3. NATURAL CONDITIONS OF THE ORINOCO RIVER DELTA

CHAPTER 3. NATURAL CONDITION OF THE ORINOCO RIVER DELTA

3.1 General

The purpose of this chapter is to clarify river and coastal characteristics of the Orinoco River Delta, especially three major distributaries, namely, the Rio Grande, Macareo and Manamo channels (Fig. 3-1), which is the basis of the formulation of a master plan for integrated river improvement of the Orinoco River. The hydrographic basin of Orinoco covers about 1,015,000km^2 and its length is about 2,063km.

The available information on the characteristics of the Delta is still limited, especially on the coastal area. For the study of river characteristics, 1 dimensional mathematical simulation for the whole delta was conducted to supplement the available information.

3.2 River Characteristics

3.2.1 Morphology of the Delta

The Orinoco Delta (Fig. 3-2-1) is influenced by 6 major factors that basically control its geologic framework and environmental characteristics as follows[1],

(1) Water and sediment discharge from the Orinoco River.
(2) Longshore currents that transport fine sediments to the Delta from the Amazon region.
(3) Wave, tide and current regime of the continental shelf
(4) Tropical climate of the region
(5) Sea level rise
(6) Tectonic setting of the Delta and its proximity to the South American-Caribbean plate boundary.

The Orinoco River is the major supplier of water and sediment to the Delta and strongly influences water and sediment distribution, especially in the upper Delta. The annual average water discharge in the apex of the Delta is in excess of 36,000 m^3/s, which ranks third largest in the world, and the annual sediment load is about 150 million-ton per year, which ranks about tenth largest in the world. Few data are available to indicate clearly where the Orinoco River sediments are eventually deposited. The sediment from the Orinoco River deposits both in the emergent delta and in the inner continental shelf which is the submerged extension of the Orinoco Delta.

[1] This section 3.2.1 is basically based on "PDVSA/DAO, Characterization of the Delta del Orinoco, Venezuela, January 1999".

In addition, sediment load of about 250 million-ton per year is moved by longshore transport along the coasts of French Guiana, Surinam and Guyana from the Amazon River mouth and eventually deposited in the Orinoco Delta.

The hurricanes and large storms are very rare in the delta and only wave, tide and current regimes basically influence the morphology of the delta.

The ranges of tide level vary along the coast (delta front). The maximum tide level ranges from 1.5 to 1.7 m at Boca Grande and slightly lower tidal ranges occur along central portions of the coast. Also the effects of tides are clearly evident in the large bays such as Boca Grande because fluvial and tidal currents produce a complex networks of funnel-shaped channels. This kind of funnel-shaped channels can be recognized in the mouths of Manamo and Macareo Channels. Waves onshore are directed by the easterly trade winds.

The lower Orinoco Delta shows two distinct channel patterns. Distributaries of the southeastern Delta between Rio Grande Channel and Araguao Channel form anastomosing patterns and discharge into numerous small bays along the Atlantic Coast. In contrast, distributaries located northwest of Araguao Channel typically converge near the coast. Convergent channel patterns are not typically observed in deltas, however, those of the Orinoco Delta could reflect past episodes of mudcape progradation and northwestward deflection of channel courses.

Arcuate beach ridges and sandy accretionary shorelines are common along parts of the northeastern and eastern Delta coast especially between Boca de Mariusa and Boca de Araguao. The arcuate shape of the coast and beach ridges northwest of Boca de Araguao indicates that sand from the Rio Grande and large distributaries is transported northwest by longshore currents and deposited along the coast.

The tropical climate is also a key factor for the development of the delta. This kind of climate contributes not only to the plenty of rainfall and the subsequent high river flow in the Delta but also to the active vegetation growth on the emergent land. As a result peat layer accumulation has developed in the delta.

Sea level is quite possibly the principal factor affecting development of modern deltas and certainly affects the development of the Orinoco Delta as well. It is said that 18,000 years ago the sea level was 125 m below the present level. As glaciers melted and sea level rose, shorelines shifted landward across the shelf until about 6,500 years ago when sea level rise decelerated and deltas prograded seaward, resulting in the deposition, especially due to sedimentation.

Holocene and late Pleistocene sea level histories in the vicinity of the Orinoco Delta are poorly known. It can be said that the present broad triangle delta area was surrounded by the Guayana Shield at the southern boundary and the Quaternary uplands at the western boundary and the present emergent delta was formed by the sediment depositions during the past 10,000 years.

3.2.2 Geometrical Characteristics

(1) Rio Grande Channel

The Rio Grande Channel, the largest branch in the Delta, is managed and maintained as navigation canal by INC. It flows eastward until the Atlantic Ocean, receiving the major tributaries draining the Guyana Shield (the Precambrian shield). Total length of the channel is 339 km from the mile 0 in Boca Grande to Palua and can be divided into 14 sections as shown in Fig. 3-2-3.

For navigation purpose the river sections of Rio Grande Channel have been dredged up to 34 feet (10.2 m) below LWL[2]. There are four (4) main dredging sections as shown in the table of Fig. 3-2-3. The total length of these sections is 146 km, which is about 40 % of the total length of Rio Grande Channel. The dredging sections are briefed below.

1) San Felix Section

The dredging segment in San Felix Section is located from the Palua Port to the San Felix Port along the right bank of the Orinoco River. In the wider section, mid-channel islands are formed and currently deep waterway is formed along the left bank, while the channel along the right bank remains shallow. Since the San Felix Port and Palua Port are located on the right bank, dredging is required to provide deep canal access to these ports.

2) Aramaya - Los Castillos

From San Felix to Los Castillos (Fig. 3-2-4) the channel itself is straight while wide and narrow reaches are formed alternatively. The both banks are formed by geologically old formations and the narrow sections such as Punta Cabrian are very stable because of the exposed rocks.

The downstream sections of Aramaya section (Aramaya to Los Castillos) have mid channel islands (Tapatapa island and Iguana island) developed in wide sections resulting into the deep water path adjacent to the islands. Considering this channel configuration, also in Aramaya section the right side islands might be developed and the discharge might concentrate in the left side and form a deep water path.

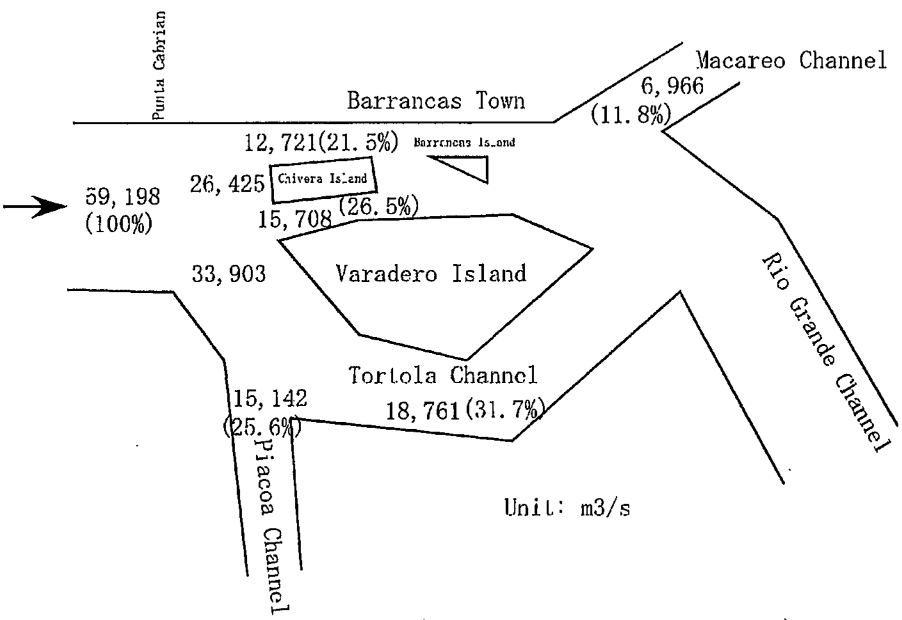
[2] The Datum of Waterlevel Gauge
In river sections of Rio Grande, the waterlevel gauges' data are referred to LWL (N.A.B.; Nivel de Aguas Bajas in Spanish), which is the lowest waterlevel on record. In Boca Grande section, the waterlevel gauges are referred to B.M.M.V. (Bajamar Media de Mareas Vivas), which is the lower low water level (LWL) in the sea. The relation between the elevation above MSL and the referred datum is shown in Fig. 3-2-2.

3) Guarguapo – Barrancas - Ya-Ya

The sections from Guarguapo to Ya-Ya (Fig. 3-2-5) correspond to the vicinity of the Orinoco Delta. As one hypothesis, the past channel was so wide to cover the present left bank of the Rio Grande Channel and the Piacoa Channel. The sections from Guarguapo to Ya-Ya have developed extremely large islands such as Tortola Island, Chivera Island and Varadero Island. Due to the presence of these islands the river flow passing Punta Cabrian is diverted into the Rio Grande canal, Tortola channel and others resulting in decreased discharge for each channel.

According to the discharge measurement conducted by INC-MARNR on September 1995, the discharge of the navigation channel in Guarguapo Section is only 21.5 % of the total upstream discharge because about 80 % of the discharge at Punta Cabrian is flowing to the Tortola(31.7%), Piacoa(25.6%) channels and the channel(26.5%) between Isla Varadero and Isla Chivera. This is the main reason for the sections from Guarguapo to Ya-Ya being shallow.

The ratio of diverted discharge at downstream of Punta Cabrian corresponds to the ratio of the channel widths.



Discharge Distribution (September 1995, by INC-MARNR)

4) Araguaito Section

In this section, the upstream section of the Tres Canos Island is dredged. The sedimentation in Araguaito section can be regarded as a result of local channel configuration. (transition region of S curve).

5) Sacupana – Guasina Sections

At the upstream edge of the Guasina Island (Fig. 3-2-6) the channel width widens abruptly and the 50 % of the upstream discharge is diverted to the Rio Grande channel, not to the navigation canal. This is the main reason for the sections from Sacupana to Guasina being shallow.

6) Downstream of Paloma Section

Paloma section is starting from Vuelta Diablo point and its downstream sections are meandering and have narrow channel widths and deep depths. The ratio of channel width to depth below HWL is comparatively small among all sections of Rio Grande Channel.

The inner side of the meandering sections has regular sandbar formations. The outer side of the channel is lower than 30 m below LWL and its bank slope is approximately 1:2.

7) Downstream of Curiapo Section

These sections are part of funnel-shaped estuary and the channel width is more than 10 km wide. The waterlevel even in rainy season is influenced by tide level. The Curiapo Section (Fig. 3-2-7 and Fig. 3-2-8) has shallow depth corresponding to the discontinuous reaches between tidal channels.

The geometrical and hydrological characteristics of the Rio Grande Channel are shown in Fig. 3-2-9.

(2) Macareo Channel

The Macareo Channel starts from Ya-Ya Section of the Rio Grande Channel and flows northeastward until the Sea, receiving the Tucupita Channel. Total length of the channel is 194 km (Fig. 3-2-10).

The geometrical and hydrological characteristics of the Macareo Channel are shown in Fig. 3-2-11.

In contrast to the Rio Grande Channel, the Macareo Channel width is narrow reflecting its low discharge (15 % of the Rio Grande discharge). This can be seen from the relation between channel width and depth below HWL (Fig. 3-2-12) as well.

The Macareo Channel is an irregularly meandering channel with regular point bars (Fig. 3-2-13). Islands in the channel are not developed since the sand transport as bed load from the Rio Grande Channel is small except for the most upstream reaches of the Macareo Channel.

Natural alluvial dikes composed of sand flank are developed at the upstream reach of the Macareo Channel. A few swamp ponds are also located outside of the natural levees. This river configuration means that the channel flanked by sandy bank is morphologically old and comparatively stable.

The midstream reach is different from that of the upstream. The midstream reach is also meandering like the upstream, however, distinct alluvial dikes are not formed yet.

As an example, at 100 km point, an abandoned cutoff channel is found, which used to be a part of the meandering channel. The separation took place at least after 1953 according to the Navigation Chart of Macareo in 1953. It can be said that the Macareo Channel is still in developing regime as to its morphology.

According to the simulation on riverbed change, the cross sectional average depth is strongly effected by its channel width.

(3) Manamo Channel

The Manamo Channel starts at 20 km downstream of Ya-Ya and flows northward into Atlantic Ocean through Manamo Gate at Volcan, receiving the major tributaries draining Monagas State. The total length is 203 km (Fig. 3-2-14).

The geometrical and hydrological characteristics of the Manamo Channel are shown in Fig. 3-2-15.

The Manamo Channel is an irregularly meandering channel like Macareo Channel, however, its hydraulic condition is quite different.

At 188 km of Manamo Channel, there is Manamo Gate constructed by CVG in 1960s for the purpose of flood control and agricultural land development. This gate is a sluice gate to control the upstream waterlevel. The operation started in 1967. The Manamo Channel is divided into two (2) separate reaches by this gate.

At the upstream of the gate there are several islands resulting in sedimentation. This sedimentation is affecting the island located at the most upstream reach of the Macareo Channel.

The downstream of the gate is completely affected by tidal flow because the upstream discharge is fully regulated by the gate even in rainy season.

It can be said that the existing bed elevation profile at downstream of the gate was formed before the closing of Manamo Channel because no sediment movement is expected under the present hydraulic condition.

The downstream of 50 km can be regarded as estuary, where the channel width is wide and the channel networks have been developed due to the presence of islands.

3.2.3 Discharge, Waterlevel and Velocity

(1) Rio Grande Channel

1) Discharge of the Channel

The annual average discharge at the head of the Orinoco Delta is estimated to be 35,000 m^3/s. The monthly discharge in August (rainy season) and March (dry season) at the head of the Orinoco Delta are 68,000 m^3/s and 7,200 m^3/s, respectively (Fig. 3-2-16 and Table 2.3.1).

2) Water Level at Palua Station

The results of frequency analysis for the maximum and minimum water level at Palua station is shown in Fig. 3-2-17. The frequency of maximum water level follows the Normal Distribution, however, the frequency of minimum water level has distribution in the range of small non-exceedance probability compared with Normal Distribution. Log Normal Distribution shows a good fit with the frequency distribution of the minimum water level, especially in the range of small non-exceedance probability.

Table 3.2.2 shows the probable water level by return period at Palua Station.

Fig. 3-2-16 also shows the water level at Palua Station. The maximum water level on record is MSL+12.58 m on August 4th in 1976 and the minimum water level on record is MSL+0.41 m on April 8th in 1964. The return periods for the maximum and the minimum events are estimated to be approximately over 100 years and 60 years, respectively (Table 3.2.2).

3) Water level of Rio Grande Channel

Table 3.2.3 shows the statistical information on tide level in Boca Grande, the mouth of Rio Grande based on the tide projection data in 1998 (INC). Only in the case of 1998, the mean tide level is 0.13 m above Mean Sea Level (MSL). The HWL and LWL are 1.02 m above MSL and –0.77 m above MSL, respectively.

Table 3.2.1 MONTHLY WATER LEVEL AND DISCHARGE AT PALUA STATION

Waterlevel

Unit: MSL+m

Month	Period 1943-1998			Period 1943-1998			1996	1997	1998
	Average of Historical Daily Maximum	Average of Historical Daily Value	Average of Historical Daily Minimum	Maximum of Monthly Average	Average of Monthly Average	Minimum of Monthly Average	Monthly Average		
Jan.	4.26	2.47	1.19	4.13	2.47	1.25	2.53	3.64	1.69
Feb	3.36	1.63	0.72	2.87	1.63	0.78	2.06	2.40	1.35
Mar	2.83	1.36	0.56	2.76	1.36	0.67	2.14	2.25	1.48
Apr	3.33	1.71	0.68	3.27	1.71	0.79	1.85	1.86	1.91
May	7.38	3.97	1.50	7.38	3.97	1.57	3.51	3.75	4.99
Jun	9.36	7.11	3.51	9.21	7.11	3.63	7.20	6.74	7.78
Jul	11.44	9.48	6.13	11.44	9.48	6.13	10.01	8.96	10.48
Aug	12.27	10.74	8.58	12.24	10.74	8.65	11.26	10.02	11.28
Sep	11.48	10.40	8.35	11.39	10.40	8.38	10.93	8.63	11.02
Oct	10.22	8.53	5.84	10.02	8.53	5.96	9.39	5.99	8.71
Nov	9.09	6.36	4.22	9.07	6.36	4.27	7.10	4.27	5.95
Dec	7.30	4.42	2.75	7.26	4.43	2.75	5.58	3.12	5.95
Average	7.69	5.68	3.67	7.59	5.68	3.74	6.13	5.14	6.05

Discharge

Unit: MSL+m

Month	Period 1943-1998			Period 1943-1998			1996	1997	1998
	Average of Historical Daily Maximum	Average of Historical Daily Value	Average of Historical Daily Minimum	Maximum of Monthly Average	Average of Monthly Average	Minimum of Monthly Average	Monthly Average		
Jan.	28,328	16,661	6,055	27,514	16,766	6,692	17,627	24,386	10,919
Feb	22,679	10,108	1,475	19,715	10,154	2,076	14,486	17,144	7,583
Mar	19,451	7,702	-102	18,926	7,680	981	15,334	15,767	8,906
Apr	22,426	10,609	1,113	22,156	10,576	2,177	12,514	12,615	12,411
May	46,808	26,317	9,069	46,804	26,200	9,757	23,670	25,152	32,751
Jun	57,763	45,179	23,698	56,943	45,108	24,368	45,781	43,142	49,062
Jul	68,495	58,412	39,568	68,495	58,316	39,568	61,177	55,597	63,659
Aug	72,611	64,975	53,581	72,486	64,924	53,961	67,639	61,275	67,756
Sep	68,727	63,244	52,259	68,278	63,187	52,444	65,933	53,825	66,416
Oct	62,320	53,201	37,858	61,238	53,183	38,632	57,912	38,742	54,189
Nov	56,341	40,805	28,028	56,214	40,861	28,372	45,267	28,372	38,345
Dec	46,306	29,229	18,980	46,051	29,235	19,000	36,094	21,116	30,130
Average	47,688	35,537	22,632	47,068	35,516	23,169	38,620	33,094	36,844

Table 3.2.2 PROBABILITY ANALYSIS OF WATER LEVEL AT PALUA STATION

Period:1943-1998 (56 years)

Method: Log Peason Type 3, Normal and Log Normal

Annual Minimum					Annual Maximum			
Return Period	Non Exceedance Probability	Minimum Waterlevel in MSL+m			Return Period	Non Exceedance Probability	Maximum Waterlevel in MSL+m	
year	-	Log Peason Type3	Log-Normal Distribution		year	-	Log Peason Type3	Normal Distribution
2	0.500	0.94	0.94		2	0.500	11.18	11.17
5	0.200	0.68	0.68		5	0.800	11.66	11.66
10	0.100	0.57	0.58		10	0.900	11.91	11.91
20	0.050	0.49	0.50		20	0.950	12.11	12.12
30	0.033	0.46	0.46		30	0.967	12.22	12.23
40	0.025	0.43	0.44		40	0.975	12.29	12.30
50	0.020	0.42	0.43		50	0.980	12.34	12.36
60	0.017	0.41	0.41		60	0.983	12.38	12.40
70	0.014	0.40	0.40		70	0.986	12.41	12.44
80	0.013	0.39	0.40		80	0.988	12.44	12.47
90	0.011	0.38	0.39		90	0.989	12.46	12.49
100	0.010	0.37	0.38		100	0.990	12.48	12.52
200	0.005	0.34	0.35		200	0.995	12.61	12.66

Table 3.2.3 Tide at Pedernales and Boca Grande

Datum & Unit: MSL in m

Station	Location		Daily Tide			Spring and Neap Tide	
			High	Low(Ebb)	Diff.	High	Low
Boca Grande	North 8°37'18"	West 60°36'11"	0.76	-0.80	1.57	1.07	-1.02
Pedernales(Manamo Channel)	North 9°59'00"	West 62°14'00"	0.43	-1.04	1.47	0.60	-1.23

Source: Boca Grande 1998 Tide Projection by INC

Source: Pedernales Nov.1998-Mar.1999 Tide Measurement by JICA

The tidal amplitude at Boca Grande exceeds 1.7 m and decreases to 0.6 m at upstream in Barrancas where the river floods during summer give rise to a water level up to 10 m.(Fig. 3-2-18)

The reverse flow due to tidal backwater effect can reach up to Guarguapo section, 278 km upstream from Mile 0 according to the results of simulation.

The tidal range is small, however, compared to the difference between high and low stages of the channel, which ranges from 3.6 m in the middle delta to 10m at Barrancas. During the high water season, the lower delta is almost entirely flooded.

The water level slopes of rainy and dry season are 1/25,000 and 1/210,000, respectively.

The annual maximum and minimum velocity at Barrancas Section are 1.0 m/s and 0.2 m/s as cross sectional average value, respectively.

(2) Manamo Channel

The discharge distribution among Rio Grande, Macareo and Manamo before and after the closure of Manamo Gate is shown in Fig. 3-2-19. Manamo Gate resulted in an annual average discharge of 2,000 m^3/s distributed between Macareo and Rio Grande Channels. The percentage of the discharge of Macareo Channel to Rio Grande increased from 11 % to 14 % at the bifurcation point from the Rio Grande Channel. Before the closure of Manamo Channel with gate, the annual average discharge of Manamo Channel was 2,300 m^3/s.

The discharge through the Manamo Gate at present controlled as 130 m^3/s and 200 m^3/s in dry season and rainy season, respectively.

At present the water level of Manamo Channel varies in a range between 0.7 m and 1.2 m, [3]while before the closure there was about 7 m seasonal variation. The lowest water level on record at the upstream of the gate was 0.12 m (MSL) in 1995.

The annual maximum and minimum velocity at 70 km from the river mouth are 0.5 m/s and 0 m/s as a cross sectional average value, respectively, as a result of tidal flow.

(3) Macareo Channel

Fig. 3-2-20 shows the simulated water level and discharge variations of the upstream reach of Manamo Channel. The water level varies from 7.1 m in August to less than 1 m in March.

The annual maximum and minimum velocities at 140 km from the river mouth are 0.9 m/s and 0.2 m/s as a cross sectional average value, respectively.

---

[3] La Salle, El Rio Orinoco-Aprovechamiento Sustentable, pp37

3.2.4 Sediment Transport

(1) Orinoco Delta

1) Bed Material

The grading curves of bed material in Rio Grande, Macareo and Manamo Channels are shown in Fig. 3-2-21 to Fig. 3-2-25.

The characteristics of bed material of Rio Grande Channel are as follows,

- Generally the diameter ranges from 0.1 mm to 1 mm.
- The average of Mean Diameter, d_{50}, is 0.4 mm.
- The bed material of Rio Grande is "Medium Sand" and "Very Fine Sand", while finer sand or silt may exist on the river bank.
- The square of geometric standard deviation, $\sigma^2 = d_{84.1}/d_{15.9}$, is 3.3. The bed material of Rio Grande can be treated as an uniform material represented by d_{50}.

Compared with Rio Grande Channel, the bed materials of Manamo and Macareo Channels are composed of finer sand and silt as a resut of low flow velocity due to the water level control by Manamo Gate.

2) Total Sediment Load of the Orinoco River

The total sediment load of the Orinoco River has been evaluated by some researchers from the United States Geological Survey (USGS) over 20 years and it is reported approximately as 150 million ton per year at Musinasio Station.

The amount of bed load is reported to be 34 – 54 million ton per year (approx. 15 million m^3 per year).

It is stated that most of the sediment is transported as suspended sediment and the bed load transport can fall within the range of error of the measured suspended sediment loads[4].

Fig. 3-2-26 shows the suspended sediment concentration measured at Punta Cabrian (INC-MARN) in comparison to the suspended sediment concentration at Puerto Ayacucho (USGS data). The calculated total suspended sediment load at Punta Cabrian is 180 million ton per year, which corresponds to the value of USGS.

---

[4] R.H. Meade ,Suspended Sediment of the Modern Amazon and Orinoco Rivers, Quaternary International,Vol.21,1994

(2) Rio Grande Channel

Fig. 3-2-27 shows the annual variation of shear velocity and ratio of shear velocity to falling velocity of sediment in Rio Grande Channel (1-D simulation results). The following aspects can be explained.

Even in dry season, almost all bed material can move as total bed material load because the shear velocity exceeds the critical shear velocities of bed materials.

The ratios $U_*/W_f=3$ and $U_*/W_f=1$ represent the condition that bed material could suspend up to water surface and that bed material could suspend from the bed, respectively. The average bed material of 0.4 mm in diameter is transported from May to December. The average bed material does not move from January to April.

The sediment finer than 0.1 mm can reach the river mouth without deposition all the year.

The sedimentation takes place at the end of rainy season in all river sections (not only in the dredged sections).

(3) Macareo Channel

The sediment transport mechanism in the Macareo Channel is same as that in the Rio Grande Channel. The present bed elevation fluctuates annually in the range of equilibrium state.

(4) Manamo Channel

The downstream of Manamo Gate has few bed material load except for the tidal reaches. The total suspended sediment load does not contribute to the bed elevation change because the discharge itself is small.

3.2.5 Course Changes due to Meandering and Sand Bar

(1) Orinoco Delta

According to the results of satellite image analysis, the annual river course change is insignificant in the Orinoco Delta.

The difference in the river course between 1987 and 1998 is also minor in the whole delta. The only difference in river course is detected in the mid-channel reaches in San Felix and Barrancas sections.

(2) Rio Grande Channel

There are some major alluvial rivers in the world that can change their course laterally in an order of 1-2 km such as the Bramaputra River in the South Asia. The catchment area of the Bramaputra River (935,000 km^2) is same as the Orinoco River, however, the annual sediment transport is 726 million ton, which is about 3 times of Orinoco.

Since the dredged sections have been fixed for a few decades, the Rio Grande Channel can be said to be comparatively stable. (Fig. 3-2-28)

The sedimentation process in the sections of Noina and upstream of Boca Grande can be recognized based on the comparison between the Navigation Charts of 1959 and 1995. The comparatively fine sediment transported by the river channel is accumulated at the river mouth. (Fig. 3-2-29, 30 and 31)

(3) Macareo Channel

The upper reach of the Macareo Channel is meandering and has levee system with backswamp areas. The bank erosion was recognized in the reach during site visit.

At 100 km, the meandering progressed well, which resulted in cutoff of the channel at least after 1953. The new channel does not have natural levee, which means the channel itself is in progress of meandering in this reach.

Since 1953, the bed elevation was lowered mainly due to the discharge increase by Manamo gate (Fig. 3-2-32).

The Macareo Channel, especially its middle reach, is still in developing phase, from a river morphology viewpoint.

(4) Manamo Channel

In the early time of the Orinoco Delta development process, it is said that the Manamo Channel was the primary stream in the Delta. The Delta has progradated from northwestern part to the southeastern part and the Rio Grande Channel has become the main river in the Delta.

At present, even with the Manamo Gate, the Manamo Channel has already been morphologically matured to allow the main stream flow in the Rio Grande Channel. In this sense it is considered the morphological effect by the gate to the downstream reach of the Manamo Channel is insignificant.

The downstream reach of the Gate is strongly dominated by tidal flow rather than fluvial flow. Hence the tidal channel configuration can be expected further in future.

Sedimentation has proceeded in the upstream reach of Manamo Gate mainly due to the blockage of the bed load by the Gate.

3.2.6 Salinity Concentration

(1) Rio Grande Channel

According to the previous study[5], salinity intrusion is not recognized in the river sections, while tidal flow can reach up to Palua Port, 339 km upstream from Mile 0.

(2) Manamo Channel

According to the previous studies (CVG in 1960's and CVG in 1990's and also refer to Fig. 3-2-33), the salinity intrusion over 500 ppm was recognized at 90 km from the river mouth. It should be noted that according to Fig. 3-2-33 the salinity concentration at the river mouth ranged from 200 ppm to 30,000 ppm in 1964. It was before the closure by the Manamo gate.

After the closure in 1967, the salinity intrusion is recognized up to 90 km from the river mouth. As evidence to supplement the previous studies, the JICA measurement in 1998-1999 (Fig. 3-2-34 to 37) detected salinity concentration only in the river mouth. It means that even at the river mouth under a certain hydraulic condition, the river water is not significantly affected by the sea water intrusion. This is because it is affected by various factors such as the inflow from the tributaries in Monagas State.

(3) Macareo Channel

The JICA measurement in 1998-1999 (Fig. 3-2-34 to 37) detected salinity concentration only in the river mouth. Compared to the Manamo Channel, the Macareo Channel has larger flow with an average discharge of 3,600 m^3/s. Hence salinity intrusion is limited at the most to 30 km upstream from Punta Pescadores.

3.2.7 Navigational River Characteristics

In this section, in order to evaluate the navigational potential of the 3 channels of Rio Grande, Macareo and Manamo, channel length, depth, width, sinuosity and channel stability were considered.

---

[5] Fundacion La Salle, Suspended Matter and Bottom Deposits of the Orinoco Delta, Netherlands Journal of Sea Research, 1978

(1) Channel Length

1.Rio Grande Channel (Palua - Boca Grande 0 km point)	=	339 km
2.Macareo Channel (Palua - Macareo 173 km point - Macareo 0 km point)	=	267 km
3.Manamo Channel (Palua - Macareo 173 km point - Manamo 0 km point)	=	297 km

The Macareo Channel has the shortest route length among the 3 channels, however, their difference is not very significant.

(2) Channel Sinuosity

The Macareo and Manamo channels are irregularly meandering while the Rio Grande Channel is mostly straight or braided with only some meandering sections.

Supposing the vessel length (L) of the Panamax type is 800 feet (240 m), generally the radius of channel should be larger than 4*L=960 meter[6]. The Rio Grande Channel satisfies this condition, however, the Macareo and Manamo Channels do not meet this condition. (Fig. 3-2-38, 39 and 40)

(3) Channel Depth

The cross sectional average depth of the Rio Grande Channel is 11 m below LWL, which is the largest among the 3 channels. Almost all the year round except for a few dry months, the total water depth exceeds 34 feet (10.4 m) in the Rio Grande Channel. (Fig. 3-2-41)

The cross sectional average depths of Macareo and Manamo channels are 8 m and 7 m below LWL, respectively. Rio Grande Channel depth is appropriate for the navigation of large vessel having deep draft. (Fig. 3-2-42)

(4) Channel Width

The minimum and average widths of Rio Grande Channel are larger than that of Macareo and Manamo Channels. Presently in the Rio Grande Channel the Panamax type vessel is navigating under the natural channel width. However the Macareo and Manamo Channels would require significant channel improvement to allow for the navigation of Panamax type vessels. (Fig. 3-2-43)

[6] Ministry of Transportation (Japan), The technical standards for port facilities,vol.2,1989,pp-3

(5) Channel Stability

The morphology of Macareo Channel is still in progress. Although the upstream part of the channel, which belongs to the upper delta, is basically flanked by natural levees, stable channel in the downstream part has not yet formed.

The Manamo Channel itself is extremely stable because the Manamo Gate controls the discharge from the upstream. However, it is very expensive to reconstruct the gate for navigation of Panamax type vessel.

Based on the channel characteristics illustrated above and also summarized in Table 3.2.4, it is concluded that the Rio Grande Channel has the highest potential for navigation.

Table 3.2.4 NAVIGATION POTENTIAL OF 3 CHANNELS

Item	Rio Grande Channel	Macareo Channel	Manamo Channel
Length	339 km including Boca Grande	194 km	203 km
Length of the section its depth is smaller than 34 feet	40 km in river sections and 78 km in Boca Grande	47 km	114 km
Average Depth below LWL	11 m	8 m	7 m
Channel Width (Min / Ave.)	420 m / 2100 m	340 m / 630 m	160 m / 580 m
Channel Pattern	Mostly Straight & Braided / Some sections Meandering	Iregularly Meandering	Iregularly Meandering
Channel Stability	Comparatively Stable	Still in Progress (Cutoff and Bank Erosion)	Used be in Progress, but the downstream reach by the Gate became Stable
Others			Presence of Manamo Gate at 188km
Navigation Potential	○	×	×