THE REPUBLIC OF VENEZUELA
MINISTRY OF ENVIRONMENT
AND NATURAL RESOURCES
DGSPROA-UNH

JAPAN INTERNATIONAL
COOPERATION AGENCY

STUDY
ON
COMPREHENSIVE IMPROVEMENT
OF
[illegible] RIVER BASIN

FINAL REPORT

VOLUME II

MAIN REPORT

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TOKYO, JAPAN

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STUDY
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COMPREHENSIVE IMPROVEMENT
OF
THE APURE RIVER BASIN

FINAL REPORT

VOLUME II

MAIN REPORT

NOVEMBER 1993

NIPPON KOEI CO., LTD.
NIKKEN CONSULTANTS, INC.
KOKUSAI KOGYO CO., LTD.
TOKYO, JAPAN

This report consist of the following five volumes.

VOLUME I : EXECUTIVE SUMMARY

VOLUME II : MAIN REPORT

VOLUME III : SUPPORTING REPORT

- PART-A : TOPOGRAPHIC SURVEY
- PART-B : GEOLOGICAL AND GEOMORPHOLOGICAL STUDIES
- PART-C : AGRICULTURE AND LAND USE SURVEY
- PART-D : HYDROLOGICAL AND HYDRAULIC STUDIES
- PART-E : STUDY ON CHANNEL STABILIZATION FOR NAVIGATION
- PART-F : STUDY ON FLOOD MANAGEMENT
- PART-G : CONSTRUCTION PLAN AND COST ESTIMATE
- PART-H : SOCIO-ECONOMY AND PRELIMINARY PROJECT EVALUATION
- PART-I : ENVIRONMENTAL SURVEY

VOLUME IV : DATA BOOK I

VOLUME V : DATA BOOK II

The cost estimate was made based on February 1993 price level and expresses in Bolivares according to the following exchange rate.

US$ 1.00 = Bs. 82.00 = ¥ 119.72

(As of February 17, 1993)

PREFACE

In response to a request from the Government of the Republic of Venezuela, the Government of Japan decided to conduct Study on Comprehensive Improvement of The Apure River Basin and entrusted the study to Japan International Cooperation Agency (JICA).

JICA sent to Venezuela a study team headed by Mr. Yoichi Takeuchi, Nippon Koei Co., Ltd., and composed of members from Nippon Koei Co., Ltd., Nikken Consultants, Inc. and Kokusai Kogyo Co., Ltd. four times between March 1992 and October 1993.

The team held discussions with the officials concerned of the Government of Venezuela, and conducted field surveys at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Venezuela for their close cooperation extended to the team.

November 1993

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

November 1993

Mr. Kensuke Yanagiya
President
Japan International Cooperation Agency
Tokyo, Japan

Dear Mr. Yanagiya

Letter of Transmittal

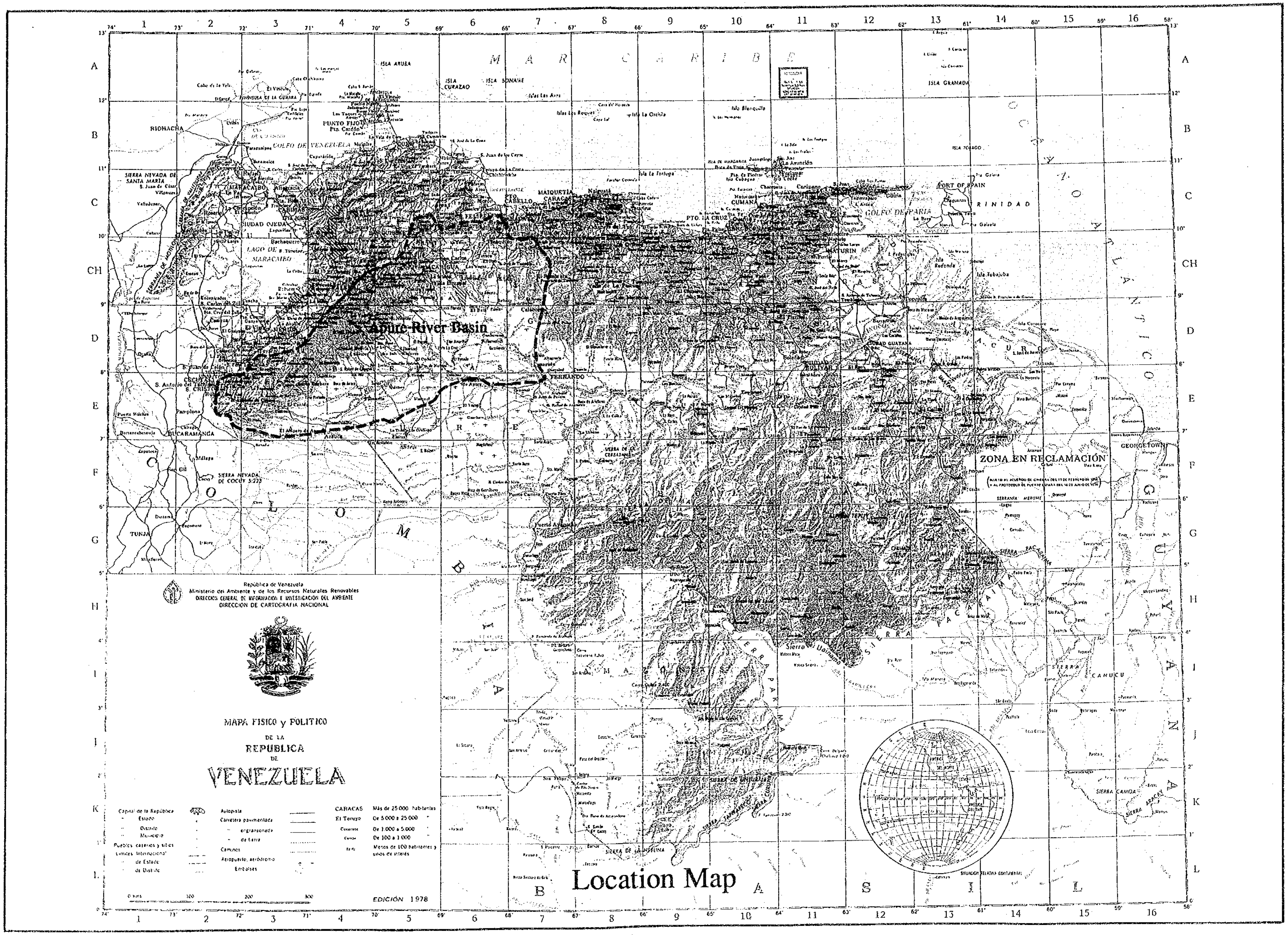
We are pleased to submit herewith the Final Report of Study on Comprehensive Improvement of The Apure River Basin. This Report deals with formulation of the basic concepts and measures for stabilization of the river channel for navigation and mitigation of the flood damages at master plan level.

The Report consists of five (5) volumes, Executive Summary, Main Report, Supporting Report, Data Book I and Data Book II. Main outputs presented in the Report are channel stabilization plan for navigation and flood management plan. The former proposes several measures to stabilize the channel such as derivation channel, anabranch treatment, alignment normalization, etc., while the latter proposes dike construction along the river channel to mitigate flood damages in the protection area selected.

We would like to express our grateful acknowledgment to the personnel of your Agency, Advisory Committee, Ministry of Foreign Affairs, Ministry of Construction and Embassy of Japan in Venezuela, and also to officials and individuals of the Government of Venezuela for their assistance and advice extended to the Study Team. We sincerely hope that the results of this study would contribute to the improvement of the Study Area.

Very truly yours,

Yoichi Takeuchi
Team Leader
Study on Comprehensive Improvement
of The Apure River Basin



Location Map

SUMMARY

INTRODUCTION

1. BACKGROUND: Upon request of the Government of Venezuela, Government of Japan decided to render technical cooperation to the Study on Comprehensive Improvement of the Apure River Basin (the Study) through its executing agency, Japan International Cooperation Agency (JICA).

2. OBJECTIVE OF STUDY: Objective of the Study is to formulate the basic concepts and measures for the comprehensive improvement of the Apure river basin for the stabilization of river channels and the mitigation of flood damages. In the course of the Study technology transfer was performed.

3. STUDY WORKS: Total period of the Study was twenty one (21) months from the commencement in March 1992 to the submission of the final report in November 1993 dividing into four (4) phases, each of which consists of field survey in Venezuela and home work in Japan.

4. SCOPE OF STUDY AREA: The study area covers:

   1) River reaches of the main Apure river from the confluence of the Orinoco river to Guasdualito and the Portuguesa river from San Fernando to El Baul for the Study of channel stabilization;
   2) Area bounded by the Apure, Masparro and Portuguesa rivers for the study of flood damage mitigation; and
   3) Whole Apure river basin for the hydrological study related to the Study.

5. APURE RIVER: The Apure river which is one of the largest tributaries of the Orinoco river originates at the northwest point of the Andes mountains in Venezuela near the border to Colombia. The catchment area is 111,800 km^2 at San Fernando. Length of the main Apure river is 681 km from the confluence of the Orinoco river to Remolino bridge near Guasdualito. Major tributaries of the Apure are the Portuguesa, Masparro, Paguey, Canagua, Suripa, Caparo, Uribante, and Sarare rivers from the Andes mountains; and the Guaritico river from the plain area on right bank.

SURVEY AND BASIC STUDIES

6. SURVEY AND INVESTIGATION: The following survey and investigation were carried out by the Study Team during the field survey period:

   1) Topographic survey : Twice in May to July 1992 and January to March 1993
   2) Material investigation : River bed and river bank materials
   3) Hydrological investigation
   4) Agricultural and land use survey
   5) Socio-economic survey
   6) Environmental survey

7. BASIC STUDIES: On the basis of data and information obtained from MARNR and survey and investigation conducted by the Study Team, the following basic studies were made for the channel stabilization and flood management plans;

   1) Geomorphological study
   2) Study on runoff characteristics
   3) Flood analysis
   4) Channel flow analysis

STUDY ON CHANNEL STABILIZATION PLAN

8. PREVIOUS STUDIES AND WORKS: Previous studies and works in the study area are as follows in brief:

   1) Improvement of the Apure river initiated in 1960s. 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.
   2) As for the fluvial navigation, construction of four (4) fluvial ports have been planned and the works are ongoing at San Fernando, Bruzual and Guasdualito of the Apure river and El Baul of the Portuguesa river. Studies and designs of some channel improvement works are also being implemented.
   3) Master plan study for the fluvial navigation of the Orinoco-Apure system is scheduled to be conducted soon separately.

9. CHANNEL STRETCHES: For the conveniences of descriptions for studies and planning, the Apure and Portuguesa rivers were divided into the following channel stretches:

1) Apure River

St-A1	:	From river mouth (Orinoco river) to San Fernando port
St-A2	:	From San Fernando port to confluence of Portuguesa river
St-A3	:	From confluence of Portuguesa river to Nutrias port (Bruzual)
St-A3.1	:	From Confluence of Portuguesa river to Apurito
St-A3.2	:	From Apurito to Nutrias port
St-A4	:	From Nutrias port to Santos Luzardo port (Guasdualito)
St-A4.1	:	From Nutrias port to Suripa river
St-A4.2	:	From Suripa river to Santos Luzardo port

2) Portuguesa River

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

10. CHARACTERISTICS OF CHANNEL:

1) General channel features of respective stretches are as follows:

a. Stretch-A1: Ground slope is 1/8,500. Large scale anabranches develop in this stretch. River is not braided. Average river width is 257 m for the main Apure and 340 m including anabranches.

b. Stretches-A2 and A3.1: Ground slope is 1/7,200. Large scale anabranches develop in this stretch. River is not braided. Average river width is 251 m for the main Apure and 342 m including anabranches.

c. Stretch-A3.2: Ground slope is 1/5,000. River is braided and average river width is 522 m fluctuating much from 200 m to 880 m.

d. Stretch-A4.1: Ground slope is 1/4,200. There are several confluence of tributaries. River is braided and average river width is 501 m fluctuating much from 220 m to 800 m.

e. Stretch-A4.2: Ground slope is 1/2,500. There is no confluence of major tributaries and channel is not braided. Average river width is 265 m.

f. Stretch-P1 and P2: Ground slope is very mild as approx. 1/17,000. River is meandering without islands and average river width is 140 m near Camaguan.

2) According to the comparative study on the topographic maps of the year 1988 (scale 1/10,000) and those of the year 1960 to 1966 (scale 1/25,000), variations of left and right banks were very active historically in the Stretches-A3.2 and A4.1.

3) Channel characteristics of sections were studied comparatively based on the sections surveyed in June/July of 1992 and January/February of 1993 as follows:

a. River channels in Camaguán site are deep and narrow with width-depth ratio (B/hm) of 19, while Guasdualito and Bruzual sites are relatively flat with width-depth ratios of 72 and 82, respectively.

b. Regarding the maximum channel depth, channel width and river bank shifting, changes through a flood season in Guasdualito and Bruzual are remarkable. The channels in Camaguán site are stable comparing with those of other two sites.

11. EVALUATION OF CHANNEL CAPACITY FOR NAVIGATION: Navigability of river channel was examined for water depth, width and radius of curvature of channel making use of channel flow calculations as presented below.

1) Channel Size Criteria:

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

2) Channel Flow Criteria: Ordinal daily discharge was adopted as criteria for navigable period. The ordinal daily discharge is defined as the daily discharges ranking from the annual minimum based on the average flow duration at major stream gauging stations along the main Apure and Portuguesa rivers.

3) Evaluation result for Apure river: Shortage of water depth is the principal problem of the Apure river. Judging from the critical water depth, navigable

months of the Apure river were evaluated to be eight(8) months for St-A1, six(6) months for St-A2 and A3 and four months for St-A4. For the navigation longer than nine (9) months, channel width also become critical:

4) Evaluation result for Portuguesa river: Shortage of channel width and curvature are the principal problems of the Portuguesa river. Judging from the critical channel width, navigable months of the existing Portuguesa river were evaluated to be eight (8) months for St-P1 and seven (7) months for St-P2. The critical channel sections increase abruptly for the navigation longer than nine (9) months.

12. PRINCIPLES OF CHANNEL STABILIZATION FOR NAVIGATION: In order to improve channel capacity for navigation, two principal measures were considered, i.e., (1) flow improvement to increase channel discharge and (2) channel improvement to provide enough channel section. Efforts were made to incorporate ideas and schemes studied by PROA and other authorities concerned of MARNR.

13. FLOW IMPROVEMENT: Based on the results of evaluation of effects of possible measures, the following principles for the formulation of channel stabilization plan were derived:

1) Flow improvement of upper Apure : Caparo-Uribante Viejo derivation channel will be taken up.
2) Flow improvement of middle Apure : Bocono-Masparro derivation channel will be discarded, since its hydraulic effects are low.
3) Flow improvement of upper Portuguesa: The Cojedes-El Frasco derivation channel will not be considered for the present study.

14. CHANNEL IMPROVEMENT: Based on the results of evaluation of effects the following principles for the formulation of channel stabilization plan were derived:

1) Treatment of anabranches at Chirel site and Bravo/Garzas site will be taken up for the plan.
2) 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.

3) Improvement of channel section: Until 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.

15. 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 limit of channel improvement works was assumed to be 10 % of the total channel length, and is considered to be the physical target of the mid-term plan. Physical target of the long-term plan shall be discussed in line with the navigation master plan to be prepared.

16. COST ESTIMATE: The cost required for the implementation of the project was estimated in US$ by using the prevailing exchange rate in February, 1993. Project cost was estimated and is summarized below.

1)	Short-Term Plan	:	US$ 53,705,000
2)	Mid-Term Plan	:	US$ 74,587,000
3)	STP + MTP	:	US$ 128,293,000

17. ECONOMIC CONSIDERATION: The benefit of fluvial navigation was estimated for reduction of the transportation cost in comparison with the land transportation, for the extended navigation period by the channel stabilization works. Since navigation master plan has not been prepared yet, some economic considerations on the channel stabilization plan were made based on a cargo data obtained from PROA.

	Plan	EIRR(%)	B/C	B-C (US$ 1,000)
1)	Short-Term Plan	17.7	1.72	38,677
2)	STP + MTP	13.7	1.46	46,666

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

river and surrounding areas would be more or less brought about from the implementation of the channel stabilization works. Among them, changes in anabranches downstream of the closing and submerged dike, and sites for disposal of dredged materials would be important. 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

STUDY ON FLOOD MANAGEMENT PLAN

19. STUDY AREA: The area subject to the present flood management study is 21,200 km^2 bounded by the Apure river in south, Portuguesa river in north and east and local road route 2 in west. The study area is vast and presently mostly in natural conditions, so that environmental aspect should be carefully considered. A drastic change of hydraulic conditions of the area resulting from implementation of the flood management works will give strong impact to the environment of the area.

Major rivers in the study are the Apure river and Portuguesa river mentioned above and also the Guanare river which runs through the center part of the study area.

20. HYDRAULIC CHARACTERISTICS: The habitual inundation area is widely distributed in the study area. The total inundation area comes to a half of the study area. The inundation caused by flooding of rivers is distributed along the major rivers in the study area.

The possibility of solution of drainage problems in the study area is roughly classified into three categories according to the study by MARNR. The areas of low and almost no possibilities occupy a half of the study area. The areas with possibility are distributed in upper and middle basins and partly on the left bank area of the Apure river, while most of the lower basins have almost no possibility of solution of drainage problems.

The present discharge capacities of the rivers in and around the study area are fairly small for their catchment areas.

21. EXISTING AND PROPOSED FLOOD CONTROL FACILITIES: The existing and proposed flood control facilities located in and around the study area are as follows:

(1) River Dike
 1) Existing : 7 locations
 2) Proposed : 1 location

(2) Dam
 1) Existing : 7 dams
 2) Proposed : 2 dams

(3) Floodway and Diversion Channel
 1) Existing : 1 floodway
 2) Proposed : 1 diversion channel

22. EXISTING AND PROPOSED PROJECT: The existing and proposed projects in the study area are as follows:

(1) Existing
 1) Guanare-Masparro agricultural development project

(2) Proposed
 1) Extension of the Guanare-Masparro Project
 2) Railway project (right bank of the Portuguesa river)

23. EXISTING LAND USE PLAN: Zoning plans of Barinas, Portuguesa and Cojedes states have been prepared by MARNR, which aim to picture the future development of the respective states till the year 2010. The proposed land use is mostly for agriculture use (cattle breeding).

24. BASIC CONSIDERATION FOR PLANNING: In order to mitigate the inundation, increase of discharge capacities of the rivers in the area will be primary consideration. However, it will incur concentration of flood flow to San Fernando funnel, and large increase of discharge capacity of the funnel is not expectable. Therefore, improvement method which incur flood concentration to San Fernando will not be appropriate for the present study. Also, the flood inundation contributes to the life of inhabitants in the area as water resources though it causes damages. Consideration from environmental aspect is important as the study area is presently mostly in the natural conditions.

25. PROTECTION AREA: The protection area was selected applying the criteria that it should have possibility of solution of drainage problems and land use assignment in the future. Consequently, the following four (4) areas were selected.

1)	Area "A" :	Area extending on the right bank side of Caño Igüés
2)	Area "B" :	Area extending on the right bank side of the Guanare river
3)	Area "C" :	Area extending on the left bank side of the Apure river
4)	Area "D" :	San Fernando city and its surrounding area

Area "D" was selected for the reason that the flood management works for Areas "A", "B" and "C" in the upstream may influence to the area and therefore increase of safety degree against flood will be necessary to protect San Fernando city from flood.

26. DESIGN SCALE OF THE PLAN: The return period of 10 years was employed as design scale of the plan, which is commonly applied to the rural area in Venezuela. The design rainfall with 10-year return period corresponds to 96% of rainfall in 1981 which is the largest rainfall recorded in the study area.

27. POSSIBLE MEASURES: The possible measures for the present flood management planning will be as follows:

1) Dike
2) Diversion Channel
3) Retarding basin (natural and artificial)
4) Dam
5) Widening and deepening of present river channel

According to the preliminary study on the above measures, the following facts were revealed.

1) One-side dike is recommendable.
2) Existing and proposed dams have almost no effect to the study area.
3) Widening and deepening of present river channel is not applicable considering present and hydraulic topographic conditions.

28. ALTERNATIVE PLANS FOR AREA "A": Possible measures to protect Area "A" were selected as follows:

a) Dike against flooding and
b) Dam for flood peak cut.

However, as dam plan was discarded because there exist no proposed and feasible dams effective for protection of the Area "A". Considering that the inundation in and around the protection area is mainly caused by flooding of the Portuguesa river and Caño Igüés, the following three (3) alternative plans were formulated.

1) Plan A1: Dike on the right bank of the Portuguesa river (187 km long)
2) Plan A2: Dike on the right bank of Caño Igüés (190 km long)
3) Plan A3: Dike on the right bank of the Portuguesa river and left bank of Caño Igüés (185 km long)

29. ALTERNATIVE PLANS FOR AREA "B": Possible measures to protect Area "B" were selected as follows:

a) Dike against flooding,
b) Dam for flood peak cut and
c) Improvement of existing river channels.

However, dam plan was discarded because there exist no proposed and feasible dams effective for protection of the Area "B" other than existing Bocono-Tucupido dam. To prevent the flooding of the Guanare river and also to mitigate the inundation in the area, the following three (3) alternative plans were formulated.

1) Plan B1: Dike on the right bank of Guanare river (145 km long)
2) Plan B2: Dike on the right bank of Guanare river (145 km long) and improvement of Guanare Viejo river (95 km long)

By the improvement capacity of Guanare Viejo river, this plan is divided into the following two cases.

Plan B2A: Proposed width and depth of Guanare Viejo river is 25 m and 3 m, respectively. (about 100 m^3/s in capacity)

Plan B2B: Proposed width and depth of Guanare Viejo river is 50 m and 3 m, respectively. (about 200 m^3/s in capacity)

30. ALTERNATIVE PLANS FOR AREA "C" (Fig. 19): Possible measure to protect Area "C" was selected as follows:

a) Dike against flooding
b) Apure type module to prevent specific area

To prevent the flooding of the Apure river, the following two alternative plans were formulated.

1) Plan C1: Dike on the left bank of Apure river from Nutrias port to Samanat (155 km long)
2) Plan C2: Dike on the left bank of Apure river from Nutrias port to Apurito (105 km long)
3) Plan C3: Apure type module in the areas other than wetland subject to environmental consideration

31. ALTERNATIVE PLANS FOR AREA "D": Possible measures to protect Area "D" were selected as follows:

a) Widening of the present Apure river channel,
b) Diversion channel to alleviate burden of Apure river,
c) Retarding basin to regulate flood concentration to San Fernando funnel,
d) Heightening of existing dike surrounding San Fernando and
e) Lowering of water level of downstream stretch from San Fernando.

Among them, measures a) and e) were discarded due to difficulty and small effect, respectively. Measure d) should be employed when other measures are not effective because it does not mean improvement of the hydraulic condition in the area. Regarding the measures b) and c), the following three (3) alternative plans were formulated.

1) Plan D1: Diversion channel from Portuguesa to Apurito rivers

This plan is divided into the following two (2) cases.

Plan D1A : Improvement of existing floodway (Total width of 400 m and low water channel of 60 m wide)

Plan D1B : Improvement of existing floodway and proposed diversion channel (same width as Plan D1A)

2) Plan D2: Retarding basin by Apure type module (5,200 km^2)

32. PROPOSED PLAN FOR AREA "A": Plan Al remained as proposed plan because inundation area may not extend due to topographic condition and also no serious environmental impact is expected according to the preliminary investigation though inundation depth on the left bank of the Portuguesa river increases at about 40 ~ 50 cm at maximum for the present condition. This plan will have economic effect by using the dike as road connecting national roads route 5 and route 8.

33. PROPOSED PLAN FOR AREA "B": Among the alternative plans, Plan B1 was selected because effect of improvement of existing channel in Plans B2A and B2B is as small as 3 ~ 6 cm in decrease of inundation depth though it lasts for longer period and also the cost is 2 to 3 times higher than Plan B. Prevention of flooding of the Guanare river is essential for the present flood management plan though the decrease of inundation depth of the area is about 5 cm. This plan has advantages of economic effect by using the dike as road and also to utilize existing roads of 130 km long in total as dike.

34. PROPOSED PLAN FOR AREA "C": Both of Plans Cl and C2 increase the water level of the Apure river by about 1 m for the present condition, but influence does not reach San Fernando. In case of Plan C2, overflow still occurs in the reaches downstream from Apurito because of influence of the said water level increase and influence to the area. Therefore, Plan Cl is better than Plan C2. However, if Plans Cl and C2 are not feasible, Plan C3 should be adopted to protect certain parts in the Area "C" by the Apure type module.

35. AREA "D": No plan was selected because of small effects of respective alternative plan and also no influence to the area by the flood management plan for Areas A, B and C in the upstream.

36. ENVIRONMENTAL CONSIDERATION: The study area is mostly in natural condition at present, so that consideration from environmental aspect is important. According to the preliminary study, no significant environmental impact is expected though the further detailed environmental impact analysis has to be made for final conclusion.

In the areas protected by the dikes on the right banks of Portuguesa and Guanare rivers (Areas "A" and "B", respectively), human intervention has already caused physical impact on nature and therefore the proposed dikes will not cause major ecological impact, but instead they will promote consolidation of existing incipient farming development by protecting them from flooding of rivers.

On the other hand, Area "C" protected by the dike on the left bank of the Apure river has much less human intervention than Areas "A" and "B". Therefore, the environmental impact by the dike should be analyzed before dike construction.

37. PROPOSED FLOOD MANAGEMENT PLAN: The flood management plan to be proposed is formulated by integration of the following component plans proposed for respective protection areas.

Plan A1 for Area "A" (Dike for Portuguesa river)
Plan B1 for Area "B" (Dike for Guanare river)
Plan C1 or C3 for Area "C" (Dike for Apure river or Apure type module)

As no significant change occurs in inundation by integration of the respective component plans comparing with the result of hydraulic study for each plan, this plan was adopted as the proposed flood management plan.

38. COST ESTIMATE: The project cost required for implementation of the proposed flood management plan was estimated in US$ by using the prevailing exchange rate in February, 1993. The project cost estimated is summarized below:

1) Plan A1: US$ 34,185,000
2) Plan B1: US$ 25,553,000
3) Plan C1: US$ 34,110,000
4) Overall: US$ 93,848,000

39. ECONOMIC CONSIDERATION: The benefits produced by the implementation of the proposed flood management plan are flood reduction benefit and land enhancement benefit. Based on the project cost and benefits estimated, economic internal rate of return (EIRR) and benefit-cost ratio (B/C) for respective plans are as follows:

Plan	EIRR (%)	B/C	B-C (US$ 1,000)
A1	11.0	1.39	9,124
B1	11.0	1.45	7,295
C1	6.6	0.82	-5,212
Overall	9.2	1.15	7,614

FORMULATION OF MASTER PLAN

40. ARRANGEMENT OF PLANS: The Study on Comprehensive improvement of the Apure River Basin includes two component plans, i.e., channel stabilization and flood management plans. These plans could be formulated independently, since the channel stabilization will not give radical changes to flood flows and the flood management does not influence to low flow for navigation.

CHANNEL STABILIZATION PLAN

41. SHORT-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 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 under 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.

42. MID-TERM PLAN: 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 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-Uribante Viejo derivation channel under 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.

43. 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 sequence of project works would be as follows:

1) Project Preparation: 1st to 5th year
2) Short-Term Plan: 1st to 7th year
3) Mid-Term Plan: 6th to 17th year
4) Long-Term Plan: Not scheduled (After 18th year)

FLOOD MANAGEMENT PLAN

44. LONG-TERM PLAN: The target of the long-term plan is to accomplish the entire flood management plan proposed. The long-term plan largely consists of the following works.

1) Construction of dike on the right bank of Portuguesa river (187 km long)
2) Construction of dike on the right bank of Guanare river (145 km long)
3) Construction of dike on the left bank of Apure river (155 km long)

45. SHORT-TERM PLAN: The short-term plan aims at implementation of the priority works and effective works in the long term plan. In the proposed flood management plan, the following two works are taken up as the short-term plan.

1) Partial dike for Portuguesa river (103 km long) from national road route 8 to Nueva Florida in relation with railway project.

2) Partial dike for Guanare river (25 km long) to connect existing roads to use them as road dike.

46. IMPLEMENTATION SCHEDULE: The short-term plan shall be implemented first and then the long-term plan. The sequence of project works for flood management would be as follows:

1) Preparatory Period: 1st to 5th year
2) Short-Term Plan: 2nd to 10th year
3) Long-Term Plan: 8th to 20th year

STUDY ON COMPREHENSIVE IMPROVEMENT
OF
THE APURE RIVER BASIN

FINAL REPORT

VOLUME II : MAIN REPORT

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ABBREVIATIONS

MARNR	:	Ministerio del Ambiente y de los Recursos Naturales Renovables (Ministry of Environment and Natural Resources)
JICA	:	Agencia de Cooperación Internacional de Japón (Japan International Cooperation Agency)
PROA	:	Programa Orinoco-Apure (Orinoco-Apure Program)
DHM	:	Dirección de Hidrología y Metereología (Direction of Hydrology and Meteorology)
INC	:	Instituto Nacional de Canalizaciones (National Institute of Canalizations)
ICN	:	Instituto de Cartografía Nacional (National Cartography Institute)
DC	:	Dirección de Cartografia (Direction of Cartography)
DPRH	:	Dirección de Planificacion de los Recursos Hidráulicos, Suelo, Vegetación y Fauna (Direction of Planning of the Hydraulic Resources, Soils, Vegetation and Fauna)
DPC	:	Dirección de Planes Conservacionistas (Direction of Conservation Plans)
DEP	:	Dirección de Estudios y Proyectos (Direction of Studies and Projects)
PROFAUNA	:	Servicio Autónomo de Profección Fomento de la Fauna Silvestre (Wildlife Protection and Development Services)
CVS	:	Corporación Venezolana del Suroeste (Southwest Venezuelan Corporation)

CVG	:	Corporación Venezolana de Guayana (Venezuelan Guayana Corporation)
LNH	:	Laboratorio Nacional de Hidraulica (National Hydraulic Laboratory)
AUDUBON	:	Sociedad Conservacionista Audubon de Venezuela (Venezuelan Chapter of the Audubon Society)
BID	:	Banco Interamericano de Desarrollo (Interamerican Development Bank)
FUDENA	:	Fundación para la Defensa de la Naturaleza (Foundation for the defence of Nature)
INPARQUES	:	Instituto Nacional de Parques (National Institute of Parks)
UCV	:	Universidad Central de Venezuela (Central University of Venezuela)
UNELLEZ	:	Universidad Nacional Experimental de Los Llanos Occidentales "Ezequiel Zamora" (National Experimental University of the Western Llanos " Ezequiel Zamora")

I. INTRODUCTION

1.1 Background

Upon request of the Government of Venezuela, the Government of Japan decided to render technical cooperation to the Study on Comprehensive Improvement of the Apure River Basin (the Study) through its executing agency, Japan International Cooperation Agency (JICA). The scope of Work for the Study was agreed on October 16, 1991 between the Ministry of Environment and Natural Resources (MARNR) of the Government of Venezuela and JICA.

1.2 Objective of Study

The objective of the Study is to formulate the basic concepts and measures for the comprehensive improvement of the Apure river basin for the stabilization of river channels and the mitigation of flood damages.

In the course of the Study technology transfer was performed.

1.3 Scope of Study

According to the Scope of Work agreed on October 16, 1991, the Study shall cover the following areas as shown in Fig. 1.3.1:

1) River reaches of the main Apure river from Guasdualito to the confluence with the Orinoco river of approximate length of 630 km, and the Portuguesa river from El Baúl to San Fernando of approximate length of 250 km for the Study of channel stabilization

2) Area of about 30,000 km^2 bounded by the Apure, Masparro and Portuguesa rivers for the study of flood damage mitigation

3) Whole Apure river basin for the hydrological study related to the Study

In order to attain the objective set forth in the foregoing section, studies were carried out mainly in the following fields:

1) Channel stabilization
2) Flood management
3) Hydrology and hydraulics
4) Geology and geomorphology
5) Agronomy, agriculture and land use
6) Environment
7) Socio-economy and preliminary economic evaluation
8) Construction plan and cost estimate
9) Topographic survey

1.4 Study Works

(1) Overall Work Program and Major Activities

Total period of the Study was scheduled for twenty (20) months from the commencement in March 1992 to the submission of the final report in October 1993. The overall work schedule is shown in Fig. 1.4.1. The study period is divided into four (4) phases, each of which consists of filed survey in Venezuela and home work in Japan.

(2) Organization for Study

In order to implement the Study work effectively in collaboration with MARNR and JICA Study Team, an organization was established for the Study as shown in Fig. 1.4.2.

Various agencies of MARNR are related to the Study, i.e., PROA, LNH, DHM, DC, DPRH, DEP, DPC, and SUS. PROA and LNH jointly function as a leading agency of MARNR for the Study.

Technical Coordinator was designated for daily contact with the Study Team and four (4) groups of counterparts were organized as follows. These counterpart personnel participated in the Study on the part-time basis.

1) Channel Stabilization Study Group
2) Flood Management Study Group
3) Hydrological Study Group
4) Survey and Investigation Group
   Topographic survey
   Geomorphological survey
   Agronomical and agricultural survey
   Environmental survey
   Socio-economy
   Cost estimate

Personnel related to the Study are listed in Table 1.4.1.

(3) Major Activities of Study Team

The Study was carried out almost on schedule. Major activities of the Study Team are presented below for respective phases.

1) Phase-1 Study

   a) Field Survey: March to August 1992
      Discussion on Inception Report
      Data collection and field investigation

   b) Home Work: September to December 1992
      Analysis and preparation of alternative schemes Preparation of Interim Report

2) Phase-2 Study

   a) Field Survey: January to March 1993
      Discussion on proposed alternative schemes
      Additional data collection and field investigation First seminar and workshop
      Workshop on computer programs
      Workshop on environmental study

   b) Home Work: May to June 1993
      Analysis, evaluation and formulation of proposed river improvement plan

3) Phase-3 Study

a) Filed Survey: June 1993
Discussion on proposed river improvement plan

b) Home Work: July to September 1993
Finalization of river improvement plan
Preparation of Draft Final Report

4) Phase-4 Study

a) Field Survey: September to October 1993
Discussion on Draft Final Report
Second seminar

b) Home Work: October 1993
Submission of Final Report

II. STUDY AREA

2.1 Location and Topography

The study area covers the Apure river basin which is one of the largest tributary of the Orinoco. The area is located in 7° to 10° north latitude and 66° to 73° west longitude (Fig. 2.1.1).

The basin is bounded by the coastal mountains (Cordillera de la Costa) on the north and the Andes mountains (Los Andes) on the west. The coastal mountains extend from east to west ranging from 2,000 m to 3,000 m MSL in altitude and the Andes mountains run from southwest to northeast ranging from 3,000 m to 5,000 m MSL in altitude. Mt. Bolivar which is the height mountain in Venezuela is one of the peaks of the Andes mountains.

A vast plain called as Venezuelan Llanos exists between the Orinoco river and the Andes/coastal mountains. It extends 1,000 km from east to west and 200 km to 400 km from north to south located in the central part of Venezuela. The plain is divided into western, central and eastern Llanos. The Apure river basin covers the major part of the western Llanos and a part of the central Llanos ranging from 140 m to 40 m MSL.

The Apure river originates at the northwest point of the Los Andes mountains in Venezuela near the border to Colombia. The catchment area is 111,800 km^2 at San Fernando. The length of the main Apure river is 681 km from the confluence of the Orinoco river to Remolino bridge near Guasdualito.

The major tributaries of the Apure are the Guárico river from the coastal mountains; the Portuguesa, Masparro, Pagüey, Canagua, Suripa, Caparo, Uribante, and Sarare rivers from the Andes mountains; and the Guaritico river from the plain area on the right bank. The tributaries from the south eastern slope of the Merida mountains transport a lot of sediment and form large complex alluvial fans at the outlet of the mountainous area.

The area from the confluence of the Apure and Portuguesa rivers to the Orinoco river is the lowest in the basin. In this area an inland delta is formed.

2.2 Geology

Geological map of the Apure river basin is shown in Fig. 2.2.1. At the west side of the Apure basin, the Andes Mountains (Merida Mountains) runs in a direction from NE to SW. The Andes Mountains mainly consist of the Paleozoic granitic rocks and meta-sedimentary rocks accompanied with the Mesozoic meta-sedimentary rocks and sedimentary rocks on the Precambrian basement.

At the piedmont of the Andes Mountain, tertiary sedimentary rocks lie on the older rocks. The Andes mountains is highly cut by NE-SW normal faults. Among them, the biggest one is the Bocono Fault running in the central part of the Mountains. This fault is a first class active one and divides the Andes Mountains into two parts. Direction of displacement shows right lateral and many earthquakes have been happen along this fault.

At the north side of the Apure basin, the Coastal Mountains runs in a direction of E-W. The Coastal Mountains consist of the Mesozoic sedimentary rocks, meta-sedimentary rocks, meta-volcanic pyroclastic rocks and granitic rocks on the Paleozoic basement. At the piedmont of the Coastal Mountains, tertiary sedimentary rocks lie on the older rocks. In the Coastal Mountains, many active faults run in the same direction as the axis of the Mountains. The biggest one is the Caribe Fault running in the north edge of the Mountains. This fault is a right-arterial fault as same as the Bocono fault in the Andes Mountains. This fault meets with the Bocono fault in the Barquisimeto basin.

The Mesozoic rocks and tertiary rocks contact with many over-thrust faults in the piedmont. Along the Caribe Fault, many earthquakes have happened as well as the Bocono Fault. Since the Cretaceous, the Andes and the Coastal Mountains have been affected by up-lift crustal movement. On the other hand, the Apure basin has been affected by subsidence. Consequently, the Mesozoic and Tertiary formations deposit thickly in the basin. These formations are presently covered with Quaternary formations.

2.3 Meteorology and Hydrology

Climate of the study area falls, as a whole, under the tropical sabana climate by Koppen's classification as shown in Fig. 2.3.1. Annual isohyetal map is shown in Fig. 2.3.2. Average monthly rainfall, temperature and evaporation are presented in Fig. 2.3.3 selecting six (6) stations, i.e., three (3) in the mountainous area and another three (3) in the plain area.

Rainfall is most distinctive to the climate of the study area. The annual rainfall ranges from 1,200 mm to 1,600 mm in the plain area and amounts to 2,800 mm in the mountainous area. Rainy season of the study area is from April to November.

The maximum temperature is observed in March and minimum in July, although the variation is slight. In the plain area monthly average temperature ranges from 25° to 29 °C throughout the year. The maximum evaporation occurs in March as well as the temperature, and the minimum in June at every stations.

Water level of the Apure river forms single cycle hydrograph in a year with peak in August and bottom in March or April. Its daily and monthly fluctuations are slight. For example, difference between the highest and lowest water levels in a year is about 6 to 7 m at San Fernando and 4 m at Bruzual, while the fluctuation in a month is only 0.5 m or less.

The Apure river conveys 60 billion m^3 of water in a year and its average discharge is approximately 2,000 m^3/s. The recorded highest and lowest water levels at San Fernando are 45.6 m MSL and 36.5 m MSL, respectively.

2.4 Socio-Economy

The Apure river basin covers all of Barinas, Portuguesa and Cojedes provinces; a part of Tachira and Apure provinces; and small portions of Mérida, Trujillo, Lara, Yaracuy, Carabobo and Guárico provinces (Fig. 2.4.1).

Tachira province is located in the southwest of Venezuela on the Andes region. It is bounded by the Zulia province on the north, Merida province on the west, Barinas and Apure provinces on the south and Colombia on the east. Its surface area is 11,100 km^2 with a population of 807,700 persons in 1990. The capital is San Cristobal. The major agricultural products are coffee, cattle, potato, vegetable, fruit, and bean. The main mining product is carbon. It has an attractive tourist scenery.

Barinas province is located in the southwest of Venezuela, in the west of Los Llanos. It is bounded by the Apure river on the south, provinces of Portuguesa, Cojedes and Trujillo on the north, Tachira and Merida on the west and Guarico on the east. Its surface area is 35,200 km^2 with a population of 424,500 persons in 1990. The capital is Barinas. The main agricultural products are cotton, maize, timber, cattle, pork, rice and sesame. Crude oil is produced on the northeast of San Silvestre.

Cojedes province is located in the western center of Venezuela. It is bounded by the provinces of Lara, Yaracuy and Carabobo on the north, Barinas on the south, Guarico on the east, and Portuguesa and Lara on the west. Its surface area is 14,800 km^2 with a population of 182,100 persons in 1990. The capital is San Carlos. The main agricultural products are cattle, rice, sorghum and maize.

Portuguesa province is in the west of Venezuela. It is bounded by the provinces of Lara and Trujillo on the north, Barinas on the south, Cojedes on the east, and Barinas and Trujillo on the west. Its surface area is 15,200 km^2 with a population of 576,400 persons in 1990. The capital is Guanare. The major agricultural products are rice, sorghum, sesame, cotton, maize and bean.

Apure province is located in the southeast of Los Llanos. It is bounded by the Apure river on the north, the Orinoco river on the east and Colombia on the south and west. The area of this province is 76,500 km^2 and the population is 285,400 persons in 1990. The capital is San Fernando de Apure. The major agricultural products are cattle, kidney bean, rice, pork, banana, maize, cotton and timber. The central part of the province is protected by the right dike of the Apure river. Apure module project is located there. Recently, crude oil was discovered in the Arauca river on the border to Colombia.

III. SURVEY AND INVESTIGATION

3.1 Topographic Survey

The topographic surveys carried out in phase 1 field survey are as follows:

1) Cross sectional survey
2) Leveling survey

The survey sites are shown in Fig. 3.1.1. The phase 1 field work was done from the beginning of May to the end of July 1992 and the phase 2 work from the beginning of January to the middle of March 1993. Detail of the survy is descrived in the Supporting Report : Part-A.

3.1.1 Channel Cross Sectional Survey

The survey plan to select cross section survey sites was prepared based on the collected existing survey data.

Three sites of Guasdualito, Bruzual and Camaguán were selected to observe variation of river bed conditions. The monumentation, control point survey, cross sectional survey and data processing were carried out as follows.

(1) Monumentation

In the phase 1 survey, cross section posts were installed with steel bar and concrete on the both river banks at each survey site. The number of cross section posts installed is 359 points.

In the phase 2 survey, as a first step of the survey works, cross section posts installed in the phase 1 were inspected. According to the inspection, it is found that a lot of posts were damaged and lost due to much erosion or sedimentation. These posts were recovered. The number of recovered posts is 145 points.

(2) Control Point Survey

The position of cross section post was measured with a Geodimeter and the traverse network was connected to the ICN (Instituto de Cartografia Nacional) station.

In the phase 1 survey, control points of 376 points were surveyed at Guasdualito, Bruzual and Camaguan. The accuracy of traverse survey network at Guasdualito and Bruzual was within the specified range, but that for Camaguan was not numerically evaluated because no known point exists near survey site and therefore position of open traverse was observed by a ground positioning system (GPS). However, the survey at Camaguan may have almost same accuracy as those at Guasudalito and Bruzual sites since the same survey method was applied.

In the phase 2 survey, the horizontal and vertical positions of recovered cross section posts were measured.

(3) Cross Sectional Survey

The total station was set at a cross section post on the river bank and then distance and angle were measured by the total station. The data were recorded in personal computer and position of the survey boat was calculated by a range-bearing method. The survey boat was sailed along the cross section line for measuring the river bed topography.

The water depth was measured by a digital echo sounder and the data were recorded in personal computer.

Cross sectional survey was carried out at the following three sites both in phase 1 and phase 2, but six (6) lines at Bruzual site could not be surveyed in phase 2 due to insufficient water depth.

1) Guasdualito site

Guasdualito site which extends between Remolino bridge and a point of 3 km downstream from confluence of the Uribante river and the Apure river. The cross section line interval is approximately 500 m. The number of cross sections surveyed is 48 lines.

2) Bruzual site

Bruzual site which extends between San Vicente and a point of 3 km downstream from the Bruzual bridge of the Apure river. The cross section line interval is approximately 500 m. The number of cross section surveyed is 50 lines.

3) Camaguan site

Camaguan site which extends between Camaguan and a point of 10 km upstream from Camaguan of the Portuguesa river. The cross section line interval is approximately 200 m. The number of cross sections surveyed is 52 lines.

(4) Additional Cross Sectional Survey

The PROA and other organizations have carried out cross section survey on the Apure river and the Portuguesa river to grasp the basic river information for the river channel study.

The additional cross sectional survey was carried out at San Fernando (3 sections), Setenta (1 section), Masparro (1 section) and Uribante (1 section) in phase 1 and Apurito-San Fernando (14 sections) and El Negro-La Maciera (21 sections) in phase 2.

(5) Data Processing

Data processing work was carried out by the following procedure.

a) Data Correction

In the field, the position and depth are recorded in different type of personal computer. As the data recorded in the field have some irregular values in the position and depth file, the data are corrected manually one by one.

b) Data Integration

Position and depth are separately recorded in micro floppy disk. The depth data are converted to IBM format and both data are integrated in one file.

c) Data Compilation

Angle and distance from total station, coordinate of boat, elevation of river bed and deviation from course line are calculated based on the integrated file. The calculated data are stored in the compilation file.

d) Chart Drawing

Finally, cross section chart of the river is produced from the compilation file using a computer and plotter.

Results of the cross sectional survey are shown in Data Book I as cross section charts.

3.1.2 Leveling Survey

The leveling survey consists of the following. Total distance of leveling was 430 km.

(1) Leveling for Cross Section Post

The survey was carried out along one of the river banks in order to give elevations to the cross section posts. Accuracy of the leveling work was 40 mm per 5 km at maximum, which meets the specification.

(2) Leveling for Proposed Water Level Gauging Station

The survey was carried out to establish bench marks near the proposed water level gauging station sites. The elevations of the bench marks were measured from the known bench marks.

(3) Leveling for Staff Gauge

The survey was carried out to establish bench marks at the staff gauge sites installed at La Union, San Antonio, La Capilla (1), La Capilla (2), Paso Igues, Coco de Mono and Costa de Guanare to observe the inundation depth. The leveling was made based on the known bench marks.

3.2 Material Investigation

Material investigation consists of sampling of river bed material, bore hole drilling, sampling of material by test pit and laboratory test of materials. The sites of material investigation are listed in Table 3.2.1 and shown in Figs. 3.2.1 and 3.2.2. Detail of the investigation is described in the Supporting Report : Part-B.

3.2.1 River Bed Material Investigation

(1) Method of Investigation

The samples of 37 nos. were obtained from river beds of the Apure river and its tributaries and 2 samples from the Orinoco river at Puerto Ordaz. Sampling points are on the present river beds and the sampling was made by shovels after removing surface soil.

(2) Result of Investigation

The investigation sites are located on the foot of Coastal Mountains and Andes Mountains at about 200 m in altitude. The maximum diameters of these materials range from 10 to 50 cm except some samples.

The materials with smaller diameters were found at the sampling sites of Verde, Cojedes and Uribante rivers because of influence of dam, basin and flood plain. They consist of sands.

On the other hand, materials with larger diameters were found at the sampling sites of Pao river, Canagua, Acequia and Bumbum rivers due to rapid flow.

3.2.2 Bore Hole Drilling

(1) Method of Investigation

Drilling works of bore holes were carried out at 13 river banks in the Apure river basin. The drilling sites are located on the river banks beside the river channels which are 2 to 10 m high above river bed. Drilling depth was 20 m. Standard penetration test (SPT) was carried out at 1 m interval.

(2) Result of Investigation

According to results of the drilling and SPT, the Apure river basin is widely covered with alluvial soil which changes its thickness at different places. Under the alluvial soil, diluvial soil is distributed. Top alluvial soil was deposited by cutting the diluvial soil. These Pleistocene series are mainly distributed as buried terrace and a part of them sometimes directly exposes on the surface of the basin.

Tops of the alluvial soils consist of silt and clay of which thicknesses are about 1 to 7 m, while lower parts of them consist of sandy soil of which thickness is more than about 10 to 20 m. Tops of the diluvial soils consist of silt and clay which have thicknesses of about 5 to 15 m, while lower parts of them consist of sandy soils which have thicknesses of more than about 10 m. The clayey soils of alluvial and diluvial formations contain some thin sandy soils in the layers.

3.2.3 Test Pitting

(1) Method of Investigation

Disturbed samples by test pitting were obtained at 13 river banks in the Apure river basin. Test pitting sites are beside the bore hole sites. Sampling depth is about 1 m from the ground surface.

(2) Result of Investigation

Soil types and geological formations of samples obtained by test pitting are as follows:

Test Pit No.	Soil Type	Geological Formation
1, 2, 3	Clayey Silt	AC1
4	Fine Sand	AS1
5, 6	Clayey Silt	AC1
7	Clayey Silt	DC1
8	Silty Sand	AS1
9, 10	Silty Sand	AC1
11	Silty Sand	DC1
12, 13	Sandy Silt	AC1

Test pit samples are top soils of drilling hole at river banks and consist of alluvial clayey soil (AC1 formation), alluvial sandy soil (AS1 formation) and diluvial clayey soil (DC1 formation). These soils show low N-values compared with lower positioned soils due to weathering.

3.2.4 Laboratory Test

(1) Method and Purpose

All the laboratory tests were carried out based on the standard of ASTM (American Society for Testing and Material). The laboratory tests carried out are specific gravity, moisture content, grain size, liquid and plastic limits and standard compaction. The laboratory test of the materials aims to grasp the basic physical properties of the material in major rivers of the Apure river basin.

(2) Result of Laboratory Test

1) River bed material

a) Grain size analysis

The grain size distribution curves of river bed materials are shown in Fig. 3.2.3. The mean diameters (D50) of the materials at the sites on the foot of the mountain largely range between 0.05 mm and 30 mm because of steeper slopes.

The mean diameters of the materials of Apure and Orinoco rivers range between 0.03 mm and 0.5 mm. They do not change so much from upper reaches to lower reaches because other tributaries join with them.

The river bed materials in the Portuguesa river mainly consist of clay, silt and sand. The mean diameters therefore range between 0.004 mm to 0.3 mm.

b) Specific gravity and moisture content

Mean values of specific gravity and moisture content of rivers in the piedmont, the Apure and Portuguesa rivers are given in Table 3.2.2. No remarkable difference is recognized among rivers. Mean specific gravities are within general values of sand and silt between 2.5 and 2.7. Mean moisture contents are lower than general values of sandy and silty soils of 20 to 60 %. This may be because of natural drying of samples.

c) Liquid limit and plastic limit

Mean liquid limit and mean plastic limit of fine material are given in Table 3.2.2. No remarkable difference are recognized among rivers. Those values of the samples range between 17 % and 45 % which are in lower ranges of general values. This is because the fine materials contain a lot of sandy soil.

2) River bank materials

a) Grain size analysis

The grain size distribution curves of river bank materials of the Apure and Portuguesa rivers are shown in Fig. 3.2.4. Mean diameters (D50) of both rivers roughly range from 0.001 mm to 0.1 mm and particle sizes of the upstream points are naturally larger than those of the downstream.

b) Specific gravity and moisture content

Mean specific gravities and mean moisture contents by geological formation are given in Table 3.2.2. Mean specific gravity of clayey soil ranges from 2.70 to 2.74. On the other hand, that of sandy soil ranges from 2.65 to 2.74.

Specific gravity of clayey soil is generally around 2.5, while that of sandy soil 2.7. The measured specific gravity of clayey soil is a little higher than the general value. This may be because the sample contains sandy soil.

Mean moisture content of sandy soil is 18 %, while that of clayey soils ranges from 17 % to 36 %. The measured moisture content of sandy soil is close to the lower range of general value. On the other hand, moisture content of clayey soil is lower than the general value, but it may be normal in the area having dry season and wet season.

c) Liquid limit and plastic limit

Mean liquid limits and mean plastic limits by geological formation are given in Table 3.2.2. Mean liquid limit measured is 17 to 22 % and mean plastic limit 33 to 42 % excluding AC1 layer (first clay). Those values are rather smaller than the general values. This may be because the sample contains sandy soil.

3) Embankment Material

a) Grain Size Analysis

Samples of 13 nos. were obtained by test pitting. Among them, sample of TP-4 is fine sand and TP-8 is silty fine sand. Other samples are clayey silt or sandy silt. The grain size distribution curves of all samples are shown in Fig. 3.2.5.

b) Specific gravity and moisture content.

Maximum, minimum and mean values of all samples are given in Table 3.2.2. Mean specific gravity is 2.71 which is close to value of normal soil (around 2.7). On the other hand, mean moisture content is 14.6 % which is low compared with normal soil (40 % to 60 %). Especially, minimum value of 6.6 % is too low. This may be because the sample was originally dry or stock condition of the sample was not good.

c) Liquid limit and plastic limit

Maximum, minimum and mean values of all samples are given in Table 3.2.2. Mean liquid limit and plastic limit are 31 % and 11 %, respectively. They are lower than those of normal soil. On the plasticity chart, all plasticity indexes are plotted above A-line. It means that compressibility is medium and soils have enough strength in dry condition.

3.3 Hydrological Investigation

The following hydrological investigations were conducted during the study period:

1) Data collection and review
2) Inundation observation
3) Discharge measurement
4) Sediment observation
5) Water level observation
6) Water quality test

Detail of the hydrological investigation is described in the Supporting Report: Part-D.

3.3.1 Data Collection and Review

(1) Topographic Maps and Photos

In order to analyze the river system, basin boundary and conditions of basin and channel, the following topographic maps and photos were collected.

1) Topographic maps
   a) Scales of 1/1,000,000, 1/500,000 and 1/250,000 for the whole study area
   b) Scales of 1/100,000 and 1/25,000 for the area along the main Apure and the Portuguesa rivers
   c) Scale of 1/10,000 for the area along the main Apure river excluding a stretch of 30 km downstream from Apurito
2) Photos taken by CVS from airplane continuously along river course
   a) From Guasdualito to Bruzual taken on March 14, 1989
   b) From Burzual to Confluence of the Orinoco river taken on March 29, 1989
   c) From Guasdualito to Bruzual taken on October 13, 1989

(2) Meteorological and Hydrological Observatories and Data

1) Existing Observation System: Observation, maintenance and data compilation works of the meteorological and hydrological stations are shared by the field and the central offices of the Directorate of Hydrology and Meteorology (Direccion de Hidrologia y Meteorologia).

2) Meteorological Raingauge Stations: Location of meteorological and raingauge stations is shown in Fig. 3.3.1. All the measuring equipment in these stations are automatic recording type.
Arrangement of raingauge network in the study area was started in 1944 and there are 167 stations at present. Stations are located densely in the high land and mountainous area and are sparse in the plain area (Los Llanos).

3) Stream Gauging Station: Arrangement of gauging network along the Apure river and its tributaries was started in 1970 and there are 36 stations at present. At 28 stations among them, recording gauges are installed and discharge and sediment are also observed. At most stream gauging stations, discharge rating curves were prepared based on the discharge measurements. Location of these gauging stations is shown in Fig. 3.3.2.

(3) Data on Hydrological Studies

Hydrological and hydraulic studies made by the MARNR were collected and reviewed. Most of the hydrological studies have been made for dam projects and the hydraulic studies are for channel stabilization for navigation.

3.3.2 Inundation Observation

The inundation observation was carried out from May to November, 1992 to know behavior of inundation in the study area.

In order to observe inland water levels, staff gages were installed by MARNR at the following seven (7) sites shown in Fig. 3.3.3 and observation was made daily in principle by MARNR.

1) La Union
2) San Antonio
3) La Capilla 1 (East)
4) La Capilla 2 (West)
5) Costa de Guanare
6) Igüés
7) Coco de Mono

Besides the above staff gage observation, observation by car and boat crossing the subject area was carried out weekly at four routes shown in Fig. 3.3.3. The observation work was carried out by Venezuelan firm under JICA Study Team. According to the observation, inundation depth is estimated at 0.5 to 2 m.

In parallel with the above inundation observation on ground, reconnaissance by airplane was carried out in May, June and August, 1992 to suppliment the ground observation.

Though the observation results were reflected to inundation anlysis and flood management planning, it was difficult to know the inundation condition through this observation because of vast survey area, complicated inundation and poor accessibility.

3.3.3 Discharge Measurement

Discharge measurements were carried out at the existing four (4) stations (Fig.3.3.4) in collaboration with MARNR staff as follows:

Measurement (in 1992)	P.Remolino (Jun. 19)	Bruzual (Jun. 9)	S.Fernando (Jul. 14)	Camaguán (Jul. 15)
1) JICA current meter	All	All	-	All
2) MARNR current meter	Partial	Partial	All	
3) Float/Surface (nos)	10	15	-	-
4) Rod float/50 cm (nos)	10	15	-	-
5) Rod float/100 cm (nos)	10	Partial (5)	-	-

The following meters were used for the discharge measurement:

1) JICA current meter : Electro-magnetic current meter
2) MARNR current meter : Propeller type current meter
3) Float: Three (3) types of standard floats developed by Ministry of Construction, Japan, i.e., Surface float, 50 cm long rod float, and 100 cm long rod float.

JICA and MARNR current meters gave practically same values. Results by the floats were also accurate enough, resulting in the range from 95 % to 108 % of velocities by the current meter.

The current meter is in general more accurate, but there is a possibility of damages due to floating materials during measurement. On the other hand the float method is hardly affected by the floating materials and the measurement works are relatively easy and safe. The method shall be selected considering the conditions of the flow and site to be measured.

For the main Apure and Portuguesa rivers, the current meter seems to be applicable even for flood season measurements, since the rise and fall of flood water level are very gradual, flow velocity is not so rapid, and the harmful floating materials are few. The float method would be effective for the flood discharge measurement of tributaries in hilly and mountainous areas.

Our measurement results accord well with stage-discharge curves of PROA, and the PROA curves are applicable to the present study without any modification.

3.3.4 Sediment Observation

Suspended load and bed load were sampled as follows at the same time with the discharge measurement:

Measurement Item	P.Remolino (Jun.19,'92)	Bruzual (Jun.9,'92)	S.Fernando (Jul.14,'92)	Camaguán (Jul.15,'92)
1) Integrated suspended load samples (nos)	4	5	-	3
2) Bed load samples (nos)	3	3	3	3

The samples were analyzed in the laboratory of DHM.

3.3.5 Water Level Observation

Water levels at the upper and lower ends of the selected sites were observed by MARNR daily since June, 1992, to provide data necessary for the channel studies. The following sites and gauges were selected for the water level observation:

1) Guasdualito site : Upper reaches of Apure river
Remolino bridge : Existing recording gauge
Santos Luzardo port : Existing staff gauge

2) Bruzual site : Middle reaches of Apure river
San Vicente : Existing staff gauge
Bruzualbridge : Existing recording gauge

3) San Fernando site : Lower Apure river
San Fernando : Existing recording gauge
El Negro : Existing staff gauge

4) Camaguan site : Middle Portuguesa river
Camaguan : Existing recording gauge
Camaguan town : Existing staff gauge

3.3.6 Water Quality Test

Field water quality test was carried out at the sites shown in Fig. 3.3.5 by portable tester and chemical agents in May, June and July 1992 and February 1993. The test items are dissolved oxygen, PH, conductivity, turbidity, Mn, Fe and Cu.

Test sites are as follows.

(1) Camaguán (portuguesa river)
(2) La Union (portuguesa river)
(3) San Fernando (Apure river)
(4) El Samán (Apure river)
(5) Caño Corozal (Caño Corozal)
(6) El Baul (Cojedes river)
(7) Arismendi (Guanare river)
(8) Bruzual (Apure river)
(9) Guasdualito (Apure river)
(10) Upstream of Guanaparo river confluence (Apure river)
(11) Downstream of Garzas river confluence (Apure river)

The results are summarized as below.

(1)	Temperature	26.6 - 32.3 °C
(2)	Dissolved Oxygen	6.3 - 8.0 mg/l
(3)	PH	5.3 - 7.8
(4)	Conductivity	0.0 - 0.3 ms/cm
(5)	Turbidity	27 - 292 mg/l
(6)	Mn	0.0 - 0.5 mg/l
(7)	Fe	0.0 - 5.0 mg/l
(8)	Cu	0.0 - 1.0 mg/l

3.4 Agricultural and Land Use Survey

This section summarizes the results of agriculture and land use survey carried out as a component of the Study on Comprehensive Improvement of the Apure River Basin. The survey consists of mainly data collection and analysis of existing data and information related to land use and agricultural development within the study area. Field reconnaissance survey was also carried out during the study. The basic concept for land use and agricultural development stated herein is based on the analysis of the collected data and information. Detail of the survey is described in the Supporting Report : Part-C.

3.4.1 Agriculture in Venezuela

Venezuela is a country blessed with vast natural resources such as oil and other minerals, agricultural land and water resources. Very little attention was given for agricultural development during the wealthy times of high oil price. The agricultural production was highly subsidized and of low productivity. Venezuela depends largely on import for satisfying its national demand on food and fibers of agricultural origin. Approximately 67 % of the food demand is satisfied by imported agricultural products. Large amount of money is expended annually for importing agricultural products. Present agricultural production and future targets are presented in Table 3.4.1.

Targeted volumes of agricultural production were established by the Ministry of Agriculture. The land areas that should be put into production are estimated based on the production targets. The target cropping area by states is estimated making correlation of the present output of agricultural production in each state. Targets for agricultural land areas of main crops in the states of the study area are presented in Table 3.4.2.

The land area that should be dedicated for rice production in the year 2010 is more than 5 times of the land area under rice cultivation at present. Also, for other main crops the planting area for the year 2010 should be at least twice of the area planted of each crop at the present.

Extensive land areas are dedicated for livestock production, however the present level of productivity of cattle breeding is low. The production of milk in the entire country was estimated at 1,573 million liters in 1986, while the national demand was 2,980 million liters for the same year. This data indicates a deficit in milk production of 47 % of the national demand. The increase in milk production in the last few years was estimated at 2.8 % per annum, while the demand increased at 5.7 % annually. To satisfy the national demand of milk and meat, total area and unit yield should be increased substantially. It is estimated that for the year 2000 the area dedicated for cattle breeding should be about 3.5 million ha, and the unit yield should increase twice of the present yield levels.

The new agricultural policy is targeting to achieve a sustainable and accelerated growth of the output from the agriculture and livestock production sectors. Land area and productivity must increase for achieving the targets. The objectives of the national agricultural development plan indicate that the country's production should be enough for satisfying the national demand and for exporting competitive agricultural products.

Out of the total country's land area of approximately 91.65 million ha, 7.83 million ha is suitable for agricultural production and 27.77 million ha for livestock production. A large percentage of the land suitable for agriculture and livestock production is located within Barinas, Portuguesa and Cojedes States where the study area is located. The study area presents high potential for achieving sustainable and accelerated increase in agricultural and livestock production, thus contributing to attaining the national targets. Potential land use for agriculture and livestock production is presented in Table 3.4.3.

3.4.2 The Study Area

(1) Soils of the Study Area

A large percentage of soils in the study area are classified as Chromusterts and Pellusterts Great group of the Vertisol Order. The soils are lying on flat or concave topography. The soil texture is very fine with high clay content. This soils often have high bulk density because of the fluctuation in ground water level, which causes swelling and shrinking of the clay. Both surface and internal drainage are very slow. Besides the flooding problem, the high clay contains and poor drainage conditions are the main constraints for the potential agricultural use of land with this type of soil (MARNR, 1979).

The second most abundant soil types are association of Inceptisol/Mollisol, Inceptisol/Alfisol, and Mollisol/Alfisol. The most common Great group of Inceptisol is the Ustropept. The most common Mollisol Great group is Haplustoll. Tropaqualf is the most common soil Great group of Alfisol Order. The soils are mostly fine texture, clay loam or silt loam. The internal drainage varies from moderately well to imperfectly drained. The soils have deep profiles. In general, the soils are of moderate to good natural fertility. The soil pH varies mostly in the range between 5.5 and 8.0. There is no problem of soil salinity or alkalinity in the area (MARNR, 1979).

(2) Land Classification

The lands of the study area were classified by MARNR (1979) at reconnaissance level. The criteria used for land classification are based on the US Department of Agriculture classification system with some Venezuelan modification. Based on the results of that study, the land in the study area is classified into five categories as shown in Fig. 3.4.1 and Table 3.4.4.

Under "Present condition" there is no land area classified into class I because of the long dry season that limits the possibility of making an intensive land use. The lands of class IIc present minimum limitations and are highly suitable for all crops adapted to the climate prevailing in the area. The only important constraint for intensive agricultural use of IIc land class is the long dry season. If irrigation is provided, most of the class IIc lands will pass as class I (MARNR, 1979).

(3) Present Land Use and Tenure System

The present land use in the study area is classified as follow. Approximately 10 % of the area is used for agricultural purpose, 7 % for improved pasture; 45 % by natural grass and bushes, 30 % by forest; 2 % by marsh and water bodies and 6 % for other uses. Present land use in the study area is shown in Fig. 3.4.2.

The land area being used at present for agriculture purpose is still low, although a large percentage of the study area is highly suitable for intensive agricultural use. As it has been pointed out, the reduced present agricultural land use is because no measures have been taken to alleviate the damage caused by floods and the constraint of poor drainage. The present land use for agricultural production is low in both of extension and use intensity. Land is used extensively for livestock production, but with low productivity. Farm land by district within the study area is presented in Table 3.4.5.

The land tenure system within the study area includes private ownership, right of use of agrarian reform land, use of municipal land (ejidos), unregistered occupied land. The sizes of agricultural and/or livestock production units vary largely, from 2 ha for small farm size to 60,000 ha for some large livestock producing business. It has been said that "the land tenure system is one of the main constraints affecting the agricultural development in the country" and therefore in the study area too.

(4) Water Resources

There are six large rivers and many small water courses running along the study area in a north-west to south-east direction. The river discharge follows the rainfall pattern. The rivers carry large amount of water during the rainy season causing flood in large areas, but their discharges decrease significantly during the dry season. Some times difficulty in satisfying the irrigation needs occurs due to low water levels during dry season.

There are three dams constructed in the upper reaches of Masparro, Bocono, and Tucupido rivers, just upstream of the study area. Those reservoirs are used for irrigating very small portion of the study area. There are plans for constructing several other dams that will relate to the water resources of the study area.

There are important underground water resources underlying a large percentage of the study area. The MARNR (1979) reported that the aquifers in some part of the study area can yield between 150,000 to 310,000 m^3/km^2/year. In some part of the study area underground water is being used for irrigation purpose.

(5) Agricultural supporting Services

The present level of agricultural supporting services in the study area does not satisfy the farmers' needs. The agricultural extension service is limited in action. Agricultural credits are insufficient in amount and generally provided much later than the actual needed time.

3.4.3 Constraints to Agricultural Development

The main constraints affecting the agricultural development in the study area may be divided into physical and institutional constraints. The main physical constraint is the one derived from combination of land topography and soil texture. Because of these two characteristics, a large percentage of the study area is subject to frequent floods and has poor drainage condition. Concentration of rainfall in relatively short period and long dry season are other important physical constraints. The concentration of rainfall causes flooding and poor drainage condition. On the other hand, the long dry season reduces possibilities of obtaining high crops yields and intensive farming.

The institutional constraints include 1) the need for more clear and consistent definition of objectives and policy for agricultural development; 2) insufficient agricultural supporting services such as extension and credits and 3) insufficient coordination plan among the different official institutions related to agricultural development.

3.4.4 Basic Concept for Agricultural Development

In formulating the basic concept for agricultural development in the study area, special concern was put on minimizing the negative effects on the environment. The proposed land use plan considered not only production potential of the land and nation's production targets, but also compatibility of proposed uses with the environment of the area. At least 30 % of the study area to be protected by flood mitigation measures are thought to remain in natural forest condition for environmental reasons.

The proposed land use in the areas to be protected with flood mitigation measures is as follows:

Protection area A : In this area, soil of heavy texture is predominant and the land has relatively poor drainage condition. most of the land belong to class IV and less area to class III. Because of this physical condition, the proposed land use for protected area A is mostly for rice cultivation and intensive livestock production with "Apure Module" type of structures for water management. The protected area comprises approximately 205,500 ha. It is estimated that out of this total physical area, about 102,700 ha will be effectively available for the proposed use; 75,900 ha for rice cultivation and 26,800 ha for Apure type module.

Protected area B: This area includes lands of class III, IV and II in less extend. The proposed crops are cotton and rice. Smaller area is proposed for intensive livestock production. The protected area comprises approximately 164,500 ha. It is estimated that out of this total physical area, about 82,300 ha will be effectively available for the proposed use; 50,000 ha for rice cultivation and 32,300 ha for cotton cultivation

Protected area C : At this stage of the study, all the areas are considered for intensive livestock production with the development of "Apure Module type of structure for water management. The area predominant of the land of classes IV and V is in relatively poor drainage condition. More detailed study is required for assessment of the land, water and environment of this area. The present human intervention in this area is low. The area protected by the proposed dike comprises about 135,800 ha, out of which approximately 68,000 ha will be effectively available for the proposed use of Apure type module.

The proposed land use is considered to be initially under rain-fed condition. Studies for drainage and irrigation developments are proposed. It is expected that drainage and irrigation development would produce high economic benefits. Potential and Proposed land use are shown in Figs. 3.4.3, 3.4.4 and 3.4.5, respectively.

The "Apure Module" types of structures are proposed here based on their comparative potential for increasing the productivity of livestock production. Data presented by MAC (1986) indicates that the livestock supporting capacity might increase as much as ten times from the present level of 0.3 cattle heads per ha to a level of 3 heads per ha. There are still some aspects not known well about the Apure Module, such as the economic benefit and management problems. More research is required to clarify the advantage of "Apure Module."

The present study for flood mitigation aims to solve one of the main constraints affecting the agricultural development in the area. Expansion of the agricultural frontiers, increase in crop yield and increase in farming intensity are expected after the implementation of flood mitigation measures. The flood mitigation measures will contribute to achievement of national and states' objectives of food self-sufficiency and exporting of agricultural products.

The basic concept for agricultural development in the study area includes:

- Expansion of the agricultural frontier within the study area
- Intensification and stabilization of agricultural production
- Intensification, diversification and stabilization of livestock production

To take full advantage of the high potential for agricultural development in the study area, besides the flood mitigation measures, other actions not included in the scope of the present study should be taken in subsequent studies. Subsequent studies should tackle the drainage and irrigation constraints, the need for agricultural supporting infrastructures and services and the institutional constraints.

The agricultural development plan for the study area should include:

- Implementation of flood mitigation measures
- Master plan study on drainage, irrigation and, supporting infrastructure development
- Study on improvement of agricultural supporting institutions and services

3.5 Socio-Economic Survey

3.5.1 General

The Apure river basin covers all of Barinas, Portuguesa and Cojedes provinces; a part of Tachira and Apure provinces; and small portion of Merida, Trujillo, Lara, Yaracuy, Carabobo and Guarico provinces.

3.5.2 Population and Labor Force

(1) Population

According to the 1990 census, Venezuela had a population of 18,105,265. The population increased by 7.4 million compared with the 1971 census as shown in Table 3.5.1. During the 70's, the average annual growth rate of the population was 3.08 % and during the 80's, the growth rate slowed down to 2.48 %. This rate, however, indicates that the population may double in about 30 years.

Average annual growth rates of population in Barinas, Cojedes and Portuguesa provinces which are major provinces in the Project area were about 0.5 % higher than the national average both during the 70's and the 80's.

Population by provinces and its average annual growth rates are shown in Table 3.5.2.

(2) Labor Force

The economically active population defined as persons aged 15 years and over increased almost twice from 5.9 million in 1971 to 11.4 million in 1990. The average annual growth rate was 3.99 % in the 70's and 2.98 % in the 80's as shown in Table 3.5.1. The percentage of the economically active population to the total population increased gradually as 51.1 % in 1971, 53.2 % in 1981, and 55.4 % in 1990.

On the other hand, Venezuela's labor force grew from 3.0 million in 1971 to 6.2 million in 1990. Labor participation rate defined as the rate of the labor force to the economically active population increased gradually from 51.1 % in 1971, 53.2 % in 1981, and 55.4 % in 1990.

Venezuela's unemployment has been increasing rapidly as shown in Table 3.5.1. Unemployment rate is rising from 6.2 % in 1971, 9.9 % in 1981 and 14.0 % in 1990.

3.5.3 Economic Indices

(1) Gross Domestic Product

Gross domestic product (GDP) in 1991 was about Bs.3,036 billion (approximately US$53.4 billion) and GDP per capita in 1991 was Bs.153,452 as shown in Table 3.5.3. Taking a look at substantial growth of the GDP in 1984 constant price, the annual growth rate in these five (5) years is 3.8 % on average.

In 1989, the GDP and GDP per capita in 1984 constant price recorded the minimum amount in these 10 years. The growth rate of the GDP and GDP per capita is increasing gradually since then.

GDP by industrial origin in 1984 constant price is shown in Table 3.5.4. The table shows that the GDP fell off in 1989 for almost all the sectors. However, it is recovering in these years.

(2) Prices

Movement of the consumer price in Metropolitan of Caracas continued with its upward trend as shown in Table 3.5.5. The average inflation rates in the Metropolitan from 1981 to 1991 and that from 1988 to 1991 are 25.1 % and 51.6 %, respectively.

Construction price index is derived from wholesale price index of construction industry sector, which reflects the public construction cost. The price index shows the same upward trend as the consumer price but is lower than the consumer price index.

(3) Foreign Exchange Rate

Table 3.5.6 shows foreign exchange rate between local currency and US dollar since 1981. The foreign exchange rate of Bs.4.30/US$ in 1982 was rapidly devaluated to Bs.81.97/US$ in February, 1993.

3.6 Environmental Survey

3.6.1. Environmental Conditions of the Study Area

In the Apure river basin the rainy season begins in April and ends in November in most years, and deviations within these months are not unusual. For this reason, climate is not very predictable in the short term, and this fact makes it difficult to survive for some organisms. Species can count on the rainy season coming sooner or later, but do not know exactly when.

Not only local rainfall floods the areas, but also the precipitation in the higher parts of the watershed has a very important effect in sending great amounts of water and sediments to the flat lands downstream.

The actual seasonal llanos landscapes are a product of the dynamics of sediment deposition of the rivers described by Roa (1981), Vivas (1984) and Tejos, Schargel and Berrade (1990). The resulting topographic pattern described by Ramia (1959, 1974) is normally referred to as the sabanas de bancos, bajíos and esteros, describing the behavior of the system in relation to the water occupying the land surface according to the season.

Perhaps one of the most clear descriptions of the dynamics of the seasonal llanos is the one (freely interpreted) from Roa (1981). It is as follows.

Due to the great amounts of material carried and the slow flow velocity, rivers accumulate sediments in their beds. Their marginal dikes or "albardones" are elevated above the general level and from them. During the high water months, the excess water overflows or breaks the dikes, creating breaches called "salidas de madre", subsequently covering the lower areas, and depositing new materials. This is how the typical relief forms appear in these regions, in the form of deltaic arms, with their abandoned dikes and their "salidas de madre," forming the sinuous higher ground locally called "banco". These high ground structures dominate over the lower terrain for some 1 to 2 m and are never entirely covered by the water level allowing the llaneros to build their houses and villages on them. The other spaces are the lower "cubetas" called "esteros". Between the banco and the estero lies a transitional gently sloped zone, which takes some water but quickly looses it when the rains and floods cease. These are the bajíos, rather shallow and extensive."

Life diversity is great in the seasonal llanos, but perhaps more interesting than just number of species is the different organisms relate to the seasonality of the climate and specially to the water cycle. When it is dry or wet, or when the water levels are going up or down, many interesting phenomena are happening to the inhabitants of the llanos. Many species respond to the physical environmental changes with behavioral changes. For some MARNR (Ministspecies it might be the time to build nests and lay eggs and for others it is the time to fly or migrate or aestivate or simply become dormant until the right season period arrives.

It seems that all the autochthonous organisms are well adapted to use the classic space assemblage in the seasonal llanos: the banco, the bajío and the estero. As these grounds seasonally change from large to small and so on, the living beings of the llanos conform their life styles to the relative abundance of water, cover and food.

3.6.2. Institutional Setup and Regulations

(1) Institutional Setup

Main factors in the institutional setup in relation to the study area are as follows:

MARNR (Ministry of the Environment and Natural Renewable Resources) is the main central government organization that relates to the project. Within the MARNR, the office that deals with environmental impact of all development projects is the Directorate General of Environmental Quality, which has the responsibility of requesting the Environmental Impact Statements for any project that may influence the environment.

PROA (Directorate General of Orinoco Apure Program) belongs to MARNR and constitutes a special program for the development of the Orinoco Apure Axis and areas of influence. In the case of the Environmental Impact Statements necessary for specific projects, PROA must conduct the environmental studies.

PROFAUNA (Wildlife Protection and Development Services of MARNR) is in the same institutional level as PROA. It practically sustains itself with the wildlife of the area, so that any modification of the landscape that would change, modify or damage the natural production of animal species would be strongly opposed from its own position within MARNR. INPARQUES is the National Institute that plans and manages National Parks.

Ministry of Agriculture is in charge mostly of Agriculture. Any works that may harm or alter local fisheries production must be in accordance with the Directorate of National Fisheries of the Ministry. it is also responsible for the agricultural projects within the area and their development and management. IAN (National Agrarian Institute) is the official institution in charge, by mandate of law, for carrying out Venezuela's Agrarian Reform. This Central Government office is very influential in terms of defending the local peasants and small farmers.

Besides that, local governments (Governors, Municipal Councils and City Mayors), research and Teaching institutions as UNELLEZ and UCV (Venezuelan Central University) and civil organizations as cattle growers and farmers. have locally great influence in the area.

Some national civil organizations that also have influence in decisions that pertain to natural areas are those called Non Governmental Organizations (NGO) as AUDUBON and FUDENA. These are conservation organizations that have great influence in the welfare of nature.

(2) Regulations for Environmental Aspects

Among the regulations relating to the environmental aspects, they will be major.

Organic Law of the Environment (1976) is the major body of laws promoting national development under environmental guidelines in terms of attaining a better life quality for the citizen. The general development of the Orinoco Apure Axis must be planned within the framework of this law.

Law for the Enforcement of Environmental Regulations recently disclosed in 1992 is the penal extension that regulates punishment for those who break the Organic Law of the Environment.

Decree 2.213 (Partial Regulations of the Organic Law of the Environment for environmental impact evaluations.) in 1992 includes the regulations for Environmental Impact Statements to be submitted to MARNR, Directorate of Environmental Quality.

Law of Forests, Soils and Waters is devoted to the conservation and management of natural resources of soils, water and forests and all the products thus derived. A very important aspect of this Law is regulations concerning the protective zones of water bodies like large rivers, medium and smaller streams and lagoons.

Law for Protection of Wildlife specifies the management of natural wildlife species for the protection of the species and their products, the rational harvesting of natural populations and the regulation of game hunting. Wildlife refuges are considered in this law as protective areas for important wildlife species. Wildlife Refuges regulations are produced independently by PROFAUNA.

All the regulations have complex and valuable legal background to base any future actions in the region. Whenever the projects are to be considered for development in the future, the appropriate Environmental Impact Assessment studies will be initiated.

3.6.3 Survey on Distribution of Objects to be Conserved

Three kinds of objects to be conserved can be identified within or related to the study area: 1) natural communities, 2) plant and animal species and 3) officially protected areas, such as national parks and wildlife refuges, and all other not officially protected but considered in need of protection.

(1) Natural communities

Natural communities are species assemblages composing the living portion of ecosystems in the area. The typical natural landscape of the study area is formed roughly by three main plant associations: 1) tall forest along the river beds called gallery forest (bosque de galería), 2) deciduous forests in large areas away from the river , and 3) open grasslands or savannas, which in certain areas can be flooded to certain height and called sabanas de bancos, bajíos and esteros.

(2) Plant and animal species

Plant and animal species are the main components of the natural communities and ecosystems of the area under study. Most environmental impact produced by development will eventually act upon the native species not in a direct way, but through modifying the living conditions and finally making it difficult or impossible for the species to live without the appropriate kind of food, water or shelter.

1) Plants

According to Cuello et al, (1989), more than 470 plant species, belonging to 306 genera and 83 families of plants are found in the Portuguesa river area. They also report 9 species of ferns in the area.

2) Fish

Some 350 species of fish are known in the study area.

3) Amphibians and Reptiles

The Amphibians and reptiles of the llanos are two groups. In regards to these group, 9 species are known to be in some degree of danger or threatened.

The Orinoco Crocodile, Crocodylus Intermedius, is still known from scarce populations in some of tributaries of the Cojedes and Portuguesa rivers. The other very important species is Baba, Caiman Crocodilus, being subject to management programs.

4) Birds

The 150 species of birds are most common in the study area. The most endangered bird species are those subject to game or sports hunting. Some of the large birds are also in critical condition due to agricultural influence.

5) Mammals

Eleven species of this group are vulnerable. All these species have been pursued because of their skin and or meat values, and for many years the hunting pressure has decimated their populations in the area.

6) Invertebrates

These groups of animals are not well studied in the area. No information as to any species being endangered was found in the literature.

(3) Protected Areas

Protected areas directly associated with the study area are the following two (2) wildlife refuges shown in Fig. 6.1.1.

1) Chirigüare Wildlife Refuge : along the Río Guanare near La Trinidad and La Capilla, surface of about 44.500 ha, inside the study area.

2) Caño Guaritico Wildlife Refuge : along Caño Guaritico with legal protective width of 50 m including navigable part of Caño 70, adjacent to the study area

(4) Other areas

There are other areas which have been considered and proposed as special places for wildlife preservation. They are savanna wetlands, gallery forests and deciduous forest.

3.6.4 Workshop on Environment

A workshop to discuss the possible environmental effects of river and flood control plans was prepared with the purpose of inviting a number of qualified environmental and engineering professionals to contribute their opinion on the issues. It was held in Caracas, March 5, 1993.

The objectives of the workshop are:

1) To obtain specific environmental recommendations to minimize the environmental impact of the flood control and channel improvement plans.

2) To bring together, in a formal professional meeting, a number of environmental experts and PROA officials for the purpose of producing thought and discussion about fundamental issues on the channel improvement and flood control plans.

Due to the brief time allowed for the workshop meeting, each discussion group elected its own way to tackle the problems and dedicated the available time to those issues of interest to the group members.

In a general way, the outcome of the workshop has been very useful and it conforms a basis for looking further into the plans and PROA´s own policies in order to develop a better future for the area.

The workshop accomplished the two proposed objectives and produced some of the desired information, but only in a general way, because the plans are still in the basic stage. The information thus obtained is still usable as a guidance to some important environmental considerations the plans must consider.

IV. BASIC STUDIES

4.1. Geomorphological Study

The geomorphological and geological surveys and studies are described in detail in the Supporting Report : Part B. This section describes geomorphological study which will closely related to the studies on channel stabilization and flood management planning.

4.1.1 Topographic Analysis

The map with counter lines at intervals of 5 m shown in Fig. 6.1.1 was prepared based on the topographic map with a scale of 1:100,000, which cover the area subject to flood management planning. Though the topographic maps with a scale of 1:25,000 are also available, the accuracy is the same as the maps with a scale of 1:100,000, so that the maps with scale of 1:100,000 were used for efficient work.

The topographic maps of 1:100,000 have counter lines at intervals of 20 m in principle and intervals of 10 m supplementarily in low land. However, supplemental contour lines are insufficient and not continuous, so that they are completed based on point elevations in the topographic map. Then, the contour lines at intervals of 5 m were drawn based on the said point elevations.

The Apure river basin is divided into the following four geomorphological features by altitude.

- Mountains : Coastal Mountains and the Andes Mountains (height from 500 m over)
- Piedmonts : Hills including river terraces (height from 200 m to 500 m)
- Upper Llanos : Alluvial fans and natural dikes (height from 100 m to 200 m)
- Lower Llanos : Flood plains and inland delta (height from 40 m to 100 m)

The study area is located in the llanos. In the west side of Portuguesa river between Guadarram and La Union, the enclosed contour lines indicate the depressions called as "Apure Depression".

4.1.2 River Profile

Profiles of major rivers in the Apure river basin are shown in Fig. 4.1.1 which was prepared from topographic maps with a scale of 1:100,000.

The rivers generally have some discontinuous points in their profiles. In the river profiles of the Apure river basin, many nick points are recognized in the upper reaches of the mountain areas. These nick points may be originated in the presence of faults or the geological boundaries. Beside those nick points, other nick points are in presence at the boundary between the mountains consisting of hard old rocks and the hills consisting of soft younger rocks around 600 m above sea level. these nick points arrange in a straight line.

In the middle reaches, the nick points are located between 100 m and 120 m above sea level. These nick points exist at Totumito in the Apure river, 60 km downstream from the Route 5 in the Portuguesa river and 5 km down stream from Guanare City in the Guanare river. The knick point of Totumito may be formed by faulting. The knick points of the Portuguesa river and Guanare rive are formed by a presence of geological boundary between old fan and new fan. On the other hand, there is no knick point at areas lower than 100 m above sea level. The Portuguesa river has a gentle river profile compared with the Apure river.

4.1.3 River Course

Based on the geomorphological map with a scale of 1:250,000 and the topographic maps with a scale of 1:100,000, the river course features of Portuguesa, Guanare and main Apure rivers were roughly studied as mentioned below.

The Portuguesa river is stable and its river course changing is insignificant. After flowing out from the Andes mountains, the Portuguesa river changes its course from southeast to east. Near south of El Baul, it changes its course to southeast again remarkably and then flows down towards the inland delta. This river course is different from other rivers which flow down at right angle to the axis of the Andes Mountains.

The Guanare river immediately changes its course to east after flowing out for the Andes Mountains. After that, the course slightly change to south-east and flows into the inland delta. This course direction is also different from those of other rivers.

The Guanare river is not stable and affected by present tectonic movement. In recent years, its main channel moves from Arismendi to the south about 20 km in distance. This may be predominant lateral erosion to the river bank.

The main Apure river flows in the lowest area in the Apure river basin. Between Guasdualito and Suripa, it is comparatively stable because of no junctions with big tributaries, while the channel is braided between Suripa and Bruzual with hundreds meters wide.

Between Bruzual and Apurito, the river channel gradually becomes stable because of no big tributaries. On the left bank of the present Apure river, an old channel of the Apure river is recognized in parallel with the present main channel. Between Apurito and San Fernando the Apure river has two anabranches .

4.1.4 Flood Prone Area by Interpretation of Satellite Images

The flood prone area was identified based on the existing data owned by MARNR and interpretation of satellite images provided by JICA.

Twenty false color images with a scale of 1 : 250,000 were obtained from LANDSAT 3, 4 and 5 from 1981 to 1989. However, the images in 1976 and 1981 when big inundation was occurred were not available. Also, some images were covered with clouds and in poor receiving condition.

Result of interpretation is shown in Fig. 4.1.2 and Fig. 4.1.3. The inundation areas are distributed in some specific areas as follows.

- Left bank side of the Apure river (between Bruzual and San Fernando)
- Along of the Guanare river (between Guanarito and Arismedi)
- Along of the Guanaparo river and the Guanare Viejo river.
- Middle and lower reaches of the Guanare river (between La Hoyado and La Union)
- Middle reaches of the Portuguesa river (between Nueva Florida and El Baul)
- Along the Igues river

The various small pool areas which have different water levels are formed discontinuously and irregularly. Their extents are depend on flood scale. Also, they are influenced by micro land forms.

According to the result of satellite-image interpretation, the various small pool areas are formed discontinuously and irregularly. One of the remarkable flood prone area is located on the east side of the north-south line connecting El Baul with Apurito. In the south and east sides of El Baul, a remarkable flood prone area appears along the Portuguesa river in rainy season.

Other notable flood prone areas are found along the old river channels of the Guanare river and the Apure river. Along the old channel of the Guanare river, a lot of lakes are found in dry season.

4.2 Hydrological and Hydraulic Studies

4.2.1 Basin Analysis

Basin and sub-basin boundaries were drawn on the topographic map of scale 1/500,000 for the major points of interest, and the basin areas were measured. Basin and sub-basin boundaries are shown in Fig.4.2.1 and their areas are summarized below:

1) Main Apure River : 111,800 km^2 at San Fernando
   a) Remolino Br. : 8,400 km^2
   b) Bruzual : 40,000 km^2
   c) El Samán : 48,000 km^2
   d) San Fernando : 111,800 km^2

2) Portuguesa River : 54,600 km^2 at junction with Apure river
   a) El Baul : 13,200 km^2
   b) El Jobalito : 23,300 km^2
   c) Camaguán : 54,400 km^2

As seen in Fig. 4.2.2, drainage areas of the main Apure(57,200 km^2) and the Portuguesa(54,600 km^2) are almost equal at their confluence, although their river features are quite different. River channel of the main Apure is wider and braided in places, while that of the Portuguesa is narrower and meandered.

4.2.2 Rainfall Analysis

Monthly rainfall was studied for the selected stations. Annual rainfall patterns of the basin are characterized by the distinct rainy season which starts from April or May and ends in October or November. Within the rainy season the rainfall distributes rather uniformly with single or double peaks as summarized below.

Station	Situation	Rainy Season	Month of Rain Peak
San Cristobal/Estanque	High land, west	Apr.- Nov.	July
El Corozo/Palmita	High land, central	Apr.- Nov.	June/Oct.
Las Vegas/Charcot	High land, east	Apr.- Oct.	June
El Baul/Carretera	High land, east	May - Oct.	June/Aug.
Santa Lucia	Low land, central	May - Oct.	July
El Saman de Apure	Low land, east	Apr.- Oct.	June/Aug.

Basin mean monthly rainfall was also studied to estimate runoff rate. Seven (7) sub-basins and thirty nine (39) rainfall stations were selected for the calculation. In order to characterize the basin's rainfall, basin mean annual rainfall estimated for 24 years from 1967 to 1990 are presented below.

Base Station	Ave. (mm/yr)	Max (mm/yr)	Min. (mm/yr)
1) Main Apure River			
a) Remolino Br.	2,082	2,532	1,614
b) Bruzual	1,892	2,323	1,456
c) El Samán	1,851	2,282	1,442
d) San Fernando	1,608	2,003	1,282
2) Portuguesa River			
a) El Baul	1,310	1,677	1,018
b) El Jobalito	1,505	1,963	1,180
c) Camaguán	1,423	1,790	1,134

At the confluence of the Apure and Portuguesa rivers, annual basin mean rainfall of the main Apure river is 1,851 mm (at El Samán), while that of the Portuguesa is only 1,423 mm (at Camaguán) which is 75 % of the main Apure.

4.2.3 Runoff Characteristics

(1) Discharge

Daily discharge hydrographs of the stations located in the upper, middle and lower reaches is shown comparatively in Fig. 4.2.3. Flattering process of the runoff hydrograph is seen in the figure. In the mountainous upper reaches the runoff hydrograph fluctuates in short duration reflecting the rainfall pattern. Then, as going downstream, the hydrograph fluctuates weekly, monthly or longer.

(2) Annual Runoff Ratio

Annual runoff ratios of four (4) stations in the Apure river and three (3) stations in the Portuguesa river were estimated by the annual basin mean rainfall and recorded annual runoff. The result of the estimation is shown in Fig. 4.2.4.

Average runoff ratio of the main Apure river varies from 0.84 at Remolino bridge to 0.41 at San Fernando, decreasing toward downstream. The runoff ratio of the Portuguesa river varies from 0.14 at El Baul to 0.20 at Camaguán, increasing slightly toward downstream.

Runoff ratio of the Portuguesa river is remarkably small. This may come from smaller basin rainfall and losses due to evaporation and possibly groundwater movement.

(3) Discharge Correlation

Correlation of discharges between adjacent gauging stations were studied in order to verify the records and to provide basic data for discharge distribution. The correlation graphs are shown in Fig. 4.2.5.

In the figure, discharges of the downstream station were plotted on the horizontal axis. A line to show ratio of drainage areas is also illustrated on the figure. If the runoff is propotional to the drainage area, the correlation plots would be located on the drainage area line. Correlation plots of a year formed a clockwise loop line, except for correlation between Camaguan and San Fernando stations where unticlockwise loops were seen for some years.

4.3 Flood Analysis

The flood analysis is made to provide hydrological and hydraulic data for flood management planning mentioned in Chapter VI. It consists of flood runoff analysis and flood inundation analysis to cope with hydrological and hydraulic conditions of the study area. Detail of the flood analysis is described in the Supporting Report : Part-D.

4.3.1 Analysis Method

Objectives of the flood runoff analysis are to construct a flood runoff model of the Apure river basin based on the available hydrological data and to estimate the probable flood runoff for the selected flood control plans.

The Apure river basin is roughly divided into mountainous area where the rapid runoff is observed and low plain area where significant retarding of the runoff from upper basin is observed. The area subject to flood management planning presently has vast inundation area. Due to this characteristics, it is difficult to well simulate the actual phenomena of the whole basin by an ordinary hydrological method only.

To cope with such runoff phenomena and also to evaluate the effect of plans which allow inundation, Pond Model Method is employed for flood inundation analysis in the flood management study area. While, Storage Function Method is employed for flood runoff analysis in the remaining area of the Apure river basin.

The flood runoff analysis by the storage function method is described in Section 4.3.2 and flood inundation analysis by the pond model method in Section 4.3.2.

4.3.2 Flood Runoff Analysis

(1) Basin and River System Model

The Apure river basin is largely divided into the main Apure river basin and the Portuguesa river basin, the biggest tributary of the Apure river, upstream from San Fernando. They are further divided into sub-basins for the flood runoff analysis taking into account topography, river system, base points, etc.

The sub-basins divided are shown in Fig. 4.3.1. The basin is divided into 107 sub-basins and 71 channels. The catchment areas of the main Apure river basin is 57,200 km^2 and the Portuguesa river basin 54,600 km^2.

(3) Rainfall Analysis

1) Design rainfall duration

The design rainfall duration was determined to be eight (8) months from April to November for the reasons mentioned below.

Size of the whole basin is as large as about 120,000 km^2. Rainfall amount in rainy season from April to November is a major cause of habitual inundation in the downstream area due to insufficient discharge capacities. Duration of inundation in the downstream is generally four (4) months from June to September, and maximum flood water level is recorded in July or August every year.

2) Rainfall pattern

Probable rainfall is produced by enlarging or reducing an actual rainfall. In the study, rainfall in 1981, which is the largest in the Portuguesa river basin including flood management study area, is employed as the said actual rainfall. The pattern employed is that from April to September.

3) Hourly rainfall distribution

Hourly rainfall distribution was assumed to have a center concentrated pattern due to limited available hourly rainfall data. This pattern is derived from the rainfall intensity duration curve using the recorded hourly rainfall data.

In the study, rainfall intensity duration curve developed at Campo Elias located in the upstream of Guanare river was employed. Ratio of hourly maximum rainfall amount against 24-hour rainfall is 0.41 as shown in Fig. 4.3.2.

4) Representative rainfall stations

In order to estimate yearly 8-month basin mean rainfalls (from April to November) in the Apure river basin, Portuguesa river basin and the whole basin, 61 rainfall stations shown in Fig. 4.3.3 were selected as the representative stations. The average density of station arrangement is about 2,000 km^2/station.

As for the basin mean rainfalls of the large rainfalls in 1976,1981 and 1992, the numbers of rainfall station used are 47, 39 and 37, respectively depending on the data availability.

5) Basin mean rainfall

Basin mean rainfall is estimated from the recorded rainfall by Thiessen polygon method. Yearly 8-month basin mean rainfalls obtained by the method above are presented in Table 4.3.1.

6) Probable basin mean rainfall

Probable 8-month basin mean rainfalls are calculated by frequency analysis of the estimated yearly 8-month basin mean rainfalls for the Apure river basin, Portuguesa river basin and the whole basin. Frequency analysis was made by Gumbel method.

The results are tabulated in Table 4.3.2. the probable 8-month basin mean rainfall for the whole basin with 10-year return period is 1,742 mm, which corresponds to 0.959 times of the latest maximum rainfall of 1,818 mm in 1981.

(4) Storage Function Method

1) Basic equations

A storage function method was employed for calculation of flood runoff from each sub-basin and river channel. In general, there are some differences in runoff characteristics among basins. The parameters of storage function method can express those differences based on topographic data. Schematic diagram of the basin and river channel model is illustrated in Fig. 4.3.4.

a) Basin runoff model

The storage function of basin is expressed by the following equations :

$$Sl = KQ_l^P$$

$$\frac{1}{3.6} f\, r_{ave}\, A - Ql = \frac{dSl}{dt}$$

Where,	Sl	:	apparent storage in basin (m^3)
	$Ql\,(t) = Q\,(t + Tl)$	:	direct runoff from basin with lag time (m^3/sec)
	K, P	:	constants
	t	:	time interval (sec)
	f	:	runoff ratio
	rave	:	average basin rainfall (mm/hr)
	A	:	catchment area (km^2)
	Tl	:	lag time (sec)

Constants of K and P in the equation were estimated employing the following empirical formula :

$$K = k \cdot 43.4 \cdot C \cdot L^{1/3} \cdot S^{-1/5}$$

$$P = 1/3$$

where,	C	:	reserve constant (=0.12)
	L	:	river length (km)
	S	:	average river bed slope
	k	:	parameters determined by try and error

Flood runoff from sub-basin was adjusted taking lag time into consideration. The lag time was estimated by empirical formula expressed below.

$$Tl = 0.047 \cdot L - 0.56$$

where,	Tl	:	lag time in basin (hr)
	L	:	river length (km)

b) River channel model

Flood runoff through a river channel was estimated by the following equations :

$$Sl = KQ_l^P$$

$$I - Ql = \frac{dt}{dSl}$$

where,

Sl	:	apparent storage volume in river channel (m^3)
K, P	:	constants
I	:	inflow to river channel (m^3 sec)
Ql (t) = Ql (t + Tl)	:	discharge at lower boundary of channel with lag time(m^3/sec)
Tl	:	lag time (sec)

Constants of K and P were estimated by uniform flow calculation the river cross section, river bed gradient and river length.

The lag time in river channel was estimated by the empirical formula expressed below.

$$Tl = (7.36 \times 10^{-4}) \cdot L \cdot S^{-0.5}$$

where,

Tl	:	lag time in river channel(hr)
L	:	river length (km)
S	:	average river bed slope

2) Selected flood data

a) Selected flood event

The annual maximum daily mean discharges of four major points in the Apure river basin are given in Table 4.3.3 for the period from 1975 to 1990. As seen in the table, the recorded maximum discharges are as follows:

Point	Max. Discharge (m^3/s)	Occurrence Year
Bruzual (Apure R.)	3,962	1983
El. Saman (Apure R.)	4,824	1976
San Fernando (Apure R.)	8,645	1981
Camaguan (Portuguesa R.)	1,238	1981

Based on the above, the bigger floods occurred in 1976 and 1981 were selected for calibration.

b) Selected flood hydrographs

In the whole Apure and Portuguesa river basins, there are 36 water level gauging stations and 26 stations were subject to evaluation. Out of them, 13 stations were firstly selected based on the availability and reliability of data and the runoff coefficient using data from April to November for those 13 stations were examined.

Consequently, nine (9) hydrographs of the seven (7) runoff stations, 4 in 1976 and 5 in 1981, were selected for the flood runoff analysis. The hydrographs in 1981 are shown in Fig. 4.3.5.

3) Calibration of parameters

The parameters in the flood runoff model were calibrated by the actual floods. Prior to the calibration, primary runoff coefficient (f1) and saturated rainfall (Rsa) were estimated as below.

	Basin	f1	Rsa (mm)
1.	Apure river basin	0.75	2,400
2.	Upstream area of El. Baul	0.15	2,500
3.	Portuguesa river basin and right tributary areas	0.45	1,800
4.	Cojedes river basin	0.30	2,500

The f1 and Rsa of the Cojedes river basin were assumed to be 0.30 and 2,500 mm, because the Cojedes river basin is located between San. Carlos river basin and Acarigua river basin. The constants of K, P and lag time(Tl) for each sub-basin and river channel are estimated by trial and error method.

According to the simulation, both observed and simulated hydrographs coincide well. and the parameters of the model were judged applicable. Fig. 4.3.5 shows comparison of the observed and simulated hydrographs for 1981

Besides, the parameters of the model were verified by the comparison of the observed and simulated flood runoff volume. Both observed and simulated flood runoff volumes also coincide well. Moreover, specific flood runoff peaks of the 1981 flood estimated at the existing and proposed dam sites were verified by the available data.

(5) Probable Flood Runoff

Based on the probable rainfalls and flood runoff model developed in the previous section, the probable flood runoff at the respective base points which become inputs for the Pond Model Method are given in Fig. 4.3.6. The probable flood peak distributions for 10-year return period under the present condition (with existing dam), without existing dams condition and with existing and proposed dams condition are presented in Figs. 4.3.7 to 4.3.9.

On the other hand, the probable daily mean discharges were calculated as given in Table 4.3.4 by Gumbel Method. The floods in 1976 and 1981 are evaluated as 5-year and 20-year return periods, respectively.

(6) Flood Discharge Confined in River Channel

The flood control study area have a vast inundation area and flooding occurs here and there. For this, it may be difficult to confine all the inundation water in the river channel formed by dikes. However, in order to know the degree of flood concentration under the said condition the flood discharge confined in the river channel was calculated by the storage function method for the actual floods in 1981 in the Portuguese river basin assuming that the present river channels of Portuguesa and Guanare rivers remain as it is and dikes are constructed on both banks with 10 km wide.

The result is shown in Fig. 4.3.10. As seen in the figure, the calculated flood peak discharge at the downmost base point of the Portuguesa river comes to 6,600 m^3/s.

4.3.3 Flood Inundation Analysis

(1) General

As mentioned before, most of the study area have inundation and flooding problems and therefore the flood runoff phenomena in such area cannot be simulated by an ordinary hydrological runoff calculation method. Accordingly, a Pond Model Method is employed to hydraulically simulate the flood runoff in the inundation and flooding areas as flood inundation analysis.

(2) Basin and River System Model

For the flood inundation analysis by the pond model method, the objective area was divided into mesh blocks as shown in Fig. 4.3.11. The objective area is 23,900 km^2 and divided into 495 mesh blocks. A mesh block has a size of 10 km x 10 km in principle, but the mesh block for river channel has smaller size.

(3) Pond Model Method

1) Basic equations

The pond model was adopted to simulate a wide-spreading flood in the areas extending in the downstream reaches of the Portuguesa river, Igues river, Guanare river and Guanare Viejo river. In order to express two dimensional movement of flood flow in the inundation area, a sequential pond model was adopted. This model simulates the flood flow propagation between divided mesh blocks by solving the movement and continuity equations given below;

$$\frac{L}{g} \cdot \frac{dv}{dt} = (h_1 + Z_1) - (h_2 + Z_2) - L\frac{n^2 |v| v}{h^{4/3}}$$

$$F\frac{dH}{dt} = Q_{in} - Q_{out}$$

Where,	L	:	interval between mesh blocks (m)
	g	:	acceleration of gravity (m/sec^2)
	v	:	flow velocity (m/sec)
	t	:	time (sec)
	h	:	water depth of mesh (m)
	z	:	average ground elevation (m)

n	:	coefficient of roughness
F	:	area of mesh block (m^2)
H	:	water level of mesh (m)
Q_{in}	:	inflow into mesh (m^3/sec)
Q_{out}	:	outflow from mesh (m^3/sec)

2) Input data of the model

The input for the objective area covered by the pond model consists of runoff from the surrounding rivers calculated by the storage function method and rain directly falling on the objective area. The runoff said above are shown in Fig. 4.3.6 as probable flood hydrographs of inflow rivers for pond model. Rainfalls of the respective mesh blocks are given by the basin mean rainfall.

Evaporation from the inundation area was estimated based on the data of Arismendi and Bruzual meteorological stations, located in the inundation area. Average value of the daily mean evaporation in each month from June to September was calculated by the reduction ratio of 0.9, which is normally used as an average ratio for pan evaporation value applicable to the plain area in Venezuela. Consequently, the value of 4.1 mm/day was obtained for calculation.

3) Calibration of parameter

It is rather difficult to make an accurate simulation by the pond model for the objective area due to complicated flow and vast area, however, the calibration of parameters in the pond model was made by qualitative examination of inundation and check of runoff at El Saman, San Fernando, Jobalito and Camaguan gauging stations, which are located in the lower plain area.

The floods used for calibration are those in 1976, 1981 and 1992. The simulation results roughly coincide with the actual phenomena.

(4) Simulation Result for Alternative Flood Management Plans

Using the calibrated pond model, simulation for 10-year probable flood runoff was carried out for the alternative flood management plans. The runoff and rainfall pattern are those of 1981 flood as mentioned before. The cases simulated ar as follows:

No.	Plan	Condition
1	-	Present condition
2	A1	Construction of dike for Portuguesa river (right bank)
3	B1	Construction of dike for Guanare river (right bank)
4	B2A	Construction of dike for Guanare river (right bank) and improvement of Guanare Viejo river (25 m wide)
5	B2B	Construction of dike for Guanare river (right bank) and improvement of Guanare Viejo river (50 m wide)
6	C1	Construction of dike for Apure river (left bank)
7	C2	Construction of dike for Apure (left bank - shorter)
8	D1A	Improvement of present floodway
9	D1B	Improvement of present floodway and construction of diversion channel
10	D2	Construction of retarding basin by Apure type module
11	Overall	Plan A1 + Plan B1 + Plan C1

Results of the simulation for the above cases except caces 1, 2, 5 and 10 are compiled in the Supporting Report: Part-F.

The simulation results for the cases 1, 2, 5 and 10 (Plan A1, Plan B1, Plan C1 and overall plan) are shown in Figs. 6.4.15 to 6.4.18, 6.4.22 and 6.4.23.

4.4 Channel Flow Analysis

4.4.1 Water Levels and Flow Duration

(1) Water Level

Monthly changes of water levels of the Apure and Portuguesa rivers are shown in Fig.4.4.1, illustrating the average, maximum and minimum monthly water levels. Water levels of the Apure river and Orinoco river form single cycle hydrograph in a year with rising period of five (5) to six (6) months. The difference of the monthly water level in a year varies from 2.65 m at Remolino bridge to 6.06 m at San Fernando for the Apure river, and from 6.93 m at El Jobalito to 6.58 m at Camaguan for the Portuguesa river. The monthly water level changes 11.35 m at Caicara station in the Orinoco river.

It is also seen that the water level peak of the stations located in the lower reaches occurs later than those located in the upper reaches with longer rising period, probably owing to the runoff retardation due to flooding. It is also noteworthy that the peak of the Portuguesa river appears later than that of the Apure river.

(2) Low Flow Discharge

Based on the daily discharge records as available since 1975, low flow conditions were studied.

Among the existing seven (7) stations, Bruzual station would be the basic station for the main Apure river and El Jobalito station for the Portuguesa river, since these stations have relatively long period of discharge records and they are located close to the river stretches which might have navigation problems.

Average flow duration of respective stations is shown in Table 4.4.1. Features of the average flow duration are summarized below.

Station	Basin (km^2)	Min. (m^3/s)	Max. (m^3/s)	Max/Min
1. Main Apure River				
1) Remolino Br.	8,400	83	1,060	13
2) Bruzual	40,000	148	3,442	23
3) El Samán	48,000	217	3,954	18
4) San Fernando	111,800	289	5,744	20
2. Portuguesa River				
1) El Baul	13,200	9	229	25
2) El Jobalito	23,300	31	458	15
3) Camaguán	54,400	57	1,034	18

Coefficient of river regime which is defined as a ratio of annual maximum discharge to the minimum discharge (Max/Min) ranges from 13 to 25 for the main Apure and Portuguesa rivers.

4.4.2 Construction of Channel Flow Model

(1) Water Level at River Mouth of Apure

The confluence of Apure and Orinoco rivers is located at about 730 km upstream from the sea (mouth of the Orinoco) and the Caicara station is located at about 27 km downstream from the Apure confluence.

Water level at the river mouth of the Apure was estimated based on the water level records at Caicara station. According to the profile along the navigation route of the Orinoco river, the NAB slope is 1/18,400 for the stretch of 27 km from Caicara to Apure confluence. The NAB is the water level datum for navigation specified by INC based on the recorded lowest water levels at major stations.

The water level at Apure confluence was estimated from the water level at Caicara adding 1.47 m.

(2) Flow Model of Apure River

River sections surveyed in March 1992 by PROA were used for channel flow calculation supplementing some 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.

Discharge distribution for the channel flow calculation was determined based on the discharges at four (4) stations of San Fernando, El Saman, Bruzual and Puente Remolino, location of confluences of major tributaries, and basin area.

Channel roughness was estimated by the trial and error procedures so that the calculated water levels should be on the stage-discharge rating curve at the upper end station of sub-stretch for calculation. Therefore the roughness varies depending on the channel discharges, and the roughness represents all the unknown factors included in the flow model as well as channel roughness.

Water surface calculated was judged to be reasonable comparing with observed water levels and ground elevations.

(3) Flow Model of Portuguesa River

Thirty nine (39) sections are available in total over the stretch of about 249 km from river mouth (Apure river) to El Baul port. All of these section are the sounding result surveyed from water surface and are not related to the MSL-datum. These sections were surveyed on October 2 to 4 in 1989 and the water level was still high.

In order to construct channel flow model for the evaluation of navigation capacity under various channel discharges, river elevation of bed profile were assumed and channel roughness were estimated.

The profile was estimated only for the present study based on the data as available. River profile for further channel flow study should be prepared based on the actual longitudinal profile survey.

4.4.3 Extent of Influence of Orinoco River

Extent of influence of the Orinoco river to the Apure river was studied using the channel flow model under the rainy and dry season conditions for different cases of water levels at river mouth, i.e., for normal water level of the Apure (case-1), highest water level (case-2) and lowest water level (case-3) of the Orinoco river.

Results of flow calculation are shown in Fig. 4.4.2. The extent of hydraulic influence of the Orinoco river could be estimated in comparison with water levels of cases-1 and 2, and the extent of influence due to water level changes of the Orinoco river could be estimated in comparison with water levels of cases-2 and 3.

The hydraulic influence of the Orinoco river extends up to 94 km from river mouth (near Danta Flaca about 29 km downstream from Arichuna). The Apure river channel downstream from Arichuna is deemed to be formed under the influence of the Orinoco river.

On the other hand, the influence due to water level changes of the orinoco river extends up to 89 km from river mouth (near El Sausal) just downstream of anabranch reaches.

4.4.4 Bankful Channel Capacity

Bankful carrying capacity of the Apure river was estimated by the channel flow model. Estimated bankful capacity of the Apure river is shown in Fig.4.4.3. The result is summarized as follows:

Stretches (from mouth)	Bankful capacity (m^3/s)		Remarks
	Average	Minimum	
0 - 70 km	2,290	2,210	Lowest reaches
70 - 130 km	2,480	1,750	Anabranch reaches
	(1760)	(1110)	(Main Apure only)
130 - 195 km	4,140	2,990	Between anabranches
195 - 275 km	3,150	3,150	Anabranch reaches
	(1380)	(1380)	(Main Apure only)
275 - 450 km	3,380	2,500	El Saman - Bruzual
450 - 520 km	2,080	1,800	Bruzual - Suripa R.
520 - 680 km	910	600	Suripa -Guasdualito

4.4.5 Sediment Flow Features

(1) Bed Materials

Results of bed materials and bore hole investigation conducted by the Study Team are used for the study.

According to the results, grading of river bed samples differ much depending on the place of sampling. Moreover, the grading at a place differ much in a vertical depending on the layer of sampling. The samples are clearly classified into sandy soils and clayey soils. According to the boring logs, the sandy and clayey soil layers are placed alternately. The sandy soils are transported probably by the flood flow and the clayey soils are the deposit during the recession period of flood.

Sandy soils were taken up for sediment transport study. Average grading of sandy soils at respective sites were calculated and shown in Fig. 4.4.4. Longitudinal change of grain size along the river is not clear. Average grading of the whole stretch of the Apure is worked out as follows:

Specified size	d_{25}	d_{50}	d_{65}	d_{75}
Grain size (mm)	0.15	0.26	0.34	0.41

The sorting coefficient defined as square root of (d_{75}/d_{25}) of the sandy soil is 1.68 on average ranging from 1.33 to 2.68.

(2) Type of Sediment Flow

The runoff hydrographs of the Apure river form single annual cycle and the river water overflows for long period as 2 to 4 months. The dominant discharge for the river channel formation is deemed to be the bankful channel discharge.

According to the empirical diagrams for classification of sediment flows and bed forms, types of sediment flow in the Apure and Portuguesa rivers were studied under the bankful channel discharge conditions. The results are summarized below.

1) Suspended load is the dominant sediment transport of the Apure river
2) Regarding the medium scale bed configuration, the Apure and Portuguesa rivers fall under conditions of semi-sand bars and alternate bars.