JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

STATE OF RIO DE JANEIRO
THE FEDERATIVE REPUBLIC OF BRAZIL

THE STUDY ON RECUPERATION OF THE GUANABARA BAY ECOSYSTEM

VOLUME 1
SUMMARY

MARCH 1994

KOKUSAI KOGYO CO., LTD. TOKYO

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LIST OF REPORTS

The cost estimate was made based on US$ in January 1994

PREFACE

In response to a request from the Government of the Federative Republic of Brazil, the Government of Japan decided to conduct a Master Planning Study on Recuperation of the Guanabara Bay Ecosystem and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Brazil a study team headed by Dr. Akira Sugiyama, Kokusai Kogyo Co., Ltd., 6 times between March 1992 and January 1994.

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

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

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

March 1994

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

March 1994

Mr. Kensuke Yanagiya
President,
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

Dear Sir,

We are pleased to submit to you the final report on "THE STUDY ON RECUPERATION OF THE GUANABARA BAY ECOSYSTEM IN THE FEDERATIVE REPUBLIC OF BRAZIL". This report has been prepared by the Study Team in accordance with the contract signed on March 6 and October 2, 1992 and March 12 and November 1, 1993 between the Japan International Cooperation Agency and Kokusai Kogyo Co., Ltd..

The report contains the study results on the existing environmental conditions of Guanabara Bay and its basin and the Master Plan to improve the water quality and to restore the ecosystem of the bay.

The existing environmental conditions were graphically arranged on the "Environmental Information Map of Guanabara Bay and its Basin" attached to the report. The Master Plan presented in this report consists of the target year, the target water quality, the target reduction loads, effectiveness and cost of the applicable measures and the optimum combinations of measures to attain the target water quality by the target year.

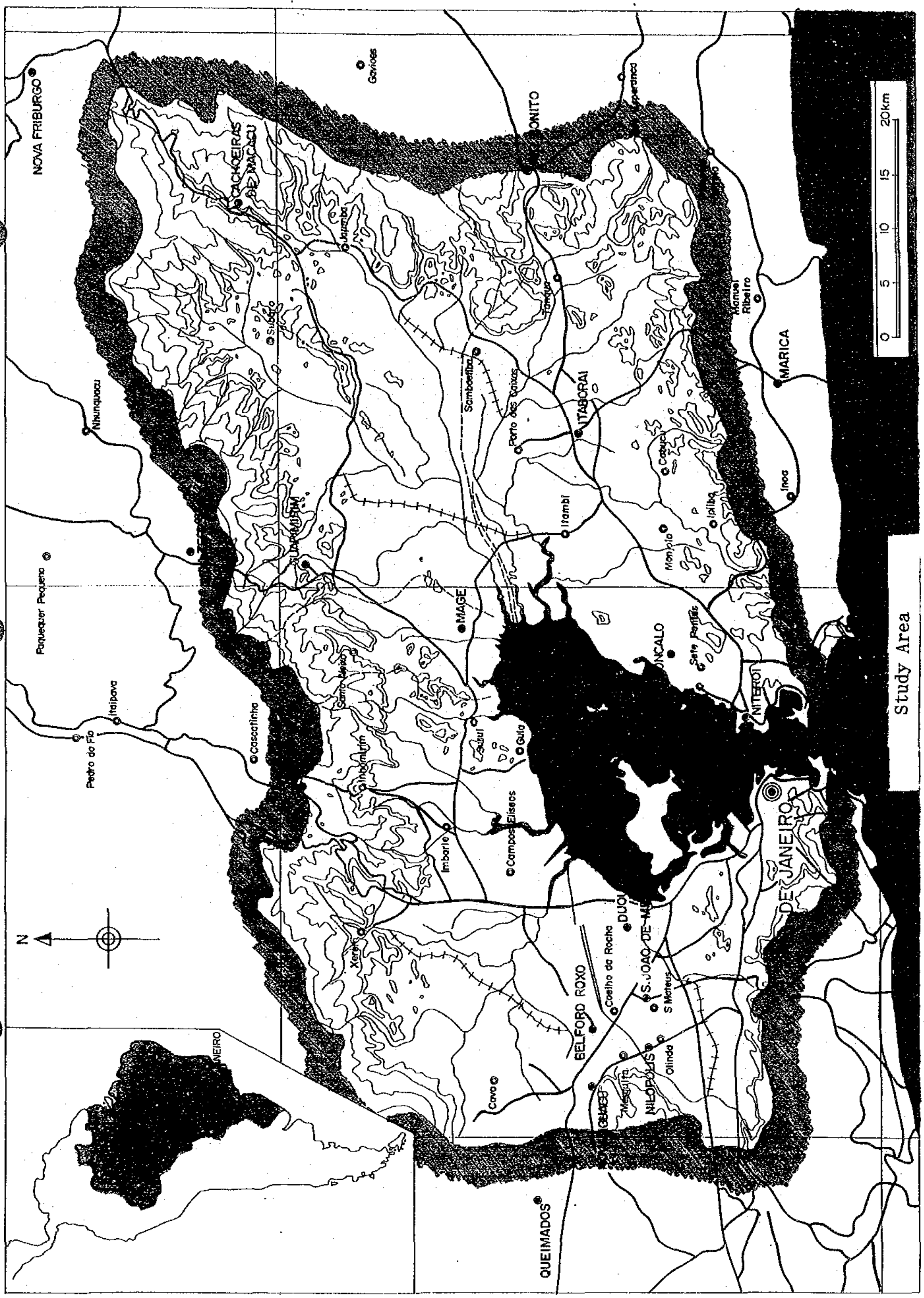
We hope that the implementation of the proposed Master Plan would greatly contribute to environmental improvement which is precious to the residents and the aquatic lives in the bay.

All members of the Study Team wish to express grateful acknowledgement to the personnel of your Agency, Advisory Committee, Ministry of Foreign Affairs, Environmental Agency, Ministry of Construction, Ministry of Transport, Municipality of Kobe, Overseas Economic Cooperation Fund, Embassy of Japan in Brazil and also to officials and individuals of Rio de Janeiro State and Federal Government of Brazil for the assistance they have extended to the Study Team.

Very truly yours,

杉山明

Akira Sugiyama
Team Leader,
The Study on Recuperation
of the Guanabara Bay Ecosystem


Study Area
NOVA FRIBURGO
Gavioes
CACHOEIRAS DE MACACU
Japuiba
Sambaetiba
Porto das Caixas
ITABORAI
MARICA
Manoel Ribeiro
Inoa
Itambi
Monjolo
MAGE
Nhunguaçu
Paquequer Pequeno
Itaipava
Pedro do Rio
Cascatinha
Santo Aleixo
Suruí
Guia
Inhomirim
Imbarie
Campos Eliseos
Xerem
BELFORD ROXO
Coelho da Rocha
S.JOAO DE ME
S.Mateus
Olinda
NILOPOLIS
Mesquita
Cava
QUEIMADOS
NITEROI
Sete Pontes
DE JANEIRO
N
0 5 10 15 20km

CONTENTS

< OUTLINE OF THE MASTER PLAN >

The outline of the Master Plan, the results of this study, are summarized as follows.

1. Area Covered under the Master Plan

The area covered under the Master Plan is Guanabara Bay (about 400 km^2 in area, of which about 50 km^2 is occupied by islands and islets), and its basin (about 4,000 km^2 in area). Twelve (12) administrative units (municipalities) are included in the study area (refer to Fig. 3-1 in the text).

2. Division of the Basin and the Water Area

For convenience, the area covered under the Master Plan was divided into five (5) basins, forty-four (44) sub-basins and nine (9) water areas. These basins, sub-basins and water areas are distinguished by the names and the numbers shown below (refer to Fig. 8-1 in the text).

Eastern basin	: Sub-basins No. 1 - 6
Northeastern basin	: Sub-basins No. 7 - 14
Northwestern basin	: Sub-basins No. 15 - 18
Western basin	: Sub-basins No. 19 - 24
Island basin	: Sub-basins No. 25 - 29
Water area	: A - I

3. Priority Areas for Countermeasures

The following eighteen (18) sub-basins and four (4) water areas were selected as priority areas where countermeasures are to be implemented for water quality improvement (refer to Fig. 16.3-1 in the text).

(1) Influential Sub-basins : twelve (12) Sub-basins which yield relatively large amounts of runoff load

(2) Potentially Critical Sub-basins : six (6) Sub-basins where the runoff load is likely to increase from now on due to population increase and to recent land use changes

(3) Important Beach and Water Areas : four (4) water areas where large social, economic and bio-resource benefits will be obtained if water quality is improved.

4. Target Years

The target years of the Master Plan are the year 2000 for the short term plan and 2010 for the medium term plan, but these are still provisionable, particularly for the long term plan.

5. Target Water Quality

The water areas in Guanabara Bay was classified into four (4) types, A to D, based on their use (refer to Table 16.5-1 and Fig. 16.5-1 in the text).

The target water quality for the long term plan was proposed on a level approximately equal to that prior to the mid 1960's. Target water quality levels for the short and mid term plans were presented for each water area type using eight (8) principal indices and five (5) supplementary indices (refer to Table 16.5-2 in the text).

6. Target Reduction Loads

About 40 % of the runoff load from the Northwestern, Western and Eastern basins should be reduced if we want to meet the water quality (BOD) in each water area with the target water quality for the mid-term plan. Accordingly, the load to be reduced in the future is the amount due to additional loads caused by the increasing population and industrial activities. Further, since the contribution rate of internal production occupies about 60 % of the BOD concentration in the Bay, reduction of nutrient salts is essential to improve the organic pollution.

7. Applicable Measures

The project for the construction of a sewer system and sewage treatment plants financed by IDB/OECF is one of the measures for the improvement of water quality in Guanabara Bay. This project commences in 1994 and the wastewater of about 2.8 million people is planned to be treated by six new primary treatment plants when Stage 1 (target year : 2000) is completed. Consequently, the measures for the priority areas were discussed on the assumption that only Stage 1 of the IDB/OECF Program is to be completed.

For the Influential Sub-basins; stabilization ponds for the basins where the necessary land is obtainable; wastewater treatment in favelas for the basins where large favela populations are found; and the ocean outfall system for the basins near the bay mouth were recommended as measures to treat the domestic wastewater in addition to the activated sludge method. Tightening the monitoring of factory discharge and the installation of joint treatment systems where similar type factories are centralized were recommended as measures to treat the industrial wastewater. In addition, preservation of forests, land use control, and improvement of garbage collection rates were recommended as measures for non-point sources. Retardation ponds, swirl separation tanks and the removal of deposited sludge were recommended as measures for river load reduction during freshets.

For the Important Beaches and Water Areas, dredging the polluted bottom sediments and widening the channels to improve the flow regime were recommended as the direct measures for the main water body.

8. Optimum Combinations of the Measures

We examined ways to attain the target water quality using combinations of the measures applicable to the study area, which enabled us to evaluate water quality improvement efficiency quantitatively. Then, the optimum combinations of measures for each basin were selected taking the effect of reducing nutrient salts and the cost for construction and maintenance into consideration (refer to Fig. 16.9-1 in the text).

(1) Eastern basin (Sub-basins No. 1 - 8)

Primary sewage treatment plant (Stage 1 in IDB/OECF Program) + Tertiary treatment

For this combination, the load exceeds the target by 5 - 10 tons/day the reduction of the industrial load (by tightning regulations, establishment of joint treatment systems for industries processing marine products and others). Further, extensive studies should be done prior to the implementation of the tertiary treatment systems as they require high-grade techniques to maintain.

(2) Northeastern basin (Sub-basins No. 7 - 14)

Stabilization pond (its scale is the same as the one to be constructed in the Sarapui area of the Northwestern basin)

Strict land use control is necessary because rapid development is likely in this basin.

(3) Northwestern basin (Sub-basins No. 15 - 18)

Primary sewage treatment plants (Stage 1 in the IDB/OECF Program) + Stabilization ponds (Iguacu area + Sarapui area).

In addition, strict land use control for the area where urbanization is in progress and the installation of the joint treatment systems for the petrochemical factories.

(4) Western basin (Sub-basins No. 19 - 24)

Primary sewage treatment plants (Stage 1 in IDB/OECF Program) + Ocean outfall system (Aregria area)

In addition, improvement of wastewater and solid waste collection in the favelas should be implemented to reduce the pollutants from non-point sources. Further it is necessary to exclude industrial wastewater containing heavy metals and toxic substances from the sewer collection system connecting with the ocean outfall system and to evaluate the environmental impact on the open sea and the coast before it is implemented.

(5) Island basin (Sub-basins No. 25 - 29)

Tertiary treatment (for Governador Island)

(6) Water areas (A - I)

Widening and deepening the channel off the west side of Governador and Fundao islands.

9. Problems remained to be solved

To implement the Master Plan, it is necessary to solve some problems, such as preparation of a comprehensive development plan for the basin to go with the Master Plan, establishment a committee for the utilization and control of water resources in the basin and so on. Further, feasibility studies should be carried out on measures requiring concrete plans and the development of techniques.

1. Introduction

1.1 Background of the Study

Guanabara Bay, which abuts Rio de Janeiro City (capital of Rio de Janeiro state in the Federal Republic of Brazil), is internationally renown for its scenery, calm waters, white sandy beaches, and verdurous mangrove forests. The area has also been diversely used for fishing, shipping, yachting, swimming, etc.

The recent significant increase in the population and industrial activity in the bay coastal areas has accelerated the contamination of the water in Guanabara Bay due to the inflow of domestic and industrial wastewater, and garbage. This has also diversely affected the use of the area, reduced the fish catch, and damaged the mangrove forests.

Viewing these conditions, the Federal Government of Brazil has realized the necessity of the crucial recuperation of the Bay and consequently requested the technical cooperation of the Japanese Government in July, 1991 for the formulation of a comprehensive water pollution control plan. Based on these conditions, the Study on the Recuperation of the Guanabara Bay ecosystem (hereinafter referred to as the "project") was commenced in March 1992 as a joint project of Japan and Brazil, and was completed in March 1994.

1.2 Objectives of the Study

This project aims (1) to understand the pollution mechanism and water pollution conditions in Guanabara Bay and its basin, and to formulate a comprehensive water pollution control plan for the recuperation of the Guanabara Bay ecosystem, and (2) to carry out technical transfer to the Brazilian counterparts during the study.

1.3 Study Area

The target area is Guanabara Bay and its basin. The bay measures approximately 400 km^2 (approximately 50 km^2 are islands and islets), and the basin measures approximately 4,000 km^2.

1.4 Scope of the Study

The following works are necessary to make the Master Plan for recuperation of the Guanabara bay ecosystem, the ultimate object of the study.

(1) Establishing the target years and the target water quality
(2) Selection of the priority areas for the countermeasures
(3) Calculation of the target reduction load (or target runoff load) for each basin
(4) Selection of applicable measures and their evaluation
(5) Cost estimation of the principal measures
(6) Estimation of socioeconomic benefits from the water quality improvement

Consequently, the following three major themes were set and the study was carried out along the procedures shown in Fig. 1-1.

(1) Understanding of the water pollution mechanism in Guanabara Bay
(2) Understanding of the socioeconomic conditions behind the water pollution
(3) Examination of the water quality improvement techniques

1.5 Organization for the Study

In the Japanese side, the study was coordinated by International Cooperation Agency (JICA) and was carried out by the Study Team consisted of twelve specialists belonging to Kokusai Kogyo Co., Ltd. under the suggestions from the Supervising Committee. The members of the Supervising Committee and th Study Team are shown in Tables 1-1 and 1-2.

In the Brazilian side, on the other hand, State Secretariat of Environment and Special Project (SEMAMPE) coordinated the study. The Implementation Planning committee and the Steering Committee headed by the deputy director of SEMAMPE and the Technical Committee headed by the President of State Foundation of Environmental Technology (FEEMA) were organized. The members of these committees are shown in Tables 1-3, 1-4 and 1-5.

1.6 Study Schedule

The study schedule was divided into three phases and the following works were carried out in each phase.

(1) Phase I : from March 1992 to September 1992
   1) Preparation works in Japan
   2) First field survey in the study area (Dry season)
   3) Analytical works on the results of the first field survey and the preparation of the Progress Report (1)

(2) Phase II : from October 1992 to February 1993
   1) Second field survey in the study area (Wet season)
   2) Analytical works on the results of the first and the second field surveys and the preparation of the Interim Report (1)

(3) Phase III : from March 1993 to March 1994
   1) Third filed survey (Supplementary survey) in the study area and preparation of the Progress Report (3)
   2) Analytical works on the results of the first, the second and the third field surveys and the preparation of the Progress Report (3)
   3) Making the draft of the Master Plan and preparation of the Interim Report (2)
   4) Preparation of the Final Report

1.7 Reports

The reports consist of five volumes ; Summary, Main Report, Supporting Reports 1 and 2 and Data Book. "Environmental Information Map on Guanabara Bay and its Basin (1/100,000 in scale)" and the explanation text are attached to the end of Summary and Main Report.

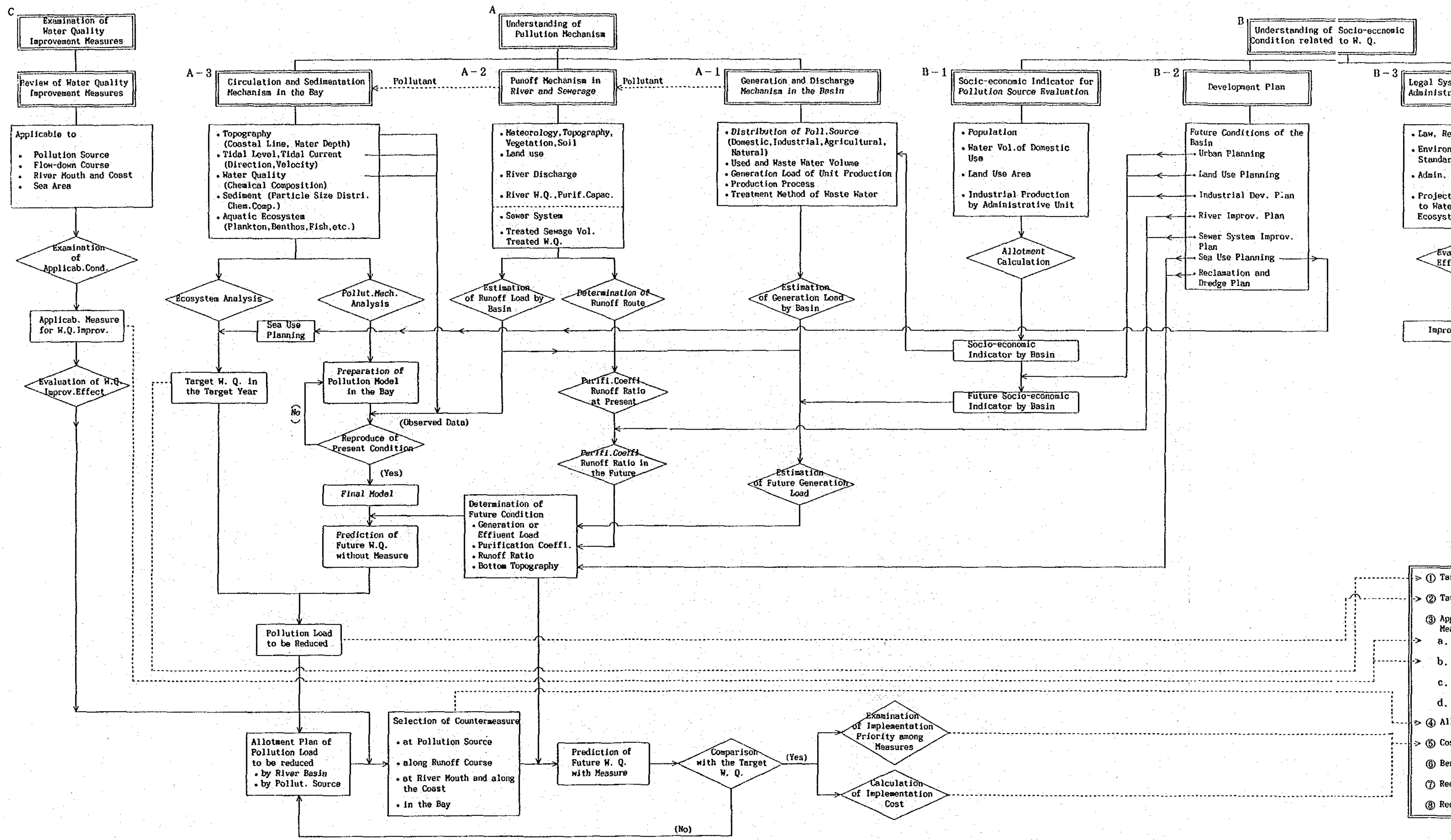
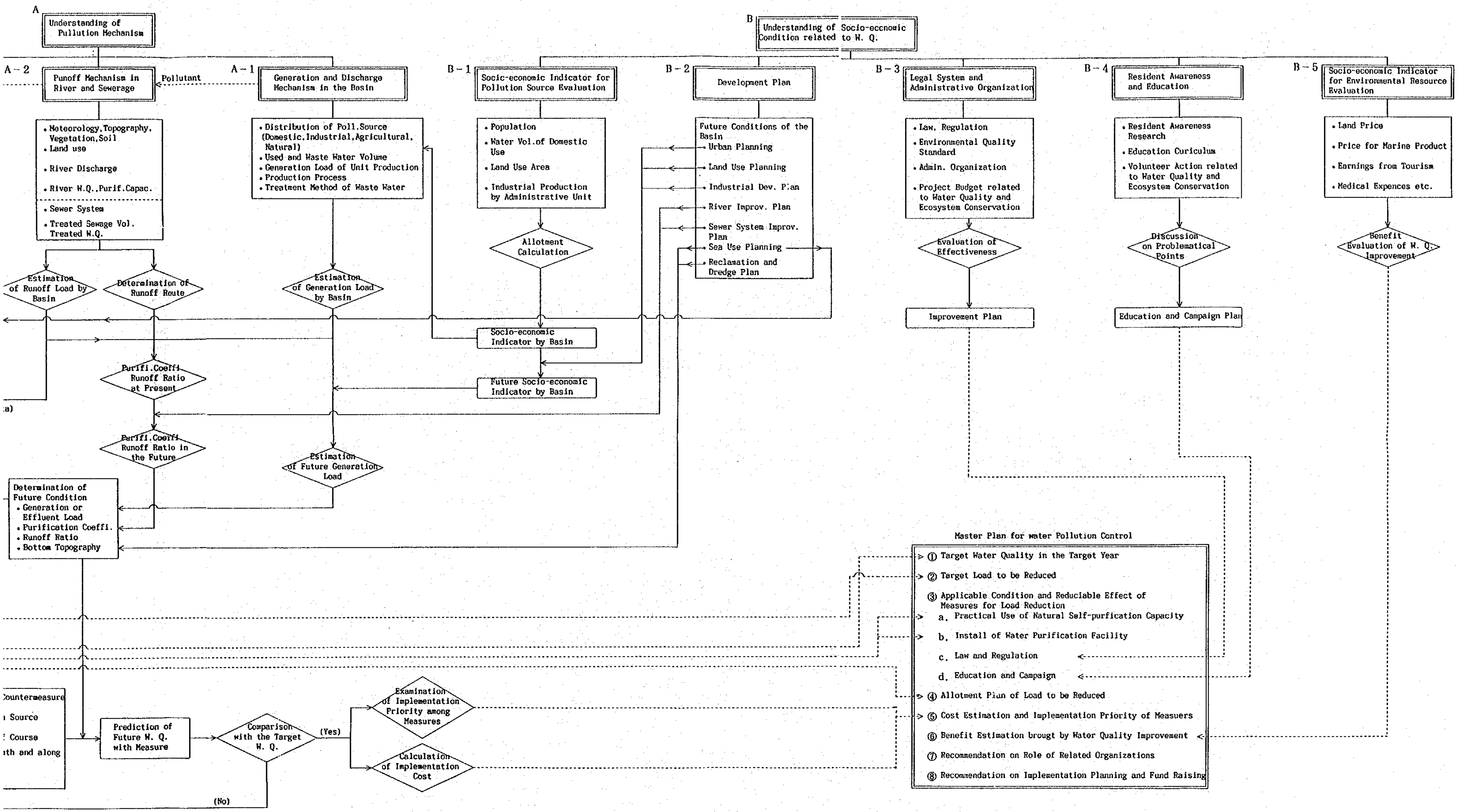


Fig. 1- 1　　Procedures of the Master Plan


A
Understanding of Pullution Mechanism
A－2
Punoff Mechanism in River and Sewerage
Pollutant
A－1
Generation and Discharge Mechanism in the Basin
• Meteorology,Topography, Vegetation,Soil
• Land use
• River Discharge
• River W.Q.,Purif.Capac.
• Sewer System
• Treated Sewage Vol. Treated W.Q.
• Distribution of Poll.Source (Domestic,Industrial,Agricultural, Natural)
• Used and Waste Water Volume
• Generation Load of Unit Production
• Production Process
• Treatment Method of Waste Water
Estimation of Runoff Load by Basin
Determination of Runoff Route
Estimation of Generation Load by Basin
Purifi.Coeffi. Runoff Ratio at Present
Purifi.Coeffi. Runoff Ratio in the Future
Estimation of Future Generation Load
Determination of Future Condition
• Generation or Effluent Load
• Purification Coeffi.
• Runoff Ratio
• Bottom Topography
B
Understanding of Socio-economic Condition related to W. Q.
B－1
Socio-economic Indicator for Pollution Source Evaluation
• Population
• Water Vol.of Domestic Use
• Land Use Area
• Industrial Production by Administrative Unit
Allotment Calculation
Socio-economic Indicator by Basin
Future Socio-economic Indicator by Basin
B－2
Development Plan
Future Conditions of the Basin
• Urban Planning
• Land Use Planning
• Industrial Dev. Plan
• River Improv. Plan
• Sewer System Improv. Plan
• Sea Use Planning
• Reclamation and Dredge Plan
B－3
Legal System and Administrative Organization
• Law, Regulation
• Environmental Quality Standard
• Admin. Organization
• Project Budget related to Water Quality and Ecosystem Conservation
Evaluation of Effectiveness
Improvement Plan
B－4
Resident Awareness and Education
• Resident Awareness Research
• Education Curiculum
• Volunteer Action related to Water Quality and Ecosystem Conservation
Discussion on Problematical Points
Education and Campaign Plan
B－5
Socio-economic Indicator for Environmental Resource Evaluation
• Land Price
• Price for Marine Product
• Earnings from Tourism
• Medical Expences etc.
Benefit Evaluation of W. Q. Improvement
Master Plan for water Pollution Control
① Target Water Quality in the Target Year
② Target Load to be Reduced
③ Applicable Condition and Reduciable Effect of Measures for Load Reduction
a. Practical Use of Natural Self-purfication Capacity
b. Install of Water Purification Facility
c. Law and Regulation
d. Education and Campaign
④ Allotment Plan of Load to be Reduced
⑤ Cost Estimation and Implementation Priority of Measuers
⑥ Benefit Estimation brougt by Water Quality Improvement
⑦ Recommendation on Role of Related Organizations
⑧ Recommendation on Implementation Planning and Fund Raising
Countermeasure
Source
Course
th and along
Prediction of Future W. Q. with Measure
Comparison with the Target W. Q.
(Yes)
(No)
Examination of Implementation Priority among Measures
Calculation of Implementation Cost

Master Plan

Table 1- 1　　List of the Supervising Committee Members

Name	Post / Institution
Senro Imai	Institute for International Cooperation, JICA
Kiyoshi Hasegawa	Public Works Research Institute Ministry of Construction
Toshio Okazumi	Kanto Regional Bureau Ministry of Construction
Yasushi Hosokawa	Port and Harbour Research Institute Ministry of Transportation
Michitaka Nakao	Environment Bureau Kobe Municipal Government
Tetsuo Hayakawa (until June,1993)	Water Quality Bureau, Environment Agency
Susumu Ohta (from July,1993)	Water Quality Bureau, Environment Agency

Table 1- 2　　List of the JICA Study Team Members

Name	Charge
Akira Sugiyama	Team Leader
Takeyasu Kikuta	Water Quality Conservation Plan
Fumio Yanata	Hydrology, Hidraulics and Meteorology
Akiko Mukade	Water and Sediment Quality Analysis (1)
Takehiko Nakane	Water and Sediment Quality Analysis (2)
Eiichi Hayakawa	Land Use
Hideo Kawai	Ecosystem
Masaru Obara	Regional Development and Socio-Economy
Constantino A. Pessoa	Water Pollution and Source Analysis
Masahiro Tajima	Pollution Runoff Mechanism
Kyoji Ishita	Pollution Mechanism in the Bay
Masaharu Kina	Coordinator

Table 1- 3 List of the Implementation Planning Committee Members

NAME	POST / INSTITUTION
Manuel Sanches (until Aptil, 1993)	President of GEDEG (Chairman),(SEMAMPE)
Roberto D'Avila (May to August, 1993)	President of GEDEG (Chairman),(SEMAMPE)
Geraldo Lessa (from September, 1993)	President of CODEG (Chairman),(SEMAMPE)
Rosangela Costa	Director of Administration (IEF)
Dora Negreiros	Special Assistant (FEEMA)
Amarilio P. de Souza	Sanitary Engineer (FEEMA)
Carolina Dubex	Sociologist (SECPLAN)
Helder G. Pinho da Costa	Engineer (FEEMA)
Leila Heizer Santos	Engineer (FEEMA)
Katia Leite Mansur	Geologist (DRM)
Marcia Marques Gomes	Biologist (UERJ)
Monica Cardoso Ferraz	Architect (SECPLAN)
Victor M. Barbosa Coelho	Engineer (FEEMA)
Mihai Constantin Cauli	Architect (SECPLAN)
Ronaldo F. de Oliveira	Biologist (FEEMA)

Table 1- 4 List of the Steering Committee Members

NAME	POST
(SEMAMPE/GEDEG/CODEG))	
Manuel Sanches (until April, 1993)	President of GEDEG (Chairman)
Roberto D'Avila (May to August, 1993)	President of GEDEG (Chairman)
Geraldo Lessa (from September, 1993)	President of CODEG (Chairman)
Helder G. Pinho da Costa	Advisor
Victor M. Barbosa Coelho	Engineer
Amarilio Pereira de Souza	Consulting Engineer
(FEEMA)	
Adir Ben Kauss	President
Eduardo R. Ferreira Neto	Director
Victoria Braile	President's Assistant
(SERLA)	
Carlos Carbonel	
(DEFESA CIVIL)	
Paulo G. dos Santos Filho	
(IEF)	
Axel Schimidt Grael	President
(CEDAE)	
Mauricio Abramant Guerbatin	President's Assistant
(GERSOL)	
Altamirando de Morais	
(COMLURB)	
Sergio Augusto da C. Lobato	President's Assistant
(INPH)	
Alberto Homsi	
(DHN)	
Ana Claudia de Paula	
(CAPITANIA dos Portos)	
Luiz Gonzaga da Silva	

Table 1- 5 List of the Technical Committee Members

Name	Charge
(FEEMA)	
Adir Ben Kauss	Chairman of Technical Sub-Committee
Rene Justen	Coordinator (until August, 1992)
Eduardo Rodrigues Ferreira Neto	Coordinator (from Sept., 1992)
Elizabeth Cristina da Rocha Lima	Water Quality Conservation Plan
Kikue Higashi	Water and Sediment Quality Analysis Ecosystem
Anselmo Frederico Neto	Hydrology and Hydraulics
Ilma Conde Perez	Pollution Source
Tania Muniz	Land Use and Socio-Economy
Maria Regina Fonseca	Pollution Mechanism
Marcio Henrique Krause de Almeida	Pollution Runoff Mechanism
Walter Yoshihiko Aibe	Hydrodynamic Model
Sergio Sahlit	Pollution Source
Elza Aparecida Baezzo Moreira	Laws and Regulations
(INPH)	
Berenice Mota Vargas	Hydrodynamic Model
Theo Agostinho Masson	Current Measurement
Paulo Cesar Maiorano	Current Measurement
Marcos Dourado	Current Measurement
Luis Carlos Pucci	Current Measurement
(COPPE/UFRJ)	
Renato Parkinson Martins	Hydrodynamic Model
Isabel Marcia Gonsalves do N. Gurguel	
Lucia Vercosa Carvalheira	
(IEF)	
Axel Schmidt Grael	Land Use
(SERLA)	
Weber Figueiredo da Silva	River Survey

2. Natural Conditions in the Basin

The northern margin of the basin is made up of mountains ranging from 1,000 - 2,000 m in elevation extending from east to west. Mountains on the southern margin, on the other hand, range from 500 - 1,000 m in elevation and extend roughly parallel to the Atlantic Ocean coast line.

From the basin, 45 large and small rivers flow into the bay. The rivers (Rio Guapimirim, Rio Cacerebu etc.) that flow into the inner bay area from the Northeastern basin have large catchment areas, and salt marshes with abundant mangroves can be seen downstream. In contrast, the rivers coming from the Western basin, that pass through Rio de Janeiro City before flowing into the bay, have small catchment areas and steep slopes which are frequently inundated.

The monthly mean temperature in Rio de Janeiro City is highest in February at 26.5 °C and lowest in July at 21.3 °C, the Guanabara bay basin is in the subtropical climatic zone. The annual mean precipitation is 1,177 mm in Rio de Janeiro City and more than 2,500 mm in the mountain areas.

According to the analysis of the LANDSAT image taken in 1991, urban areas cover approximately 20 % of the basin, 30 % of forest areas, and 40 % of grasslands (including farmlands) . When compared with the image taken in 1984; an 87 km^2 increase in urban areas and 95 km^2 decrease in forest areas took place in the past 7 year period (Fig. 2-1).

The urban areas on the western side of the bay mainly belong to Rio de Janeiro City and extend toward the Rio Iguacu and Rio Estrera basins. Those on the eastern side of the bay mainly belong to Niteroi City and extend toward Sao Goncalo and Itaborai. Forests are rarely found in areas lower than 200 m in elevation.

Rock outcrops exist in the upper mountain areas in the basin, while debris is distributed around the foot of the mountains, suggesting the occurrence of large-scale erosion and soil run-off. However, the LANDSAT image analysis and field reconnaissance survey results were not able to detect recent erosion.

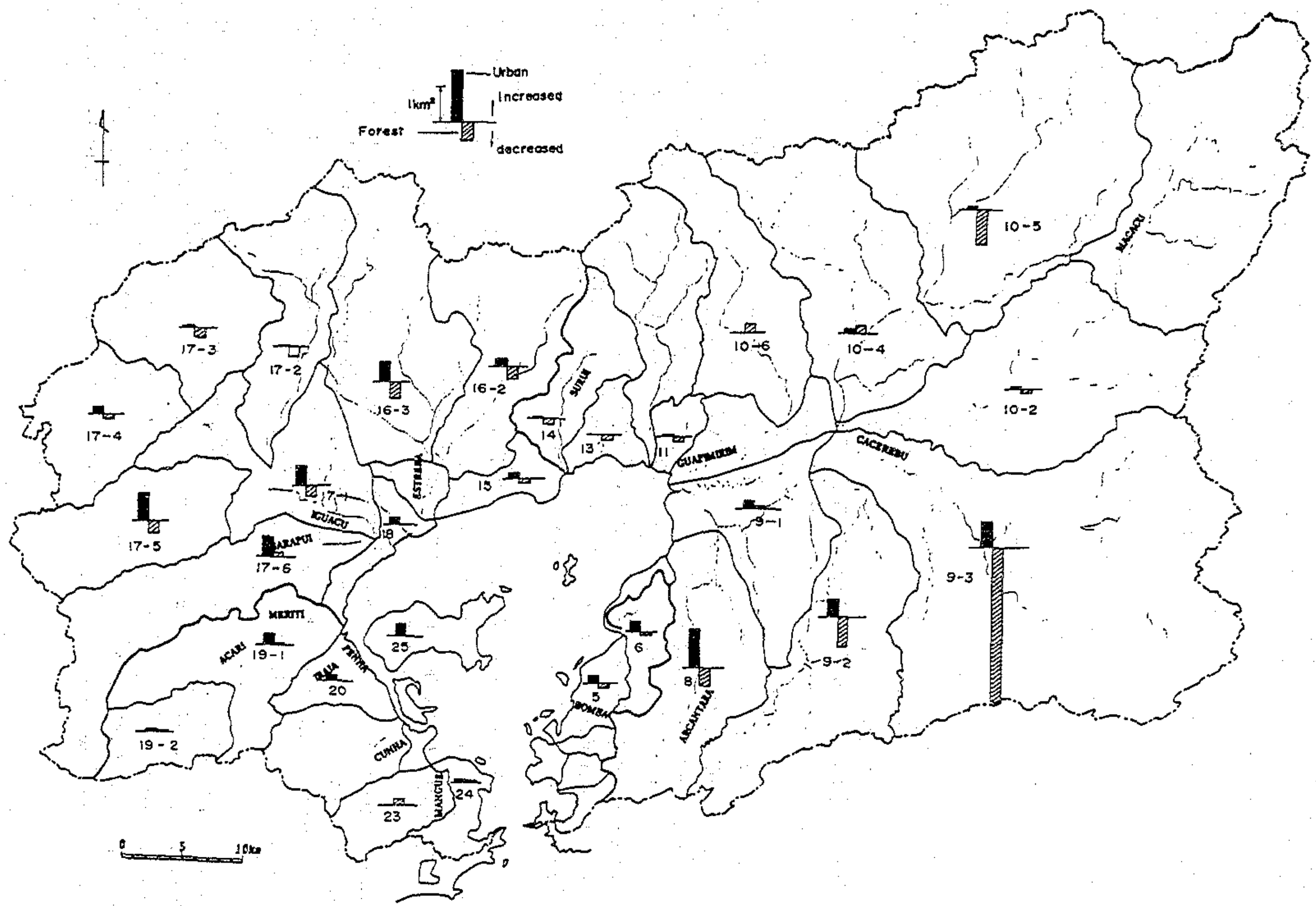


Fig. 2- 1 Area Change of Urban and Forest between 1984 and 1991

3. Socio-economic Conditions in the Basin

The basin covers 12 administrative units (municipalities), although only 7 are wholly within the basin area; the remaining 5 partly extend outside (Fig. 3-1).

Based on the 1991 Census (population of the municipalities are divided into urban and rural), the total basin population at 7,594,000, 80 % of which are concentrated in the western region (Rio de Janeiro, Sao Joan de Meriti, Nilopolis, Nova Iguacu) (Fig. 3-2).

The population density varies largely by area. The population density of 7 municipalities, including Rio de Janeiro and Niteroi, exceeds 3,000 p/km^2, while the 5 municipalities including Macacu has only less than 500 p/km^2. In contrast to the 1970's, the population growth rate in the 1980's has declined, except for the non-densely populated areas like Itaborai, Rio Bonito and Cachoeiras de Macacu where it continues to climb.

The favelas (densely populated urban residential areas composed of illegal occupants), the most serious single factor causing urban problems in Rio de Janeiro City, was estimated to have a population of approximately 800,000 in 1991, a 10 year increase of approximately 40 %. The actual population of the favelas is, however, believed to exceed this amount. The area of favelas also extend outside Rio de Janeiro.

There are only a few agricultural areas within the basin, and the cultivation of oranges, bananas and cassavas excludes the use of agricultural chemicals and fertilizers.

Guanabara bay used to produce large quantities of shrimps, crabs and other species. However, at present, the annual catch of about 5,000 fishermen only amounts to 6 tons/day of fish and 1 ton/day of shellfish.

There are abut 6,000 industries in the Guanabara Bay basin, 90 % of which are medium to small scale industries employing less than 49 employees. These industries are mainly involved in food, chemicals, metallurgy, and etc., and more than 90 % are concentrated in the western area centering around Rio de Janeiro City.

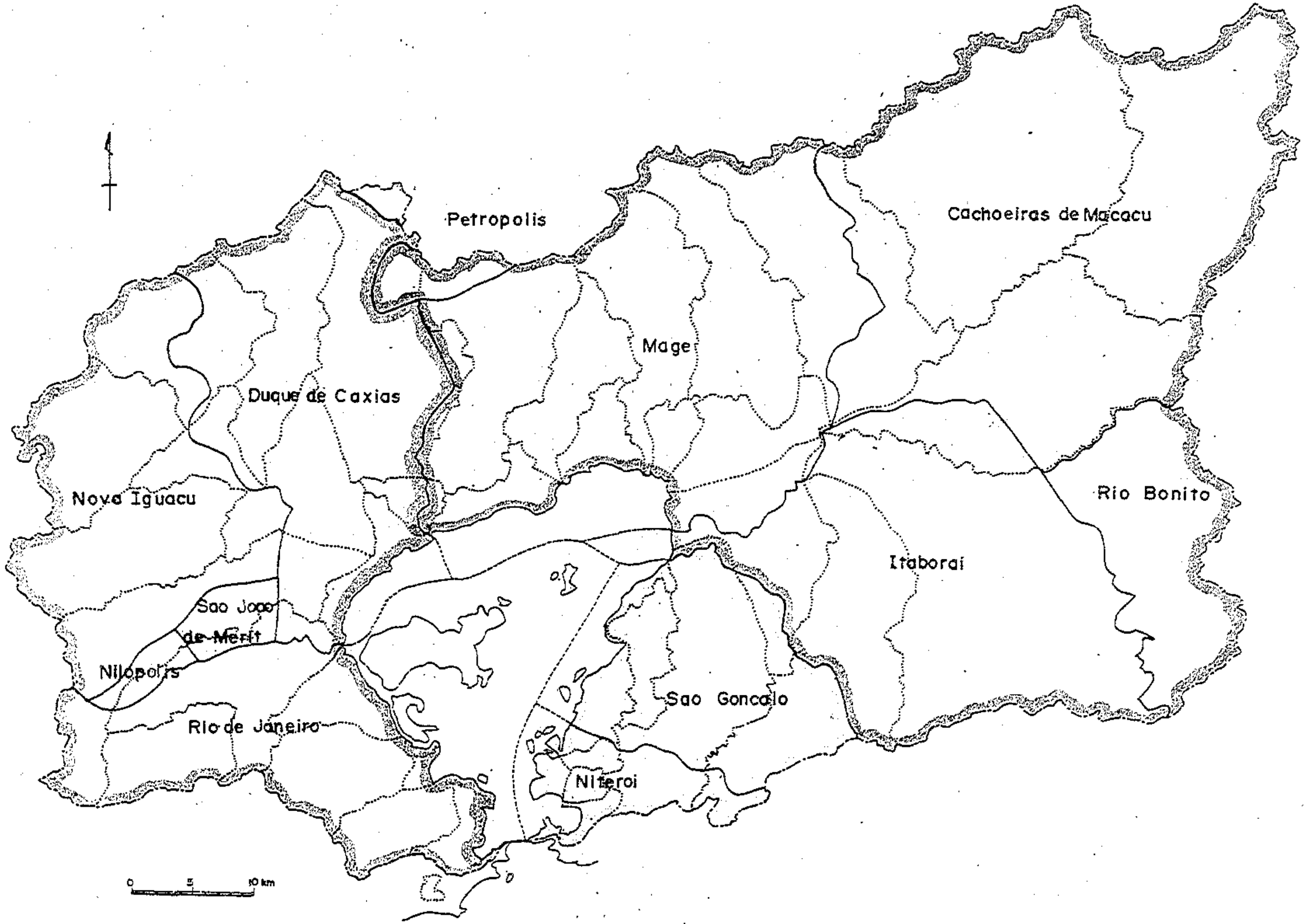


Fig. 3- 1 Administrative Units included in the Guanabara Bay Basin

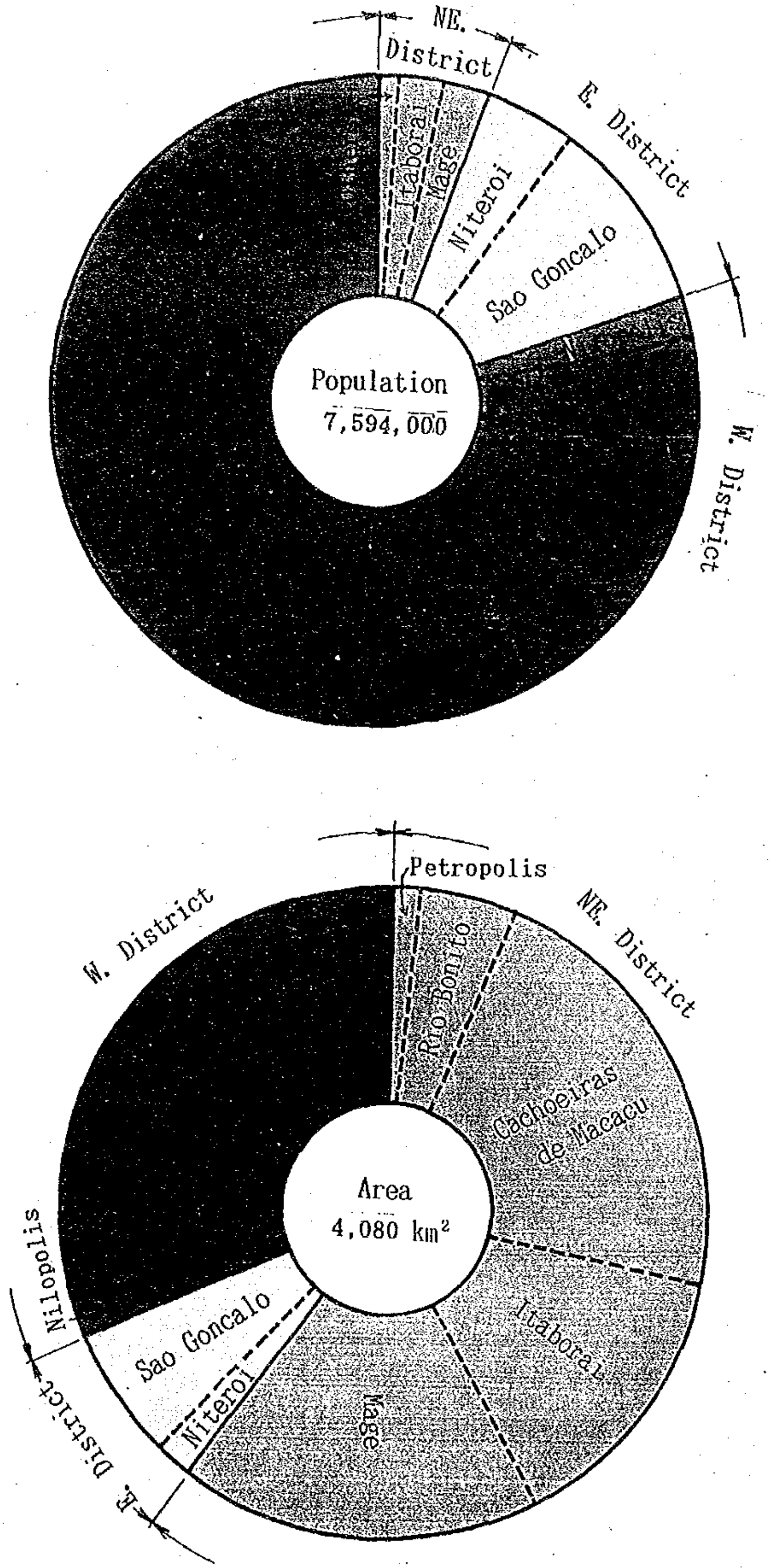


Fig. 3- 2 Ratio of Population and Area per Municipality

The 1991 Census states the crucial need for countermeasures in 8 municipalities, which excludes Rio de Janeiro, Niteroi and Nilopolis, observed to have very inefficient domestic sewage treatment facilities.

Approximately 1.5 % of the state administration budget is allocated to SEMAMPE (Environmental Bureau of the Rio de Janeiro State) and 0.5 % of the budget of Rio de Janeiro City is apportioned to the Environmental Bureau of Rio de Janeiro City.

4. Oceanographic Conditions

Guanabara bay covers an area of approximately 400 km^2, has an average depth of 5.7 m and a narrow mouth width of 1.6 km. The bottom topography of the bay is complex due to the existence of numerous islands and islets. However, deep furrows observed to extend from the bay mouth to the north-northeastward direction strongly controls the sea water exchange mechanism and water quality distribution, as will be mentioned later.

The bottom sediments in the inner bay are mainly fine grains of silt and colloids. Acoustic profiles show these to be more than 10 m thick in some areas. The sedimentation rate of the upper 20 to 50 cm in the inner bay area taken from the Pb^{210} concentration and the comparison of old and new charts is large at 2 - 3 cm/yr. Sands in the bay are mainly distributed in the deep furrows extending north-northeastward from the bay mouth.

The tidal range in the harbor of Rio de Janeiro (Fiscal Island) in the spring tide is largest at 1.46 m, averaging 1.25 m. However, the tidal range in the inner bay area (Paqueta Island) was 10 cm larger than at the bay mouth (Armacon).

The maximum velocity of the bay current was 150 cm/sec at the bay mouth area, 30 - 50 cm/sec in the central bay area, and 20 - 30 cm/sec in the inner bay area near Paqueta Island. The flow in the western channel of Governador Island was also observed to be high at 150 cm/sec, however this flow is influenced by the rivers.

Based on observations at the bay mouth, the ebb tide period of the upper layer is longer than that of the flood tide period, while both tidal periods are similar in the lower layer. More-over, although the maximum velocity in the ebb tide period of the upper layer is higher than that in the flood tide period, their velocity is almost the same at the lower layer. Accordingly, sea water exchange is thought to be more active at the lower layer than the upper layer.

Salinity in the bay is generally lower in the inner bay area. Low salinity was found even in the deep areas near the bay mouth in the rainy season when river flow increases. Further, the surface water temperature is generally higher in the dry season when river flow decreases, and it is higher in the ebb tide period than in the flood tide period. It was calculated that the water temperature and salinity in the bay are controlled by fresh water from rivers that diffuse on the surface and sea water from the bay mouth.

Discontinuous plane of seawater density (sigma-t) is formed at 1.5 to 3 m in depth in the inner bay area throughout the year. Such stratification of seawater becomes clear in the rainy season due to increase in river discharge; stratification is broken by strong winds though. The stratification of seawater is not found near the mouth of the bay (Fig. 4-1).

The dissolved oxygen (DO) concentration was often measured to be high in the inner bay area due to increase in phytoplankton production, while zero DO concentration was often observed at the bottom layer. Discontinuous plane of DO concentration was usually found at around 3 m in depth, a little above the discontinuous plane of seawater density (sigma-t).

5. Water and Sediment Pollution in the Bay

The water quality in the bay was observed to incessantly change with the tidal and meteorological conditions. The observed distributions of water quality parameters differed greatly. However, correlations with the results of river and tidal current observations show that pollution is significant in areas with bad water exchange conditions and near the mouth of rivers with large loads. Generally, the water quality in the bay is worse in the wet season than in the dry season and in the ebb tide period than in the flood tide period. The concentration of organic matter, nutrient salts and fecal coliform groups is lowest in the deeper zone, extending north-northeastward from the bay mouth, and high

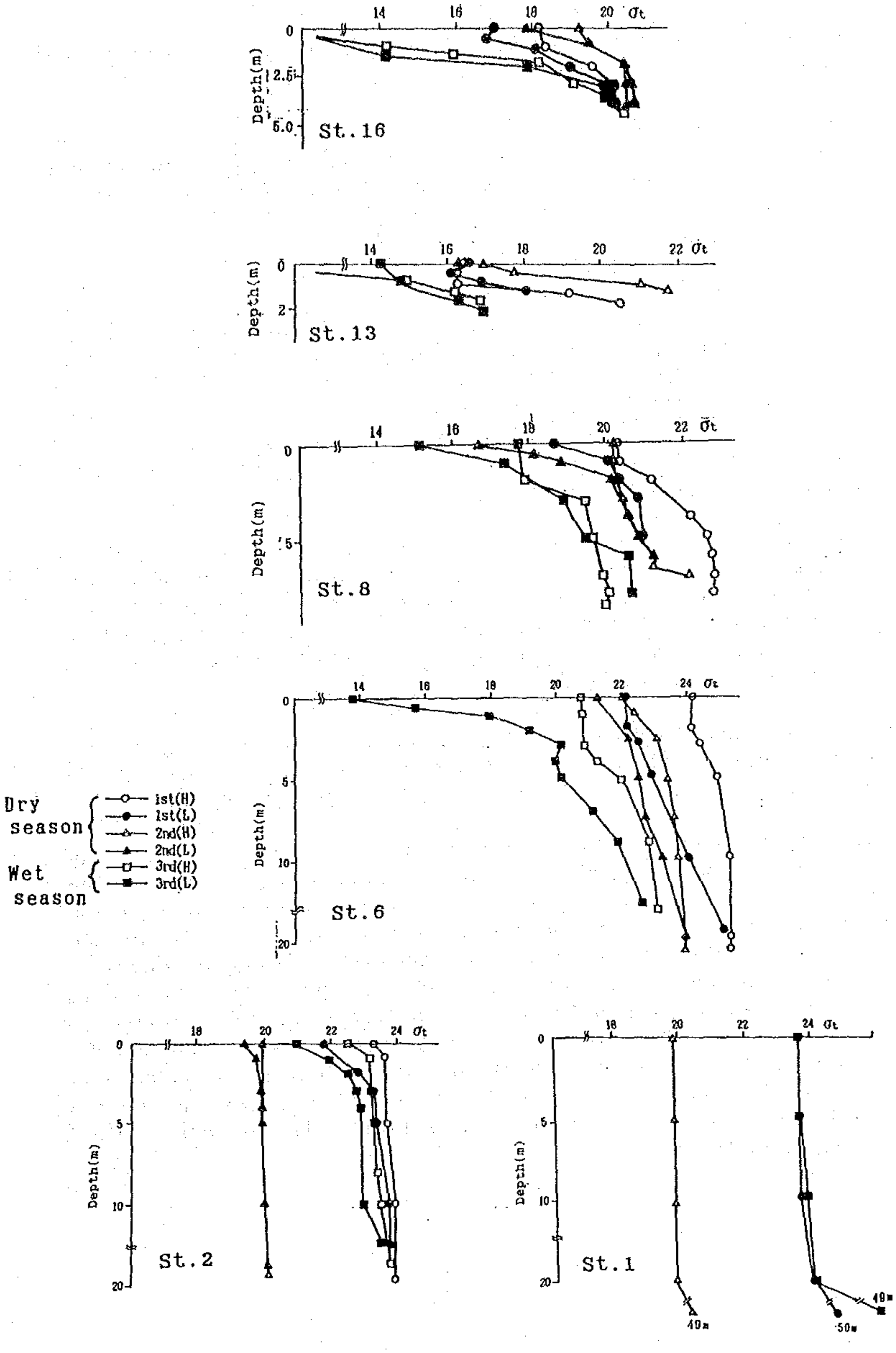


Fig. 4- 1 Vertical Distribution of Seawater Density (Sigma-t)

in the western inner bay area, in the channel off Governador-Funadao islands and Jurujuba bay.

The concentrations of heavy metals in the water were lower than water quality standards, except for Pb and T-Hg which showed values a little higher than the standard limit at a few stations. Toxic substances were less than the detectable limit or in very low concentrations.

The concentration of heavy metals in bottom surface sediments was relatively high in the western inner bay area and east of Fundao island, but was nevertheless lower than the standard value established in Japan. FEEMA reported that the concentration of Cr and Hg in surface sediments was high near the mouths of the Rio Sarapui and the Rio Meriti during the period of 1980 to 1986 but was lower from 1987 to 1989. Toxic substances such as PCB were not detected in the bay sediments.

Columnar samples of the sediments were collected from four points in the inner bay area and the pollutants found in them were analyzed. Various pollutants were observed to be highly concentrated in the superficial zone above 20 to 50 cm beneath the sea bed. The concentrations of heavy metals were relatively high in the western inner bay area.

The total release load of phosphorus (POP) from all sediments in the bay was estimated to be about one third of the inflowing load (T-P), using the release rate obtained from laboratory tests.

Nutrient (phosphorus) balance in the bay was analysed using the results of the water quality analysis and primary production, release rate, settling rate and oxygen consumption rate tests. Large amount of phytoplankton (POP) is produced in the bay due largely to insolation flux and the excessive supply of nutrient salts from the basin and the bottom sediments. The amount of phosphorus from phytoplankton production (POP) is about six times the amount of inflowing and released inorganic phosphorus (DIP)(Fig. 5-1). When the amount of phytoplankton is calculated in terms of COD(Mu), the produced COD(Mu) in the bay in the dry season is estimated to be about three times the present amount inflowing from the basin.

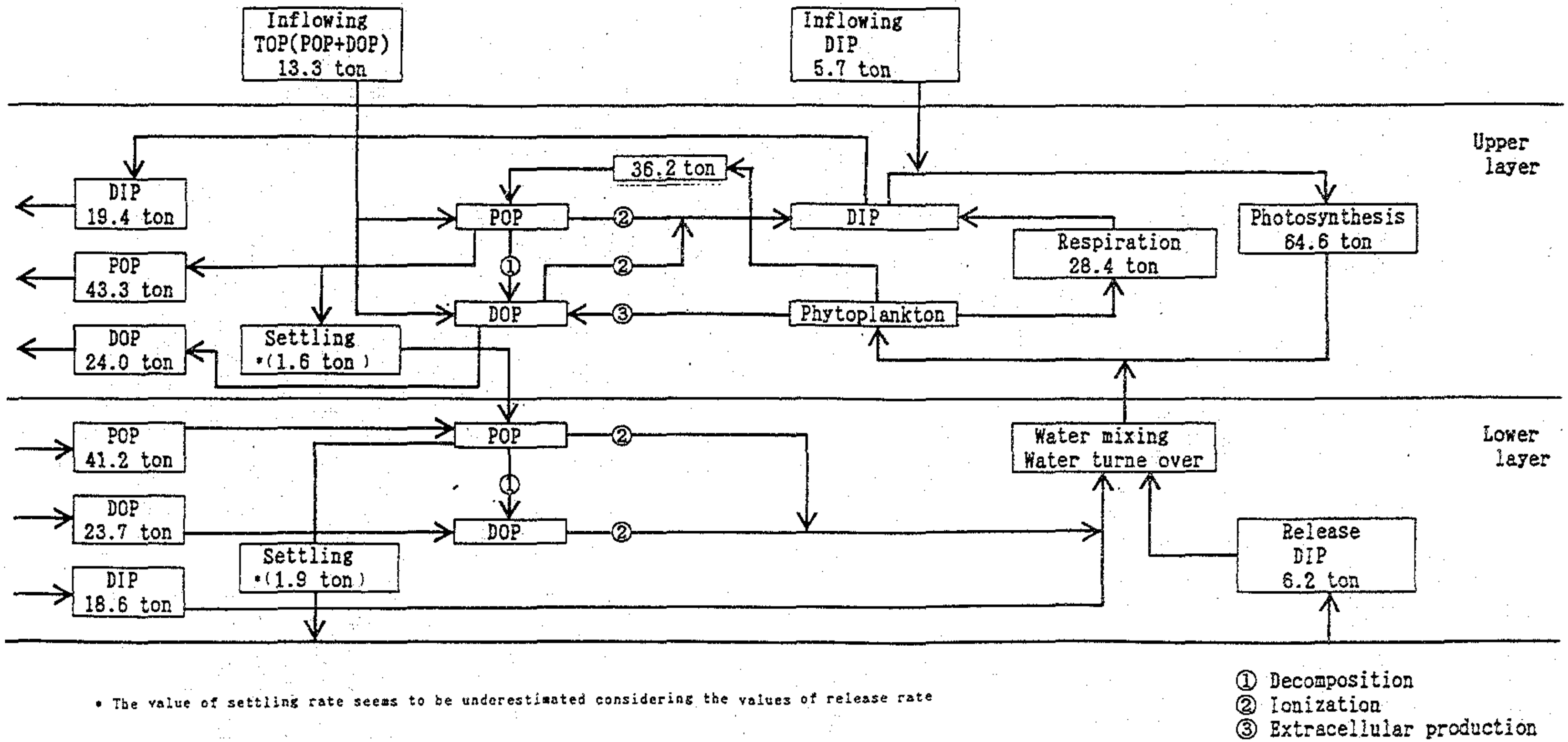


Fig. 5- 1 Phosphorus Cycle in Guanabara Bay (Wet Season)

6. Aquatic Organisms

The density of phytoplankton is high in the inner and the western side of the bay in both seasons. The predominant phytoplankton species is the diatom group and the cyanophyceae group. From the fact that the N/P ratio in the bay water is 6-15, while 5-7.5 for phytoplankton, the limiting factor in the primary production in Guanabara bay is thought to be phosphorus.

The density of the zooplankton lives (Copepoda group is predominant) is far lower than that of the phytoplankton, and a reverse correlation is found between the two. Conclusively, zooplanktons are not dependent on phytoplanktons and play a small role in internal production.

Benthos are scarcely or not virtually found in the inner bay where the bottom material is highly polluted and the DO concentration is low in the bottom layer. On the other hand, a large amount of gastropoda is found south of Governador island, though the bottom material is highly polluted and the DO concentration is low in the bottom layer. This is because the bottom material is made up of sand with silt and does not contain H_2S. Various kinds of benthos are found near the mouth of the bay.

Many kinds of fouling organisms were found in the bay, and mussels (Perna Perna), especially found in large numbers near the bay mouth are an important source of fishermen's income.

The maximum fish catch within the bay was estimated to be 6 tons/day, from the results obtained by IBAMA and the Study Team. Tainha, Parati, Sardinha, etc., enter the bay to mature, while Enchova, Linguado, Corvina, Pescadinhas, etc., go into the bay for reproduction. Guanabara Bay plays an important role in fish production.

Mangrove forests spread along the lower reaches of the Rio Guapimirim and Rio Cacerebu are well preserved, though human activities have affected the southeastern part of it. Unfortunately, however, the mangrove forests located between Rio Estrela to Rio Iguacu have deteriorated badly. The sediments in this area were found to contain high concentrations of Hg.

7. Historical Change in Environment and Current Use of the Bay

The development of the Guanabara Bay coastal area started from the middle of the 16th century. Judging from scientifc studies, water quality deterioration became evident in the 1960's and became particularly bad in the 1980's. However, the bay is still diversely utilized as a field for marine transportation, energy stock, fishing, sightseeing, recreation and living (Fig. 7-1).

The responses in questionnaires distributed to 1,700 ordinary residents, fishermen, members of environmental organizations and yacht clubs state that many people recognize the importance of the bay for the preservation of the ecosystem, and desire to improve bay water quality to facilitate full scale utilization of the bay.

Federal and state governments began to deal with the improvement of the bay's environment in the 1990's and several projects aimed at the restoration of the bay started with the financial support of international banking agencies.

8. Pollution Sources in the Basin and their Effluent Loads

The total domestic generation load calculated from the population and the unit load factor amount to 383 tons/day of BOD, a value almost coinciding with the total effluent load and attributed to poor maintenance of septic tanks. On the other hand, the total effluent load of 117 industries monitored by FEEMA amounts to about 80 tons/day of BOD. Consequently, the load discharged from industries is about 20 % of the domestic generation load in terms of BOD (Fig. 8-1), while it reaches nearly 80 % of the domestic generation load in terms of COD(Mn).

By area, generation load estimation by BOD shows that 48 % of the domestic load and 43 % of the total industrial load were supplied from the Western basin; 30 % of the former and 27 % of the latter are supplied from the Northwestern basin. The main constituents of the industrial load are from the food and chemical industries, of which the former is concentrated in the Eastern basin (mainly in Sub-basin No.5) and the latter in the Northwestern basin (mainly in Sub-basin No.17-1).

Current Use of Coast and Water Area of the Guanabara Bay
Uso Atual da Costeira e da Espelho da Água da Baia de Guanabara

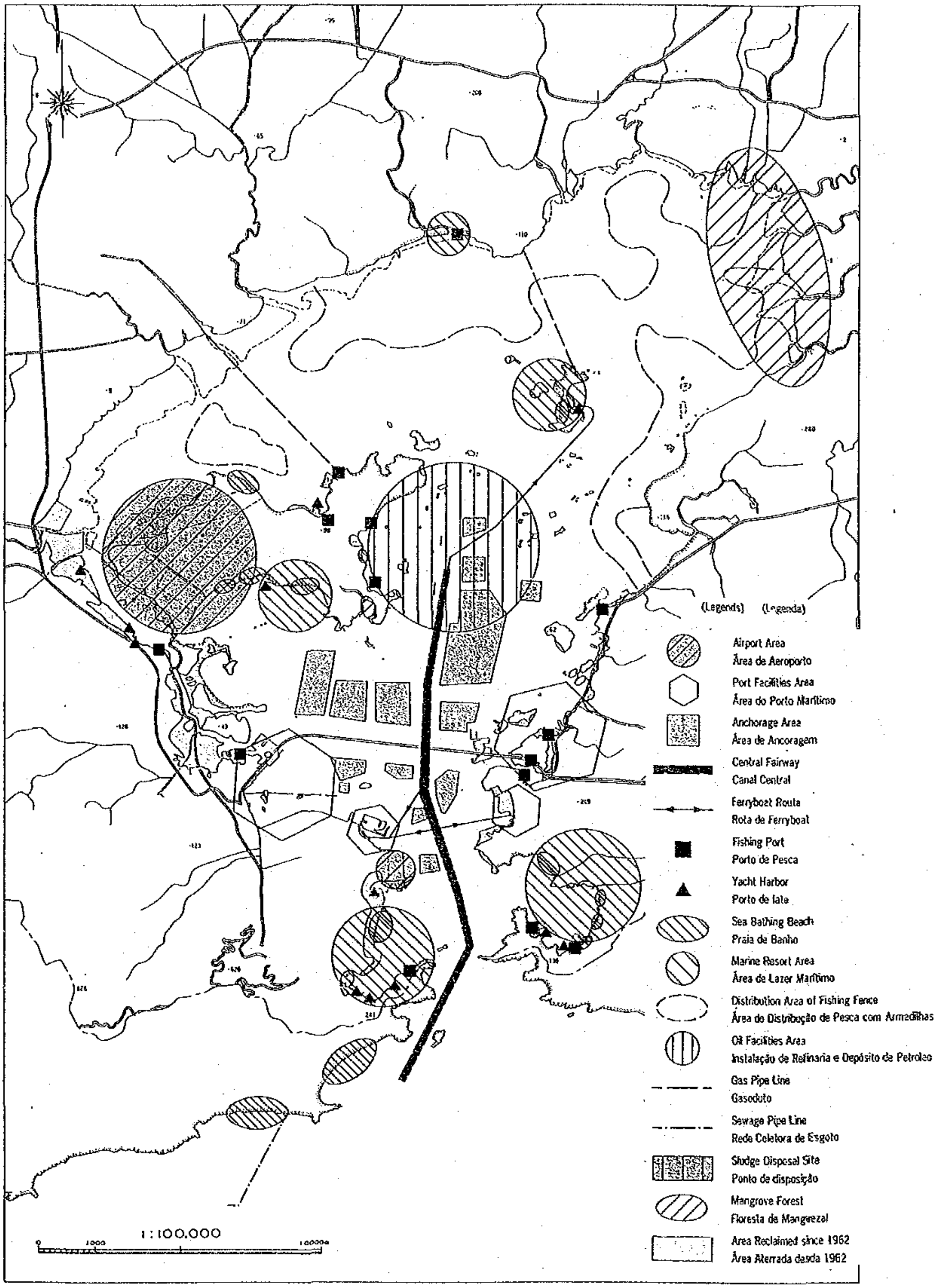


Fig. 7- 1 Utilization of Guanabara Bay

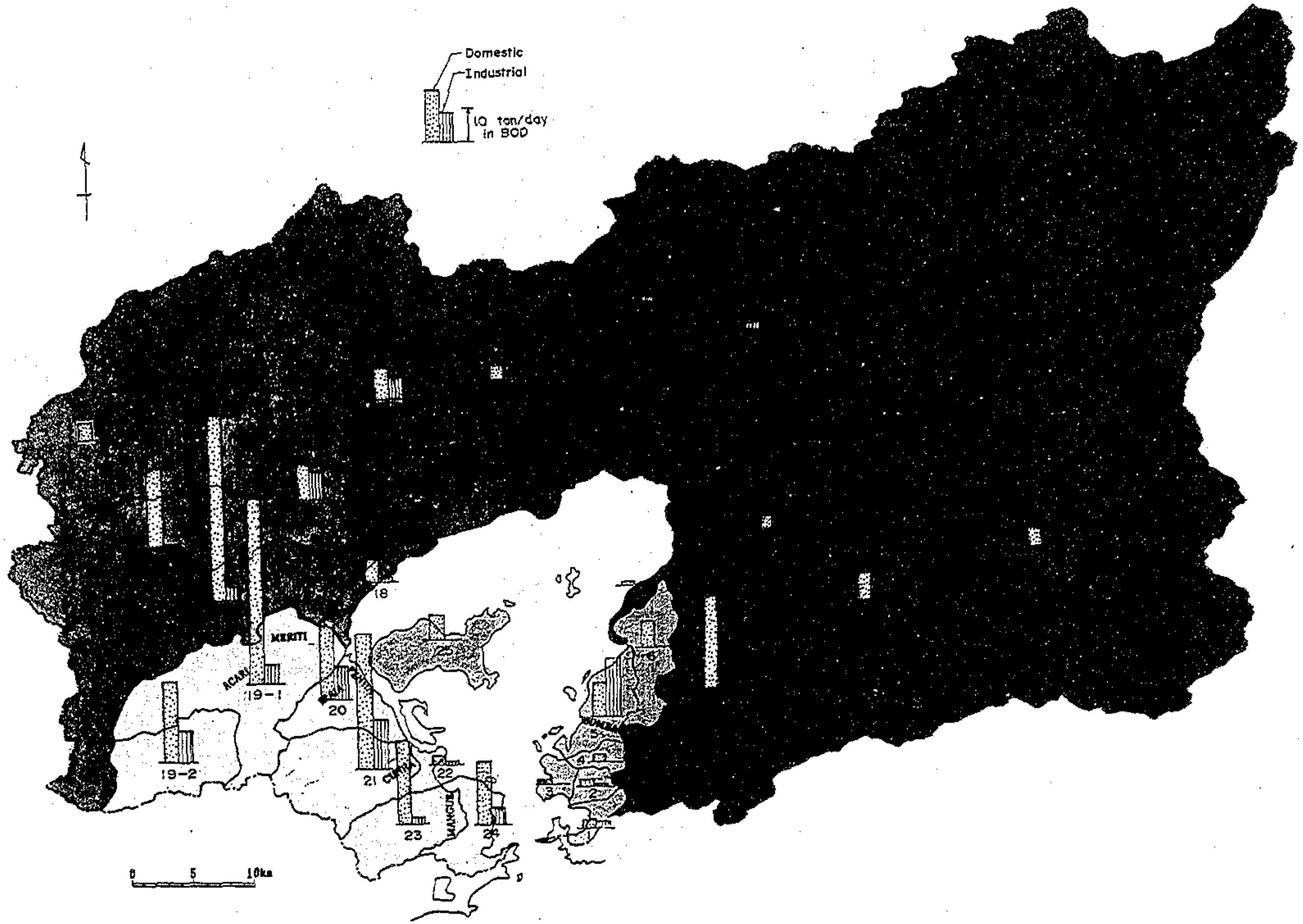


Fig. 8- 1 Distribution of Domestic and Industrial Effluent Load in BOD

Table 8- 1 Existing Sewage Treatment Plants in the Guanabara Bay Basin

No. Name	STP-1 PENHA	STP-2 ETIG	STP-3 ETEG	STP-4 ETAR-AIRJ	STP-5 ETAR-TECA	STP-6 ICARAI	STP-7 REALENGO	STP-8 ACARI
Sub-Basin No.	20	25	25	25	25	2,3	19-2	19-2
Superintendence	CEDAE	CEDAE	CEDAE	INFRAERO	INFRAERO	CEDAE	CEDAE	CEDAE
Treatment Mehtod	ASM+TF	ASM	TF	ASM	OD	ASM	TF	ASM
Av. Flow (ton/day)	122,746	22,977	3,959	2,401	1,002	60,408	2,968	11,340
Water Quality(BOD)								
Inflowed (mg/l)	217	243	345	334	219	291	179	161
Treated (mg/l)	20	26	78	84	50	27	9	7
Removal Ratio (%)	91	89	77	77	77	91	95	96
Effl. Load (kg/day)	2,494	699	305	202	50	1,633	27	80
Beneficial Pop.	493,370	103,419	25,389	14,844	4,047	325,920	9,745	33,750
Receiving Body	Guanabara B.	Guanabara B.	Guanabara B.	Guanabara B.	Guanabara B.	Guanabara B.	R. Acari	R. Acari
Sludge Volume								
Sludge Treatment	Gramacho							
Inflow of Industrial Waste Water	Nothing	Nothing	Nothing	Nothing	Nothing	?	?	Nothing

Water quality, removal ratio and effluent load are described in BOD.

Treatment Method
- ASM : Activated Sludge Method
- OD : Oxidation Ditch
- TF : Trickling Filter

There are six sewage treatment plants controlled by CEDAE (Table 8-1). The plants' total discharge of treated wastewater amounts to about 224,400 tons/day, and the total load is about 5.2 tons/day of BOD. The population served by sewage treatment is estimated less than 1,000,000, less than 13% of the total population in the basin, though the amount of industrial wastewater flowing into the sewage treatment plants is unknown.

9. Runoff Loads from the Basin

Discharge and water quality on the principal 25 rivers were observed. The water quality of all rivers with large discharge has deteriorated badly, except for Rio Guapimirim ; more than 20 mg/l of BOD and less than 5 mg/l of DO on average. In terms of runoff load, the nine largest rivers, including Rio Sao Joan do Meriti and Rio Sarapui, discharge 90-95 % of the total runoff load of the principal 20 rivers (Fig. 9-1).

Specific runoff load was calculated using the results of discharge and water quality observations on the two model rivers with contrasting land uses. By using the results of such analysis, a runoff load estimation model was formulated with population density and precipitation values as parameters, and the annual runoff load per Sub-basin was calculated on clear and rainy days.

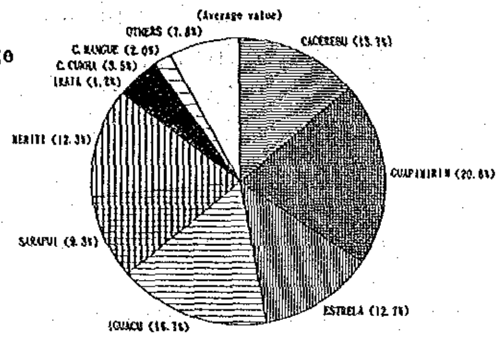
Viewing the results by area shows that the annual runoff load in the Western basin (Sub-basins No.19-24) is 45-50 %, about 30 % in the Northwestern basin (Sub-basins No.15-18). The Northeastern basin (Sub-basins No.7-14), which covers 60 % of the total basin area, shows 35 % runoff discharge and only 12 - 18 % runoff load.

Dividing the results into clear days and rainy days shows that 50 % of the annual runoff load in 1992 was discharged during rainy days, and the proportion of load coming from non-point sources was found to be huge.

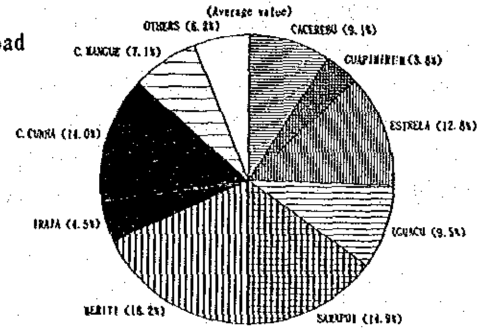
10. Numerical Simulation Model for Pollution Analysis in the Bay

The numerical model used were the hydrodynamic model, the diffusion model and the eutrophication model to predict the water quality in the bay under various conditions.

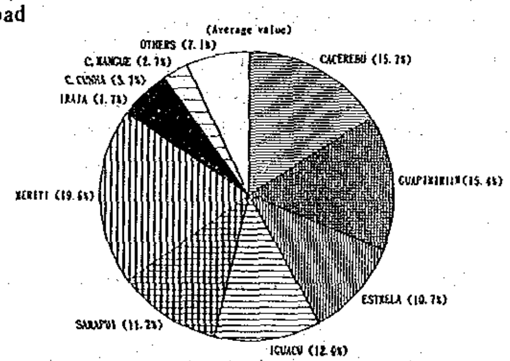
Discharge



BOD Load



COD(Mn) Load



TN Load

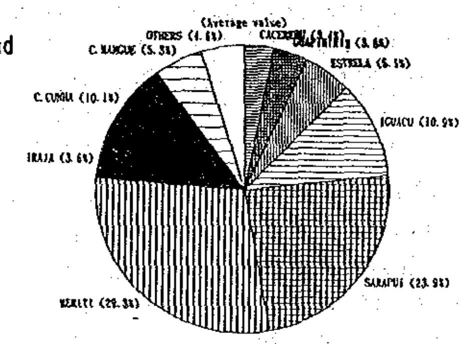


Table 9- 1 Discharge and Runoff Load Ratio among the Major Rivers (from May 1992 to April 1993)

The mesh model was adopted instead of the box model to represent the complicated submarine topography. Further, the two-layer model was adopted instead of a one-layer model considering the fact that the water quality in the bay is usually largely different at the surface and the bottom . The eutrophication model was adopted to assess the reproducibility of the organic pollution phenomena which is accelerated by large increase in phytoplankton.

11. Validity Test of the Simulation Model

The boundary conditions and the various parameters necessary for the application of these models were examined, and the present flow regime and water quality were calculated including the runoff discharge and runoff load (mean value of wet and dry seasons) within the model. Water quality was simulated under the wet and dry season because salinity and water temperature are greatly affected by river water. Conclusively, the simulated results adequately agreed with those observed in the field.

12. Future Socioeconomic Framework of the Basin

Population, basic sanitation services and economic activities were assumed according to expected and pessimistic scenarios. Minicipality populations in 2000 and 2010 were estimated after these municipalities were classified into four groups based on population growth.

13. Estimate of Future Water Quality in the Bay without Measure

The runoff load from each sub-basin, in terms of BOD, in 2000 and 2010 was predicted using the population assumed by the pessimistic scenario into the runoff load estimation model. The results show that the runoff load increases 13.6 % by 2000 and 25.5 % by 2010.

The water quality by 2000 and 2010 without measures was predicted by using the runoff load included in the numerical pollution model. The results showed that the BOD concentration in the entire bay shows an annual average increase of 0.3 mg/l (10.2 %) by 2000 and 0.6 mg/l (19.5 %) by 2010. The northeastern part of

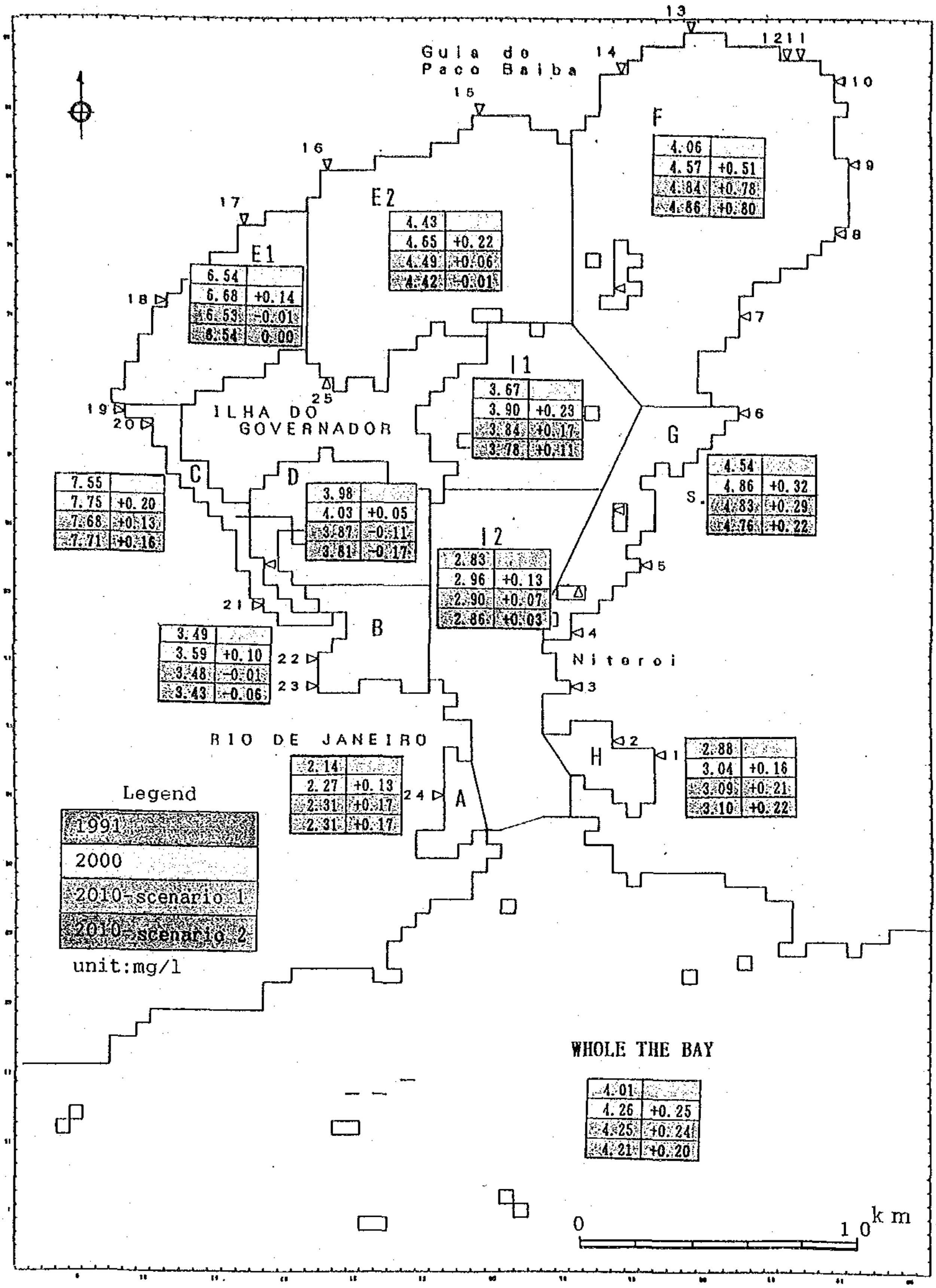


Fig. 13-1 Future Water Quality (BOD) in Guanabara Bay without Measure

the bay is considered to be the most influenced with an estimated 23 % in BOD concentration (Fig. 13-1).

14. Existing Circumstances and Issues of Software-type Measures

Regarding the existing circumstances and the issues of software-type measures for water quality improvement, various kinds of social systems effective in controlling the generation and effluent load, in Rio de Janeiro State, were examined. Though administrative and legislative systems have been formed, the enthusiasm of the state government to make them effective is lacking. Further, it is also necessary to prepare new programs by which enterprises and residents receive financial returns for their cooperation in water quality improvement.

15. Review and Evaluation of Hardware-type Measures

Hardware-type measures, techniques to remove the pollutants from the polluted water, were classified and examined on their principles, merits, demerits and actual results to judge their applicability to the study area. Though the activated sludge method is exclusively adopted in the existing and planned sewage treatment plants in the basin, the stabilization pond and the oxidation ditch methods were found to be more suitable because of the low construction costs and easy maintenance involved when a large site, like these in the suburbs, is obtained cheaply.

The joint treatment system is efficient as a measure for industrial wastewater treatment. Most of the factories in the basin are medium to small scale and their production facilities are old. Consequently, it is desirable that the state government or the relevant municipality construct industrial parks with joint treatment systems and afterwards relocate the factories to the area when production facilities are renewed.

The improvement of the wastewater and garbage collection system, retardation ponds and the swirl separation tanks are effective in reducing the load of non-point source pollution. The last two are effective in lessening the effects of flood as well as in reducing the load in freshet time.

Further, dredging the sludges, and widening and deepening of channels are effective in improving the flow regime and reducing deposited loads. Dredging, however, can only be effective for a short time period if measures that reduce pollution are not implemented.

The ocean outfall system for sewage is very effective since nutrient salts and pathogenic bacterias are also removed along with organic matter. However, a study on its effect on the environment and ecosystem outside the bay should be done in advance.

16. Master Plan

16.1 Socioeconomic Background of Environmental changes in Guanabara Bay

In the Guanabara Bay basin, population and industry have been growing and land use patterns had been changing since the 15th century and thus the pollutants flowing into the bay have also been increasing. As a result, Guanabara Bay and its basin have been gradually losing their value as an environmental resource and the latent costs necessary for the environmental improvement has been increasing. Fig.16.1-1 shows the socioeconomic structure resulting from the environmental change.

16.2 Benefits brought by the Water Quality Improvement of Guanabara Bay

Benefits from water quality improvement counter the socioeconomic losses caused by water quality deterioration. Table 16.2-1 shows the benefits.

To evaluate the investment effectiveness of an enterprise is important in deciding whether it should be implemented or not. However, an economic evaluation of an enterprise which aims to improve the environment is very difficult since the benefits it may bring about are hard to evaluate monetarily..

In this study, the dividends resulting from increase in the areas for recreation to promote water familiarization, increase in land prices and fish production were evaluated by a method devised by Victor Coelho. Results showed that the benefits from improved water recreation areas were evaluated at US$12,000,000 per year; from higher land prices, US$1,700,000,000; and from larger catches, US$400,000 per year.

16.3 Selection of Priority Areas

A large amount of investment is necessary to improve water quality and to recuperate the ecosystem of Guanabara Bay. But the investment is not effective when the amounts appropriated are inadequate. In this study, the following areas were designated as the priority areas for the allocation of investment: (1)

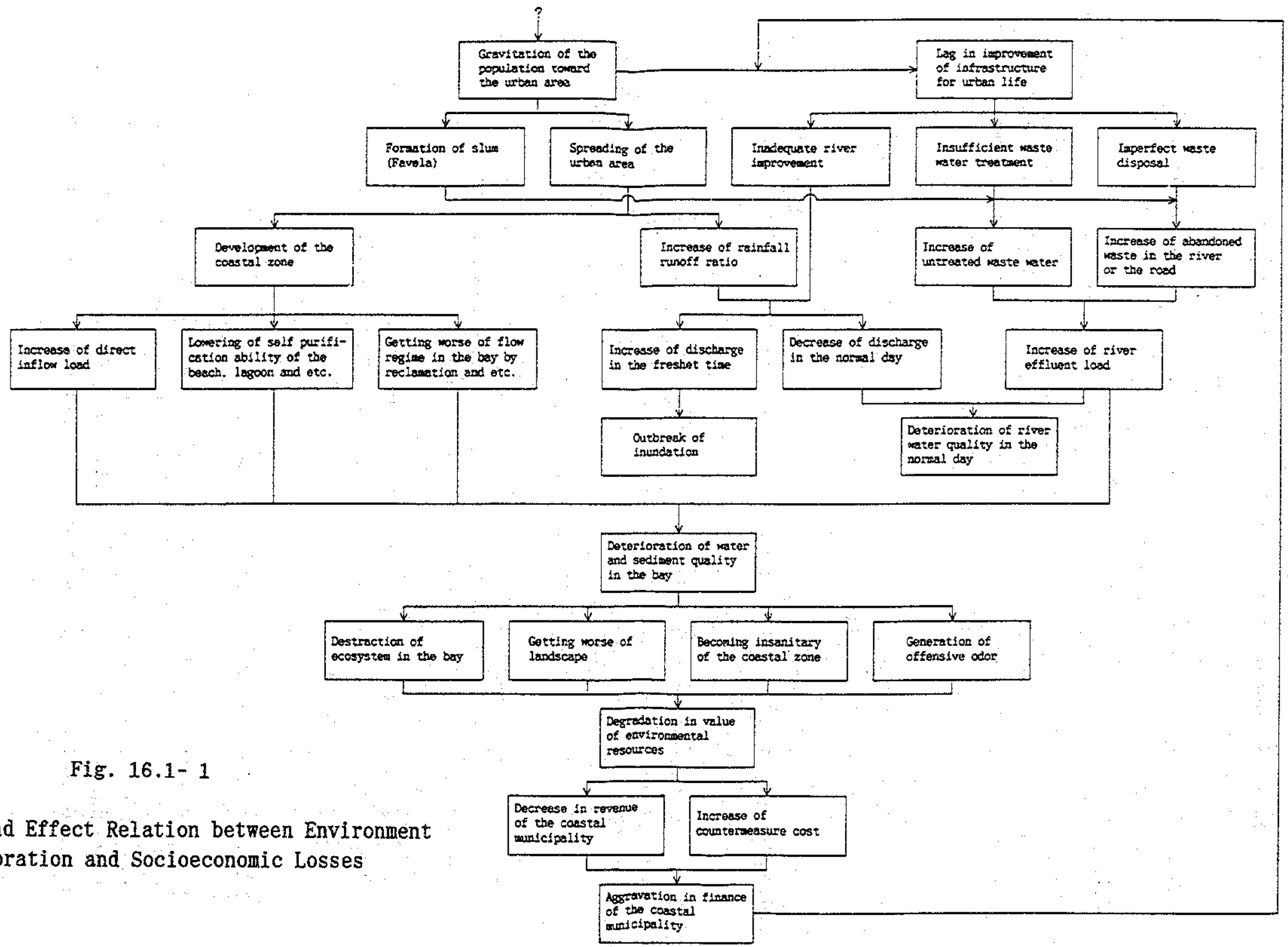


Fig. 16.1- 1

Cause and Effect Relation between Environment Deterioration and Socioeconomic Losses

Table 16.2-1 Socioeconomic Benefits brought by Water Quality Improvement of Guanabara Bay

Visible Benefit	Direct Use	Water Use	Industrial Waters, Fishery, Navigation
		Recreation	Sea Bathing, Fishing, Yachting, Sightseeing Cruises
	Indirect Use	Recreation Aesthetics Relaxation	Picnic, Walking, Bird-Watching, Sightseeing, Residential Environment
		Others	Natural Purification Capacity
Invisible Benefit	Potential Use	Optional Value	Possibility for Long-Term Use
	Non-Use	Existing Value	Heritage (Natural Preservation), Study Field

Influential Sub-basins; areas which yield relatively large amounts of runoff load, (2) Potentially Critical Sub-basins; areas where the runoff load is likely to increase from now on due to population increase and to recent land use changes, (3) Important Beaches and Water Areas where large social, economic and bio-resource benefits will be obtained if water quality is improved. Fig.16.3-1 shows these priority areas.

16.4 Target Year

The target year of the Master Plan is the year 2000 for the short term plan and 2010 for the medium term plan; a target year for the long term plan has yet to be decided. The year 2000 corresponds with the target year of Stage 1 in "The Basic Sanitation Program of the Guanabara Bay Basin" (hereinafter referred as IDB/OECF Program) and the year 2010 is near the target year of Stage 2 of the IDB/OECF Program.

16.5 Target Water Quality

The target water quality for the long term plan is at a level where the ecosystem in Guanabara Bay will be recuperated; that is a level approximately equal to that prior to the mid 1960's before water quality deterioration and the ecosystem change became conspicuous. A great amount of investment and time are necessary to attain the target water quality of the long-term plan.

The target water quality varies throughout the bay reflecting the desired use of each particular area. The water area types in Guanabara Bay were classified into four based on the current and future use, flow regime and the water quality distribution (Table 16.5-1), and then the target water quality was determined by water area type in accordance with CONAMA No.20, in which the water quality standard type in Rio de Janeiro State was established. The water area type division are shown in Fig.16.5-1 and the target water quality by water area type is shown in Table 16.5-2.

pH, BOD, DO, T-N, T-P, Fecal coliform group, SS, N-Hexan extracts were selected as the principal water quality indices; they include the indices established in CONAMA No.20 and the ones used

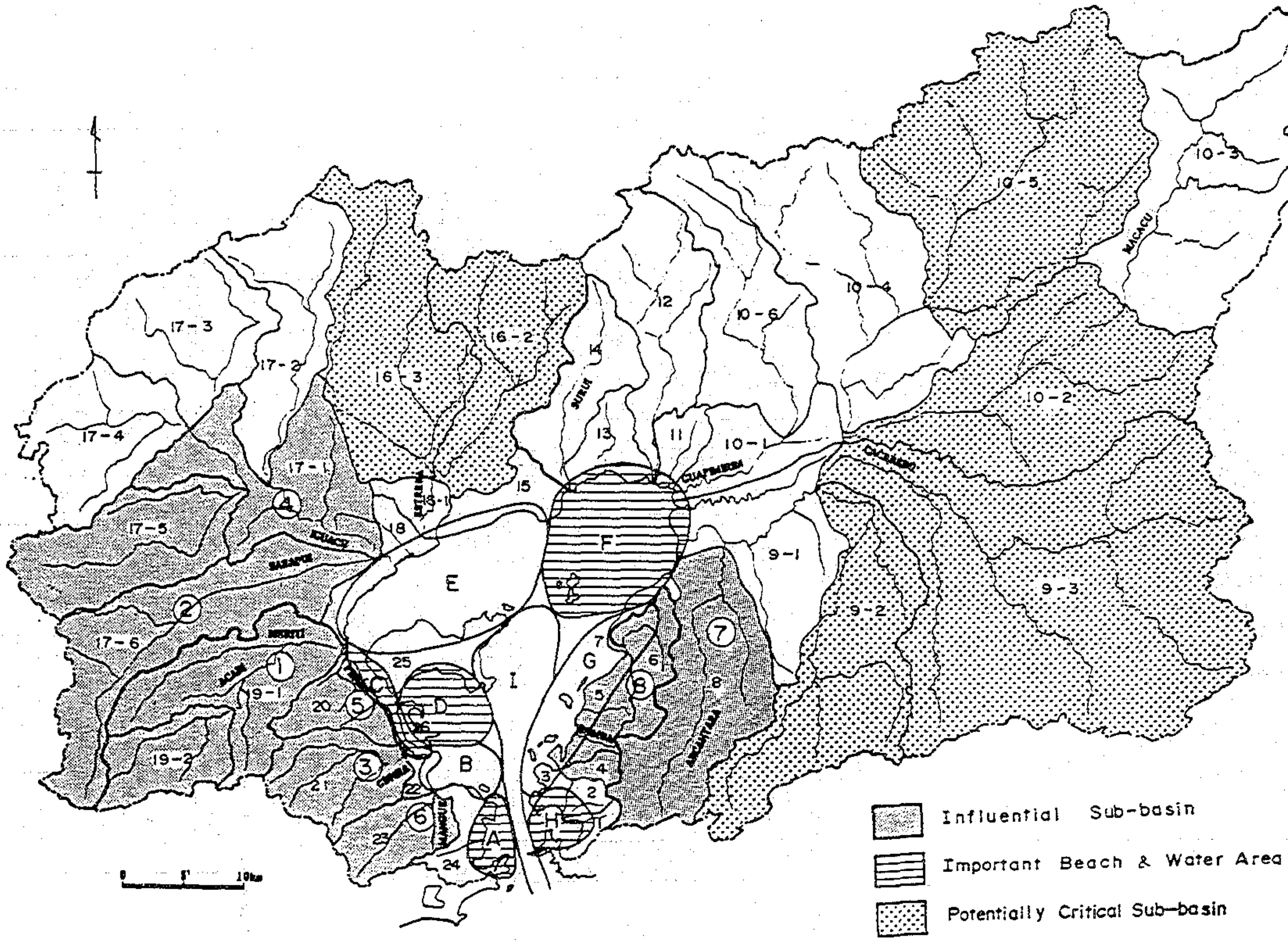


Fig. 16.3- 1 Priority Areas for Countermeasure

Table 16.5-1 Types of Water Quality for Guanabara Bay

Class	Purpose of Water Use
A	Fishery (Class 1) Recreation (Primary Contact) Uses listed in Class 5 - 6
B	Fishery (Class 2) Recreation (Secondary Contact) Conservation of Natural Environment Uses listed in Class 6
C	Commercial Navigation Industrial Water Conservation of Environment
D	Waste Dilution and Circulation

Table 16.5-2 Target Water Quality for Guanabara Bay

Principal Index

Class	pH	Biological Oxygen Demand (BOD)	Dissolved Oxygen (DO)	Total Nitrogen (T-N)	Total Phosphorus (T-P)	Number of Coliform Groups (Fecal)	Suspendid Solids (SS)	N-Hexane Extracts
A	7.8 | 8.3	3 mg/l or less	7.0 mg/l (4.5 mg/l) or more	0.3 mg/l or less	0.03 mg/l or less	1,000 MPN /100ml or less	10 mg/l or less	Not Detectable
B	7.0 | 8.5	5 mg/l or less	6.0 mg/l (3.5 mg/l) or more	0.6 mg/l or less	0.05 mg/l or less	1,000 MPN /100ml or less	25 mg/l or less	Not detectable
C	6.5 | 8.5	8 mg/l or less	4.0 mg/l (2.5 mg/l) or more	1.0 mg/l or less	0.09 mg/l or less	4,000 MPN /100ml or less	50 mg/l or less	-
D	6.5 | 8.5	10 mg/l or less	2.0 mg/l (1.5 mg/l) or more	1.5 mg/l or less	0.13 mg/l or less	-	50 mg/l or less	-

[Note] 1. Values given in parentheses for DO are target water qualities in the bottom layers.
2. With regard to the number of coliform groups for recreation (primary contact), fecal coliforms shall be less than 250 MPN/100 ml.
3. With regard to the number of coliform groups for recreation (secondary contact), fecal coliforms shall be less than 500 MPN/100 ml.

Supplementary Index

Class	Transparency	Oil Film	Floatage	Water Colour	Biotic Comunity
A	5 m or more	Not Observed	Not Observed	Greenish (Not Brownish)	Diverse Species
B	3 m or more	Not Observed Ordinarily	Not Observed Ordinarily	Greenish (Not Brownish)	Existence of Benthonic lives
C	1.5 m or more	-	-	-	-
D	1 m or more	-	-	-	-

to measure eutrophication and oil pollution. Though BOD is not always suitable as the index of organic pollution, it will be tentatively used until TOC can be reliably measured. In addition to the above mentioned indices, the supplementary indices such as transparency, oil film, flotage, water color and aquatic life were selected to promote resident participation in the monitoring activities.

16.6 Target Reduction Loads

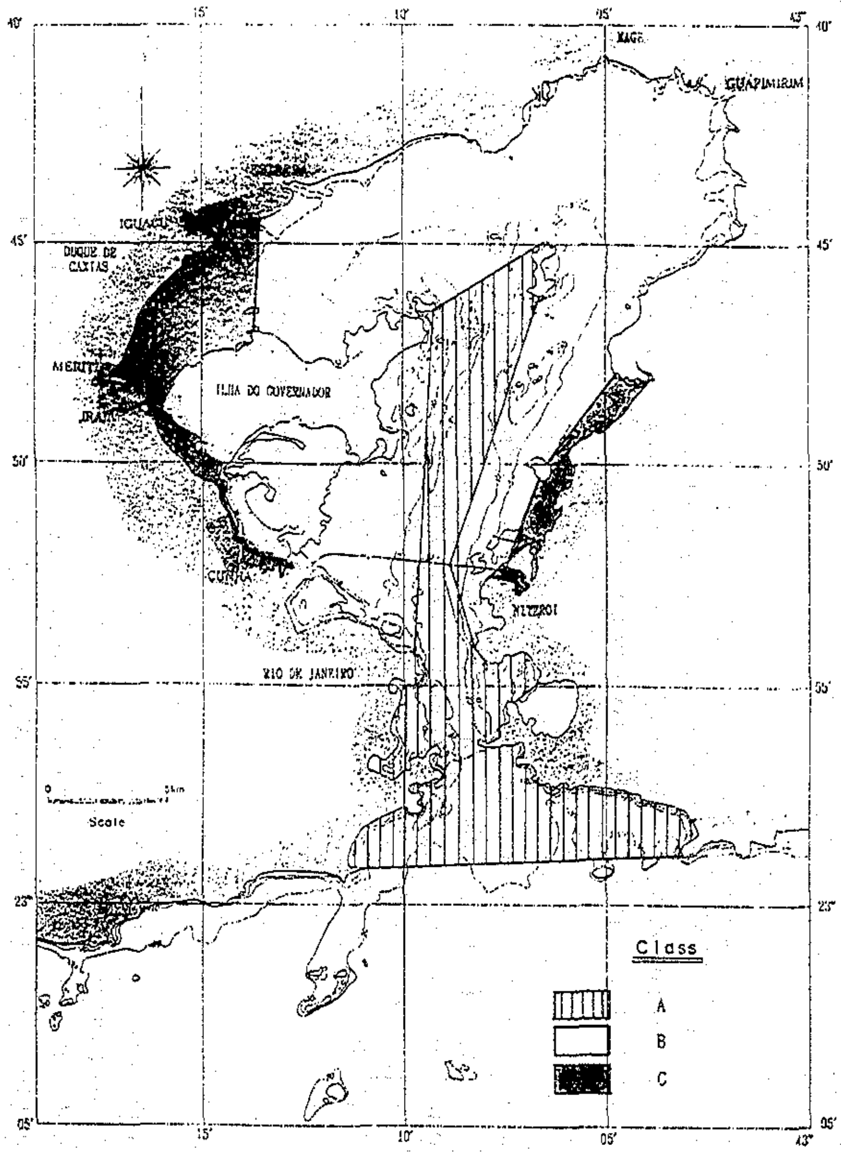
The present water quality in the bay already exceeds the target water quality for medium term plan at several areas as shown in Fig.16.6-1. It is necessary to lessen the annual average water quality (BOD concentration) to about 1.5 mg/l in Block-C, 1.0 mg/l in Block-E_1 and 0.25 mg/l in Block-H to attain the target water quality.

The most efficient way for allotment of the reduction runoff load to attain the target water quality for medium term plan in every block at present was pursued by trial and error. As a result, it was shown that at least about 40 % of the present runoff load (BOD and OP) should be reduced in the Northwestern, Western and Eastern basins.

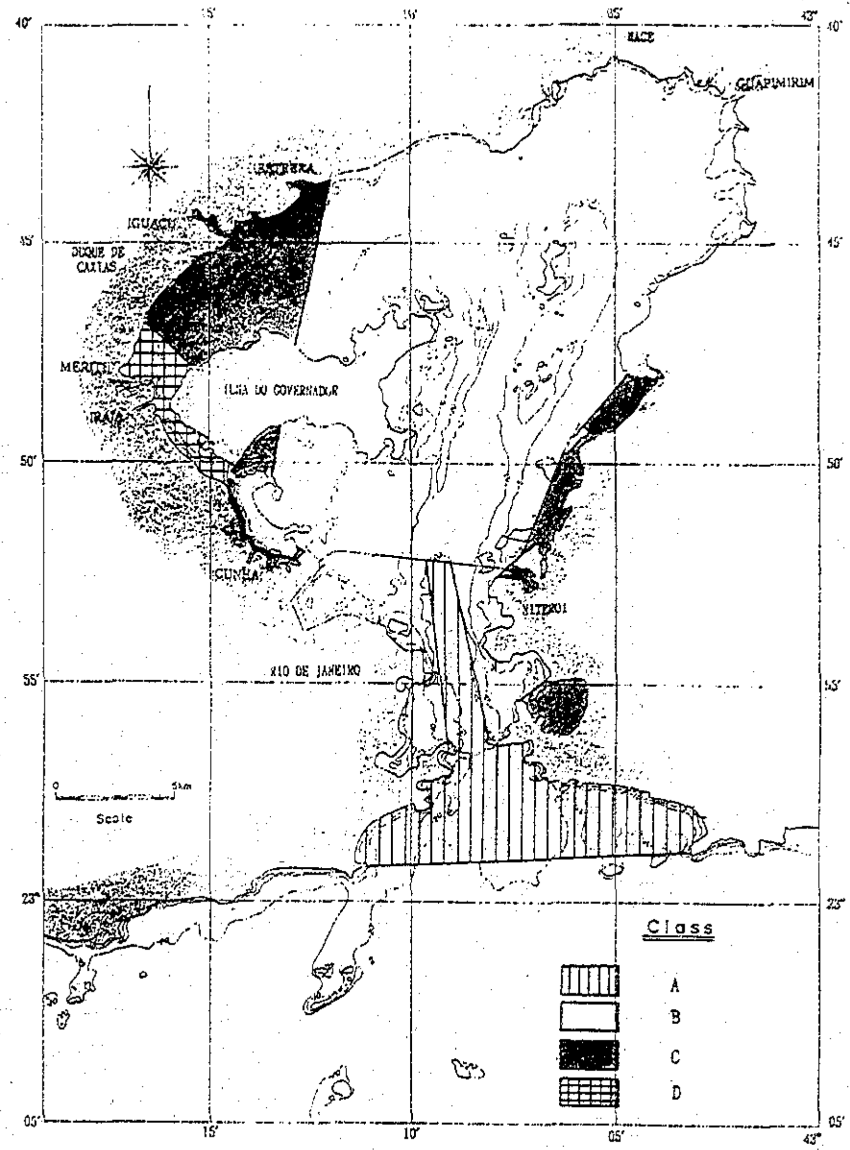
The above mentioned means that the environmental assimilating capacity of Guanabara bay is approximately 60 % of the present runoff load if we want to attain the target water quality (BOD) for medium term plan. Accordingly, the load to be reduced in the future is the amount with additional load caused by the increasing population and industrial activities.

The main factors controlling water quality (BOD) in the bay are the inflow loads from the four basins, the release load from the bottom material and the internal production load. The contribution rate of these four controlling factors was calculated for each block. Result showed that about 60 % is contributed by the internal production and about 5 % is by release (Fig.16.6-2). Accordingly, the reduction of nutrient salts which causes internal production is essential to improve the organic pollution in the bay.

If both organic material (BOD and OP) and the nutrient salts (T-P) were reduced by 40 % from the present levels, the average water quality would be improved by 0.3-0.5 mg/l (10 %) over the whole bay.



for Mid to Long-term Plan



for short-term Plan

Fig. 16.5-1 Proposed Water Area Classification

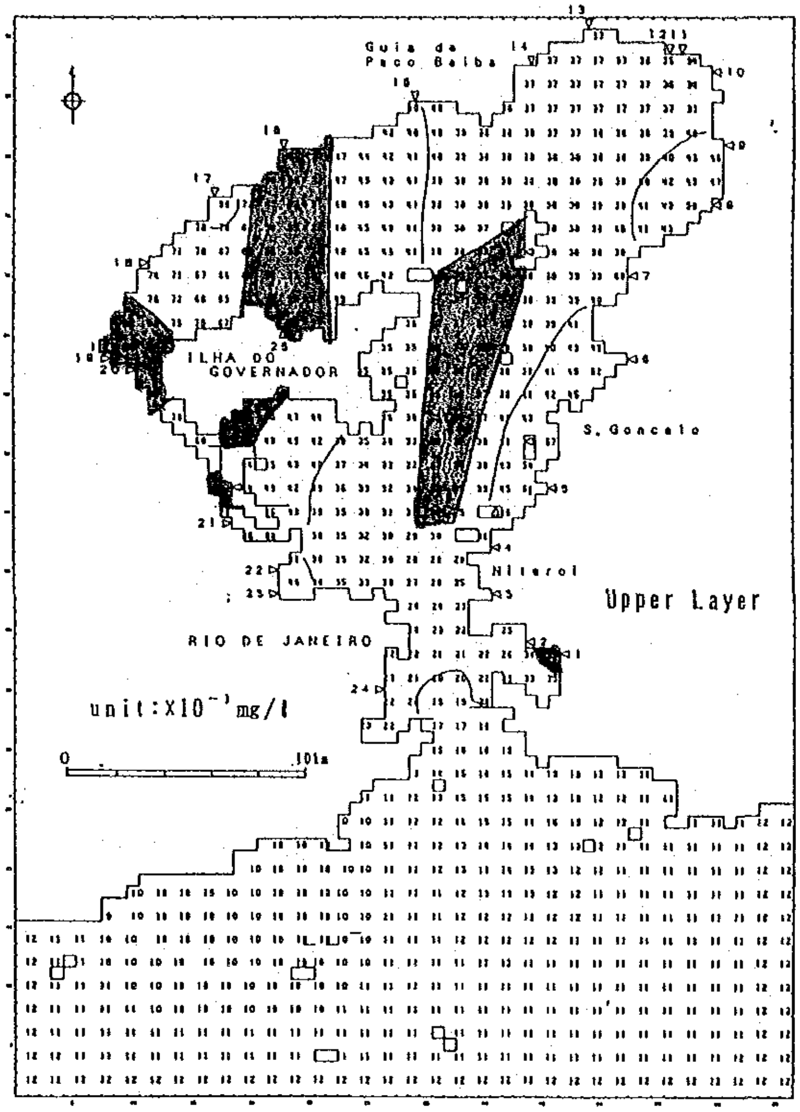
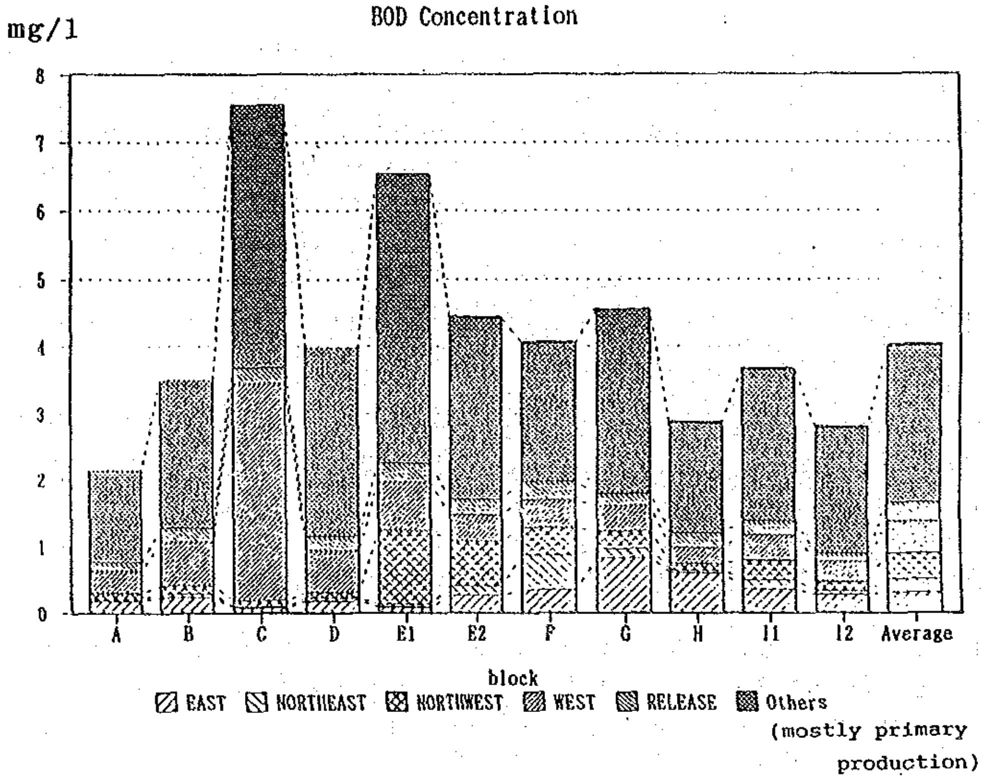


Fig. 16.6-1 Water Area where Water Quality at Present dose not meet with the Mid-term Target



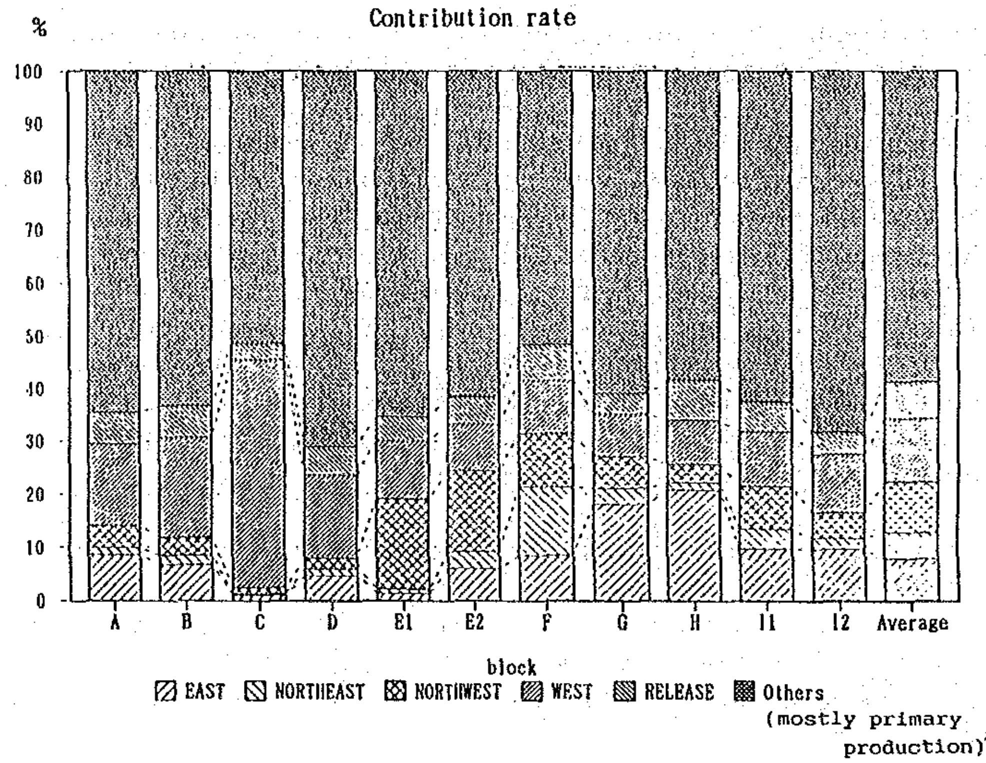


Fig. 16.6-2 Contribution Rate in Water Pollution by Factor in Each Water Area

16.7 Applicable Measures and their Effectiveness

The project for the construction of a sewer system and sewage treatment plants financed by IDB/OECF is one of the measures for the improvement of water quality in Guanabara bay. This project commences in 1994 and the wastewater of about 2.8 million people is planned to be treated by six new primary treatment plants when Stage 1 (target year: 2000) is completed. In Stage 2 (target year: 2007) secondary treatment facilities will be installed in these plants, however, the financial plan has not been clearly presented.

Consequently, the measures for the priority areas were discussed on the assumption only Stage 1 of the IDB/OECF Program is to be completed.

Table 16.7-1 shows the applicable measures for the Influential Sub-basins. Of the various measures examined regarding their applicability in the Guanabara bay basin, the effective ones were selected considering the existing circumstances of wastewater and garbage collection, types and distribution density of the pollution sources, existing and future land use, and so forth.

Stabilization ponds for the basins where the necessary land is obtainable, the wastewater treatment in favelas for the basins where large favela populations are found, and the ocean outfall system for the basins near the bay mouth were recommended as the measures to treat domestic wastewater. Tightening the monitoring of factory discharge and the installation of joint treatment systems where similar type factories are centralized were recommended as measures to treat industrial wastewater. In addition, preservation of forests, land use control, improvement of garbage collection rate were recommended as measures for the non-point sources. Retardation ponds, swirl separation tanks and the removal of deposited sludge were recommended as measures for river load reduction during freshets.

For the Important Beaches and Water Areas, dredging the polluted bottom sediments and widening the channels to improve the flow regime were recommended as the direct measures for the main water body. Measures that were recommended for the Influential Sub-basins were also recommended for the basins adjacent to the main water body.

Table 16.7-1 Applicable Measures for Influential Sub-basins

Sub-Basin No. (River Name)	Measure for Reduction of Domestic Effluent Load	Measure for Reduction of Industrial Effluent Load	Measure for Reduction of Effluent Load from Non-Point Sources	Measure to Rivers flowing into the Bay
19 (Meriti)	*Construction of Pavuna STP (Population:410,000) 2000 : primary treatment (2010 : secondary treatment) .Capacity-up of existing Acari & Realengo STP [redacted]	Tightening of monitoring to effluent load	Prevention of forests in the Pera Branca State Park	[redacted] ΔDredging
17-6 (Sarapui)	*Construction of Sarapui STP (Population:430,000) 2000 : primary treatment (2010 : secondary treatment) [redacted]	Tightening of monitoring to effluent load	.Improvement of garbage collection/ treatment system Control of land use in Nova Iguacu	ΔWidening of river (including removal of Favelas) ΔConstruction of flood-control dam ΔDredging [redacted]
21 (Cunha)	*Construction of Alegria STP (Population:1,530,000) 2000 : primary treatment 2010 : secondary treatment Ocean outfall with primary treatment (2010) [redacted]	.Construction of joint treatment plant for food & beverage factories (High concentrated organic substances)	oImprovement of garbage collection /treatment system in Favela []Reforest around Favela	ΔRemoval screen of flotage ΔDredging
17-1.5 (Iguacu)	*Construction of Bota STP (2010 : primary treatment) [redacted]	.Construction of joint treatment plant for petrochemical factories (Refractory organic substances)	oImprovement of garbage collection/ treatment system in Nova Iguacu Control of land use in Nova Iguacu	[redacted]
20 (Iraja)	*Improvement of existing Penha STP (Population:700,000; secondary treatment) Ocean outfall with primary treatment [redacted]	Tightening of monitoring to effluent load	oImprovement of garbage collection/ treatment system in Favela []Reforest around Favela	ΔDredging
23 (Mangue)	*Construction of Alegria STP 2000 : primary treatment (2010 : secondary treatment) Ocean outfall with with primary treatment (2010) [redacted]	Tightening of monitoring to effluent load	Prevention of forests in Tijuca oImprovement of garbage collection/ treatment system in Favela	ΔDredging
8 (Alcantara)	*Construction of S-III.IV.V STP (2010 : primary treatment)	Tightening of monitoring to effluent load	Control of land use in San Goncalo	[redacted]
4.5.6 (Imboassu)	*Construction of Sao Goncalo STP 2000 : primary treatment (2010 : secondary treatment) Ocean outfall with primary treatment (2005)	.Construction of joint treatment plant for food factories (processing of sea products) (high concentrated organic substances)		

[Note] * : IDB/OECF Program o : plan by COMLURB Δ : under practice by SERLA with World Bank loan
[] : IEF STP : Sewage Treatment Plant

For the Potentially Critical Sub-basins, the construction of new sewage treatment plants and land use controls were recommended to restrain the increasing generation of effluent load in future. Decentralized treatments method using stabilization ponds and oxidation ditches are suitable for the Potentially Critical Sub-basins.

The runoff loads from each basin in the target year were calculated using a runoff load estimation model to estimate the runoff load reduction effect of the IDB/OECF Program. The runoff load from the Western basin will decrease to 18 % for BOD and increase to 5 % for PO_4-P by the year 2000, assuming primary treatment facilities are completed in Stage 1. The runoff load from the Western basin will decrease to 28 % for BOD and increase to 9 % for PO_4-P by the year 2010 if the secondary treatment facilities are completed in Stage 2 (Table 16.7-2).

BOD decreases only up to 5 %, while PO_4-P increases up to 23 % from the present levels over the whole bay by the time Stage 2 is completed since many sub-basins are not included in the objective area of the IDB/OECF Program.

The runoff load in the year 2010 was calculated for three cases with different treatment areas to estimate the runoff load reduction effect of the ocean outfall system. In the Western basin, the runoff load is reduced by 27 % for BOD and 18 % for PO_4-P for Case 3, the smallest in treatment area; while it is reduced by 36 % for BOD and 33% for PO_4-P for Case 1, the largest treatment area (Fig. 16.7-3).

According to results obtained in Brazil,a stabilization pond is able to remove 90 % of the BOD load if residence time is 30 days. The reduction load of the stabilization ponds installed on the lower reaches of Rio Sarapui and Rio Iguacu was estimated on the assumption that the beneficial population is 80 % of the basin population in the year of 2010.

The reduction effect of river load(BOD) by retardation ponds was estimated on the assumption that they are able to store river water when precipitation is 10 mm to 20 mm/day. The results show that the reduction load is 10 tons/year, which is considered negligible.

Table 16.7-2 Reduction Load by IDB/OECF Program

BOD

unit : ton/day

Name of Basin	IDB/OECF Program (1st Stage)	Runoff Load			Reduction Load (2010-1991)
		1991 (Present)	2000 IDB/OECF Program (Primary)	2010 IDB/OECF Program (Secondary)	
Eastern Basin	Icarai Toque Toque S-II	40.1 t/d (100 %)	35.6 t/d (88.8%)	31.9 t/d (79.6%)	- 8.2 t/d (- 20.4%)
Northeastern Basin		44.1 t/d (100 %)	55.6 t/d (126.1%)	64.5 t/d (146.3%)	+ 20.4 t/d (+ 46.3%)
Northwestern Basin	Sarapui	98.6 t/d (100 %)	107.0 t/d (108.5%)	118.5 t/d (120.2%)	+ 19.9 t/d (+ 20.2%)
Western Basin	Alegria Pavuna	164.2 t/d (100 %)	135.8 t/d (82.7%)	117.4 t/d (71.5%)	- 46.8 t/d (- 28.5%)
Islands		7.8 t/d (100 %)	6.6 t/d (84.6%)	5.8 t/d (74.4%)	- 2.0 t/d (- 25.6%)
TOTAL		354.8 t/d (100 %)	340.6 t/d (96.0%)	338.1 t/d (95.3%)	- 16.6 t/d (- 4.7%)

PO_4-P

unit : ton/day

Name of Basin	IDB/OECF Program (1st Stage)	Runoff Load			Reduction Load (2010-1991)
		1991 (Present)	2000 IDB/OECF Program (Primary)	2010 IDB/OECF Program (Secondary)	
Eastern Basin	Icarai Toque Toque S-II	0.56 t/d (100 %)	0.65 t/d (116.1%)	0.71 t/d (126.8%)	+ 0.15 t/d (+ 26.8%)
Northeastern Basin		1.01 t/d (100 %)	1.28 t/d (126.7%)	1.49 t/d (147.5%)	+ 0.48 t/d (+ 47.5%)
Northwestern Basin	Sarapui	2.22 t/d (100 %)	2.60 t/d (117.1%)	3.03 t/d (136.5%)	+ 0.81 t/d (+ 36.5%)
Western Basin	Alegria Pavuna	4.16 t/d (100 %)	4.38 t/d (105.3%)	4.54 t/d (109.1%)	+ 0.38 t/d (+ 9.1%)
Islands		0.19 t/d (100 %)	0.20 t/d (105.3%)	0.22 t/d (115.8%)	+ 0.03 t/d (+ 15.8%)
TOTAL		8.14 t/d (100 %)	9.11 t/d (111.9%)	9.99 t/d (122.7%)	+ 1.85 t/d (+ 22.7%)

Table 16.7-3 Reduction Load by Ocean Outfall System

BOD

unit : ton/day

Name of Basin	Runoff Load				Reduction Load		
	1991	2010			1991 - Case 1	1991 - Case 2	1991 - Case 3
	(Present)	Case 1	Case 2	Case 3			
Eastern Basin	40.1 (100%)	33.8 (84.3)	33.8 (84.3)	35.6 (88.8)	- 6.3 (-15.5)	- 6.3 (-15.5)	- 4.5 (-11.2)
Northeastern Basin	44.1 (100%)	64.5 (146.3)	64.5 (146.3)	64.5 (146.3)	+ 20.4 (+46.3)	+ 20.4 (+46.3)	+ 20.4 (+46.3)
Northwestern Basin	98.6 (100%)	123.9 (125.7)	123.9 (125.7)	123.9 (125.7)	+ 25.3 (+25.7)	+ 25.3 (+25.7)	+ 25.3 (+25.7)
Western Basin	164.2 (100%)	104.7 (63.8)	111.5 (67.9)	119.2 (72.6)	- 59.5 (-36.2)	- 52.7 (-32.1)	- 45.0 (-27.4)
Islands	7.8 (100%)	6.8 (87.2)	6.8 (87.2)	6.8 (87.2)	- 1.0 (-12.8)	- 1.0 (-12.8)	- 1.0 (-12.8)
TOTAL	354.8 (100%)	333.7 (94.1)	340.5 (96.0)	350.0 (98.6)	- 21.1 (- 5.9)	- 14.3 (- 4.0)	- 4.8 (- 1.4)

PO_4-P

unit : ton/day

Name of Basin	Runoff Load				Reduction Load		
	1991	2010			1991 - Case 1	1991 - Case 2	1991 - Case 3
	(Present)	Case 1	Case 2	Case 3			
Eastern Basin	0.56 (100%)	0.53 (94.6)	0.53 (84.6)	0.61 (108.9)	- 0.03 (- 5.4)	- 0.03 (- 5.4)	+ 0.05 (+ 8.9)
Northeastern Basin	1.01 (100%)	1.49 (147.5)	1.49 (147.5)	1.49 (147.5)	+ 0.48 (+47.5)	+ 0.48 (+47.5)	+ 0.48 (+47.5)
Northwestern Basin	2.22 (100%)	3.04 (136.9)	3.04 (136.9)	3.04 (136.9)	+ 0.82 (+36.9)	+ 0.82 (+36.9)	+ 0.82 (+36.9)
Western Basin	4.16 (100%)	2.77 (66.6)	3.09 (74.3)	3.42 (82.2)	- 1.39 (-33.4)	- 1.07 (-25.7)	- 0.74 (-17.8)
Islands	0.19 (100%)	0.22 (115.8)	0.22 (115.8)	0.22 (115.8)	+ 0.03 (+15.8)	+ 0.03 (+15.8)	+ 0.03 (+15.8)
TOTAL	8.14 (100%)	8.05 (98.9)	8.37 (102.8)	8.78 (107.9)	- 0.09 (- 1.1)	+ 0.23 (+ 2.8)	+ 0.64 (+ 7.9)

As for the industrial pollution sources, the reduceable effluent load cannot be predicted at present since detailed studies on the production processes and applicable waste water treatment facilities have not yet been carried out. However, DZ 205-R5 (1991) states that the state government aims to reduce 70 % of the industrial effluent load (BOD) at minimum.

Flow regime improvement is an effective measure to improve water quality in semi-closed water areas. When the channel west of the Governador-Fundao islands is deepened to 5 m in depth and widened by 500 m, water quality (BOD) in the channel will be improved by 28 % and the effects will flow on to other areas.

The effect of dredging the polluted bottom sediments was also estimated. The result made clear that dredging had a little effect when the inflow load is as high as the present level. But it is expected that dredging exhibits its effect especially in improvement of DO concentration at the bottom layer when the inflow load is reduced in some measure.

16.8 Costs of the Measures to Reduce the Inflow Loads

Costs of the four kinds of wastewater treatment systems (activated sludge method, ocean outfall, stabilization pond, tertiary treatment), which are quantitatively comparable in their load reduction effect were roughly estimated from the material prices and the construction costs in Brazil.

The construction cost of the activated sludge treatment is 2.5 to 3 times that of the primary treatment for the treatment facilities, but the total costs of the former, including the laying cost of the sewer pipes, is about 1.2 times of the latter. Though the construction cost of the tertiary treatment plant is about 1.1 times of the secondary treatment plant, its maintenance cost is about 1.5 times of the latter. The construction cost of the ocean outfall system differs depending on the length of the trunk pipes used under the sea. Further, the construction cost of the treatment facilities per unit volume of treated wastewater is lower for the stabilization pond than for the activated sludge method.

16.9 Optimum Combinations of the Measures

16.9.1 Combinations of the Measures to meet with the Target Water Quality

A comprehensive counterplan consisting of hardware-type and software-type measures should be implemented extending through a long time to improve the water quality of Guanabara Bay around which various and many pollution sources are distributed. Here, we examined ways to attain the target water quality in terms of BOD using combinations of the measures recommended in 16.7, which enabled us to evaluate water quality improvement efficiency quantitatively.

The target runoff load in the Western basin is 98 tons/day. The following four combinations are enumerable.

(1) Second treatment plants (IDB/OECF Program, Stage 1 + Stage 2)
(2) Primary treatment plants (IDB/OECF Program, Stage 1)
+ Ocean outfall system (Aregria basin)
(3) Primary treatment plants (IDB/OECF Program, Stage 1)
+ Ocean outfall system (Aregria basin)
(4) Primary treatment plants (IDB/OECF Program, Stage 1)
+ Tertiary treatment plants

For measure (1) and (4), the runoff load exceed 19 tons/day and 8 tons/day over the target, respectively. Consequently, the reduction of the industrial load (tightning regulation, installation of joint treatment systems), improvement of the garbage collection rate and other measures are necessary to compensate the excess. Measure (2) meets the target and measure (3) makes the runoff load less than the target.

The target runoff load in the Eastern basin is 24 tons/day. The following four combinations are enumerable.

(1) Second treatment plants (IDB/OECF Program, Stage 1 + Stage 2)
(2) Primary treatment plants (IDB/OECF Program, Stage 1)
+ Ocean outfall system (Icarai basin)
(3) Primary treatment plants (IDB/OECF Program, Stage 1)
+ Ocean outfall system (Icarai basin + Toque toque basin)
(4) Primary treatment plants (IDB/OECF Program, Stage 1)
+ Tertiary treatment plants

Since all the combinations exceed 5 - 10 tons/day over the target runoff load, the reduction of industrial effluent load (tightning) regulation, installation of joint treatment systems for industries processing the marine procusts) is necessary to compensate the excess.

The target runoff load in the Northwestern basin is 59 tons/day. The following three combinations are enumerable.

(1) Second treatment plants (IDB/OECF Program, Stage 1 + Stage 2) + Stabilization pond (Iguacu basin)
(2) Primary treatment plants (IDB/OECF Program, Stage 1) + Stabilization pond (Iguacu basin + Sarapui basin)
(3) Primary treatment plants (IDB/OECF Program, Stage 1 + Stage 2) + Additional secondary treatment plants (three plants with treatment capacity of 1.2 m^3/sec)

The measures (1) and (3) exceed 176 tons/day and 29 tons/day over the target runoff load, respectively. Then, the reduction of industrial load (tightning regulation, installation of joint treatment systems for petrochemical factories) is necessary to compensate the excess.

The target runoff flood in the Northeastern basin is 44 tons/day. The following two combinations are enumerable.

(1) Stabilization pond (with the same scale of the one in the Sarapui basin)
(2) Additional secondary treatment plants (two plans with treatment capacity of 1.2 m^3/sec)

The measure (1) attains the target runoff load and the measure (2) almost meets with the target.

The target runoff load in the Island basin is 8.7 tons/day. The following combinations are enumerable.

(1) Secondary treatment plants (Governador Island, Fundon Is land)
(2) Tertiary treatment plant (Governador Islands)

Both combinations meet with the target runoff load.

16.9.2 Optimum Combinations Considering the Cost and Other Factors

Though the combinations of the measures were examined in the previous section from the view point of realizing the target load to be attained for BOD, measures which can also effectively reduce the nutrient salts (represented by T-P) are desirable since internal production in the bay is extremely large. Further, it is also desirable that construction and maintenance costs are low and the techniques required are not complicated. Considering these points, the optimum combination was selected from the alternatives already shown. The software-type measures are also presented.

The reduction load of the four combinations for the Western basin are 0.5 tons/day, 3.3 tons/day, 4.2 tons/day and 4.4 tons/day respectively in terms of T-P, combination (2) and (3) adopting the ocean outfall system and combination (4) adopting tertiary treatment are effective. Though the cost of the ocean outfall system differs with the length of the trunk pipe under the sea, combination (2) has an advantage in cost. The ocean outfall system is considerably lower in the maintenance than the secondary and the tertiary treatment.

Consequently, combination (2) is recommended for the Western basin and the improvement of the wastewater and garbage collection systems in favelas is proposed to reduce the pollutants from non-point sources. However, it is necessary to exclude industrial wastewater contained heavy metals and toxic substances from the sewer collection system connected with the ocean outfall system and to evaluate the impact of the ocean outfall system on the environment in the open sea and along the coast before it is implemented.

The reduction effect of the four combinations for the Eastern basin are 0.1 tons/day, 0.4 tons/day, 0.6 tons/day and 1.0 tons/day respectively in terms of T-P, combination (1) cannot be recommended from the view point of the nutrient salts reduction effect. Combinations (2) and (3) adopting the ocean outfall system have disadvantage in cost.

Consequently, combination (4) is recommended for the Eastern basin. In addition, joint treatment system should be applied to industries processing marine products.

The reduction effect of the stabilization pond with 30 day residence time is estimated to be about 50 % in terms of nutrient salts; this is more effective than the secondary treatment method. Its construction cost is also lower than the secondary treatment method when land price are low, and its maintenance cost is far lower than the latter.

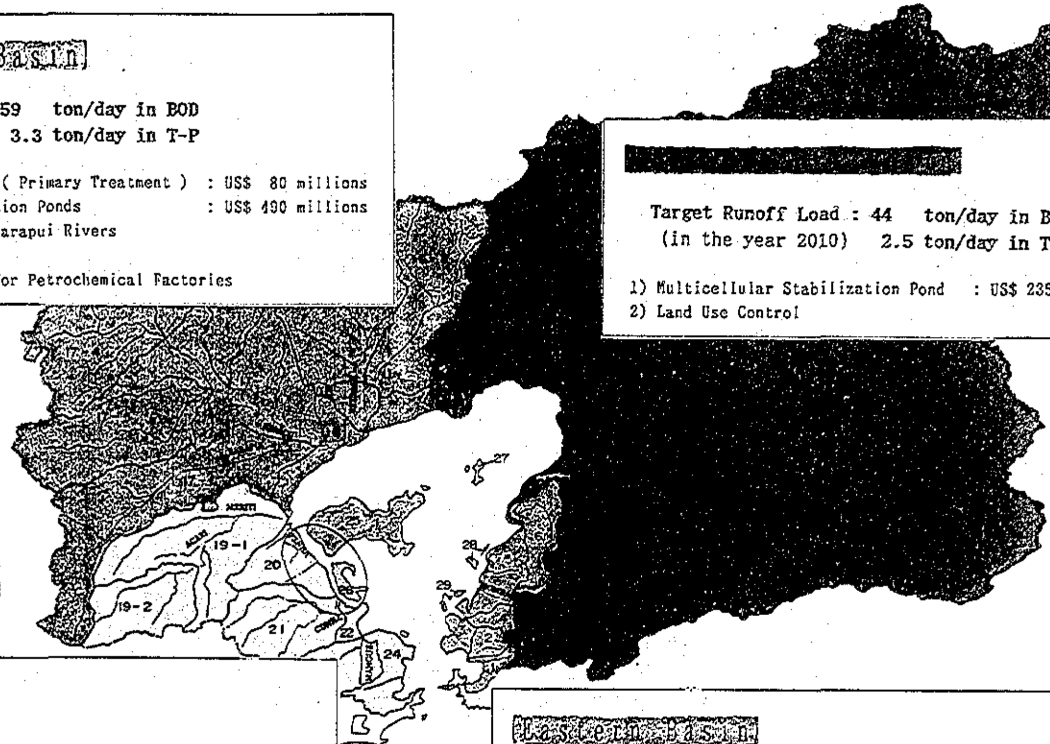
Consequently, combination (2) is recommended for the Northwestern basin. In addition, strict land use control should be adopted for the basins where urbanization is progressing most rapidly. Also joint treatment systems should be installed in petrochemical factories with large effluent loads.

Combination (1) is also desirable for the Northeastern basin due to the same reasons as the Northwestern basin. Strict land use regulations should be enforced in this basin since rapid development is expected.

For the Island basin, the tertiary treatment should be introduced to reduce the nutrient salts to the target though the runoff load ratio of this basin is little to the whole basin.

For the water area, the widening and deepening of the channel west of Governador and Fundao islands is desirable resulting the improvement of the flow regime over the whole bay.

The optimum combinations of the measures for each basin to attain the target water quality for medium and long term plans are shown in Fig. 16.9-1.



North-western Basin

Target Runoff Load : 59 ton/day in BOD
(in the year 2010) 3.3 ton/day in T-P

1) Sewage Treatment Plants (Primary Treatment) : US$ 80 millions
2) Multicellular Stabilization Ponds : US$ 490 millions
along the Iguacu and Sarapui Rivers
3) Land Use Control
4) Joint Treatment Plants for Petrochemical Factories

[redacted]

Target Runoff Load : 44 ton/day in BOD
(in the year 2010) 2.5 ton/day in T-P

1) Multicellular Stabilization Pond : US$ 235 millions
2) Land Use Control

Islands

Target Runoff Load : 7 ton/day in BOD
(in the year 2010) 0.4 ton/day in T-P

1) Tertiary Treatment Systems : US$ 25 millions
for the Governador Island

Western Basin

Target Runoff Load : 98 ton/day in BOD
(in the year 2010) 6.2 ton/day in T-P

1) Sewage Treatment Plants (Primary Treatment) : US$ 115 millions
2) Ocean Outfall System after Primary Treatment : US$ 140 millions
for the Alegria Sanitary District
3) Improvement of Sanitary Services in Favelas
(Garbage Collection & Wastewater Treatment Facilities)

Eastern Basin

Target Runoff Load : 24 ton/day in BOD
(in the year 2010) 0.8 ton/day in T-P

1) Sewage Treatment Plants (Primary Treatment) : US$ 65 millions
2) Sewage Treatment Plants (Tertiary Treatment) : US$ 55 millions
after Primary Treatment
3) Joint Treatment Plants for Sea-Product Processing Factories

Water Areas

1) Widening and Deepening the Channels

Fig. 16.9-1 Optimum Combination of Measures by Basin

17. Recommendations for the Implementation of the Master Plan

Important matters concerning the implementation of the Master Plan are as follows.

(1) Preparing a comprehensive development plan for the basin to go with the Master Plan

(2) Establishing a committee for the utilization and control of water resources in the basin

(3) Continuing the monitoring of and research on Guanabara Bay and its basin

(4) Raising funds to implement the Master Plan

(5) Defining the state agencies related to environmental administration and improving their finances

(6) Developing and applying new wastewater treatment technologies

(7) Establishing new social and economic systems to promote environmental improvement

(8) Raising resident awareness of the environment and promoting participation in improvement activities

18. Projects Recommended to be Subject to a Feasibility Study

Of the various measures proposed in the Master Plan, a study on the feasibility of the following eight projects were suggested since a concrete plan and the development of techniques should be hastened.

(1) Planning of the ocean outfall system

(2) Planning of the stabilization pond system

(3) Collection system for wastewater and solid waste in the favelas

(4) Joint treatment system for industrial wastewater

(5) Planning of the load reduction system in freshet time by retardation ponds and swirl separation tanks

(6) Planning for the water quality improvement of Jurujuba and Botafogo Bays

(7) Planning for widening and dredging of the channel west of Governador and Fundao islands

(8) Planning for land use zoning in the potentially critical sub-basins