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THE REPUBLIC OF PARAGUAY

STORM DRAINAGE SYSTEM IMPROVEMENT PROJECT IN ASUNCION CITY

MAIN REPORT

JANUARY 1987

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

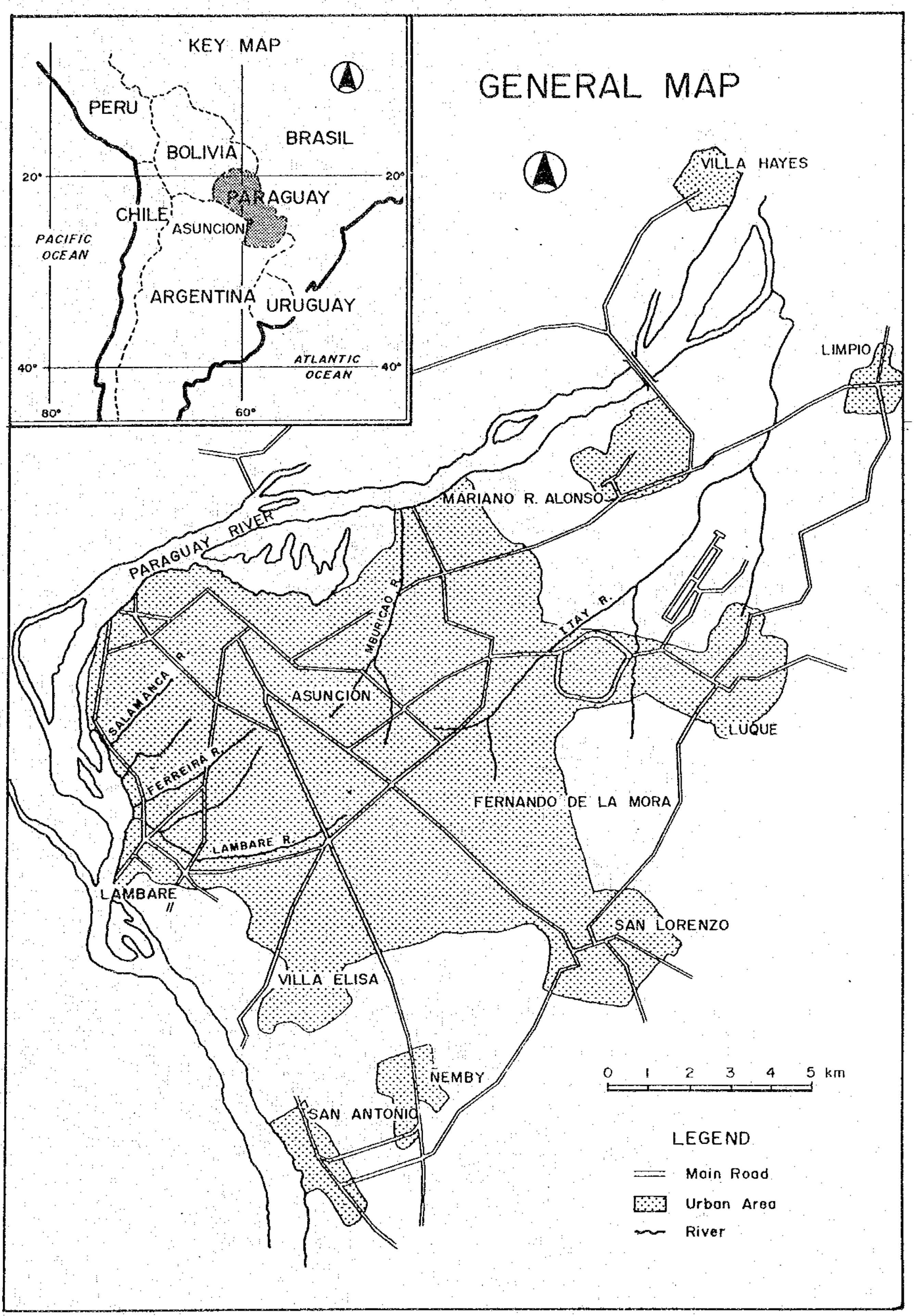
In response to the request of the Government of the Republic of Paraguay, the Japanese Government has decided to conduct a study on the Storm Drainage System Improvement Project in Asuncion City and entrusted the study to the Japan International Cooperation Agency (JICA). JICA sent to Paraguay a study team headed by Mr. Katsuhisa Abe of CTI Engineering Co., Ltd., from August to November 1985 and from June to August 1986.

The team had discussions with the officials concerned of the Government of the Republic of Paraguay and conducted a field survey in Asuncion City and its neighboring area. After the team returned to Japan, further studies were made and the present report has been prepared.

I hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries. I wish to express my deep appreciation to the officials concerned of the Government of the Republic of Paraguay for their close cooperation extended to the team.

January, 1987

KEISUKE ARITA
President
Japan International Cooperation Agency



KEY MAP
PERU
BOLIVIA
BRASIL
20°
20°
PARAGUAY
CHILE
ASUNCION
PACIFIC OCEAN
ARGENTINA
URUGUAY
ATLANTIC OCEAN
40°
40°
80°
60°
GENERAL MAP
VILLA HAYES
LIMPIO
MARIANO R. ALONSO
PARAGUAY RIVER
MBURICAO R.
ITAY R.
SALAMANCA R.
ASUNCION
LUQUE
FERREIRA R.
FERNANDO DE LA MORA
LAMBARE R.
LAMBARE
SAN LORENZO
VILLA ELISA
0 1 2 3 4 5 km
NEMBY
SAN ANTONIO
LEGEND
Main Road
Urban Area
River

S U M M A R Y

1. Introduction

1.1 General Description of Study Area

The metropolitan area of Asuncion is administratively composed of the City of Asuncion and its neighboring 10 municipalities with a total area of 71,000 ha and population of 800,000. The City of Asuncion has an area of 11,700 ha and the population of approximately 460,000 as of 1982. The central area of the city forms a ridge, from which several small rivers originate and flow into Paraguay River. The population in the year 2005 is estimated at 1,650,000 in the metropolitan area and 680,000 in the City of Asuncion. The annual rainfall in the study area is approximately 1,400 mm, but no pronounced wet-dry cycle is observed. The average monthly temperature ranged from 17°C to 28°C and the maximum temperature in the past five years was 39°C, while the minimum marked 0°C.

During heavy rainfall, the city is dotted with flooding and inundating places here and there, and the roads change their function from a transportation system to water canals. This occurs frequently, at least several times a year, and brings about considerable damage through interrupting traffic and submerging houses. Such flooding problem is caused by the poor drainage capacity of the rivers, inadequate provision of drainage facilities, as well as rapid urbanization.

Considering the above situation, it is expected that immediate action to mitigate flood damage in the area be taken at the earliest possible opportunity.

1.2 Existing Storm Drainage System

The area related to the study has the drainage area of about 41,500 ha which was divided into 31 basins. Storm water in these basins is drained into the Paraguay River by their respective rivers through road surfaces, roadside ditches, or some drainage pipes. In general, the drainage capacity of the existing rivers is very poor, so that at the time of heavy rainfall most of the rivers easily overflow on both banks. The existing systems of the drainage facilities in the study area are insufficient as well, except the area of 710 ha, or 6% of the Asuncion city area, where storm drainage facilities were installed by CORPOSANA under the Inter-American Development Bank (IDB) loan in 1984. This well-improved area is located in the central area of Asuncion City.

The other relatively big storm drainage facilities within the basin are the roadside ditches along Artigas Avenue and Aviadores del Chaco Avenue, the drainage channel in the upper reaches of Itay River, etc. However, these facilities are provided merely to solve the local drainage problems and their capacities are also insufficient.

Except for the drainage system mentioned above, there are no notable drainage facilities in the study area. In some areas, existing roads are performing the role of storm drainage facilities. Especially, the roads constructed by reclaiming the place where there may have been river channels are likely to collect storm water due to the topographical features. Much storm water run through the roads during heavy rainfall causing traffic interruption and inundation of houses. In short, no appropriate storm drainage system is provided in a large part of Asuncion City and its neighboring area.

1.3 Flood Damage

The characteristics of runoff discharge in the study area generally indicate that storm rainfall with high intensity falls on the hilly land, and storm water concentrates onto roads and into rivers. Inundation areas and flooding spots spread over Metropolitan Asuncion, but flood damage is more serious in Asuncion City and some of its neighboring cities such as Luque, San Lorenzo, Fernando de la Mora and Lambare.

It has been recognized that flood damage in the study area consists mainly of traffic interruption and inundation of houses caused by floodwaters flowing on the roads to the rivers and the inundation from the rivers themselves. These traffic interruptions and house inundations occur frequently in many places.

The recorded maximum flood took place in November 1982. The total tangible damage at the time of the recorded maximum flood in terms of inundated area, submerged houses, traffic interruption on the trunk roads, and inundated street intersections amounted to 391 ha, 1,800 houses, 64,000 vehicles, and 450 intersections, respectively. In the study area, flood damage is most serious in the Mburicao and the Itay river basins (above Aviadores del Chaco Avenue), followed by that in the Lambare river basin.

2. Formulation of Basic Plan

2.1 General Conditions

With the progress of urbanization, storm water discharge and valuable assets will steadily increase, so that it is imperative to protect the increased assets and properties by the construction of storm water control works. When construction is completed, it is common that development and utilization of even the riverine areas that have been habitually submerged will progress because inundation is reduced. Under such utilized condition of these areas, in case an upgrade storm water control works is required again, it may be impossible to execute the works due to the difficulty of house evacuation and land acquisition.

In consideration of the above-mentioned situation, therefore, the formulation of the Basic Plan for the proposed storm water control facilities showing their basic concepts has been worked out on a long-term point of view under the conditions of (1) the project scale of 10-year probability, (2) the urbanized condition in the year 2005, and (3) overall restoration of the drainage function in the planning area.

2.2 Proposed Plan and Cost Estimate

Proposed Plan

Through comparative study on various alternative cases, the proposed plan for some of the 26 basins/1 has been formulated by means of improvement works of the drainage system consisting of river channel and drainage facilities, and that for the other basins has been formulated by the installation of detention facilities as well as drainage system improvement works as tabulated below.

(1)	Basins where the plan was formulated by the improvement works of the drainage system consisting of river channel and drainage facilities and installation of detention facilities	: Jaen, Zanja Moroti, Ferreira, Las Mercedes, Mburicao, Ycua Carrillo, Santa Rosa, Itay, and Lambare
(2)	Basins where the plan was formulated by the improvement works of the drainage system	: Jardin, Salamanca, Bella Vista, Tres Puentes Cue, Villa Elisa, Nemby, San Lorenzo, Tayazuape, Zeballos Cue, Paso Cai, Varadero, Centro, Tacumbu, Villa Universitaria, Mariscal Lopez, Tablada and Valle Apua

The overall aspects of the Plan consist of river improvement of 96 km, drainage facilities installed in the area of 17,200 ha and

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/1 There are twenty-six (26) basins in the planning area, which had been narrowed down from the study area, for the formulation of the plan.

storage in public compounds of 394 ha for storm water regulation, and storage of 172,000 m^3 rainwater in house lots through the participation and cooperation of individual households.

The right-of-way required for the river improvement works is 1,056,000 m^2.

Construction Cost

The total construction cost (Base Cost) for the execution of the Basic Plan is estimated at 229,000 million Guaranies.

3. Formulation of Master Plan

3.1 General Conditions

The proposed Master Plan of storm water control has been formulated within the framework of the Basic Plan under the following conditions:

(1) The target year of the Master Plan for storm water control system shall be the year 2005;

(2) The scale of the proposed project is 3-year return period; and

(3) The improvement objectives are the trouble spots suffering from serious flood damage in the planning area.

3.2 Proposed Plan

Storm water control works of the Mburicao, Itay (upstream of Aviadores del Chaco), and Lambare river basins are planned by river channels, drainage facilities, and detention facilities, and the design discharge is controlled by the combination of these facilities; while, those of the remaining twenty-three (23) basins are planned by the improvement of river channels and drainage facilities, and the entire discharge is confined in the proposed river channels through the proposed drainage facilities described as follows:

(1)	Basins where the plan was formulated by the improvement works of the drainage system consisting of river channel and drainage facilities and installation of detention facilities	: Mburicao, Itay and Lambare
(2)	Basins where the plan was formulated by the improvement works of the drainage system	: Jardin, Salamanca, Bella Vista, Tres Puentes Cue, Villa Elisa, Nemby, San Lorenzo, Tayazuape, Zeballos Cue, Paso Cai, Varadero, Centro, Tacumbu, Villa Universitaria, Mariscal Lopez, Tablada, Valle Apua, Jaen, Zanja Moroti, Ferreira, Las Mercedes, Ycua Carrillo and Santa Rosa

The overall aspects of the proposed facilities are as follows:

(1) River Channel and Structures

River Improvement	: 89.4 km long
Revetment	: 205,000 m3
Groundsill	: 185 places
Retarding Basin	: 1 place, 350,000 m^3 of regulation capacity
Bridge	: 70 places

(2) Drainage Facilities

Pipe	: 18.7 km long and 1.0 m to 2.5 m in diameter

Box Culvert : 10.6 km long and 2.0 m wide x 2.0 m high to 3.5 m wide x 2.0 m high

Open Channel : 5.3 km long and 3.0 m wide x 2.0 m high to 3.5 m wide x 2.0 m high

(3) Detention Facilities

Storage in Public Compounds : 148 ha
Infiltration Trench : 561 km

3.3 Implementation Schedule and Cost Estimate

Implementation Schedule

The Project consists of a number of sub-projects, so that construction priority for the earliest possible execution should be given to the sub-projects covering the heavy inundation areas and the major trunk roads. Hence, the 20-year construction period (1986-2005) is divided into two, 10-year for the first phase and 10-year for the second phase of construction.

(1) Sub-Projects for 1986-1995 Execution

Priorities are placed on the three basins of Itay (upper stream area of Aviadores del Chaco Avenue), Mburicao and Lambare in accordance with the consideration mentioned above. From the economic point of view for the project implementation, only drainage system improvement works will be provided for these river basins in the former 10 years and the detention facilities required will be installed in the latter 10 years.

(2) Sub-Projects for 1996-2005 Execution

During this 10-year period, drainage sytem improvement works (river channel and drainage facilities) will be provided for the remaining basins. Detention facilities will be installed for the above-mentioned three river basins to cope with the incremental runoff discharge after 1996.

Cost Estimate

The total construction cost for fund requirement for the implementation of the Master Plan is estimated at 107,720 million Guaranies.

3.4 Project Justification

Economic Evaluation

In examining the economic viability of the Master Plan, two (2) river basins, Mburicao and Ferreira, are selected as representative of the whole basin. The economic viability of the Plan is evaluated by means of the internal rate of return (IRR) which is calculated by comparing the benefit and the economic cost. The projects showing IRRs of 9.1% and 11.4% for the Mburicao and the Ferreira river basins, respectively, can be assessed to have enough economic viability for implementation.

Financial Consideration

Assuming that all the foreign currency portion of the project cost is covered by a loan with an interest rate of 3.5% and a repayment period of 30 years including a 10-year grace period, and that the local currency portion is loaned at the interest rate of 15% per annum with a repayment period of 10 years, the total expenditure would reach 192,699 million Guaranies, while the surplus fund during the loan amortization period will accumulate to 142,797 million Guaranies resulting in a negative balance of 49,902 million Guaranies in total. However, it is possible that the difference be recovered in various ways such as subsidy or financial assistance from the central government, etc. Therefore, there may be no financial problem for implementation of the project.

4. Formulation of First Stage Project

4.1 General Conditions

The purpose of the study on the First Stage Project is to provide a means to realize immediate flood damage mitigation in the Mburicao and the Itay river basins which are currently suffering from serious flood damage.

The First Stage Project was formulated on the following conditions:

(1) The target year of the First Stage Project for storm water control system is the year 1993;

(2) A 3-year return period flood is adopted as the planning scale;

(3) Land use pattern which was used for benefit estimation and runoff discharge estimation shall correspond to that presumed in the year 1995; and

(4) The improvement objectives are the trouble spots suffering from serious flood damage in both the Mburicao and the Itay river basins.

4.2 Proposed Plan

The storm water control works will be basically carried out by means of river channel improvement and the installation of drainage facilities in both Mburicao and Itay river basins. Besides, at the downstream end of the improved section of the Itay River, the retarding will be constructed to cope with the anticipated increase of discharge due to the proposed improvement works in the upper reaches of Aviadores del Chaco Avenue in accordance with the results of the Master Plan.

(1) River Improvement

The section to be improved in this plan is 21.2 km in total length consisting of 5.6 km in Mburicao and 15.6 km in Itay River. In some portions of the above sections, revetment and/or invert will be provided to protect the river banks from erosion. All the bridges at the site where the river channel improvement works are implemented will be reconstructed. To reduce the flow velocity, groundsills with head will be installed to make the longitudinal gradient of the river course milder. In addition to the above, a retarding basin will be constructed at the downstream of Aviadores del Chaco Avenue in accordance with the reason aforementioned.

The features of the river improvement works are summarized as follows:

Particulars	Mburicao River	Itay River	Total
Channel Length to be Improved	5.6 km	15.6 km/1	21.2 km
Revetment	38,900 m^2	58,100 m^2	97,000 m^2
Invert	7,800 m^2	0	7,800 m^2
Groundsill with Head	12 units	27 units	39 units
Bridge	16 units	32 units	48 units
Retarding Basin	-.-	1 unit	1 unit

Note: /1 In the upstream section of Madame Lynch River, the installation of box culverts is presently ongoing under the jurisdiction of the municipal office, therefore, the same improvement method is taken up in this section.

(2) Drainage Facilities Improvement

The proposed drainage facilities consist of pipe, box culvert, open channel and incidental facilities. The drainage route in the Mburicao River Basin consist of 14 routes with a total length of 9.3 km. Since the subject basin is one of the advanced urbanized ones, most of the routes are planned to be embedded along the road. The drainage route in Itay River Basin consist of 10 routes with a total length of 9.6 km.

The features of the drainage facilities construction works are as follows:

Particulars	Mburicao River Basin	Itay River Basin	Total
Pipe	5.54 km	0.44 km	5.98 km
Box Culvert	3.59 km	2.64 km	6.23 km
Open Channel	0.18 km	6.56 km	6.74 km

In addition to the above, such incidental facilities as manholes, inlets, outlets, etc., are also provided in this plan.

4.3 Implementation Schedule and Cost Estimate

Implementation Schedule

The implementation of proposed construction works is four (4) years starting in early 1990 until 1993. The project is scheduled to be divided into several components and be executed on annual basis. It is desirable that the volume of work be divided annually as evenly as possible.

The project component to be implemented in each year has been determined as tabulated below in full consideration of the investment efficiency.

Year	Work Item
First Year (1990)	Improvement works of the drainage system along Artigas, Espana and Mariscal Lopez avenues and construction of retarding basin.
Second Year (1991)	Improvement works of the drainage system along Madame Lynch Avenue.
Third Year (1992)	Improvement works of Mburicao river channel and improvement works of the drainage system along Ayala Avenue.
Fourth Year (1993)	Improvement works of river channels of tributaries and provision of the related drainage facilities in the Mburicao and the Itay river basins and remaining works.

Cost Estimate

The total construction cost for fund requirement of the First Stage Project is estimated at 27,500 million Guaranies composed of the foreign currency component of 13,100 million Guaranies and the domestic currency component equivalent to 14,400 million Guaranies.

4.4 Project Justification

Benefits

Upon the completion of the First Stage Project, it can be expected that the average annual benefit is 2,108 million Guaranies in total comprising 599 million Guaranies in the Mburicao and 1,509 million Guaranies Itay river basins.

Economic Evaluation

The economic viability was examined by calculating the internal rate of return (IRR) to decide on whether or not the project will be put into implementation. The First Stage Project which gives an IRR of 11.6% is assessed to have enough economic viability for implementation.

Financial Consideration

Assuming that the foreign currency portion of the project cost is covered by a loan with an interest rate of 3.5% and a repayment period of 30 years including a 10-year grace period, the amortization for the foreign currency portion and the repayment for the local currency portion would amount to 36,907 million Guaranies in total with an annual average of 1,025 million Guaranies. The total expenditure including the operation and maintenance cost during the amortization period amounts to 42,264 million Guaranies.

The financial source overcomes the expenditure by 43,666 million Guaranies in total and 1,213 million Guaranies on an annual average. Hence, it follows that the First Stage Project can be implemented within the financial capacity of CORPOSANA.

PRINCIPAL FEATURES OF THE FIRST STAGE PROJECT

Design Scale of Project : 3-Year Return Period

Objective River Basins : Mburicao and Itay

Particulars	Mburicao River Basin	Itay River Basin	Total
River Improvement			
1. Improvement Stretch and Type of River Channel			
Existing Channel Length (including Tributaries)	11.0 km	15.6 km	26.6 km
Improved Channel Length	5.6 km	15.6 km	21.2 km
- Channel Without Any Protection	0	2.7	2.7
- Channel With Revetment	4.0	10.4	14.4
- Channel With Revetment Plus Invert	1.6	0	1.6
- Culvert	0.2	2.5	2.7
2. Retarding Basin			
- Number of Retarding Basin	0	1 place (Lower reaches of Itay River from Aviadores del Chaco Avenue)	1 place
- Volume	0	350,000 m^3	350,000 m^3
3. Appurtenant Facilities			
- Revetment	38,900 m^2	58,100 m^2	97,000 m^2
- Invert	7,800 m^2	0	7,800 m^2
- Groundsill with Head	12 units	27 units	39 units
- Bridge	16 units (including one railroad bridge)	32 units	48 units

STORM DRAINAGE SYSTEM IMPROVEMENT PROJECT
IN ASUNCION CITY, PARAGUAY

MAIN REPORT

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GLOSSARY OF TERMS AND ABBREVIATIONS

1. Government Agencies and Organizations

MOPC	:	Ministry of Public Works and Communications
ANTELCO	:	National Telecommunications Administration
CORPOSANA	:	Sanitary Works Corporation
SENASA	:	National Environmental Sanitation Services
IDB	:	Inter-American Development Bank
JICA	:	Japan International Cooperation Agency

2. Measures of Length, Height, Weight and Time

m	:	meter
cm	:	centimeter
mm	:	millimeter
km	:	kilometer
K or Km	:	kilometer point
EL.	:	elevation
M.S.L. or MSL	:	mean sea level
DL	:	datum line
kg	:	kilogram
T or t	:	ton (= 1,000 kg)
Hr or hr	:	hour
min	:	minute
s or sec	:	second

3. Measures of Area and Volume

m^2	:	square meter
m^3	:	cubic meter
cm^2	:	square centimeter
km^2	:	square kilometer (= $10^6 m^2$)
ha	:	hectare (= 10^4 m^2)
l or ltr	:	liter (= 1,000 cm^3)
No. or Nos.	:	number
pc.	:	piece

4. Derived Measures

m^3/s, m^3/sec	:	cubic meter per second
t/ha, ton/ha	:	ton per hectare
m^3/km^2	:	cubic meter per squre kilometer
mm/day	:	millimeter per day
mm/hr	:	millimeter per hour
$m^3/km^2/year$	:	cubic meter per square kilometer per year
l/s, l/sec	:	liter per second
m/s, m/sec	:	meter per second

5. Temperature, Etc.

°C	:	degree centigrade
qc	:	resistance of cone penetration test
PS	:	horsepower
%	:	percent

6. Currency

US$	:	United States Dollar
₲	:	Paraguayan Guarany
¥	:	Japanese Yen

7. Others

CIF	:	Cost, Insurance and Freight
FOB	:	Free on Board
GDP	:	Gross Domestic Product
GRP	:	Gross Regional Product
IRR	:	Economic Internal Rate of Return
F.C.	:	Foreign Currency
L.C.	:	Local Currency

CHAPTER 1. INTRODUCTION

1.1 General Description

Asuncion City, the capital of Paraguay, is located in a hilly land, although not so steep, of from 60 m to 150 m above mean sea level. It has an area of 11,700 ha and the population of approximately 460,000 in 1982. The central area of the city forms a ridge, from which several small rivers such as Mburicao, Itay, Villa Elisa, Lambare, etc., originate and flow into Paraguay River. Recently, Asuncion City has been expanding with a considerable increase in population that has been forecast to around 680,000 in the year of 2005.

During heavy rainfalls, the city is dotted with flooding and inundating places here and there, and the roads change their function from a transportation system to water canals. This occurs frequently, at least several times a year, and brings about considerable damage by interrupting traffic and submerging houses. This problem is attributed to the poor drainage capacity of the rivers, inadequate provision of drainage facilities, as well as rapid urbanization.

Under the above circumstances, CORPOSANA has launched on solving the problem since 1973. A storm water drainage system was completed in 1984 under the finance of the Inter-American Development Bank (IDB), covering the commercial and office zone, 710 ha in total, which accounts for, however, only 6% of the total area of Asuncion City. The existing system is thus so insufficient in terms of covering area to provide a drainage system for the whole city which is highly desired.

1.2 Outline of the Study

1.2.1 Study Area

The study area for the Storm Water Control System Project covers Asuncion City and the neighboring area, excluding the flooding area affected by the Paraguay River.

1.2.2 Objective of the Study

The objectives of the study are to prepare a Master Plan for storm water control system improvement in Asuncion City with the target year of 2005, together with a Basic Plan which shows the technical guideline to the Master Plan, and to carry out a Feasibility Study on the First Stage Project which will be selected on the basis of the results of the Master Plan Study.

1.2.3 Study and Staffing Schedules

The study was carried out for about one-and-a-half year from August 1985, as shown in Fig. 1-1. The Study Team consists of 12 experts recruited from CTI Engineering Co., Ltd. of Japan. The members of the Study Team are presented in Table 1-1, together with the members of the Advisory Committee which was organized for the study.

CHAPTER 2. PROJECT BACKGROUND

2.1 National Development Policy

The Government of Paraguay has launched on a national socio-economic development planning since 1963 when the Technical Planning Secretariat was created. In its early stages, development planning covered a period of two years and then five years, and a few years not covered by the plans were found. The first and second two-year plans covering the period from 1965 to 1968 were published successively. A longer period (five years) development plan was formulated for the period from 1971 to 1975, followed by the second one for 1977 to 1981. The Technical Planning Secretariat is now preparing a new five-year national development plan covering the period from 1985 to 1989.

The permanent national objectives of Paraguay are to achieve social peace and stability, uplift the welfare of the people, consolidate its territory, and overcome the mediterranean disadvantages, which have not changed for the last two decades. To approach the goal, the government set up a number of strategies in each economic sector, and the most important one called the "General Strategy for Development" which aims to strengthen the national economic foundation is increment of exports through the promotion of agro-industrial activities and substitution for import goods.

During the second five-year development plan, the gross domestic product (GDP) of Paraguay reached a total of G744,361 million at the price level of 1982, and compared with the GDP in 1977 of G495,493 million, the growth rate showed a high percentage of 10.7 a year. The GDP during this period is presented in Table 2-1.

In 1982 and 1983, however, Paraguay's economy fell to negative growth rates of -1.0% and -3.0%, respectively. Both external and internal factors have contributed to this economic recession. The major external factors include the devaluation of currencies in the neighboring countries as well as the worldwide economic recession, while the major internal factors are composed of progressive overvaluation of Paraguay's currency, poor harvests due to bad weather conditions in 1983, and also serious decrease of internal investments.

Since late 1983, the economic mood began to become brisk, and the GDP increased by approximately 4.7% in 1984. In the five-year development plan for 1985-1989, the economic growth is projected at 6.1% a year, as shown in Table 2-2.

As for infrastructures, especially sanitary and water drainage systems which are related to this study and to the welfare of the people, one of the national objectives, the 1971-1975 five-year development plan put emphasis on the expansion of the activities of the Sanitary Works Corporation (CORPOSANA) and the National Environmental Sanitation Services (SENASA).

2.2 Administration

National Level

The administrative structure of the Government of the Republic of Paraguay including the ministries may be presented as in Fig. 2-1.

Asuncion City

Asuncion City is the capital of the Republic of Paraguay. It has an autonomous form of government and thus, enjoying exclusive jurisdiction over matters related to its interests, assets and revenues and in matters of urban development, food supply, education and culture, health care and social welfare, traffic, tourism, and security (see Fig. 2-2).

Asuncion Metropolitan Area

The outskirts of Asuncion City are composed of several small communities that participate briskly in Asuncion's economic activities. Municiparities such as Luque, Lambare, Fernando de la Mora and San Lorenzo are completely integrated into Greater so that Asuncion City and its 10 outskirt municipalities decided in 1978 to form an inter-departmental association, named the "Asociacion de Municipalidad de Asuncion y su Area Metropolitana" or AMUAM, with the common aspiration of socio-economic development. Apart from the municipalities mentioned above, the association also includes Mariano Roque Alonso, Limpio, Nemby, San Antonio, Villa Elisa and Villa Hayes. The mayor of Asuncion City is the chairman of the association.

2.3 Topography and Geology

Topography

Asuncion City and its environs are on the left bank of the Paraguay River, on a peninsula-like land where the river makes a sharp curve after keeping a steady southbound course through the central part of Paraguay from its origin in the southern part of Brazil.

The said peninsula-like land assumes a hilly landmass composed of a ridge, now densely populated in terms of commercial and residential zones. Some 10 rivers, which have scarcely been improved, are running down through valleys; most of them flowing down either northward or southward to join the Paraguay River. Since the distance between the ridge (150 m above MSL) and the bank of the Paraguay River (60 m above MSL) is rather short, the valleys formed by these rivers which discharge themselves into the Paraguay River are narrow and steep. Asuncion City, therefore, seems to be built on so many terraces and its roads have to make sharp up-and-down slopes.

On the other hand, a few of the rivers flow on the eastern outskirt of Asuncion City, running down on a gentle slope to pour themselves into the Ypacaray Lake some 30 km east of the city.

Geological Features

The geology of Asuncion City is composed of aluvium and backfill, red sandstone (Misiones Sandstone), gravel bed, and dolerite (intrusive or flow) as schematically shown in Fig. 2-3. The basement consists of the Misiones Sandstone of the Triassic to the Cretaceous. Its lithofacies consist mainly of soft massive aeolian sandstone and partially of river deposits. The sandstone is medium red, and sometimes includes subangular gravel made of Silurian Sandstone and well-rounded gravel made of Pre-Cambrian Quartzite.

Although the bedding plane is not generally recognizable, a 10 cm thick mudstone bed with lamination has been observed to be horizontally spreading in the valley east of San Lorenzo. Fresh sandstone has sufficient sand, but when weathered, it has more clay and less sand. Weathered sandstone becomes hard if it is dry, while they are easily crushable if their moisture content is high. They belong to "weak rocks" according to engineering geological classifications. The groundwater is shallow because permeability is not good.

Dolerite intrusion into the basement layer can be observed on the hills at Lambare and Tacumbu, as well as at the southwest of the terminal of Colon Avenue where quarrying is being done. Dolerite aggregate can also be obtained at Villa Hayes. The rock test gives a specific gravity of 2.6, less than 1.0% water absorption, and about 20% abrasion value (of coarse aggregate) by the use of Los Angeles Machine, which qualify the material as good concrete aggregate. Alluvium sediments and backfill cover the basement, and river deposits are observed on both banks of the Paraguay River.

2.4 Population

Population census in the Republic of Paraguay was taken four times: in 1950, 1962, 1972 and 1982 as presented in Table 2-3. The table shows that the population of the whole country had increased by about 1.7 times, growing from about 1,820,000 to some 3,040,000 in the twenty years between 1962 and 1982. In this period, the average annual growth rate was 2.70% in the first ten years, somewhat decreasing to 2.55% in the latter ten years. In the same period, the population of Asuncion Metropolitan Area had increased by about twice, growing from about 410,000 to some 800,000. Thus, the population increase has been much faster than that of the whole country. As a result, the share of the metropolitan population in the country had climbed from 22.5% in 1962 to 26.3% in 1982. This means that the concentration of population toward the metropolitan area is now in progress.

On the other hand, while the population of Asuncion City had increased by about 1.6 times, growing from about 290,000 to some 460,000 in these twenty years, the share of Asuncion's population in the metropolitan area has largely declined from 70.5% to 57.3%.

It should be noted that while the average annual growth rate in Asuncion City had largely declined to 1.6% in the ten years between 1972 and 1982, the outskirt municipalities such as Fernando de la Mora, Lambare, Mariano Roque Alonso, San Lorenzo, Villa Elisa and the others had a rapid increase in population during the same period with an average annual growth rate of more than 6%. This means that in contrast with the slow down of growth rate of population within the Asuncion city proper, high growth of population and urbanization are continuing in the outskirt municipalities which still have a vast unutilized land (refer to Fig. 2-4).

The population density in 1982 were 0.074 persons/ha for the whole country, 11 persons/ha for the Metropolitan Area, and 39 persons/ha for Asuncion City. As for the sex ratio (number of males for every 100 females), which was 98.3 in 1972, it is seen that it had reversed itself to 100.3 in 1982. On the other hand, the sex ratio in the metropolitan area which was 90.5 in 1972 had slightly climbed to 91.3 in 1982, although there is a high proportion of females in this area.

2.5 Meteorology

Observatory

At present, there exist in the study area only one meteorological station, Aeropuerto Station, which started observation in 1971.

The observation items of this station include rainfall, temperature, humidity, wind direction, wind velocity, atmospheric pressure, and so on.

Meteorological data had also been collected during specific periods at other two stations: Sajonia Station from 1965 to 1976 and San Lorenzo Station from 1957 to 1980. These stations have rainfall records, but as far as the rainfall observation is concerned, the records at Armada Station covers the longest period, from 1929 to 1964.

The location of these stations is shown in Fig. 2-5.

Meteorological Characteristics

The study area is climatically situated in the subtropical zone, and a year is officially divided into four seasons: Spring, from September 21 to December 21; Summer, from December 22 to March 20; Autumn, from March 21 to June 20; and Winter, from June 21 to September 20.

According to the observation data at Aeropuerto Station, for the recent five years the average monthly temperature ranged from 17°C to 28°C and the maximum temperature during these five years was 39°C, while the minimum marked 0°C. (Refer to Fig. 2-6.)

The average humidity which fluctuates between 60% and 80% shows a low value in September to October and a relatively high value in May to June. Although wind velocity in the study area averages at around 5.0 km/hr without showing any marked fluctuation by season or direction, wind directions are predominantly from North, East and South throughout the year and no clear seasonal trend is observable.

Evaporation at San Lorenzo from 1976 to 1980 shows a mild fluctuation within the range between 2.0 mm/day and 3.5 mm/day throughout the year. (Refer to Fig. 2-6.)

The annual average rainfall in the study area is approximately 1,400 mm. Light rainfall usually occurs from June to September and heavy rainfall from November to April, though no pronounced wet-dry cycle can be seen. (Refer to Fig. 2-7.)

Rainfall is basically caused by the mingling of the hot humid winds from North Brazilian Grosso, famous for its high humidity and the cool dry winds from the south. Besides, localized rainfall is sometimes brought by a cumulonimbus in hot seasons.

2.6 Infrastructures

Transportation

The transportation system in Paraguay can be broadly categorized into highways, railways, commercial aviation, ports and waterway systems. The national highways, Route I to Route XII, and their branches cover a distance of 12,634 km and 1,558 km of these are paved. These highways mainly connect Asuncion City with other remote big cities; Route I connects Asuncion with Encarnacion, and Route II and VII link Asuncion with Ciudad Presidente Stroessner.

The Paraguayan railway system, one of the oldest railways in South American countries, offers twice-a-week services between Asuncion and Encarnacion, covering a distance of 376 km. In 1983, this railway conveyed 258,777 passengers and 139,450 tons of cargo, the bulk of which passed through Carlos Antonio Lopez Station located in Asuncion City.

Paraguay has only one international airport in the Metropolitan Asuncion Area, Presidente Stroessner Airport, which is used by Brazilian, Bolivian, Argentine, Chilean, Spanish and American (Eastern) airlines. Paraguayan Airlines operate long distance flights to the United States, European and Central American countries, as well as flights to its neighboring countries such as Brazil and Argentina. Military Transport Airlines and National Transport Airlines offer on a regular basis services of domestic air transportation, linking Asuncion with Encarnacion, Pedro Juan Caballero, Concepcion, Ciudad Presidente Stroessner, and other towns.

There are a number of ports along the Paraguay River which include Asuncion, Villeta, San Antonio, Encarnacion, Casado, Villa Elisa, Ita Pyta Punta, Conception, and so on. The largest port is Asuncion Port which is catering to import-export services. It is the only one of its kind that is equipped with loading-unloading facilities and an storage capacity that can be considered as modern.

Paraguay and Parana rivers are being used as the waterway systems which connect Paraguay with its neighboring countries of Argentina and Brazil, respectively.

Communications

The National Telecommunications Administration (ANTELCO) monopolizes the operation of telecommunication services in Paraguay, though some private enterprises operate telecommunication services for specific areas under annual licenses granted by ANTELCO. Direct communication with the world are maintained through 6 radio, 75 telephone, and 107 telex connections.

Telephone services in Paraguay are maintained by the combination of a modern microwave system, a satellite system, and a manual system. As of the end of 1980, nine automatic exchanges were installed in the Metropolitan Asuncion Area with nearly 45,000 lines, while throughout the interior of the country there are 36 exchanges with some 14,000 installed lines.

The telex system which is based on the Xentex system has an installation capacity of 1,300 lines. The number of subscribers rapidly increased from 198 to 657 during the 1975-1982 period, though its utilization rate still remains at about 50%.

Water Supply and Sewage Service

There are two agencies in charge of Paraguayan sanitation. One is the Sanitary Works Corporation (CORPOSANA, Corporacion de Obras Sanitarias) and the other is the National Environmental Sanitation Services (SENASA, Servicio Nacional de Sanitarias).

The services of CORPOSANA cover potable water supply and sewage disposal in the City of Asuncion and communities of more than 4,000 inhabitants, and storm water drainage in the city of Asuncion only; while, SENASA is responsible for providing potable water to population centers with less than 4,000 inhabitants.

In Asuncion City, CORPOSANA supplies potable water to 443,700 inhabitants through 80,665 pipe connections. The water purification plant has a production capacity of 240,000 m^3/day, and the annual production volume reached 52.3 MCM in 1984.

CORPOSANA's sewage disposal service covers the major cities of Asuncion, Encarnacion, Puerto Presidente Stroessner and Pedro Juan Caballero. The sewerage system in Asuncion City consists of collection pipes of 745 km and branch pipes of 386 km in total. The beneficiaries amount to 71,059 people living in an area of 4,737 ha.

2.7 Industry

Paraguay's economy, as is often the case with other developing countries, is eminently dependent on the primary and secondary economic sectors. The former, including agriculture, forestry and animal husbandry, accounts for some 26% of the gross domestic product (GDP), while the latter composed of mining, manufacturing and construction shares about 24% in recent years. Especially noticeable are agricultural and manufacturing outputs which may affect the GDP because of their high shares of 15% and 17%, respectively. The GDP by economic sectors and their shares are summarized in Table 2-4.

The high growth rate of agricultural output during this decade has practically enabled Paraguay to achieve self-sufficiency in foodstuffs. In addition, this sector provides 40% of the jobs available to the economically active population and supplies all the processed goods and industrial raw materials for export. Cotton and soybean are the most important agricultural crops, which contribute outstandingly to the Paraguayan economy both in absolute terms and in relation to other crops by sharing 14.8% and 21.8%, respectively, of the total agricultural production in 1982.

Cotton fiber produced in Paraguay is enjoying a good international reputation due to its high quality and favorable price, as seen in its exports volume of 98,416 tons worth 30,737 million Guaranies in 1983. In monetary terms, cotton ranked first among Paraguayan exports for the last five years. In 1984, 481,859 tons worth 21,928 million Guaranies of soybean, the second-key agricultural commodity, were exported. The other export commodities include tobacco, corn and sugarcane.

Manufacturing output reaches some 70% of the total production of the secondary economic sector. The bulk of manufacturing production is based on the processing of agricultural, livestock and forestry raw materials. Outstanding are textile manufacturing and livestock processing which account for 20% and 19%, respectively, of the total manufacturing production in 1983.

Contrary to the national economic structure, the tertiary sector is remarkably dominant in Metropolitan Asuncion, as witnessed by its high share of more than 80% of the gross regional product. Its activities are concentrated in the City of Asuncion, and it is noticeable that economic activities concerning insurance and finance have a high share of 60-70% in relation to its national total, followed by the sector of electricity, water supply and sanitary services by more than 50% and the sector of restaurants and hotels by some 40%. The primary sector shares less than 2% of the gross regional product.

2.8 Land Use

Urban Structure of Asuncion

Asuncion City has its urban core on the riverside where the government administratrive organizations and the commercial and business establishments are concentrated. Outward to the east, there spread the residential areas commercial zones and industrial zones along the trunk roads.

In the last forty years or so, the city gradually expanded its perimeter in the shape of a fan. Specifically, the city has developed towards the southeast direction from Micro-Centro down along Eusebio Ayala Avenue and Mariscal Lopez Avenue.

The urban infrastructures that support the city development are the six trunk roads extending radially from the center of the city. They have been playing a very important role as urban arteries of transportation. The city has also a grid pattern road system as substructure.

Along the six trunk roads, each area has its own special feature in terms of the land use such as residential area (high, middle, and low class), commercial area, warehousing and industrial area, and so on.

Present Land Use

As mentioned earlier, Asuncion Metropolitan Area consists of the Asuncion city proper and the 10 outskirt municipalities, with a total area of 71,000 ha. Out of this area, 24,800 ha of land have now been urbanized and 35,000 ha is currently used for agriculture and pasture (livestock grazing ground). The remaining 11,200 ha is made up of the lower level land which is frequently submerged by the floodwaters of the Paraguay River.

The urbanized area consists of most parts of Asuncion City and Lambare, Fernando de la Mora, Luque, and Villa Elisa, and 80% of San Lorenzo. Presently, land in this urbanized area is used as residential area (41.0%), commercial area (3.1%), industrial area (1.9%), recreational area (2.7%), public facilities (15.5%), roads (22.4%), and unused area (13.4%). (Refer to Fig. 2-8.)

The area of Asuncion City is 11,700 ha, most parts of which have been urbanized, except the lowlying land along the Paraguay River. Land in the city is presently used as residential area (45.9%), commercial area (3.6%), industrial area (0.7%), recreational area (3.6%), public facilities (10.8%), roads (17.5%), unused area (6.5%), and unutilizable area (11.4%).

2.9 Labor Force and Income Level

Based on the national census of 1982, the economically active population of Paraguay is estimated at 1,029,680, which consist of 820,990 men and 208,690 women older than 12 years. The employment ratio in relation to the total population is as low as 34% so that two-thirds of the population are economically supported by the remaining one-third. This is because of absolutely insufficient employment opportunities and the characteristic trait of the population structure in which population below 12 years old accounts for about one-third of the total.

Of the economically active population, those engaged in agriculture have the largest share of more than 40%, followed by those in the manufacturing sector of 12%, as shown in Table 2-5. Unemployment at the national level reached 7.1% in 1983 and 8.4% in 1984 due to economic recession in the early 1980's. The rates in the urban areas are higher than the national level; 9.7% in 1983 and 11.9% in 1984.

The minimum wage of workers in the capital zone and in other rural areas was legally raised twice in 1985; by 10% in February and 20% in October on the cumulative basis. The daily wage of laborers for construction in the capital zone range from 1,741 Guaranies to some 2,000 Guaranies, which are higher than those in the rural areas by about 15%.

2.10 Related Development Projects

City Development Project

The projects now under way or under construction within Asuncion City are shown in Table 2-6. It is noteworthy that large-scale public facilities such as Banco Central del Paraguay, the new municipal building, and so on, are being projected to form the suburban cores on the perimeter of the fan that make up Asuncion City.

Previously Executed Drainage Project

In 1967, a master plan for the storm drainage system covering an area of approximately 3,400 ha in Asuncion City was formulated. On the basis of the plan, CORPOSANA selected the area of 710 ha in total to be provided urgently with a storm drainage system, and it executed the project for this area under the finance of IDB through the feasibility study and detailed design.

The project was conducted in two stages. The first stage which covered the area of 200 ha was started in 1973 and completed in 1976. As for the project scale, 10-year return period was applied to the first stage.

The second stage covering the remaining area of 510 ha was completed in 1984 after a construction period of about 4 years. The project scale was lowered to 5-year return period and for some specific areas, 3-year return period, because of economic reasons.

Other Related Projects

Two master plan studies are now going on in Asuncion Metropolitan Area. One is the Urban Transport Study in Asuncion Metropolitan Area and the other is the Asuncion Sewerage and Sewage Treatment Master Plan.

(1) The Urban Transport Study in Asuncion Metropolitan Area

This study began in August 1984 and was completed in September 1986. It is being undertaken by JICA upon the request of the Government of Paraguay.

The objectives of the study are to prepare a master plan for the transportation system in Asuncion Metropolitan Area with the target year of 2000. The study area is the entire Metropolitan Area consisting of Asuncion City and the outlying ten municipalities comprising an area of 71,000 ha.

(2) Asuncion Sewerage and Sewage Treatment Master Plan

This study started in March 1985 and is expected to be completed in January 1987. It is being undertaken by a team of British consultants which was commissioned by the Government of Paraguay.

The objectives of the study are to formulate a sewerage and sewage treatment master plan and execute a feasibility study for the project in Asuncion City and its vicinity with the target year of 2010. The study area is about 27,800 ha, encompassing Asuncion City and other six surrounding municipalities.

CHAPTER 3. EXISTING STORM DRAINAGE CONDITIONS

3.1 Storm Drainage System

3.1.1 Outline of the System

The area related to this study has the drainage area of 41,500 ha which was divided into 31 basins (Refer to Fig. 3-1). Twenty (20) of these basins having an area of 34,500 ha have rivers, while the remaining eleven (11) basins of 7,000 ha do not have any river.

In the basins that have rivers, storm water is drained into the Paraguay River by their respective rivers after collecting storm water from road surfaces, roadside ditches, or some drainage pipes, while storm water in the basins where there is no river channel pours directly into Paraguay River through the road surfaces, roadside ditches, or the drainage pipes. The drainage capacity of the existing rivers and drainage systems is very poor except the drainage facilities installed in a small area.

3.1.2 River Channels

The twenty (20) rivers mentioned in 3.1.1 can be grouped into three based on the viewpoint of riverbed gradient and flow capacity as summarized in Table 3-1. The first group is composed of seven (7) rivers including Lambare and Ferreira which originate from the ridge at the center of Asuncion City and flow down southward to Paraguay River. The total catchment area of these seven rivers is 9,087 ha and shares 26% of that of all rivers, and it is occupied by the middle and low class houses. The rivers in this group have steep slopes of about 1/50 to 1/100. The other feature of this group is that the rivers have generally larger river cross sections, excluding some cases, than the other group, which can generally afford the floods of 1 to 2-year return period.

The second group comprises nine (9) rivers, all of which originate from the ridge at the center of Asuncion City and flow northward to Paraguay River. The total catchment area of these nine rivers is 4,148 ha and shares 12% of the total catchment area of all rivers.

The featrure of this group is that the rivers have, excluding some basins slopes of about 1/70 to 1/170 which are gentler than those of the first group and can only afford the floods of about 1-year return period. The utilization of land in the cathcment area is featured by the existing business area and high class residential zone.

The third group is composed of four (4) rivers of Itay River which flows northward to Paraguay River and the rivers of San Lorenzo, Tayazuape and Ycua Dure which flow westward to Lake Ypacarai. The total catchment area of these rivers is 21,252 ha and shares 62% of the total catchment area of all rivers. This group has features that each river has a big catchment area, a gentle slope of the riverbed and a small river cross section. The average riverbed gradient of each river is between 1/110 and 1/330. The flow capacity of the rivers is small owing also to the small river cross section and floods occur several times a year. The utilization of land in the catchment area of these rivers is mostly for stock farms and agricultural farms, except for housing area at the upstream areas of Itay River and San Lorenzo River.

3.1.3 Storm Drainage Facilities

The study area can be divided into two (2) categories on the basis of the progress of improvement of the drainage facilities, i.e., the well improved area and the poorly-drained area. The former comprises the area of 710 ha where the storm facilities were installed by CORPOSANA under the Inter-American Development Bank (IDB) loan (refer to Fig. 3-1). This well-improved area, which is located in the central area, is the most important area of Asuncion City in relation to the political and commercial activities of Paraguay.

Among the 31 river basins of the planning area, the said well improved area covers an area of only 2% and most of the remaining area is under the unimproved condition as shown in Fig. 3-1.

Improvement works on storm drainage facilities for the Centro Basin were executed in two periods. Works for the first period of improvement were done in three years from 1973 to 1976 based on the project scale to cope with floods of 10-year return period at an area of 200 ha within the 710-ha improvement area. The length of drainage pipes installed during this period was 9,100 m.

The works for the second period of improvement works were done in five years from 1979 to 1984 based on the project scale of 5-year return period on the remaining 510 ha of the improvement area. The length of pipes installed during this period was 14,100 m.

During the above-said second period, the other improvement works were carried out at several places in the poorly drained areas of Las Mercedes and Mburicao basins to eliminate local floods, and the lengths of installed pipes are about 2,200 m and 1,700 m, respectively.

The other relatively big storm drainage facilities within the study area are the roadside ditches along Artigas Avenue and Aviadores del Chaco Avenue, the drainage channel in the upper reaches of Itay river, and so on. However, these facilities are provided merely to solve the local drainage problems and their capacities are also insufficient.

Except for the above, there are no notable drainage facilities in the study area. In some areas, existing roads are performing the role of storm drainage facilities. Especially, the roads constructed by reclaiming the place where there may have been river channels are likely to collect storm water due to their topographical particularity. Much storm water runs through the roads during heavy rainfall causing traffic interruption and inundation of houses.

3.2 Inundation and Flood Damage

Except the data compiled by CORPOSANA and the information published in newspapers, there are a few data on flood in the study area. To augment the available data, the contents of flood damage were gathered through interview-surveys with residents.

From the collected data, it was identified that the highest frequency of flood causing the most serious damage a year was observed in 1983 and the recorded maximum flood was in November 1982.

Although some minor damage caused by storm water that flow on the roads still exist, this study was carried out on only the conspicuous flood damage, as mentioned hereinafter.

Causes of Flood

The characteristics of runoff discharge in the study area generally indicate that storm rainfall with high intensity falls on the hilly land, and storm water concentrates onto roads and into rivers. On the other hand, rapid urban development, construction of houses, construction of paved roads, etc., which resulted in the reduction of permeable areas, have been accelerating the increment of runoff. Furthermore, most of the river channels and ditches serving to drain the runoff discharge have poor flow capacities and have not been improved and maintained properly.

Contents of Flood Damage

It has been recognized that flood damage in the study area consists mainly of traffic interruption and inundation of houses that are caused by floods flowing on the roads to the rivers and the inundation from the rivers themselves. Damage to agricultural crops and others are negligible.

Flood Damage in the Study Area

The inundation areas and flooding spots spread over Metropolitan Asuncion but flood damage are more serious in Asuncion City and some of its neighboring cities of Luque, San Lorenzo, Fernando de la Mora and Lambare. In the other surrounding cities like Villa Hayes, Limpio, Mariano R. Alonso, Villa Elisa, Nemby and San Antonio, flood damage is slight or negligible because people live in flood-free places from the topographic point of view. In the study area outside Metropolitan Asuncion, inundation and flood damage is also negligible because the towns and villages are sparsely populated and thus, assets are few. Fig. 3-2 shows the aforementioned inundation areas and flooding spots at the time of the recorded maximum flood.

(1) Flood Damage in Sub-Basins

As for the 31 basins into which the study area is divided, 22 basins are found to have been suffering from flood damage and 15 of them have habitual flood damage as shown in Fig. 3-3. The total tangible damage in the study area at the time of the recorded maximum flood in terms of inundated area, submerged houses, traffic interruption on the trunk roads, and inundated street intersections amounted to 391 ha, 1,800 houses, 64,000 vehicles, and 450 intersections, respectively. The damage in the 15 basins during the same period is shown in Table 3-2 and flood damage evaluation considering flood frequency and other situations is in Table 3-3.

Judging from these tables, the flood damage is most serious in the Mburicao and the Itay river basins (above Aviadores del Chaco Avenue), followed by that in the Lambare river basin.

(2) Traffic Interruption on Trunk Roads

In the study area, six trunk roads such as Artigas Avenue, Espana Avenue (General Franco, General Genes, Aviadores del Chaco), Mariscal Lopez Avenue, Eusebio Ayala Avenue, Fernando de la Mora Avenue and Gneral Maximo Santos Avenue radiate outwards from the central area and they are connected with each other by lateral circumferential roads (Madame Lynch Avenue and others). During heavy rains, the smooth flow of traffic is interrupted on several points on these roads. The frequency of traffic interruption and volume of traffic especially on those enumerated above is high and big compared with the other roads that are affected.

The number of vehicles affected at the time of the recorded maximum flood on the said roads were estimated independently in each road as shown in Table 3-4.

3.3 Organization and Management

3.3.1 Existing Organization and Management System

As far as the study on existing organization and management is concerned, it has been confined to the agencies involved in storm water drainage in Paraguay; namely, the CORPOSANA and the SENASA. CORPOSANA is responsible for storm drainage services to only the Asuncion Metropolitan Area. Its history and main functions are briefly presented hereinafter.

CORPOSANA, an independent agency attached to the Ministry of the Interior but with its own administration, organization, and resources was originally organized as the Corporacion de Obras Sanitarias de Asuncion by Law 244 and Decree 9669 of 1954. The agency's original objective was to provide potable water and sewerage services to Asuncion City. Subsequently, its functions and responsibilities were modified and amplified in 1958 under Law 166 to increase a number of water connections in the Metropolitan of Asuncion. Soon afterwards, Law 713 of March 1962 authorized CORPOSANA to extend its functions in the construction and maintenance of sewers in Asuncion.

In March 1966, Law 1095 further amplified and changed CORPOSANA's objectives to promote, operate and maintain water and sewerage in major towns with population of above 4,000 in the interior. Accordingly, CORPOSANA changed its name in the following year of 1967 to Corporacion de Obras Sanitarias by abandoning the suffix of "de Asuncion" to make it clear that it was no more serving only for Asuncion but nationwide to attend to services in the fields of city water and sewerage system.

In 1973, the restructuring of CORPOSANA took place under Law 405 and Decree 29697, so that its functions and responsibilities came to cover the water supply, sewerage and storm water drainage in Asuncion City and in major towns having the population greater than 4,000.

CORPOSANA's management structure is divided into several divisions, each with specific functions, as shown in Fig. 3-4. The function on storm water drainage belongs to the Sewerage Division (Gerencia de Alcantarillado) as shown in Fig. 3-5. This division has been primarily attending at the operation and maintenance of both foul and storm sewerage systems within the City of Asuncion, and it is composed of around 60 personnel including one (1) division manager, six (6) professional staff and four (4) administrative staff.

In connection with the repayment of the loan of Inter-American Development Bank (IDB) for the 710-ha Asuncion storm water drainage system in the central part of the city, CORPOSANA emposes levies on all its residents with surcharge in proportion to the value of their real estate holdings.

3.3.2 Laws and Regulations

Laws and regulations concerning water management are not firmly established in Paraguay. For some time in the past, the water law originally enacted in the neighboring country of Argentina has been used as the basis of Paraguay's own water management regulation. It is understood that drafting of Paraguay's independent law concerning water management is underway.

While legal care has been rather neglected on rivers and river water use, the Government of Paraguay has now come to be confronted by the problems arising from pollution of river water due, particularly, to the industrial wastes liberally flowing out of the chemical and pharmaceutical plants and factories that are operating through international licenses. Some concerned institutions like SENASA are seriously studying countermeasures to this kind of hazard to people's health through the formulation of relevant laws and regulations.

CHAPTER 4. BASIC CONCEPT FOR STORM WATER CONTROL

In general, augmentation of flood damage in areas being rapidly urbanized is attributed to insufficient drainage capacity in relation to the volume of storm water runoff as schematized below:

Urbanization of a river basin	=>	- Increment of runoff - Increment of assets with multiplication of urban functions - Deterioration of drainage capability	=>	Augmentation of flood damage

Flood damage, without any appropriate countermeasure for drainage of storm water, tends to augment in a river basin being urbanized, and the following may be some of the countermeasures:

(1) Improvement and maintenance of drainage facilities;

(2) Control of incremental runoff and reduction of existing runoff from an entire river basin; and

(3) Institutional establishment and legal regulation for land-use in the habitually inundated areas of assets which are vulnerable to flood damage.

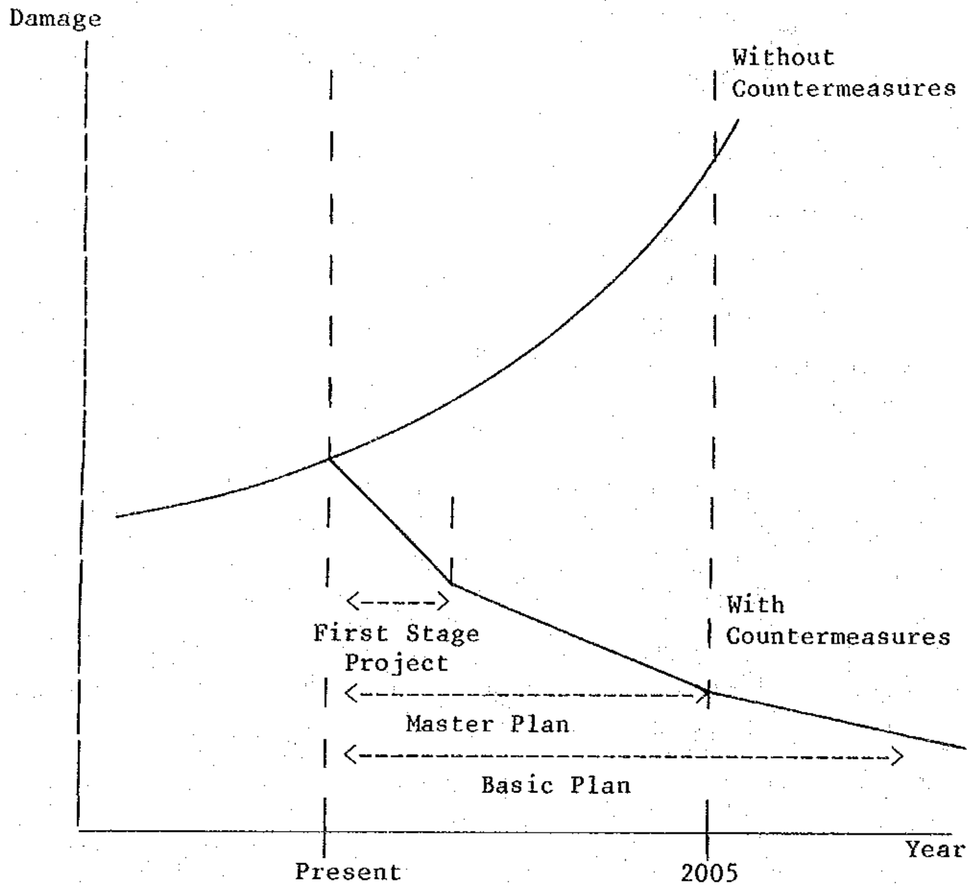
To facilitate better understanding, the causes and their countermeasures are tabulated as follows:

Causes of Flood Damage	Countermeasures	
	Lower Reaches (Drainage Area)	Upper Reaches (Runoff Area)
Increment of runoff	Improvement and maintenance of drainage facilities	Installation of detention facilities
Increment of assets	Regulation of land-use	---
Deterioration of drainage capability	Improvement and maintenance of existing facilities	---

Drainage facilities and river improvement works have been considered to be the most effective system to control storm water. In river basins under rapid urbanization, however, detention facilities such as storm water infiltration and storage works should be incorporated in the comprehensive storm water control system. This requires cooperation and understanding of not only residents and house owners living along the river channels but also government agencies responsible for urban planning and development. It also needs institutional arrangement when the proposed system is put into implementation.

This project covers a vast area including the city of Asuncion and its neighboring areas. Therefore, it needs an enormous amount to finance its implementation, so that it has to be forwarded stepwisely.

Relation curves between damage and a certain lapse of time are drawn under the conditions of with and without countermeasures to show differences, as illustrated in the following:



It takes a long time and an enormous cost to put the Basic Plan into implementation so that improvement works for the storm water drainage system should be provided step by step, as shown in the above figure. The stepwise plans are defined as follows:

Basic Plan	:	The plan to be formulated to define the framework of a technically ideal system for the far future.
Master Plan	:	The plan proposed within the frame-work of the Basic Plan on a more realistic manner for the target year (2005).
First Stage Project	:	The urgent plan to be prepared to mitigate severe flood damage in the specific area.

CHAPTER 5. STUDY AND ANALYSIS

5.1 Future Development of the Study Area

5.1.1 Urbanization Plan

Runoff discharge is dependent on the development conditions in the urban drainage area, so that strict reference was made to the detailed data regarding the future urban development in the whole study area to obtain an accurate estimate on future runoff discharge.

Population growth and land use patterns in the future are main factors for projecting the future urban development. In Asuncion City and its neighboring area, these factors were predicted by two studies, the Urban Transport Study in Asuncion Metropolitan Area and the Asuncion Sewerage and Sewage Treatment Master Plan (refer to 2.10, Related Development Projects). The two studies differ in their target year and study area according to their study objectives. The target year and study area of the former are 2000 and 71,000 ha, respectively, while those of the latter are 2010 and 27,800 ha.

In this study, the findings of the Urban Transport Study regarding population prediction and future land use have been adopted in view of the following reasons:

- The Urban Transport study area includes almost all of the area of the storm drainage project.

- The Urban Transport Study had already finished its study on the future land use plan sufficiently.

5.1.2 Population and Land Use

Population

In the Urban Transport Study, the metropolitan area including the City of Asuncion and the ten surrounding municipalities has been divided into 40 zones. Future population in the year 2000 has been predicted zonewise on the basis of the past population growth trend considering the accommodation capacity of unused lands that may be fully utilized in the future. The population in 2000 was thus estimated at 1,452,000 in the Metropolitan Area and 635,000 in the city of Asuncion.

The population in 2005, the target year of the present study, is calculated by extending the zonewise trend of population growth from 1992 to 2000, and the total amount of the 40 zones' population in 2005 will be 1,647,000 in the Metropolitan Area and 678,000 in Asuncion City. (Refer to Fig. 5-1.)

On the other hand, the study area of this study which comprises the Metropolitan Area is divided from the geographical point of view into 31 basins, which are further divided into 65 subbasins. The population in 1984 and in 2005 in each basin were calculated by distributing the population in the aforesaid 40 zones in 1984 and in 2005 among the 65 subbasins in proportion to their respective areas.

Land Use

The skeleton of Asuncion City is composed of six trunk roads radiating outwards in a fan-like shape from the central area, and the lateral circumferential roads link these trunk roads together. The trunk roads link the central area of Asuncion City to the surrounding cities of Lambare, Fernando de la Mora, San Lorenzo, Luque and Mariano R. Alonso. Along these roads are commercial, residential and industrial areas. (Refer to Fig. 5-2.)

Future land use in the year 2000 was predicted under the Urban Transport Study as follows: Residential areas of medium density which now accounts for approximately one-half of the total residential area in Asuncion City will cover most of the area by the year 2000, and will also expand toward the neighboring cities of Lambare and Fernando de la Mora. Residential areas of low density, now surrounding the commercial cores of the neighboring cities of San Lorenzo, Nemby, Luque and Mariano R. Alonso are gradually expanding toward the outskirts or farmlands. Large parks, military facilities, airports and other public facilities are concentrated in the region midway between Asuncion and Luque, and major facilities such as the Asuncion National University and the National Agricultural and Livestock Experimental Research Station are scheduled to be constructed in the zone west of San Lorenzo.

Based on the future conditions of the urbanized area mentioned above, the land use patterns have been broken down into eight different categories: commercial, residential (high, medium and low density), industrial, public facilities (schools, hospitals, military and other government agencies), parks (green areas and sports facilities), farmland, unused land and roads.

The land use area in each basin in 1984 and 2000 has been estimated from the land use map by the Urban Transport Study. The estimation of the land use area in the year 2005 has been made by extending the trend of each categorized land use area from 1984 to 2000. Table 5-1 shows the areas of the future basinwise land use for each of these categories.

5.1.3 Factors for Runoff Discharge

Runoff coefficient, which is the main factor for the estimation of runoff discharge, is subject to the building-to-land ratio in the area. It is difficult to clarify the building-to-land ratio in the whole study area due to insuffient data. Therefore, in this study, a representative area in each categorized area has been taken for sample study. Based on the study, the building-to-land ratio in each categorized area has been clarified as shown in Table 5-2.

5.2 Hydrological Study

5.2.1 Rainfall Analysis

Rainfall analysis in this study focussed on the provision of the probable rainfall intensity for short duration and the model hyetograph.

Probable Rainfall Intensity for Short Duration

The probable rainfall intensity for short duration is studied on the basis of the combined data of three stations in the study area judging from the condition of data available, to wit:

- Armada Station : 1929 to 1944
- Sajonia Station : 1965 to 1973
- San Lorenzo Station : 1972 to 1981

The probable rainfall which was obtained by applying Gumbel Method to the aforesaid rainfall data was calculated for 1.1, 2, 3, 5, and 10-year probabilities. The rainfall intensity-duration curve derived from the probable rainfall is shown in Fig. 5-3, together with the coefficient of the equation for the curve.

Model Hyetograph

A model hyetograph is needed for calculating a discharge hydrograph which is used for the study of the effect of a storm water control facility. The hyetograph is provided on the basis of the said rainfall intensity-duration curve.

The model hyetograph is shown in Fig. 5-4.

5.2.2 Runoff Analysis

Several studies on runoff analysis such as the selection of runoff calculation method, study of runoff coefficient, concentration time, etc., are preliminarily made herein for the calculation of probable discharge discussed hereinafter. Furthermore, studies are made on the regulation effects of one unit of detention facilities consisting of storage and infiltration facilities which are selected as the applicable method of storm water control.

Runoff Calculation Method

Since a peak runoff discharge together with the flood hydrograph needs to be provided for the study of the effect of detention facilities, the unit hydrograph method based on the rational formula, among several calculation methods, is used to convert the model hyetograph into the flood hydrograph.

In case detention facilities are provided, the said flood hydrograph which becomes the inflow discharge to the facilities is further regulated resulting in outflow discharge. The storage function method, which is reliable to assess the effect of the detention facilities, is applied to the calculation of the outflow discharge converted from the inflow discharge.

Runoff Coefficient

As for the coefficient for land use factors such as roof, road, interspace, park, etc., the values commonly used were applied to this study.

According to the study results concerning land use pattern, the study area is basically composed of the following land categories; namely, commercial area, high density residential area, medium density residential area, low density residential area, park, public facility, industrial area, farmland, and unused land. Thereupon, the runoff coefficient for land use categories of commercial area and the three types of residential areas were estimated on the basis of the factorwise proportion prevailing in several sample areas.

The average runoff coefficient of the basin was calculated by summing up the runoff coefficients of all the subbasins according to their 8-typed land use pattern. The equation used for this purpose is as follows:

$$f = \frac{(A_1 \times f_1) + (A_2 \times f_2) + (A_3 \times f_3) + \ldots(A_8 \times f_8)}{A}$$

where,

f : Runoff Coefficient of the basin

A : Area of the basin

$A_1 \ldots A_8$: Area of each land use category in the basin

$f_1 \ldots f_8$: Runoff Coefficient of each land use category

The study area has been rapidly developing; thus, land use pattern has changed. Under this situation, study on land use pattern were made for three cases: Past (1965), Present (1984), and Future (2005). In accordance with this study, runoff coefficients were also calculated for the same cases, as shown in Table 5-3 and Fig. 5-5.

Concentration Time

Since concentration time is subject to change in rainfall intensity, the following equation is applied to estimate the concentration time.

$$Tc = c \times A^{0.22} \times r_e^{-0.35}$$

where,

Tc : Concentration time (min)

A : Catchment area of basin (km^2)

r_e : Average effective rainfall during concentration time (mm/hr)

c : Coefficient

In the above equation, coefficient "c" is decided considering the development condition of the target area as shown in Table 5-4.

Effect of Storage Facilities

Among several types of storage facilities, two types are proposed as applicable; namely, storage in public compounds and storage in house lots. In this study, the effect of one unit of each type was investigated and the results on the effect of storage facilities are described as follows:

(1) Effect of Storage in Public Compounds

The effect of one unit of storage in a public compound is known by the difference in peak discharge between the inflow and the outflow hydrographs of storm water.

Eventually, the maximum inflow discharge of 1.0 m^3/s can be regulated to the maximum outflow discharge of 0.13 m^3/s by using the full capacity of the storage facilities regardless of the probability. From the above, the regulation effect of one unit of the facility is regarded as 0.87 m^3/s.

(2) Effect of Storage in House Lots

Considering that a private house has the roof of 100 m^2 in area on an average, it is assumed that one unit of storage facilities in a house lot, which is designed to regulate the storm water from the roof, can collect the storm water for the area. For this inflow discharge, the effect of storage facilities with storage capacity fully utilized is expected as shown in Table 5-5.

In this table, the regulated discharge of 0.0012 m^3/s by the storage capacity of 1.0 m^3 which is found from the difference between inflow discharge of 0.0038 m^3/s and outflow discharge of 0.0026 m^3/s correspond to 43 mm/hr in a form of rainfall depth for the area of 100 m^2.

Effect of Infiltration Facilities

Prior to this study, field investigations were performed to know the infiltation capacity of the study area. Based on the results, the effect of one unit of infiltration facilities for the runoff discharge was studied under the following conditions:

- The trench-type of infiltration facilities is employed in this study.

- Trench will be provided only for residential areas to collect storm water from rooftops, since storm water from areas such as roads, gardens, parking areas, etc., may remarkably deteriorate the function of infiltration facilities due to trash flowing with the water.

- Trench lengths of 10 m and 20 m to be provided to each house are employed and the height of 0.6 m and width of 0.6 m are adapted to the trench size, considering the previously executed systems in other countries.

The effect of 10 m long infiltration trench for storm water falling on a 100-m^2 roof of one private house corresponds to the regulation of the discharge of 0.76 ltr/s which coincides with 27 mm/h in a form of rainfall depth for the area of 100 m^2. Similarly, a 20-m long trench has the regulation effect of 1.52 ltr/s (54 mm/h). (Refer to Table 5-5.)

5.2.3 Probable Discharge

Probable discharge is calculated on the basis of the rainfall and runoff analyses described in the foregoing section. As to the probability of calculation, 1.1, 2, 3, 5 and 10-year return periods were applied in relation to the project scale to be employed for the study on detention facilities.

<u>Discharge Without Detention Facilities</u>

Probable discharge was calculated in the following cases:

Case 1: Discharge under past river basin condition in 1965.

Case 2: Discharge under present river basin condition as of 1984.

Case 3: Discharge in the future river basin condition as of 2005 without drainage facilities.

Case 4: Discharge in the future river basin condition as of 2005 with drainage facilities.

Table 5-6 shows the calculation results.

Discharge With Detention Facilities

The probable discharge in case of providing detention facilities was calculated on the basis of the future river basin condition in the year 2005, but in two conditions: with and without drainage facilities.

As for the condition of extent to provide the facilities, the following cases are applied. Tables 5-7 and 5-8 show the calculation results of these cases.

Case	Type of Facilities	Condition of Extent to Provide Facilities
Case 1	Without Facilities	-
Case 2	Storage in Public Compounds	The area of 2.5% of each basin
Case 3	-do-	The area of 5.0% of each basin
Case 4	Storage in House Lots	1.0 m^3 of water tank capacity for each house lot
Case 5	-do-	2.0 m^3 of water tank capacity for each house lot
Case 6	Infiltration Trench	10 m long for each house
Case 7	-do-	20 m long for each house

The calculations show that more than 10% of the peak discharge without the detention facilities can be regulated by providing detention facility.

5.3 Incremental Discharge and Flood Damage

Incremental Discharge and Assets

The population increment, as mentioned in 5.1.2, will expand the residential area resulting in the reduction of the permeable area expressed by the variation of runoff coefficient as mentioned in 5.2.3. The considerable increment of runoff coefficient can be seen in several areas such as Mburicao, Itay and Lambare (refer to Fig. 5-6). Runoff discharge augmentation due to land development is brought about under this condition and flooded area will naturally increase in case no countermeasure is taken.

The population increment will also promote the accumulation of assets through the conversion of unused land into residential area. Thus, flood damage will augment by the synergistic effect of assets and runoff discharge increments.

Fig. 5-7 shows the incremental runoff discharge and assets in the habitually inundated areas in the future in the upper reaches of Artigas Avenue in Mburicao river basin as an example.

Based on the progress of development, the incremental storm water runoff discharge in each basin fluctuated by approximately 20% to 50% from 1965 to 1984 with an estimated additional 30% to 50% increase from 1984 to 2005. Assets in the flooded area are also presumed to increase by approximately 50% from 1984 to 2005, though the increment values vary widely in each basin.

Incremental Flood Damage

The amount of flood damage coming up within the inundable area which was known by counting tangible damages to houses, household effects and traffic was appraised in terms of annual damage. The results show that flood damage in the each basin will increase two to five times in 2005 as much as that at present.

Fig. 5-8 shows the possible increase of the total flood damage amount in the area where the map of 1:5,000 scale is available.

5.4 Identification of Storm Water Control Facilities

5.4.1 Outline of Control Facilities

For the storm water control system in urbanized areas, two systems are generally applied, i.e., the drainage system and the detention facilities.

Drainage System

The concept of the drainage system is to discharge storm water safely and quickly from the objective area. The drainage system can be categorized into two; one is the river channel and the other is the drainage facilities.

Detention Facilities

The concept of the detention facilities is to reduce discharge into rivers by controlling the runoff of storm water and thus reduce the discharge load of the rivers.

5.4.2 Drainage System

River Channel

To cope with storm water discharge through the river channels in the urbanized area, four (4) measures are generally employed, as follows:

(1) Improvement works of river channel
(2) Construction of floodway
(3) Provision of retarding basin
(4) Installation of pumping station (Mechanical drainage)

River channel improvement works are the basic measures applicable to all rivers within the planning area. The floodway is to divert all or a part of flood to another river or into the sea through a newly constructed channel. The retarding basin can reduce the peak load of floods at the downstream by temporarily retaining a part of flood at the middle reaches of the concerned river, and if the retarding basin method is employed, a required area of land has to be acquired at a suitable location in the middle reaches of the river. The above three (3) measures are applicable to this study from the topographic viewpoint.

As regards mechanical drainage, pumping stations are not required to be planned in this study since all areas have sufficient slopes and suitable topographic conditions for the gravity discharge methods.

Drainage Facilities

The drainage facilities are those designed to discharge storm water from the drainage area to the rivers, and comprises underground conduits (pipe and culvert) and open channel. The applicability of these two types of facilities is subject to the land use patterns in the area concerned. (Open channels are generally advantageous in terms of construction cost if an enough open space is available.)

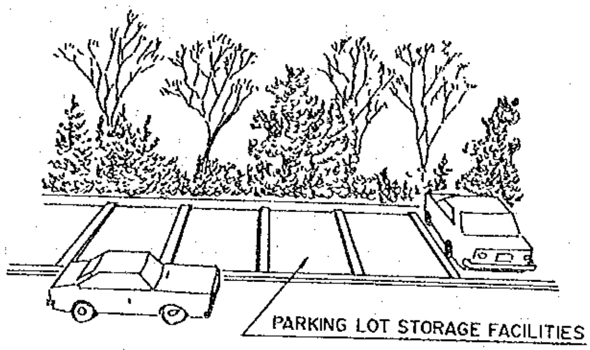
5.4.3 Detention Facilities

Detention facilities can be grouped into either storage facilities or infiltration facilities according to their functions. The former is to reduce runoff discharge to the downstream by retaining storm water at the upstream area, and it comprises the parking lot storage, the between houses storage, the storage in parks, and the storage in house lots.

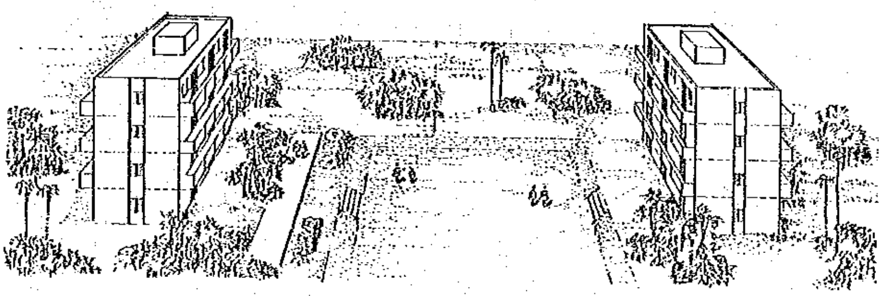
The latter is to reduce runoff itself by infiltration into the ground, and comprises the infiltration trench (including infiltration inlet) and the infiltration well facilities. Table 5-9 shows the features of the detention facilities.

Facilities mentioned in the said table are fully capable of fulfilling their functions satisfactorily, and can be used in the study area. Among them, the parking lot storage facilities, the between-houses storage facilities and the infiltration well facilities will not be employed in this study for the following reasons:

(1) Parking lot storage facilities are less efficient and less economical due to their smaller effective depth when compared with other storage facilities.



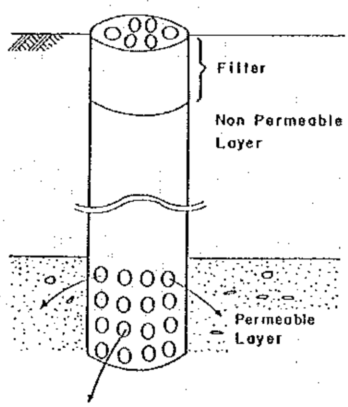
(2) Between-house storage facilities may not be practical to consider at present since there is no large-scale housing compound in the planning area and furthermore, the future possibility is still obscure.



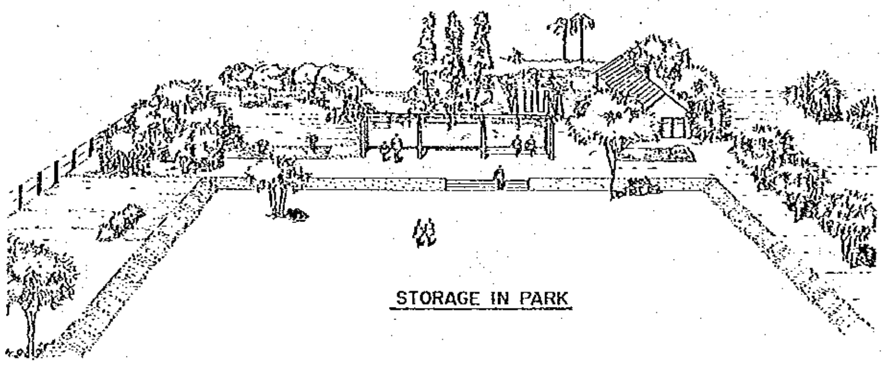
BETWEEN HOUSE STORAGE

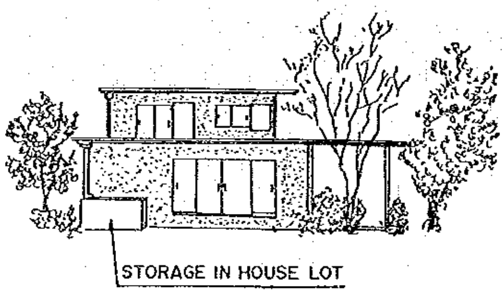
(3) For infiltration wells, geological data covering the planning area are insufficient for evaluation of the effect of these facilities.

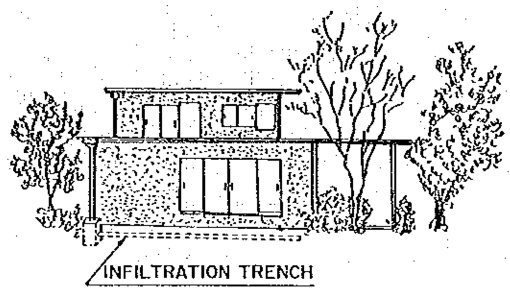
INFILTRATION WELL



Accordingly, this study will include storage facilities comprising the storage facilities in public facility compounds, storage facilities in parks, and storage facilities in house lots. Infiltraion facilities comprising the infiltration trench facilities are also applicable in this study. As for the storage facilities in parks and the storage facilities in public facility compounds, they are almost equivalent in their functions and structures, so that hereafter they will be treated as storage facilities in public compound.







The storage facilities in house lots require the inhabitants' cooperation in their maintenance and operation. These facilities are usually employed with the enaction of proper laws and/or regulations requiring for the participation of inhabitants.

CHAPTER 6. FORMULATION OF THE BASIC PLAN

6.1 Concepts and Premises

With the progress of urbanization, storm water discharge and valuable assets will steadily increase, so that it is imperative to protect the increased assets and properties by the construction of flood control works. When construction is completed, it is common that development and utilization of even the riverine areas that have been habitually submerged will progress because inundation is reduced. Under such utilized condition of these areas, in case an upgrade storm water control works is required again, it may be impossible to execute the works due to the difficulty of house evacuation and land acquisition.

In consideration of the above-mentioned situation, therefore, the formulation of the Basic Plan for the proposed storm water control facilities showing their basic concepts should be worked out on a long-term point of view, taking the importance in Paraguay of Asuncion City and its neighboring area into account.

For the smoother realization of the proper storm water control works of the Basic Plan in the future, it is important to conduct the works to be readily executed or the ones that can be executed at present such as acquisition of land along the river channel or the restraint of the utilization of land in areas regarded as flood danger zones.

In view of the above, the Basic Plan was formulated under the premises and terms prescribed as follows:

(1) The Basic Plan will be formulated on the basis of the urbanized conditions which are presumably arrived at in the year 2005. Land use pattern on which the storm water drainage system will be framed shall correspond to that presumed in 2005, and runoff discharge in each basin shall be what has been estimated as arising from the land use practices in 2005.

(2) Storm water control facilities to be proposed in the plan shall be an appropriate combination of the storm water drain-

age system and the detention facilities.

(3) The above-said facilities shall cover all the urban areas in the planning area.

(4) Possibility for the acquisition of right-of-way necessary for the project will be studied based on the existing land use condition of the planning area.

6.2 Definition of Planning Area

The planning area is defined as the area to be provided with the storm water drainage system as selected from the study area in consideration of the future city development and expected flood damage. The study area for the formulation of the basic plan is defined in the scope of works as the area which covers Asuncion City and its neighboring area. In this context, such area or areas coming under the categories mentioned in the premises below may be classified as planning area.

(1) Since it is presumed that the areas that have been habitually suffering from flood damage would be in critical condition if urbanization is pushed forward without properly arranging for flood control, such area or areas presently suffering from flood damage should be given priority in the installation of storm water control facilities.

(2) In general, urbanization almost inevitably accompanies and complicates storm water drainage problems. Therefore, the locality that may be vulnerable to flood hazards caused by rapid urbanization should be included in the planning area.

The results of the study on flooding conditions and urbanization trends in the study area have been carefully assessed and evaluated by the above premises in determining the planning area, as shown in Table 6-1 and in Fig. 6-1.

6.3 Project Scale

The project scale is set on a 10-year probability in view of the following considerations.

Social Consideration

The storm water control project now under study has a precedence in terms of what was implemented through the financial support of the Inter-American Development Bank (IDB) on the 710 ha of the central part of Asuncion City. The IDB-supported project was implemented in two stages in different scales, i.e., 10-year return period for a part of the said area which was undertaken in the first stage, and 5-year return period for the remaining area and 3-year return period for the other problematic spots in the second stage.

Taking into account the higher degree of land utilization and living standard of the residents in the future, it is proposed to apply the highest value of the scale of the project supported by IDB.

Financial Consideration

The financial capabilities of the principal execution agencies may have some constraints even in the case of execution of works with the project scale of 3 or 5-year probability. Therefore, the execution of works in the too big scales may likely be regarded as unrealistic even if the Basic Plan is put into execution for the future.

Technical Consideration

Generally speaking, a bigger scale is usually employed in planning a flood control project on a large river. However, for the rivers covered by this project, it is not necessary to apply a too big scale on the ground that all the rivers in the planning area have small basins that are almost equivalent to their drainage channels.

6.4 Alternative Study

6.4.1 Study Cases

In case acquisition of right-of-way for the construction works are available, storm water control works have been generally performed through improvement by the combination of river channel and drainage facilities in view of lower costs and safety considerations.

As repeatedly mentioned before, it might be difficult in such urbanized areas as Asuncion City, Fernando de la Mora, etc., to acquire land for the drainage system improvement including river improvement works because a large number of houses has to be considered for evacuation. Therefore, as its countermeasure, detention facilities are proposed for regulating the storm water.

There are several types of detention facilities and they can be divided in two groups from the viewpoint of maintenance and administration, i.e., one that is controlled by government authorities and one that is controlled by government authorities but with civilian cooperation. Detention facilities of each group have their own respective advantages in the provision of construction cost, etc., as well as management.

Taking the above viewpoints into consideration, three cases shown below are taken up for consideration as alternatives.

Study Case	Flood Control Facilities To Be Planned	Administration Method
Case I	River and Drainage Facilities	Government Authorities
Case II	River, Drainage and Detention Facilities	- do -
Case III	- do -	Government Authorities in cooperation with citizens

With regard to Study Cases II and III in the foregoing table, the regulation ratio which is shared by the improvement of river channel/ drainage facilities and installation of the detention facilities is studied for the optimum combination of the control facilities.

6.4.2 Findings of Alternatives

Cost estimation was made for the river channel improvement works, drainage facilities and/or detention facilities to be provided for the respective river basins in order to identify the combination with the least cost. Land acquisition and house evacuation have also been studied to recognize the social problems possible to take place due to project implementation in the respective river basins. The findings of these studies are summarized in Tables 6-2 and 6-3.

6.5 Optimum Plan and Construction Cost

6.5.1 Principles of Planning

Design Discharge

The design discharge on each basin is presented in Table 6-4.

River Improvement

In general, planning of river improvement works involves alignment planning, longitudinal profile planning and cross sectional planning. However, only maps with the scale of 1:5,000 are available for this study and these maps do not even cover the entire planning area. Accordingly, it is difficult to work out the alignment planning. The longitudinal profile planning and the cross sectional planning are made in this study to prepare the Basic Plan.

(1) Longitudinal Profile Planning

In most cases, the longitudinal profile of a proposed river channel is, from the technical and economic viewpoints, planned based on the existing riverbed gradient. However, the existing longitudinal profile of most rivers in the planning area have steep slopes, and they cannot be maintained because of scouring when the existing riverbed gradients are employed for the planned longitudinal profile.

Therefore, the riverbed gradients are made gentle to keep the flow velocity within the allowable limits by providing groundsills with head in the river course to compensate for the difference in riverbed elevations between the existing and the planned profiles. As a matter of course, the existing riverbed gradients will be applied to the longitudinal plans whenever the flow velocity in the existing river channel remains within the specified limit.

(2) Cross Section Planning

Simple channel cross sections are applied for cross section planning from the technical and economic points of view. Furthermore, excavated river channels are employed in this study considering safety and easiness of drainage, except the portions where the excavated river channel is not practicable by the topographic conditions; namely, the portion of confluence with Paraguay River, etc., because most of the rivers in the planning area are in the urbanized area.

Moreover, in case that the river channels are constructed under the roads or if the routes of the river channels are scheduled to be used for roads in the future, box culvert will be employed for the closed conduit channels.

(3) Bank Protection

For the study on the Basic Plan, the principles mentioned below are applied to select the appropriate type of bank protection works for the river channel.

The excavated river channels can be classified into channels with revetment and channels without revetment. The former is applied to the rivers in the urbanized area where land acquisition for the improvement works is difficult, and the latter is applied to the rivers in areas where land acquisition is considered not difficult.

If land acquisition is too difficult in a highly urbanized area, river channel with revetments and inverts will be applied to the rivers in such area because it can allow more flow discharge than the channel with revetment only.

(4) Formula for Flow Capacity

The flow capacity of the river channels will be calculated by the following Manning's Formula:

$$Q = A \times v$$

$$v = 1/n \times I^{1/2} \times R^{2/3}$$

$$R = A/P$$

where,

Q : Discharge quantity (m^3/s)
v : Flow velocity (m/s)
n : Roughness coefficient
I : Gradient
R : Hydraulic mean depth (m)
A : Cross sectional area (m^2)
P : Wetted perimeter (m)

(5) Other Standards

For the planning of river improvement works, Table 6-5 gives the standards used such as allowable maximum flow velocity, roughness coefficient and free board for river channels.

Drainage Facilities

Planning of drainage facilities will be made in accordance with the following conditions:

(1) Objective Area for Planning

The objective area for planning drainage facilities is limited to the urban area, but farmlands and fields for military drills are excluded from the objective area.

(2) Calculation of Runoff Discharge for Drainage Facilities

The runoff discharge for the drainage facilities is calculated according to the following rational formula:

$$Q = (C \times I \times A) / 360$$

where,

Q : Peak discharge (m^3/s)

C : Runoff coefficient (see Table 6-6)

I : Average rainfall intensity within concentration time (mm/hr)

A : Drainage area (ha)

(3) Dimensional Calculation of Drainage Facilities

The Manning's Formula is applied to the calculation of flow capacity of drainage facilities as well as the river channel. The roughness coefficient for the Manning's Formula of n = 0.013 is applied for proposed concrete pipes or concrete box culverts.

The flow velocities are planned at the minimum of 0.8 m/s and at the maximum of 5.0 m/s.

In consideration of the availability of pipes in the local market, the minimum diameter of 500 mm is applied with 2,500 mm as the maximum. When drainage pipes bigger than 2,500 mm are required, box culverts are employed.

Detention Facilities

(1) Type of Detention Facilities

The applicable detention facilities in this study are as described in the foregoing, i.e., storage in public compounds, storage in house lots, and the infiltration trench. The combination of detention facilities is considered in the following two groups in view of their operation and management.

- Combination of the storage in public compounds and the infiltration trench maintained by government authorities concerned.

- Combination of the storage in public compounds and the storage in house lots maintained by government authorities in cooperation with the citizens.

The share of the combination of facilities in the capacity of detention is studied based on a premise that the rainfall on the roof of houses should be controlled by the storage in house lots or the infiltration trench, and the rainfall on the other impermeable area should be controlled by the storage in public compounds. The shares of the above-said two combinations of facilities are set at 50% to 50% based on the fact that the ratio between the total roof-top and impermeable areas in the residential area is approximately 1:1. (Refer to Table 6-7.)

(2) Calculation of Detention Effect

The effect of detention was calculated based on the following formula by using the runoff discharge obtained in 5.2, Hydrological Study, for both cases of whether or not the detention facilities are installed. (See Table 6-8.)

$$d = D/(Q_o - Q_1) = D/q$$

where,

d : Quantity of detention facilities required for regulation of 1.0 m^3/s of runoff discharge:

- Storage in public compounds ($ha/m^3/s$)
- Infiltration trench ($m/m^3/s$)
- Storage in house lots ($m^3/m^3/s$)

D : Quantity of detention facilities used for the said runoff calculation:

- Storage in public compounds (ha)
- Infiltration trench (m)
- Storage in house lots (m^3)

Q_0: Runoff discharge when detention facilities are not provided (m^3/s)

Q_1: Runoff discharge when detention facilities are provided (m^3/s)

q : Effect of detention facilities (m^3/s)

6.5.2 Proposed Storm Water Control System

<u>Selection of the Proposed System</u>

The plans for optimum storm water control facilities were determined through the following considerations:

(1) For basins where there is no problem in the acquisition of land required for the proposed widening of river channel, the study case that gives the lowest construction cost is selected as the preferable one.

(2) In case acquisition of a vast tract of land and evacuation of a substantial number of houses are required for the river channel improvement works, the scope of river improvement may have to be adjusted to the extent that no social problem against the project occurs. (Refer to Fig. 6-2.)

As a result, out of the design discharge, the discharge that cannot be confined in the proposed river channel will be regulated by the proposed detention facilities. (Study Case II and III)

(3) With regard to the comparison between Study Case II and Study Case III, an ample time before the execution of the project can be expected for the introduction of civilian cooperation in accordance with the enactment of new laws and regulations related to storm water control.

In this context, Study Case II and III were evaluated equally in terms of maintenance and operation of the facilities, so that the selection of the optimum was based on which one has the less construction cost. (Refer to Table 6-9.)

The optimum combination of storm water control facilities varies basin by basin. From the viewpoint of construction cost, storm water control by means of river channel and drainage facilities (Case I) is superior to other cases in every basin. However, land acquisition and house evacuation in nine (9) basins such as Ferreira, Mburicao, Itay and Lambare, as shown in Fig. 6-2, will come up to a considerable extent and may bring about social problems. Thus, it becomes necessary to apply the combination of river channel/ drainage improvement works and detention facilities (Case II and Case III) to these basins, but Case III costs less than Case II in all the basins concerned. In conclusion, storm water should be controlled by river channel and drainage facilities in some basins and in combination with detention facilities in others, as follows:

Optimum Combination	River Basins	Remarks
River Channel and Drainage Facilities (Case I)	Jardin Salamanca Bella Vista Tres Puentes Cue Villa Elisa Nemby San Lorenzo Tayazuape Zeballos Cue Paso Cai	
	Varadero Centro Tacumbu Villa Universitaria Mariscal Lopez Tablada Valle Apua	Only drainage facilities are provided because of no river channel
River Channel and Drainage Facilities in combination with Detention Facilities (Case III)	Jaen Zanja Moroti Ferreira Las Mercedes Mburicao Ycua Carrillo Santa Rosa Itay Lambare	

Features of the Proposed System

The Plan under Study Case I calls for the improvement of river channels and drainage facilities, and the entire discharge is confined in the proposed river channels through the proposed drainage facilities; while, the Plan under Study Case III calls for river channels, drainage facilities, and detention facilities, and the design discharge is controlled by the combination of these facilities.

The alloted shares of the design discharge to drainage systems and detention facilities of the Plan under Study Case III are as shown in the following table.

River Basin	Design Discharge (m3/s)		
	Entire Basin	River Channel	Detention Facilities
Jaen	70	62	8
Zanja Moroti	36	30	6
Ferreira	115	100	15
Las Mercedes	56	48	8
Mburicao	320	270	50
Ycua Carrillo	110	85	25
Santa Rosa	75	64	11
Itay	770	650	120
Lambare	590	470	120

In connection with the above table, the final allocation of shares of the design discharge to drainage systems and detention facilities was made upon the results of a further investigation on the possibility of the required land procurement.

The overall aspects of the Plan consist of river improvement of 96 km, drainage facilities installed on the area of 17,200 ha and storage in public compounds of 394 ha for storm water regulation, and storage of 172,000 m3 rainwater in house lots through the participation and cooperation of individual households.

The basinwise breakdown of the proposed facilities is shown in Table 6-10. The right-of-way required for the river improvement works is 1,056,000 m2, and the river widths are shown in Table 6-11 and in Fig. 6-3.

6.5.3 Standard Drawing of Typical Structures

The standard drawings of the facilities under the Plan are presented as follows:

(1) River Structures

The standard cross sections of the river channel, groundsill and retarding basin are shown in Figs. 6-4 and 6-5.

(2) Drainage Facilities

Drainage facilities consist of gutters, inlets, manholes, and drain pipes or box culverts, and their standard structural drawings are shown in Fig. 6-6.

(3) Runoff Detention Facilities

Runoff detention facilities under the proposed plan consist of storage in public compounds and storage in house lots. Their standard structural drawings are shown in Fig. 6-7.

6.5.4 Construction Cost

This project calls for construction materials such as cement, structural steel, steel bar, lumber, stone aggregates, concrete pipe, etc., and for construction equipment such as bulldozer, buckhoe, dump truck, mobile crane, etc. Almost all of the above materials and equipment are locally available, however, structural steel and construction equipment may have to be imported.

In the preparation of the required cost estimate, special consideration and evaluation were given to the information on availability and market prices of labor, materials, construction equipment, etc., obtained from local government offices and local contractors/suppliers. The cost estimate was based on the prices as of August 1986, the exchange rate of US$1.00 = 650 Guaranies = Y155, and on the contract price.

Project construction cost consists of direct cost involving materials, labor, and equipment; and indirect cost such as preparatory works, miscellaneous works, temporary works, taxes, profit, etc. The indirect cost is fixed at 30% of the direct cost. Moreover, compensation cost is considered in the project to take care of forced evacuation of houses, and procurement of the required construction lots. And cost of engineering service and physical contingencies are included in the construction cost.

The construction cost for the execution of the Optimum Plan is 229,000 million Guaranies, as shown in Table 6-12.

CHAPTER 7. FORMULATION OF THE MASTER PLAN

7.1 Concepts and Premises

The proposed Master Plan which is scheduled to be in effect on or before the year 2005 will be formulated within the framework of the Basic Plan. The concepts and premises for formulation of the plan will be prescribed as follows:

(1) The target year of the Master Plan for storm water control system shall be the year 2005. The Plan will be, therefore, formulated on the basis of the urbanized conditions which are presumably existing in 2005.

- Runoff discharge in each basin shall be what has been estimated as arising from the land use pattern in 2005.

- Land use pattern on which the storm water control system will be framed shall correspond to that presumed in 2005.

(2) Storm water control system to be proposed in the Plan shall be an appropriate combination of the storm water drainage facilities and the detention facilities, in the same manner as of the Basic Plan.

(3) The scale of the entire project will be decided technically, socially and financially to enable its implementation within the given period of time until the year 2005.

7.2 Planning Area

The planning area for the Master Plan covers the same area as the Basic Plan.

7.3 Scale of Storm Water Drainage Project

Infrastructure projects like storm water control system improvement works are different from those meant for tangible economic benefits such as irrigation, power generation, industrial plant, etc. What really matters in this kind of project is public welfare, i.e., how the project can adequately solve the flooding problems in the planning area. Accordingly, their scale and implementation feasibility should not be judged merely on the basis of economic indices such as Internal Rate of Return (IRR), but from all points including social and financial aspects.

Under these circumstances, and through deliberate consideration of the conditions mentioned hereinafter, it is proposed to decide the scale of the project as 3-year return period.

(1) Social Consideration

A storm water drainage project has been conducted by IDB for the specific area of 710 ha. The scale of the project is as described in Section 6.3 of the preceding chapter.

Since the present study is aimed at flood mitigation in most of the planning area as much as possible up to the year 2005 under a limited financial condition, the idea regarding the project scale which was adopted by the preceding study should be taken into account. Considering the developed urban condition, enhanced living standard, etc., as of the year 2005, it seems to be appropriate to assure the capacity of storm water control against at least the minimum scale of the preceding project.

(2) Financial Consideration

From the public nature of the project, it is desirable that it should be implemented as quickly and as widely as possible. Needless to say, however, project implementation will also need to be considered from the financial point of view.

The financial standing of CORPOSANA has been endorsed, on the occasion of its undertaking the storm drainage system in the central part of Asuncion, through enactment of Law 902 which authorizes CORPOSANA to levy the residents of the Metropolitan Area surcharges at the rate of 0.1 to 0.3% of their real estate, to fulfill its loan repayment obligations with the IDB, as well as to create a reserve fund for new projects. By subtracting the total repayment to the IDB, the accumulated budgetary allowance from 1987 to 2005 for the implementation of the storm water control project for the whole planning area amounts to 25,600 million Guaranies which seems to be too small to cover its required construction cost. It is thus preferable to limit the project scale to the possible extent that can be financially feasible.

7.4 Alternative Study

7.4.1 Study Cases

To ensure the implementation of the project by the year 2005, the plan will have to be properly adjusted to meet the prevailing financial situations. In this connection, three (3) cases are taken up as alternatives in view of the improvement objectives; (1) overall restoration of drainage system, (2) improvement of the trouble spots, and (3) improvement along the trunk roads. These three cases are further divided into three divisions each according to the facilities to be applied, as shown in the following table.

Study Case	Improvement Objectives	Facilities To Be Applied	Administration Method	Remarks
Case I-1	Overall Restoration	A	Government Authorities	Complete provision of facilities along river channels and drainage ditches, including detention facilities. (Ref. to Fig. 7-1.)
Case I-2	-ditto-	B	-ditto-	
Case I-3	-ditto-	C	Government Authorities in cooperation with citizens.	
Case II-1	Trouble Spots Improvement	A	Government Authorities	Improvement works at trouble spots habitually affected by flood damage and/or places presumed to be suffered from flood damage through future urbanization. (Ref. Fig. 7-2.)
Case II-2	-ditto-	B	-ditto-	
Case II-3	-ditto-	C	Government Authorities in cooperation with citizens.	
Case III-1	Improvement Along Trunk Roads	A	Government Authorities	Improvement works at damaged spots on the trunk roads such as Artigas, Espana, M.A.C. Lopez, Ayala, Fernando de la Mora and General Maximo Santos, and Madame Lynch. River improvement works may be provided as the case demands. (Ref. Fig. 7-2.)
Case III-2	-ditto-	B	-ditto-	
Case III-3	-ditto-	C	Government Authorities in cooperation with citizens.	

Note: 1. In facilities to be planned, "A" is a combination of river channel and drainage facilities, "B" is a combination of river channel and drainage facilities plus detention facilities (including infiltration trench), and "C" is a combination of river and drainage facilities plus detention facilities (including storage in house lots).

2. Cooperation of residents in controlling storm water will be necessary only in the case of installation of storage facilities in house lots.

3. As to Case III with detention facilities, the detention facilities are not effective for mitigation of flood damage on only the trunk roads because of their functions. Case III-2 and Case III-3 are studied only for reference.