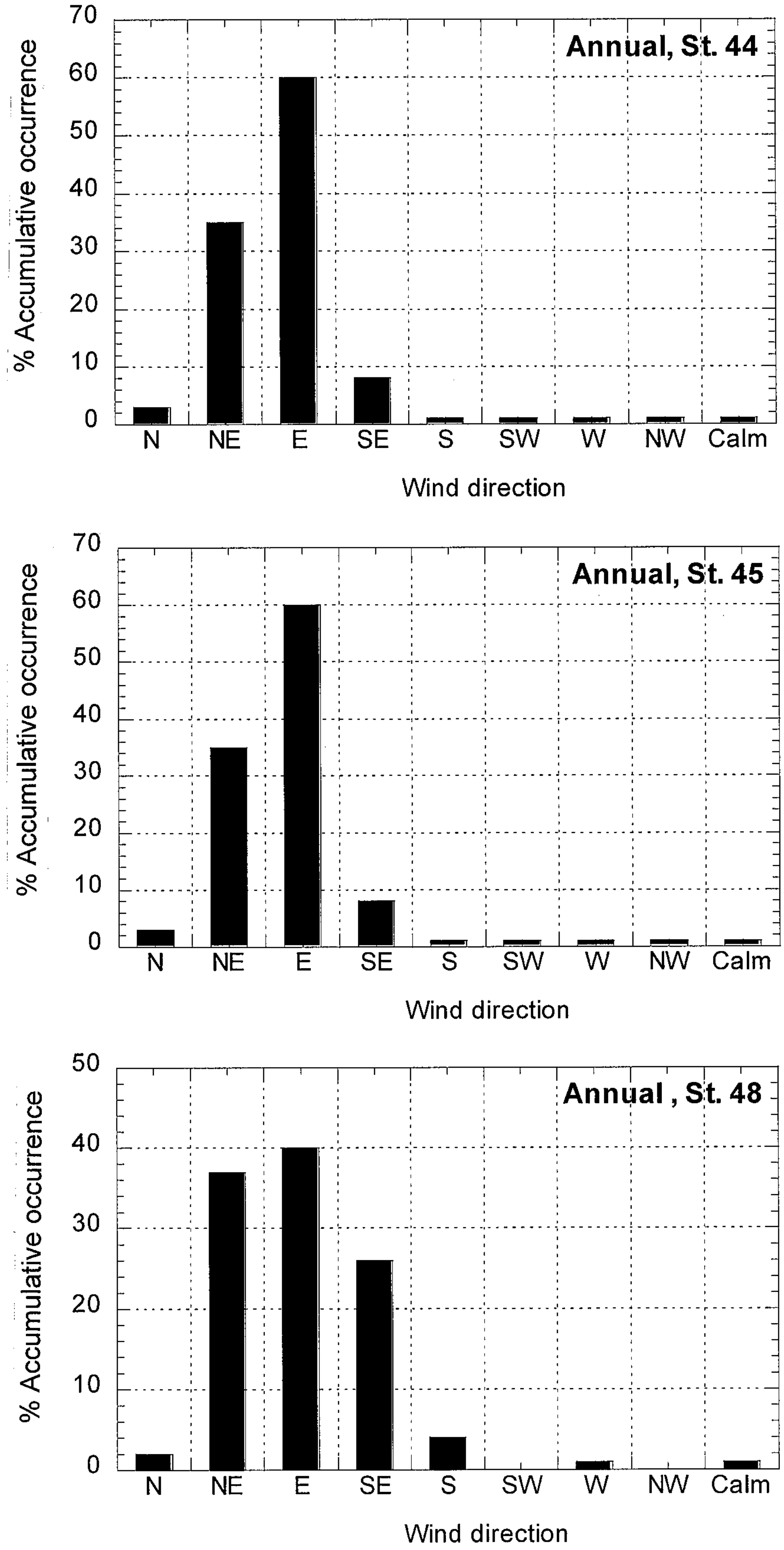


Fig. 3-3-2 Distribution of Wind Direction at Stations 44, 45 and 48

3.3.2 Wave

Wave data in front of the study area are synthesized from the data available at stations 44, 45 and 48 shown in Fig. 3-3-1. Annual wave data at these stations are summarized in Tables 3.3.4 through 3.3.6. At each location data is also presented on a quarterly base, as shown in Supporting Report section 3.3.

The data show the relation between wave heights and periods. From these data it can be noticed that prevailing wave period is around 6 to 7 sec., which means that waves are mainly wind waves. Hence, prevailing wave directions could be assumed as those of winds. The equivalent mean-energy wave is calculated and has a wave height of about 1.6-1.7 m with a period of about 6-7 sec. Moreover, Fig. 3-3-3 shows the wave climate off the Venezuelan coasts, Font (1982). It can be seen that offshore the Orinoco Delta wave height is about 1.5 m and wave direction is almost NE, which is one of the wind main directions. The monthly distribution of wave height offshore the Orinoco Delta is shown in Fig. 3-3-4

Table 3.3.4 Wave Data at St. 44

H(m) \ T(sec)	< 6	6.5	8.5	10.5	12.5	>13	U.K	Total
0.25	10	1	0	0	0	0	4	15
1.25	19	21	8	2	1	0	5	56
2.25	2	11	8	1	1	0	2	25
3.25	1	1	1	1	0	0	0	4
4.75	0	0	0	0	0	0	0	1
6.75	0	0	0	0	0	0	0	0
8.75	0	0	0	0	0	0	0	0
>10	0	0	0	0	0	0	0	0
Total	31	34	17	4	2	1	11	100

Table 3.3.5 Wave Data at St. 45

H(m) \ T(sec)	< 6	6.5	8.5	10.5	12.5	>13	U.K	Total
0.25	7	1	0	0	0	0	1	9
1.25	29	22	5	1	0	1	1	59
2.25	4	12	8	2	0	1	1	27
3.25	0	1	1	2	1	0	0	5
4.75	0	0	0	0	0	0	0	0
6.75	0	0	0	0	0	0	0	0
8.75	0	0	0	0	0	0	0	0
>10	0	0	0	0	0	0	0	0
Total	40	35	14	4	1	2	3	100

Table 3.3.6 Wave Data at St. 48

H(m) \ T(sec)	< 6	6.5	8.5	10.5	12.5	>13	U.K	Total
0.25	10	1	0	0	0	0		13
1.25	24	25	6	1	1	0		60
2.25	4	9	8	2	1	0		23
3.25	0	1	1	0	0	0		3
4.75	0	0	0	0	0	0		0
6.75	0	0	0	0	0	0		0
8.75	0	0	0	0	0	0		0
>10	0	0	0	0	0	0		0
Total	38	36	15	3	1	1		100

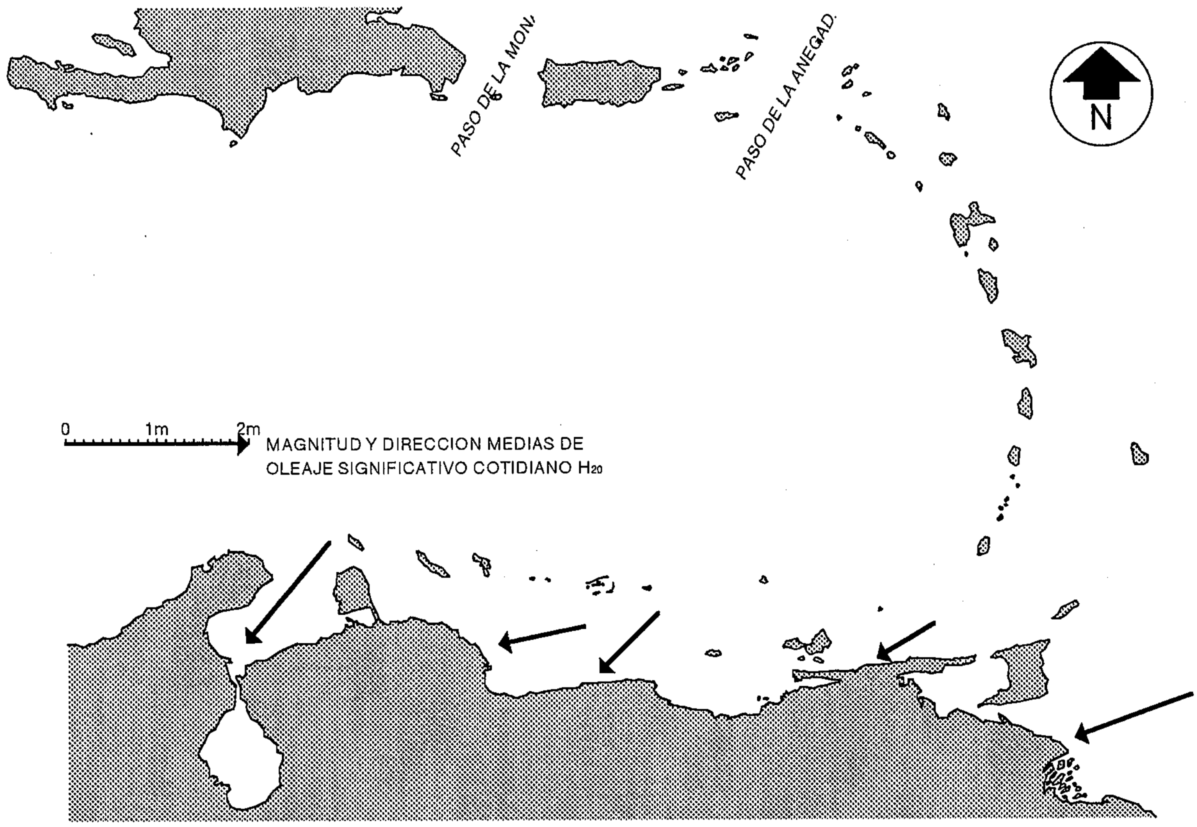


Fig. 3-3-3 Regime of Daily Waves Along the Venezuelan Coast

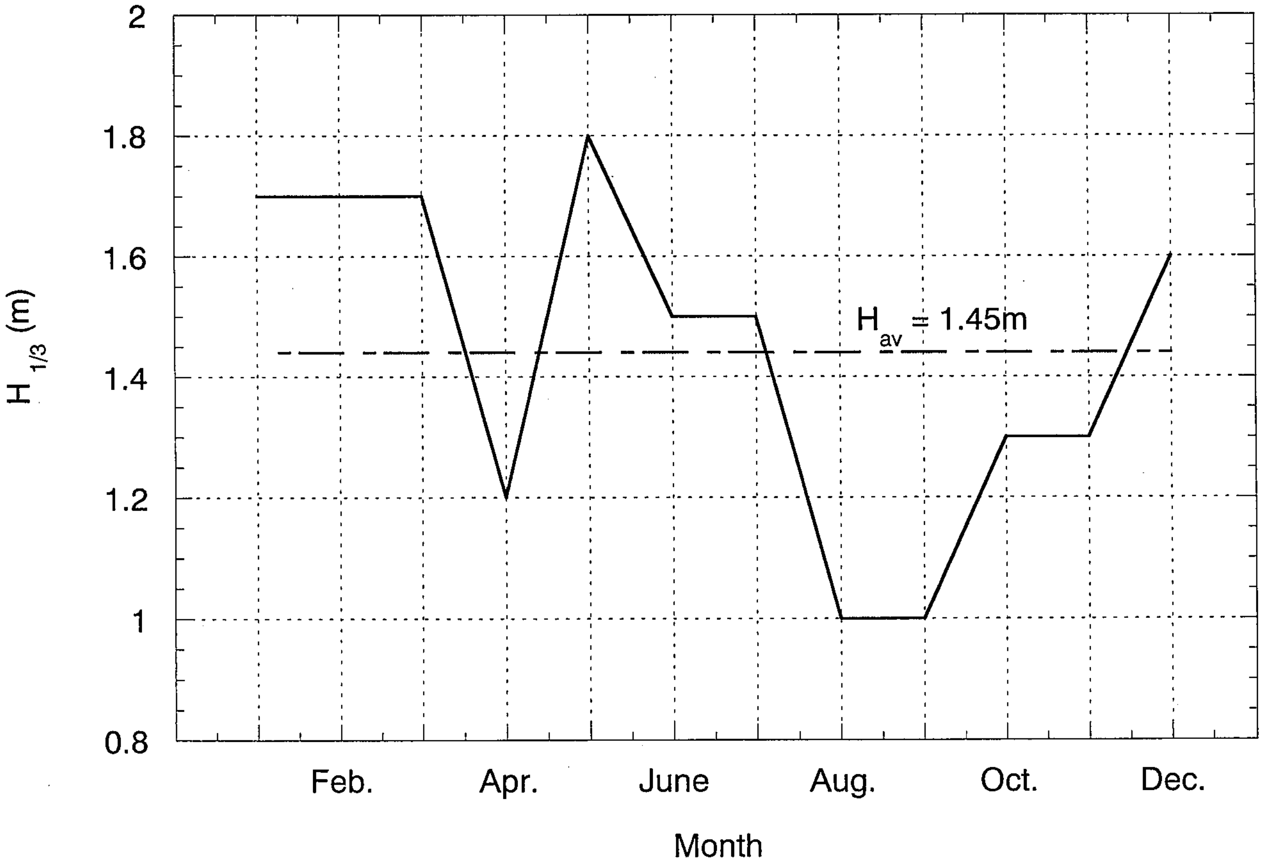


Fig. 3-3-4 Monthly Wave Height Distribution at the Orinoco Delta
(After J. Font, 1982)

3.3.3 Tides and Tidal Currents

Tides along the coastal lines of the Orinoco Delta are semidiurnal with a maximum tidal range of about 1.8~2m near Boca Pedernales Entrance (latitude: 10° 01', long: 62° 12') and 1.5~1.7m at Island Roman Isidro (latitude: 8° 39', long: 60° 35') near Rio Orinoco Entrance. Figure 3-3-5 shows the computed tidal levels for the 2nd half of the month of October 1998 at both Boca Pedernales and Island Roman Isidro. It is worth mentioning here, that calculated levels are referred to local datums of local tidal stations situated at the above mentioned locations. Further, these calculations show the tidal range at each location.

Herrera and Masciangioli (1984) measured tidal currents at different locations in front of the Orinoco Delta as shown in Fig. 3-3-6. They reported that the mean current speed at stations 2 and 4 is about 8-14 cm/s with prevailing directions NE-SW, as shown in Fig. 3-3-7.

3.3.4 Ocean Current

The South Equatorial Current flows in a northwesterly direction off the coasts of Suriname, Guyana and Venezuela at average rate of about 1.25 knots. Moreover, occasional sets in other directions may be experienced with rates up to 1.5 knots. The effect of currents is less marked landward of the -100m depth contour especially within 30 miles of the coast where tidal influence may predominate.

The South Equatorial Current enters the Caribbean Sea in a general west-north westerly direction with rates of up to about 3 knots. Part of it divides off the southeast coast of Trinidad and flows northwestward along the east coast of the island. The other part flows westward south of Trinidad to enter the Gulf of Paria and then sets northwest at 1-2.5 knots emerging through the Rocas del Dragon to join the main west-going South Equatorial Current in the Caribbean Sea.

3.3.5 Hurricanes

In the Northern Hemisphere hurricanes and extra-topical storms occur usually north to latitude 10°. Fig. 3-3-8 shows the hurricane tracks close to the Venezuelan coasts during the period 1871-1974, (i.e. for more than 100 years). As can be seen, hurricanes do not represent a hazardous factor to the study area.

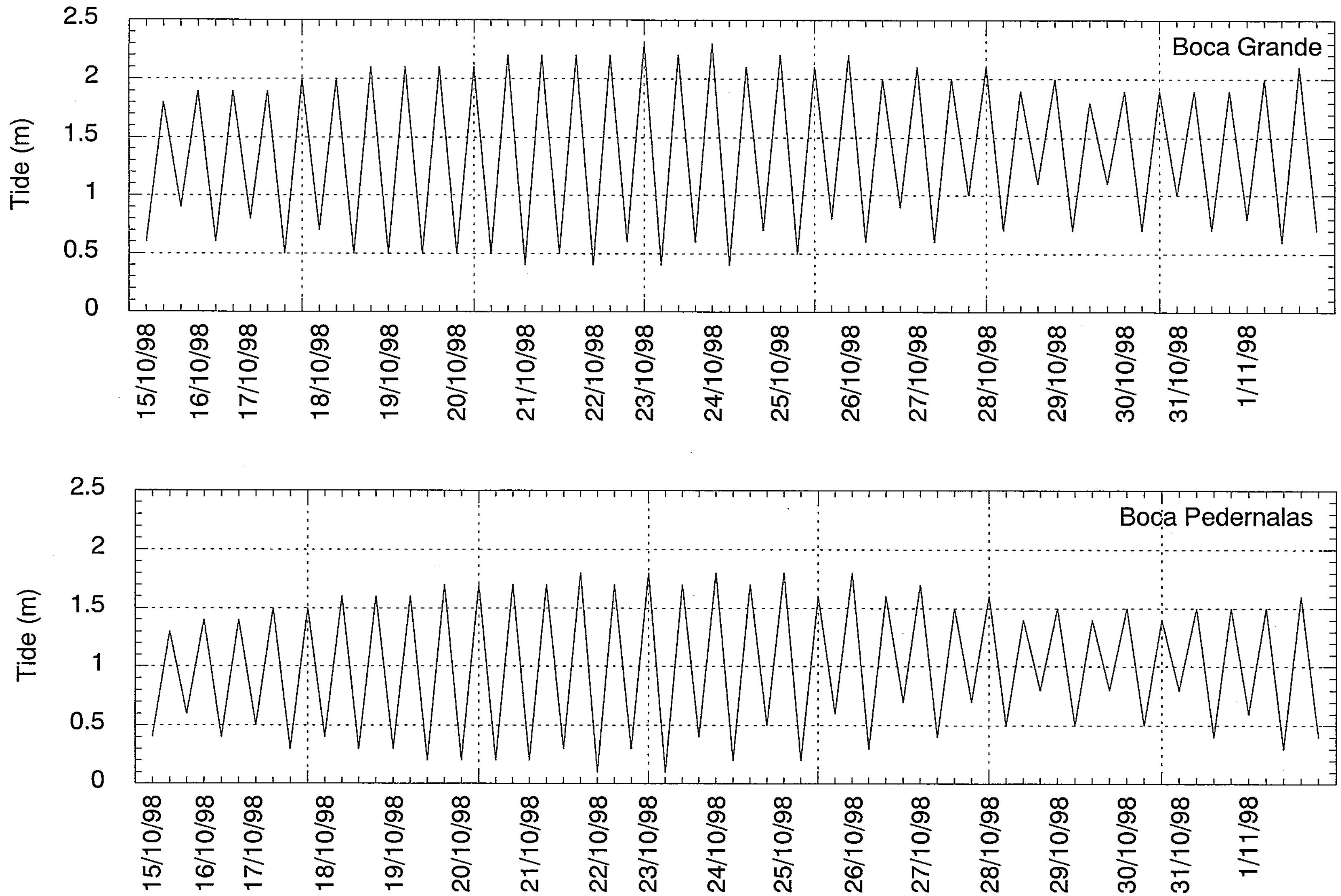


Fig. 3-3-5 Computed Tidal Levels

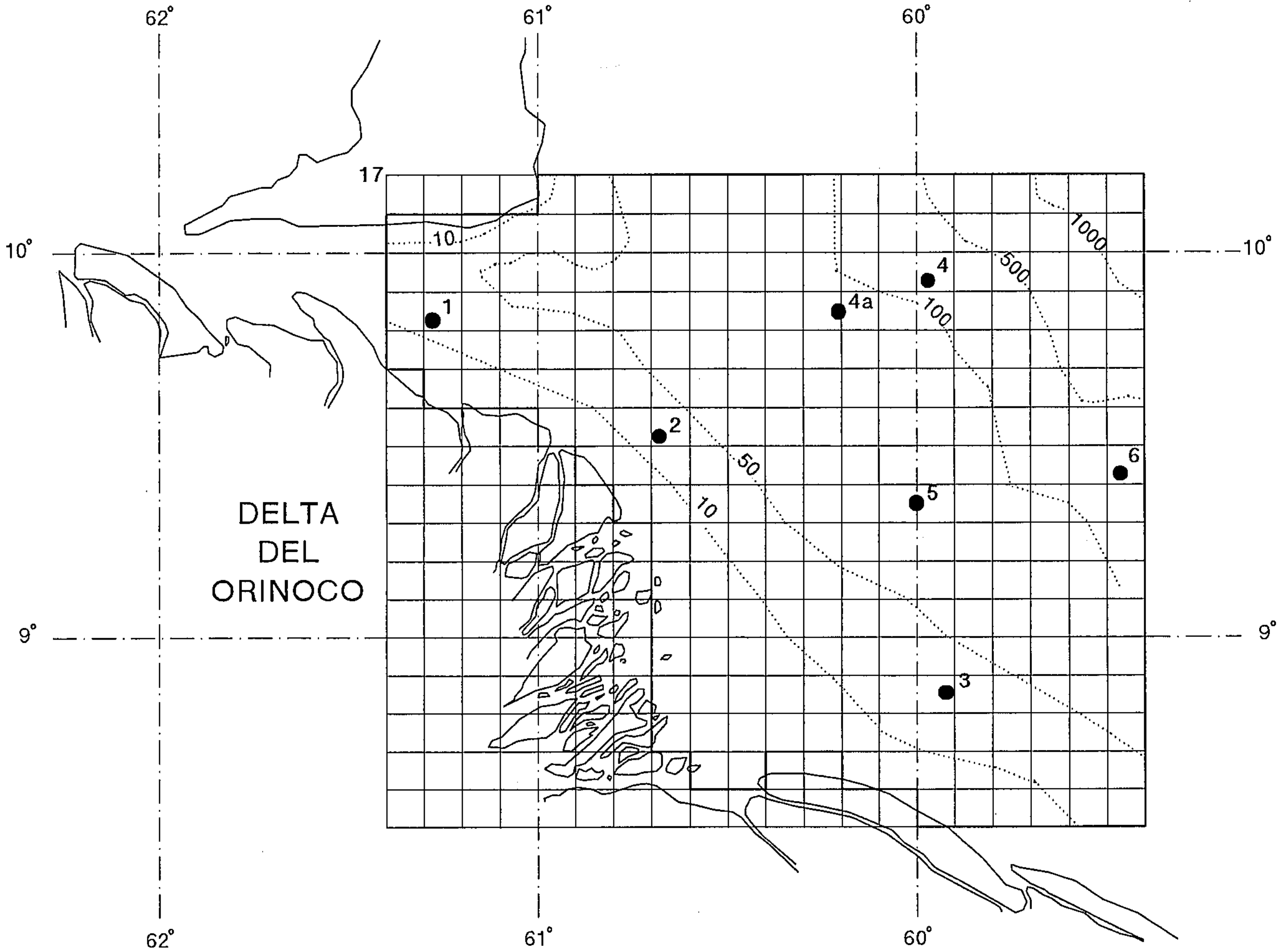


Fig. 3-3-6 Location of Observation Stations at the Orinoco Delta
(after, Herrera and Masciangioli, 1984)

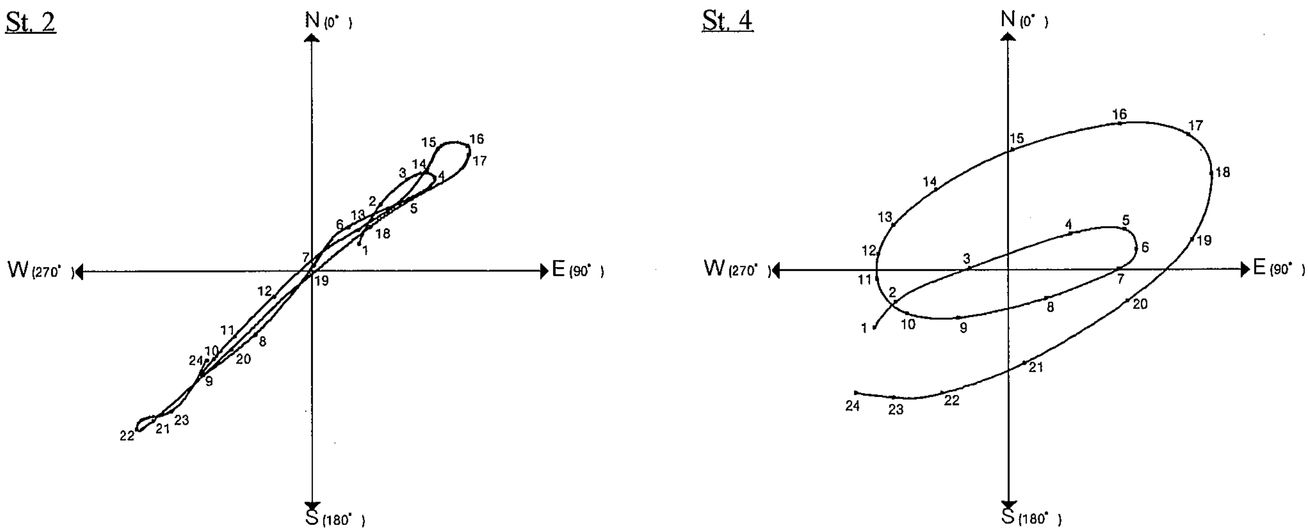


Fig. 3-3-7 Vectors of Tidal Currents at Stations 2 & 4
(after, Herrera and Masciangioli, 1984)

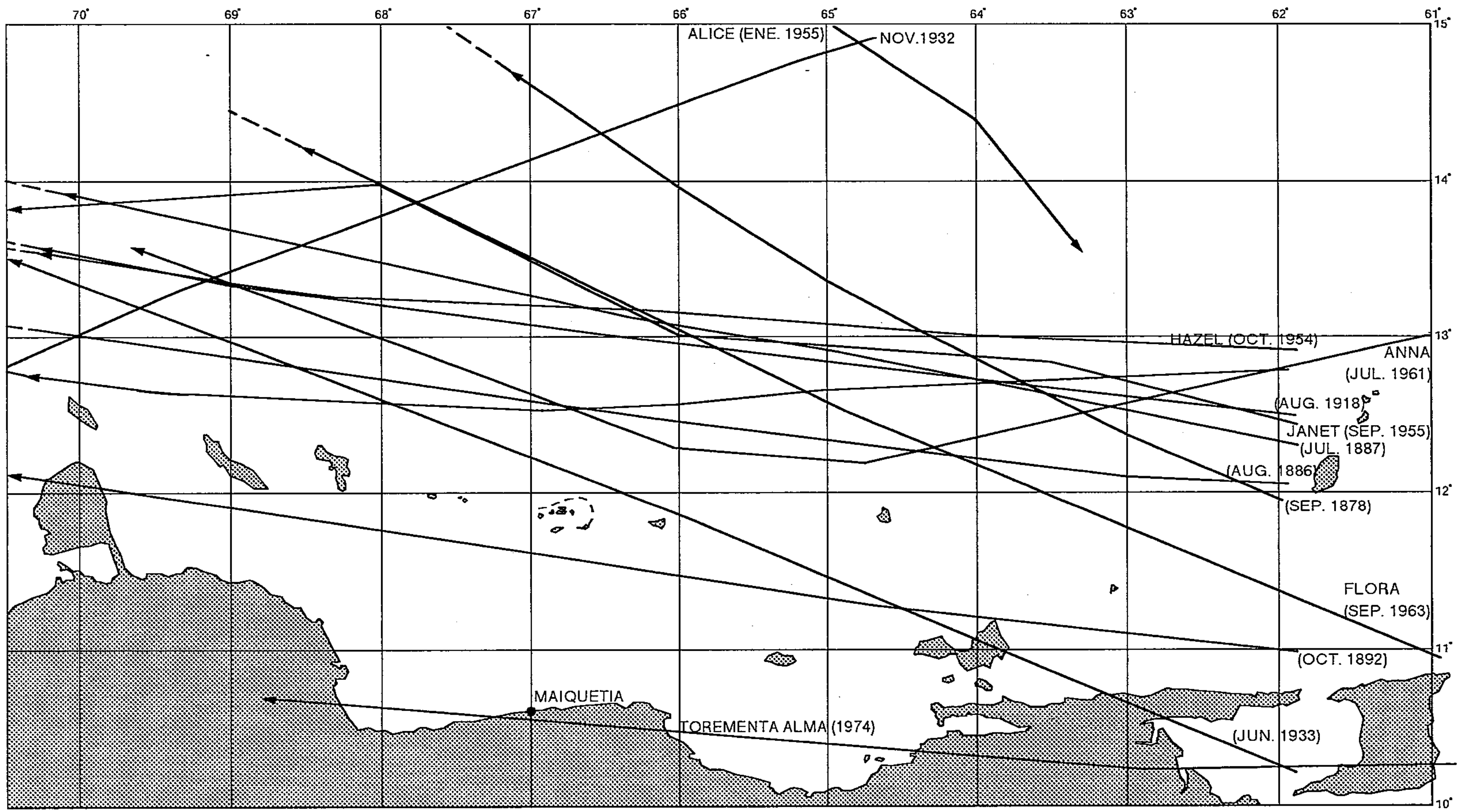


Fig. 3-3-8 Hurricane Tracks Close to Venezuelan Coastlines (1871 - 1974)

3.3.6 Coastal Morphology

River deltas, which are found throughout the world, result from the interaction of fluvial and marine forces. According to Wright (1985), " deltas are defined more broadly as coastal accumulations, both subaqueous and subaerial, of river-derived sediments adjacent to, or in close proximity to, the source stream, including the deposits that have been secondarily modeled by waves, currents or tides."

Table 3.3.7 shows the classification of delta according to Bernard and Leblanc (1965). In transition type delta, as in the case of Orinoco, sandy sediments have already reached to the middle and down stream reaches and entered diversion channels. Sand entered to diversions deposited there, especially near the diversion point at initial stage and made the channel meandered. The meandering propagated to its down reaches gradually and brought some changes to net flow system, Suga (1995). In Orinoco delta, northern part of net system of channels has already partly decayed, and main channels have currently shifted from north to south.

Table 3.3.7 Classification of Delta

Category	Example of delta	Tidal Range (m)					Sediment material		Sediment run-off
		0	1	2	3	4	With Sand	No Sand	10^6 t/year
Bird feet type	Mississippi						*		
	Po						*		
Arc shoal type	Rhein								
Lagoon type	Mississippi								
Fam shape type	Yellow						*		1900
Net shape type	Ganges							*	2200
Transition type	Orinoco						*		200
	Yangtze						*		500

(Source: Bernard and Leblanc, 1965)

To study the characteristics of the coastal area of the Orinoco Delta efforts were made to collect available aerial photographs and marine charts as well as satellite images. Table 3.3.8 summarizes the collected charts and aerial photographs as a result of these efforts.

This study will mainly be performed by analyzing these photographs and charts. Hence, these data were digitized to pick-up shorelines to get more information about the coastal characteristics. The digitized photos and charts are shown in Supporting Report section 3.3.

Table 3.3.8 List of Collected Aerial Photos and Charts

No.	Date	Remarks
1	1960	Aerial Photo
2	Aug. 1983	Aerial Photo
3	July 1998	Radar Sat
4	June 1995	Chart No. 24381, Boca Grande and Approaches, DMA, USA
5	1996*	Chart No. 572, Essequio River to Corentyn River, Hydro. of the Navy, U.K.
6	1998*	Chart No. 1480, Tobago to Tortuga, Hydro. of the Navy, U.K.
7	1998*	Chart No. 481, Serpent's Mouth, Hydro. of the Navy, U.K.
8	1998*	Chart No. 517, Trinidad to Cayenne, Hydro. of the Navy, U.K.

(*: Date of small correction)

For a comparative study of shoreline changes the aerial photographs of 1960 and the satellite image of 1998 will be used since the 1983 photos do not have grids and no matching points could be identified. The outcomes of this comparative study show that there is no significant change in the coastal area especially west to longitude 61°, Fig. 3-3-9 to 3-3-10. Moreover, Fig. 3-3-11 shows the results of shoreline changes around Boca de Macareo and Boca de Manamo, based on the satellite images of 1998 and 1978.

Fig. 3-3-12 shows the net sediments movement around the south American continent, Silvester and Hus (1997). As can be seen that around the study area net sediment is from SE to NW directions, which is also the orientation of coastlines and depth contours as can be seen from Supporting Report section 3.3. The orientation of the coastline in the study area (SE-NW) is almost perpendicular to the prevailing wave direction that is NE. Further, river/stream-mouth deflections, in and around the study area, infer that local longshore transport is in the SE-NW direction.

Orinoco delta around the Boca Grande area is a typical example of an active delta with a river-dominant type delta especially around the mouth of Rio Grande. Unlikely, it is believed that the delta is rather stable west of longitude 61°. Further, funnel shape of the river outlets west of longitude 60° 30', is an evidence of the influence of tides and tidal currents, especially during the low-level periods of the river. This infers that this area of the delta is a tide-dominant.

In fact the hydrodynamic forces around the mouth of Rio-Grande are rather complicated as can be seen from Fig. 3-3-13. The interaction between all these forces along with bottom topography and man made activities (dredging, disposal, construction, etc.) shape/determine the morphological characteristics of the area.

Fig. 3-3-14 shows the depth contours around Boca-Grande, which is digitized from one of the collected charts. As can be seen that east of longitude 60° depth contours are more or less straight and parallel to the shoreline, which indicate that in this area river effluents do not have a major role in shaping depth contours. Furthermore, west of longitude N 60° 30', depth contours have funnel shape which infers the predominance of tidal forces rather than the river ones. In general, the river-sediment discharge has minor effect on shaping depth contours for depths equal or greater than MLWS-38m.

Further, Fig. 3-3-15 shows cross-shore profiles around the Boca-Grande area. The locations of these profiles are shown in Fig. 3-3-14. Section A-A is little far east of the mouth of Boca-Grande, therefore the effect of the river is almost nil, as anticipated, and the bottom slope is rather steep. On the other hand, sections B-B and C-C are highly affected by the river effluents and bottom slopes are flatter than those at section A-A especially for depths shallower than MLWS-18m.

The coastal area around the mouth of Macareo river is shown in Fig. 3-3-16 that is digitized from one of the collected charts. Depth contours are parallel and more uniform than those at Boca Grande. Further, the bottom slope at this part of the coastal area of the delta is steeper than that around Boca Grande. Figure 3-3-17 shows the profile at section A-A shown in Fig. 3-3-16. As can be seen the bottom has rather mild slope (1/320) up to depth MLWS-5m and then has steeper slope (1/50) between depths MLWS-5 and MLWS-30m.

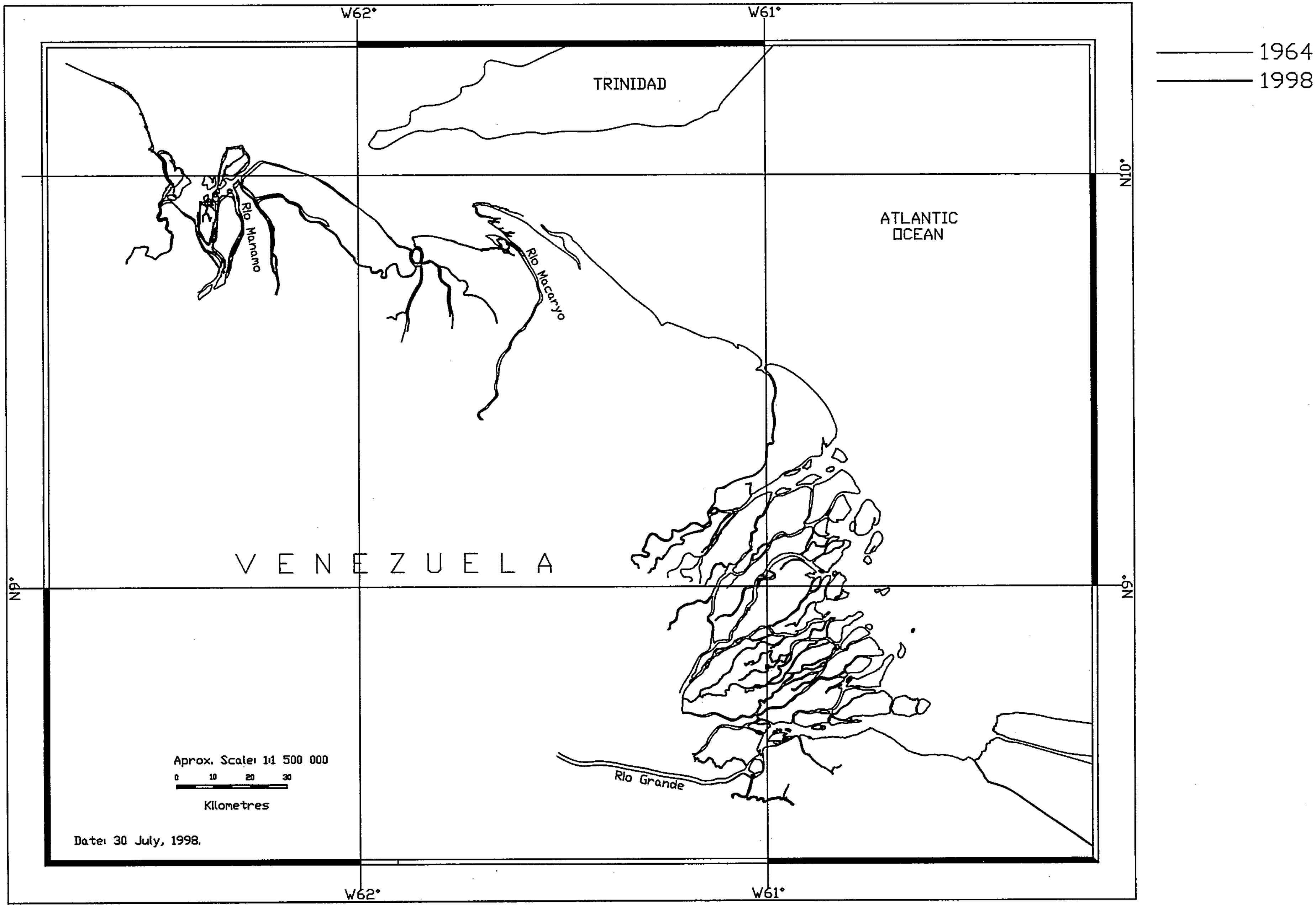


Fig. 3-3-9 Shoreline Changes

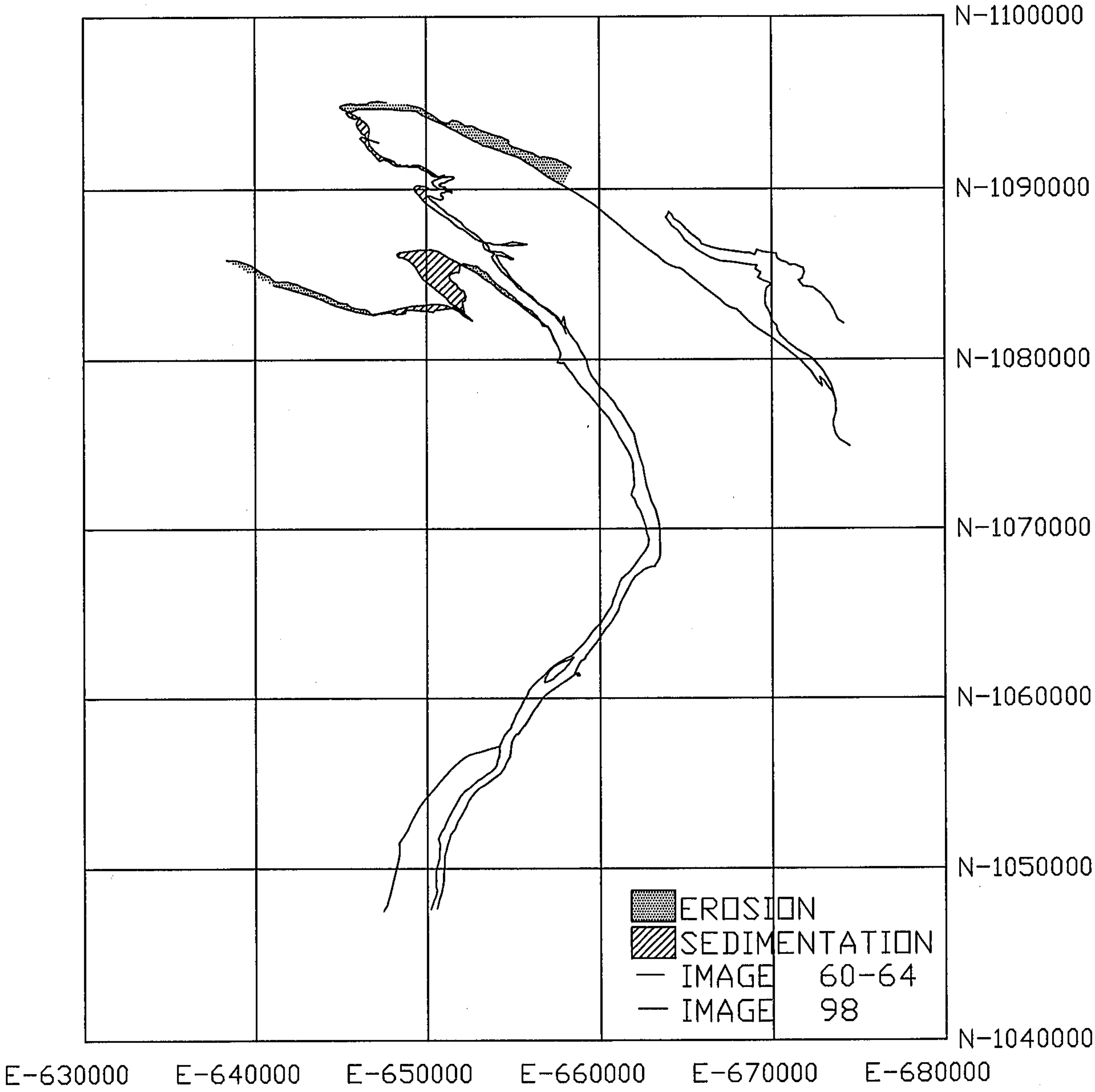
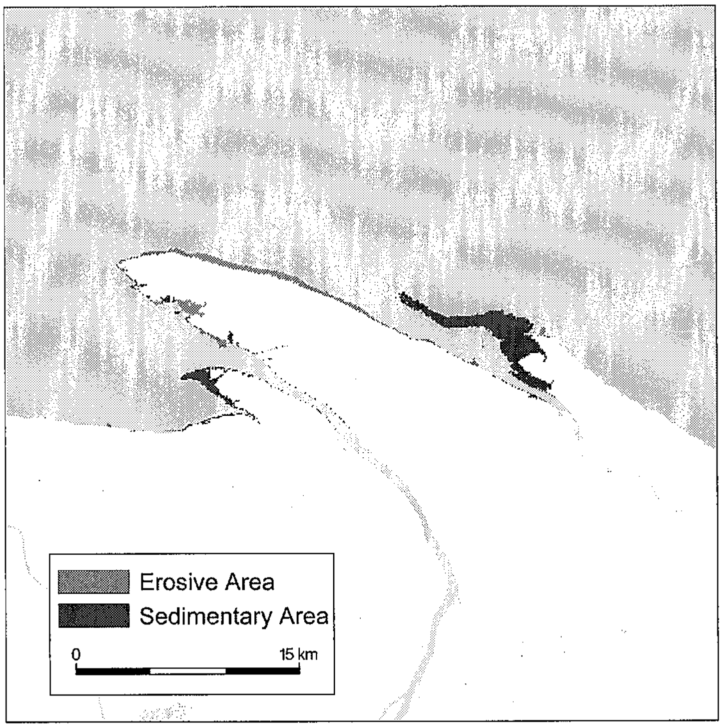


Fig. 3-3-10 Shoreline Changes at Boca de Macareo



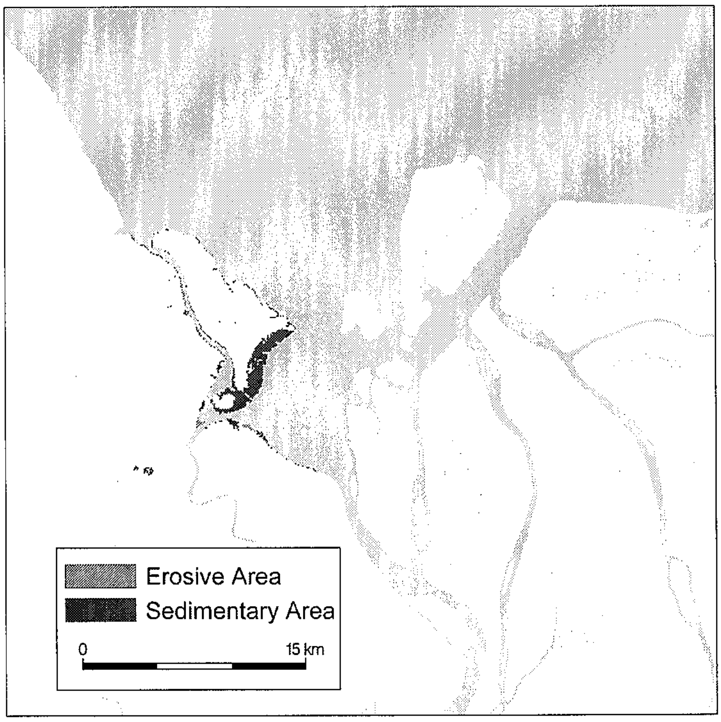


Fig. 3-3-11 Shoreline Changes Based on Satellite Images Analysis

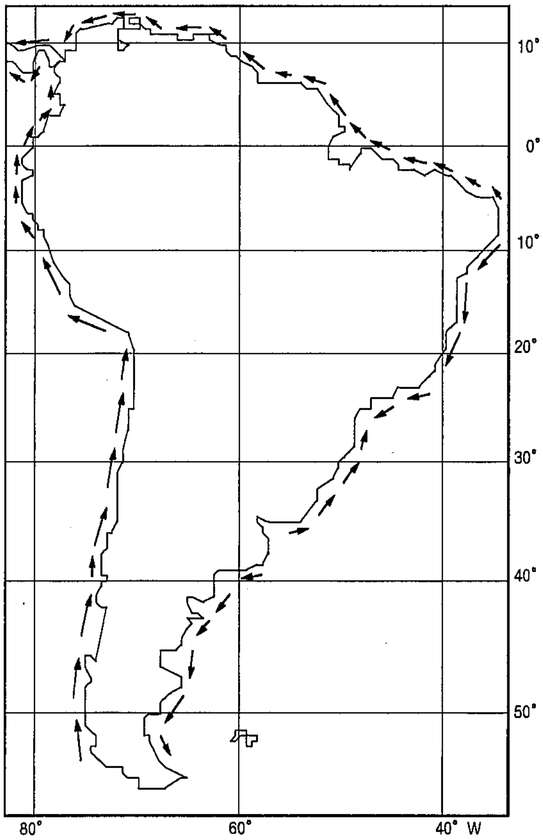


Fig. 3-3-12 **Net Sediment Movement Around the South American Continent, After Silvester and Hus (1997)**

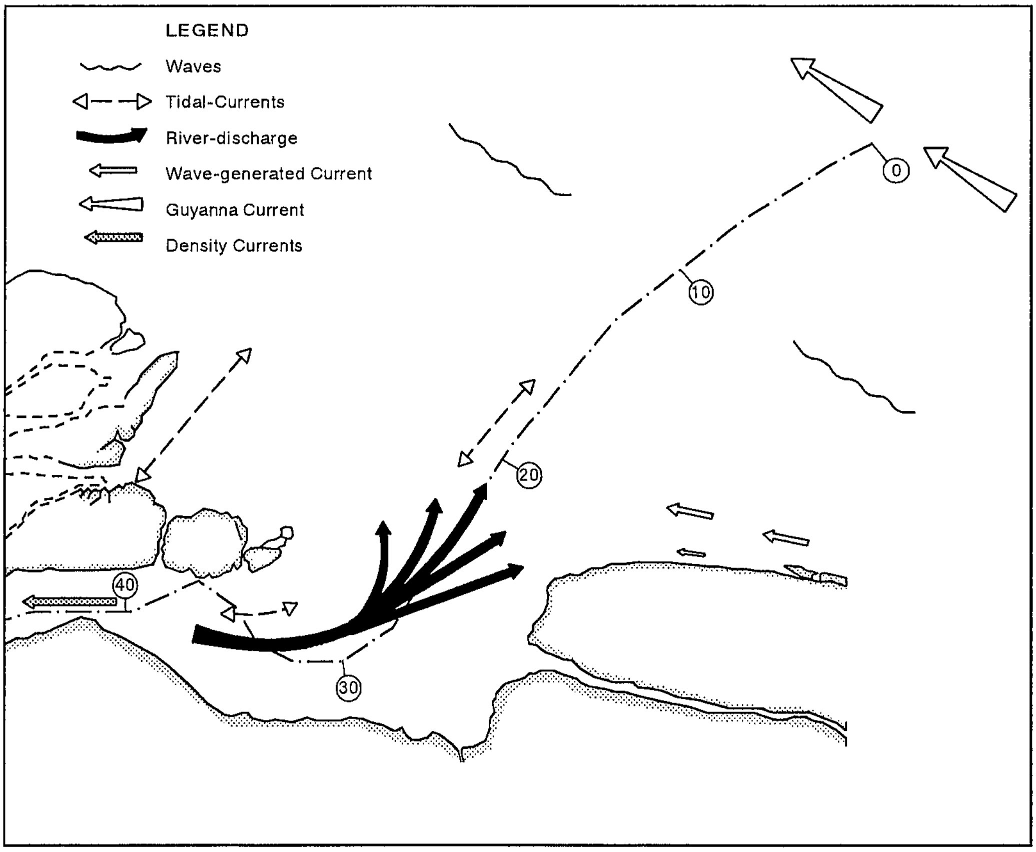


Fig. 3-3-13 **Schematic Presentation of the Hydrodynamic Forces Around Boca Grande**

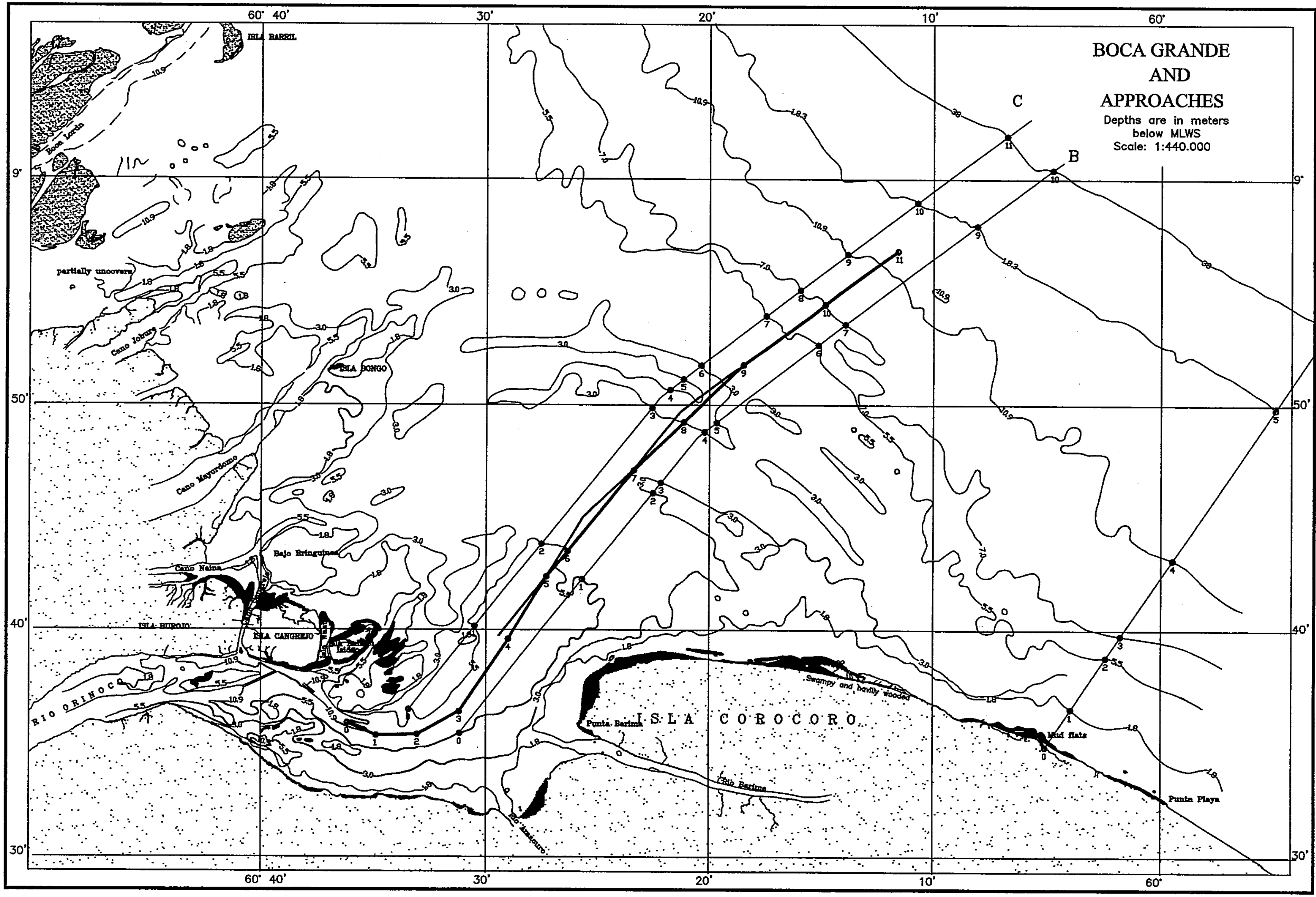


Fig. 3-3-14 Coastal Area Around Boca Grande

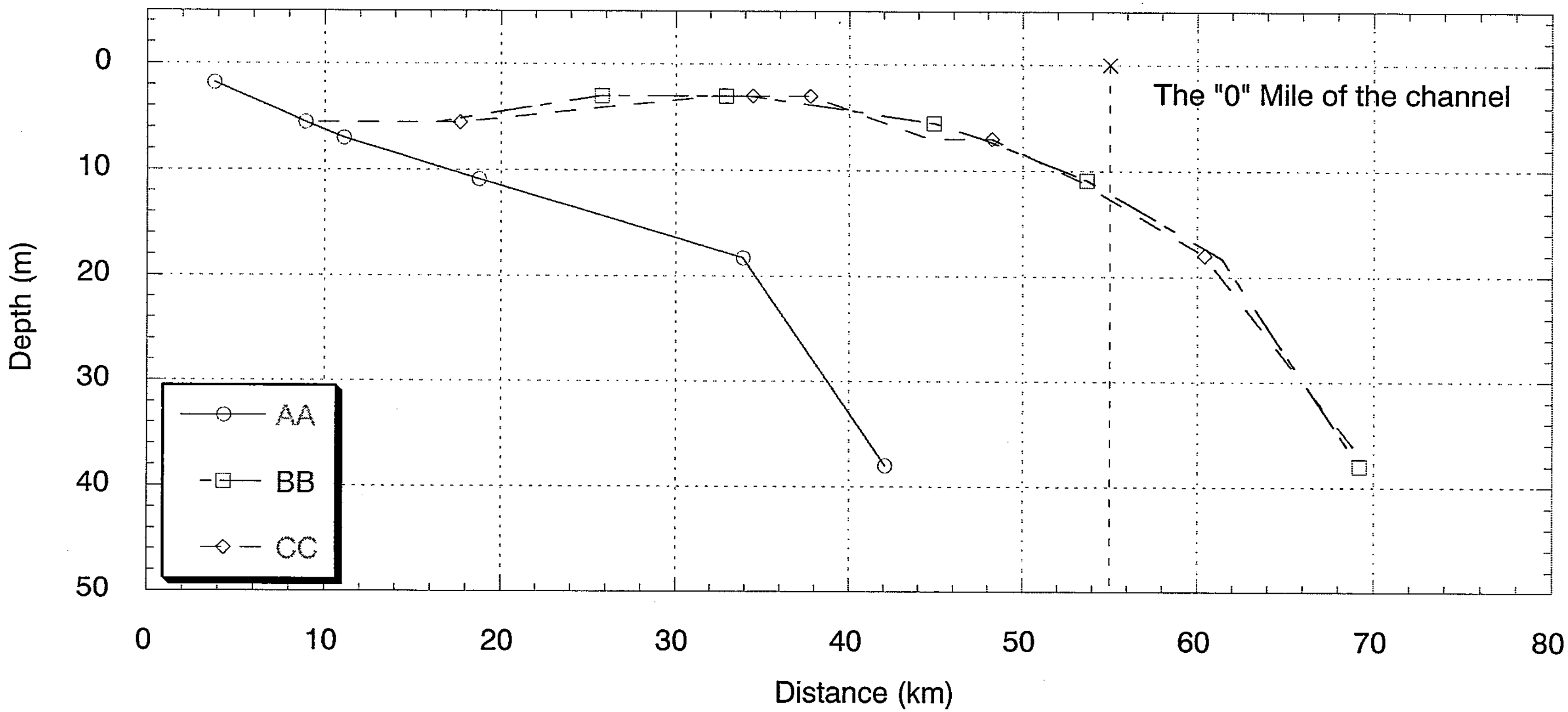


Fig. 3-3-15 Cross-Shore Profiles Around Boca Grande

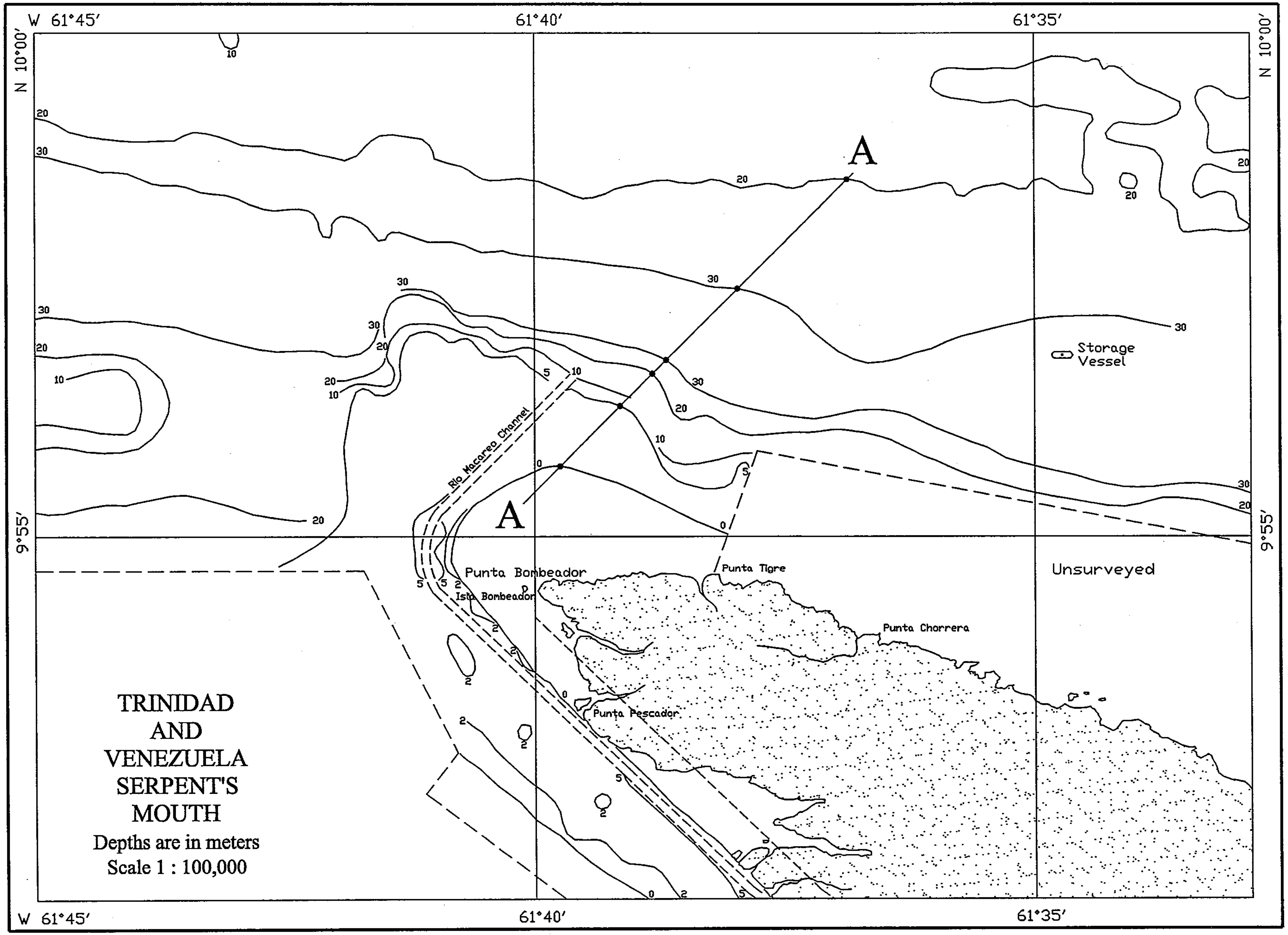


Fig. 3-3-16 Coastal Area Around Punta Bombeador

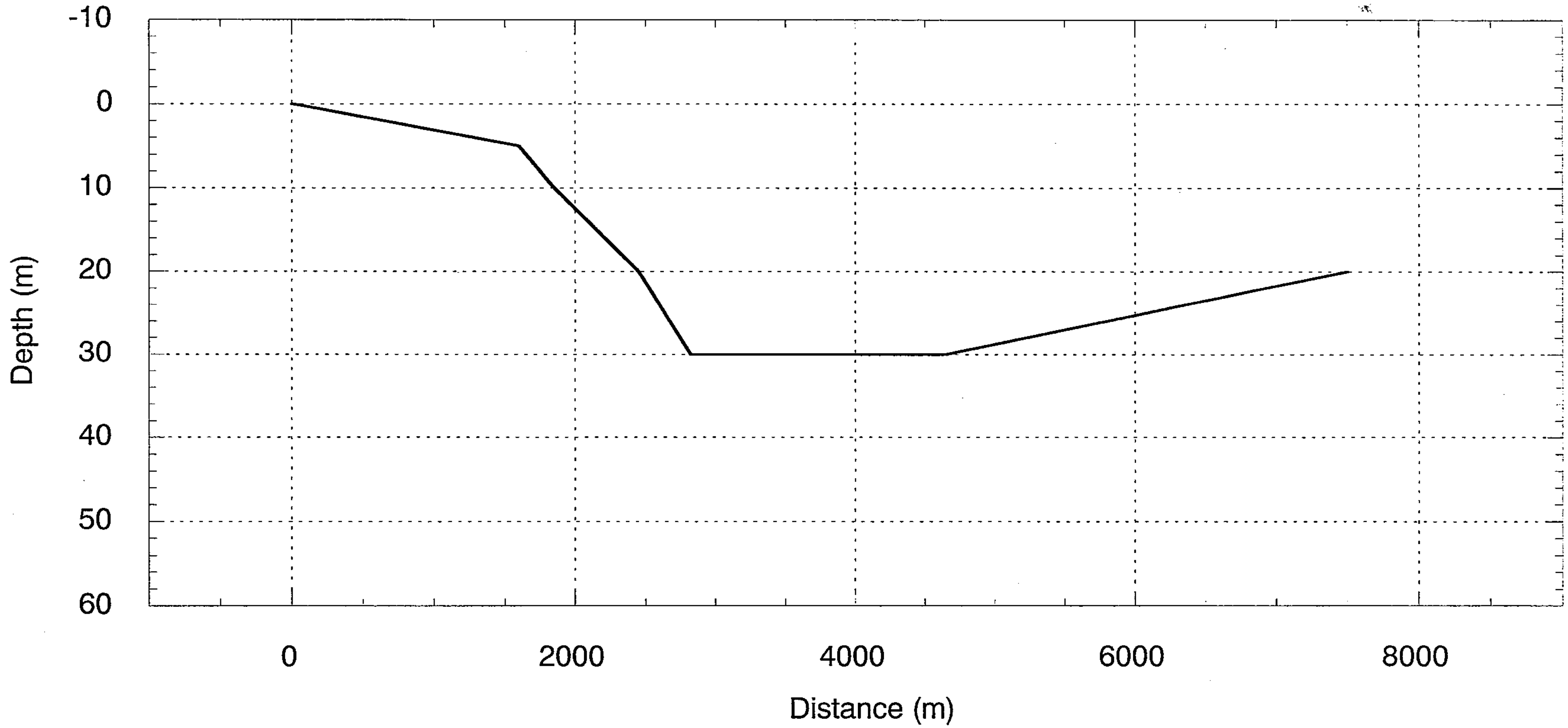


Fig. 3-3-17 Cross-Shore Profiles Around Punta Bombeador

3.3.7 Estimation of Sedimentation Volume

Longshore sediment transport is among the most important nearshore processes that control the nearshore area morphology. Many empirical models exist in the literature for estimating the volume of longshore sediment transport. Though they are widely in use, the accuracy of these models are questionable since their estimates may vary by a factor of 2 or more. Hence, it is more accurate and reliable to use dredging records, if available, in estimating accretion rates at harbor navigation channels.

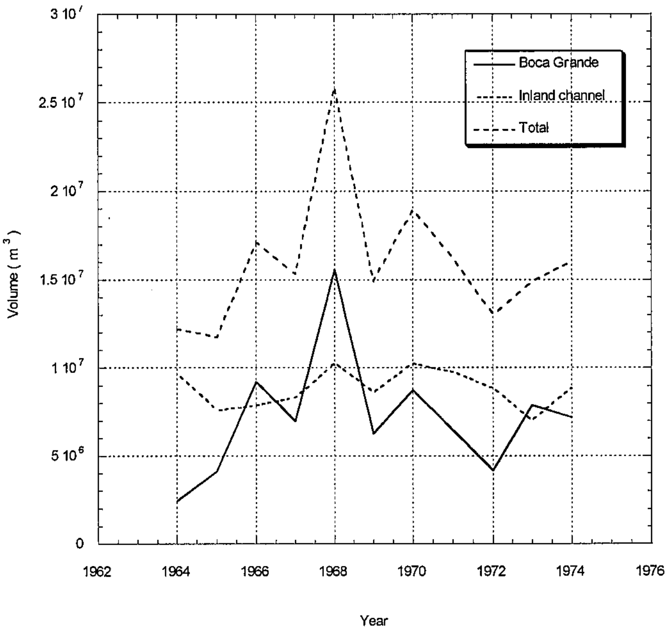


Fig. 3-3-18 Dredging Volume in the Orinoco River

Fig. 3-3-18 shows the dredging volume in the Orinoco River, including the Boca-Grande reach, for the period between 1964 to 1974, Perez et. al (1979). Based on this data the average annual dredging volume in Boca Grande reach was about 7,000,000 m^3. This means that an average depth, over the whole reach of Boca Grande (74 km by 120 m), of about 0.8 m needed to dredged annually.

Moreover, Fig. 3-3-19 shows a dredging record for the Boca-Grande reach, Nouel and TAMS (1991). This figure shows that the sedimentation problem along the outer navigation channel has different magnitudes, even some reaches needed not to be dredged. The total dredged volume was about 10,420,000 m^3, which means an average dredged depth of about 1.2m needed to be dredged.

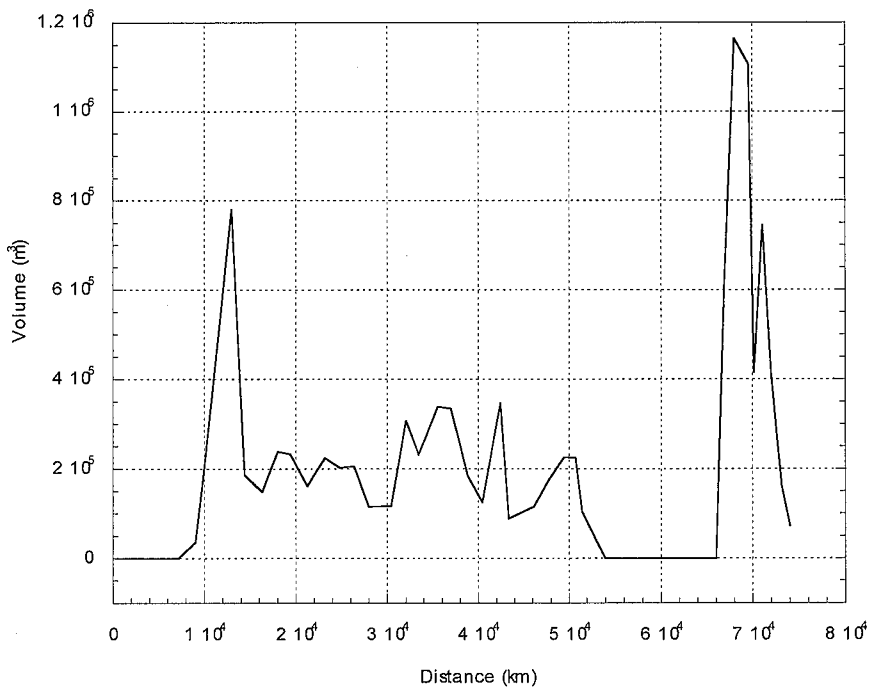


Fig. 3-3-19 Dredging Record in Boca Grande

Moreover, results of depth surveys of the outer channel at Boca Grande performed at April 1997 (pre-dredging) and September 1997 (post-dredging) are used to calculate the average depths along the channel. Cross sections almost every 1km are picked up and the average depth at each cross section is computed. Fig. 3-3-20 shows the longitudinal average depth at every 1km cross-section along the channel, in April and September 1997 as well as the channel design depth. The difference between the channel overall average depth in both cases is about 1.5m. This means that dredging amount was about 13,320,000 m^3.

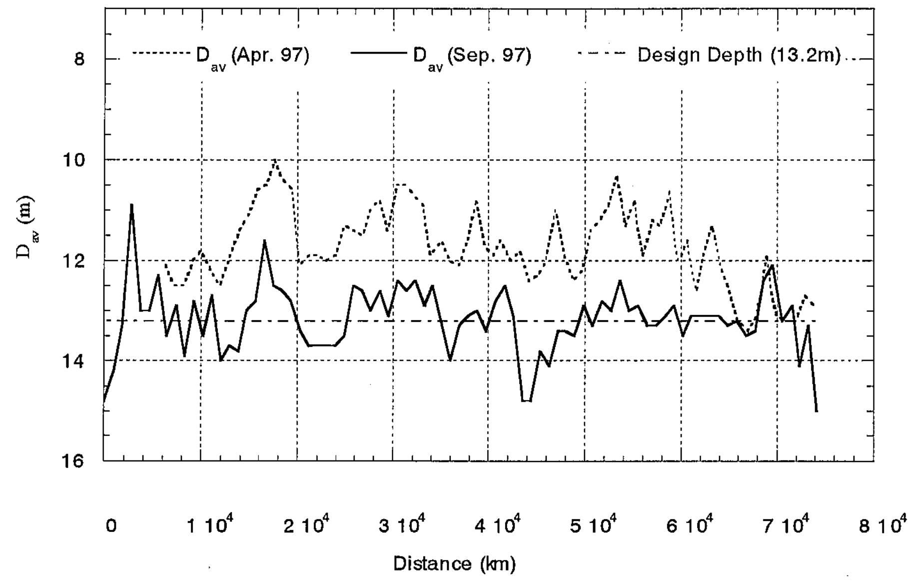


Fig. 3-3-20 Longitudinal Average Depth

From the above figures, it can be seen that the average dredging depth is increasing in recent years and this is due to that recent efficiency of dredging activities has been decreased. More discussion regarding this matter will be given in section 6.8 of this report. However, it is believed that an average depth of about 0.8-1.0m, based on the dredging record of 1964-1974 period, is more realistic for estimating the annual average sedimentation rate along the channel at Boca Grande.

On the other hand, it is believed that the sedimentation rate at the mouth of Macareo will be less than at Boca Grande for the following reasons.

1. The area is well protected from open sea, i.e. less exposed to wave energy.
2. The Macareo river discharge is much less than that of Rio Grande.
3. Depth contours in front of Macareo are steeper than those at Rio Grande area.

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