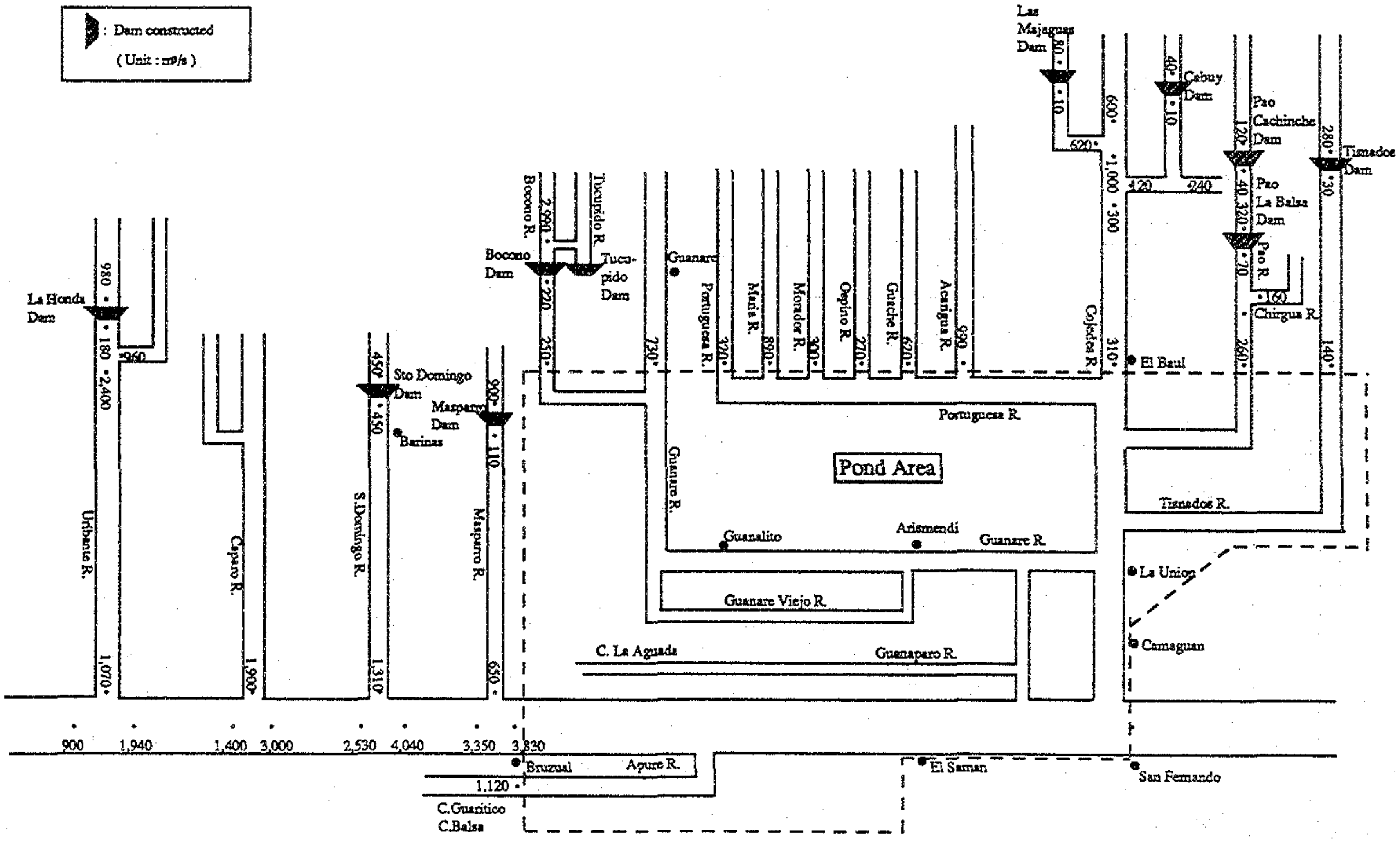

Fig. 5.4.14 Probable Flood Peak Discharge Distribution with Existing Dams (10-year Return Period)

THE REPUBLIC OF VENEZUELA
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OF THE APURE RIVER BASIN

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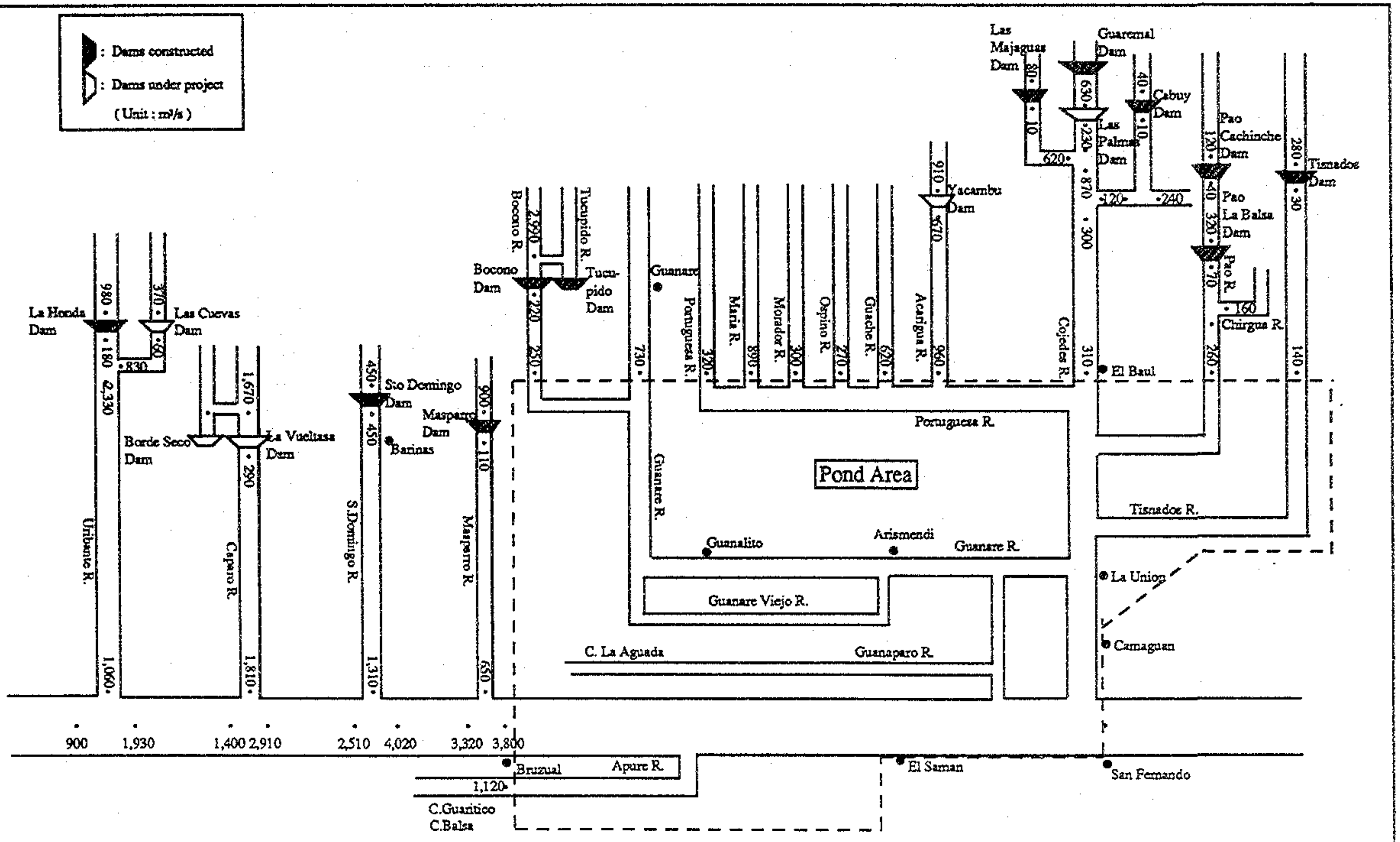

Fig. 5.1.14 Probable Flood Peak Discharge Distribution with Existing and Proposed Dams (10-year Return Period)

THE REPUBLIC OF VENEZUELA
COMPREHENSIVE IMPROVEMENT
OF THE APURE RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

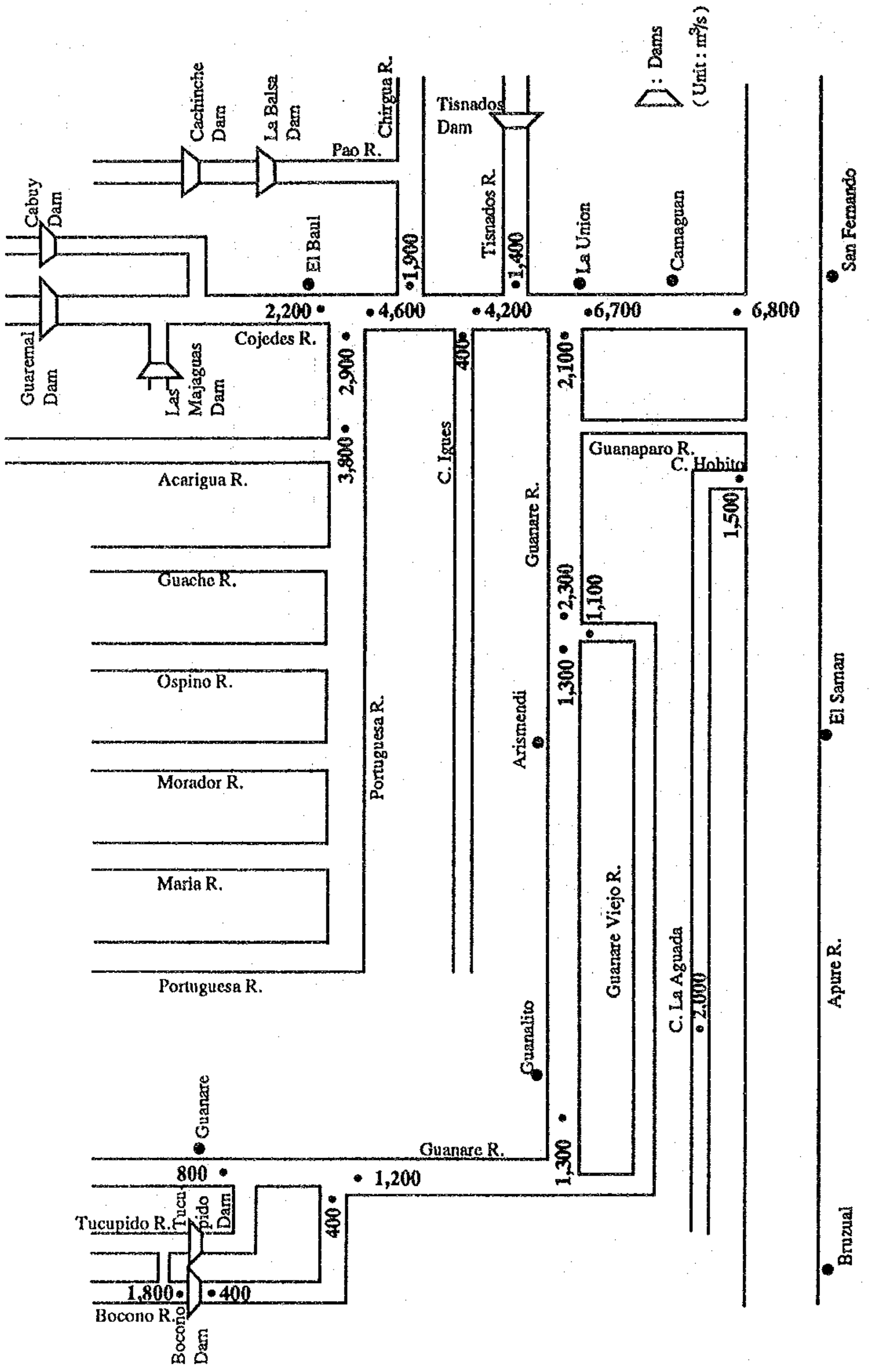

Fig. 5.4.16 Flood Discharge Distribution Under Confinement Condition (Flood in 1976)

THE REPUBLIC OF VENEZUELA
COMPREHENSIVE IMPROVEMENT
OF THE APURE RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

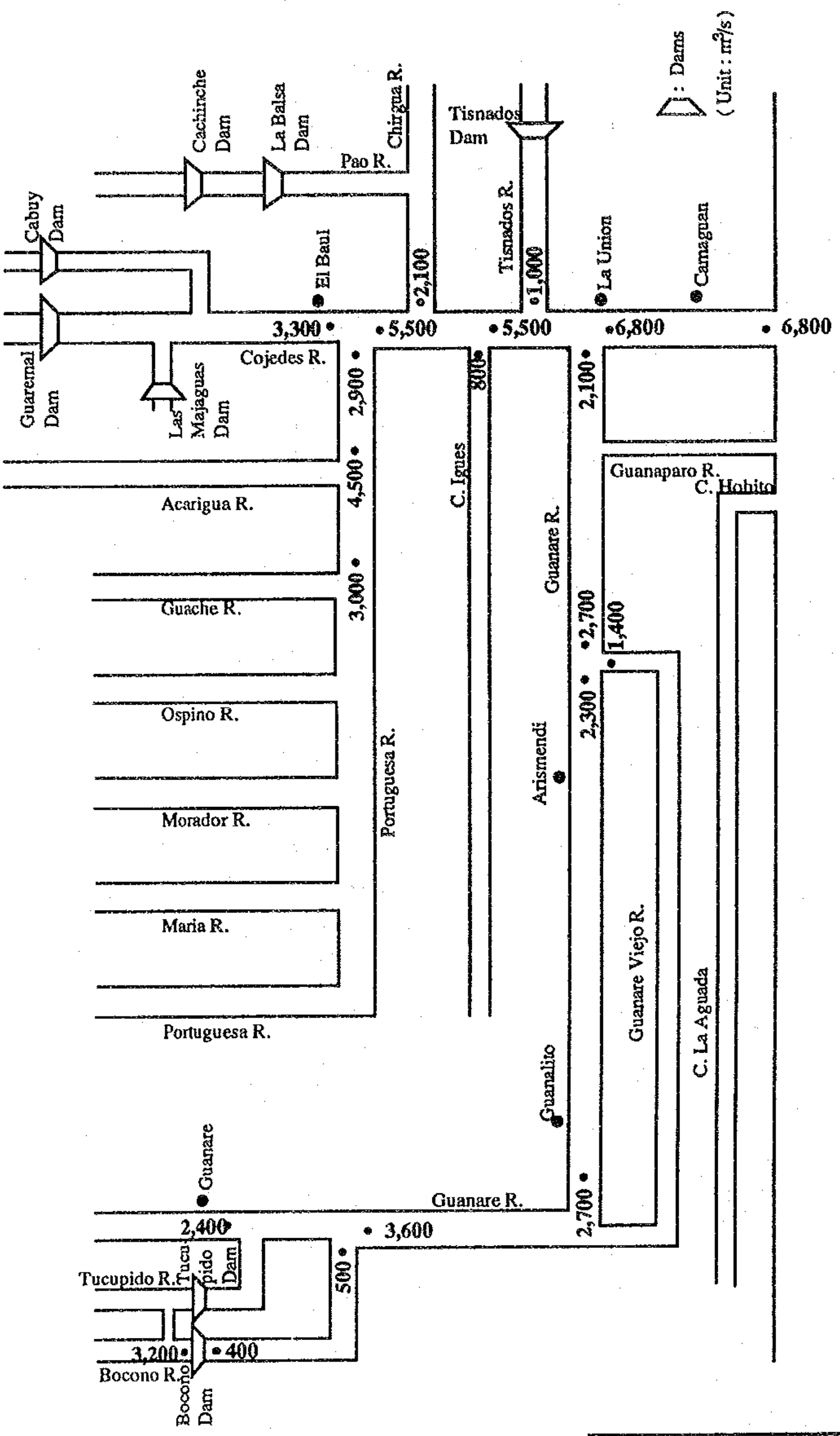

Fig. 5.4.17 Flood Discharge Distribution Under Confinement Condition (Flood in 1981)

THE REPUBLIC OF VENEZUELA
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OF THE APURE RIVER BASIN

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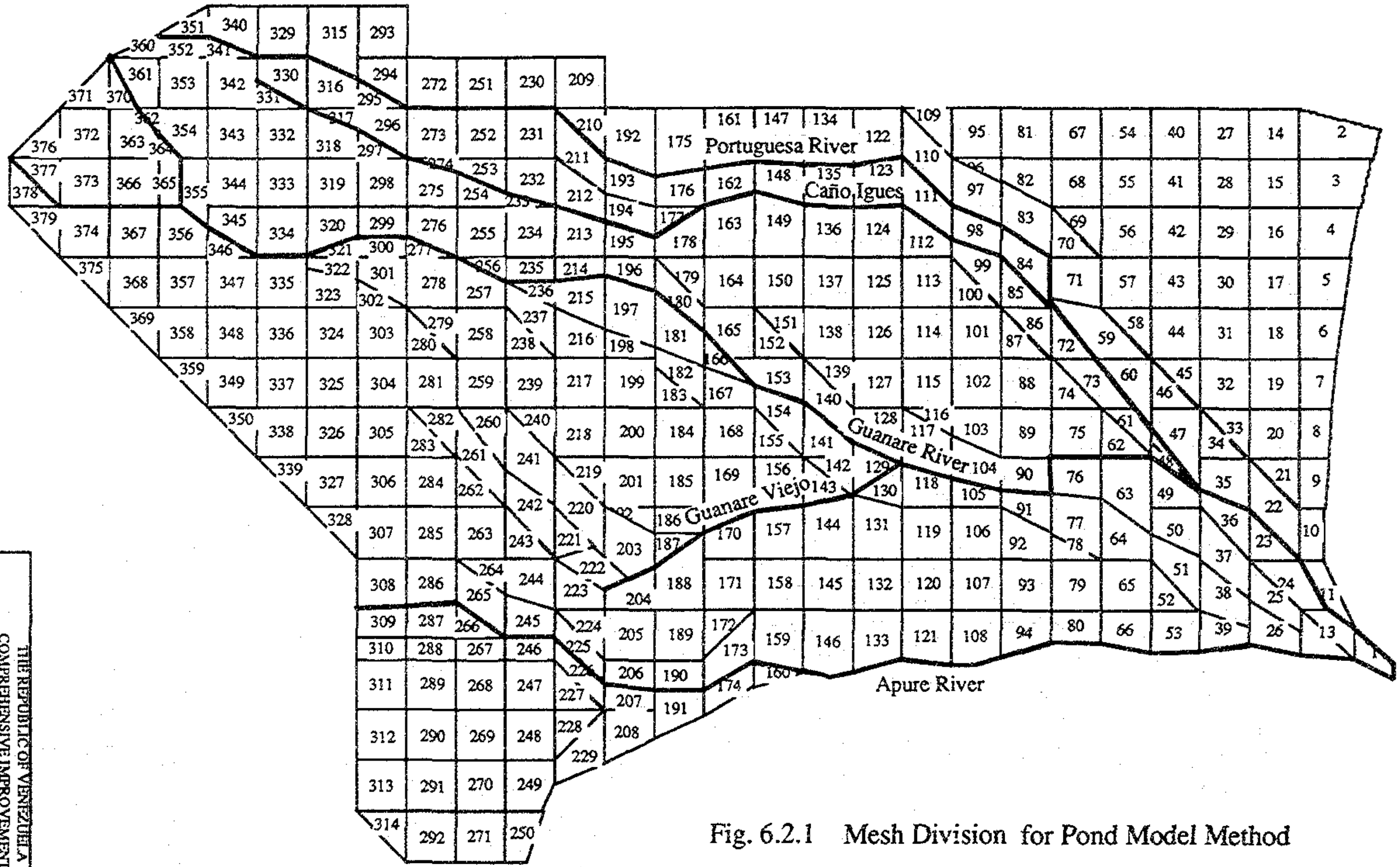

Fig. 6.2.1 Mesh Division for Pond Model Method

THE REPUBLIC OF VENEZUELA
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OF THE APURE RIVER BASIN

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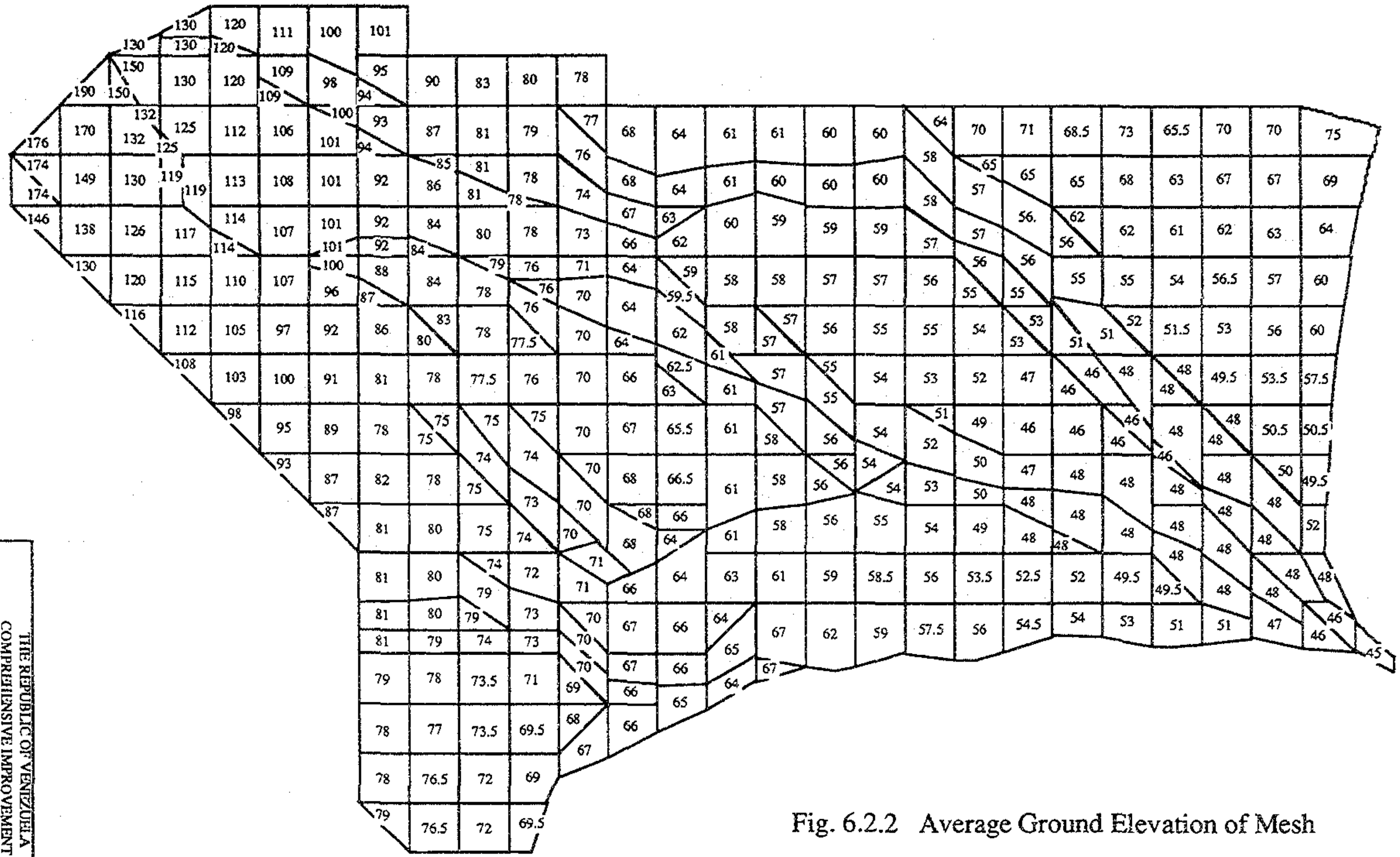

Fig. 6.2.2 Average Ground Elevation of Mesh

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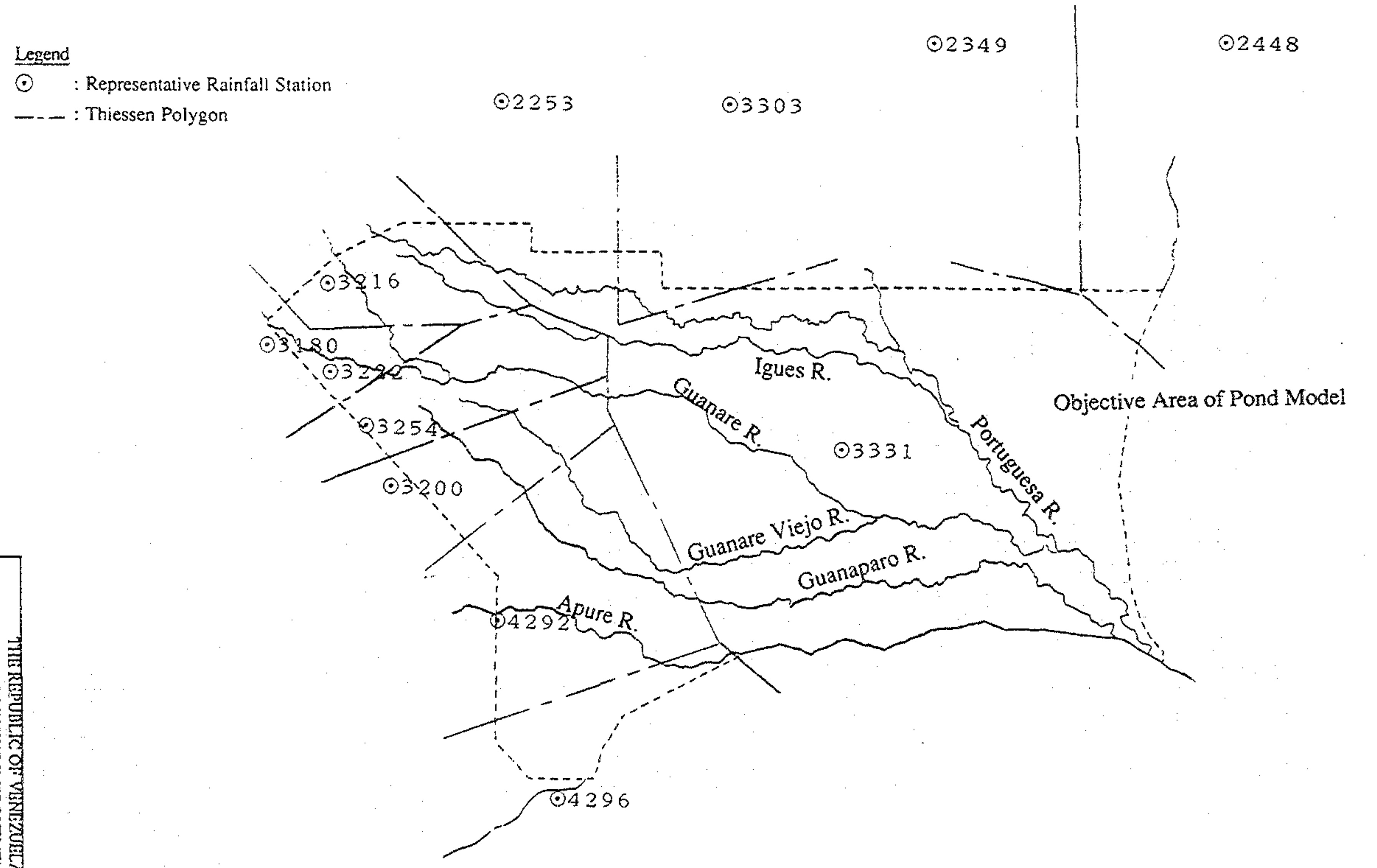

Fig. 6.3.1 Representative Rainfall Stations Used for Pond Model

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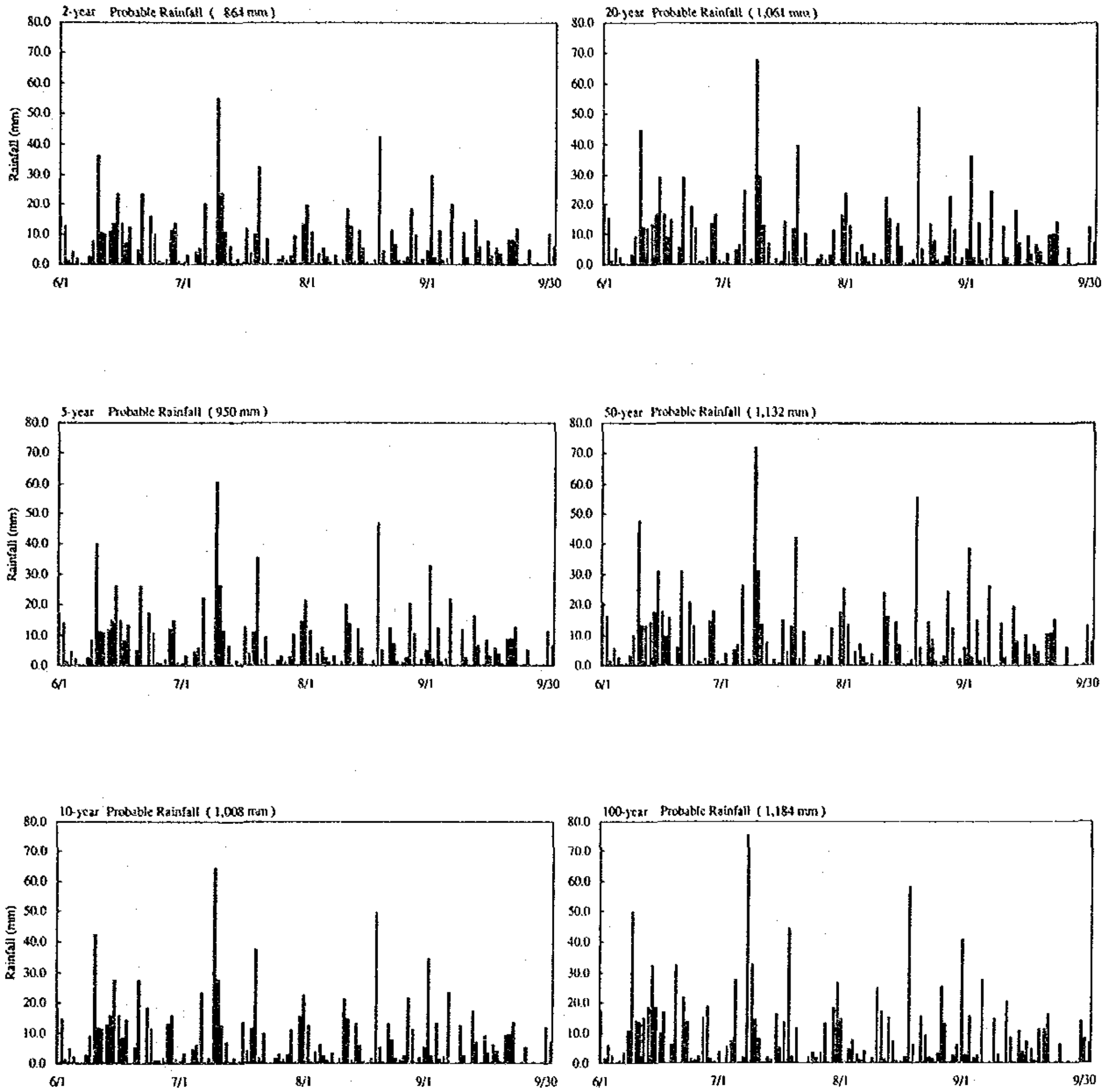

Fig. 6.3.2 Probable Basin Mean Rainfall for Pond Model

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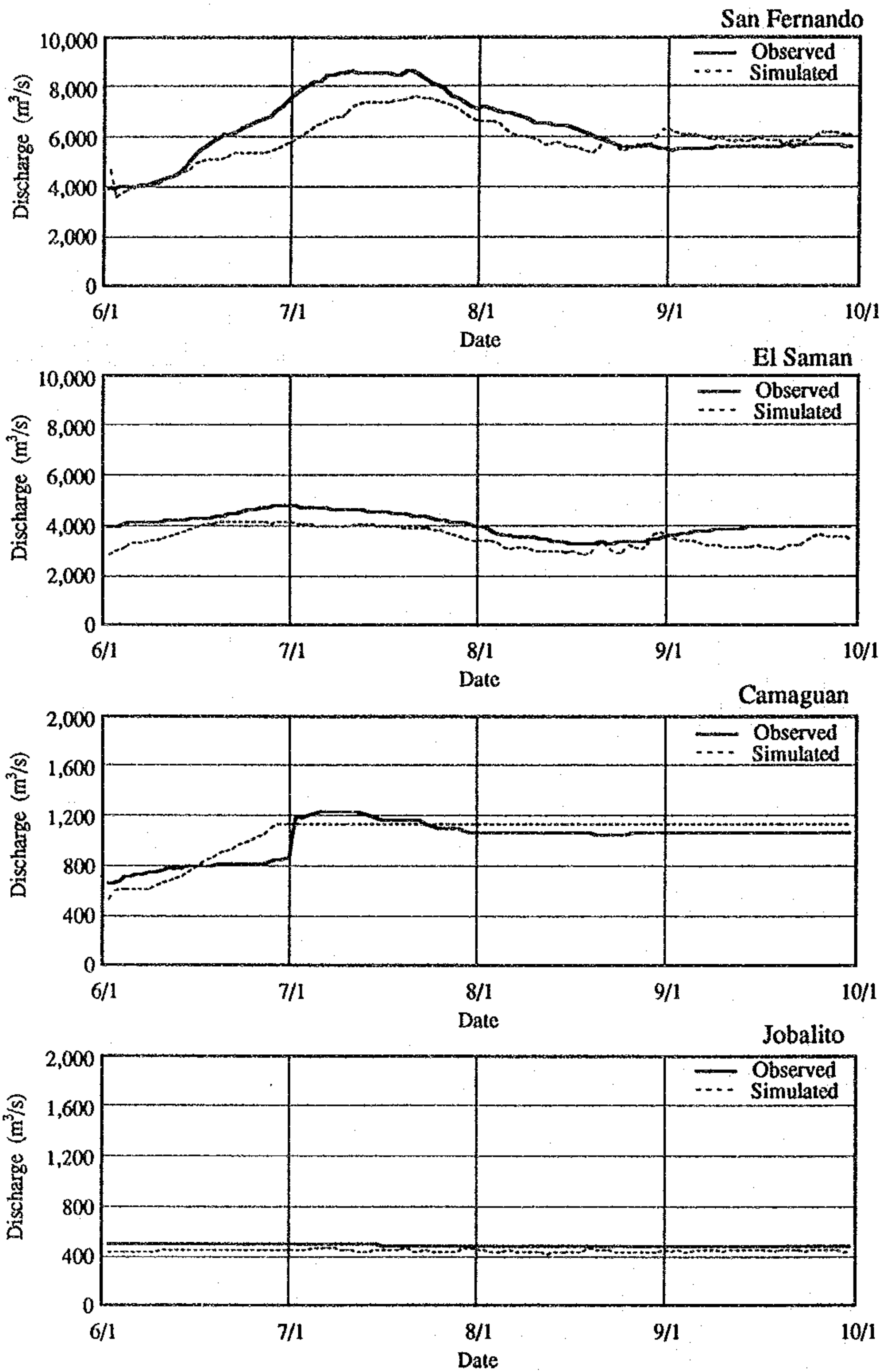

Fig. 6.3.3 Observed and Simulated Hydrographs of Flood in 1981

THE REPUBLIC OF VENEZUELA
COMPREHENSIVE IMPROVEMENT
OF THE APURE RIVER BASIN
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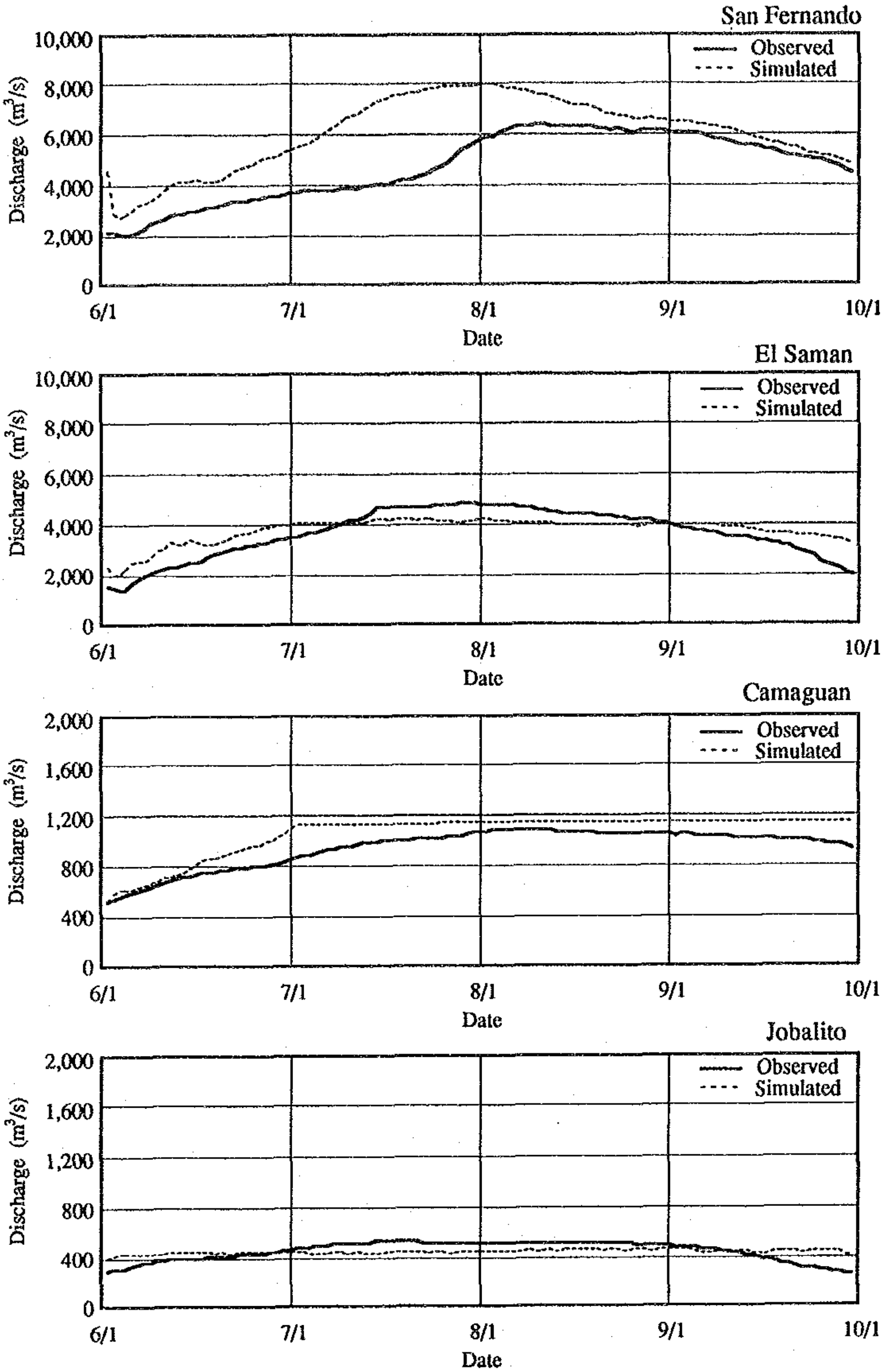

Fig. 6.3.4 Observed and Simulated Hydrographs of Flood in 1976

THE REPUBLIC OF VENEZUELA
COMPREHENSIVE IMPROVEMENT
OF THE APURE RIVER BASIN
JAPAN INTERNATIONAL COOPERATION AGENCY

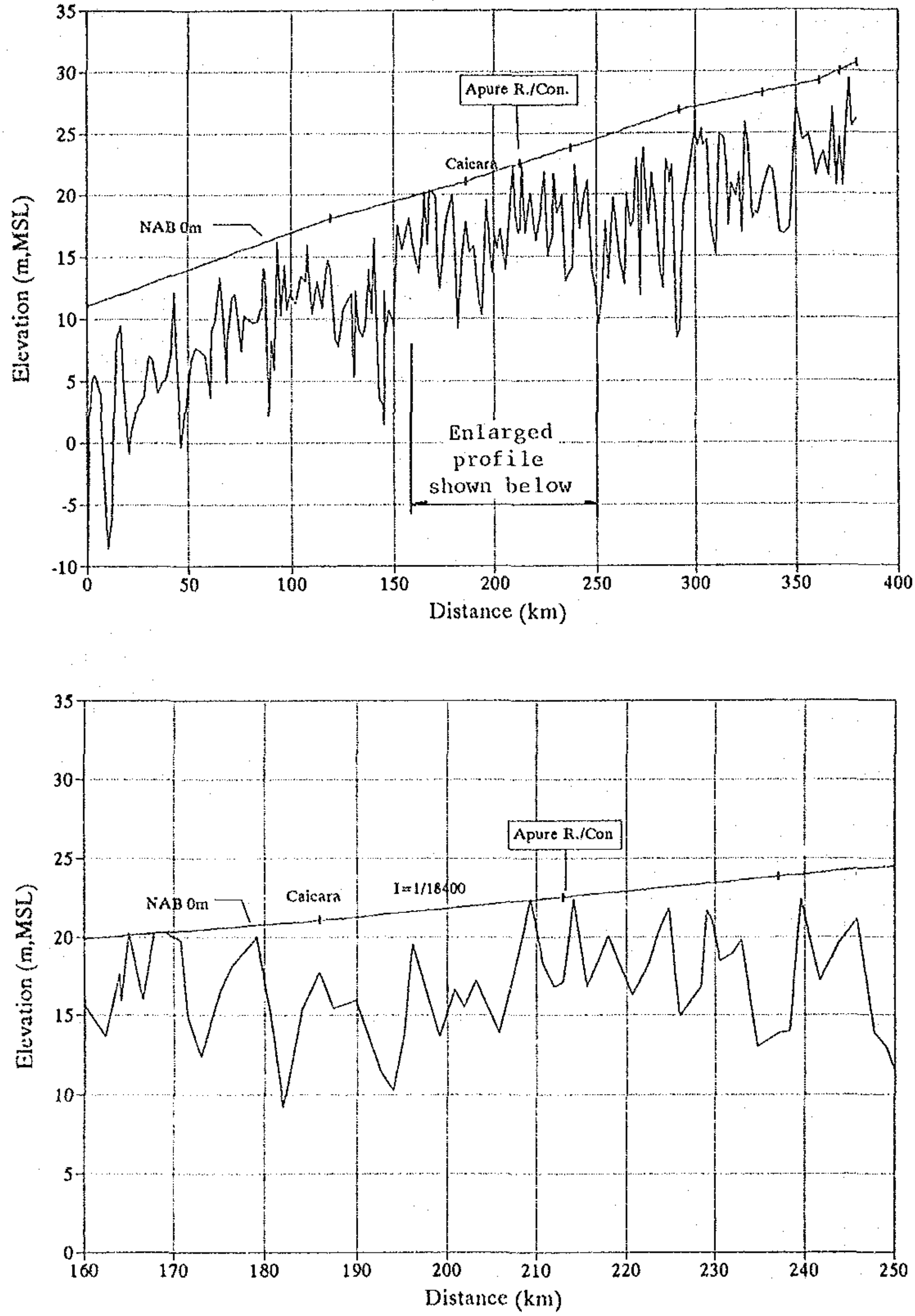

Fig. 7.1.1 NAB of Orinoco River near Apure Confluence

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JAPAN INTERNATIONAL COOPERATION AGENCY

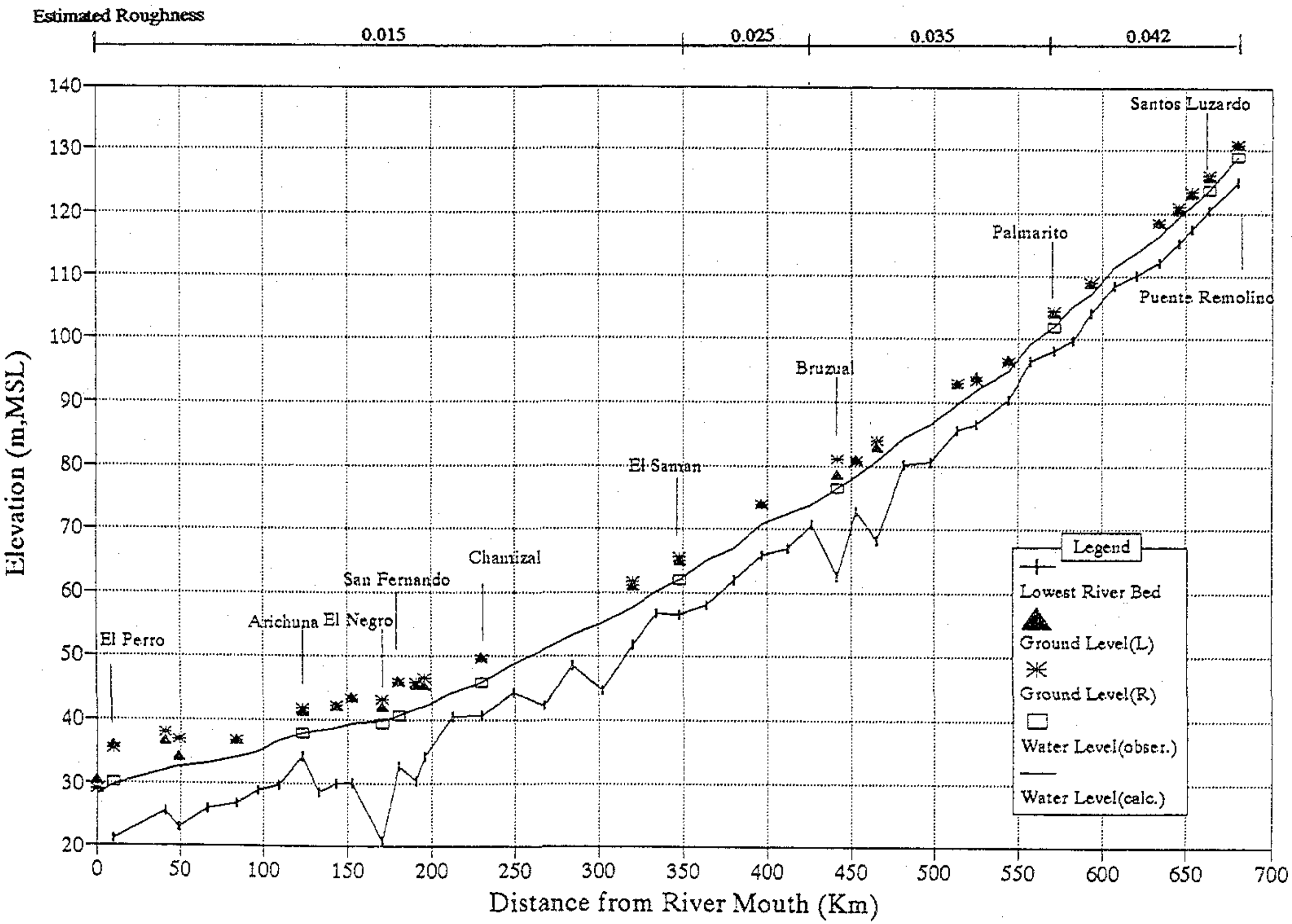

Fig. 7.1.2 Calibration of Non-uniform Flow Model
Water-Level and Discharge = Jun. 1 '92

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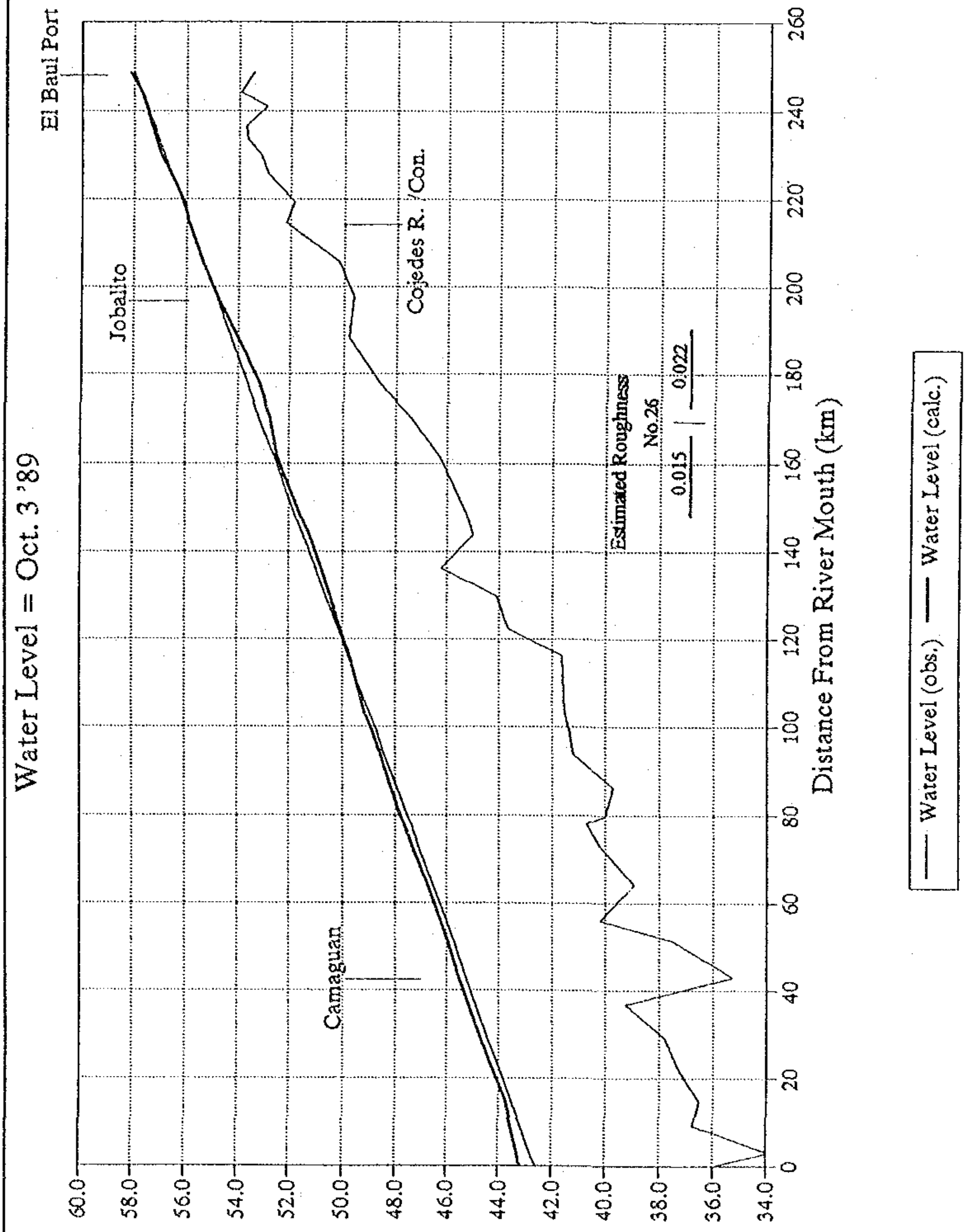

Fig. 7.1.3 Estimated River Bed Profile of Portuguesa River

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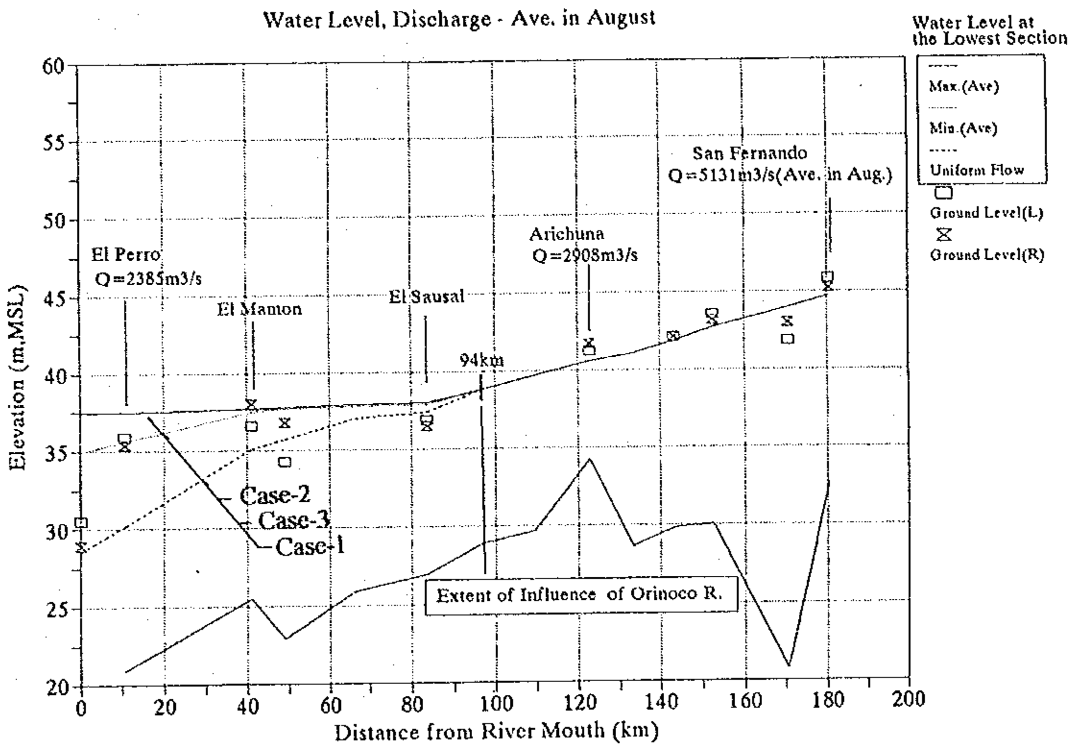

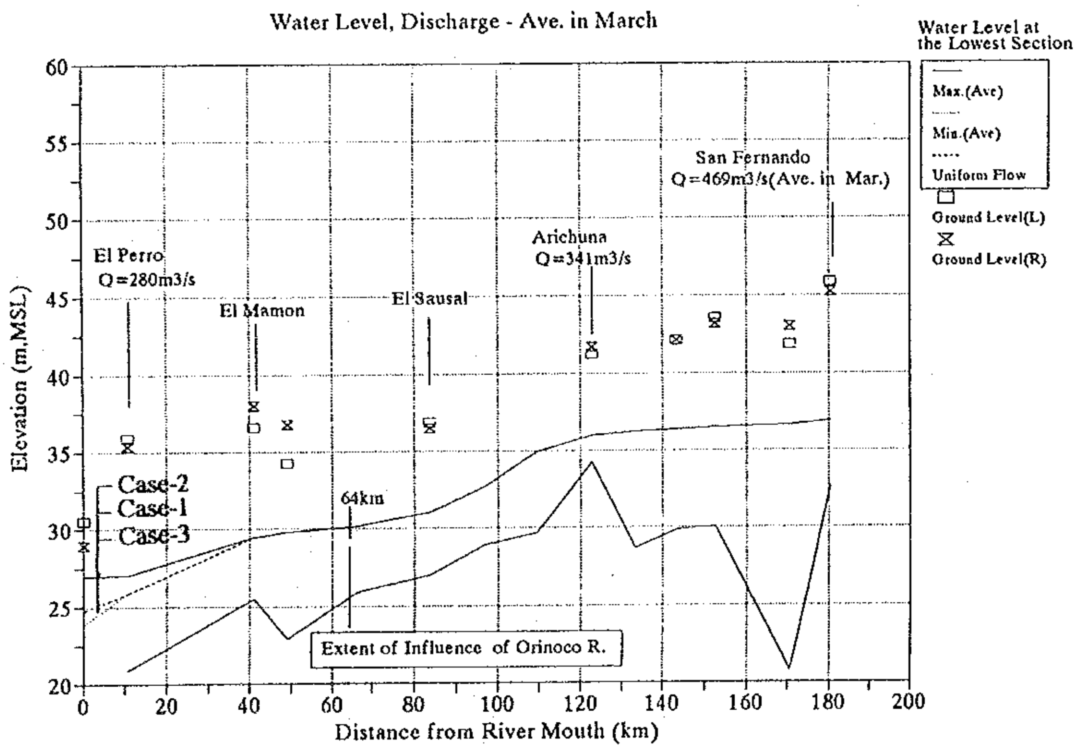

Fig. 7.2.1 Extent of Influence of Orinoco River

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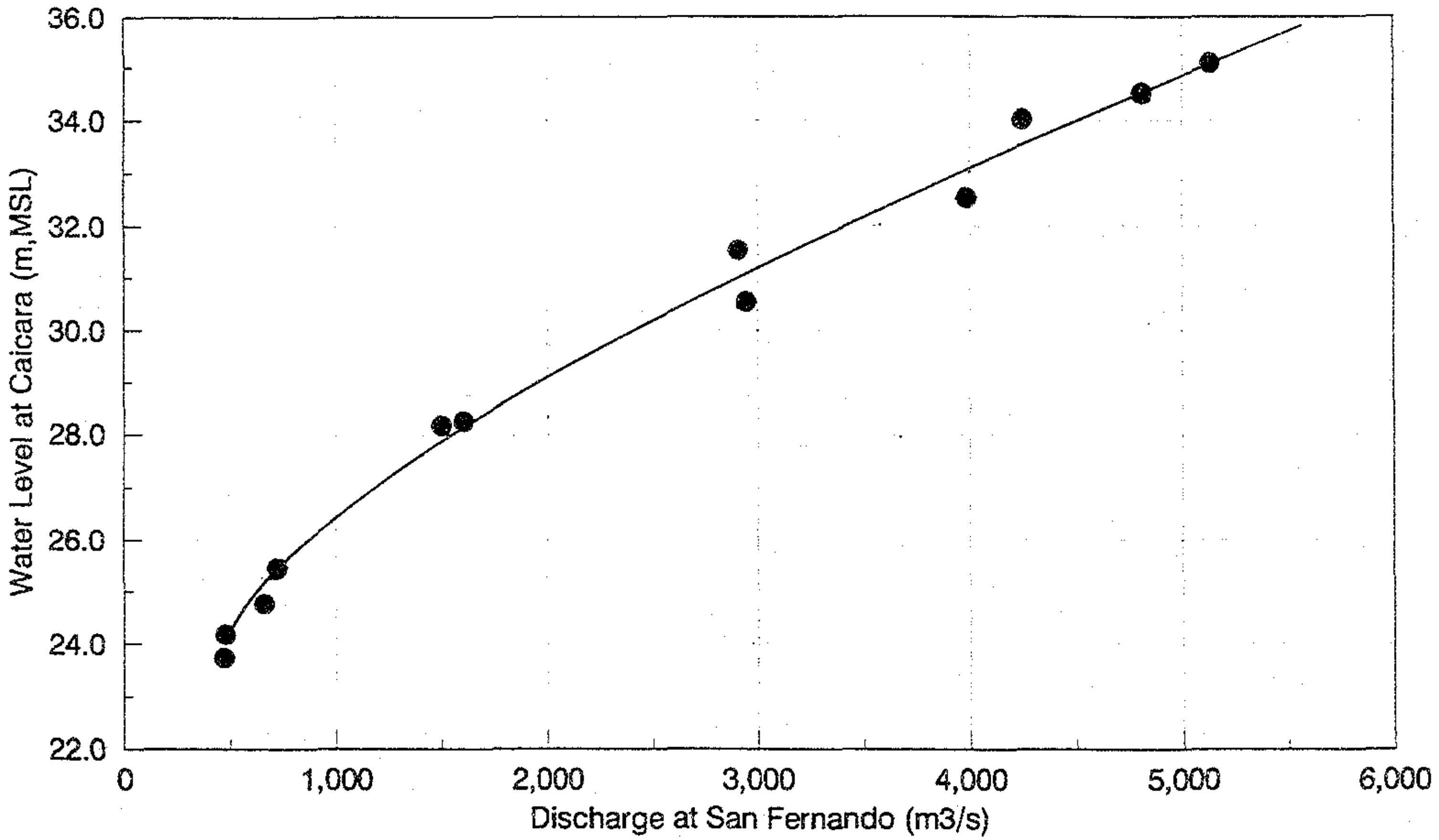

Fig. 7.3.1 Relationship between Monthly Discharge of San Fernando and Water Level at Caicara

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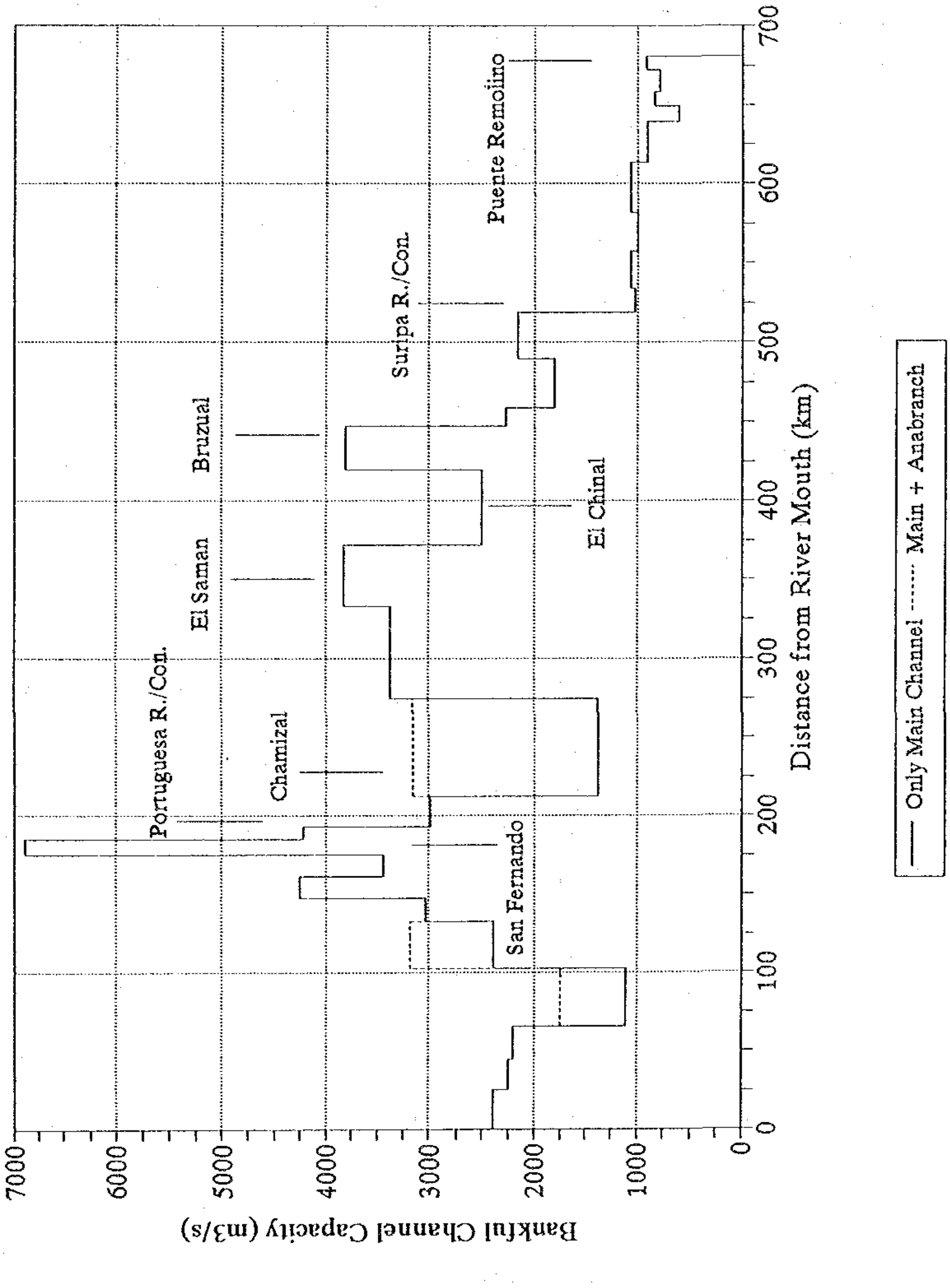

Fig. 7.3.2 Bankful Channel Capacity of Apure River

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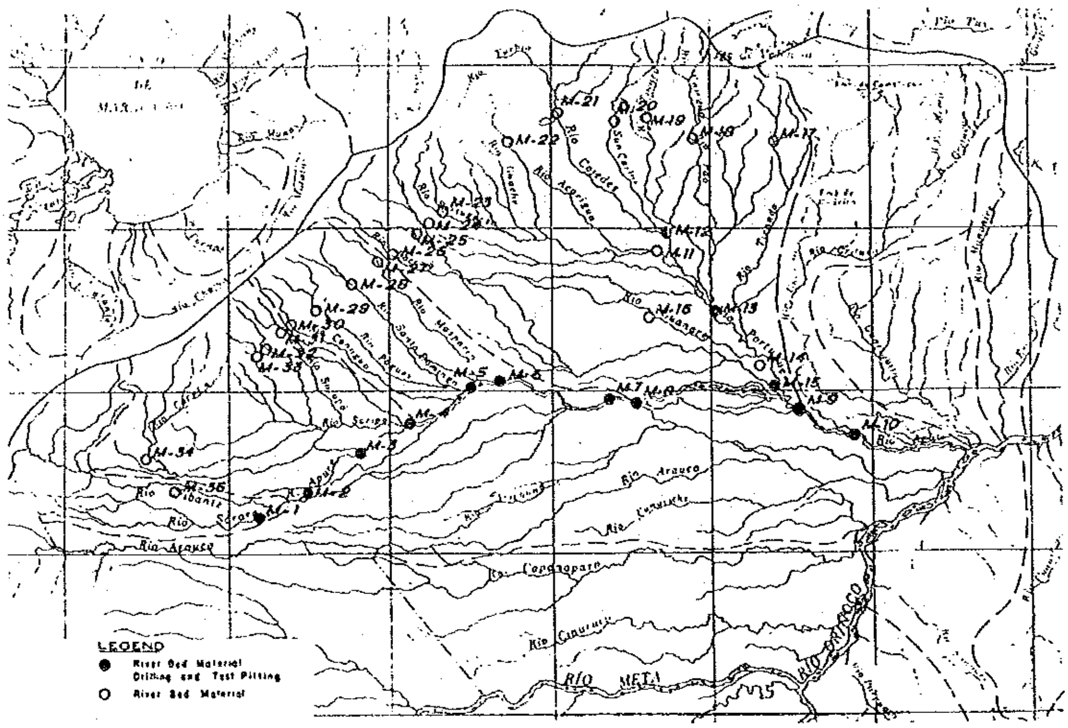

Site	River Bed	Bore Hole	Test Pit
1). Apure River:			
a) Puente Remolino	M-1	P-1	TP-1
b) Torumito	M-2	P-2	TP-2
c) Palmarito	M-3	P-3	TP-3
d) Suripa	M-4	P-4	TP-4
e) San Vicente	M-5	P-5	TP-5
f) Bruzual	M-6	P-6	TP-6
g) El Saman	M-7	P-7	TP-7
h) Apurito	M-8	P-8	TP-8
i) San Fernando	M-9	P-9	TP-9
j) Arichuna	M-10	P-10	TP-10
(Sub-total)	(10)	(10)	(10)
2). Portuguesa River:			
a) Paso La Portuguesa	M-11		
b) El Baul (Cojedes River)	M-12	P-11	TP-11
c) Guadarrama	M-13		
d) El Socorro		P-12	TP-12
e) La Union	M-14		
f) Camaguan	M-15	P-13	TP-13
g Arismendi (Guanare River)	M-16		
(Sub-Total)	(6)	(3)	(3)
3). Tributaries Crossing Route-5 and Route-3:			
a) Verde River	M-17		
b) Pao River	M-18		
c) Tinaco River	M-19		
d) San Carlos River	M-20		
e) Cojedes River	M-21		
f) Acarigua River	M-22		
g) Portuguesa River	M-23		
h) Guanare River	M-24		
i) Tucupido River	M-25		
j) Boconó River	M-26		
k) Masparo River	M-27		
l) Santo Domingo River	M-28, 28A, 28B		
m) Paguey River	M-29		
n) Canagua River	M-30		
o) Acequia River	M-31		
p) Bumbum River	M-32		
q) Socopó River	M-33		
r) Caparo River	M-34		
s) Uribante River (Guacas)	M-35		
(Sub-Total)	(21)	(0)	(0)
4). Orinoco River:			
a) Puerto Ordaz (1)	M-36		
b) Puerto Ordaz (2)	M-37		
(Sub-total)	(2)	(0)	(0)
Total Nos. Sites	(39)	(13)	(13)

Fig. 7.4.1 Location of Soil Investigation Sites

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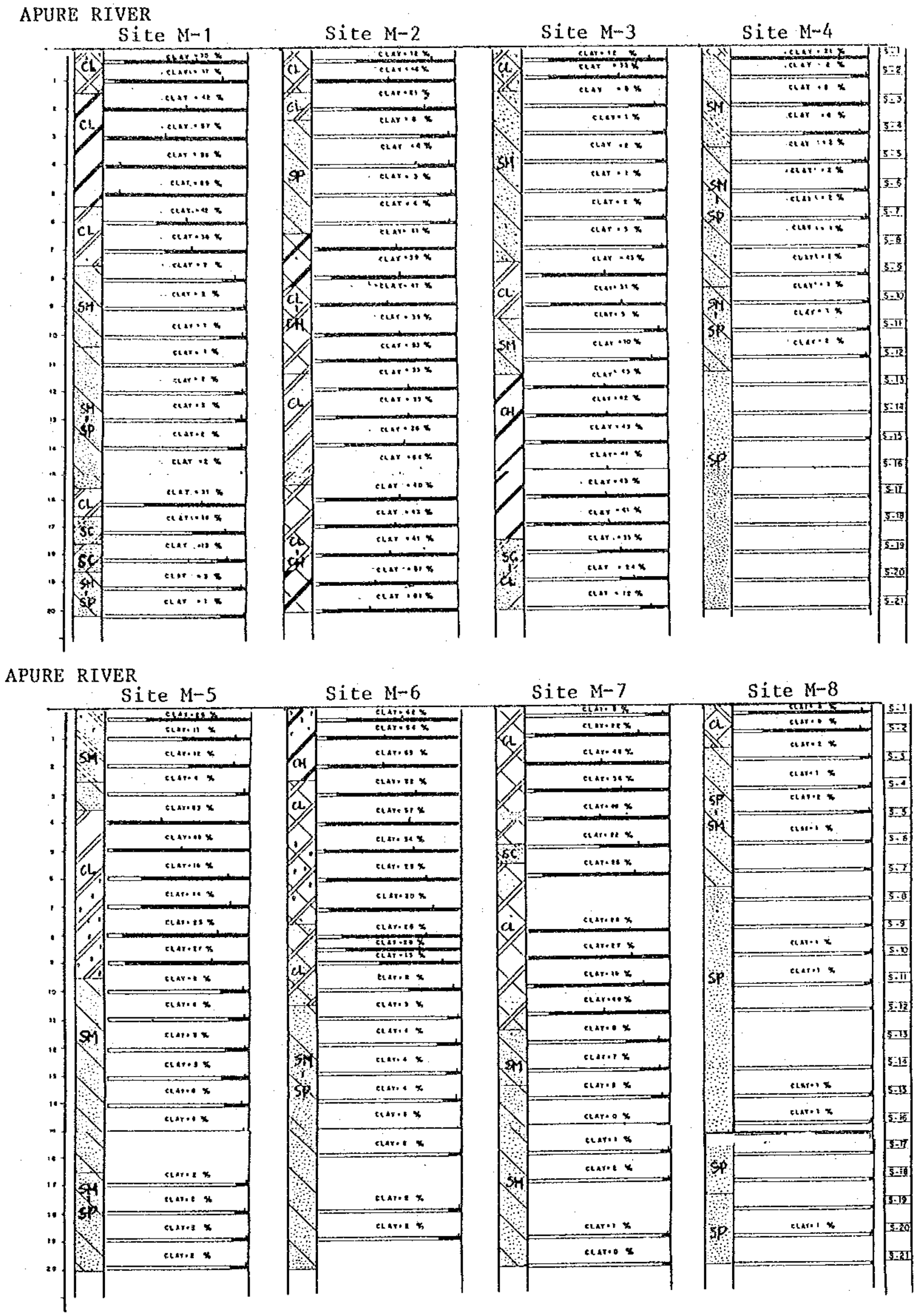

Fig. 7.4.2 Boring Logs Along Apure and Portuguesa River (1/2)

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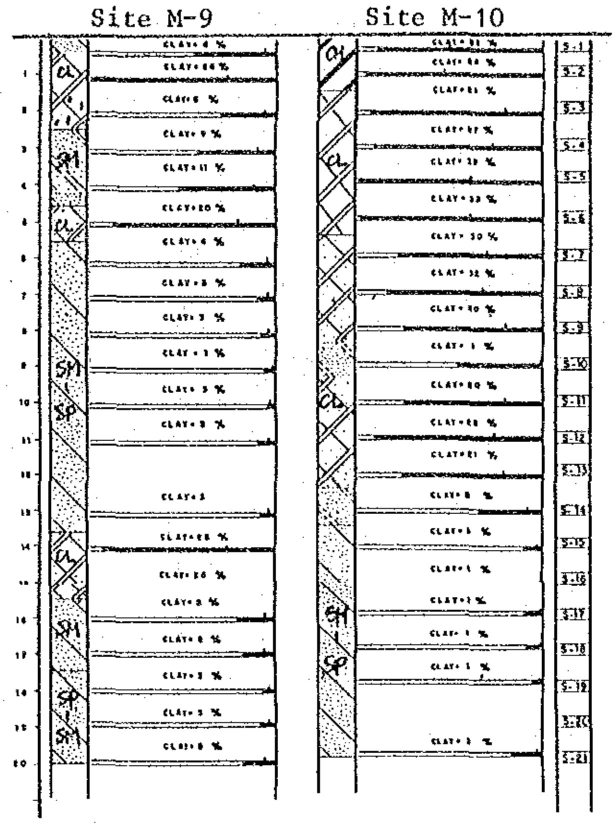
APURE RIVER



REMARKS:

CL: Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
CH: Inorganic clays of high plasiticity, fat clays.
SP: Poorly graded sands, gravelly sands; little or no fines.
SM: Silty sands, poorly graded sand-silt mixtures.
SC: Clayey sands, poorly graded sand-clay mixtures.

PORTUGUESA RIVER

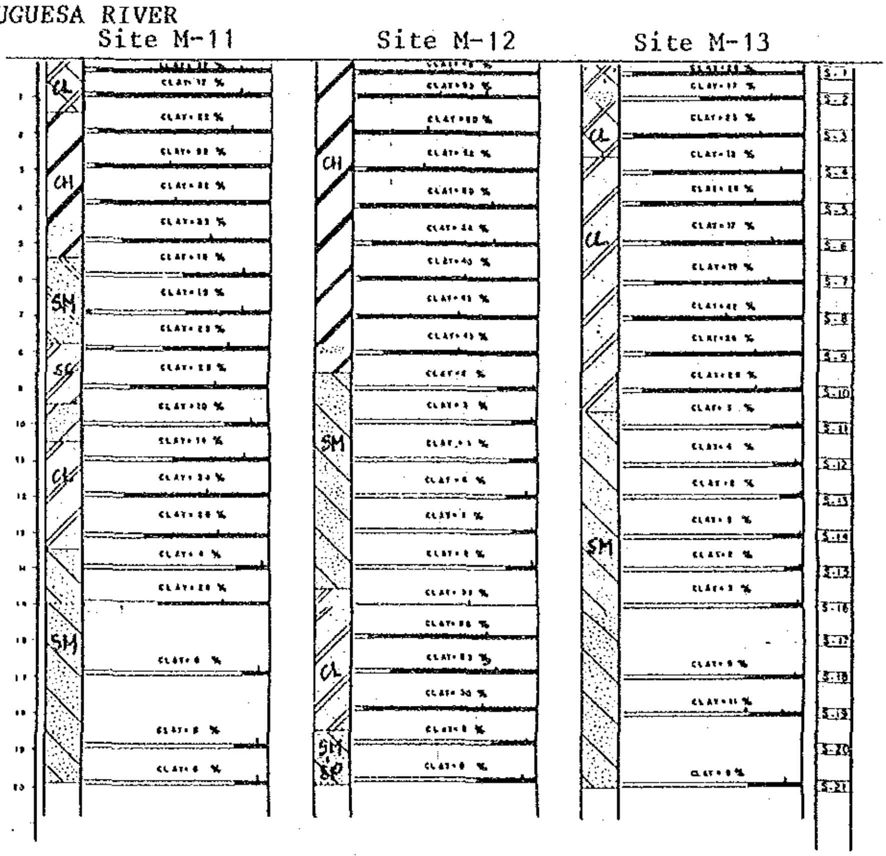


Fig. 7.4.2 Boring Logs Along Apure and Portuguesa River (2/2)

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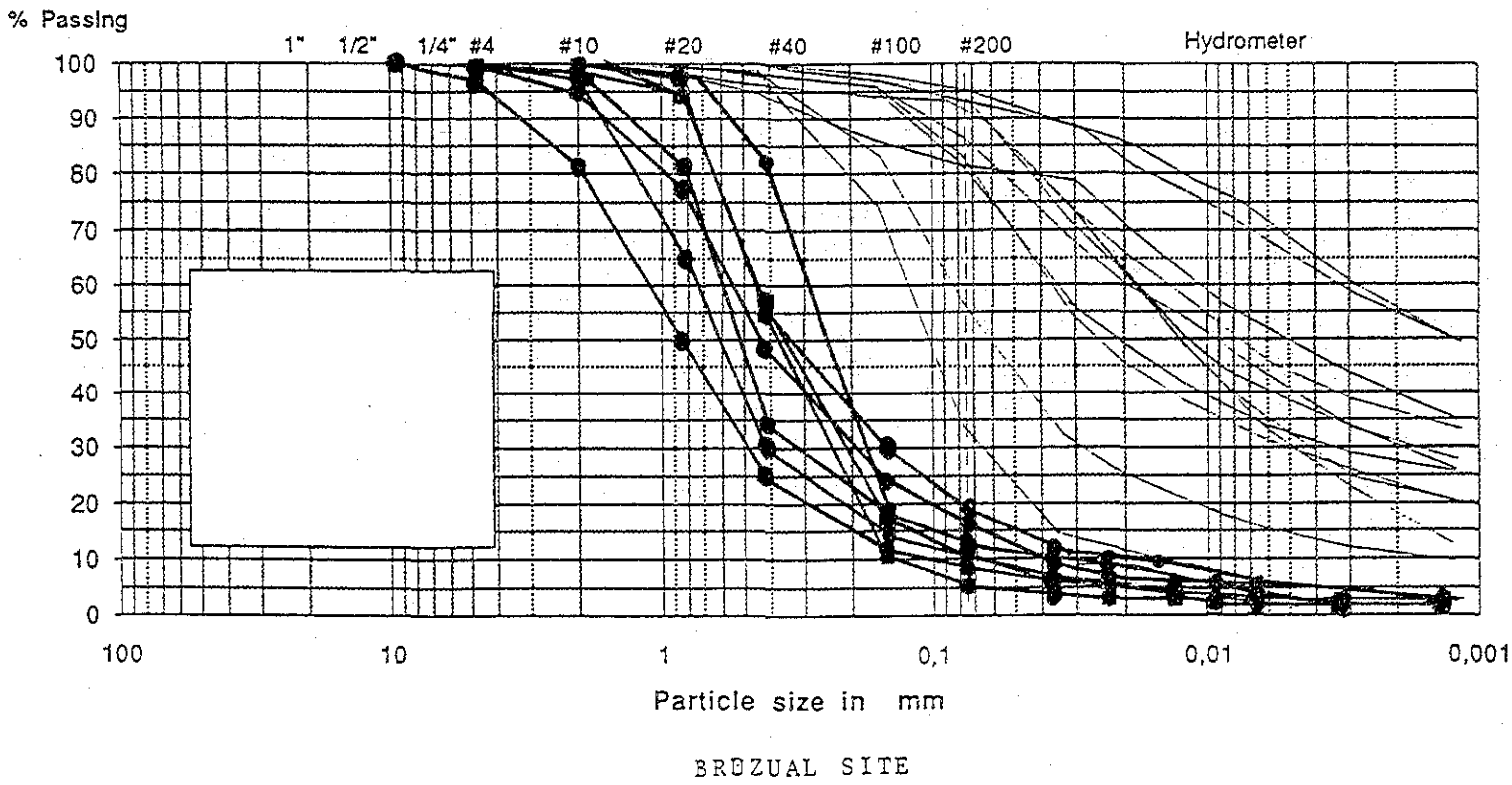

Fig. 7.4.3 Grading of Borehole Sample at Bruzual

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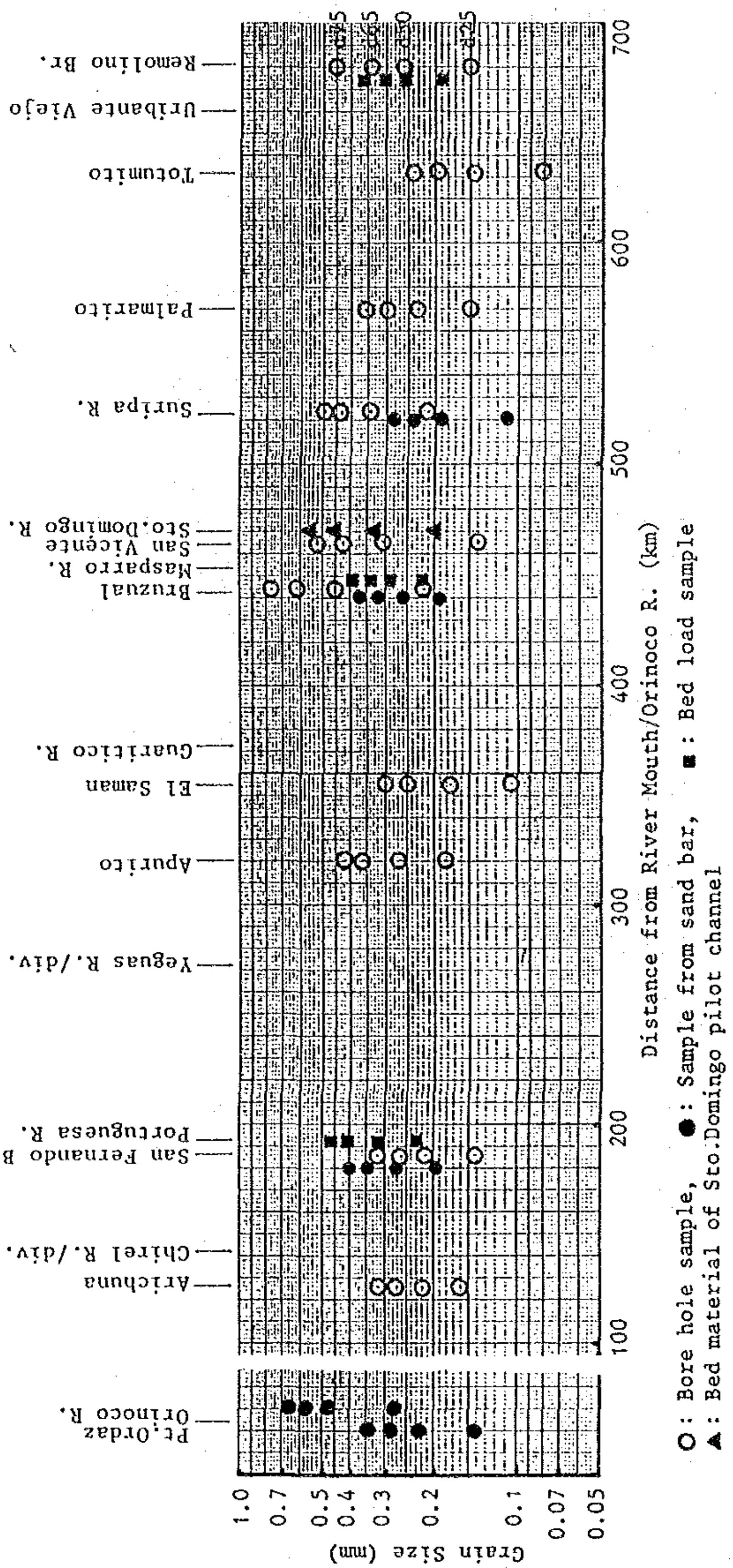

Fig. 7.4.4 Average Grain Size of Sandy Soils

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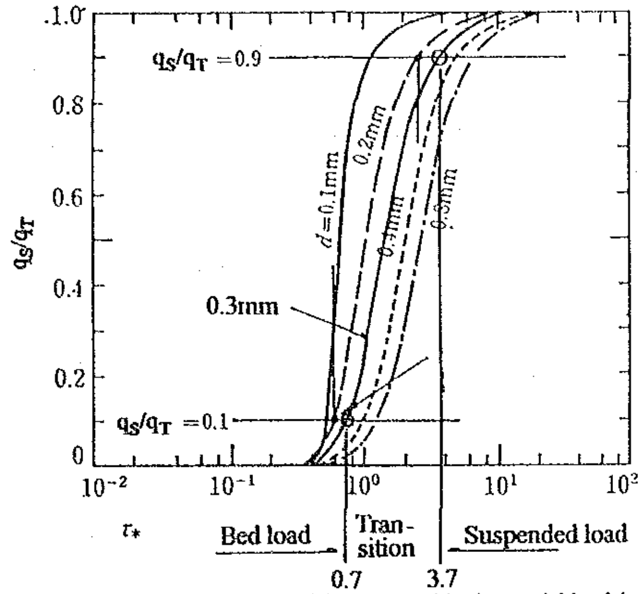
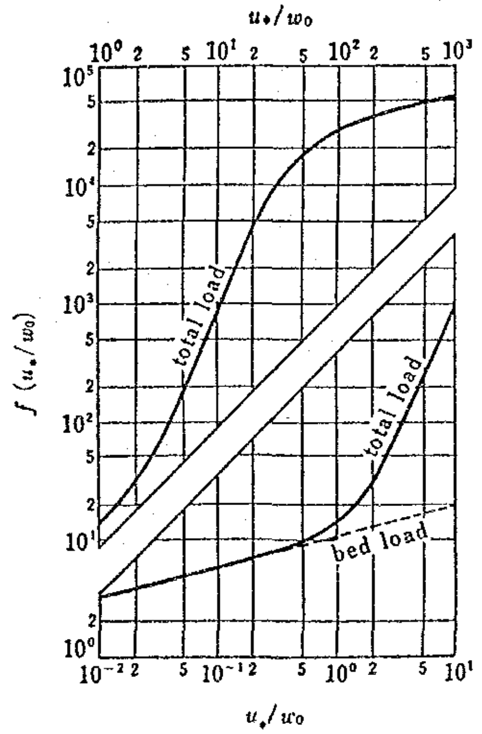


Ratio of suspended load (q_S) to total bed material load (q_T)
(Tsujimoto and Nakagawa)



Relationship between $f(u_*/w_0)$ and u_*/w_0 (Albertson)

Fig. 7.4.5 Empirical Diagrams for Sediment Flow

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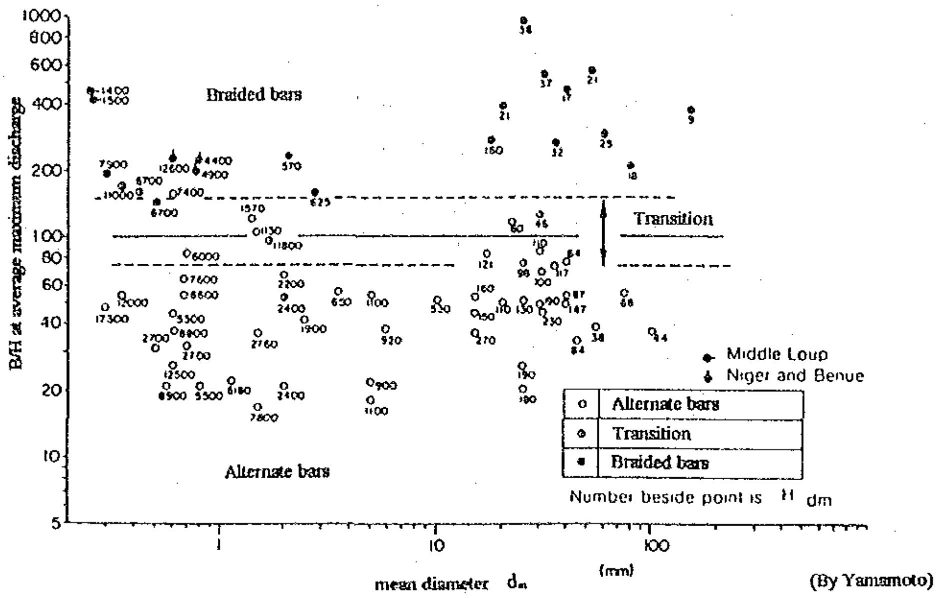

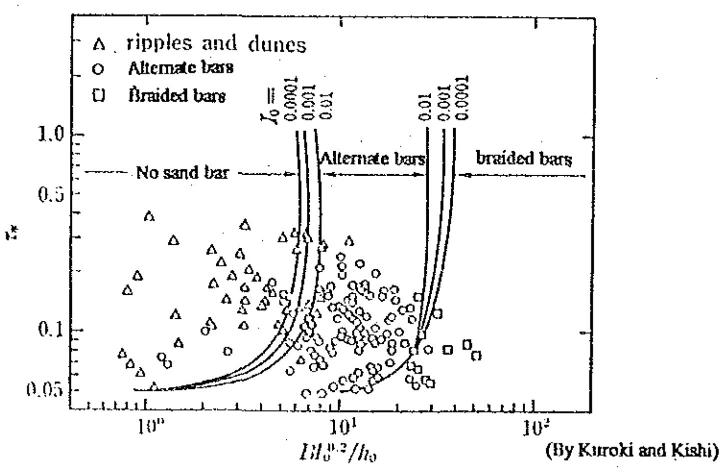

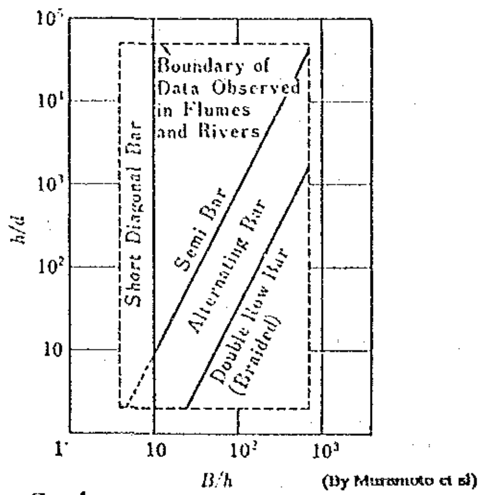

Fig. 7.4.6

Classification of Medium Scale Bed Configuration

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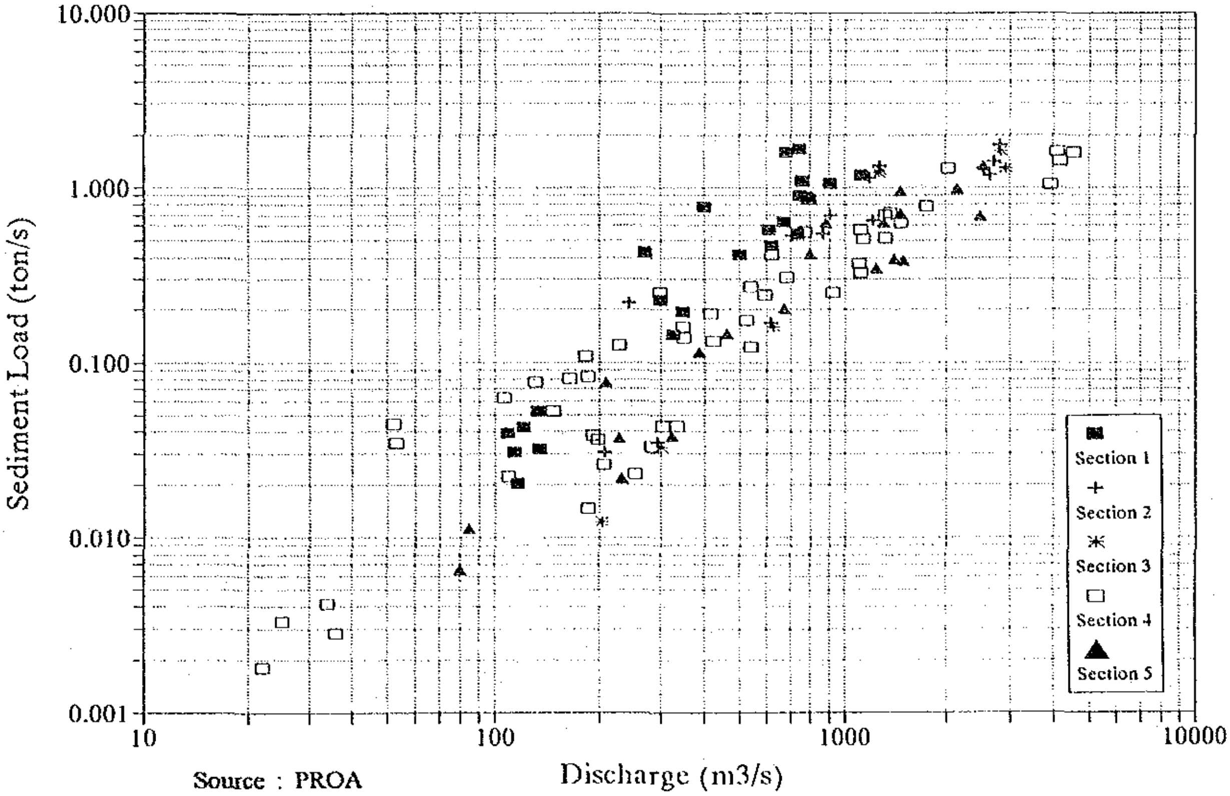

Source : PROA

Section 1 : Puente Remolino ~ Suripa River /con. (Puente Remolino + Palmalito)
Section 2 : Suripa River / con. ~ Bruzual (Bruzual)
Section 3 : Bruzual ~ El Saman (El Saman)
Section 4 : El Saman ~ San Fernando
(Boca de la Rompida + El Foment + Mis Deseos + Chamizal
+ Brazo las Yeguas + San Fernando)
Section 5 : San Fernando ~ River Mouth (El Sausal + El Perro)

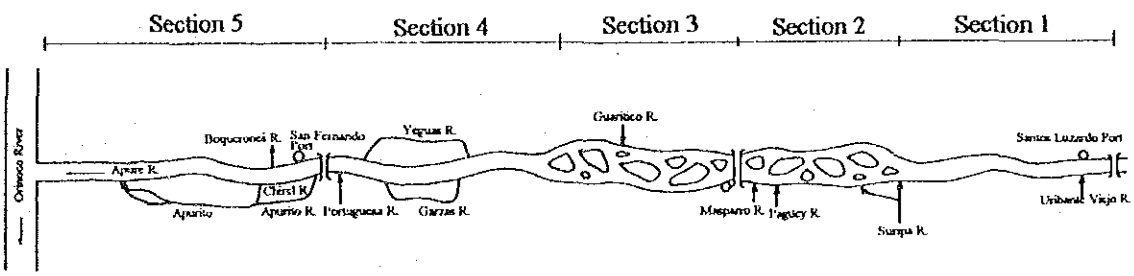

Fig. 7.4.7 Relationship between Sediment Load and Discharge

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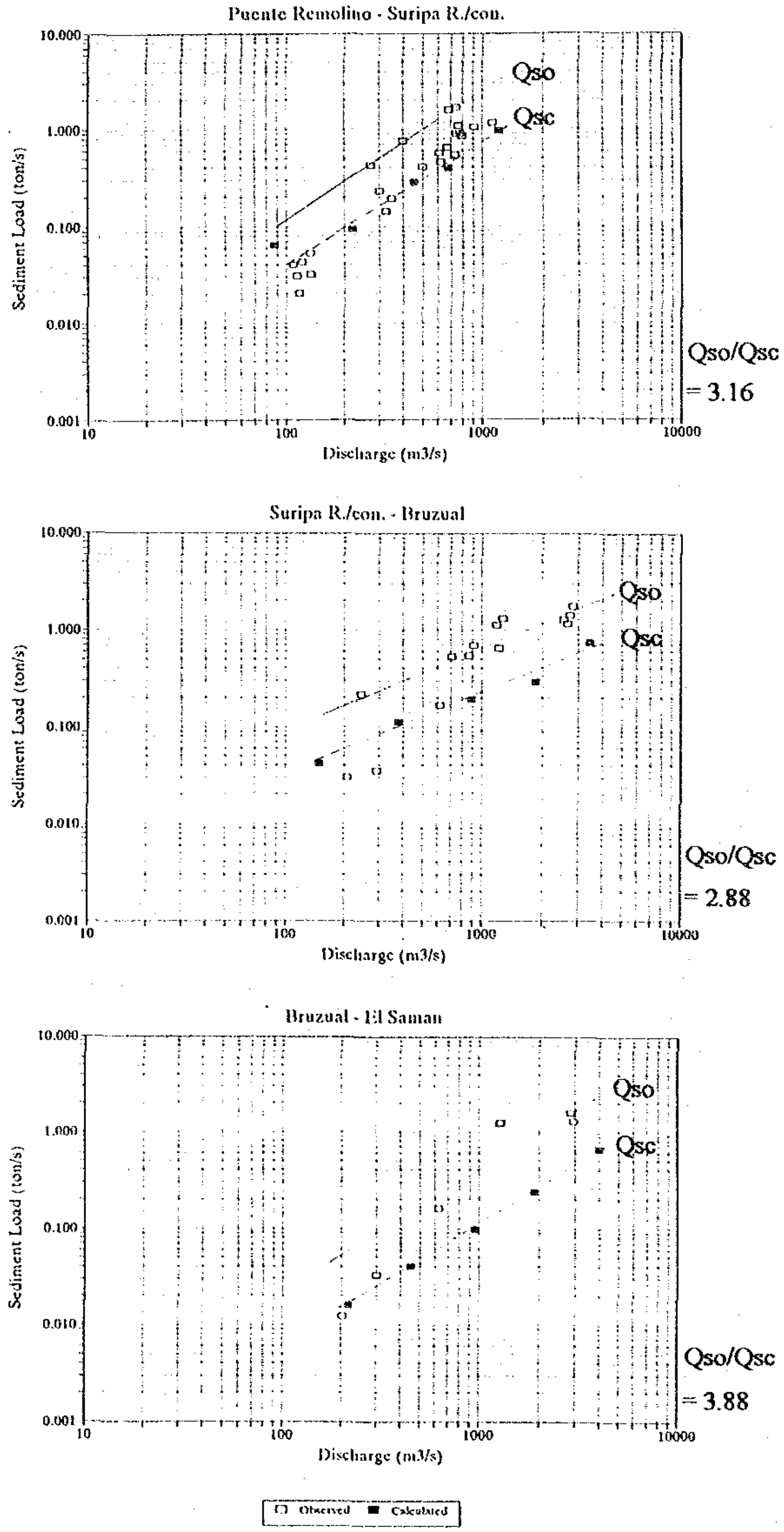

Fig. 7.4.8 Comparison of Observed and Calculated Suspended Load (1/2)

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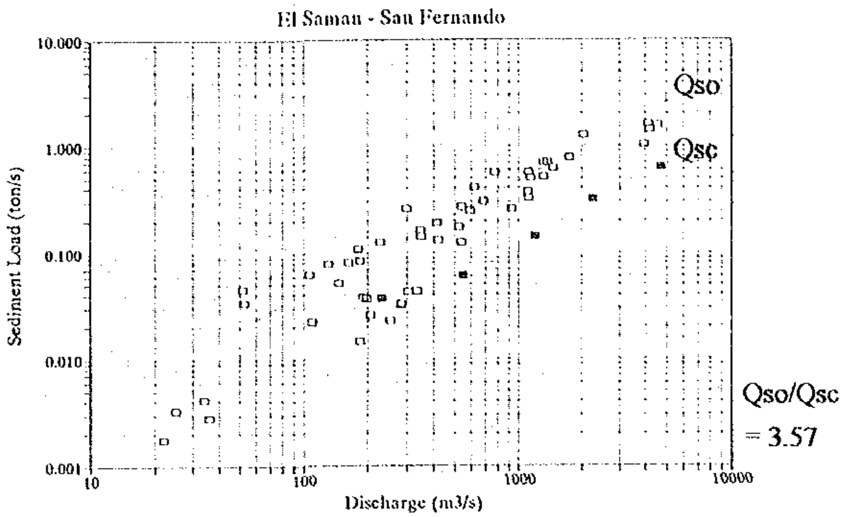

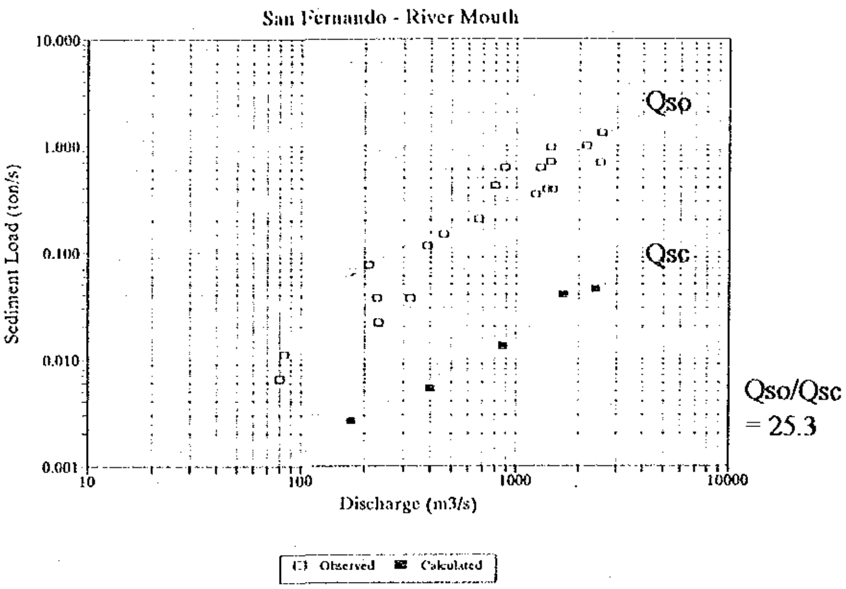

Fig. 7.4.8 Comparison of Observed and Calculated Suspended Load (2/2)

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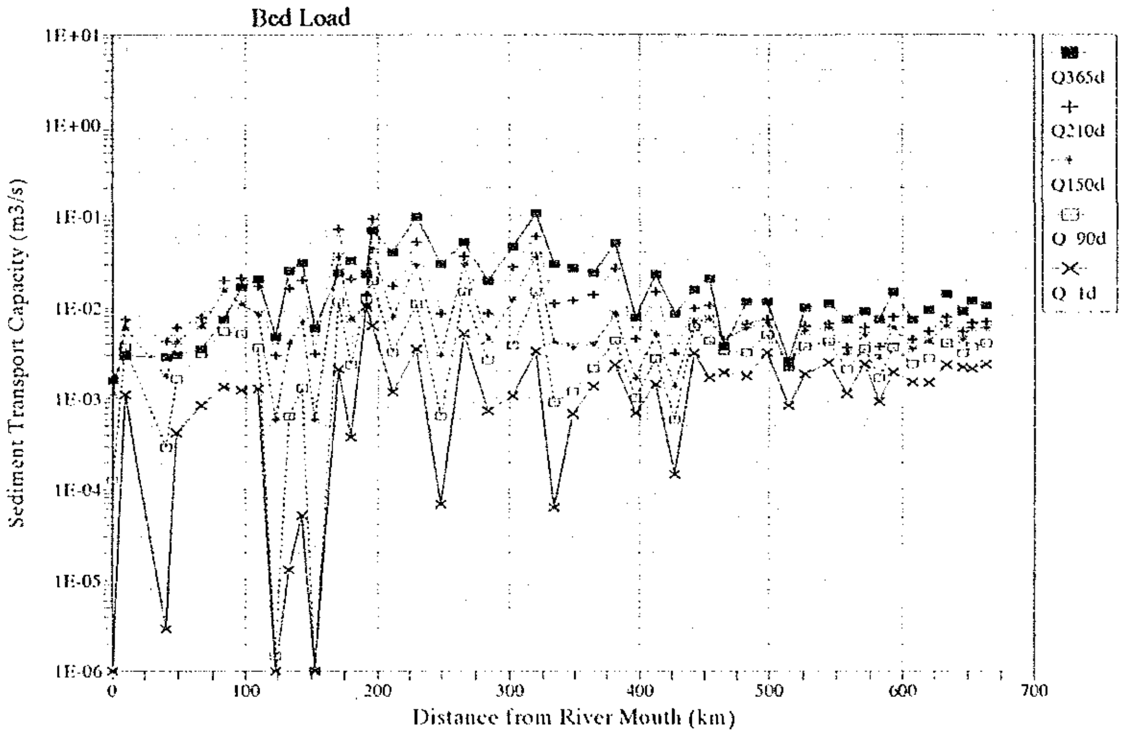

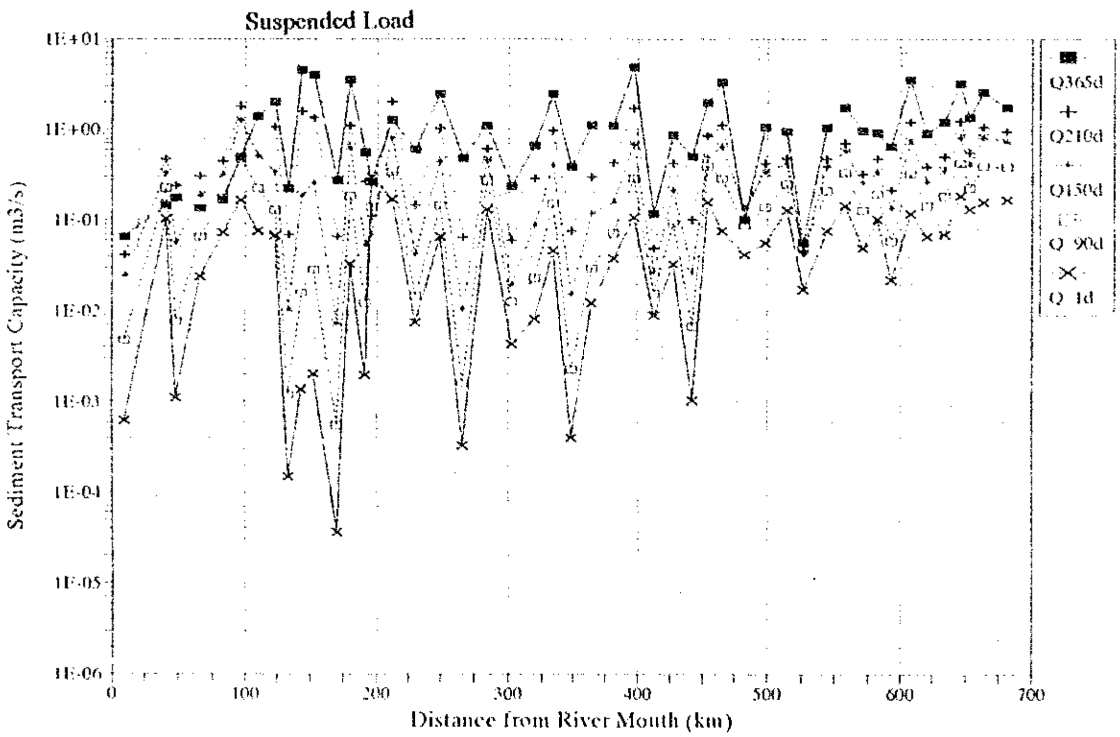

Fig. 7.4.9 **Sediment Transport Capacity of Apure River**

THE REPUBLIC OF VENEZUELA COMPREHENSIVE IMPROVEMENT OF THE APURE RIVER BASIN
JAPAN INTERNATIONAL COOPERATION AGENCY

PART-E

STUDY ON CHANNEL STABILIZATION FOR NAVIGATION

STUDY ON COMPREHENSIVE IMPROVEMENT OF THE APURE RIVER BASIN

FINAL REPORT

VOLUME III : SUPPORTING REPORT
PART-E : STUDY OF CHANNEL STABILIZATION FOR NAVIGATION

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I. INTRODUCTION

This Supporting Report: Part-E compiles study results on channel stabilization of the main Apure and Portuguesa rivers for fluvial navigation.

Study on channel stabilization aims to formulate channel improvement plan for navigation purposes. Flow of study is shown in Fig. 1.1.1.

The Study started from the review of previous studies and works based on the data and information collected. Then the characteristics of the existing channel were studied from the geometric and hydraulic aspects. The planning of channel improvement measures for navigation were made on the basis of the review and the channel studies.

II. PREVIOUS STUDIES AND WORKS

2.1 Water Resources Development Projects

Channel flow is an important factor of the fluvial navigation and its changes due to water resources development are also of important concern to the study. In view of this, water resources development projects, among others, dam projects in the study area were reviewed.

(1) Existing and Proposed Dams

Existing and proposed dams in the study area were inventoried in Table 2.1.1 together with their major features. Locations of these dams are shown in Fig. 2.1.1. There are 22 dams in the study area including proposed dams as follows:

	Project	Existing	Under con-struction	Proposed
1)	Uribante-Caparo project	1	2	1
2)	Guanare-Masparro project	3	-	1
3)	Other dams in Apure river basin	1	-	-
4)	Other dams in Portuguesariver basin	5	2	6
	Total	10	4	8

(2) Uribante-Caparo Project

The project aims mainly to develop hydro-power of 1,274 MW in total, constructing dams in the Uribante river (1,000 m MSL), Doradas river (700 m MSL), Camburito river (200 m MSL) and Caparo river (200 m MSL) having a basin area of about 4,580 km^2 in total (Fig. 2.1.2).

Component project works and their construction status are as follows:

1) Uribante river
   a) La Honda dam : Existing
   b) Uribante-Doradas tunnel : Existing
   c) San Agaton power station : Existing
      - Installed capacity : 300 MW
   d) Linda-Doradas diversion tunnel : Proposed

2) Doradas river
   a) Las Cuevas dam : Proposed
   b) Doradas-Camburito tunnel : Proposed
   c) La Colorada power station : Proposed
      - Installed capacity : 460 MW

3) Camburito river
   a) Borde Seco dam : Under construction

4) Caparo river
   a) La Vueltosa dam : Under construction
   b) La Vueltosa power station : Proposed
      - Installed capacity : 514 MW
   c) Caparo-Uribante Viejo diversion channel for navigation : Proposed

When the project is completed, the river flow will be controlled as follows:

```
Uribante R. ---> La Honda Dam ---> Uribante R.
                       |
                       v
              San Agaton power sta.
                       |
                       v
Doradas R.  --->(Las Cuevas Dam)---> Doradas R.
                       |
                       v
             (La Colorada power sta.)
                       |
                       v
Camburito R.---> Borde Seco Dam --> Camburito R.
                       |                  |
                       v                  |
Caparo R.    ---> La Vueltosa Dam --------->|
                       |                  |
                       v                  v
           (La Vueltosa power sta.)--> Caparo R.
                                          |
                                          v
                          (Caparo-Uribante Viejo Div.Ch.)
                                          |
                                          v
                                  Uribante Viejo R.
                                          |
                                          v
                                       Apure R.
```

Note: Facility in ( ) is proposed and not yet started for its construction

(3) Guanare-Masparro Project

Guanare-Masparro project is an integrated area development project including various components of infrastructure works such as water resources development, road and education facilities, conservation and recovery of natural resources covering an area of about 950,000 ha which consists of 500,000 ha for development and 450,000 ha for conservation, and recovery of natural resources (Fig. 2.1.3).

As to the water resources development, four (4) dams with three (3) reservoirs play an important role as follows:

1) Masparro dam: Existing
   a) Irrigation : 67,500 ha
   b) Hydro-power : Masparro hydro-electric station will have a capacity to generate 25 MW during dry season. Work for the station is not started yet.

2) Bocono-Tucupido dams: Existing
   a) Irrigation : Two dams jointly have capacity to irrigate 300,000 ha of agricultural lands. The existing Bocono-Tucupido irrigation system covers an area of 9,200 ha of which 7,200 ha are subject to irrigation.
   b) Hydro-power : Peña Larga hydro-electric station located at the foot of Bocono dam will have a capacity to generate 80 MW (40 MW x 2 units). The electric plant work is ongoing by CADAFE.

3) Guanare dam: Proposed.
   a) Three (3) possible sites are being evaluated and the most promising site is Mesa de Cavaca.
   b) The dam will have irrigation and flood control functions. The Guanare irrigation system covers an area of about 7,690 ha.

2.2 Navigation Plan

Master plan study for the fluvial navigation of the Orinoco-Apure system is scheduled to be conducted separately. The master plan study is not started yet. Although the master plan for fluvial navigation is not prepared yet, navigation plan has been discussed among PROA and other authorities concerned because of the daily needs of navigation, and some works are being implemented in the field.

According to the information obtained so far from PROA, the existing navigation plan was outlined hereunder. The existing plan has a nature of short term navigation improvement plan.

(1) Principle of Navigation Improvement

1) Sequence of project implementation : Considering the easiness of implementation and difference of channel conditions by stretches, the following sequence of project implementation has been decided;

1st : Stretch-A1 from the Orinoco river to San Fernando port
2nd : Stretches-A2,P1 and P2 from San Fernando port to El Baul port
3rd : Stretch-A3 from San Fernando port to Nutrias port (Bruzual)
4th : Stretch-A4 from Nutrias to Santos Luzardo port (Guasdualito)

2) Level of improvement : To equip necessary facilities to attain eight (8) months navigation by effective use of the existing river channel.

(2) Construction of Fluvial Ports

Construction of four (4) ports have been planned for the Apure and Portuguesa rivers at the sites presented below and the work is ongoing.

1) San Fernando port : constructed
2) El Baul port : under construction
3) Nutrias port/Bruzual : constructed
4) Santos Luzardo port : constructed

General view of San Fernando port is shown in Fig. 2.2.1 as an example. Facilities of other ports are planned and designed principally based on the same standards as San Fernando port.

(3) Criteria for Carrier and Standard Canal Section

Barges and boats are used for transportation of goods, and the size of barge with tugboat would be critical for the navigation canal section. The following sizes of barge and tugboat are adopted as size criteria for channel improvement study (Table 2.2.1):

	Item	Apure R.	Portuguesa R.
1)	Barge		
	a) Width (Ws)	13 m	10 m
	b) Length (Ls)	60 m	40 m
2)	Tugboat		
	a) Length (Lt)	20 m	20 m
3)	Channel (Assuming no navigational aid)		
	a) Depth (Dc)	≥ 2.00 m	≥ 1.70 m
	b) Width (Wc)	≥ 3xWs (*)	≥ 30 m
	c) Radius of curvature (Rc)	≥ 4x(Ls+20) (*)	≥ 240 m

(*) Ws and Ls for the Apure river may change by composition of barge(s).

2.3 Previous Study and Works

River improvement of the Apure initiated in 1960s as well as water resources development for such as hydro-power generation, irrigation and municipal water supply and flood control.

Channel improvement works implemented so far are mostly for protection of towns, public facilities and agricultural lands from flood water and bank erosion. Recently, studies and works of the Apure river as navigation channel are started paying attention to its unique situation in the country. Major previous works and studies of the Apure river are as follows:

1) Dike projects (existing) of Apure river for:
   a) San Fernando - Biruaca - Achaguas - Apurito road dike;
   b) Apurito - San Fernando dike;
   c) San Vicente - Palmarito dike; and
   d) Old channel closing dike at Pto. Nutrias/Bruzual.
2) Bank protection works (existing) of Apure river for:
   a) Guasdualito town,
   b) Totumito town,
   c) Palmarito town,
   d) Quintero town,
   e) San Vicente town,
   f) Bruzual bridge,
   g) El Saman town,
   h) Apurito town,
   i) Confluence of Portuguesa river,
   j) Town, bridge and airport of San Fernando,
   k) Road at El Negro, and
   l) Arichuna town.
3) Apurito guide dike project (existing)
4) Submerged dike on Chirel river (ongoing)
5) Cut-off channel of Portuguesa river (proposed)
   a) Cut-off channel at Camaguan
   b) Cut-off channel at La Muerta
6) Caparo-Uribante Viejo derivation channel (proposed)
7) Channel improvement of upper Portuguesa river (proposed)
   a) Stabilization of Acarigua river - Turen pilot channel system
   b) Marginal dike of Portuguesa and Rico river
8) Cojedes-El Frasco derivation channel (proposed)

These studies and works are briefed in Table 2.3.1 and their location is shown in Fig. 2.3.1.

III. CHARACTERISTICS OF CHANNEL

3.1 Channel Stretches

For the conveniences of description, river channel was divided into several stretches according to the location of fluvial ports and the river features as follows:

Apure River

1) Stretch-A1 or St-A1	:	From river mouth (confluence of the Orinoco river) to San Fernando port
2) Stretch-A2 or St-A2	:	From San Fernando port to confluence of the Portuguesa river
3) Stretch-A3 or St-A3	:	From confluence of the Portuguesa river to Nutrias port (Bruzual)
a) Stretch-A3.1	:	From confluence of the Portuguesa river to Apurito
b) Stretch-A3.2	:	From Apurito to Nutrias port
4) Stretch-A4 or St-A4	:	From Nutrias port to Santos Luzardo port
a) Stretch-A4.1	:	From Nutrias port to confluence of the La Tigra river
b) Stretch-A4.2	:	From confluence of the La Tigra river to Santos Luzardo port

Portuguesa River

5) Stretch-P1 or St-P1	:	From river mouth (confluence of the Apure river) to confluence of the Cojedes river
6) Stretch-P2 or St-P2	:	From confluence of the Cojedes river to El Baul port (Paso La Portuguesa)

3.2 General Channel Features

Longitudinal profile and river width of the existing Apure river were studied using the topographic maps of scale 1/10,000 in the following procedures:

1) Longitudinal profile of ground elevation was prepared using spot elevations on both banks at intervals of 5 km of longitude.

2) River width was measured along the main Apure river at every 5 km of longitude, classifying into width of main channel, anabranch and island.

3) Schematic channel system were also prepared to show the locations of tributaries, anabranches and branches.

Results of study are shown in Fig. 3.2.1 for longitudinal river bank profile and Fig.3.2.2 for river width and channel system. Principal features of the Apure river are presented for respective stretches as follows:

1) Stretch-A1 : From river mouth (Orinoco river junction) to San Fernando, having ground slope of 1/8,500. Large scale anabranhces develop in this stretch. River is not braided. In the downstream reaches from Arichuna, ground elevation fluctuates much probably due to the effect of the Orinoco river. Average river width is 257 m ranging from 120 m to 600 m for the main Apure and 340 m ranging from 135 m to 600 m including anabranches.

2) Stretches-A2 and A3.1 : From San Fernando to Apurito, having ground slope of 1/7,200. Large scale anabranches develop in this stretch. River is not braided. Average river width is 251 m ranging from 100 m to 560 m for the main Apure and 342 m ranging from 250 m to 560 m including anabranches.

3) Stretch-A3.2 : From Apurito to Bruzual, having ground slope of 1/5,000. River is braided and average river width is 522 m which varies much from 200 m to 880 m.

4) Stretch-A4.1 : From Bruzual to Suripa river junction, having ground slope of 1/4,200. There are several confluence of tributaries with much sediment. River is braided and average river width is 501 m which varies much from 220 m to 800 m.

5) Stretch-A4.2 : From Suripa river junction to Guasdualito, having ground slope of 1/2,500. There is no confluence of large tributaries and channel is not braided. Average river width is 265 m ranging from 100 m to 370 m.

3.3 Historical Variation

(1) River Course and Banks

In comparison with the topographic maps of year 1988 (scale 1/10,000) and those of year 1960 to 1966 (scale 1/25,000), variations of left and right banks were studied. The results are shown in Fig. 3.3.1. Average rates of variation are summarized as follows:

Stretch	Range of Change	
	Left bank (m)	Right Bank (m)
Stretch-A1: River mouth-San Fernando	+190 to -125	+200 to -50
Stretch-A2/A3.1: San Fernando-Apurito	+75 to -45	+200 to -50
Stretch-A3.2: Apurito-Bruzual	+200 to -360	+200 to -200
Stretch-A4.1: Bruzual-La Tigra	+550 to -345	+275 to -715
Stretch-A4.2: La Tigra-Guasdualito	+190 to -390	+215 to -465

Remarks:
- For bank shifting; + : erosion, - : sedimentation
- Variations due to channel works and river course change are excluded.

From the above, the following channel characteristics are found for the existing Apure river:

1) Stretches-A1,A2 and A3.1 : Activities of bank erosion and sedimentation in these stretches are relatively low as a whole. This may be due to no direct sediment inflow from the tributaries and diversion of flow to several anabranches. Large river bank changes near the town of San Fernando are due to channel works at the confluence of the Portuguesa river and at the town of San Fernando for channel normalization.

2) Stretches-A3.2 and A4.1 : Bank erosion is most active in the stretch-A4.1, while the activity is medium or low in the stretch-A3.2. The active channel movement in stretch-A4.1 would be brought about by the runoff and sediment inflow from the left tributaries coming from the Andes.

3) Stretch-A4.2 : Erosion prevails on the left bank and sedimentation prevails on the right bank, which indicates the river course is shifting toward left bank side as a whole. Activities of bank erosion are moderate comparing to the other stretches. The river width was reduced much on average.

Shifting of river courses are shown in Fig. 3.3.2 selecting typical sites in Guasdualito, Bruzual and San Fernando which correspond to the sites selected for the channel observation.

(2) River Section

PROA has been conducting cross sectional survey at the selected stations of the main Apure and Portuguesa rivers since 1988 as well as hydrological observations. Available survey sections are listed in Table 3.3.1.

Using the PROA survey sections, characteristics of river sections and their changes were studied. Surveyed cross sections were first superposed for each site and verify the sectional data. Some survey data which were unreasonably different from other survey results in their channel width and bed elevation were eliminated. Representative river sections are shown in Fig. 3.3.3.

In order to grasp the channel characteristics, mean channel depth and ratio of mean depth to the maximum depth were worked out for each section and shown in Table 3.3.2. Longitudinal river depth and changes of river depth of representative sections are shown in Fig. 3.3.4.

From the above data, the following are seen:

1) River depth increase toward downstream in general. Around San Fernando bridge and Bruzual bridge, channels are deeper.

2) Annual tendency of river bed lowering or raising is not found in these data.

3) Seasonal change of river depth, i.e., the difference of mean river depth in dry season and rainy season is not clear on these data.

4) As an index of channel stability, variation index: (max-min)/mean was calculated for the sections with at least five (5) years of survey data. The variation index varies from 0.12 to 0.58. Sections of lower and higher values of the coefficient are as follows:

Section	Location	(Max-Min)/mean
(Lower three: relatively stable)		
1. San Fernando	180.47 km	0.12
2. El Chinal	397.07 km	0.18
3. El Saman	348.12 km	0.21
(Higher three: changeable)		
1. Totumito	633.36 km	0.58
2. Santos Luzardo	663.38 km	0.57
3. San Vicente	465.41 km	0.51

3.4 Variation through Flood Season

Variation of channel through flood season was studied based on the river survey results of June/July in 1992 and January/February in 1993 conducted by JICA survey party. Survey were conducted at the following three sites:

1) Guasdualito site from Remolino bridge to Santos Luzardo port of the Apure river
2) Bruzual site from San Vicente to Bruzual of the Apure river
3) Camaguan site from Camaguan town to 10 km upstream of the Portuguesa river.

In order to clarify the channel characteristics, the following channel characteristics were studied based on the survey data:

1)River bank elevation : Hb
2)River width : B
3)Sectional area : A
4)Channel depth
  Maximum depth : hmax
  Mean depth : hm = A/B

5) River bed elevation

Lowest bed	:	Hmax = Hb - hmax
Mean bed	:	Hm = Hb - hm
6)Distance to hmax	:	E (from left bank)
7)Eccentricity	:	Ec = | E - B/2 |/B
8) Depth ratio	:	hmax/hm

The results are shown in Tables 3.4.1 through 3.4.3 for respective sites.

(1) Variation of Channel Characteristics

Channel characteristics of June/July in 1992 and January/February in 1993 were compared for the aforementioned channel characteristics. The results are shown in Figs. 3.4.1 through 3.4.3 for respective sites. The variation of channel characteristics during a flood season is summarized below.

Item	Guasdualito	Bruzual	Camaguán
Maximum depth : hmax (+:increased, -:decreased)			
Average max.depth (m)	6.25	8.14	10.87
Average variation (m)	-0.06	+0.32	+0.06
Range of variation (m)	+2.29/-2.27	+3.31/-2.66	+1.43/-0.98
Percentage: ave (max)	1.0 (37)	3.9 (41)	0.6 (13)
Mean depth : hm (+:increased, -:decreased)			
Average depth (m)	3.58	5.07	7.49
Average variation (m)	-0.14	-0.38	+0.07
Range of variation (m)	+1.46/-1.45	+1.54/-2.75	+1.44/-1.78
Percentage: ave (max)	3.9 (41)	7.5 (54)	0.9 (24)
Channel area : A (+:increased, -:decreased)			
Average area (m2)	880	2014	1023
Average variation (m2)	-69	-137	-8
Range of variation (m2)	+229/-312	+343/-1259	+138/-223
Percentage: ave (max)	7.8 (35)	6.8 (63)	0.8 (22)
Channel width : B (+:increased, -:decreased)			
Average width (m)	258	415	139
Average variation (m)	-9.6	+9.15	-2.29
Range of variation (m)	+66/-177	+225/-218	+20/-49
Percentage: ave (max)	3.7 (67)	2.2 (54)	1.6 (35)
Left bank (+:increased, -:decreased)			
Average (m)	+4.0	+3.3	+1.4
Range (m)	+180/-70	+232/-68	+23/-14
Percentage: ave (max)	1.6 (70)	0.8 (56)	1.0 (17)
Right bank (+:increased, -:decreased)			
Average (m)	+5.6	+12.4	+0.9
Range (m)	+175/-62	+46/-225	+26/-20
Percentage: ave (max)	2.2 (68)	3.0 (54)	0.6 (19)

Remarks: The percentages for left and right banks are to average channel width.

From the above, changes in river section during a flood season are outlined as follows:

1) River channels in Camaguán site are deep and narrow, while those of Guasdualito and Bruzual sites are relatively flat. Width depth ratio in these sites are as follows:

Site	B (m)	hm (m)	B/hm
a) Guasdualito	258	3.58	72
b) Bruzual	415	5.07	82
c) Camaguán	139	7.49	19

2) It is clearly known that the channels in Camaguan site are stable comparing with those of other two sites.

3) Regarding the maximum or deepest channel depth, changes in Guasdualito and Bruzual are remarkable. The maximum change of channel depth through a flood was 2.3 m (or 37 % of average maximum depth) in Guasdualito site and 3.3 m (or 41 %) in Bruzual site, while it was 1.4 m (or 13 %) in Camaguan site.

4) Regarding lateral changes, the channel width and left and right banks varied, at maximum, around 70 % of river width in Guasdualito site, and around 55 % in Bruzual. In Camaguán site, river width varied around 35 % at maximum and river banks around 20 % of river width.

(2) Depth Ratio of Channel Section

Relationship between depth ratio (hmax/hm) and eccentricity (Ec) was examined and shown in Fig. 3.4.4. The depth ratios are summarized as follows according to Tables 3.4.1 through 3.4.3:

Item	Guasdualito 1992	1993	Bruzual 1992	1993	Camaguan 1992	1993
Depth ratio (hmax/hm)						
Maximum	3.32	3.47	2.58	3.05	1.95	2.13
Minimum	1.23	1.17	1.10	1.17	1.18	1.16
Average	1.77	1.85	1.52	1.77	1.46	1.45
(Max-Min)/Ave.	1.18	1.24	0.97	1.06	0.53	0.67
Eccentricity(Ec)						
Maximum	0.48	0.48	0.49	0.48	0.44	0.39
Average	0.35	0.37	0.33	0.32	0.25	0.25

From the above, the following are considered:

1) The maximum values of the hmax/hm-value are around 3.5, 3.0 and 2.0 for Guasdualito, Bruzual and Camaguán sites, respectively. The channel bed can be said flatter in Camaguán site as a whole.

2) Distributions of plots of Guasdualito site is similar to those of Bruzual site, having increasing tendency of depth ratio for increasing Ec-value. The upper limit of hmax/hm-value could be expressed approximately as follows for the channel sections in Guasdualito and Bruzual sites:

$$hmax/hm = 4.9 \times Ec + 1.3$$

3) Distribution for Camaguán site is quite different from those of other two sites. The upper limit of hmax/hm-value has no significant tendency for the change of Ec-value. Reasons of this distribution are not clear.

4) Significant changes of depth ratio in 1992 and 1993 sections are not observed for Guasdualito and Camaguán sites. For Bruzual site, the upper limit of hmax/hm-value in 1992 is almost half of that of 1993. This might be caused by filling-up due to low flows.

(3) Changes of Roughness

Four stretches were selected for the study on changes of roughness during flood season. They are aforementioned three (3) sites, i.e., Guasdualito, Bruzual and Camaguán sites and additional San Fernando sites.

Roughness was estimated daily by non-uniform flow calculation based on the channel sections surveyed in June/July 1992 and daily water level observed at the lower and upper ends of each stretch for the period from May 1992 to April 1993 in the following manners:

1) Channel stretches for study

Description	Apure R. Guasdualito	Bruzual	S.Fernando	Portuguesa R. Camaguán
Stretch (km)	22	23	8	10
W.L.station:				
-UpperSta.	RemolinoBr.	SanVicente	S.Fernando	Camaguan
G.D. (m,MSL)	125.21	74.12	36.24	40.20
-Lower sta.	S.Luzardo Pt.	Bruzual Br.	El Negro	Camaguan Town
G.D. (m,MSL)	119.92	70.50	34.95	37.83
Discharge sta.	Remolino Br.	Bruzual Br.	S.Fernando	Camaguan Town
-Survey	June '92	June/July '92	July '92	July '92
-Intervals (m)	500	1000	200	500

Remarks : G.D. = Gage datum

2) Channel discharges were estimated by daily water level using rating curve at the discharge station located in each stretch for study

3) Roughness was estimated daily by channel flow calculations, in trial and error procedures, so that the water level calculated under an assumed roughness starting from the recorded water level at the lower station should coincides with the recorded water level at the upper station.

Results of calculations are shown in Figs. 3.4.5 through 3.4.8 and summarized below.

1) Roughness was estimated as an index to show channel bed changes based on surveyed river section in June/July 1992, recorded water levels and discharge estimated by rating curve. The roughness is therefore affected by the accuracy of modeling of channel flow.

2) Roughness during flood water levels higher than river bank was not estimated because flow pattern changed to overland flows.

3) Roughness estimated for Camaguán is too high, which comes from steeper water surface slope. The surface slope is about 1/4,000 (or 0.00025) according to the observed water levels, while prevailing ground surface slope is milder than 1/10,000 (or 0.0001). There might be error of gauge datum in water level gauging stations(s). Assuming difference of water level to be smaller by 0.5 m, 1.0 m and 2.0 m, the roughness was also estimated only for reference.

4) Relationship between discharge and n-value is summarized below.

Item		Guasdualito	Bruzual	S.Fernando	Camaguán
a)	Ranges of n-value				
	Minimum	0.021	0.018	0.012	0.035
	Maximum	0.055	0.061	0.021	0.13
	Max/Min	2.6	3.4	1.8	3.7
b)	Relationship	Definitive	Variable	Variable	Definitive
c)	Change of n-value for increasing discharge	Decreasing	Decreasing as a whole	Increasing as a whole	Decreasing

IV. EVALUATION OF CHANNEL CAPACITY FOR NAVIGATION

4.1 Criteria

Existing channel capacity for navigation was evaluated for the following six (6) major channel stretches based on the criteria of channel size and channel flow.

Apure River

1) St-A1 : From river mouth (Orinoco river) to San Fernando port
2) St-A2 : From San Fernando port to confluence of Portuguesa river
3) St-A3 : From confluence of Portuguesa river to Nutrias port (Bruzual)
4) St-A4 : From nutrias port to Santos Luzardo port (Guasdualito)

Portuguesa River

5) St-P1 : From river mouth (Apure river) to confluence of Cojedes river
6) St-P2 : From confluence of Cojedes river to El Baul port

Navigability was examined for water depth, radius of curvature and width of navigation channel. The critical sections due to shortage of water depth and channel width were examined in comparison with water level calculated for various channel flow conditions and the actual river section. The critical radius of curvature was studied on the topographic maps of scale 1/10,000 for most of the Apure river and those of scale 1/25,000 for a part of the Apure river near Apulito and the whole Portuguesa river.

(1) Channel Size Criteria

(Items)	(Apure River)	(Portuguesa River)
Water depth	≥ 2.00 m	≥ 1.70 m
Radius of curvature	≥ 560 m	≥ 240 m
Channel width	≥ 80 m	≥ 30 m

(2) Channel Flow Criteria

For the conveniences of description of navigability the following terms are used hereinafter:

1) n-day discharge (or Qnd) : Ordinal daily discharge which corresponds to n-th daily discharge from the minimum in a year.

2) Navigable months : Number of months in which channel flow satisfies the channel size criteria for navigation.

3) Navigation months : Number of months intended to be navigable in a year.

For the evaluation of navigability, the following ordinal daily discharge was adopted as criteria for navigable period. The ordinal daily discharges are based on the average flow duration at respective stream gauging stations along the main Apure and Portuguesa rivers:

Apure River

Ordinal daily discharge (Qnd)	Navigation months (mon.)	Ordinal daily discharge (m^3/s)			
		P. Remolino Sta.	Bruzual Sta.	El Samán Sta.	S.Fernando Sta.
Q1d	12	83	148	217	289
Q30d	11	104	203	270	391
Q60d	10	137	276	346	511
Q90d	9	208	380	449	669
Q120d	8	319	586	629	961
Q150d	7	424	890	961	1,469
Q180d	6	514	1,490	1,376	2,164
Q210d	5	599	1,849	1,886	2,839

Portuguesa River

Ordinal daily discharge (Qnd)	Navigation months (mon.)	Ordinal daily discharge (m^3/s)		
		El Baul Sta.	Jobalito Sta.	Camaguán Sta.
Q1d	12	9	31	57
Q30d	11	12	37	72
Q60d	10	15	43	89
Q90d	9	20	57	120
Q120d	8	26	82	179
Q150d	7	35	119	275
Q180d	6	57	190	438
Q210d	5	80	254	613

Note: El Baul sta. is located in El Baul town along the Cojedes river.

4.2 Evaluation of Apure River

(1) Channel Flow Calculation

River sections surveyed in March 1992 by PROA were used for channel flow calculation supplementing some additional sections with INC sounding results. Forty nine (49) sections were incorporated with the channel flow model for the entire stretch of 681 km from river mouth (Orinoco river) to Remolino bridge.

Water level and discharge records are available at four (4) stations of San Fernando, El Samán, Bruzual and Puente Remolino. Discharge distribution and channel roughness for the calculation are determined based on the discharges at four stations, location of confluences of tributaries and basin area. The roughness varies depending on the channel discharges representing all the unknown factors included in the flow model as well as the roughness of channel itself.

Making use of the channel flow model, channel water levels were calculated under various different flow conditions, i.e., 1, 30, 60, 90, 120, 150, 180 and 210 day discharges. For each case the discharge distribution was determined and channel roughness was estimated by trial and error procedures. Roughness estimated for various flow conditions are shown in Table 4.2.1.

(2) Critical Depth (Dc < 2.00 m)

Sounding maps prepared by the INC are available at the intervals of about 150 m for the Apure river. The sounding maps were used for the comparison with the calculated water level. The sounding map, however, is not available for the lowest 95.74 km stretch. Navigation route was drawn on the sounding map of the Apure river prepared by the INC, mostly connecting the deepest point of the river, and longitudinal profile was prepared.

River bed on the sounding map is presented by the depth from NAB-datum and partly from the water level at the survey time. The river bed elevation of each section in MSL-datum was estimated based on several sections of which elevations were known, assuming linear water surface in-between.

On the other hand, required water depth for navigation is 2.00 m considering the draft of barge and some allowance. Therefore, the critical river bed which enables the navigation of barge is assumed to be 2.00 m below the calculated water level.

Critical river bed profiles for 60, 90 and 120-day discharges are shown in Fig. 4.2.1 for example in comparison with INC river bed profile. Result of evaluation is shown in Table 4.2.2 and summarized below.

Navigation months	No. of critical sections St-A1 (Sect)(%)	St-A2 (Sect)(%)	St-A3 (Sect)(%)	St-A4 (Sect)(%)
12	43 (9.4)	24 (15.2)	367 (23.2)	423 (29.1)
11	25 (5.5)	18 (11.4)	331 (20.9)	359 (24.7)
10	21 (4.6)	17 (10.8)	272 (17.2)	289 (19.9)
9	11 (2.4)	13 (8.2)	214 (13.5)	192 (13.2)
8	3 (0.7)	6 (3.8)	148 (9.4)	95 (6.5)
7	1 (0.2)	3 (1.9)	38 (2.4)	45 (3.1)
6	0 (0)	1 (0.6)	6 (0.4)	26 (1.8)
5	0 (0)	0 (0)	0 (0)	18 (1.2)
Total	(458)	(158)	(1581)	(1455)

Note: Sections in the lowest stretch of 95.74 km of St-A1 is not included because of no section data

(3) Critical Width (Wc < 80 m)

River width at the elevation of critical river bed (2.00 m below calculated water level) was examined for sections incorporated in the channel flow model of the Apure river. The result is shown in Table 4.2.3 and Fig. 4.2.2. The critical sections with channel width less than 80 m are shown below for respective navigation month or flow conditions.

Navigation months	No. of critical sections St-A1 (Sect)(%)	St-A2 (Sect)(%)	St-A3 (Sect)(%)	St-A4 (Sect)(%)
12	6 (55)	0 (0)	9 (56)	12 (71)
11	4 (36)	0 (0)	9 (56)	9 (53)
10	1 (9)	0 (0)	7 (44)	5 (29)
9	1 (9)	0 (0)	4 (25)	2 (12)
8	0 (0)	0 (0)	1 (6)	0 (0)
7	0 (0)	0 (0)	1 (6)	0 (0)
6	0 (0)	0 (0)	1 (6)	0 (0)
Total	(11)	(3)	(16)	(17)

(4) Critical Radius of Curvature (Rc < 560 m)

Radius	No. of critical curvatures St-A1 (km/sect)	St-A2 (km/sect)	St-A3 (km/sect)	St-A4 (km/sect)
Rc < 560 m (sect)	12 (14)	0 (-)	16 (16)	12 (18)
Rc < 320 m (sect)	6	0	5	5
Chan. length (km)	167.3	24.9	250.0	221.2

(5) Summary

1) Result of evaluation is shown in Fig. 4.2.3 schematically.
2) Shortage of water depth is the principal problem of the Apure river. For the navigation longer than nine (9) months, channel width also become critical.
3) Judging from the critical water depth, navigable months of the existing Apure river were evaluated as follows, assuming that critical sections less than 1.0% were navigable with minor improvement:

Stretch :	St-A1	St-A2	St-A3	St-A4
Navigable months :	8	6	6	4

4.3 Evaluation of Portuguesa River

(1) Channel Flow Calculation

Channel sections reported in EVALUACION PRELIMINAR DE LA PREFACTIBILIDAD DE NAVEGACION DEL RIO PORTUGUESA (Preliminary Evaluation of Pre-feasibility of Navigation in Portuguesa River), April 1990, were used for the study. Thirty nine (39) sections are available in total over the stretch of about 249 km from river mouth to El Baul port. All of these sections are surveyed from water surface and are not related to the MSL-datum.

Channel flow model was constructed using the channel sections assuming water surface slope and channel roughness, and the critical sections were studied on these sections principally in the similar manner as the Apure river.

(2) Critical Depth (Dc < 1.70 m)

Critical river bed elevation for respective channel flow conditions is shown in Fig. 4.3.1. The critical river bed elevation is set at 1.70 m below calculated water level. The critical sections for channel depth are summarized below.

Navigation months	No. of critical sections St-P1 (Sect)(%)	St-P2 (Sect)(%)
12	3 (10)	0 (0)
11	1 (3)	0 (0)
10	1 (3)	0 (0)
9	1 (3)	0 (0)
8	0 (0)	0 (0)
Total	(31)	(8)

(3) Critical Width (Wc < 30 m)

Channel width at 1.70 m below water surface is shown in Table 4.3.1 and Fig. 4.3.2. The critical sections of which channel width are less than 30 m are shown below for respective navigation months or flow conditions.

Navigation months	No. of critical sections St-P1 (Sect)(%)	St-P2 (Sect)(%)
12	15 (48)	8 (100)
11	9 (29)	8 (100)
10	7 (23)	5 (63)
9	3 (10)	3 (38)
8	0 (0)	1 (13)
Total	(31)	(8)

(4) Critical Radius of Curvature (Rc < 240 m)

Radius	No. of critical curvatures St-P1(km/sect)	St-P2(km/sect)
Rc < 240 m (sect)	27 (8)	5 (7)
Rc < 150 m (sect)	5	2
Chan. length (km)	214.8	33.7

(5) Summary

1) Result of evaluation is shown in Fig. 4.3.3
2) Shortage of channel width and radius of curvature is the principal problems of the Portuguesa river.
3) The critical channel sections increase abruptly for the navigation longer than nine (9) months. The situation is more serious in Stretch-P2 (upstream from confluence of the Cojedes river).
4) Judging from the critical channel width, navigable months of the existing Portuguesa river were evaluated to be eight (8) months for St-P1 and St-P2, assuming that existing critical sections less than 1.0 % or only one section for calculation were navigable with minor improvement.

V. CHANNEL STABILIZATION MEASURES FOR NAVIGATION

5.1 Principles of Channel Stabilization

In order to improve channel capacity for navigation, two (2) principal measures were considered, i.e., (1) flow improvement to increase channel discharge and (2) channel improvement to provide enough channel section.

Various schemes for the flow and channel improvement studied by PROA and other authorities concerned were also imcorporated. These schemes are shown in Fig. 5.1.1.

(1) Flow Improvement

There are several existing dams in the upstream reaches of the main Apure and Portuguesa rivers. Released water from reservoir for hydro-power generation would contribute to increase channel discharge in the dry season.

Some reservoir space which is not used effectively now also could be used to increase channel discharge. However, this measure may not be economically feasible and will realize only when the released water is used for multipurpose.

In order to utilize the river water effectively for navigation, derivation channel would be effective, leading the water to the upstream of critical sections. It would be more effective if the released water from hydro-power plant is combined with the derivation channel scheme.

(2) Channel Improvement

Various measures are conceivable for channel improvement:

1) Treatment of anabranches : By closing or controlling diversion of discharge into anabranch, discharge in the main channel could be increased and stabilized.

2) Normalization of alignment : In order to attain smooth navigation in the river, the critical bends would be normalized by realignment works or cut-off channels.

3) Improvement of channel section : In the stretches where channel depth and/or width are critical, channel improvement work to provide enough section for navigation would be required.

(3) Facilities and Works

Channel stabilization for fluvial navigation would include the following types of works:

1) Flow Improvement
   a) Dam works
   b) Derivation channel works
2) Treatment of Anabranches
   a) Submerged dike works
   b) Closing dike works
3) Normalization of Alignment
   a) Realignment works of severe bend
   b) Cut-off channel works
4) Improvement of Channel Section
   a) Island treatment works
   b) Channel dredging works
   c) River training works
   d) Temporary canalization works
5) Bank protection

In this chapter, principles for plan and design of aforementioned works are discussed. The natural forces to shift the river course and to reform the channel section would be by far large comparing with the works to be implemented, and the available budget for the works are limited. It is essential to plan and design the works so as to harmonize with the behavior of the natural river as much as possible.

In order to harmonize with the natural river, characteristics and behavior of river should be first studied and investigated, and function of the facilities should be examined by hydraulic model tests and prototype tests in field.

Principles and preliminary ideas for facility design were presented in subsequent sections. The facilities and works presented in this section are therefore not definitive. They should be improved and developed based on the further studies and investigation, hydraulic model tests, and experience through actual works in field.

5.2 Flow Improvement

5.2.1 Component Schemes for Flow Improvement

(1) Dams

New dams for navigation purpose were not considered because they clearly do not pay, but those constructed or proposed for other purposes were studied for navigation use of their released water.

Dams for the flow improvement study were selected from the dams inventoried in Chapter 2, screening them by the following criteria:

1) Dams constructed or under construction were taken up for the study. Scheduled dams are principally excluded and are considered only when needed in the course of study.
2) Dams with small storage capacity (less than 100 mil. m^3) are excluded.
3) Dams on the Pao, Chirgua and Tiznados rivers are excluded because they are less effective for navigation due to their location.
4) Dams which have other reservoir in downstream are excluded.

Finally the following dams were selected for study:

1) Dams for Uribante-Caparo project (Uribante-Caparo dams):
   a) La Honda dam : Existing
   b) Borde Seco dam : Under construction
   c) La Vueltosa dam : Under construction

2) Dams for Guanare-Masparro project (Guanare-Masparro dams):
   a) Bocono dam : Existing
   b) Masparro dam : Dam is existing but the power plant is not constructed yet

3) Dams of Cojedes river (Cojedes dams):
   a) Las Majaguas dam : Existing
   b) Las Palmas dam : Under construction

(2) Derivation Channels

After reviewing the ideas and schemes prepared by PROA, the following three (3) derivation channels were taken up for the study:

1) Caparo-Uribante Viejo derivation channel : To lead water of the Caparo river to the Apure river at just downstream of Santos Luzardo port through the Uribante Viejo river.

2) Bocono-Masparro derivation channel : To lead water of the Bocono river to the Apure river at upstream of Nutrias port (Bruzual) through the Masparro river.

3) Cojedes-El Frasco derivation channel : To lead water of the Cojedes river to the main Portuguesa river at upstream of El Baul port

A trans-basin channel scheme to take Arauca water into the Apure river near Guasdualito is conceivable. However, this scheme was not considered, because the Arauca river is an international river and the realization of trans-basin may take long time and is difficult to take it into schedule.

(3) Component Schemes

For the flow improvement, the following component schemes in combination with dams and derivation channels were considered for further study:

1) *Upper Apure flow improvement scheme : A scheme consisting of Uribante* Caparo dams and Caparo-Uribante Viejo derivation channel

2) Middle Apure flow improvement scheme : A scheme consisting of Guanare-Masparro dams and Bocono-Masparro derivation channel

3) Upper Portuguesa flow improvement scheme : A scheme consisting of Cojedes dams and Cojedes-El Frasco derivation channel

For respective flow improvement schemes, two stages, i.e., initial and final stages, were considered depending on the development stage of power generation and related projects. Major dimensions of dams for respective development stages are shown in Table 5.2.1. General location maps of derivation channels for study are shown in Figs. 5.2.1 through 5.2.3.

5.2.2 Evaluation of Effects

Flow improvement measures were evaluated in two stages, i.e., evaluation of (1) hydraulic effects and (2) degree of navigation improvement.

Hydraulic Effects

Changes of channel discharge due to dams and derivation channels were estimated based on the following procedures:

1) Channel discharge was estimated principally from the average flow duration based on the past records.

2) Where flow records were not available, discharges were estimated by the specific discharge or unit area discharge based on the nearest station or similar basin.

3) Effects of existing dams such as La Honda and Bocono dams were considered to have been incorporated in the flow records.

4) In case water flow was derived from dams and/or derivation channel, the 90 % of discharge was considered effective to the flow improvement of the downstream reaches.

The results of discharge calculations for respective flow improvement measures are shown in Table 5.2.2 taking examples of 7-month and 12-month navigation. The results are summarized in Table 5.2.3 for various navigation periods and Fig. 5.2.4 for 7 and 12-month navigation.

Navigation Improvement

The critical sections for channel depth were examined by flow calculations under various flow conditions. The results are shown in Table 5.2.4 and Figs. 5.2.5 and 5.2.6. The critical sections were expressed by critical channel length assuming one critical section is equivalent to 150 m of critical channel length.

(1) Upper Apure Flow Improvement Scheme

The upper Apure flow improvement scheme principally depends on the released water from San Agaton power station of La Honda reservoir and La Vueltosa power station of Borde Seco/La Vueltosa reservoir, and Caparo Uribante Viejo derivation channel. The effect of existing San Agaton power station was considered to have been incorporated already in the flow records accordingly in the average flow duration.

The released water from La Vueltosa power station and its effects to the downstream reaches are as follows:

	Item	Initial stage	Final stage
1)	Discharge		
	a) Present channel discharge (m^3/s)	424 to 876	424 to 876
	b) Released water (m^3/s)	145	205
	c) Effect to downstream		
	Increase in Q150d (m^3/s)	+45 to +76	+25 to +43
	Increase in Q1d (m^3/s)	+74 to +123	+95 to 160
2)	Critical channel length		
	a) 7-month navigation: Q150d		
	Present condition (km)	13.1	13.1
	After flow improvement (km)	7.7	9.6
	Percentage (%)	(58.8)	(73.3)
	b) 12-month navigation: Q1d		
	Present condition (km)	128.6	128.6
	After flow improvement (km)	85.8	76.1
	Percentage (%)	(66.7)	(59.2)

For the 7-month navigation, for example, the scheme contributes to reduce the critical length by 41.2 % in total at the initial stage, and by 26.7 % at the final stage.

The effect is more important in the stretch between the confluences of the Suripa and the Uribante Viejo rivers which includes one of the most critical stretches for navigation. This scheme contributes to the improvement of navigation by one to two months for the upstream reaches of the Suripa river confluence, while for the downstream reaches by one month or less.

Similar effects could be expected too under the final stage conditions.

(2) Middle Apure Flow Improvement Scheme

The middle Apure flow improvement scheme principally depends on the released water from Peña Larga hydro-electric station of Bocono-Tucupido reservoir and Masparro hydro-electric station. The effect of Peña Larga station was considered to have been incorporated already in the flow records.

The released water from Masparro hydro-electric station and its effects to the downstream reaches are as follows:

Item	Initial stage	Final stage
1) Discharge		
a) Present channel discharge (m^3/s)	424 to 876	424 to 876
b) Released water (m^3/s)	24	8
c) Effect to downstream		
Increase in Q150d (m^3/s)	+56 to +7	+8 to -35
Increase in Q1d (m^3/s)	+69 to +12	+16 to -27
2) Critical channel length		
a) 7-month navigation: Q150d		
Present condition (km)	13.1	13.1
After flow improvement (km)	11.4	12.9
Percentage (%)	(87.0)	(98.5)
b) 12-month navigation: Q1d		
Present condition (km)	128.6	128.6
After flow improvement (km)	118.4	127.1
Percentage (%)	(92.1)	(98.8)

The effects of this scheme are not much, reducing the critical channel length by 13.0 % in total, for example, for 7-month navigation at the initial stage. The effects will be very small for the final stage reducing the critical length only by 1.5 %. This comes from the increase of irrigation water to be taken from the released water for power generation. This situation indicates that the effect of flow improvement facilities such as Bocono-Masparro derivation channel would not be expected for flow improvement in future.

However, Bocono-Masparro derivation channel constructed for other purposes such as irrigation for effective use of Bocono-Tucupido reservoir could contribute to the flow improvement at the initial stage.

(3) Upper Portuguesa Flow Improvement Scheme

The Portuguesa has channel capacity for almost eight (8) month navigation. If it is intended to increase the navigation period more than nine (9) months, the river is critical over the whole stretch for width and radius of curvature. The situation is more serious in the upper Portuguesa river for about 34 km long from confluence of the Cojedes river to El Baul port.

In order to improve the navigation capacity of the Portuguesa river, the following measures could be considered solely or in combination:

1) Right dike of the upper Portuguesa river to prevent the spilling water into the Igues river
2) Cojedes-El Frasco derivation channel to lead water of the Cojedes river to the Portuguesa river at the upstream of El Baul port to increase low flow discharge
3) Channel improvement

The right dike scheme and the derivation channel scheme are for flow improvement and the channel improvement scheme will be adopted complementarily.

Right Dike of Upper Portuguesa River

The upper Portuguesa river has been silted up at the downstream of the confluence of the Acarigua river (Canal Piloto). Because of the channel siltation the flow of the upper Portuguesa river spills over and drained into the Igües river. The flow at El Baul port located downstream is decreasing.

Channel improvement works of the Acarigua river including the silted-up Portuguesa river are being studied and designed by PROA. Right dike of the upper Portuguesa river will prevent the Portuguesa river water from spilling and would function to maintain water and sediment flow properly.

Cojedes-El Frasco Derivation Channel

Cojedes-El Frasco derivation channel aims to lead a part of the Cojedes river water to the main Portuguesa river upstream of El Baul port. The existing drainage channel L-5 (Longitudinal 5) in Turen III Project area could be used as the derivation channel. Construction of hydraulic control structure at the head of the derivation channel and connection channel with the Portuguesa river at the lower portion of the derivation channel would be necessary.

According to the preliminary study on Las Majaguas dam (existing) and Las Palmas dam (under construction), these dams have little effects for flow improvement for navigation in the Portuguesa river.

The Cojedes-El Frasco derivation channel will not be considered for the present study. But the derivation channel might be incorporated in future for the enhancement of navigation capacity based on the master plan after examining the economic viability.

PROA is studying the Cojedes-El Frasco derivation channel.

5.2.3 Principles of Facility Design

(1) Dams

Construction of new dam for flow improvement for navigation is not considered. Released water from hydro-electric station will be used for this purpose. Compensation dam may be needed to regulate the released water uniformly, which would also be a part of works for hydro-power generation.

(2) Derivation Channel

Site

Caparo-Uribante Viejo derivation channel are planned in the upper Apure river.

Function

1) To derive water from the Caparo river to the Uribante Viejo river to improve channel flow of the Apure river between the Uribante Viejo river confluence to the Caparo river confluence.

2) To release water to the downstream reaches of the Caparo river to maintain the existing normal functions during dry season.

3) Not to divert flow into the derivation channel during rainy season so as not to cause radical changes of water and sediment flows in the Uribante Viejo and main Apure rivers.

Description of Works

The derivation channel works principally include new derivation channel works and control gate works at the head. Some improvement works of the existing Uribante Viejo river and related structures such as bridges may be needed.

Facility Design

Design of Caparo-Uribante Viejo derivation channel has been made by CVS.

5.3 Treatment of Anabranches

5.3.1 Approach to Anabranch Treatment

(1) Sites and Related Rivers

Two (2) sites of large scale anabranches exist along the Apure river in the downstream and upstream reaches of San Fernando as follows:

1) Chirel/Apurito site : The site is located at the downstream of San Fernando, extending to about 90 km from San Fernando to La Maciera. The following anabranches and distributaries are related to this site
   a) Upper Apurito river : The upper Apurito river bifurcates at just downstream of San Fernando town. The upper Apurito river from the bifurcation to confluence with the Chirel river has been silted up and has little flow capacity.
   b) Boquerones river : A distributary
   c) Chirel/Apurito river : The Chirel river is a channel to join the Apure and Apurito rivers. The Apurito river after joining the Chirel river bifurcates the Caujarito and the Chirere rivers. The Apurito river and the Chirere river finally return to the Apure river at La Maciera.

2) Bravo/Garzas site : The site is located at the upstream of San Fernando, extending to about 90 km from Apurito town to confluence of the Guanaparo river. The following anabranches are related to this site:
   a) Apure Viejo/La Ceiba river : The Apure river bifurcates at just downstream of Apurito town and its distributary, La Ceiba river, returns to the Apure river. The river, however, has been closed by the right dike of the Apure river.
   b) Canafistolito river : A small scale anabranch of the Apure river
   c) Yeguas river : The Yeguas river is the longest anabranch in this site. According to the field survey and inspection from air, river flow is closed naturally during dry season
   d) Upper Garzas river : The upper Garzas river from bifurcation from the Apure to confluence with the Bravo river has been silted up and the flow capacity during dry season is negligible small
   e) Rompida river : A channel to join the Apure and Yeguas rivers

f) Bravo/Garzas river : The Bravo river is a channel to join the Apure and Garzas rivers. The Garzas river after joining the Bravo river flow parallel to the Apure for about 20 km and returns to the Apure river.

(2) Approaches

Channel discharge in the main Apure river could be stabilized and increased, by closing these anabranches or regulating diversion discharge into these anabranches. In order to close or regulate the anabranches the following works are conceivable:

1) Closing dike works to close the anabranch completely : Effect to increase discharge in the main channel is sure. The closing dike should be applied only to minor anabranches, since the closure may cause radical changes in main river flow and channel features and give serious environmental impacts.
2) Submerged dike works to regulate diversion discharge into anabranch allowing the passage of flood water and rural boats.

Influence of anabranch treatment will extend over a hundred kilometer along the river and the impacts to social and natural environment would be extensive. The existing anabranches have been formed as an integrated effects of water and sediment movements for long years. Treatment of anabranches therefore should be planned based on the careful investigation and studies.

In planning the anabranch works, mechanism of water and sediment flow should be grasped through hydraulic and geomorphological investigation. Otherwise the proposed works may lose their function in a short period or may cause instability of river channels.

In the anabranch site, river channels are relatively stable, since the energy of river flow is divided into plural channels. When the river flow is gathered to the main Apure river, the behavior of river channel might be activated.

The following investigation would be necessary before the final decision of anabranch treatment plan and their facility design:

1) Existing water use in and along the anabranch to be closed or regulated should be investigated, since the work would affect much the flow in anabranch.

2) Hydraulic and morphological influence of the works should be studied for facility design and should be monitored in field after the construction. Especially in case some changes in the anabranch such as changes in diversion

discharge are observed, the causes of change should be first studied and the result should be reflected to the plan and facility design.

3) Environmental investigation should be conducted in the related area to clarify the existing environmental conditions of the area, existence of specific objects to be conserved, and the impacts of works to the objects and their ecological systems.

5.3.2 Evaluation of Effects

(1) Case Study on Complete Closure of Anabranches

In order to grasp the maximum extent of effects, studies were made on the following cases:

Case-1 : Complete closure of the Chirel river
Case-2 : Complete closure of the Boquerones river
Case-3 : Naturally opening of the Yeguas river, which is now closed naturally
Case-4 : Complete closure of Garzas river together with the Bravo river

Channel flow calculations were made for the respective cases under the various discharges corresponding to navigation months. As a result, critical river bed profiles and water level changes under the 120-day discharge (or 8-month navigation) are shown in Figs. 5.3.1 and 5.3.2.

According to the flow calculation result the length of critical channel length were estimated for various navigation months and shown in Table 5.3.1.

From the above, the extent of effects are summarized for 120-day discharge or 8-month navigation as follows:

Cases	Reduction in W.L. at max (m)	Reduction in critical length (km)
Case-1 (Chirel)	+0.8	+0.5
Case-2 (Boquerones)	+1.0	+0.5
Case-3 (Yeguas)	-0.7	-6.9
Case-4 (Garzas)	+1.6	+6.8

Effects of closure of the Garzas river are large comparing with those of other rivers. The principal objectives of the Chirel and Boquerones river works would be to assure the present diverging condition in case diversing flows are increasing.

Negative effects due to re-opening of the Yeguas river are large. The conditions of bifurcation points of the Yeguas and Pompida rivers should be observed carefully.

(2) Treatment of Chirel Site

In consideration of the case study results for complete closure, the following scheme was constructed for the study of Chirel site:

1) Chirel river will be closed partially by submerged dike, if the diversion discharge to the Chirel river is increasing.
2) Boquerones river is left as it is, since the channel seems to be stable.
3) Upper Apurito river will be left as it is, since the river has been closed naturally.

Effects of partial closure of the Chirel river were studied as follows:

1) Submerged dike : Crest elevation was taken at 36.01 m MSL which corresponds to water level for mean lowest daily discharge (Qld) (Fig. 5.3.3).
2) Relationship of discharge diversion was estimated based on the channel section at the bifurcation as shown in Table 5.3.2 and the said Fig. 5.3.3.
3) According to the channel flow calculations, length of critical channel sections was estimated (Fig. 5.3.3).
4) Effects of Chirel river works at respective critical sites are shown in Fig. 5.3.4.

In view of the above results, flow improvement effects of the Chirel submerged dike is not much. However, it is said that the discharge of the main Apure is decreasing due to increase of diversion discharge into the Chirel river. If so, the Chirel submerged dike could function as consolidation works to stabilize the diversion of flow. The actual situation of discharge diversion and its historical changes are needed to be confirmed.

(3) Treatment of Bravo/Garzas Site

The following scheme was constructed for the study of Bravo/Garzas site:

1) Bravo river will be closed partially by submerged dike.
2) Cañafistolito and Rompida rivers would be closed completely by closing dikes.
3) Yeguas and Upper Garzas rivers are left as they are, since they are closed naturally during dry season.

4) Apure Viejo river will be left as it is, since it has been closed by right dike.

Effect of partial closure of the Bravo river were studied as follows:

1) Submerged dike (Fig. 5.3.5): Crest elevation was taken at 46.57 m, MSL which corresponds to water level for mean lowest daily discharge (Q1d).
2) Relationship of discharge diversion was estimated based on the channel section at the bifurcation as shown in Table 5.3.3 and the said Fig. 5.3.5.
3) According to the channel flow calculations, length of critical channel sections was estimated (Fig. 5.3.5).
4) Effects of Bravo river works at respective critical sites are shown in Fig. 5.3.6.

In view of the above results, flow improvement effects could be expected to the Bravo submerged dike. However, careful study and investigation are needed before the final decision is made.

5.3.3 Principles of Facility Design

Following facilities are studied for anabranches to unify the channel flow and accordingly to increase the depth of navigation channel:

1) Submerged dike works
2) Closing dike works

Definite plan and design of these works should be based on the studies and investigation of influence to present water use, changes in flows and channels and environmental impact.

(1) Submerged Dike Works

<u>Site</u>

Submerged dike is considered at the divergence of the following major anabranches of the Apure river:

1) Chirel river
2) Bravo river

The following rivers may also need the submerged dikes, in case that the river bed at the divergence will get lowered:

3) Boquerones river
4) Garzas river
5) Yeguas river

Function

The submerged dike aims to stabilize and regulate the flow diverging into anabranch during the low flow period. The dike should be designed satisfying the following conditions to maintain the existing functions of anabranches:

1) The submerged dike should not affect much to the flood flow conditions in the main channel and the anabranch so as not to cause radical changes of river channel and environmental conditions thereabout.

2) The submerged dike should be the fixed type weir which would not need any artificial operation.

3) The submerged dike should allow passage of rural boats between main channel and anabranch as much as possible even during the low flow period.

Description of Works

The submerged dike works consist of low fixed weir and navigation way with river bed consolidation works and revetment works.

Principles of Design

1) Location : On the anabranch at its divergence from the main channel selecting relatively stable site with less influence of the main channel.

2) Crest elevation of submerged dike : Equal to the water level (H1) which corresponds to the average annual minimum discharge (Q1).

3) Flow area : Bankful flow area at the submerged dike section should not be less than 80 % of the existing channel, so as not to give radical changes in flood flow conditions.

4) Length of submerged dike : Length of submerged dike should be decided considering the existing channel width (Bex) and the requirement presented in the above item as follows:

Bd = Bex; in case Bex x hd >= 0.8 x Aex

Bd = 0.8 x Aex / hd; in case Bex x hd < 0.8 x Aex

where

Bd	:	Length of submerged dike
Bex	:	Existing channel width
hd	:	Height from dike crest to river bank
Aex	:	Bankful flow area of the existing channel

5) Navigation way : Navigation way for rural boats shall be provided on the left or right bank side of the submerged dike depending on the navigation route in the adjacent river sections. The navigation way shall have enough width and depth for navigation during the low water period. Tentatively the bed width is determined as five (5) meter and the bed elevation as 2 m below the water level (H1) corresponding to the average annual minimum discharge (Q1).

6) Structure : The submerged dike should satisfy the following structural requirements:
   a) The submerged dike should have smooth shape to minimize the disturbance of flood water flow over the dike.
   b) The dike body should be firm and stable against the overflow of flood water.
   c) Appropriate river bed consolidation works should be provided to protect the dike body from the failure due to bed scouring.
   d) Appropriate revetment works should be provided to prevent river banks at the dike section from scouring and floating materials.

(2) Closing Dike Works

Site

Closing dikes are planned at the divergence of the following minor anabranches of the Apure river:

1) Rompida river
2) Canafistolito river

Function

The closing dike aims to close the anabranch completely throughout the year.

Description of Works

The closing dike principally consists of earth dike with slope protection works.

Principles of Design

1) Location : On the anabranch at any suitable place for closure of the channel

2) Dike materials : Earth from river bed or other borrow pits nearby

3) Structure : The closing dike should satisfy the following structural requirements.
   a) Crest elevation : Equal to the surrounding ground elevation
   b) The dike width should be wide enough against the possible erosion due to long duration overflow water during the flood period.
   c) Slopes of the closing dike should be mild, and upstream and downstream portions of dike should be compacted well. The downstream slop should be protected with revetment and foot protection works.

5.4 Normalization of Channel Alignment

Following works are planned at the critical sections to normalize the alignment, so as to alleviate severe bends and/or to shorten navigation length in meandering reaches:

1) Realignment works
2) Cut-off channel works

(1) Realignment Works

Site

Realignment works are planned at the severe bends in the main channel for navigation. For selection of sites for realignment works, the following criteria are introduced:

1) The bends of which radius of curvature (Rc) are less than four (4) times of ship length (Ls) shall be subjected to the works. Applying this to the Apure and Portuguesa rivers, the sites which need realignment works are selected at the following severe bends:

   Rc < 560 m; for the Apure river
   Rc < 240 m; for the Portuguesa river

2) For immediate implementation as an urgent improvement:

   Rc < 320 m; for the Apure river

   Rc < 150 m; for the Portuguesa river

Function

The realignment works aim to alleviate the curvature at the severe channel bends for smooth navigation operation.

Description of Works

The realignment works generally include channel dredging/excavation works to enlarge the channel curvature and groyne works to guide the river flow to new channel.

Principles of Design

1) Curvature : Radius of curvature (Rc) of realigned channel shall meet the following criteria:

   Rc >= 560 m; for the Apure river

   Rc >= 240 m; for the Portuguesa river

2) Channel section : Along the new alignment the channel required for navigation shall be dredged as follows

   a) Width (W):

      W >= 80 m; for the Apure river

      W >= 30 m; for the Portuguesa river

   b) Bedelevation (Hb):

      Hb<= Hnm - (draft + 0.5m)

   Where Hnm denotes water level corresponding to the flow for designed navigation month.

3) Groyne works : Head of groyne works should be aligned along the designed outer bank of new channel. For the milder slope rivers, permeable types such as pile groyne are the typical works.

(2) Cut-off Channel Works

Site

Cut-off channel works are planned at the severe meandering reaches in the main river to be used for navigation.

Function

The cut-off channel works aim to construct a new channel to shorten the navigation length and to avoid channel improvement works due to critical curvature, depth and width. Some cut-off channels aim to normalize the channel alignment.

Description of Works

The cut-off channel works generally include dredging/excavation works of new channel, closing dike works for the channel to be abandoned and earth dike works along the new channel. Groyne works and revetment works may also be needed to guide the river flow to new channel smoothly and safely.

Principles of Design

1) Alignment of cut-off channel : Alignment of cut-off channel shall be straight principally. In case curved alignment is adopted at the junctions with the existing channel and other places, the radius of curvature (Rc) should be more than five (5) times of average width of the adjacent existing river sections so as to alleviate the local scouring at the curve, i.e.:

   $$Rc >= 5 \times Bex$$

2) Channel section : Although the cut-off channel may be constructed as a pilot channel, the pilot channel should have full functions for navigation. Width and depth of the new channel shall be designed as follows:

   a) Width (W) : More than the length of ship (Ls) considering the emergency of engine trouble, etc. In case some barges are connected for navigation, length of unit barge with tugboat should be taken as Ls. Therefore, for the Apure and Portuguesa rivers:

      $W >= Ls = 80$ m; for Apure river

      $W >= Ls = 60$ m; for Portuguesa river

   b) Bed elevation (Hb):

      $$Hb <= Hnm - (draft + 0.5m)$$

      Where Hnm denotes water level corresponding to the flow for designed navigation month.

3) Closing dike works : The same criteria as those for anabranch treatment works shall be applied.

4) Earth dike : Using the dredged materials, earth dike shall be constructed along the cut-off channel. The dike shall be located keeping away from the cut-off channel considering the influence of bank erosion and flood water levels. The earth dike would function as an inspection road of the new channel as well as a flood dike.

5) Groyne: The same criteria as those for realignment works shall be applied.

5.5 Improvement of Channel Section

Following works are planned at the critical sections in order to secure the depth and width required for the fluvial navigation:

1) Island treatment works
2) Channel dredging works
3) River training works
4) Temporary canalization works

(1) Island Treatment Works

<u>Site</u>

Island treatment works are planned at the critical channel section where river channel is divided by the permanent island.

<u>Function</u>

The island treatment works aim to increase and maintain the main channel depth for navigation closing the channel behind the island by closing dike or pile works.

<u>Description of Works</u>

The island treatment works include closing dike works of channel behind the island. Groyne works may also be necessary to guide the river flow to the main channel.

<u>Principles of Design</u>

1) Selection of channel for navigation: Channel to be used for navigation should be selected considering the present river use, problems of bank erosion, smooth alignment for navigation and flood water flow, etc.

2) Closing dike works : The closing dike works shall be applied where the channel to be closed is relatively small and its complete closure would not cause radical changes in conditions of the main navigation channel. Design criteria of the closing dike shall be the same as those for anabranch treatment works.

3) Pile works : If the channel to be closed is relatively large, the pile works shall be applied and monitor the effects of works and changes of main channel.

4) Groyne works : Groyne works may be provided to guide the flow to a main channel and stabilize the channel. The same criteria as those for realignment works shall be applied.

(2) Channel Dredging Works

Site

Channel dredging works are planned in the following critical sites:

1) Important navigation channel which requires urgent improvement

2) The site where other improvement measures are not applicable due to geological, technical and social reasons.

3) Local sites which require maintenance dredging works

Function

The channel dredging works aim to secure the channel section required for the r mechanical measures. The effect of the works are very sure, but sometimes it may req maintenance dredging works after every flood seasons.

Description of Works

The channel dredging works include dredging and spoil bank yard works. Groyne works may also be needed to guide the flow to the dredged channel.

Principles of Design

1) Alignment : Alignment of navigation channel to be dredged should be of smooth curve favorable to navigation and flood water flow. Channel should not be dredged only at the critical sections, but also in the adjacent reaches so as to guide the flow smoothly.

2) Channel section : The channel section to be dredged should satisfy the following:

   a) Width (W):

      W >= 80 m; for the Apure river

      W >= 30 m; for the Portuguesa river

   b) Bed elevation (Hb):

      Hb <= Hnm - (draft + 0.5 m)

      Where Hnm denotes water level corresponding to the flow for designed navigation month.

3) Spoil bank yard : Dredged material shall be disposed in the lowlying lands and river channels to be abandoned.

4) Groyne works : Groyne works may be provided in some cases to guide the flow to the dredged channel.

(3) River Training Works

Site

River training works are planned at the critical channel sections where river channel is braided with sand bars.

Function

The river training works aim to train and stabilize the river course, and increase and maintain the channel depth for navigation by guiding the water flow and narrowing the low water channel by series of groynes. Generally staged approach would be necessary for the implementation to monitor the effect and would take time to realize the final results.

Description of Work

Series of groyne works should be considered for river training of the Apure and Portuguesa rivers.

Principles of Design

1) Alignment : Alignment of low water channel for navigation should be of smooth curve favorable to navigation and flood water flow.

2) Groyne works : Pile groyne would be applicable with longitudinal groyne at the head facing to the navigation channel. The same criteria as those for the realignment works shall be applied.

3) Width (W) of channel between the groyne should be more than the length of ship (Ls), i.e.:

$W >= Ls = 80$ m; for Apure river
$W >= Ls = 60$ m; for Portuguesa river

(4) Temporary Canalization Works

Temporary canalization works aim to improve sporadic and local critical sections as remedial measures. The works may be needed recurrantly at the beginning of every dry seasons. For the channel with less navigation transport, the temporary canalization works may play more important role than the permanent works for economical reason.

Various measures have been proposed and implemented so far. The effects, however, are not always definite. In order to develop effective measures for the Apure and Portuguesa rivers, the approach of trial and error may be required supported by laboratory tests and prototypes experience.

The major temporary canalization works are as follows:

1) Bandalls
2) Floating panels (surface panels)
3) Bottom panels

5.6 Bank Protection

Due to lateral movement of river courses and local scour, towns and villages, farm lands, public roads, bridges and other river facilities such as dikes and groynes are suffering from damages.

Almost all the towns and villages along the Apure river are more or less protected by the revetment and groyne works.

In planning the measures to protect river bank from scouring due to flow, countermeasures should be discussed on the following principal measures and an appropriate measure should be selected in consideration of technical and economic viability:

1) Revetment works : To protect bank slope directly from scouring due to flow by covering the slope

2) Groyne works : To guide main river flow keeping away from the scouring river bank by a series of groynes.

3) Realignment works of river course : To realign river course away from the river bank to be protected, improving the existing channel alignment by realignment works or cut-off channel works which were presented in the foregoing section.

4) Relocation of facilities : To relocate facilities such as road and river facilities evacuating from the site suffering from scouring.

In this section, design principles of revetment works, and groyne works were taken up for further discussion. These works are also expected to stabilize the river courses preventing lateral movement of river courses.

In addition to the above, vane array works were also introduced here. The vane array works are newly developed measures to regulate lateral sediment movement by the function of vanes installed on river bed, and alleviate local river bed scouring at the bend.

(1) Revetment Works

Site

Revetment works are planned for the river banks scoured due to attacking water flows, and river banks at the structure site such as weir and gate.

Function

The revetment works aim to protect the bank slope directly from scouring. The revetment works generally consist of slope protection, sure-footing (foundation), and foot protection works.

Slope Protection Works

Slope protection works are the main part of the revetment works, which prevent the bank slope from scouring due to water flow and damage due to floating materials such as logs.

There are various types of slope protection works as follows:

1) Stone and concrete block masonry (dry and wet types): For steeper bank slope of medium and small size rivers
2) Stone and concrete block pavement (dry and wet types)
3) Concrete flame pavement
4) Interconnected concrete block pavement: Commonly as temporary works
5) Gabion pavement: Commonly as temporary works

The types of slope protection shall be selected depending on the size of river, channel conditions, gradient of bank slope, kinds of soil, etc.

Back-fill gravel should be placed behind the surface covering such as stone and block as drain and filter to prevent the soil from washing away.

Sure Footing (Foundation) Works

Sure-footing works are the foundation to support and stabilize the slope protection works. Type of sure-footing works is selected depending on the kind of foundation soil, working condition, and river conditions.

In case the foundation soil is firm and stable, the foundation would be placed directly on the river bed. If the foundation soil is poor, pile or sheet pile works would be adopted. Where water depth during the construction period is deep or local scouring at the foot is foreseen, sheet pile foundation would be used.

Foot Protection Works

Foot protection works should be provided for the revetment works in case the scouring may occur at the foot of revetment due to direct flow attack and other causes.

The foot protection works aims to stabilize the sure-footing works and accordingly the slope protection works by reducing flow velocity and preventing scouring at the foot of revetment. Failure of revetment works often occurs due to the failure of foundation. The role of the foot protection works are very important.

The foot protection works shall be resistible to tractive force of flow, durable, and adjustable to the fluctuation of river bed. Therefore the foot protection works should provide with appropriate flexibility, roughness and weight.

Typical foot protection works are shown below. The works shall be selected depending on the characteristics and conditions of the river:

1) Pitching stone
2) Timber mattress
3) Stone basket
4) Concrete block
5) Deformed concrete block
6) Groynes

Principles of Design

1) Alignment of revetment works shall be designed as smooth as possible considering the flow direction in the upstream and downstream reaches so as not to create eddy flow and dead water zone.

2) Height of the revetment works shall be up to design high water level. In case of no dike and flood water overtop river bank, the height shall be up to the river bank.

3) Bottom of the revetment works shall be put deep enough against the scouring at the foot during floods.

4) In case the slope length exceeds 10 m, berm with at least 1 m width shall be provided.

(2) Groyne Works

Site

Groyne works are planned for the river bank scoured due to attacking water flows and for the river reaches of which water flow should be guided or stabilized. The groyne works for the mild slope channel as the Apure and the Portuguesa rivers are discussed below.

Function

The groyne works principally function as follows:

1) To decrease flow velocity near the bank increasing the friction against flow
2) To change flow direction and protect the site forming the wake zone of the groynes.

Description of Works

Type of the groyne shall be selected depending on the purpose in due consideration of alignment and cross-sectional features of river channel, discharge, water level, bed materials, river bed fluctuation, etc.

The groynes are classified into permeable and impermeable types, and overflow and non-overflow types. Effect of the impermeable type and non-overflow type groynes is large, but the force of flow acting on the groyne is also large. The acting force may cause bigger local scouring and damage the groyne structure itself.

In the mild slope rivers, permeable type groynes such as pile groyne and low impermeable type groyne are commonly adopted.

Principles of Design

1) In general the groyne works are designed and evaluated of its effects as a series of groynes, since single strong groyne may disturb the river flow and cause scouring around the groyne.

2) The length, height and intervals of the groyne shall be decided considering river conditions, purpose of groyne, influence to adjacent river reaches and opposite river bank, and stability of groyne itself.

3) In most cases, the length of groyne is less than 10 % of river width.

4) According to the empirical relation, the wake length of impermeable non-overflow type groyne is 14.5 times of groyne length for the groyne placed at right angle to the flow. The wake length, however, reduces until 2.5 to 3 times of groyne length, when the scouring at the head of the groyne developed fully.

5) For the impermeable overflow type groyne, the friction to flow reaches to maximum when intervals of groynes are set at about 10 times of groyne height.

6) Height of permeable groyne is designed, in most cases, at 0.5 m to 1 m higher than the average low water level so as to reduce scouring around the groyne.

7) Crown of groyne is commonly designed with slope of 1/10 to 1/100 lowering toward river center, so that the groyne should have more friction near the bank to keep the main flow far away and less friction to prevent deep scouring at the head.

8) Scoured maximum water depth at the head of upper-most groyne is estimated as 1.8 times of water depth before scouring.

(3) Vane Array Works

Site

The vane array works could be planned at the bends of developed meandering channel to alleviate local deep scouring.

Function

The vane array works aims to alleviate local scouring at the meandering bends and shift the thalweg toward river center keeping some distance from the river bank.

Description of Works

The vane array works fall under the same category as bottom panel which had been put into practice since the end of 19th century. In 1980s Odgaard et al made theoretical studies based on the secondary flow in meandering section and used the term "vane".

Recently Fukuoka et al proposed design method of vane array works based on laboratory tests and prototype tests in actual river in Japan. The proposed method are briefly introduced here, although the works implemented so far in field are still limited.

Principles of Design

1) The vane array works shall consist of arrays of vanes installed on river bed. The vane is composed of cylindrical pile and vane of trapezoidal shape.

2) Angle of vane to flow shall be 20°, so that the lift due to vane would be maximum.

3) Length (l) and height (Hi) of name above the sectional mean rarer the hed with mean depth of (ha) shall be as follows:

   l = (0.5 to 2) x ha

   Hi = (1/4 to 1/3) x ha

4) Depth of foundation : Depth of vane to be penetrated into ground shall be determined based on the scouring around the vane and its stability under ordinary and flood flow conditions. According to the experimental results, the scouring depth is estimated as follows from the diameter of cylindrical pile (D):

a) 2 x D; at the foot of cylindrical pile
b) 4 x D; at the external side of vane

5) The vane shall be arranged zigzag in an array

6) Location of vane array shall be as follows:
   a) Single array : b/B = 0.2 0.25
   b) Double arrays : b/B = 0.2 0.25; 0.4 0.5
   where
   b: Lateral distance of array from outer river bank
   B: River width

7) The vane array shall be arranged so that the offset ratio of secondary flow should be within the range of 0.5 to 0.6 as a whole.

5.7 Sample Drawings

In order to materialize the channel improvement measures, sample drawings of facilities are attached as follows to introduce principles and ideas of the facility design:

1) Submerged dike works	:	Fig.5.7.1
2) Closing dike works	:	Fig.5.7.2
3) Realignment works	:	Fig.5.7.3
4) Cut-off channel works	:	Fig.5.7.4
5) Island treatment works	:	Fig.5.7.5
6) River training works	:	Fig.5.7.6
7) Temporary canalization works	:	Fig.5.7.7
8) Revetment works	:	Fig.5.7.8
9) Groyne works	:	Fig.5.7.9

VI. FORMULATION OF CHANNEL STABILIZATION PLAN

6.1 Principles

Based on the discussions made in the foregoing chapter, the following principles for the formulation of channel stabilization plan were derived:

1) Upper Apure flow improvement : Caparo-Uribante Viejo derivation channel shall be taken up. Works related to dams will not be included, since new dams are not proposed but the released water from the power generation will be used.

2) Middle Apure flow improvement : This scheme will be discarded, since its hydraulic effects are low in the initial stage, and moreover, it will get lower in future due to the increase of irrigation water demand.

3) Upper Portuguesa flow improvement : Right dike of the upper Portuguesa river shall be taken up within a framework of flood management plan. The Cojedes-El Frasco derivation channel will not be considered for the present study, but might be incorporated in future for enhancement of navigation capacity based on the navigation master plan after examining the economic viability. Therefore, channel improvement works will be the principal measures for the Portuguesa river.

4) Treatment of anabranches at Chirel site and Bravo/Garzas site will be taken up for the plan, since the treatment of Chirel site would be effective for stabilization of the bifurcation, and the treatment of Bravo/Garzas site would also be effective for flow improvement of the main Apure river. These measures, however, needs further studies and investigation on channels, facilities and environment.

5) Normalization of channel alignment : Realignment and cut-off channel will be the principal measures for the section of critical radius of curvature in the meandering reaches.

6) Improvement of channel section :Then the island treatment and channel dredging would be the principal measures. The other improvement works of channel section such as river training and temporary works are expected to be adopted gradually depending on the progress of development of measures, accumulating the technology and experience through hydraulic model tests in laboratory and prototype tests in the Apure river.

6.2 Project Works

(1) Work Division

Considering the location of site, functional unit of work, and staging of construction, the project works were discussed dividing the work site as follows:

1) Flow Improvement
   a) Caparo-Uribante Viejo derivation channel

2) Treatment of Anabranch
   a) Chirel site
   b) Bravo/Garzas site

3) Channel Improvement

   Apure River

   a) Stretch-A1 : River mouth to San Fernando port
   b) Stretch-A2 : San Fernando port to Portuguesa R.
   c) Stretch-A3 : Portuguesa R. to Nutrias port
   d) Stretch-A4 : Nutrias port to Santos Luzardo port

   Portuguesa River

   e) Stretch-P1 : River mouth to Cojedes R.
   f) Stretch-P2 : Cojedes R. to El Baul port

(2) Kind of Works

1) Derivation Channel
   a) Preparatory works
   b) New channel works
   c) Control gate works
   d) Related works
   e) Miscellaneous works

2) Anabranch Treatment
   a) Preparatory works
   b) Submerged dike works
   c) Closing dike works
   d) Miscellaneous works

3) Channel Improvement
   a) Preparatory works

b) Realignment works
c) Cut-off channel works
d) Channel dredging works
e) Island treatment works
f) River training works
g) Miscellaneous works

(3) Arrangement of Staged Plans

Three (3) stages of plans were considered for the channel stabilization plan, i.e., short-term plan, mid-term plan and long-term plan.

The short-term plan aims to accomplish the following physical target:

1) Apure river : To attain eight (8) month navigation from river mouth to San Fernando port (St-A1) and seven (7) month navigation for the Apure river from San Fernando port to Santos Luzardo port (St-A2, A3 and A4).

2) Portuguesa river : To attain eight (8) month navigation from San Fernando port to El Baul port (St-A2, P1 and P2).

The short-term plan includes the following works:

1) Derivation channel works : Caparo-Uribante Viejo derivation channel with water release of La Vueltosa power station at the initial development stage.

2) Anabranch treatment works : Chirel site and Bravo/Garzas site

3) Alignment normalization works : For critical bends with Rc<320 m for the Apure river and Rc<150 m for the Portuguesa river

4) Channel section improvement works : For 8 month navigation for St-A1, A2, P1 and P2, and 7 month navigation for St-A3 and A4.

The mid-term plan aims to accomplish the following physical target:

1) Apure river : To attain nine (9) month navigation from river mouth to San Fernando port (St-A1) and eight (8) month navigation for the apure river from San Fernando port to Santos Luzardo port (St-A2, A3 and A4).

2) Portuguesa river : To attain nine (9) month navigation from San Fernando port to El Baul port (St-A2, P1 and P2).

The mid-term plan includes the following works:

1) Flow improvement by Caparo-Urivante Viejo derivation channel with water release of La Vueltosa power station at the final development stage.

2) Alignment normalization works : For critical bends with Rc<560 m for the Apure river and Rc<240 m for the Portuguesa river.

3) Channel section improvement works : For 9 month navigation for St-A1, A2, P1 and P2, and 8 month navigation for St-A3 and A4.

Physical target of the long-term plan shall be discussed in line with the navigation master plan to be prepared. The channel works to realize the physical target of the long-term plan would be principally the channel section improvement works.

The above physical target of the staged plans were set based on the consideration made on the channel improvement for navigation as follows, reviewing the result of evaluation of the existing channel:

1) The existing channel would be navigable if the critical section is less than 1.0 % of the total with minor channel improvement. On the other hand, the limit of channel improvement for navigation at the present stage was assumed to be up to 10 % of total stretches. Then, the navigable months are summarized as follows:

Item		Apure R.				Portuguesa R.		
		A1	A2	A3	A4	A2	P1	P2
Existing	Dc	8	6	6	4	7	11	12
	Wc	8	12	8	8	12	8	8
	Min.	8	6	6	4	7	8	8
Limit of imp.	Dc	12	9	8	8	9	12	12
	Wc	11	12	8	9	12	9	8
	Min.	11	9	8	8	9	9	8

In the above, the navigable months of stretch-A2 are different due to the difference of critical depth of for the Apure and the Portuguesa rivers, i.e., 2.00 m and 1.70 m, respectively.

2) Judging from the above and the length of the stretches for improvement, the existing navigable months and limit of improvement were set as presented

below. The limit of channel improvement at the present stage was considered as the physical target of mid-term plan (MTP)and the physical target of the short-term plan (STP)was set in-between.

Stretch	Navigation months		
	Existing	STP	MTP
a) Apure River			
River mouth - S.Fernando port	8	8	9
S. Fernando port - Nutrias port	6	7	8
Nutrias port - S.Luzardo port	4	7	8
b) Portuguesa River			
S.Fernando port - El Baul port	7	8	9

Critical sections and countermeasures of respective staged plans were summarized and shown in Table 6.2.1. Their locations are shown in Fig. 6.2.1 for the Apure river and in Fig. 6.2.2 for the Portuguesa river.

(4) Quantity of Works

Quantity of works of the Apure and Portuguesa rivers was estimated for respective kinds of works and for respective work divisions. Results of estimate are shown in Tables 6.3.1 and 6.3.2 together with cost.

6.3 Cost Estimate

Project cost was estimated at the price level of February 1993. Currency of the project cost was expressed in US$ by using the prevailing exchange rate in February, 1993 as follows:

US$1 = Bs.82 = ¥119.72; Bs.1 = ¥1.46

Results of project cost estimate are shown in Tables 6.3.1 and 6.3.2, and is summarized below.

	Work item	STP (US$1,000)	MTP (US$1,000)	STP+MTP (US$1,000)
1)	Construction cost	40,013	55,576	95,589
	a) Preparatory works (10%)	3,637	5,053	8,690
	b) Derivation channel	3,020	0	3,020
	c) Anabranch treatment	1,029	0	1,029
	d) Alignment normalization	20,941	27,813	48,754
	e) Section improvement	10,326	21,239	31,565
	f) Miscellaneous works (3%)	1,060	1,471	2,531
2)	Land acquisition	5	2	7
3)	Administration cost	2,001	2,780	4,781
4)	Engineering services cost	6,803	9,448	16,251
5)	Physical contingency (10%)	4,883	6,781	11,664
6)	Total	53,705	74,587	128,293

Detail of the cost estimate is described in the Supporting Report; Part G.

6.4 Economic Consideration

The fluvial navigation has the advantages of the low-cost and massive load transportation. The benefit of fluvial navigation is to be estimated mainly for the transportation cost reduction, in comparison with the land transportation, for the extended navigation period by the channel stabilization works.

The effect of channel stabilization plan shall be evaluated in accordance with the navigation master plan, because the channel stabilization plan would be a part program of the master plan.

In this section some preliminary economic considerations on the channel stabilization plan were made based on a cargo data obtained from PROA. Detailed discussions on the economic aspects are presented in the Supporting Report; Part H.

Project benefit was estimated as a reduction in transportation costs during fluvial navigation period extended by the channel stabilization. The project benefit and economic project cost are shown below in brief together with annual operation and maintenance costs.

Plan	Proj.cost ($1,000)	Opera.cost ($1,000/yr)	Mainte.cost ($1,000/yr)	Benefit ($1,000/yr)
Short-term plan	45,111	2,198	451	10,992
Mid-term plan (STP+MTP)	107,765	4,173	1,078	20,864

Results of preliminary evaluation of the channel stabilization plan are shown in Table 6.4.1 and summarized below.

Plan	IRR (%)	B/S	B-C (US$1,000)
Short-term plan	17.7	1.72	38,677
Mid-term plan (STP+MTP)	13.7	1.46	46,666

Remarks : B/C and B-C were estimated under the discount rate of 8%/yr.

6.5 Environmental Considerations

The study area for the channel stabilization plan cover the stretch of the main Apure river from confluence with the Orinoco river to Santos Luzardo port, and the Portuguesa river from confluence with the Apure river to El Baul port.

The channel stabilization for navigation would be attained by channel improvement and flow improvement. The channel improvement includes works of anabranch treatment, alignment normalization, channel section improvement, and bank protection.

The following changes in river and surrounding areas would be more or less brought about from the implementation of the channel stabilization works.

Changes in river flow due to derivation diversion channel and ana-branch treatment works:

1) Flow will cease in the channel abandoned by the closing dike.

2) Flow will be controlled to be low in the source river downstream of the derivation channel and the anabranch downstream of the submerged dike.

3) Flow will increase in the main Apure river downstream of confluence of the derivation channel and bifurcation of anabranch.

<u>Changes in river bank due to river training and bank protection works:</u>

4) River bank during dry season may shift toward river center because of sedimentation in the wake zones of the groyne.

5) River bank will be covered by the slope protection works.

<u>Changes in river bed and river bank conditions due to channel dredging and disposal:</u>

6) River bed will be lowered and agitated by river dredging.

7) Lowlying lands in the river bank will be filled up by dredged materials.

Among the above changes due to the channel stabilization works, items 1), 2) and 7) are more important. Other items would give minor impact to the environment, since the works are of small scale and sporadic.

Regarding items 1), 2) and 7), further intensive study and investigation would be necessary at the design stage on the following aspects, but not limited to:

1) Existing water use

2) Existing ecological condition

3) Identification of objects to be conserved

Based on the study and investigation, the plan and design should be revised, if necessary, to conserve the ecological system and/or to compensate the right of resident people.

VII. IMPLEMENTATION PROGRAM

7.1 General

Implementation program for the channel stabilization plan was discussed here. However, since the navigation master plan is not prepared yet, discussions on appropriate project size, implementation schedule and project evaluation are difficult to made. Therefore the programs discussed here are preliminary level and should be reviewed and revised so as to comply with the navigation master plan after its preparation.

The channel stabilization plan is composed of three (3) staged plans, i.e., short-term plan, mid-term plan, and long-term plan.

The proposed plans are in line with the principles and policies of the Ministry, since component schemes of the plan are mostly based on the ideas and schemes prepared by PROA and other authorities concerned.

7.2 Short-Term Plan

(1) Physical Target

Physical target of the short-term plan is to accomplish the following navigable months for immediate implementation:

1) Apure river: To attain eight (8) month navigation from river mouth to San Fernando port (St-A1) and seven (7) month navigation from San Fernando port to Santos Luzardo port (St-A2, A3 and A4).

2) Portuguesa river: To attain eight (8) month navigation from San Fernando to El Baul port (St-A2, P1 and P2).

(2) Improvement Works

1) Derivation Channel Works: Caparo-Uribante Viejo derivation channel with water release of La Vueltosa power station at the initial development stage.

2) Anabranch Treatment Works:
   a) Chirel site: Submerged dike across the Chirel river
   b) Bravo/Garzas site: Submerged dike across the Bravo river and closing dikes across the Rompida and Cañafistolito rivers.

3) Alignment Normalization Works:
   a) Apure river: For the critical bends with radius of curvature (Rc)<320 m
   b) Portuguesa river: For the critical bends with Rc<150 m

4) Channel Section Improvement Works:
   a) St-A1 : For 8 month navigation
   b) St-A2 : For 8 month navigation
   c) St-A3 : For 7 month navigation
   d) St-A4 : For 7 month navigation
   e) St-P1 : For 8 month navigation
   f) St-P2 : For 8 month navigation

7.3 Mid-Term Plan

(1) Physical Target

Physical target of the mid-term plan is to accomplish the following navigable months by full employment of existing schemes and measures:

1) To attain nine (9) month navigation from river mouth to San Fernando port (St-A1) and eight (8) month navigation for the Apure river from San Fernando port to Santos Luzardo port (St-A2, A3 and A4).

2) To attain nine (9) month navigation from San Fernando to El Baul port (St-A2, P1 and P2).

(2) Improvement Works

1) Derivation Channel Works: No work was considered, but Caparo-Uribante Viejo derivation channel with water release of La Vueltosa power station at the final development stage.

2) Alignment Normalization Works:
   a) Apure river: For the critical bands with radius of curvature (Rc)<560 m
   b) Portuguesa river: for the critical bends with Rc<240 m

3) Channel Section Improvement Works:
   a) St-A1 : For 9 month navigation
   b) St-A2 : For 9 month navigation
   c) St-A3 : For 8 month navigation
   d) St-A4 : For 8 month navigation
   e) St-P1 : For 9 month navigation
   f) St-P2 : For 9 month navigation

7.4 Long-Term Plan

Physical target of the long-term plan shall be discussed in line with navigation master plan.

Improvement works for the long-term plan will be mostly the channel section improvement works.

7.5 Implementation Schedule

The short-term plan shall be implemented first and then the mid-term plan depending on the increase of the cargo to be transported and the economic viability. The implementation schedule is tentatively proposed in Fig.7.5.1 which shall be revised in line with the navigation master plan.

Sequence of project works would be as follows:

1) Project Preparation: 1st to 5th year
   a) Navigation master plan study
   b) Feasibility study
   c) Financing

2) Short-Term Plan:
   a) Preparation: 1st to 2nd year
   b) Detailed design : 1st to 2nd year
   c) Construction works : 3rd to 7th year
      - Urgent channel works : St-A4 for 6 month navigation
      - Channel works : St-A1
      - Channel works : St-A2, P1 and P2
      - Anabranch treatment work : Chirel site and Bravo/Garzas site
      - Channel works : St-A3
      - Channel works : St-A4
      - Caparo-Uribante Viejo derivation channel

3) Mid-Term Plan:
   a) Preparation : 6th to 7th year
   b) Detailed design : 6th to 7th year
   c) Construction works : 8th to 17th year
      - Channel works : St-A1
      - Channel works : St-A2, P1 and P2
      - Channel works : St-A3
      - Channel works : St-A4

4) Long-Term Plan: Not scheduled (After 18th year)