JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

STATE SECRETARIAT OF PLANNING AND GENERAL COORDINATION,
PARANÁ STATE, THE FEDERATIVE REPUBLIC OF BRAZIL

THE MASTER PLAN STUDY ON
THE UTILIZATION OF WATER RESOURCES IN PARANÁ STATE
IN
THE FEDERATIVE REPUBLIC OF BRAZIL

FINAL REPORT

SECTORAL REPORT VOLUME I

WATER QUALITY AND SEWERAGE

December, 1995

Yachiyo Engineering Co., Ltd.
Tokyo, Japan

and

Nippon Koei Co., Ltd.
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1125401 (8)

Cost Estimate is Based
on The Price Level of August, 1994,
According to The Following Exchange Rate.

US$ 1.00 = ¥ 98.87
(as of August, 1994)

COMPOSITION OF FINAL REPORT

1. EXECUTIVE SUMMARY

2. MAIN REPORT
   - I. Strategy for Paraná State
   - II. Master Plan for Iguaçu River Basin
   - III. Master Plan for Tibagi River Basin

3. SECTORAL REPORT
   - A. Socio-economy
   - B. Meteorology, Hydrology and Surface Water Resources
   - C. Hydrogeology and Groundwater Resources
   - D. Domestic and Industrial Water
   - E. Agriculture
   - F. Hydroelectric Power Generation
   - G. Water Utilization Plan
   - H. Flood Control
   - I. Water Quality and Sewerage
   - J. Soil Erosion and Forest
   - K. Ecology
   - L. Water Environment Management
   - M. Institution
   - N. Cost Estimate, and Economic and Financial Assessment

4. DATA BOOK

THE MASTER PLAN STUDY ON
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IN THE FEDERATIVE REPUBLIC OF BRAZIL
SECTORAL REPORT VOL. I
WATER QUALITY AND SEWERAGE

TABLE OF CONTENTS

List of Tables

List of Figures

List of Abbreviation

CEPA	:	State Commission for Agricultural Planning *Comissão Estadual de Planejamento Agrícola*
COMEC	:	Coordination of the Metropolitan Area of Curitiba *Coordenação da Região Metropolitana de Curitiba*
CONAMA	:	National Council of Environment *Conselho Nacional do Meio Ambiente*
COPATI	:	Inter Municipal Concessionaire for the Environmental Protection of the Tibagi River Basin *Consórcio Intermunicipal para a Proteção Ambiental de Bacia do Rio Tibagi*
COPEL	:	Energy Company of the State of Paraná *Companhia Pananaense de Energia*
CORPRERI	:	Permanent Regional Commission Against Floods in the Iguaçu River *Comissão Regional Permanente Contra as Cheias do Rio Iguaçu*
DAGRI	:	Agricultural Operation Department *Departamento Operacional da Agricultura*
DEPEC	:	Livestock Department *Departamento de Pecuária*
DERAL	:	Economy Department *Departamento de Economia*
DNAEE	:	National Department of Water and Electric Energy *Departamento Nacional de Águas e Energia Elétrica*
ELETROBRAS	:	Brazilian Central Electric Joint-stock Company *Centrais Elétricas Brasileiras S.A.*
ELETROSUL	:	Electric Center of the South *Centrais Elétricas do Sul do Brasil S.A.*
EMATER	:	Paraná State Technical Assistance and Rural Extension Company *Empresa Paranaense de Assistência Técnica e Extensão Rural*
EMBRAPA	:	Brazilian Agriculture and Livestock Research Company *Empresa Brasileira de Pesquisa Agropecuária*

FAMEPAR	:	Institute for Municipal Assistance of Paraná State *Instituto de Assistência aos Municípios do Estado do Paraná*
FAO	:	Food and Agriculture Organization *Fundo das Nações Unidas para Alimentação e Agricultura*
IAP	:	Environmental Institute of Paraná *Instituto Ambiental do Paraná*
IAPAR	:	Agricultural Research Institute of Paraná *Instituto Agronômico do Paraná*
IBAMA	:	Brazilian Institute of Environment and Renewable Natural Resources *Instituto Brasileiro do Meio Ambiente e de Recursos Naturais Renováveis*
IBDF	:	Brazilian Forest Development Institute (current IBAMA) *Instituto Brasileiro de Desenvolvimento Florestal*
IBGE	:	Brazilian Institute of Geography and Statistic *Instituto Brasileiro de Geografia e Estatística*
IPARDES	:	Economic and Social Development Institute of the State of Paraná *Instituto Paranaense de Desenvolvimento Econômico Social*
JICA	:	Japan International Cooperation Agency *Agência de Cooperação Internacional do Japão*
MERCOSUL	:	South Common Market in Brazil, Argentina, Uruguay and Paraguay *Merca do Cone Sul*
MINEROPAR	:	Paraná State Mineral Company *Minerais do Paraná S/A*
PROSAM	:	Environmental Sanitation Program for Curitiba Metropolitan Region *Programa de Saneamento de Região Metropolitan de Curitiba*
SANEPAR	:	Sanitation Company of the State of Paraná *Companhia de Saneamento do Paraná*
SEAB	:	State Secretariat of Agriculture and Supply *Secretaria de Estado da Agricultura e do Abastecimento*
SEDU	:	State Secretariat of Urban Development *Secretaria de Estado do Desenvolvimento Urbano*

SEFA	:	State Secretariat for Treasury Secretaria de Estado da Fazenda
SEID	:	State Secretariat for Industry, Commerce and Economic Development *Secretaria de Estado da Indústria, Comércio e do Desenvolvimento Econômico*
SEMA	:	State Secretariat of Environment *Secretaria de Estado do Meio Ambiente*
SEPL	:	State Secretariat of Planning and General Coordination *Secretaria de Estado do Planejamento e Coordenação Geral*
SETR	:	State Secretariat of Transport *Secretaria de Estado dos Transportes*
SIMEPAR	:	Meteorological System of Paraná *Sistema Meteorológico do Paraná*
SETI	:	State Secretariat of Science, Technology and Higher Education *Secretaria de Estado da Ciência, Technologia e Ensino Superior*
SUCEAM	:	Superintendency of Erosion Control and Environmental Sanitation *Superintendência do Controle de Erosão e Saneamento Ambiental*
SUREHMA	:	Superintendency of Water Resources and Environment *Superintendência dos Recursos Hidricos e Méio Ambriente*
UEL	:	State University of Londrina *Universidade Estadual de Londrina*
UNDP	:	United Nation Development Program *Programa das Nações Unidas para o Desenvolvimento*

CHAPTER 1 INTRODUCTION

1.1 Objectives of the Study

The objectives of the study on water quality and sewerage are as follows:

1. To understand the present condition of river water quality in the Study area.
2. To evaluate the present condition of water pollution on the basis of Brazilian environmental standards about water quality.
3. To predict future water quality (2005 and 2015) by pollution analysis.
4. To formulate a plan of river water quality improvement toward the target year of 2015.

1.2 Contents of the Study

Figure-1.1 shows the flow-chart of the study on water quality and sewerage. The Study consists of 2 stages, Strategy study and Master plan study.

(1) Strategy Study

In the Strategy study, firstly the present condition of water quality was studied through data collection and review. Secondly, river water quality in 2005 and 2015 was predicted on the basis of pollution analysis.

Furthermore, the characteristics and problems of water quality in each river basin were identified, and plans for pollutant load reduction and water quality improvement were worked out toward the target year of 2015.

(2) Master Plan Study

On the basis of the Strategy study, pilot basins were selected. The second stage of the study, i.e. the Master plan study was conducted for formulating detailed plans for water quality improvement in the pilot basins. Water quality simulation was carried out in this study.

1.3 Study Area

The Study area covers the whole Paraná State, including 11 river basins as shown in Table-1.1 and Figure-1.2.

Table-1.1 River Basin in Paraná State

River Name	Basin Area (km^2)
Cinzas	9,291
Iguaçu	55,318
Itarare	5,198
Ivai	35,879
Litoranea	5,766
Paraná	13,156
Paranapanema	9,797
Piquiri	24,708
Pirapo	5,006
Ribeira	9,129
Tibagi	24,635
Total	197,882

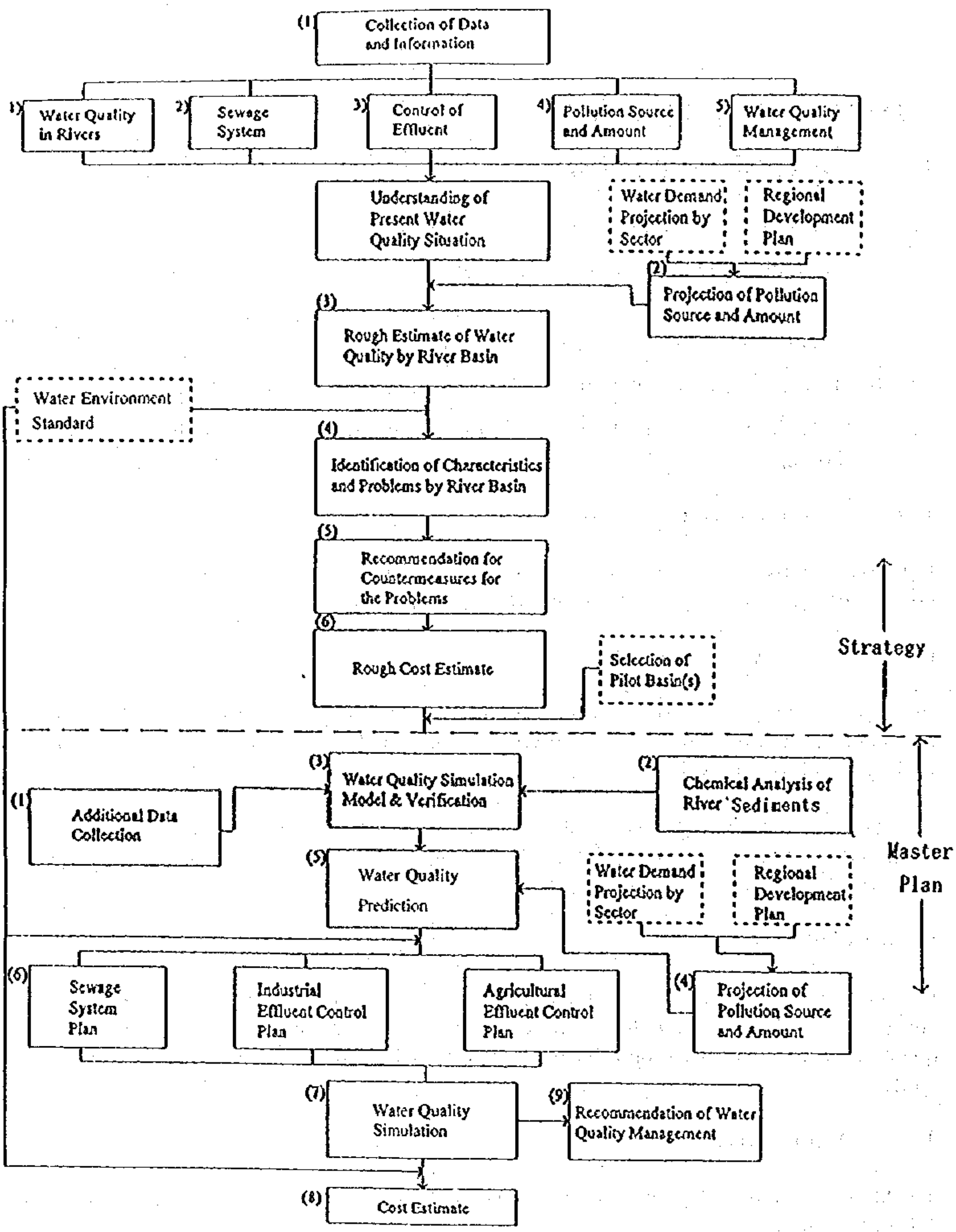


Figure-1.1 Flow Chart of Water Quality Study

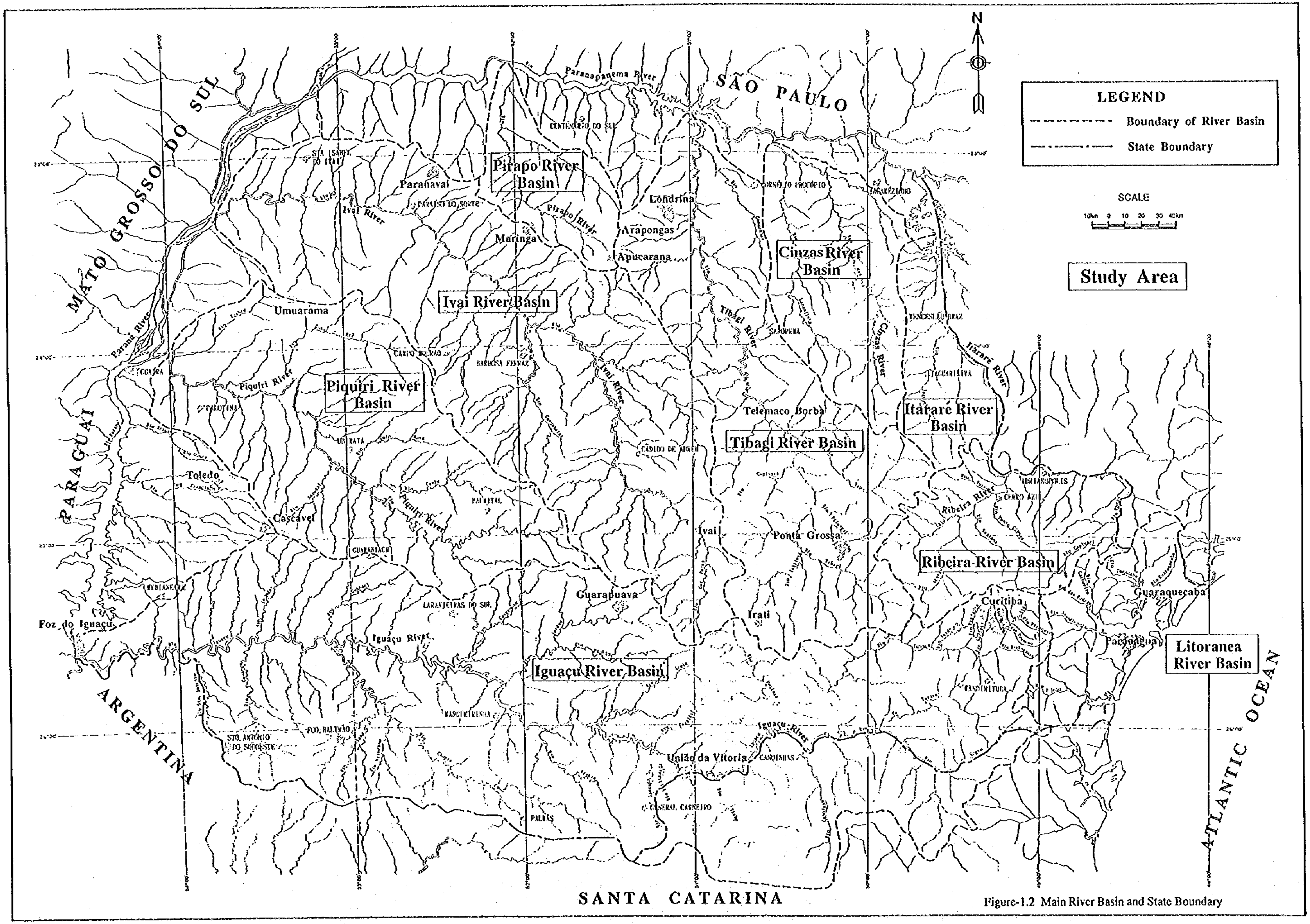


Figure-1.2 Main River Basin and State Boundary

CHAPTER 2 BASIC STUDY

2.1 Natural Conditions

(1) Rainfall

Annual rainfall varied by region and year and was recorded as 1400 - 2400 mm/year during the 20 years from 1974 to 1993 in Paraná State with an average value of 1700 mm/year. The rainy season is usually in summer from December to January.

(2) Temperature

In Paraná State the annual mean temperature was between 16 °C and 22 °C and averaged as 20 °C according to the data of 1974 to 1993. The highest temperature observed during these 20 years was 41.5 °C at Paranavai, and the lowest temperature was -6.8 °C at Palmas.

(3) Wind Direction and Wind Velocity

During the 20 years from 1974 to 1993, wind direction in Paraná State as a whole was north in January (rainy season, summer), while that in July (dry season) was north-east.

Mean wind velocity was stable throughout a year, as 2.0 to 5.0 m/sec.

2.2 Current Conditions of Water Quality and Sewerage System

2.2.1 Water Quality

(1) Water Quality Observation Data

In this study, "Result of the Study on the Water Quality in Paraná State" prepared by SUREHMA (the former IAP) was used as the major data source on water quality. These data were based on the water quality monitoring conducted from 1982 to 1993 for the 11 rivers in Paraná State. Figure-2.1 shows the locations of the 152 observation stations.

The items of water quality monitoring include water temperature, DO, fecal coliform, pH, BOD, T-N, T-P, turbidity and T-S. Table-2.1 shows the maximum and minimum values of each water quality item by river basin.

1) Water Temperature

   Water temperature varied seasonally. The range of water temperature observed in the 11 river basins was similar, and was between 15 °C and 25 °C during the 12 years.

2) Dissolved Oxygen (DO)

   DO is a parameter relating to the degree of organic pollution. It usually shows a reverse correlation with BOD.

   In most of the rivers, the maximum DO was about 10 mg/l. However, the values varied in a broad range in some rivers such as Iguaçu and Paranapanema where the minimum DO of 0.10 mg/l was observed.

Table-2.1 River Water Quality Observation Data (1982 ~ 1993)

River Basin	Temp (°C)		DO (°C)		Fecal Coliform (MPN/100 ml)		pH		BOD (mg/l)		T-N (mg/l)		T-P (mg/l)		Turbididy (JTU)		T-S (mg/l)	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
CINZAS	25.6	20.6	9.80	7.10	49,000	13	8.3	6.7	4	1	1.99	0.12	0.53	0.01	210	3.2	408	22
IGUAÇU	24.8	15.3	12.26	0.10	999,999	2	10.0	6.0	564	1	53.76	0.01	11.48	0.00	440	0.4	2,926	6
ITARARE	26.0	20.0	9.46	3.61	920,000	5	7.8	6.2	10	1	9.30	0.10	0.17	0.01	142	2.0	2,183	58
IVAI	24.5	17.0	10.72	3.63	999,999	2	9.5	6.5	9	1	2.08	0.01	0.59	0.00	550	0.4	520	25
LITORANEA	22.5	18.5	11.34	3.72	54,000	14	7.9	5.9	12	1	2.03	0.01	0.32	0.01	106	1.0	220	11
PARANÁ	23.3	19.3	11.36	6.58	350,000	33	7.8	6.9	5	1	1.10	0.01	0.22	0.01	130	15.0	269	53
PARANAPANEMA	26.0	23.5	8.96	0.10	7,900	7	8.1	7.1	6	1	1.73	0.05	0.71	0.00	77	15.0	213	51
PIQUIRI	23.8	18.2	10.28	3.22	500,000	4	9.3	4.9	5	1	5.50	0.01	1.39	0.01	350	0.3	441	20
PIRAPO	24.5	17.0	10.12	7.46	540,000	90	8.0	7.0	3	1	10.00	0.11	0.77	0.01	188	8.0	256	70
RIBEIRA	18.3	17.0	10.70	7.00	540,000	70	8.4	7.1	3	1	1.60	0.01	0.19	0.00	95	3.0	2,385	29
TIBAGI	25.4	17.3	10.96	3.40	700,000	2	9.9	6.0	13	1	5.10	0.56	0.43	0.01	1,160	2.0	910	4

Source: Arranged by Study Team by using the Data from IAP

3) Fecal Coliform

In river water, there usually exist several thousand fecal coliform bacteria in a 100 ml sample. A higher count of fecal coliform indicates that the water may have been contaminated by pathogenic bacteria from soil wastes of human beings as well as livestock.

In Cinzas, Litoranea and Paranapanema River basins, the maximum fecal coliform counts were in the orders of 10^3 - 10^4 , and water was less contaminated. However, in the other river basins, higher fecal coliform counts (10^5) show the contamination of river water by pathogenic bacteria.

4) pH

In surface waters, pH value is usually between 6 and 9. The highest value of pH 10 was observed in Iguaçu river basin and 9.9 in Tibagi river basin. In the other river basins, pH was within the normal range.

5) Biological Oxygen Demand (BOD)

BOD is an index which shows the amount of organic pollutant substances in a water sample, and the normal value of BOD is 1~3 mg/l for river waters.

The extremely high value of 564 mg/l was observed in Iguaçu river basin, and the maximum BOD of over 10 mg/l was observed in Itarare, Litoranea, and Tibagi basins. However, those high BOD values were not observed continuously but only occasionally.

6) Total Nitrogen (T-N) and Total Phosphate (T-P)

T-N includes nitrate (NO_3-N), nitrite (NO_2-N), ammonium (NH_4-N) and organic nitrogen (Org.-N).

In natural waters, T-N and T-P are indicators of eutrophication. Higher T-N and T-P were only observed in Iguaçu river basin, because of its heavier organic pollution as was shown by the higher BOD.

7) Turbidity

Turbidity becomes higher during flood season. In Paraná state the maximum turbidity of river water was usually about one to several hundred JTU except the highest value of 1,160 JTU happened in Tibagi river basin.

8) Total solid (T-S)

T-S indicates the total solid substances including dissolved solids and suspended solids in a water.

A higher T-S than 2,000 mg/l was observed in Iguaçu, Itarare, and Ribeira rivers. This indicated that an inflow of salinity may have happened occasionally in these rivers.

(2) Characteristic Water Quality Parameter

As a result of the review of the water quality observation data, it is found that there exists a correlative relationship among most of the water quality items, especially those relating to organic pollution, such as DO, BOD, T-N, T-P. For instance, in the Iguaçu river as the highest BOD has been recorded, the highest T-N and T-P and the lowest DO have been recorded as well. Therefore, a parameter can be chosen from them to characterize the water quality in a river basin. Because organic pollution from both domestic sewage and industrial wastewater are the main sources of water pollution in Paraná State, BOD is such chosen as the characteristic water quality parameter for pollution analysis in this study.

(3) River Water Quality Characterized by BOD

Figure-2.2 shows the maximum, average and minimum BOD values at each of the observation stations in the 11 river basins.

In Brazil, the quality of river water is classified by BOD concentration as follows:

A) Class 1 - BOD less than 3 mg/l

B) Class 2 - BOD 3-5 mg/l

C) Class 3 - BOD 5-10 mg/l

D) Class 4 - BOD more than 10 mg/l

It can be seen from Figure-2.2, in most of the rivers, water quality can meet class 1 or class 2. The most polluted river basin is Iguaçu (2), i.e. the upper Iguaçu basin where BOD was higher than 10 mg/l. This is due to the high pollutant load of domestic sewage and industrial wastewater from Curitiba M.A.

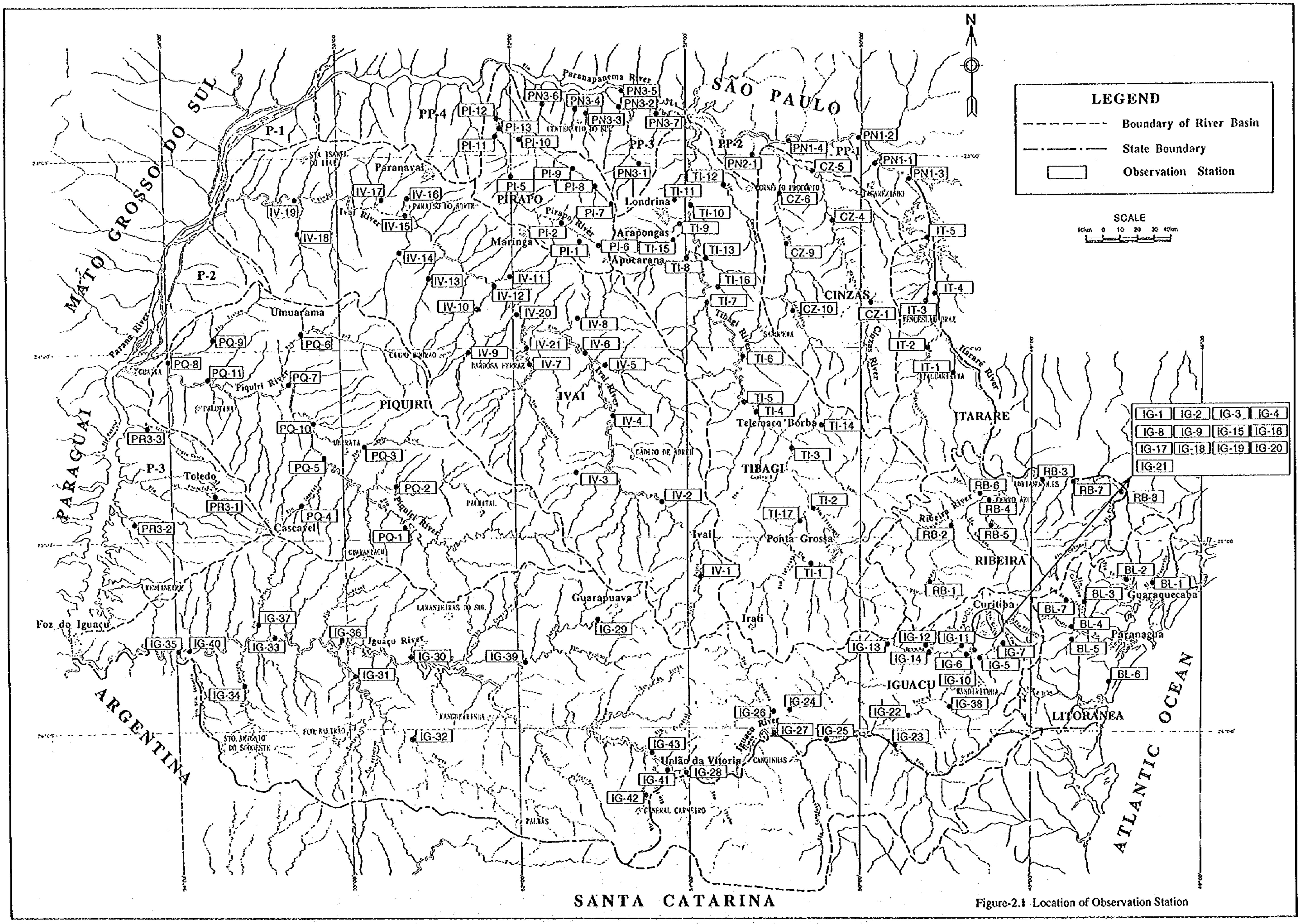
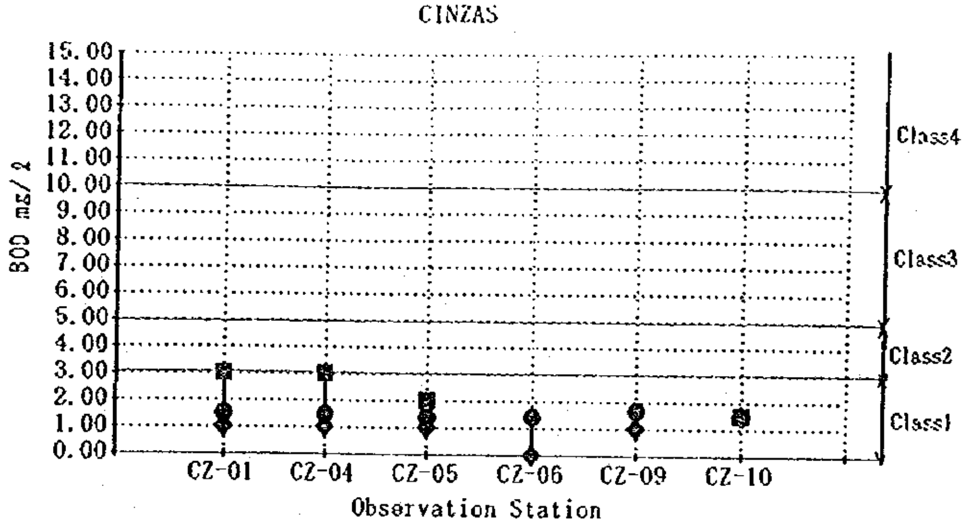
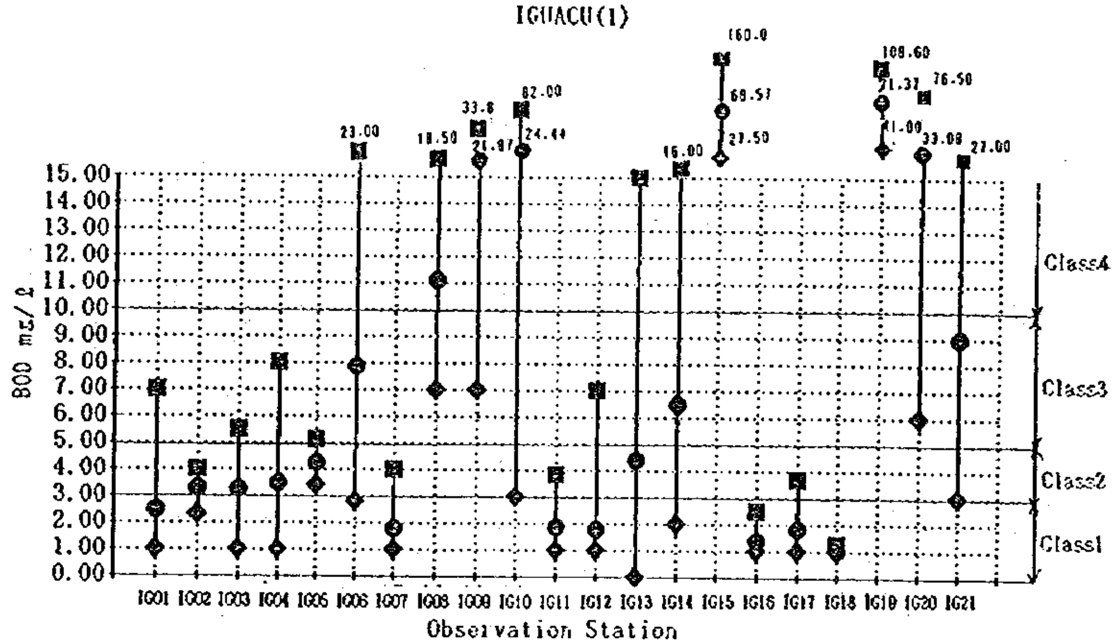
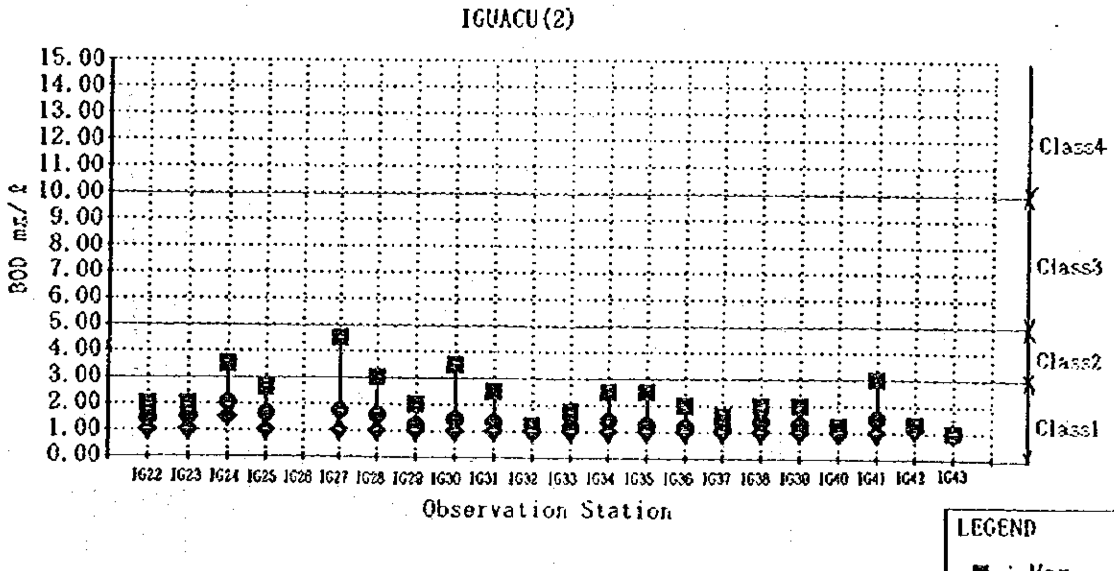


Figure-2.1 Location of Observation Station







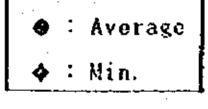


Figure-2.2 BOD (Max, Mean, Min.) of River Water in Paraná State (1)

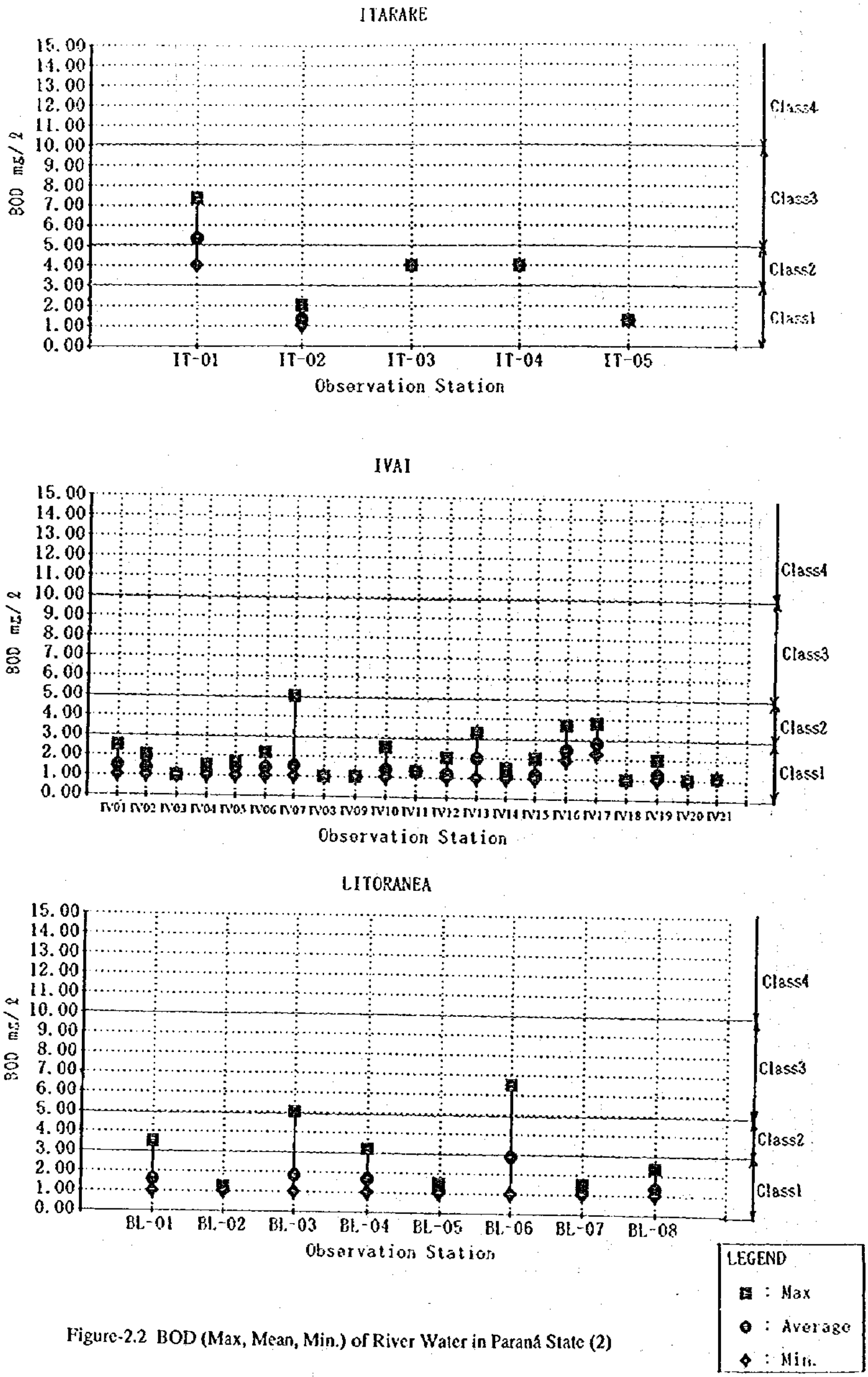


Figure-2.2 BOD (Max, Mean, Min.) of River Water in Paraná State (2)

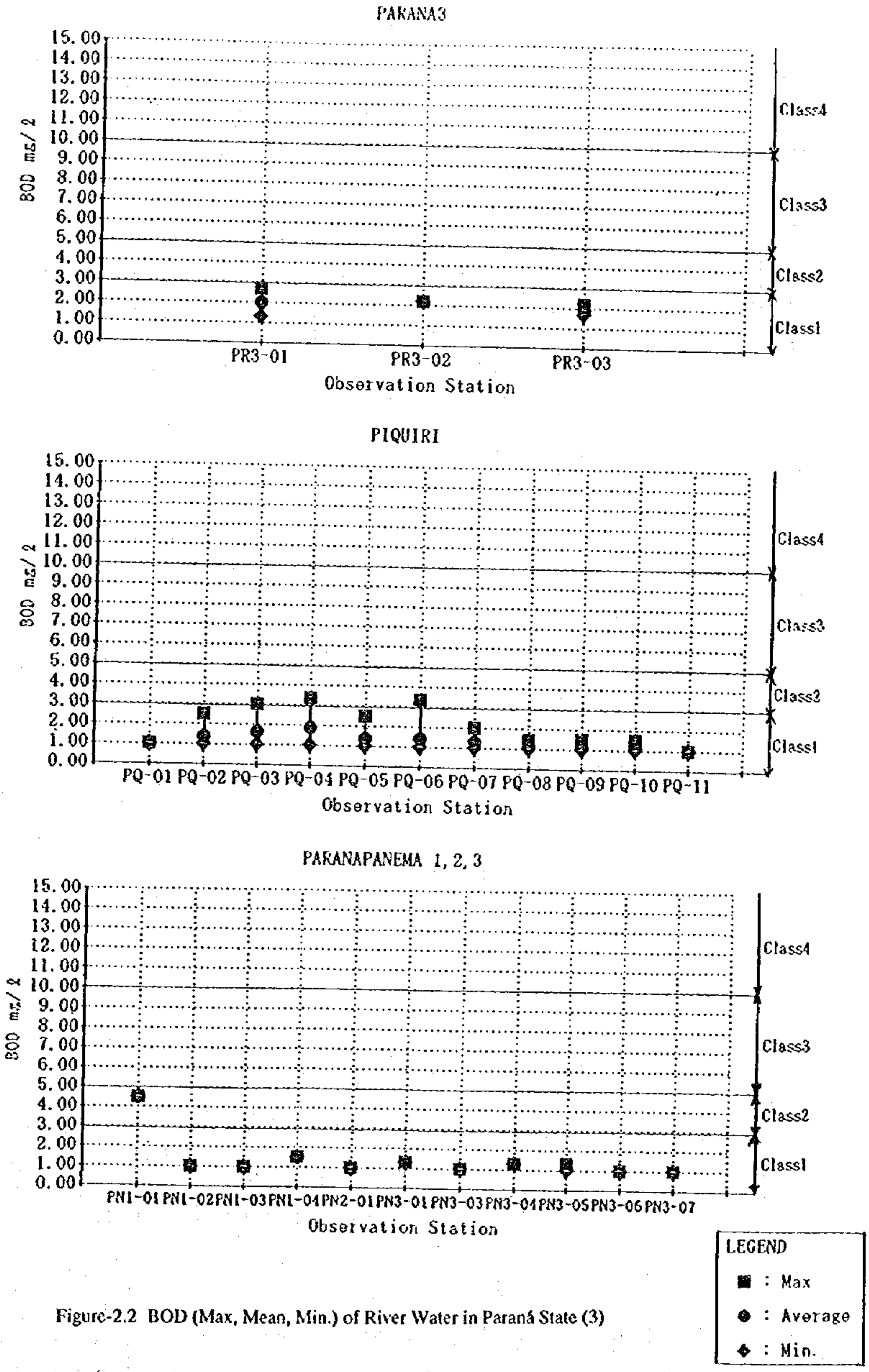
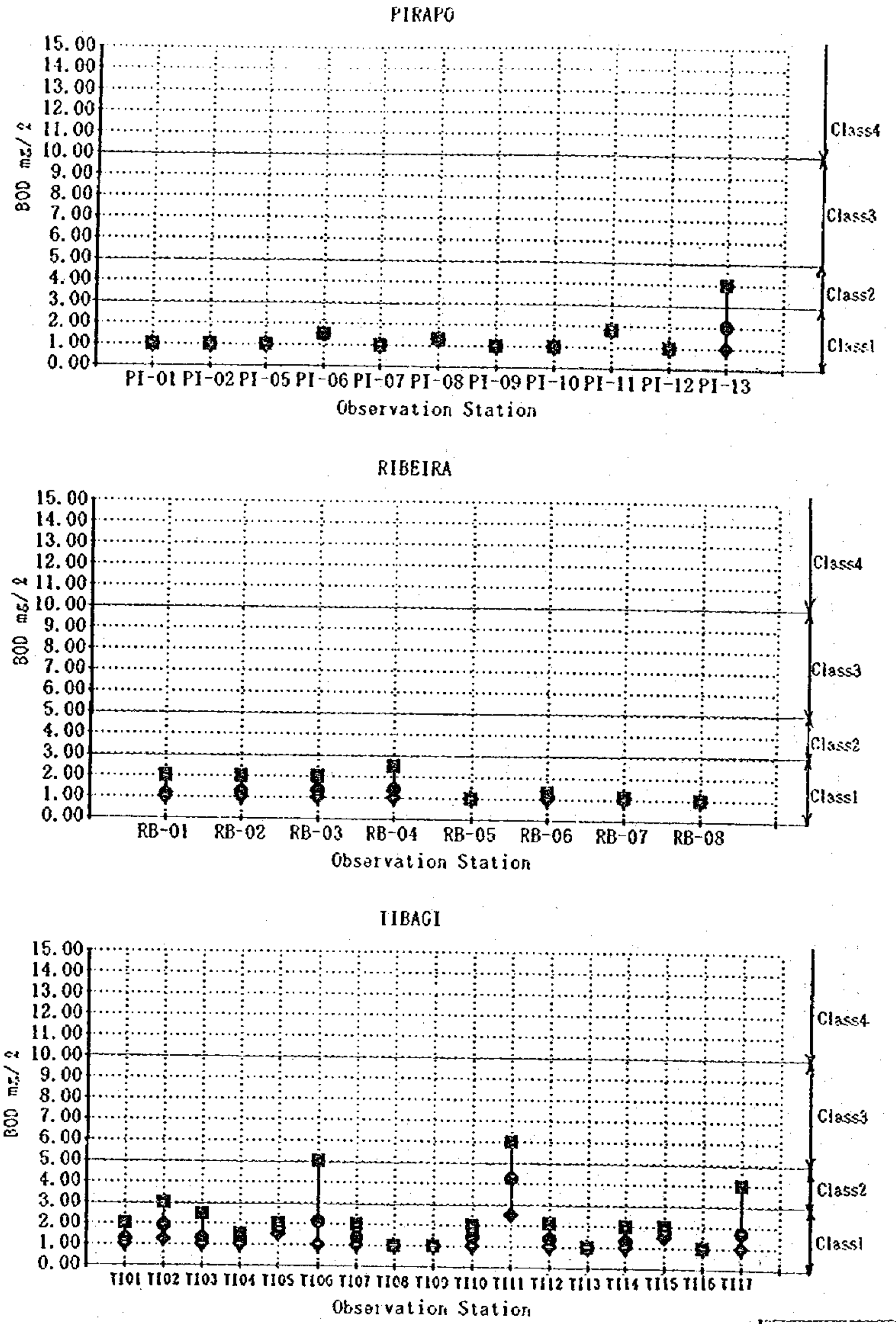


Figure-2.2 BOD (Max, Mean, Min.) of River Water in Paraná State (3)



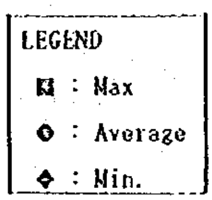


Figure-2.2 BOD (Max, Mean, Min.) of River Water in Paraná State (4)

2.2.2 Water Environmental Standards

(1) Water Quality Standards

On 18 July, 1986, Water Environmental Standards were put forward by National Environment Council (CONAMA Resolution No. 20). The standards classified the quality of natural waters such as rivers, lakes and so on according to the purpose of water utilization. As shown in Table-2.2, there are 9 classes for water quality: classes 1 to 4 for freshwater; classes 5 and 6 for saline water; classes 7 and 8 for brackish water; and special class in addition to them.

Table-2.2 Water Quality Standards in Brazil

Items	Fresh Water				Saline Water		Brackish Water	
	class 1	class 2	class 3	class 4	class 5	class 6	class 7	class 8
a) Floating Matter (mg/l)	V.A *	V.A *	V.A *	V.A *	V.A *	V.A *	---	V.A *
b) Suspended Solids (mg/l)	---	---	---	---	---	---	---	---
c) Fecal Coliform (ind. 100 ml)	< 200	< 1,000	< 4,000	< 4,000	< 1,000	< 4,000	< 1,000	< 4,000
d) Total Coliform (ind. 100 ml)	< 1,000	< 5,000	< 20,000	> 20,000	< 5,000	< 20,000	< 5,000	< 20,000
e) BOD_5 (mg/l)	< 3	< 5	< 10	> 10	< 5	< 10	< 2	---
f) DO (mg/l)	> 6	> 5	> 4	> 2	> 6	> 4	> 5	> 3
g) pH	6.0~9.0	6.0~9.0	6.0~9.0	6.0~9.0	6.5~8.5	6.5~8.5	6.5~8.5	6.5~8.5

* V.A: Virtually absent

Special Class: Fresh water whose total coliform is absent in any sample taken for water supply without disinfection.

(2) Wastewater Discharge Regulation

According to CONAMA Resolution No. 20, the quality of industrial wastewater to be discharged into a water body has been regulated as shown in Table-2.3. For comparison, Japanese regulations are also shown in the table.

Table-2.3 Industrial Wastewater Discharge Regulations

Item			Brazil Industries	Japanese Industries
a)	pH		5 ~ 9	5.8 ~ 8.6
b)	Temprature	(°C)	< 40	< 40
c)	Sedimentable Materials	(ml/l)	V.A. *	---
d)	BOD	(mg/l)	---	160
e)	COD	(mg/l)	---	160
f)	SS	(mg/l)	---	200
g)	Oil, Grease : Mineral	(mg/l)	20	5
	: Vegetable	(mg/l)	50	30
h)	NH_4-N	(mg/l)	5.0	---
	T-As	(mg/l)	0.5	0.5
	Ba	(mg/l)	5.0	---
	B	(mg/l)	5.0	---
	Cd	(mg/l)	0.2	0.1
	CN	(mg/l)	0.2	1.0
	Pb	(mg/l)	0.5	1.0
	Cu	(mg/l)	1.0	3.0
	Cr^{3+}	(mg/l)	2.0	2.0
	Cr^{6+}	(mg/l)	0.5	0.5
	Sn	(mg/l)	4.0	---
	Phenol	(mg/l)	0.5	5.0
	Soluble Fe	(mg/l)	15.0	10.0
	F	(mg/l)	10.0	15.0
	Soluble Mn	(mg/l)	1.0	10.0
	Hg	(mg/l)	2.0	---
	Ni	(mg/l)	0.1	---
	Ag	(mg/l)	0.1	---
	Se	(mg/l)	0.05	---
	S	(mg/l)	1.0	---
	SO_3	(mg/l)	1.0	---
	Zn	(mg/l)	5.0	5.0
	Parathion	(ng/l)	1.0	1.0
	Carbon Sulfide	(ng/l)	1.0	---
	Tri Chlorine	(ng/l)	1.0	0.3
	Chroroform	(ng/l)	1.0	---
	Tetra Carbon Chloride	(ng/l)	1.0	0.1
	Dichloride	(ng/l)	1.0	---
	Other Pesticide	(ng/l)	0.05	---
	Harmful Matter	(ng/l)	N.D.	---
	Coliform	(Ind./ml)	---	3,000
	T-N	(mg/l)	---	120
	T-P	(mg/l)	---	16

* : Virtually absent

2.2.3 Sewerage System

(1) Sewer System

In Paraná state, only urban areas are served by sewer systems, and the percentage of the served population differs with river basin. According to the data of 1990 provided by SANEPAR, the lowest percentage was 1.2 % in Ribeira river basin while the highest percentage was 46.8 % in Paranapanema river basin. The average percentage of population served by sewer system in Paraná state was 23.5%.

Table-2.4 shows the population served by sewer system in each of the river basins in Paraná state.

Table-2.4 Population Served by Sewer System

Basin	Population		Served Population			
	Total	Urban Area	Total	(%)	Urban	(%)
Cinzas	282,630	143,970	38,634	13.7	38,634	26.8
Iguaçu	4,130,764	3,282,544	834,309	20.2	834,309	25.4
Itarare	110,254	51,869	7,733	7.0	7,733	15.0
Ivai	1,283,663	710,830	96,888	7.5	96,888	13.6
Litoranea	156,525	120,156	19,134	12.2	19,134	15.9
Paraná	726,857	524,253	63,911	9.6	63,911	13.3
Paranapanema	334,329	214,540	63,441	19.0	63,441	46.8
Piquiri	898,952	525,498	41,764	4.6	41,764	7.9
Pirapo	375,026	306,482	69,070	18.4	69,070	22.5
Ribeira	52,489	52,765	621	0.4	621	1.2
Tibagi	1,366,884	1,084,922	415,858	30.4	415,858	38.3
Total	9,718,373	7,017,829	1,651,363	16.8	1,651,363	23.5

Source: SANEPAR, Water and Sewer Autonomous service and SUREHMA

(2) Sewage Treatment

According to the data of 1990 provided by SANEPAR, the percentage of urban population served by sewage treatment was 15.4 % in Paraná state and 15.6 % in Curitiba metropolitan.

2.2.4 Industrial Wastewater Treatment

Most of the industries in Paraná state are equipped with wastewater treatment facilities. Table-2.5 shows the current condition of industrial wastewater treatment, and Table-2.6 shows the quantity and quality of industrial effluent from some of the industries, according to the data of 1992 provided by IAP. On the average, BOD removal ranges between 83 and 100 % in all the river basins except a lower removal of 65 % in Iguaçu river basin. The average BOD removal in Paraná state is 97 %. Although the BOD removal is comparatively high on average, there are still some industries from which industrial effluents of high BOD concentration are discharged to rivers. The effluents from some paper mills and tanners have a BOD concentration as high as 600-800 mg/l.

Table-2.5 Current Condition of Industrial Wastewater Treatment

No.	River Basin	No. of Industry	Influent BOD (kg/day)	Effluent BOD (kg/day)	Reduction (%)	Effluent Volume (m^3/day)
1	Cinzas	23	202,092	975	100	15,623
2	Iguaçu	128	51,861	18,000	65	61,733
3	Itarare	11	15,277	2,602	83	5,209
4	Ivai	117	561,583	6,723	99	92,005
5	Litoranea	3	482	49	90	496
6	Paraná	26	65,084	4,324	93	17,467
7	Paranapanema	36	539,349	3,757	99	40,844
8	Piquiri	42	179,428	2,907	98	16,042
9	Pirapo	31	430,459	6,886	98	44,918
10	Ribeira	1	34	1	97	30
11	Tibagi	74	118,899	15,568	87	110,931
Total (Average)		492	2,164,548	61,792	(97)	405,298

Souce: IAP (1992)

Table-2.6 Industrial Wastewater Effluent from Some Industries

River Basin	Type of Industry	No. of Industry	Effluent BOD (kg/day)	Eff. Vol. (m^3/day)	Eff. BOD Con. (mg/l)
Cinzas	distillation	5	562	12,653	44
Iguaçu	paper	23	14,357	21,186	678
	slaughter house	8	929	12,627	74
	dairy	20	966	2,277	424
	tanner	8	856	1,749	489
Itarare	paper	5	2,586	5,130	504
Ivai	distillation	13	3,106	59,736	52
	slaughter house	3	293	625	469
	tanner	7	2,342	3,872	605
Litoranea	oil	2	49	495	99
Paraná	starch	6	3,337	8,285	403
	tanner	3	704	825	853
Paranapanema	distillation	9	2,666	33,800	79
Piquiri	distillation	3	1,519	4,200	362
Pirapo	distillation	5	3,656	36,000	102
	tanner	5	2,643	4,400	601
Ribeira	---	---	---	---	---
Tibagi	paper	7	13,020	81,200	160
	dairy	11	632	4,936	128
	refrigerator	9	627	4,408	142
	textile	7	696	10,492	66

Source: IAP (1992)

CHAPTER 3 POLLUTION ANALYSIS

3.1 Current Conditions of Pollutant Loads and Future Predictions

3.1.1 Pollution Sources and Pollutant Run-off

Generally speaking, pollutants discharged into rivers are from artificial and natural sources. The artificial source includes domestic sewage, industrial wastewater and livestock wastes, and the natural source includes the pollutants derived by ecological phenomena and so on. Figure-3.1 shows these pollution sources and the processes of pollutant run-off to rivers.

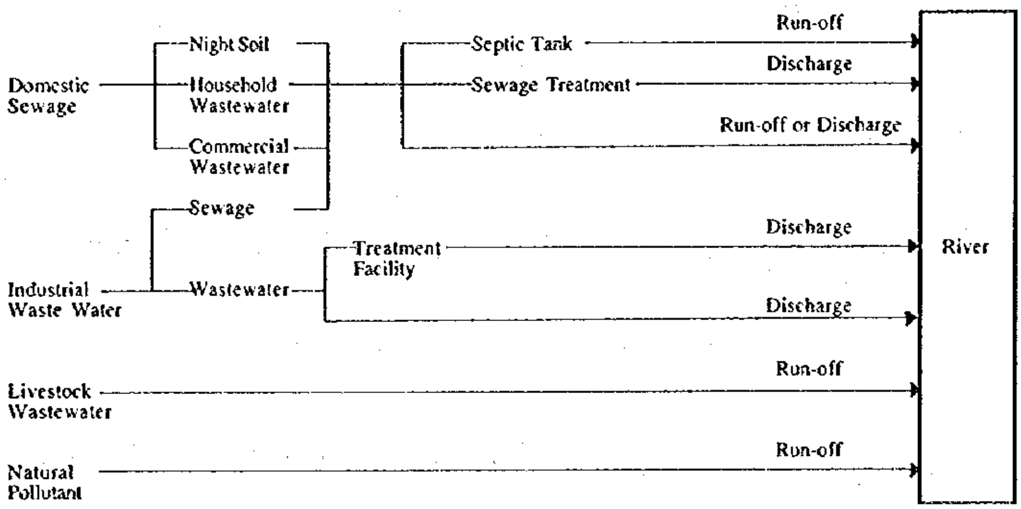


Figure-3.1 Pollutant Loads and Their Run-off

3.1.2 Pollutant Load from Domestic Sewage

(1) Pollutant Load Factor

a) Household Sewage

Sewage from a household includes household wastewater and night soil. Table-3.1 shows the pollutant load factors of this kind according the data provided by SANEPAR. These data are currently used for sewerage planning.

Table-3.1 Pollutant Load Factors of Domestic Sewage

Sewage Quantity	100~120 l/P•day
BOD Load	54 g/P•day
SS Load	300 mg/l

The sewerage quantity in the table is about 80% of the planned water consumption.

b) Commercial wastewater

Commercial wastewater includes wastewater from restaurants, offices, hotels, etc. Generally speaking, the population in the metropolitan areas may be different in daytime and night time due to commercial activities. If it is so, in addition to the household sewage, pollutants from the commercial wastewater must be taken into account. However, since the population in Curitiba M.A. and other urban areas does not vary greatly between day time and night time, it is thought that the commercial wastewater has not to be calculated separately, and the pollutant load of this kind is included in the domestic sewage calculated by using the pollutant load factors shown in Table-3.1.

(2) Calculation of Pollutant Loads

1) Calculation method

The methods to calculate the pollutant loads from domestic sewage are as follows:

a) When sewage treatment is not provided

If sewage treatment is not provided, the discharge pollutant load shall be calculated as follows:

Discharge load = Pollutant Load Factor x Population

b) When sewage treatment is provided

If sewage treatment is provided, the discharge pollutant load shall be calculated as follows:

Pollution load = Pollutant Load Factor x Population served x (1 - BOD removal rate)

The BOD removal rate varies with sewage treatment method as is shown Table-3.2.

Table-3.2 Sewage Treatment Methods and BOD Removal

	Treatment Method	BOD Red. (%)
a	Activated Sludge Method	95
b	Anaerobic Digestion (RALF)	75
c	Anaerobic Dige. + Aerobic Treat.	80
d	Decanter + Anaerobic D.	85
e	Imhoff Tank	45
f	Stabilization Pond	70
g	Trickling Filter (1 set)	65
h	Anaerobic Digest. + Stabilization Pond	80
i	Lagoon Pond	80

2) Pollutant load in 1993

a) Population data

The urban and rural populations by river basin in 1993 are shown in Table-3.3.

Table-3.3 Population by River Basin (1993)

River Basin	Urban	Rural	Sub Total
Cinzas	173,259	103,079	276,338
Iguaçu	2,606,871	677,585	3,284,456
Itarare	73,946	39,017	112,963
Ivai	759,404	398,374	1,157,778
Litoranea	146,600	41,137	187,737
Paraná	530,615	151,377	681,992
Paranapanema	283,653	77,706	361,359
Piquiri	410,525	305,258	715,783
Pirapo	366,357	48,163	414,520
Ribeira	60,394	82,895	143,289
Tibagi	1,048,084	214,796	1,262,880
Total	6,459,708	2,139,387	8,599,095

b) Pollutant load

Table-3.4 shows the discharge pollutant load from domestic wastewater in each river basin in 1993.

Table-3.4 Domestic Sewage Discharge Loading (1993)

River Basin	Urban Area																				Rural Area	
	Population (1000 P.)	Served Population (%)									BOD Removal (%)									BOD Load (kgBOD/d)	Population (1000 P.)	BOD Load (kgBOD/d)
		a	b	c	d	e	f	g	h	i	a	b	c	d	e	f	g	h	i			
Itarare	73.9																			3,991	39.0	2,106
Cinzas	173.3																			9,358	103.1	5,567
Tibagi	1,048.1	7.2	5.5	14.3	7.2	0.3	0.4	0.2	12.4		95	75	80	85	45	70	65	80	80	34,530	214.8	11,599
Pirapo	366.4																			19,786	48.2	2,603
Ivai	759.4																			41,008	398.4	21,514
Piquiri	410.5																			22,167	305.3	16,486
Iguaçu	2,606.9	19.2	8.2							2.6	95	75							80	103,510	677.6	36,590
Riberia	60.4																			3,262	82.9	4,477
Litoranea	146.6																			7,916	41.1	2,219
Paraná	530.6																			28,652	151.4	8,176
Paranapanema	283.7																			15,320	72.1	3,893

Note: a~i represent sewage treatment methods shown in Table-3.2.

(3) Pollutant Loads in 2005 and 2015

The pollutant loads from domestic sewage are predicted for the years of 2005 and 2015.

1) Population Data

Future populations were estimated by the JICA Study Team as shown in Table-3.5.

Table-3.5 Population in 2005 and 2015 by River Basin

River Basin	2005			2015		
	Urban	Rural	Sub Total	Urban	Rural	Sub Total
Cinzas	214,914	63,793	278,707	255,628	39,594	295,222
Iguaçu	3,403,571	574,021	3,977,592	4,064,912	473,499	4,538,411
Itarare	123,872	26,210	150,082	197,088	17,627	214,715
Ivai	954,663	259,819	1,214,482	1,128,079	179,749	1,307,828
Litoranea	179,800	39,562	219,362	207,400	35,502	242,902
Paraná	729,104	86,797	815,901	890,612	50,767	941,379
P.Panema	343,800	41,562	385,362	394,702	22,605	417,307
Piquiri	535,095	192,480	727,575	641,981	126,787	768,768
Pirapo	477,424	23,871	501,295	566,505	12,188	578,693
Ribeira	79,999	73,760	153,759	97,080	61,647	158,727
Tibagi	1,310,207	158,042	1,468,249	1,528,114	118,502	1,646,616
Total	8,352,449	1,539,917	9,892,366	9,972,101	1,138,467	11,110,568

2) Pollutant Load

The pollutant loads from domestic sewage in 2005 and 2015 are calculated and the results are shown in Tables-3.6 and 3.7. In order to predict the river water quality in the future if no improvement is made in sewage treatment, the population served by sewage treatment is taken as the same as that in 1993 in the calculation. Since the total population will increase, the served percentages shown in Tables-3.6 and 3.7 become lower.

Table-3.6 Domestic Sewage Discharge Loading (2005)

River Basin	Urban Area																			Rural Area	
	Population	Served Population (%)									BOD Removal Rate (%)										
	(1000 P.)	a	b	c	d	e	f	g	h	i	a	b	c	d	e	f	g	h	i	(kgBOD/d)	(1000 P.)	(kgBOD/d)
Itarare	123.9																			6,691	26.2	1,415
Cinzas	214.9																			11,605	63.8	3,445
Tibagi	1,310.2	5.7	4.4	11	5.7	0.3	0.3	0.2	9.9		95	75	80	85	45	70	65	80	80	48,765	158.0	8,532
Pirapo	477.4																			25,780	23.9	1,291
Ivai	954.7																			51,554	255.9	13,819
Piquiri	535.1																			28,895	192.5	10,395
Iguaçu	3,403.6	15	6.3							2.0	95	75							80	146,503	574.0	30,996
Riberia	80.0																			4,320	74.0	3,996
Litoranea	179.8																			9,709	39.6	2,138
Paraná	729.1																			39,371	86.8	4,687
Paranapanema	343.8																			18,565	41.6	2,246

Table-3.7 Domestic Sewage Discharge Loading (2015)

River Basin	Urban Area																				Rural Area	
	Population	Served Population (%)									BOD Removal Rate (%)									BOD Load	Population	BOD Load
	(1000 P.)	a	b	c	d	e	f	g	h	i	a	b	c	d	e	f	g	h	i	(kgBOD/d)	(1000 P.)	(kgBOD/d)
Itarare	197.1																			10,643	17.6	950
Cinzas	255.6																			13,802	39.6	2,138
Tibagi	1,528.1	4.9	3.8	9.8	4.9	0.2	0.3	0.2	8.5		95	75	80	85	45	70	65	80	80	60,452	118.5	6,399
Pirapo	566.5																			30,591	12.2	659
Ivai	1,128.1																			60,917	179.7	9,704
Piquiri	642.0																			34,668	126.8	6,847
Iguaçu	4,064.9	12	5.3							1.7	95	75							80	182,145	473.5	25,569
Riberia	1,528.1																			82,517	118.5	6,399
Litoranea	207.4																			11,200	35.5	1,917
Paraná	890.6																			48,092	50.8	2,743
Paranapanema	394.7																			21,314	22.6	1,220

3.1.3 Pollutant Loads from Industrial Wastewater

(1) Pollutant Loads in 1993

The current conditions of industrial wastewater have already been discussed in Chapter 2, and the pollutant loads in 1993 are summarized in Table-3.8.

Table-3.8 Industrial Wastewater BOD Load

River Basin	No. of Ind.	Generated BOD Load (kg BOD/d)	Reduction Rate (%)	Discharge BOD Load (kg BOD/d)	Heavy Pollution Industry
Itarate	11	15,277	83.0	2,602	Paper
Cinzas	23	202,092	99.5	975	Distillation
Tibagi	74	118,899	86.9	15,568	Paper Diary Textile
Pirapo	31	430,459	98.4	6,886	Distillation Tanner
Ivai	117	561,583	98.8	6,723	Distillation Slanghter house Tanner
Piquiri	42	179,428	98.4	2,907	Distillation
Iguaçu	128	51,861	65.3	18,000	Paper Slaughter house Diary Tanner
Ribeira	1	34	97.1	1	
Litoranea	3	482	89.8	49	Oil
Paraná	26	65,084	93.4	4,324	Starch Tanner
Paranapanema	36	539,349	99.3	3,7575	Distillation
Total (Average)	492	2,164,548	(97.1)	61,792	

(2) Method of Future Prediction

Future increase in industrial wastewater BOD load is supposed to be directly proportional to the GRDP growth rate.

Table-3.9 shows the GRDP in 1993 and the predicted GRDP in 2005 and 2015. The prediction is based on the GRDP growth rates in Paraná State from 1981 to 1993.

Table-3.9 Future Prediction of GRDP

Item	1993	2005	2015
GRDP (US$)	9,295.2	17,446.1	29,110
GRDP Growth Rate*	1.00	1.88	3.13

* Growth Rate of GRDP are based on 1993

(3) Pollutant Loads in 2005 and 2015

The pollutant loads from industrial wastewater in 2005 and 2015 are calculated according to the GRDP growth rates. The results are shown in Table-3.10.

Table-3.10 Prediction of Industrial Pollutant Load

River Basin	1993	2005		2015	
	BOD Load (kg DOB/d)	GRDP Growth Rate	BOD Load (kg DOB/d)	GRDP Growth Rate	BOD Load (kg BOD/d)
Itarare	2,602	1.88	4,892	3.16	8,222
Cinzas	975	1.88	1,833	3.16	3,081
Tibagi	15,568	1.88	29,268	3.16	49,195
Pirapo	6,886	1.88	12,946	3.16	21,760
Ivai	6,723	1.88	12,639	3.16	21,245
Piquiri	2,907	1.88	5,465	3.16	9,186
Iguaçu	18,000	1.88	33,840	3.16	56,880
Ribeira	1	1.88	2	3.16	3
Litoranea	49	1.88	92	3.16	155
Paraná	4,324	1.88	8,129	3.16	13,664
Paranapanema	3,757	1.88	7,063	3.16	11,872
Total	61,792	1.88	116,169	3.16	195,263

3.1.4 Pollutant Loads from Livestock

(1) Pollutant Load Factors

Since there are no guidelines in Brazil for livestock pollutant calculation, Japanese guidelines are referred and the pollutant load factors are set as follows:

Cattle	:	600 g/head/day
Pigs	:	200 g/head/day
Chickens	:	9 g/head/day

(2) Pollutant Loads

The pollutant loads from livestock are calculated for 1993, 2005 and 2015. The results are shown in Tale-3.11. The numbers of livestock are predicted by JICA Study Team.

Table-3.11 Pollutant Load of Livestock Wastewater

River Basin	1993 Pig Heads x 1000	Pig BOD Load Factor (g BOD/h/d)	Pig BOD Load (kg BOD/d)	Cattle Heads x 1000	Cattle BOD Load Factor (g BOD/h/d)	Cattle BOD Load (kg BOD/d)	Chicken Heads x 1000	Chicken BOD Load Factor (g BOD/h/d)	Chicken BOD Load (kg BOD/d)	Total BOD Load (kg BOD/d)
Itarare	47	200	9,400	173	600	103,800	1,610	9	14,490	127,690
Cinzas	115	200	23,000	564	600	338,400	3,413	9	30,717	392,117
Tibagi	200	200	40,000	665	600	399,000	5,649	9	50,841	489,841
Pirapo	74	200	14,800	524	600	314,400	2,457	9	22,113	351,313
Ivai	415	200	83,000	2,770	600	1,662,000	7,174	9	64,566	1,809,566
Piquiri	388	200	77,600	1,539	600	923,400	6,023	9	54,207	1,055,207
Iguaçu	1,061	200	212,200	1,611	600	966,600	23,053	9	207,477	1,386,277
Ribeira	48	200	9,600	63	600	37,800	1,519	9	13,671	61,071
Litoranea	8	200	1,600	20	600	12,000	237	9	2,133	15,733
Paraná	388	200	77,600	1,018	600	610,800	7,969	9	71,721	760,121
Paranapanema	72	200	14,400	773	600	463,800	1,568	9	14,112	492,312

River Basin	2005 Pig Heads x 1000	Pig BOD Load Factor (g BOD/h/d)	Pig BOD Load (kg BOD/d)	Cattle Heads x 1000	Cattle BOD Load Factor (g BOD/h/d)	Cattle BOD Load (kg BOD/d)	Chicken Heads x 1000	Chicken BOD Load Factor (g BOD/h/d)	Chicken BOD Load (kg BOD/d)	Total BOD Load (kg BOD/d)
Itarare	67	200	13,400	205	600	123,000	2,424	9	21,816	158,216
Cinzas	164	200	32,800	670	600	402,000	5,139	9	46,251	481,051
Tibagi	283	200	56,600	789	600	473,400	8,504	9	76,536	606,536
Pirapo	105	200	21,000	622	600	373,200	3,699	9	33,291	427,491
Ivai	589	200	117,800	3,284	600	1,970,400	10,801	9	97,209	2,185,409
Piquiri	549	200	109,800	1,825	600	1,095,000	9,067	9	81,603	1,286,403
Iguaçu	1,506	200	301,200	1,910	600	1,146,000	34,703	9	312,327	1,759,527
Ribeira	68	200	13,600	75	600	45,000	2,286	9	20,574	79,174
Litoranea	11	200	2,200	24	600	14,400	357	9	3,213	19,813
Paraná	550	200	110,000	1,208	600	724,800	11,997	9	107,973	942,773
Paranapanema	102	200	20,400	916	600	549,600	2,360	9	21,240	591,240

River Basin	2015 Pig Heads x 1000	Pig BOD Load Factor (g BOD/h/d)	Pig BOD Load (kg BOD/d)	Cattle Heads x 1000	Cattle BOD Load Factor (g BOD/h/d)	Cattle BOD Load (kg BOD/d)	Chicken Heads x 1000	Chicken BOD Load Factor (g BOD/h/d)	Chicken BOD Load (kg BOD/d)	Total BOD Load (kg BOD/d)
Itarare	67	200	13,400	237	600	142,200	2,911	9	26,199	181,799
Cinzas	164	200	32,800	771	600	462,600	6,172	9	55,548	550,948
Tibagi	283	200	56,600	907	600	544,200	10,213	9	91,917	692,717
Pirapo	105	200	21,000	716	600	429,600	4,442	9	39,978	490,578
Ivai	589	200	117,800	3,780	600	2,268,000	12,969	9	116,721	2,502,521
Piquiri	549	200	109,800	2,100	600	1,260,000	10,888	9	97,992	1,467,792
Iguaçu	1,506	200	301,200	2,198	600	1,318,800	41,675	9	375,075	1,995,075
Ribeira	68	200	13,600	86	600	51,600	2,745	9	24,705	89,905
Litoranea	11	200	2,200	27	600	16,200	429	9	3,861	22,261
Paraná	550	200	110,000	1,390	600	834,000	14,407	9	129,663	1,073,663
Paranapanema	102	200	20,400	1,055	600	633,000	2,833	9	25,497	678,897

3.1.5 Natural Pollutant Loads

(1) Pollutant Load Factor

Referring to Japanese guideline, the natural pollutant factor is set as 0.7 kg BOD/km^2/day in this Study.

(2) Pollutant Load

The pollutant load in each of the river basins is calculated from the above mentioned BOD load factor and the basin area. The results are shown in Table-3.12.

Table-3.12 Natural Pollutant Load by River Basin

River Basin	Area of Basin (km^2)	BOD Load Factor (kg BOD/km^2/d)	BOD Load (kg BOD/d)
Itarare	5,198	0.7	3,632
Cinzas	9,291	0.7	6,752
Tibagi	24,635	0.7	17,299
Pirapo	5,006	0.7	3,516
Ivai	35,879	0.7	25,635
Piquiri	24,708	0.7	17,281
Iguaçu	55,318	0.7	47,122
Ribeira	9,129	0.7	6,391
Litoranea	5,766	0.7	4,036
Paraná	13,156	0.7	8,770
Paranapanema	9,797	0.7	6,907

3.2 Pollution Analysis

3.2.1 Pollutant Load and River Water Quality

River water quality is affected by the amount of the pollutant load run-off into the river and its decay in the river course. A conceptual flow of pollutant load is shown in Figure-3.2 which illustrates the processes of the generation, discharge, run-off and flow-out of the pollutant load (BOD) in a river basin. The definitions of the parameters shown in Figure-3.2 are given in Table-3.13. These parameters are frequently used for pollution analysis.

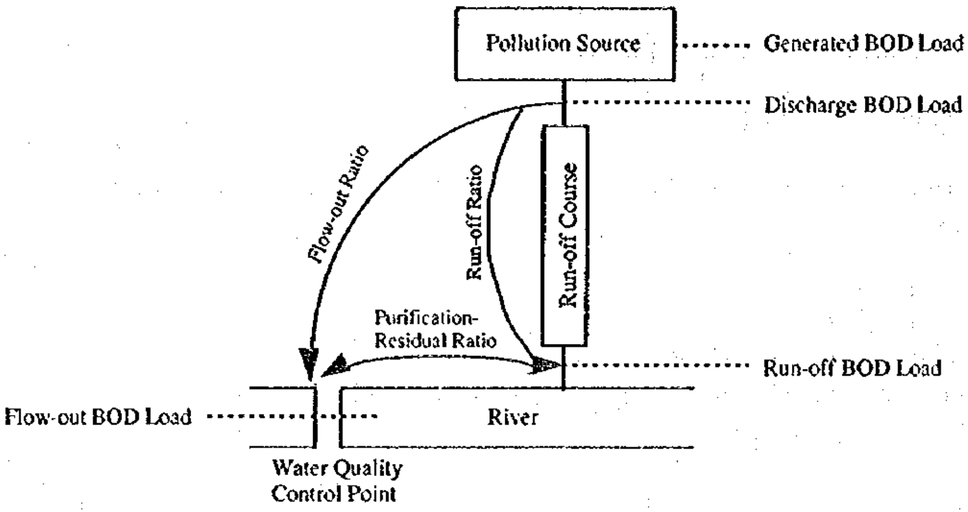


Figure-3.2 Conceptual Flow of Pollutant Load

Table-3.13 Definition of the Parameters Used for Pollution Analysis

Parameter	Definition
Generated BOD Load	Quantity of BOD generated from pollution sources (Kg/day)
Discharge BOD Load	Quantity of BOD discharged out of the pollution sources (Kg/day)
Run-off BOD Load	Quantity of BOD entering a river (Kg/day)
Flow-out BOD Load	Quantity of BOD flowing out of a cross section of the river course at a water quality control point (Kg/day)
Run-off Ratio	The ratio of the run-off BOD load to the discharge BOD load of the same origin
Purification-residual Ratio	The ratio of the flow-out BOD load to the run-off BOD load of the same origin
Flow-out Ratio	The ratio of the flow-out BOD load to the discharge BOD load of the same origin

3.2.2 Analysis of Present Condition

(1) Method of Analysis

Analysis of the present condition was conducted in order to determine some of the fundamental parameters for the prediction of river water quality in future. The procedures of analysis are as follows:

1) Divide each river basin into several blocks and select water quality control points in consideration of the catchment areas of its tributaries (see Figure-3.3);
2) Calculate the discharge BOD load from each pollution source;
3) Calculate the run-off BOD load by taking into consideration the run-off ratio;
4) Calculate the flow-out BOD load based on the current water quantity;
5) Evaluate the purification-residual ratio.

(2) Analysis Result

The result of analysis is shown in Table-3.14.

Table-3.14 Pollution Analysis of River Basin (1993)

River Basin	River Name	Control Point	River			Discharge BOD Load (kgBOD/day)					Run-off Ratio					Run-off BOD Load (kgBOD/day)						Purification Residual Ratio
			Ave.Water Quality (mg/l)	Average Flow (m3/sec)	Flow-out BOD Load (kgBOD/day)	Domestic Wastewater		Industrial Waste Water	Livestock Waste Water	Natural Load	Domestic Wastewater		Industrial Waste Water	Livestock Waste Water	Natural Load	Domestic Wastewater		Industrial Waste Water	Livestock Waste Water	Natural Load	Total	
						Urban	Rural				Urban	Rural				Urban	Rural					
ITARARE	JAGUARIAIVA	IT-02	1.33	18.13	2,083	1,247	659	814	39,967	1,137	0.8	0.10	1.0	0.05	0.1	998	66	814	1,998	114	3,990	0.52
CINZAS	CINZAS	CZ-01	1.55	18.09	2,423	1,955	1,161	204	81,952	1,411	0.8	0.10	1.0	0.05	0.1	1,564	116	204	4,098	141	6,123	0.40
		CZ-05	1.38	34.18	4,075	5,454	3,245	568	228,604	3,936	0.8	0.10	1.0	0.05	0.1	4,363	325	568	11,430	394	17,080	0.24
TIBAGI	TIBAGI	TI-01	1.26	40.56	4,416	9,179	2,090	2,802	88,171	3,114	0.8	0.10	1.0	0.05	0.1	7,343	209	2,802	4,409	311	15,074	0.29
		TI-03	1.93	40.72	6,790	18,455	4,201	5,636	177,322	6,262	0.8	0.10	1.0	0.05	0.1	14,764	420	5,636	8,866	626	30,312	0.22
		TI-06	2.09	153.34	27,690	32,173	7,317	9,823	309,090	10,916	0.8	0.10	1.0	0.05	0.1	25,738	732	9,823	15,455	1,092	52,840	0.52
		TI-10	1.45	211.73	26,526	30,662	10,298	13,824	434,979	15,362	0.8	0.10	1.0	0.05	0.1	24,530	1,030	13,824	21,749	1,536	62,669	0.42
PIRAPO	PIRAPO	PI-13	2.04	49.43	8,712	18,225	2,398	6,342	323,559	3,238	0.8	0.10	1.0	0.05	0.1	14,580	240	6,342	16,178	324	37,664	0.23
IVAI	IVAI	IV-02	2.36	21.57	4,398	4,018	2,106	659	177,337	2,512	0.8	0.10	1.0	0.05	0.1	3,214	211	659	8,867	251	13,202	0.33
		IV-04	1.14	67.89	6,687	9,639	5,054	1,580	425,248	6,024	0.8	0.10	1.0	0.05	0.1	7,711	505	1,580	21,262	602	31,660	0.21
		IV-12	1.19	199.13	20,474	27,108	14,218	4,444	1,196,123	16,945	0.8	0.10	1.0	0.05	0.1	21,686	1,422	4,444	59,806	1,695	89,053	0.23
		IV-15	1.17	262.71	26,557	31,822	16,697	5,217	1,404,223	19,893	0.8	0.10	1.0	0.05	0.1	25,458	1,670	5,217	70,211	1,989	104,545	0.25
		IV-19	1.25	355.97	38,445	38,545	20,223	6,320	1,700,992	24,097	0.8	0.10	1.0	0.05	0.1	30,836	2,022	6,320	85,050	2,410	126,638	0.30
PIQUIRI	PIQUIRI	PQ-01	1.00	33.58	2,901	3,791	2,819	497	180,440	2,955	0.8	0.10	1.0	0.05	0.1	3,033	282	497	9,022	296	13,130	0.22
		PQ-05	1.38	111.87	13,338	10,152	7,549	1,331	483,285	7,915	0.8	0.10	1.0	0.05	0.1	8,122	755	1,331	24,164	792	35,164	0.38
		PQ-07	1.29	219.41	24,455	15,714	11,691	2,061	748,142	12,252	0.8	0.10	1.0	0.05	0.1	12,571	1,169	2,061	37,407	1,225	54,433	0.45
		PQ-11	1.00	262.97	22,721	18,841	14,013	2,471	896,926	14,689	0.8	0.10	1.0	0.05	0.1	15,073	1,401	2,471	44,846	1,469	65,260	0.35
IGUACU	IGUACU	IG-18	1.03	1.29	115	65	76	36	2,773	94	0.8	0.10	1.0	0.05	0.1	52	8	36	139	9	244	0.47
		IG-14	6.48	22.03	12,334	79,466	1,242	612	47,133	1,602	0.8	0.10	1.0	0.05	0.1	63,573	124	612	2,357	160	66,826	0.18
		IG-13	4.88	30.73	12,957	80,087	1,976	972	74,859	2,545	0.8	0.10	1.0	0.05	0.1	64,070	198	972	3,743	255	69,238	0.19
		IG-24	2.01	50.85	8,831	81,185	3,294	1,620	124,765	4,241	0.8	0.10	1.0	0.05	0.1	64,948	329	1,620	6,238	424	73,559	0.12
		IG-28	1.59	232.03	31,875	89,461	13,171	6,480	499,060	16,964	0.8	0.10	1.0	0.05	0.1	71,569	1,317	6,480	24,953	1,696	106,015	0.30
		IG-36	1.65	532.17	75,866	99,322	24,916	12,258	944,055	32,090	0.8	0.10	1.0	0.05	0.1	79,458	2,492	12,258	47,203	3,209	144,620	0.52
		IG-40	1.04	662.11	59,495	101,358	30,737	15,120	1,164,473	39,582	0.8	0.10	1.0	0.05	0.1	81,086	3,074	15,120	58,224	3,958	161,462	0.37
	NEGRO	IG-25	1.64	76.21	10,799	4,811	4,320	2,124	163,581	5,560	0.8	0.10	1.0	0.05	0.1	3,849	432	2,124	8,179	556	15,140	0.71
	JORDAO	IG-39	1.31	49.67	5,622	2,360	2,122	1,044	80,404	2,733	0.8	0.10	1.0	0.05	0.1	1,888	212	1,044	4,020	273	7,437	0.76
	CHOPIN	IG-31	1.32	78.13	8,911	4,039	3,623	1,782	137,241	4,665	0.8	0.10	1.0	0.05	0.1	3,231	362	1,782	6,862	467	12,704	0.70
RIBEIRA	RIBEIRA	RB-03	1.33	86.87	9,982	2,592	3,553	1	48,490	5,074	0.8	0.10	1.0	0.05	0.1	2,074	355	1	2,425	507	5,362	1.00
LITORANEA	NHUNDIAQUARA	BL-04	1.70	4.86	714	302	86	2	598	153	0.8	0.10	1.0	0.05	0.1	242	9	2	30	15	298	1.00
	MARUMBI	BL-05	1.10	1.61	153	70	22	0	142	36	0.8	0.10	1.0	0.05	0.1	56	2	0	7	4	69	1.00

3.2.3 Analysis for Future Prediction

(1) Method of Analysis

Method of analysis for the future prediction of river water quality is as follows:

1) Predict the discharge BOD load of each pollution source;

- Domestic load: according to future population

- Industrial load: according to a proportional increase of BOD load with the increase of GRDP

- Livestock load: according to future livestock number

2) Calculate the run-off BOD load;

3) Calculate the flow-out BOD load by using the purification-residual ratio obtained from the above mentioned analysis of present condition, and evaluate water quality at each control point by using the draught river flow rate ($Q_{10,7}$);

4) Calculate the permissible flow-out BOD load at each control point in accordance with the target water quality of BOD ≤ 5mg/L;

5) Calculate the difference between the predicted flow-out BOD load and the permissible flow-out BOD load, and estimate the quantity of BOD load to be reduced in future.

(2) Result of Water Quality Prediction by the Year 2005

1) The result of the pollution analysis for each river in Paraná State is shown in Table-3.15.

2) The result of the water quality prediction for each river in Paraná State is shown in Table-3.16.

3) As is shown in Table-3.16, for the Rivers of Cinzas, Tibagi, Pirapo, Ivai, and Iguaçu, BOD concentrations are higher than 5 mg/L at some of the control points and the calculated flow-out loads exceed the permissible flow-out load. In order to improve water quality, measures have to be taken for pollutant load reduction.

(3) Result of Water Quality Prediction by the Year 2015

1) The result of the pollution analysis for each river is shown in Table-3.17.

2) The result of the water quality prediction is shown in Table-3.18.

3) As is shown in Table-3.18, besides the 5 rivers mentioned above, the calculated flow-out BOD load in Ribeira River also exceeds the permissible flow-out BOD load. Therefore, pollutant load reduction plans have to be formulated for the 6 river basins.

Table-3.15 Pollution Analysis of River Basin (2005)

River Basin	River Name	Control Point	Discharge BOD Load (kgBOD/day)					Run-off Ratio					Run-off BOD Load (kgBOD/day)					
			Domestic Wastewater		Industrial Waste Water	Livestock Waste Water	Natural Load	Domestic Wastewater		Industrial Waste Water	Livestock Waste Water	Natural Load	Domestic Wastewater		Industrial Waste Water	Livestock Waste Water	Natural Load	Total
			Urban	Rural				Urban	Rural				Urban	Rural				
ITARARE	JAGUARIAIVA	IT-02	2,095	443	1,531	49,522	1,137	0.8	0.1	1.0	0.05	0.1	1,676	44	1,531	2,476	114	5,841
CINZAS	CINZAS	CZ-01	2,425	718	383	100,540	1,411	0.8	0.1	1.0	0.05	0.1	1,940	72	383	5,027	141	7,563
		CZ-05	6,766	2,009	1,069	280,453	3,936	0.8	0.1	1.0	0.05	0.1	5,413	201	1,069	14,023	394	21,100
TIBAGI	TIBAGI	TI-01	11,725	1,534	5,268	109,176	3,114	0.8	0.1	1.0	0.05	0.1	9,380	153	5,268	5,459	311	20,571
		TI-03	23,584	3,089	10,595	219,566	6,262	0.8	0.1	1.0	0.05	0.1	18,867	309	10,595	10,978	626	41,375
		TI-06	41,106	5,384	18,468	382,724	10,916	0.8	0.1	1.0	0.05	0.1	32,885	538	18,468	19,136	1,092	48,526
		TI-10	43,305	7,576	25,990	538,604	15,362	0.8	0.1	1.0	0.05	0.1	34,644	758	25,990	26,930	1,536	53,633
PIRAPO	PIRAPO	PI-13	23,744	1,188	11,923	393,719	3,238	0.8	0.1	1.0	0.05	0.1	18,995	119	11,923	19,686	324	51,047
IVAI	IVAI	IV-02	5,054	1,355	1,239	214,170	2,512	0.8	0.1	1.0	0.05	0.1	4,043	136	1,239	10,709	251	16,378
		IV-04	12,118	3,245	2,970	513,571	6,024	0.8	0.1	1.0	0.05	0.1	9,694	325	2,970	25,679	602	39,270
		IV-12	34,079	9,131	8,354	1,444,555	16,945	0.8	0.1	1.0	0.05	0.1	27,263	913	8,354	72,228	1,695	110,453
		IV-15	40,003	10,724	9,808	1,695,877	19,893	0.8	0.1	1.0	0.05	0.1	32,002	1,072	9,808	84,794	1,989	129,665
		IV-19	48,460	12,987	11,881	2,054,284	24,097	0.8	0.1	1.0	0.05	0.1	38,768	1,299	11,881	102,714	2,410	157,072
PIQUIRI	PIQUIRI	PQ-01	4,941	1,777	935	219,975	2,955	0.8	0.1	1.0	0.05	0.1	3,953	178	935	10,999	296	16,361
		PQ-05	13,235	4,763	2,503	589,173	7,915	0.8	0.1	1.0	0.05	0.1	10,588	476	2,503	29,459	792	43,818
		PQ-07	20,488	7,371	3,875	912,060	12,252	0.8	0.1	1.0	0.05	0.1	16,390	737	3,875	45,603	1,225	67,830
		PQ-11	24,559	8,834	4,645	1,093,443	14,689	0.8	0.1	1.0	0.05	0.1	19,647	883	4,645	54,672	1,469	81,316
IGUACU	IGUACU	IG-18	81	59	68	3,519	94	0.8	0.1	1.0	0.05	0.1	65	6	68	176	9	324
		IG-14	109,053	1,053	1,151	59,824	1,602	0.8	0.1	1.0	0.05	0.1	87,242	105	1,151	2,991	160	91,649
		IG-13	109,891	1,674	1,827	95,014	2,545	0.8	0.1	1.0	0.05	0.1	87,913	167	1,827	4,751	255	94,913
		IG-24	111,371	2,792	3,046	158,357	4,241	0.8	0.1	1.0	0.05	0.1	89,097	279	3,046	7,918	424	100,764
		IG-28	122,559	11,156	12,182	633,430	16,964	0.8	0.1	1.0	0.05	0.1	98,047	1,116	12,182	31,672	1,696	144,713
		IG-36	135,880	21,109	23,045	1,198,238	32,090	0.8	0.1	1.0	0.05	0.1	108,704	2,111	23,045	59,912	3,209	196,981
		IG-40	139,697	26,039	28,426	1,478,003	39,582	0.8	0.1	1.0	0.05	0.1	111,758	2,604	28,426	73,900	3,958	220,646
	NEGRO	IG-25	6,043	3,656	3,993	207,624	5,560	0.8	0.1	1.0	0.05	0.1	4,834	366	3,993	10,381	556	20,130
	JORDAO	IG-39	2,965	1,798	1,963	102,053	2,733	0.8	0.1	1.0	0.05	0.1	2,372	180	1,963	5,103	273	9,891
	CHOPIM	IG-31	5,076	3,067	3,350	174,193	4,665	0.8	0.1	1.0	0.05	0.1	4,061	307	3,350	8,710	467	16,895
RIBEIRA	RIBEIRA	RB-03	3,429	3,175	2	62,864	5,074	0.8	0.1	1.0	0.05	0.1	2,743	318	2	3,143	507	6,713
LITORANEA	NHUNDIAQUAR	BL-04	367	81	3	753	153	0.8	0.1	1.0	0.05	0.1	294	8	3	38	15	358
	MARUMBI	BL-05	86	22	1	178	36	0.8	0.1	1.0	0.05	0.1	69	2	1	9	4	85

Table-3.16 River Basin Water Quality Prediction(2005)

River Basin	River Name	Control Point	Run-off BOD Load (kgBOD/d)	Purification Risidual Ratio	Flow-out BOD Load (kgBOD/d)	River Flow (Q10.7) (m3/sec)	Average BOD (mgBOD/l)	Permissible Flow-out Load (kgBOD/d)	Difference between Calculated and Permissible Loads (kgBOD/d)	
									as Flow-out	as Run-off
ITARARE	JAGUARIAIVA	IT-02	5,841	0.52	3,037	8.00	4.39	3,456	(419)	-806
CINZAS	CINZAS	CZ-01	7,563	0.40	3,025	3.20	10.94	1,382	1,643	4,108
		CZ-05	21,100	0.24	5,064	8.80	6.66	3,802	1,262	5,258
TIBAGI	TIBAGI	TI-01	20,571	0.29	5,966	8.60	8.03	3,715	2,251	7,762
		TI-03	41,375	0.22	9,103	17.00	6.2	7,344	1,759	7,995
		TI-06	47,710	0.52	24,809	25.60	11.22	11,059	13,750	26,443
		TI-10	56,949	0.42	23,919	32.20	8.6	13,910	10,009	23,830
PIRAPO	PIRAPO	PI-13	51,047	0.23	11,741	15.00	9.06	6,480	5,261	13,153
IVAI	IVAI	IV-02	16,378	0.33	5,405	4.20	14.89	1,814	3,591	10,882
		IV-04	39,270	0.21	8,247	7.60	12.56	3,283	4,964	23,638
		IV-12	110,453	0.23	25,404	14.00	21	6,048	19,356	38,712
		IV-15	129,665	0.25	32,416	146.00	2.57	63,072	(30,656)	-122,624
		IV-19	157,072	0.30	47,122	140.00	3.9	60,480	(13,358)	-44,527
PIQUIRI	PIQUIRI	PQ-01	16,361	0.22	3,599	30.00	1.39	12,960	(9,361)	-42,550
		PQ-05	43,818	0.38	16,651	69.00	2.79	29,808	(13,157)	-34,624
		PQ-07	67,830	0.45	30,524	108.00	3.27	46,656	(16,132)	-35,849
		PQ-11	81,316	0.35	28,461	98.00	3.36	42,336	(13,875)	-39,643
IGUACU	IGUACU	IG-18	324	0.47	152	0.85	2.07	367	(215)	-457
		IG-14	91,649	0.18	16,497	8.00	23.87	3,456	13,041	72,450
		IG-13	94,913	0.19	18,033	11.80	17.69	5,098	12,935	68,079
		IG-24	100,764	0.12	12,092	25.00	5.6	10,800	1,292	10,767
		IG-28	144,713	0.30	43,414	51.20	9.81	22,118	21,296	70,987
		IG-36	196,981	0.52	102,430	120.20	9.86	51,926	50,504	97,123
		IG-40	220,646	0.37	81,639	161.20	5.86	69,638	12,001	32,435
	NEGRO	IG-25	20,130	0.71	14,292	49.50	3.34	21,384	(7,092)	-9,989
	JORDAO	IG-39	9,891	0.76	7,517	28.20	3.09	12,182	(4,665)	-6,138
	CHOPIM	IG-31	16,895	0.70	11,827	40.10	3.41	17,323	(5,496)	-7,851
RIBEIRA	RIBEIRA	RB-03	6,713	1.00	6,713	72.80	1.07	31,450	(24,737)	-24,737
LITORANE	NHUNDIAQUA	BL-04	358	1.00	358	2.56	1.62	1,106	(748)	-748
	MARUMBI	BL-05	85	1.00	85	0.77	1.28	333	(248)	-248

Table-3.17 Pollution Analysis of River Basin(2015)

River Basin	River Name	Control Point	Discharge BOD Load (kgBOD/day)					Run-off Ratio					Run-off BOD Load (kgBOD/day)					
			Domestic Wastewater		Industrial Waste Water	Livestock Waste Water	Natural Load	Domestic Wastewater		Industrial Waste Water	Livestock Waste Water	Natural Load	Domestic Wastewater		Industrial Waste Water	Livestock Waste Water	Natural Load	Total
			Urban	Rural				Urban	Rural				Urban	Rural				
ITARARE	JAGUARIAIVA	IT-02	3,332	297	2,573	56,903	1,137	0.8	0.1	1.0	0.05	0.1	2,666	30	2,573	2,845	114	8,228
CINZAS	CINZAS	CZ-01	2,884	448	644	115,148	1,411	0.8	0.1	1.0	0.05	0.1	2,307	45	644	5,757	141	8,894
		CZ-05	8,046	1,247	1,796	321,203	3,936	0.8	0.1	1.0	0.05	0.1	6,437	125	1,796	16,060	394	24,812
TIBAGI	TIBAGI	TI-01	13,845	1,150	8,855	124,689	3,114	0.8	0.1	1.0	0.05	0.1	11,076	115	8,855	6,234	311	26,591
		TI-03	27,841	2,317	17,809	250,764	6,262	0.8	0.1	1.0	0.05	0.1	22,273	232	17,809	12,538	626	53,478
		TI-06	48,526	4,039	31,042	437,104	10,916	0.8	0.1	1.0	0.05	0.1	38,821	404	31,042	21,855	1,092	58,679
		TI-10	53,633	5,681	43,685	615,133	15,362	0.8	0.1	1.0	0.05	0.1	42,906	568	43,685	30,757	1,536	111,131
PIRAPO	PIRAPO	PI-13	28,172	605	20,041	451,822	3,238	0.8	0.1	1.0	0.05	0.1	22,538	61	20,041	22,591	324	65,555
IVAI	IVAI	IV-02	5,972	950	2,082	245,247	2,512	0.8	0.1	1.0	0.05	0.1	4,778	95	2,082	12,262	251	19,468
		IV-04	14,315	2,279	4,993	588,092	6,024	0.8	0.1	1.0	0.05	0.1	11,452	228	4,993	29,405	602	46,680
		IV-12	40,268	6,415	14,043	1,654,166	16,945	0.8	0.1	1.0	0.05	0.1	32,214	642	14,043	82,708	1,695	131,302
		IV-15	47,272	7,528	16,486	1,941,956	19,893	0.8	0.1	1.0	0.05	0.1	37,818	753	16,486	97,098	1,989	154,144
		IV-19	57,262	9,121	19,970	2,352,370	24,097	0.8	0.1	1.0	0.05	0.1	45,810	912	19,970	117,619	2,410	186,721
PIQUIRI	PIQUIRI	PQ-01	5,929	1,172	1,571	250,992	2,955	0.8	0.1	1.0	0.05	0.1	4,743	117	1,571	12,550	296	19,277
		PQ-05	15,876	3,137	4,207	672,249	7,915	0.8	0.1	1.0	0.05	0.1	12,701	314	4,207	33,612	792	51,626
		PQ-07	24,581	4,855	6,513	1,040,665	12,252	0.8	0.1	1.0	0.05	0.1	19,665	486	6,513	52,033	1,225	79,922
		PQ-11	29,468	5,821	7,808	1,247,623	14,689	0.8	0.1	1.0	0.05	0.1	23,574	582	7,808	62,381	1,469	95,814
IGUACU	IGUACU	IG-18	97	49	114	3,990	94	0.8	0.1	1.0	0.05	0.1	78	5	114	200	9	406
		IG-14	141,149	869	1,934	67,833	1,602	0.8	0.1	1.0	0.05	0.1	112,919	87	1,934	3,392	160	118,492
		IG-13	142,160	1,382	3,072	107,734	2,545	0.8	0.1	1.0	0.05	0.1	113,728	138	3,072	5,387	255	122,580
		IG-24	143,950	2,300	5,119	179,557	4,241	0.8	0.1	1.0	0.05	0.1	115,160	230	5,119	8,978	424	129,911
		IG-28	157,449	9,207	20,477	718,227	16,964	0.8	0.1	1.0	0.05	0.1	125,959	921	20,477	35,911	1,696	184,964
		IG-36	173,526	17,415	38,735	1,358,646	32,090	0.8	0.1	1.0	0.05	0.1	138,821	1,742	38,735	67,932	3,209	250,439
		IG-40	178,596	21,476	47,779	1,675,863	39,582	0.8	0.1	1.0	0.05	0.1	142,877	2,148	47,779	83,793	3,958	280,555
	NEGRO	IG-25	7,031	3,019	6,712	235,419	5,560	0.8	0.1	1.0	0.05	0.1	5,625	302	6,712	11,771	556	24,966
	JORDAO	IG-39	3,451	1,485	3,299	115,714	2,733	0.8	0.1	1.0	0.05	0.1	2,761	149	3,299	5,786	273	12,268
	CHOPIM	IG-31	5,908	2,533	5,631	197,512	4,665	0.8	0.1	1.0	0.05	0.1	4,726	253	5,631	9,876	467	20,953
RIBEIRA	RIBEIRA	RB-03	65,518	5,081	2	71,385	5,074	0.8	0.1	1.0	0.05	0.1	52,414	508	2	3,569	507	57,000
LITORANEA	NHUNDIAQUAR	BL-04	427	70	6	846	153	0.8	0.1	1.0	0.05	0.1	342	7	6	42	15	412
	MARUMBI	BL-05	103	16	1	200	36	0.8	0.1	1.0	0.05	0.1	82	2	1	10	4	99

Table-3.18 River Basin Water Quality Prediction(2015)

River Basin	River Name	Control Point	Run-off BOD Load (kgBOD/d)	Purification Risidual Ratio	Flow-out BOD Load (kgBOD/d)	River Flow (Q10.7) (m3/sec)	Average BOD (mgBOD/l)	Permissible Flow-out Load (kgBOD/d)	Difference between Calculated and Permissible Loads (kgBOD/d) as Flow-out	as Run-off
ITARARE	JAGUARIAIVA	IT-02	8,228	0.52	4,279	8.00	6.19	3,456	823	1,583
CINZAS	CINZAS	CZ-01	8,894	0.40	3,558	3.20	12.87	1,382	2,176	5,440
		CZ-05	24,812	0.24	5,955	8.80	7.83	3,802	2,153	8,971
TIBAGI	TIBAGI	TI-01	26,591	0.29	7,711	8.60	10.38	3,715	3,996	13,779
		TI-03	53,478	0.22	11,765	17.00	8.01	7,344	4,421	20,095
		TI-06	58,679	0.52	30,513	25.60	13.80	11,059	19,454	37,412
		TI-10	111,131	0.42	46,675	32.20	16.78	13,910	18,855	36,260
PIRAPO	PIRAPO	PI-13	65,555	0.23	15,078	15.00	11.63	6,480	8,598	21,495
IVAI	IVAI	IV-02	19,468	0.33	6,424	4.20	17.70	1,814	4,610	13,970
		IV-04	46,680	0.21	9,803	7.60	14.93	3,283	6,520	31,048
		IV-12	131,302	0.23	30,199	14.00	24.97	6,048	24,151	48,302
		IV-15	154,144	0.25	38,536	146.00	3.05	63,072	(24,536)	-98,144
		IV-19	186,721	0.30	56,016	140.00	4.63	60,480	(4,464)	-14,880
PIQUIRI	PIQUIRI	PQ-01	19,277	0.22	4,241	30.00	1.64	12,960	(8,719)	-39,632
		PQ-05	51,626	0.38	19,618	69.00	3.29	29,808	(10,190)	-26,816
		PQ-07	79,922	0.45	35,965	108.00	3.85	46,656	(10,691)	-23,758
		PQ-11	95,814	0.35	33,535	98.00	3.96	42,336	(8,801)	-25,146
IGUACU	IGUACU	IG-18	406	0.47	191	0.85	2.60	367	(176)	-374
		IG-14	118,492	0.18	21,329	8.00	30.86	3,456	17,873	99,294
		IG-13	122,580	0.19	23,290	11.80	22.84	5,098	18,192	95,747
		IG-24	129,911	0.12	15,589	25.00	7.22	10,800	4,789	39,908
		IG-28	184,964	0.30	55,489	51.20	12.54	22,118	33,371	111,237
		IG-36	250,439	0.52	130,228	120.20	12.54	51,926	78,302	150,581
		IG-40	280,555	0.37	103,805	161.20	7.45	69,638	34,167	92,343
	NEGRO	IG-25	24,966	0.71	17,726	49.50	4.14	21,384	(3,658)	-5,152
	JORDAO	IG-39	12,268	0.76	9,324	28.20	3.83	12,182	(2,858)	-3,761
	CHOPIM	IG-31	20,953	0.70	14,667	40.10	4.23	17,323	(2,656)	-3,794
RIBEIRA	RIBEIRA	RB-03	57,000	1.00	57,000	72.80	9.06	31,450	25,550	25,550
LITORANE	NHUNDIAQUA	BL-04	412	1.00	412	2.56	1.86	1,106	(694)	-694
	MARUMBI	BL-05	99	1.00	99	0.77	1.49	333	(234)	-234

CHAPTER 4 WATER QUALITY IMPROVEMENT PLAN

4.1 Target Water Quality

The target water quality is BOD concentration of less than 5 mg/L, i.e. water quality Class 2 for rivers in Brazil. The values of the permissible flow-out BOD load shown in Table-3.16 and Table-3.18 are calculated in accordance with this target water quality.

4.2 BOD Load Reduction Plan

The BOD load to be reduced for each of the 6 river basins can be obtained from the calculation results shown in Table-3.16 and Table-3.18 for the years of 2005 and 2015, respectively. At each of the water quality control points, the difference between the calculated flow-out BOD load and the permissible flow-out BOD load, if it is a positive value, is the minimum amount of BOD load to be reduced in order to meet the target water quality at that point. Because the water quality at each control point is governed by the BOD load from its upstream side, the amount of BOD load to be reduced for the most polluted point, i.e. the point where the difference between the calculated and permissible BOD loads is the largest, will be the BOD load to be reduced for the whole river. Therefore, for each of the river basins, BOD load reduction plan is derived from the last column of Table-3.16 for 2005 and Table-3.18 for 2015. The results are shown in Table-4.1.

Table-4.1 BOD Load Reduction Plan

Unit: Kg /day (as run-off BOD load)

River Basin	2005	2015
Cinzas	5,258	8,971
Tibagi	26,443	37,412
Pirapo	13,153	21,495
Ivai	38,712	48,302
Iguaçu	97,123	150,581
Ribeira	-	25,550

4.3 Sewage Treatment Plan

Of the pollutants from various pollution sources, the natural pollutant load is difficult to be reduced, and industrial wastewater have already been treated at a relatively high BOD removal. Therefore the domestic pollutant load should be the main objective of reduction. This needs implementation of sewage treatment facilities especially in the densely populated urban areas.

The sewage treatment plans for the years of 2005 and 2015 are shown in Table-4.2. The sewage quantities are calculated from the BOD load values in consideration of the BOD load factor (54 g/person/day), runoff ratio (0.8), BOD removal of treatment process (0.95 for standard activated sludge treatment, 0.80 for anaerobic + aerobic treatment) and unit discharge quantity (170 litter/person/day).

Table-4.2 Sewage Treatment Plan

Period	~ 2005		2005 ~ 2015		Total		
River Basin	Treatment Quantity (m3/day)	Population to be Served	Treatment Quantity (m3/day)	Population to be Served	Treatment Quantity (m3/day)	Population to be Served	Treatment Method
Cinzas	16,000	94,000	12,000	71,000	28,000	165,000	b
Tibagi	83,000	488,000	35,000	206,000	118,000	694,000	b
Pirapo	42,000	247,000	26,000	153,000	68,000	400,000	b
Ivai	122,000	718,000	30,000	176,000	152,000	894,000	b
Iguaçu	300,000	1,765,000	174,000	1,024,000	474,000	2,789,000	a
Ribeira	-	-	80,000	471,000	80,000	471,000	b

a: Standard Activated Sludge Process

b: Anaerobic (RALF) + Aerobic Treatment

4.4 Cost Estimation

Table-4.3 shows the estimated costs for the implementation of sewage treatment facilities by the years of 2005 and 2015. The current unit construction cost in Paraná state, including that for sewage treatment plant and sewer pipelines, is referred in the calculation. By the year of 2005, a total amount of US $ 430.5 million will be needed for the construction, and by 2015 US $ 273.1 million will be further needed. The total construction cost will amount to US $ 703.6 million.

Table-4.3 Cost of the Water Quality Improvement Project

Unit: 1,000 US $

River Basin	2005	2015
Cinzas	12,200	9,200
Tibagi	63,500	26,800
Pirapo	32,100	19,900
Ivai	93,300	22,900
Iguaçu	229,400	133,100
Ribeira	-	61,200
Subtotal	430,500	273,100
Total	703,600	

CHAPTER 5 STUDY OF THE RIVER SEDIMENTS OF THE PILOT RIVER BASINS

5.1 Outline of the Study

5.1.1 Objective of the Study

The Objective of the present Study is to investigate the accumulation of heavy metals and agricultural chemicals in the bottom sediments of the Iguaçu River and the Tibagi River. The study shall provide basic data for evaluating the effects of heavy metals and agricultural chemicals on river water quality in the future.

TECPAR (Instituto de Technologia de Paraná), an institute of chemical analysis in Paraná State, was recommissioned to conduct the collection and analysis of the sediment samples from the two rivers, under the supervision of the JICA Study Team.

5.1.2 Location of Sediment Sampling Points

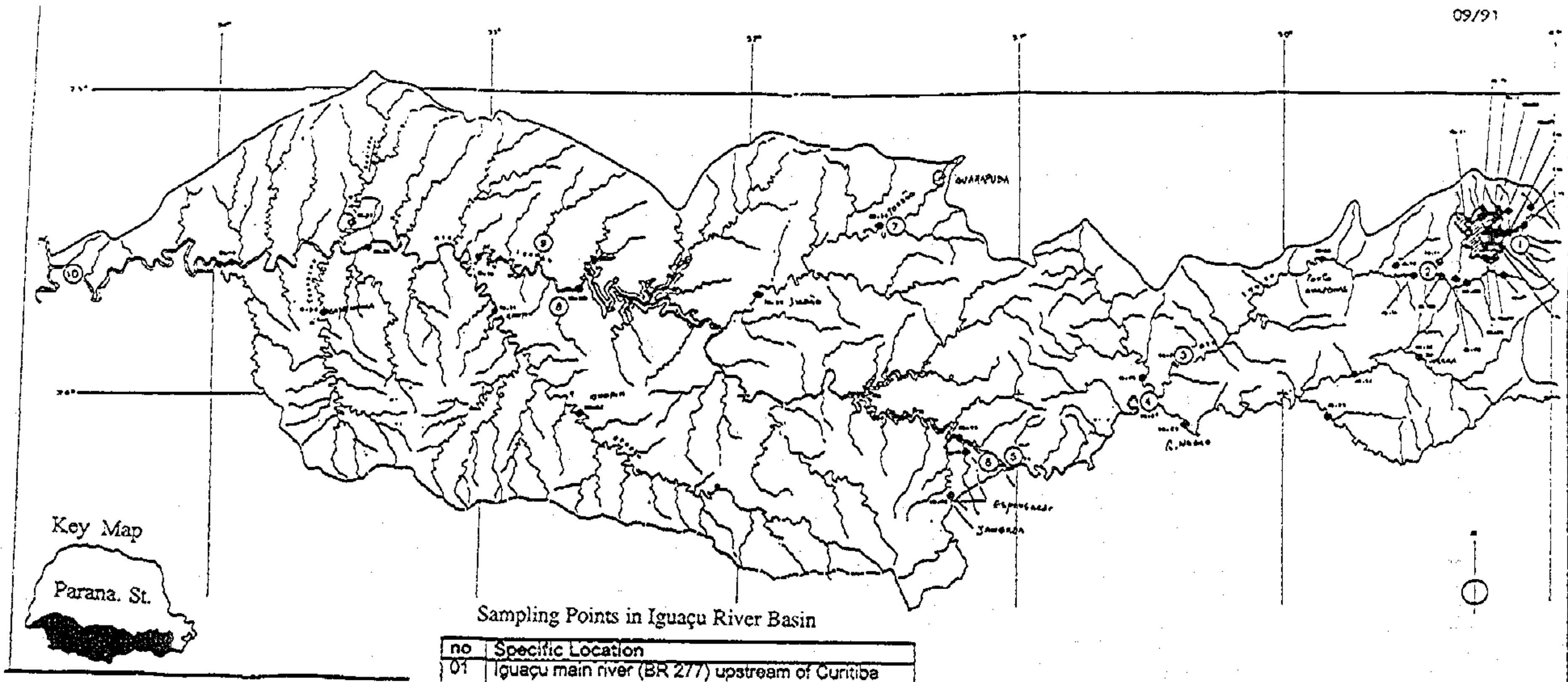
Figure-5.1 shows the ten sediment sampling points along the Iguaçu River. Samples were collected from the main river course at seven points (St. 1, 2, 3, 5, 6, 9, and 10), and its tributaries at three points (St. 4, 7, and 8).

Figure-5.2 shows the sediment sampling points along the Tibagi River. Samples were collected from the main river course at three points (St. 2, 3, and 10), and its tributaries at six points (St. 1, 4, 6, 7, 8, and 9).

All these sampling points were selected from places where the quality of river sediment was suspected to be affected by domestic discharge, industrial wastewater and agricultural wastewater. For example, of the sampling points in the Iguaçu Basin, St. 7 and 8 are located at the two tributaries where the influence of agricultural chemicals is suspected. Most of the sampling points on the main river course are located at the downstreams of the urban areas. The locations of the sampling points in the Tibagi Basin are of similar characteristics.

5.1.3 Analysis Items

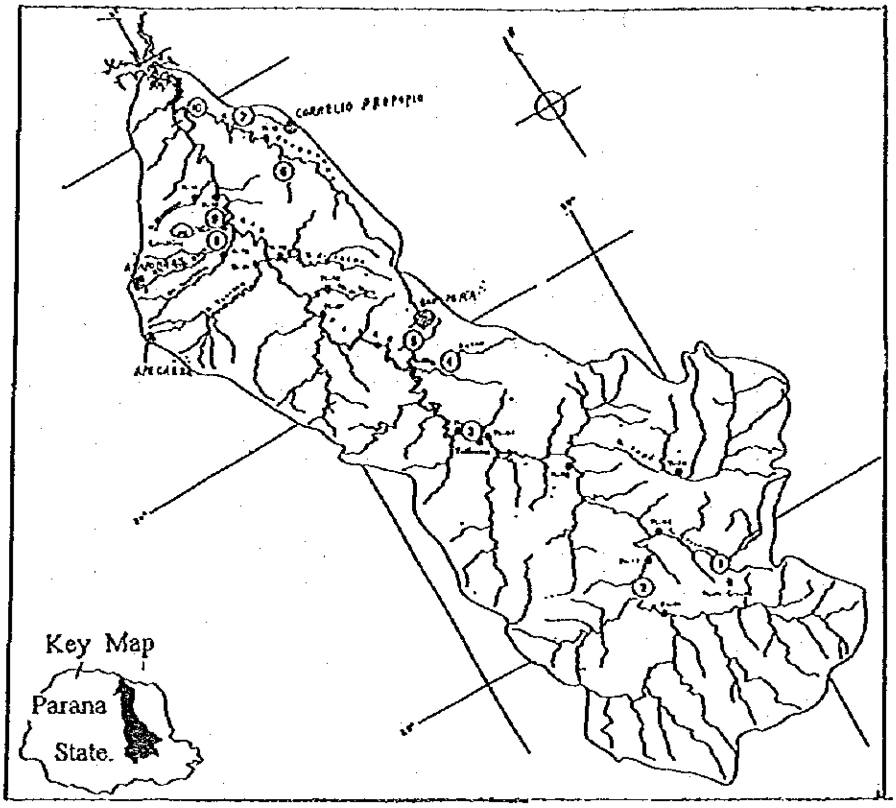
As shown in Table-5.1, ten kinds of heavy metals, eleven kinds of chlorinated agricultural chemicals, and eleven kinds of phosphorinated agricultural chemicals were analyzed for each sample.



Sampling Points in Iguaçu River Basin

no	Specific Location
01	Iguaçu main river (BR 277) upstream of Curitiba
02	Iguaçu main river (Guajuvira Pluviometric Station)
03	Iguaçu main river (São Mateus Pluviometric Station)
04	Negro River, Tributary of Iguaçu River outfall
05	Iguaçu River, besides Timbó River and União da Vitória City (Fazenda Santa Martha Pluviometric Station
06	Iguaçu main river, dowstream of Porto União (União da Vitória Pluviometric Station)
07	Jordão River, Tributary of Iguaçu, upstream of São João River
08	Paz River (Rio Pães), Tributary of Iguaçu at Saudades do Iguaçu Municipal District
09	Cobras River, Tributary of Iguaçu, near bridge besides Quedas do Iguaçu and Nova Laranjeiras
10	Iguaçu main river., near bridge PR 182 (Marmelândia)

Figure-5.1 Sediments Sampling Points in Iguaçu River Basin



Sampling Points in Tibagi River Basin :

no	Specific Location
01	Pitangui River, Tributary of Tibagi, dowstream of Ponta Grossa
02	Tibagi main river (Uvaia Pluviometric Station)
03	Tibagi main river, downstream of Telemaco Borba
04	Antas River, Tributary of Tibagi, downstream
05	Lageado Liso River, Tributary of Tibagi, upstream of Sapopema (Lageado Liso Pluviometric Station)
06	Córrego Limoeiro, Tributary of Tibagy, dowstream
07	Congonhas River, Tributary of Tibagi dowstream of Cornelio Procopio
08	Taquara River, tributary of Tibagi
09	Águas do Jacutinga River, tributary of Tibagi
10	Tibagi main river., upstream of Rio Congonhas

Figure-5.2 Sediments Sampling Points in Tibagi River Basin

Table-5.1 Analytical Items of Pilot River Sediment

Heavy Metals	Detection Limit mg/kg	Organo-chlorinated Chemical	Detection Limit mg/kg	Organo-phosphorated Chemical	Detection Limit mg/kg
Arsenic, as As	10	BHC	0.01	Methyl parathion	0.05
Lead, as Pb	30	DDT	0.01	Ethyl Parathion	0.05
Cadmium, as Cd	2.5	Aldrin	0.01	Malathion	0.05
Copper, as Cu	10	Endrin	0.01	Dimethoate	0.05
Tin, as Sn	100	Endosulfan	0.01	Metasystox	0.05
Mercury, as Hg	0	Heptachlor	0.01	Ethion	0.05
Chromium, as Cr	1	Dieldrin	0.10	Tiomedan	0.05
Manganese, as Mn	1	DDD	0.01	Methamidophos	0.05
Zinc, as Zn	1	DDE	0.01	Manocrotophos	0.05
	mg/100 g	Mirex	0.01	Profenofos	0.05
Iron, as Fe	25	Alachlor	0.01	Trichlorfon	0.05

5.1.4 Analytical Methods

(1) Sample Collection

All samples were collected using the methods established by Instituto Ambiental do Paraná. At each site, three samples were collected from the two sides and the center of the river with dredging apparatus. They were then mixed as a representative sample of that site. All samples collected were kept ice-cooled before analysis.

(2) Analysis

1) Total Solids

Each sample was fully mixed and part of it was centrifugalized for 20 minutes at 5000 rpm. The separated solids were then dried at 105-120 °C for two hours and the dried quantity was weighed for determining the total solids of the sample.

2) Preparation of Samples for Analysis of Heavy Metals

a) For Arsenic (As)

Standard Methods for the Examination of Water and Wastewater (APHA/AWWA/WPCF) 17th ed. 1989. Method 3500-As D.

b) For other heavy metals

Standard Methods for the Examination of Water and Wastewater (APHA/AWWA/WPCF) 18th ed. 1992.

3) Quantitative Analysis of Heavy Metals

a) Arsenic (As)

Standard Methods for the Examination of Water and Wastewater (APHA/AWWA/WPCF) 17th ed. 1989. Method 3,500-As D.

b) Other heavy metals

Standard Methods for the Examination of Water and Wastewater (APHA/AWWA/WEF), 18th ed. 1992.

Mercury (Hg):	Method 3112 B
Tin (Su):	Method 3111 D
Iron (Fe), Cadmium (Cd), Zinc (Zn):	Method 3111 B
Chromium (Cr), Manganese (Mn), Lead (Pb), Copper (Cu):	Method 3120 B

4) Quantitative Analysis of Agricultural Chemicals

Miles, J.R.W.; Harris, C.R.; Maya, P. Inceticide Residues in Organic Soil of the Holland Marsh, Canada, 1872. J. Econ. Entomol. 71 (1): 97-101, 1978.

In: Manual de Análise de Resíduos de Pesticidas - S. Paulo - Brasil, 1982.

5.2 Analysis Results and Discussion

5.2.1 Analysis Results

The analysis results for the river sediments are shown in Table-5.2.

Table-5.2 Results of Iguaçu, Tibagi River Basin Sediments Analysis

	IGUAÇU RIVER BASIN										TIBAGI RIVER BASIN									
-HEAVY METALS	01	02	03	04	05	06	07	08	09	10	01	02	03	04	05	06	07	08	09	10
- as mg/kg of dry solid																				
Arsenic, As	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Lead, as Pb	< 30	< 30	< 30	< 30	< 30	< 30	97	116	133	56	< 30	< 30	< 30	< 30	< 30	109	85	130	123	61
Cadmium, as Cd	< 2,5	< 2,5	< 2,5	< 2,5	< 2,5	< 2,5	< 2,5	3,5	3	< 2,5	< 2,5	< 2,5	< 2,5	< 2,5	< 2,5	3	< 2,5	< 2,5	3	3
Copper, as Cu	55	50	29	< 10	17	< 10	148	269	356	181	32	< 10	< 10	236	34	278	203	278	500	170
Tin, as Sn	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100
Mercury, as Hg	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8	< 0,8
Chromium, as Cr	283	364	110	46	216	11	62	64	372	76	30	45	10	25	30	95	223	77	188	64
Manganese, as Mn	569	696	842	524	642	302	1026	2441	2480	1450	106	100	178	336	1050	3084	2000	1507	2795	1822
Zinc, as Zn	110	160	90	45	60	30	160	185	172	135	50	25	40	80	80	170	120	185	260	140
- as mg/100g of dry solid																				
Iron, as Fe	3210	3000	3210	1520	2160	1110	11500	14900	16200	9400	2200	890	1470	2420	4650	15700	14900	14900	16200	10200
ORGANOCHLORINATED MATERIAL																				
- as mg/kg of dry solid																				
BHC	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
DDT	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
Aldrin	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
Endrin	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
Endosaulfan	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
Heptachlor	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	0,04	0,05	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	0,03	<0,01	0,03	<0,01	<0,01
Heptachlor Epoxi	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	0,06	<0,01	<0,01
Dieldrin	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
DDD	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
DDE	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
Mirex	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
Alachlor	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
ORGANOPHOSPHORATED MATERIAL																				
- as mg/kg of dry solid																				
Methyl parathion	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
Ethyl parathion	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
Malation	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
Dimethoate	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
Metamydox	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
Ethion	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
Tiomedan	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
Methamidophos	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
Monocrotophos	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
Profenofos	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
Trichlorfon	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05

5.2.2 Discussion

(1) Heavy Metals

The contents of heavy metals in river sediments are greatly affected by the geological formation of the river bottom. The river sediments at St. 7, 8, 9, and 10 in the Iguaçu River Basin and St. 6, 7, 8, 9, and 10 in the Tibagi River Basin contained large quantities of Fe, Mn, Zn, and Cu. These are possibly minerals from the rocks at the river bottom. But the concentrations of Pb at these points are higher than that of natural origin and are thought to be related to artificial reasons. The high values of Zn at St. 1 and 2 in the Iguaçu River are also considered to be due to artificial effects.

The higher content of Cr in the Curitiba area (St. 1 and 2, Iguaçu River Basin) is considered to be due to industrial wastewater discharge. Cr is also in higher quantities at St. 5 and 9 in the Iguaçu River Basin and St. 7 and 9 in the Tibagi River Basin.

Figures-5.3 and 5.4 show the concentrations of Cu, Cr, Pb and Zn at all the sampling points in the two river basins, and Table-5.3 shows the points where the concentration of some heavy metals are considered to be high due to artificial effects. Further and more detailed studies shall be required to investigate the sources of these heavy metals at these points.

Table-5.3 Locations of High Concentration of Heavy Metals

Name of River	Metal	St.1	St.2	St.3	St.4	St.5	St.6	St.7	St.8	St.9	St.10
Iguaçu R.B.	Pb							O	O	O	O
	Cr	O	O			O				O	
	Zn	O	O								
Tibagi R.B.	Pb						O	O	O	O	O
	Cr							O		O	

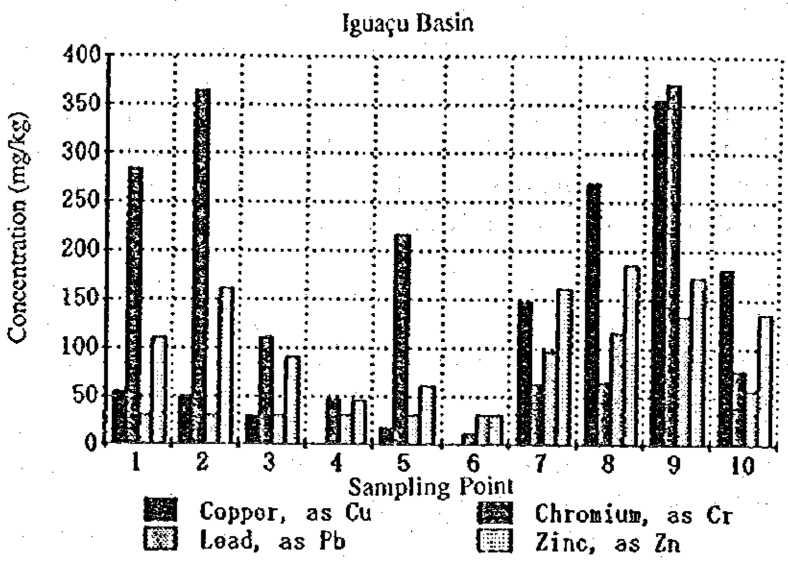


Figure-5.3 Heavy Metales in Iguaçu River Sediments

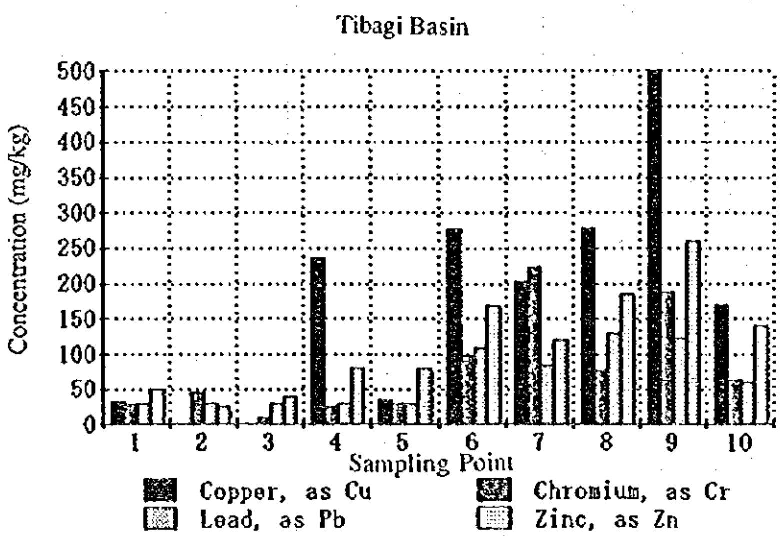


Figure-5.4 Heavy Metales in Tibagi River Sediments

(2) Agricultural Chemicals

1) Organochlorinated Chemicals

There are no regulations or standards concerning the concentrations of agricultural chemicals accumulated in soils or river sediments in Brazil. However the sale of organochlorinated chemicals has been prohibited in Paraná Province since 1987 and the use of such chemicals has been prohibited completely in the whole country since September 1995. At most of the sampling points, the concentrations of all the chlorinated agricultural chemicals are below the detection limits. Only Heptachlor has been detected at St. 7 and 8 in the Iguaçu River Basin and St. 6 and 8 in the Tibagi River Basin. This is considered to be attributed to the residuals from years before, since this chemical has a property of long retention time in the sediments.

2) Organophosphorated Chemicals

The levels of the organophosphorated chemicals are below the detection limits at all the sampling points. There is no any residual organophosphorated agricultural chemical in the river sediments because of the short retention properties of these chemicals.

CHAPTER 6 POLLUTION ANALYSIS OF MAIN MUNICIPALITIES IN THE PILOT RIVER BASINS

6.1 Present Condition and Future Prediction of Pollutant Load of the Pilot River Basins

6.1.1 Present Condition of Pollution Load and the River Water Quality

(1) Iguaçu River Basin

Judging from the present pollution level, the Iguaçu River Basin can be divided into the Upper River Basin (Iguaçu ST.1 - ST.21) and the Middle/Lower River Basin (Iguaçu ST.22 - ST.43) in order to make the analysis easier. Figure-6.1 illustrates the average BOD values for these two basins, based on the water quality data measured by IAP in the past 12 years from 1982 to 1993.

The BOD values in Figure-6.1 are the annual average values of all the water quality monitoring points in each basin. The difference between the two basins is clear. For the Upper River Basin, BOD exceeded 5 mg/l for most of the years with the highest value of 24 mg/l in 1986. The reason of river water pollution is due to the discharge of large quantity of domestic and industrial wastewater from the densely populated Curitiba M.A.

For the Middle/Lower Iguaçu River Basin, the annual average BOD values were 2-3 mg/l through all these years. This is because of the lower pollutant load in this basin and the larger quantity of water flow where pollutants from the upper stream can be diluted.

(2) Tibagi River Basin

Figure-6.2 illustrates the annual average BOD values of all the water quality monitoring points in Tibagi River Basin, based on IAP's water quality data of 1982 - 1993.

Generally speaking, the water quality of Tibagi River is good and can meet Class 1 (BOD less than 3 mg/l) according to IAP's classification of river water quality.

6.1.2 Pollutant Load Prediction

(1) Iguaçu River Basin

Iguaçu Basin is the most densely populated area in Paraná State. Domestic sewage and industrial wastewater are the main pollution sources to the river. Table-6.1 shows the predicted discharge BOD loads of these two kinds by the years of 2005 and 2015 with a comparison with those in 1993. It is understood from this table that besides an increase of the total BOD load in the whole basin, the percentage of domestic BOD load from the urban area will increase from 70% in 1993 to 74% in 2005 and 75% in 2015. This is due to the high rate increase in urban population in contrast with a decrease of the population in the rural area. Therefore, pollutant load reduction should mainly be carried out in the urban area, especially the large municipalities.

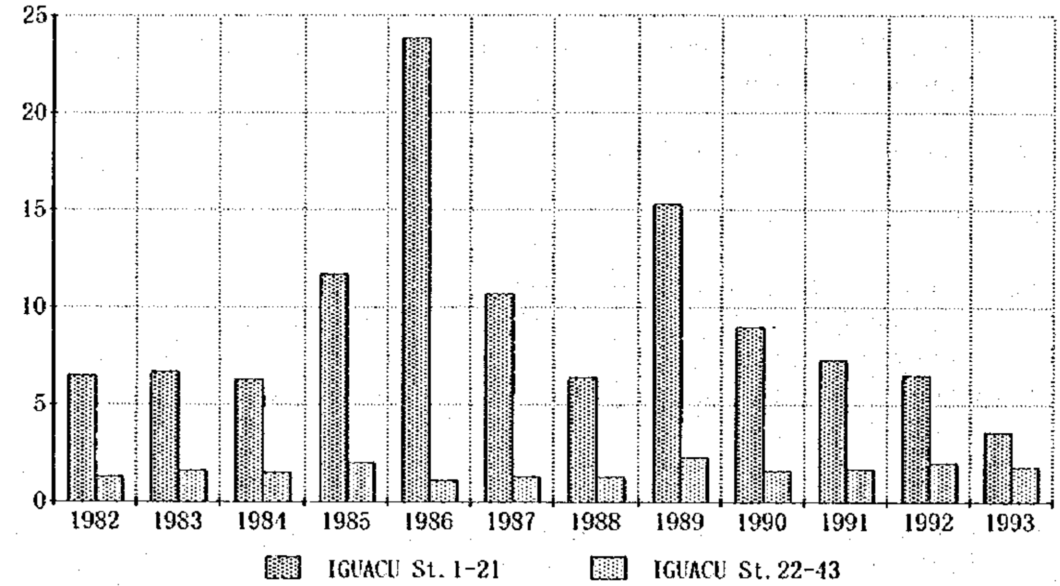


Figure-6.1 BOD Average of Iguaçu River Basin (1982 ~ 1993)

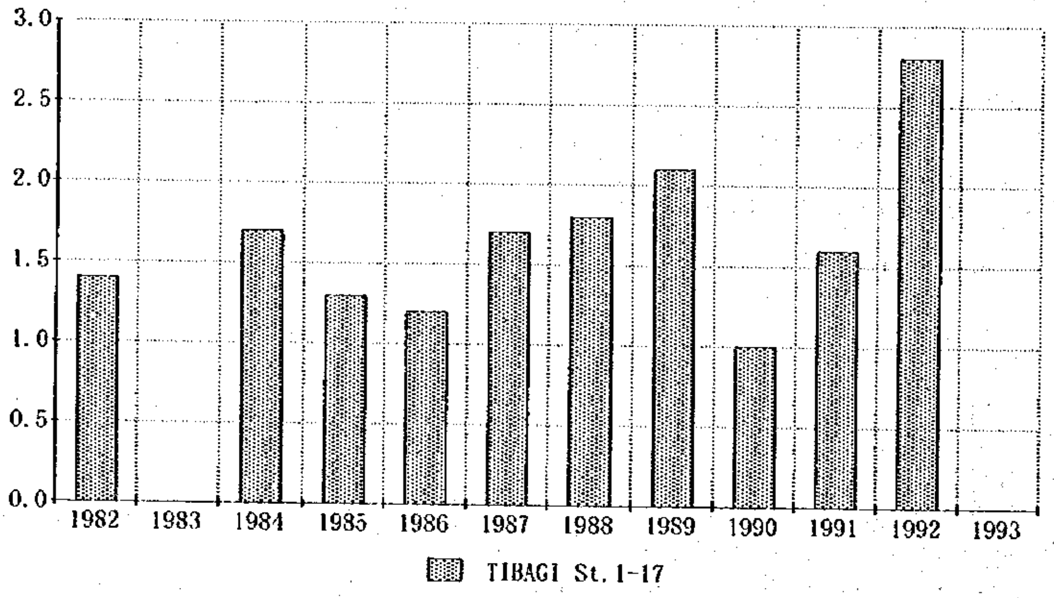


Figure-6.2 BOD Average of Tibagi River Basin (1982 ~ 1993)

Table-6.1 Pollutant Load Prediction of Iguaçu Basin

Unit: KgBOD/day

Item	1993	2005	2015
Domestic (Urban Area)			
Population	2,837,310	3,831,190	4,671,360
BOD Load	153,215	206,884	252,253
Domestic (Rural Area)			
Population	925,830	835,160	734,240
BOD Load	49,995	45,099	39,649
Industrial BOD Load	18,630	29,017	43,573
Total BOD Load	221,840	281,000	335,475

(2) Tibagi River Basin

Table-6.2 shows the predicted discharge BOD loads of domestic sewage and industrial wastewater in the Tibagi Basin by the years of 2005 and 2015 with a comparison with those in 1993.

In this basin, the domestic BOD load from the urban area will also increase due to an increase in the urban population. Therefore, pollutant load reduction in the urban area should be mainly considered

Table-6.2 Pollutant Load Prediction of Tibagi Basin

Unit: KgBOD/day

Item	1993	2005	2015
Domestic (Urban Area)			
Population	1,175,818	1,430,343	1,738,970
BOD Load	63,494	77,238	93,904
Domestic (Rural Area)			
Population	381,686	328,830	295,220
BOD Load	20,611	17,757	15,942
Industrial BOD Load	12,335	19,624	29,035
Total BOD Load	96,440	114,619	138,881

6.1.3 Target Cities for Pollutant Load Reduction

(1) Iguaçu River Basin

Table-6.3 shows the domestic BOD loads from several large cities in Iguaçu Basin area and their populations. The largest BOD load is from Curitiba M.A. followed by Foz do Iguaçu and Cascavel. It is apparent that Curitiba M.A. should be given the top priority, and then Cascavel City which is situated at the upstream of a small tributary. As for Foz do Iguaçu City, since it is situated at the downstream of Iguaçu River where the run-off BOD load, although it is considerably high, can be diluted by the abundant river flow, pollutant load reduction is less emergent. Therefore Curitiba M.A. and Cascavel City are selected as the target cities in Iguaçu basin for pollutant load reduction.

Table-6.3 Pollutant Load from Large Cities in Iguaçu Basin

City	1993		2005		2015	
	Population	BOD (kg/day)	Population	BOD (kg/day)	Population	BOD (kg/day)
Curitiba M.A.	1,908,360	103,051	2,524,380	136,317	3,040,510	164,188
Foz Do Iguaçu	204,365	11,036	353,920	19,112	479,380	25,887
Guarapuava	117,385	6,339	154,360	8,335	179,920	9,716
Cascavel	185,746	10,030	250,280	13,515	303,280	16,377
Francisco Beltrao	48,417	2,615	73,320	3,959	100,490	5,426

(2) Tibagi River Basin

Table-6.4 shows the domestic BOD loads from several large cities in Tibagi Basin area and their populations. The largest BOD load is from Londrina followed by Ponta Grossa. These two cities are selected as the target cities in Tibagi basin for pollutant load reduction.

Table-6.4 Pollutant Load from Large Cities in Tibagi Basin

City	1993		2005		2015	
	Population	BOD (kg/day)	Population	BOD (kg/day)	Population	BOD (kg/day)
Londrina	38,0979	20,573	488,396	26,373	579,760	31,307
Ponta Grossa	22,6776	12,246	269,880	14,574	306,720	16,562
Apucarana	88,221	4,764	110,160	5,949	129,880	7,014
Arapongas	61,063	3,297	70,520	3,808	78,620	4,245
Telemaco Borba	57,538	3,107	80,350	4,339	99,820	5,390

6.2 Pollution Load Reduction Plan for the Main Municipalities

6.2.1 Target Water Quality

According to IAP's regulation for river water quality, most of the rivers in Iguaçu and Tibagi basins are specified as Class 2 (BOD 3 - 5 mg/l). Therefore, BOD ≤ 5 mg/l should be set as the target water quality as has been done in Chapter 4 for the main streams of these rivers. However, at the immediate downstream of a large municipality, to reach such a target often needs a thorough treatment of almost all the sewage water, because of (1) a limited quantity of river flow to dilute the discharged pollutant, (2) a short flow distance to perform self-purification and (3) a high background BOD concentration of river water due to pollutants from industrial effluent or other sources. Preliminary investigations on the pollutants from Critiba M.A. show that even if domestic sewage were 100 % treated at the highest removal efficiency, say 95 % by a standard activated sludge method, BOD ≤ 5mg/l would not be realized for river waters at the immediate downstream of the city, unless the BOD load from industrial effluent would be sufficiently reduced meanwhile. For this reason, it is proposed in this study that for the two pilot basins, water quality at each of the control points along the main stream, Class 2 should be the target of water quality improvement, but for water quality in the large municipality area, Class 3 can be set as a target of pollutant load reduction on condition that no impact is anticipated on the downstream side of the main stream. This conforms to IAP's regulation since several rivers in Curitiba, Londrina and Ponta Grossa have already been specified as Class 3.

Considering the present conditions of water quality in the 4 target cities in the two basins, the target water qualities for pollutant load reduction are proposed as below:

Curitiba M.A.	BOD ≤ 10 mg/l	(Class 3)
Cascavel	BOD ≤ 5 mg/l	(Class 2)
Londrina	BOD ≤ 10 mg/l	(Class 3)
Ponta Grossa	BOD ≤ 10 mg/l	(Class 3)

6.2.2 Iguaçu River Basin (Curitiba M.A. and Cascavel)

(1) Quantity of Diluting Water

1) River Water Flow

The river flow (draught flow $Q_{10.7}$) is calculated from the specific flow rate and the city areas as follows:

CURITIBA M.A. $Q_{10.7}$ = 0.231(m^3/s/100km^2) x 2,800 (km^2)
= 6.468 m^3/sec = 558,835 m^3/day

CASCAVEL $Q_{10.7}$ = 0.420m^3/s/100km^2 x 250 km^2
= 1,050m^3/sec = 90,720m^3/day

2) Quantity of Diluting Water

The quantity of water which dilutes the run-off BOD consists of the base flow in the river ($Q_{10.7}$) and the quantity of domestic sewage and industrial wastewater flowing into the river. Table-6.5 shows the calculated quantity of diluting water for the two cities.

Table-6.5 Quantity of Diluting Water

Unit: m^3/day

City	Year	$Q_{10.7}$	Domestic Sewage Discharge	Industrial Wastewater Discharge	Total
Curitiba	2005	558,835	362,935	32,805	954,575
M.A.	2015	558,835	535,130	49,318	1,143,283
Cascavel	2005	90,720	31,035	3,189	124,944
City	2015	90,720	48,525	4,783	144,028

(2) Pollution Analysis

1) Pollution Analysis of the Present Condition of Curitiba M.A.

a) Method of Analysis

Analysis of the present condition is conducted in order to determine the purification-residual ratio which is the fundamental parameter for the prediction of river water quality in future. The procedures of analysis are as follows:

(i) Calculate the discharge BOD load from each pollution source;

(ii) Calculate the run-off BOD load by taking into consideration the run-off ratio;

(iii) Calculate the flow-out BOD load based on the current water quantity;

(iv) Evaluate the purification-residual ratio.

b) Result of Analysis

The result of analysis is shown in Table-6.6. The purification-residual ratio is evaluated as 0.34. This value is used for the future water quality prediction described in the following sections.

Table-6.6 Pollution Analysis of Present Conditions of Curitiba M.A.

	Item	Calculated Value
(1)	Population	
	Total	1, 908,860
	Sewage treatment served	658,620
	No sewage treatment served	1,249,740
(2)	Domestic Discharge Load (kg/day)	
	Total	103,051
	Treated by existing system	35,565
	Untreated	67,486
(3)	Run-off BOD Load (kg/day)	
	Total	70,379
	From untreated domestic load	53,989
	From treated domestic load	5,335
	From industrial load	11,055
(4)	Quantity of Diluting Water (m^3/sec)	801,290
(5)	Measured Water Quality (BOD mg/l)	30
(6)	Calculated Flow-out Load (kg/day)	24,040
(7)	Purification-residual Ratio	0.34

2) Pollution Analysis for 2005 and 2015

a) Analysis methods

i) The domestic and industrial discharge BOD loads are calculated as follows:

- Domestic load : From the population predicted for the future.

- Industrial load : Directly proportional to the GRDP growth rate.

ii) Target water qualities for the two cities are set as

Curitiba M.A. : BOD < 10 mg/l

Cascavel: BOD < 5 mg/l

iii) The permissible BOD load is calculated according to the target water quality.

iv) The quantity of pollution reduction is evaluated from the difference between the predicted run-off BOD load and the permissible run-off BOD load.

b) Calculation results

The calculation results are shown in Table-6.7.

Table-6.7 Pollution Analysis and Pollutant Reduction Plan for Curitiba M.A. and Cascavel

Item	Curitiba M.A.		Cascavel	
	2005	2015	2005	2015
Urban Population	2,520,380	3,040,510	250,280	303,280
Discharge BOD Load				
From domestic sewage (kg/day)	136,100	164,188	13,515	16,377
From industrial wastewater (kg/day)	16,361	23,216	216	305
Permissible Flow-out Load				
Target Water Quality (BOD mg/l)	10	10	5	5
Diluting Water (m^3/day)	954,575	1,143,285	124,944	144,028
BOD Load (kg/day)	9,546	11,432	625	720
Permissible Run-off Load (kg/day)	28,076	33,624	2,083	24,000
Permissible Run-off Load of the Domestic Wastewater (kg/day)	11,715	10,408	1,867	2,095
BOD Load Reduction for Domestic Wastewater				
Total BOD Load (kg/day)	136,100	164,188	13,515	16,377
Treated Load by existing system (kg/day)	28,452	28,452	2,318	2,318
Reduction Load (kg/day)	93,004	122,726	8,864	11,440
Quantity of Sewage Treatment				
Method of Treatment	Standard Activated Sludge	Standard Activated Sludge	Anaerobic + Aerobic Treatment	Anaerobic + Aerobic Treatment
BOD Removal Efficiency (%)	95	95	80	80
BOD Load Factor (g/person/day)	54	54	54	54
Unit Discharge (lit./person/day)	144	176	124	160
Treatment BOD Load (g/day)	97,899	129,185	11,080	14,300
Population to Serve	1,813,000	2,392,315	205,185	264,815
Quantity of Sewage Treatment (m^3/day)	261,064	421,047	25,443	42,370

(3) Plans of Pollutant Load Reduction by 2005 and 2015

Based on the result of calculation shown in Table-6.7, the BOD loads to be reduced for Curitiba M.A. are 93,004 and 122,726 kg/day by the years of 2005 and 2015, respectively, and those for Cascavel are 8,864 and 11,440 kg/day. This needs implementation of sewage treatment facilities of capacities to remove these amounts of pollutants.

Plans of sewage treatment are also shown in the table. For Curitiba M.A., the standard activated sludge process shall be applied in consideration of its high treatment efficiency (95% BOD removal) for a reduction of the great amount of pollutants. For Cascavel City, the method of anaerobic digestion followed by aerobic treatment (80% BOD removal) will be applied.

6.2.3 Tibagi River Basin (Londrina and Ponta Grossa)

(1) Quantity of Diluting Water

1) River Water Flow

The river flow (draught flow $Q_{10,7}$) is calculated from the specific flow rate and the city areas as follows:

Londrina $Q_{10,7}$ $= 0.091(m^3/s/100km^2) \times 1,500\ (km^2)$

$= 1,365\ m^3/sec = 117,936\ m^3/day$

Ponta Grossa $Q_{10,7}$ $= 0.214\ m^3/s/100km^2 \times 650\ km^2$

$= 1,391 m^3/sec = 120,182\ m^3/day$

2) Quantity of Diluting Water

Table-6.8 shows the calculated quantity of diluting water for the two cities, which consists of the base flow in the river ($Q_{10,7}$) and the quantity of domestic sewage and industrial wastewater flowing into the river.

Table-6.8 Quantity of Diluting Water

Unit: m^3/day

City	Year	$Q_{10,7}$	Domestic Sewage Discharge	Industrial Wastewater Discharge	Total
Londrina	2005	117,936	68,375	26,716	213,027
	2015	117,936	97,400	39,487	254,823
Ponta Grossa	2005	120,182	28,068	2,569	150,819
	2015	120,182	39,260	3,798	163,240

(2) Pollution Analysis for 2005 and 2015

1) Analysis methods

The methods of analysis are basically the same as that described in the former section for Iguaçu River Basin. The target water qualities for Londrina and Ponta Grossa are set as

Londrina : BOD < 10 mg/l

Ponta Grossa: BOD < 10 mg/l

and the purification-residual ratio is assumed to be 0.3 referring to the result of pollution analysis for Curitiba M.A.

2) Calculation results

The calculation results are shown in Table-6.9.

Table-6.9 Pollution Analysis and Pollutant Reduction Plan for Londrina and Ponta Grossa

Item	LONDRINA		PONTA GROSSA	
	2005	2015	2005	2015
Urban Population	488,390	579,760	269,880	306,720
Discharge BOD Load				
From domestic sewage (kg/day)	26,373	31,307	14,573	16,563
From industrial wastewater (kg/day)	5,012	11,778	1,964	2,902
Permissible Flow-out Load				
Target Water Quality (BOD mg/l)	10	10	10	10
Diluting Water (m^3/day)	213,027	254,823	150,819	163,240
BOD Load (kg/day)	2,130	2,548	1,508	1,632
Permissible Run-off Load (kg/day)	8,520	12,740	5,027	5,440
Permissible Run-off Load of the Domestic Wastewater (kg/day)	551	1,000	3,063	2,538
BOD Load Reduction for Domestic Wastewater Load				
Total BOD Load (kg/day)	26,373	30,307	14,573	16,563
Treated Load by existing system (kg/day)	10,458	10,458	4,492	4,493
Reduction Load (kg/day)	15,226	20,849	6,252	8,897
Quantity of Sewage Treatment				
Method of Treatment	Standard Activated Sludge	Standard Activated Sludge	Anaerobic + Aerobic Treatment	Anaerobic + Aerobic Treatment
BOD Removal Efficiency (%)	95	95	80	80
BOD Load Factor (g/person/day)	54	54	54	54
Unit Discharge (lit./person/day)	140	168	104	128
Treatment BOD Load (g/day)	16,027	21,919	7,815	11,121
Population to Serve	296,803	406,413	144,722	205,944
Quantity of Sewage Treatment (m^3/day)	41,552	68,277	15,051	26,361

(3) Plans of Pollutant Load Reduction by 2005 and 2015

Based on the result of calculation shown in Table-6.9, the BOD loads to be reduced for Londrina are 15,226 and 20,894 kg/day by the years of 2005 and 2015, respectively, and those for Ponta Grossa are 6,252 and 8,897 kg/day.

Plans of sewage treatment are also shown in the table. For Londrina, the standard activated sludge process will be applied in consideration of its high treatment efficiency (95% BOD removal) for a reduction of the great amount of pollutants. For Ponta Grossa, the method of anaerobic digestion followed by aerobic treatment (80% BOD removal) will be applied.

CHAPTER 7 POLLUTION ANALYSIS FOR THE WHOLE PILOT RIVER BASINS

7.1 Objective and Methodology

(1) Objective

The objective of pollution analysis is to investigate the water quality at each of the control points in the whole pilot river basins in 2005 and 2015 on condition that pollutant reduction plans are implemented in the main municipalities (Curitiba M.A. and Cascavel for the Iguaçu Basin and Londrina and Ponta Grossa for the Tibagi Basin). If the target water quality cannot be met at some of the control points, additional plans shall have to be worked out for pollutant reduction in the related areas.

(2) Methodology

The pollution analysis of the whole river basin consists of two steps. Firstly the pollutant loads flowing to the river from various pollution sources are analyzed, and secondly water qualities at each of the control points in 2005 and 2015 are predicted. For water quality prediction, a water quality simulation model is formulated on the basis of Streeter-Phelps formula. As will be described in detail in the following sections, this model can mainly simulate the self-purification process in a river course where organic pollutants are removed by biological degradation, sedimentation and adsorption.

7.2 Future Prediction of Pollutant Loads by Sub-basins

7.2.1 Division of Sub-basins

In order to select water quality control points for pollution analysis, each of the pilot basins is divided into several sub-basins each containing one or two water quality control points according to the geographic and hydrological characteristics of the main streams and their tributaries, and the current condition of sewage and wastewater discharge. The division of sub-basins is shown in Figure-7.1 for the Iguaçu River Basin (20 sub-basins and 22 control points) and Figure-7.2 for the Tibagi River Basin (17 sub-basins and 18 control points).

7.2.2 Pollution Sources and Pollutant Load Factors

Generally speaking, pollutants discharged into rivers are from artificial and natural sources. The artificial source includes domestic sewage, industrial wastewater and livestock wastes, and the natural source includes the pollutants induced by ecological phenomena and so on.

In this study, the above mentioned pollution sources are considered, and the corresponding pollutant load factors (as BOD) are set as follows referring to Brazil and Japanese Standards.

(1) Domestic pollutant load: using a pollutant load factor of 54 g/person/day

(2) Industrial pollutant load: converting existing data to BOD load per unit GNDP (g/1,000 US$) for future prediction

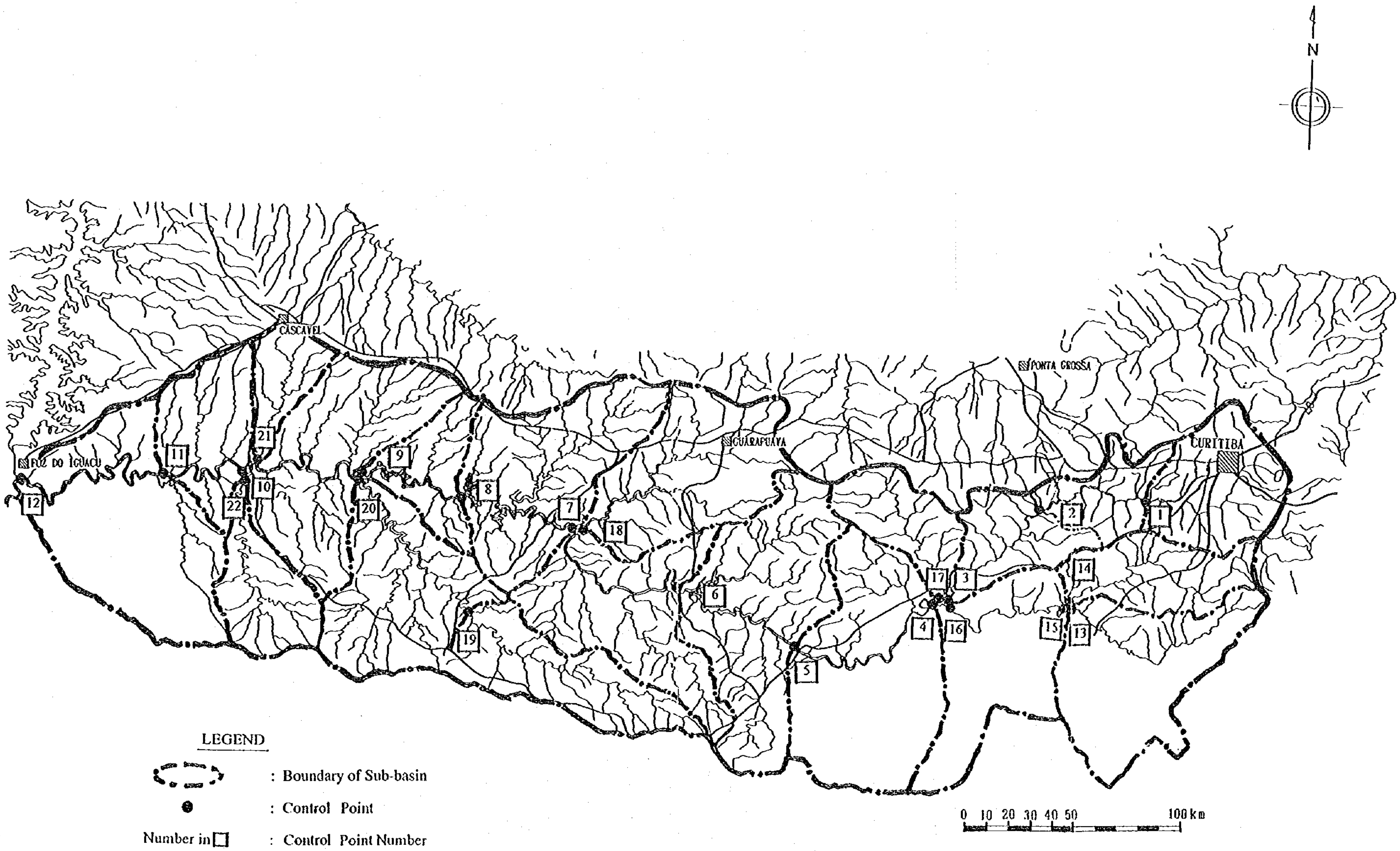


Figure-7.1 Water Quality Control Points in Iguaçu River Basin

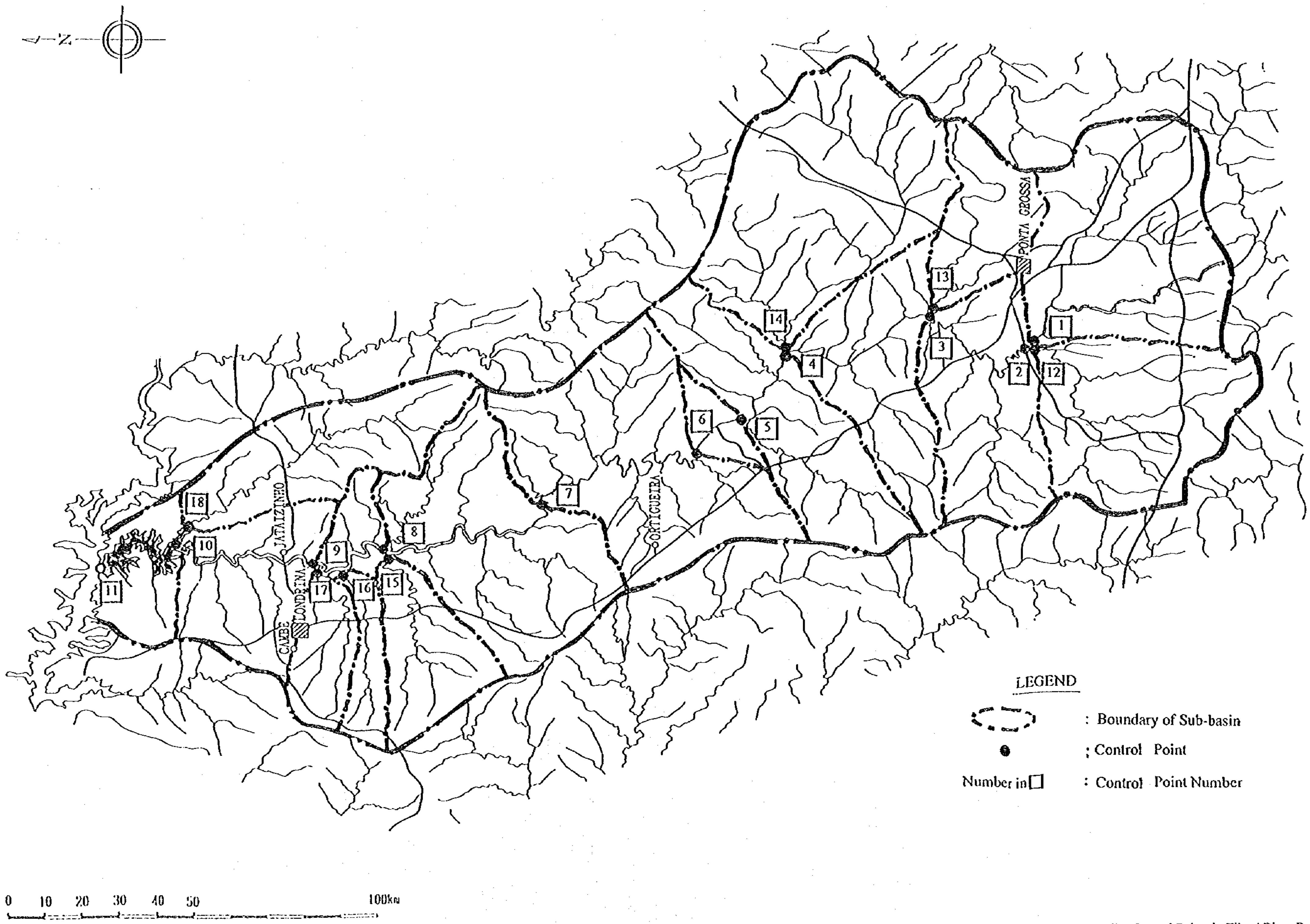


Figure-7.2 Water Quality Control Points in Tibagi River Basin

(3) Livestock pollutant load: using pollutant load factors of

- 600 g/head/day for cattle
- 200 g/head/day for pig
- 9 g/head/day for chicken

(4) Natural pollutant load: using a pollutant load factor of 0.7 $kg/Km^2/day$

7.2.3 Prediction of Domestic Pollutant Loads

The domestic pollutant loads are calculated by multiplying the predicted population in each of the sub-basins and the pollutant load factor of 54 g/person/day.

(1) Urban Population and BOD Load

Urban population in each sub-basin is the sum of the populations in cities and towns where more than 10,000 people will live by the year of 2015. Tables 7.1 and 7.2 show the predicted urban population and calculated BOD load in each of the sub-basins in the two river basins in comparison with the data of 1993. For a sub-basin where there are 2 water quality control points (such as the sub-basin with C.P. 4 and 5 and that with C.P. 15 and 16 in Iguaçu Basin and that with C.P. 2 and 3 in Tibagi Basin), the calculated BOD load is considered to be the direct load to the control point on the downstream side with the other only as a reference point for water quality. In the following sections, all the tables showing pollutant load prediction results are arranged in this way.

(2) Rural Population and BOD Load

Tables 7.3 and 7.4 show the rural population and BOD load in the years of 2005 and 2015 by sub-basins in the Iguaçu and Tibagi River Basins, respectively, in comparison with the 1993 data.

Table-7.1 Urban Population and BOD Load in the Iguaçu River Basin

Control point	Population and BOD Load					
	1993		2005		2015	
	Person	BOD kg/day	Person	BOD kg/day	Person	BOD kg/day
1	1,908,360	103,051	2,524,380	136,317	3,040,510	164,188
2	0	0	0	0	0	0
3	16,489	890	21,120	1,140	25,010	1,351
4	0	0	0	0	0	0
5	39,979	2,159	41,120	2,220	41,460	2,239
6	12,551	678	20,310	1,097	26,680	1,441
7	4,783	258	9,090	491	12,660	684
8	35,183	1,900	47,080	2,542	67,020	3,619
9	16,343	883	19,260	1,040	19,880	1,074
10	7,965	430	9,500	513	10,720	579
11	8,529	461	9,580	517	10,400	562
12	265,697	14,348	429,280	23,181	565,930	30,560
13	20,643	1,115	24,120	1,302	27,140	1,466
14	20,074	1,084	24,860	1,342	28,970	1,564
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	5,948	321	9,040	488	11,610	627
18	117,385	6,339	154,360	8,335	179,920	9,716
19	39,184	2,116	48,870	2,639	58,610	3,165
20	132,451	7,152	188,940	10,203	241,560	13,044
21	185,746	10,030	250,280	13,515	303,280	16,377
22	0	0	0	0	0	0
Total	2,837,310	153,215	3,831,190	206,884	4,671,360	252,253

Table-7.2 Urban Population and BOD Load in the Tibagi River Basin

Control point	Population and BOD Load					
	1993		2005		2015	
	Person	BOD kg/day	Person	BOD kg/day	Person	BOD kg/day
1	128,609	6,945	152,840	8,253	173,590	9,374
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	7,631	412	12,760	689	17,150	926
5	7,753	419	11,800	637	15,110	816
6	57,538	3,107	80,350	4,339	99,820	5,390
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	28,519	1,540	29,200	1,577	27,930	1,508
10	42,613	2,301	57,660	3,114	70,480	3,806
11	9,922	536	11,340	612	12,560	678
12	40,539	2,189	50,420	2,723	58,660	3,168
13	113,388	6,123	134,940	7,287	153,360	8,281
14	53,633	2,896	72,310	3,905	88,270	4,767
15	88,221	4,764	110,160	5,949	129,880	7,014
16	61,063	3,297	20,520	1,108	78,620	4,245
17	486,122	26,251	627,120	33,864	747,080	40,342
18	50,267	2,714	58,920	3,182	66,460	3,589
Total	1,175,818	63,494	1,430,340	77,238	1,738,970	93,904

Table-7.3 Rural Population and BOD Load in the Iguaçu River Basin

Control point	Population and BOD Load					
	1993		2005		2015	
	Person	BOD kg/day	Person	BOD kg/day	Person	BOD kg/day
1	109,402	5,908	105,940	5,721	96,520	5,212
2	11,551	624	13,460	727	14,550	786
3	30,242	1,633	31,670	1,710	31,100	1,679
4	0	0	0	0	0	0
5	15,201	821	16,770	906	17,500	945
6	47,280	2,553	49,340	2,664	46,880	2,532
7	13,912	751	14,450	780	14,040	758
8	75,355	4,069	71,500	3,861	64,290	3,472
9	38,072	2,056	30,840	1,665	26,300	1,420
10	111,998	6,048	89,700	4,844	73,120	-3,948
11	13,908	751	11,860	640	11,260	608
12	85,132	4,597	56,090	3,029	35,060	1,893
13	20,411	1,102	23,060	1,245	23,920	1,292
14	36,922	1,994	39,400	2,128	39,210	2,117
15	0	0	0	0	0	0
16	7,943	429	8,510	460	8,490	458
17	32,047	1,731	33,650	1,817	33,730	1,821
18	61,185	3,304	63,630	3,436	60,980	3,293
19	28,720	1,551	26,300	1,420	23,110	1,248
20	115,682	6,247	93,080	5,026	70,230	3,792
21	25,102	1,356	15,840	855	10,560	570
22	45,765	2,471	40,070	2,164	33,390	1,803
Total	925,830	49,995	835,160	45,099	734,240	39,649

Table-7.4 Rural Population and BOD Load in the Tibagi River Basin

Control point	Population and BOD Load					
	1993		2005		2015	
	Person	BOD kg/day	Person	BOD kg/day	Person	BOD kg/day
1	20,599	1,112	20,740	1,120	19,510	1,054
2	0	0	0	0	0	0
3	24,347	1,315	27,180	1,468	27,120	1,464
4	8,995	486	6,660	360	4,310	233
5	23,835	1,287	23,070	1,246	20,480	1,106
6	9,397	507	4,990	269	2,710	146
7	42,484	2,294	33,650	1,817	31,150	1,682
8	25,978	1,403	23,670	1,278	22,880	1,236
9	8,737	472	4,900	265	3,200	173
10	7,921	428	3,660	198	1,980	107
11	1,853	100	640	35	270	15
12	48,469	2,617	46,500	2,511	42,970	2,320
13	6,067	328	5,240	283	4,170	225
14	31,951	1,725	30,840	1,665	27,520	1,486
15	24,838	1,341	21,830	1,179	20,590	1,112
16	4,275	231	2,480	134	1,220	66
17	35,512	1,918	20,710	1,118	13,090	707
18	56,428	3,047	52,070	2,812	52,050	2,811
Total	381,686	20,611	328,830	17,757	295,220	15,942

7.2.4 Prediction of Industrial Pollutant Loads

The prediction of the industrial pollutant loads is based on the data of 1993 provided by IAP. The industrial pollutant loads in the years of 2005 and 2015 are assumed to be proportional to the growth rate of GRDP. The results shown in Tables 7.5 and 7.6 are obtained by multiplying the 1993 data and the corresponding GRDP growth rates for the Iguaçu and Tibagi Basins, respectively, in comparison with the 1993 data.

Table-7.5 Industrial Pollutant Loads in Iguaçu Basin

Unit:BODkg/day

C.P.	1993	2005	2015
1	11,055.0	16,361.4	23,215.5
2	8.5	13.9	22.4
3	1.8	3.0	5.0
4	0	0	0
5	2,483.0	4,171.4	6,853.1
6	268.0	466.3	737.0
7	0	0	0
8	10.8	18.8	29.7
9	0	0	0
10	97.0	168.8	267.7
11	0	0	0
12	209.0	363.7	576.8
13	544.0	946.6	1,501.4
14	172.0	264.9	375.0
15	0	0	0
16	0	0	0
17	78.0	131.0	215.3
18	3,060.0	5,110.2	8,353.8
19	34.0	58.8	92.5
20	539.0	830.1	1,175.0
21	70.0	107.8	152.6
22	0	0	0
Total	18,630.1	29,016.7	43,572.8

Table-7.6 Industrial Pollutant Loads in Tibagi Basin

Unit:BODkg/day

C.P.	1993	2005	2015
1	1,245.0	2,041.8	3,274.4
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	3,197.0	5,371.0	8,599.9
7	0	0	0
8	0	0	0
9	48.0	66.7	89.3
10	85.0	118.2	158.1
11	0	0	0
12	10.0	13.9	18.6
13	0	0	0
14	2,010.0	3,115.5	4,381.8
15	461.0	714.6	1,005.0
16	180.0	279.0	392.4
17	5,073.0	7,863.2	11,059.1
18	26.0	40.3	56.7
Total	12,335.0	19,624.2	29,035.3

7.2.5 Prediction of Livestock Pollutant Loads

The livestock pollutant loads are calculated by multiplying the number of each kind of livestock by its pollutant load factor. The predicted numbers of livestock in 2005 and 2015 are provided by EMATER. Tables 7.7 and 7.8 show the calculated results by sub-basins in the two pilot river basins.

Table-7.7 Livestock Pollutant Loads in Iguaçu River Basin

C.P.	Cattle			Pig			Chicken		
	1994	2005	2015	1994	2005	2015	1994	2005	2015
1	20,520	22,860	28,140	11,440	12,760	12,760	45,110	57,899	69,532
2	2,280	2,640	3,120	700	800	800	1,565	2,011	2,410
3	12,780	15,360	17,640	4,800	5,360	5,360	2,250	2,889	3,465
4	0	0	0	0	0	0	0	0	0
5	22,200	26,640	30,660	4,120	4,620	4,620	14,760	21,834	26,217
6	40,080	48,120	55,320	19,840	22,140	22,140	1,701	2,178	2,619
7	13,200	15,780	18,180	1,980	2,220	2,220	0	0	0
8	96,780	115,920	133,440	18,320	20,480	20,480	25,416	32,625	39,186
9	45,480	54,480	62,760	6,540	7,300	7,300	5,046	6,475	7,772
10	131,160	157,140	168,180	38,440	42,960	42,960	110,902	142,355	170,951
11	28,680	34,680	39,600	10,960	12,220	12,220	6,747	8,663	10,401
12	108,600	130,440	149,760	25,860	26,900	26,900	12,550	16,115	19,338
13	8,760	10,440	12,060	3,640	4,080	4,080	14,211	18,243	21,906
14	25,500	30,540	35,100	5,220	5,820	5,820	15,177	19,485	23,395
15	0	0	0	0	0	0	0	0	0
16	2,220	2,700	3,120	2,700	3,020	3,020	0	0	0
17	12,060	14,460	16,680	5,960	6,540	6,540	10,273	13,181	15,839
18	74,100	88,800	102,240	14,020	15,660	15,660	0	0	0
19	68,280	81,480	93,780	4,760	5,340	5,340	6,912	8,874	10,656
20	146,100	175,080	201,600	49,680	55,480	55,480	204,066	261,954	314,568
21	56,010	67,200	77,340	7,380	8,080	8,080	14,236	18,268	21,951
22	50,700	58,260	69,960	12,000	14,700	14,700	52,875	67,878	81,504

Table-7.8 Livestock Pollutant Loads in Tibagi River Basin

C. P.	Cattle			Pig			Chicken		
	1994	2005	2015	1994	2005	2015	1994	2005	2015
1	43,440	52,080	60,000	6,480	7,280	7,280	15,346	19,703	23,661
2	0	0	0	0	0	0	0	0	0
3	12,660	15,180	17,460	1,920	2,140	2,140	550	707	848
4	66,420	79,680	91,680	5,580	6,220	6,220	0	0	0
5	14,880	17,880	20,520	700	780	780	0	0	0
6	4,980	6,000	6,900	480	540	540	0	0	0
7	59,160	70,980	81,720	4,160	4,640	4,640	336	431	515
8	29,820	35,700	41,100	1,640	1,820	1,820	225	290	347
9	13,260	15,960	18,360	780	780	780	1,179	1,512	1,818
10	16,920	20,280	23,340	2,780	3,120	3,120	12,606	16,178	19,436
11	2,100	2,520	2,940	260	300	300	1,016	1,303	1,566
12	21,600	25,920	29,820	7,160	8,000	8,000	0	0	0
13	0	0	0	0	0	0	0	0	0
14	58,200	69,780	80,340	4,640	5,180	5,180	21,883	28,087	33,732
15	17,400	20,880	24,060	680	760	760	1,067	1,370	1,646
16	4,260	5,100	5,880	4,580	5,120	5,120	2,125	2,729	3,275
17	101,220	119,940	142,620	6,000	6,700	6,700	22,643	29,071	34,909
18	46,620	49,200	67,320	2,400	2,700	2,700	120	154	185

7.2.6 Natural Pollutant Loads

The natural pollutant loads are calculated by multiplying the area of each sub-basin and the pollutant load factor of 0.7 kg BOD/km^2/day. This kind of pollutant loads will not vary in the future. Table-7.9 shows the calculated results for the Iguaçu and Tibagi River Basins.

Table-7.9 Natural Pollutant Loads of Iguaçu and Tibagi Basins

IGUACU River Basin				TIBAGI River Basin			
C.P.	Basin Area (km^2)	Unit Load (kgBOD/km^2/d)	Pollution Load (kgBOD/d)	C.P.	Basin Area (km^2)	Unit Load (kgBOD/km^2/d)	Pollution Load (kgBOD/d)
1	2,830	0.7	1,981	1	2,805	0.7	1,964
2	1,389	0.7	972	2	0	0	0
3	1,773	0.7	1,241	3	1,565	0.7	1,096
4	0	0	0	4	1,578	0.7	1,105
5	5,949	0.7	4,164	5	1,818	0.7	1,273
6	5,617	0.7	3,932	6	382	0.7	267
7	4,245	0.7	2,972	7	2,715	0.7	1,901
8	4,699	0.7	3,289	8	2,583	0.7	1,808
9	1,747	0.7	1,223	9	293	0.7	205
10	4,760	0.7	3,332	10	1,516	0.7	1,061
11	2,411	0.7	1,688	11	408	0.7	286
12	6,044	0.7	4,231	12	1,969	0.7	1,378
13	4,472	0.7	3,130	13	1,001	0.7	701
14	2,289	0.7	1,602	14	3,007	0.7	2,105
15	0	0	0	15	1,068	0.7	748
16	3,878	0.7	2,715	16	397	0.7	278
17	1,834	0.7	1,284	17	406	0.7	284
18	4,446	0.7	3,112	18	1,124	0.7	787
19	3,005	0.7	2,104				
20	4,071	0.7	2,850				
21	1,267	0.7	887				
22	1,974	0.7	1,382				

7.3 Pollution Analysis

7.3.1 Fundamental Parameters

(1) Streeter Phelps Formula and Self-Purification Coefficient

Streeter Phelps Formula is a widely used equation showing the basic relationship between the concentration of organic matters (BOD) and their runoff time in a river course. The expression of the formula is as follows:

$$C(t) = C_0 e^{-kt}$$

where, C_0 : initial BOD concentration (mg/l)

$C(t)$: BOD concentration after a runoff time of t (day)

k : self-purification coefficient (1/day)

The self-purification coefficient k is a general parameter reflecting the actions of biological degradation, sedimentation and adsorption which bring about a decay of BOD in a river flow. For the pollution analysis for the two river basins, the k value is estimated as 1.5 for the main river flow and 0.8 for the tributaries based on an analysis of the current condition of pollutant load and water quality in the two river basins.

(2) Run-off Ratio

The run-off ratio (the ratio of the run-off BOD load to the discharge BOD load) for each kind of pollution source is set as follows referring to Japanese Standards:

Domestic sewage	Urban area	0.8
	Rural area	0.1
Industrial wastewater (treated)		1.0
Livestock wastewater	Cattle	0.05
	Pig	0.05
	Chicken	0.03
Natural Pollutants		0.01

(3) Quantity of River Flow

The average drought flow ($Q_{10,7}$) is used for the pollution analysis. Tables 7.10 and 7.11 show the values at each of the control points in the two river basins. These are used as the quantities of diluting water in water quality calculation.

(4) River Flow Velocity

The runoff time of pollutant in a river course is determined by the distance of flow and river flow velocity. Based on the collected information about the hydrological characteristics of the two river basins, the average flow rate is assumed as 0.4 m/sec in the river course.

Table-7.10 Water Flow at each C.P. in Iguaçu River Basin

C. P. No.	C. A. (km²)	Distance (km)	$Q_{10.7}$ (m^3/sec)	Flow Velocity (m/sec)	Note
1	2,830	60	6.53	0.40	
2	1,389	50	8.36	0.40	
3	1,773	65	13.75	0.40	
4	0	0	41.14	0.40	
5	5,949	85	66.61	0.40	
6	5,617	65	85.43	0.01	DAM(G.B.Mda Rocha Netto)
7	4,245	80	115.37	0.01	DAM(Segredo)
8	4,699	60	131.50	0.01	DAM(Salto Santiago)
9	1,747	60	160.57	0.01	DAM(Salto Osorio)
10	4,760	50	184.40	0.40	
11	2,411	70	190.91	0.40	
12	6,044	70	205.52	0.40	
13	4,472	90	11.25	0.40	
14	2,289	90	5.76	0.40	
15	0	0	17.00	0.40	
16	3,878	50	25.30	0.40	
17	1,834	60	2.09	0.40	
18	4,446	90	12.20	0.01	DAM(Salto Curucaca)
19	3,005	100	8.69	0.40	
20	4,071	90	16.31	0.01	DAM(J.de Mesquita Filho)
21	1,267	55	2.42	0.40	
22	1,974	90	4.41	0.40	

C.P. : Control Point
C.A. : Control Area

Table-7.11 Water Flow at each C.P. in Tibagi River Basin

C. P. No.	C. A. (km²)	Distance (km)	$Q_{10.7}$ (m^3/sec)	Flow Velocity (m/sec)	Note
1	2,805	60	5.31	0.40	
2	0	0	9.04	0.40	
3	1,565	40	18.38	0.40	
4	1,578	50	30.51	0.40	
5	1,818	25	34.60	0.40	
6	382	15	35.41	0.40	
7	2,715	60	40.64	0.01	DAM(Pres. Vargas)
8	2,583	55	46.24	0.01	DAM(Apucaraninha)
9	293	30	47.60	0.40	
10	1,516	50	50.27	0.40	
11	408	25	50.61	0.40	
12	1,969	70	3.73	0.40	
13	1,001	70	1.67	0.40	
14	3,007	50	4.83	0.40	
15	1,068	50	1.11	0.40	
16	397	40	0.32	0.40	
17	406	40	0.31	0.40	
18	1,124	90	1.25	0.40	

C.P. : Control Point
C.A. : Control Area

(5) Consideration of Water Flow in a Dam

In the two pilot basins several dams are constructed. On condition that there is a dam between two water quality control points, the influence of a longer residence time or slower flow of water in the dam on water quality has to be considered in the calculation. By a comparison of the sectional areas of water flow in the river course and in the dam region, the water flow rate in the dam is assumed as 0.01 m/sec.

7.3.2 Water Quality Simulation Procedures

The general procedures of water quality simulation are as follows:

(1) Division of sub-basins and selection of water quality control points as mentioned above.

(2) Calculation of the run-off BOD load at each of the control points by using the discharge BOD loads calculated in Tables 7.1 to 7.9 and the run-off ratios mentioned above.

(3) Starting water quality calculation from the first water quality control point by calculating firstly the BOD concentration after dilution and secondly the BOD concentration after flowing downstream to the next water quality control point.

For each of the two river basins, the water quality calculation mentioned in (3) is a successive calculation from the upstream to the downstream of the main river flow, as well as the flows from its tributaries. At each water quality control point, both the flow-out BOD from upstream and the run-off BOD at that point are accounted.

Figs. 7.3 and 7.4 show the water quality calculation flow charts for the Iguaçu and Tibagi Basins, respectively.

7.3.3 Simulation Results

(1) Iguaçu River Basin

Table-7.12 shows the results of water quality prediction for the 12 control points along the main stream of the Iguaçu River. The BOD concentrations at most of these points are lower than 1.0 mg/l by both the years of 2005 and 2015, except for No. 1 at the immediate downstream of Curitiba M.A., where the target water quality is set as 10 mg/l. The lowest BOD value appears at control points No. 6 to No. 9 as only 0.01 mg/l. This is because dams are built in these sub-basins where water flows very slowly and self-purification efficiency is very high. The results indicate that if pollutant load from Curitiba M.A. and Cascavel City can be reduced as has been planned in Chapter 6, the water quality in the whole river basin can be soundly improved. Therefore, sewage treatment implementation should mainly be planned for the two large municipalities.

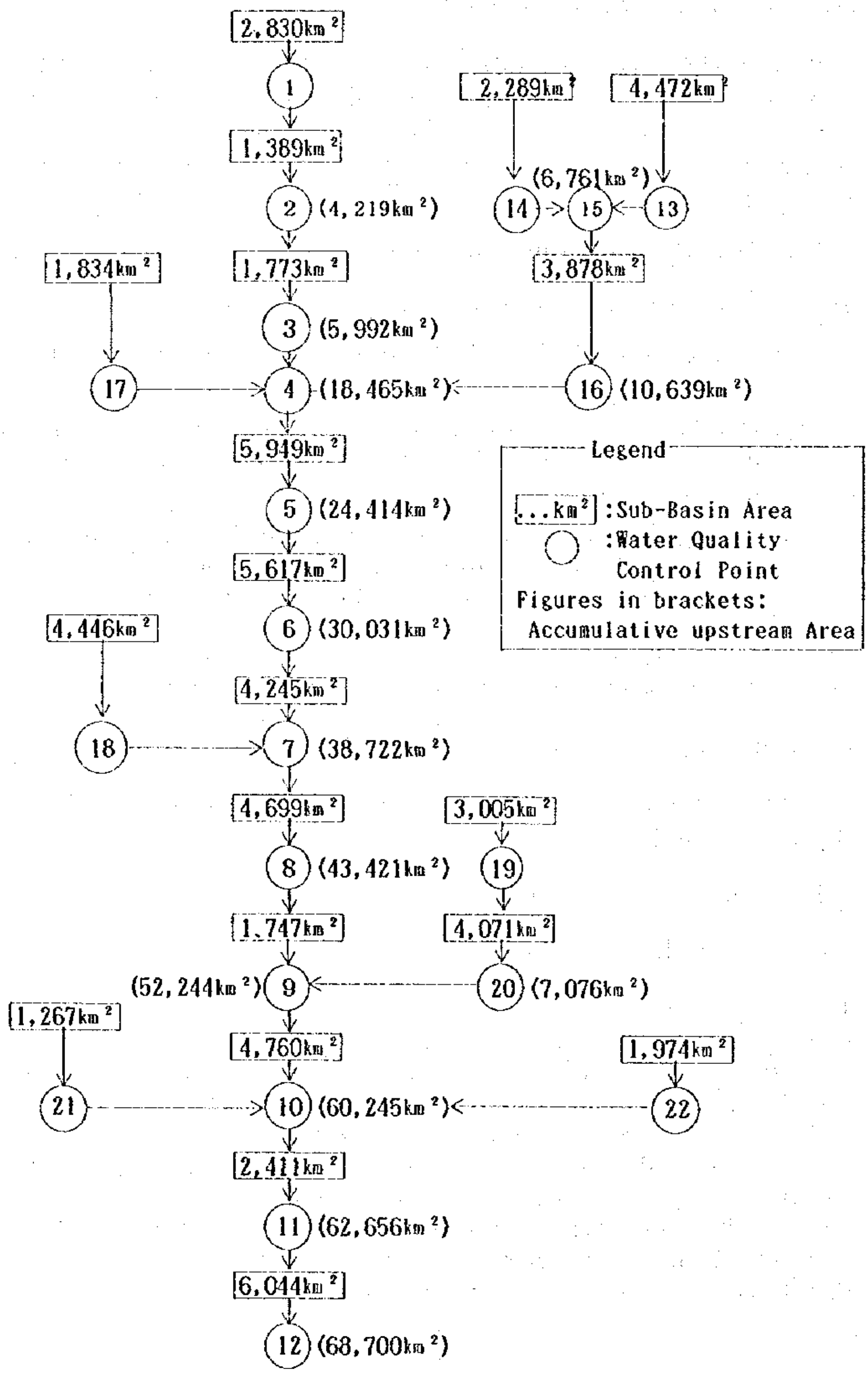


Figure-7.3 Water Quality Calculation Flow Chart for Iguaçu River Basin

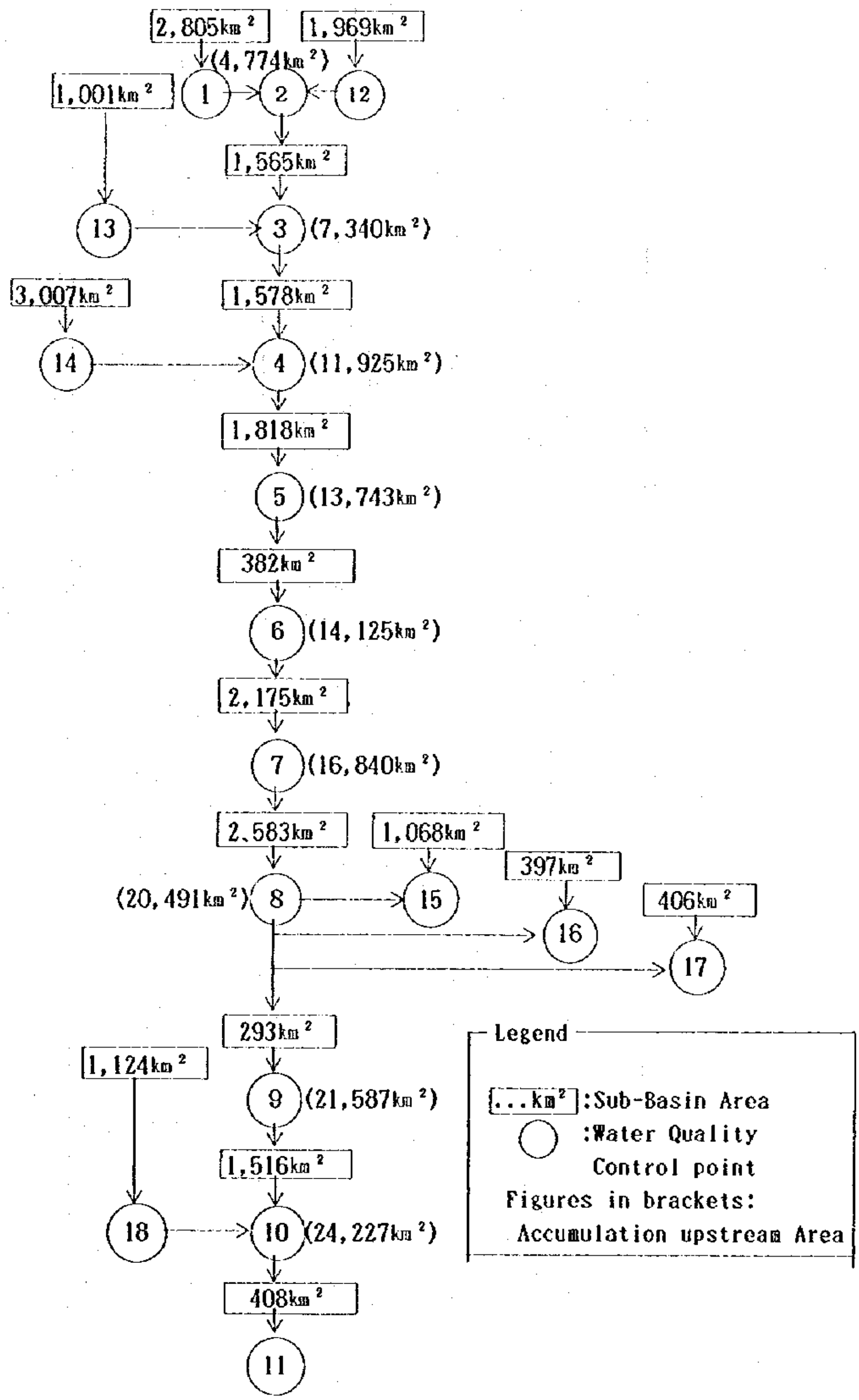


Figure-7.4 Water Quality Calculation Flow Chart for Tibagi River Basin

Table-7.12 Water Quality Prediction of Iguaçu River

Unit: mgBOD/l

Water Quality Control Point	2005	2015
No.1	4.02	5.84
No.2	0.53	0.71
No.3	0.42	0.47
No.4	0.35	0.39
No.5	0.08	0.10
No.6	0.01	0.01
No.7	0.01	0.01
No.8	0.01	0.01
No.9	0.01	0.01
No.10	0.21	0.23
No.11	0.06	0.06
No.12	0.13	0.16

(2) Tibagi River Basin

Table-7.13 shows the results of water quality prediction for the 11 control points along the main stream of the Tibagi River. The BOD concentrations at most of these points are lower than 2.0 mg/l by both the years of 2005 and 2015, except for No. 1 and No.2 near Ponta Grossa. The lowest BOD value appears at control points No. 7 and No. 8 as only 0.01 mg/l, because dams are built in these sub-basins. The results indicate that if pollutant load from Londrina and Ponta Grossa can be reduced as has been planned in Chapter 6, the water quality in the whole river basin can be soundly improved. Therefore, sewage treatment implementation should mainly be planned for the two large municipalities.

Table-7.13 Water Quality Prediction of Tibagi River

Unit: mgBOD/l

Water Quality Control Point	2005	2015
No.1	2.83	3.35
No.2	2.55	2.95
No.3	0.55	0.63
No.4	0.94	1.08
No.5	0.51	0.59
No.6	1.89	2.64
No.7	0.01	0.01
No.8	0.01	0.01
No.9	0.76	0.91
No.10	0.33	0.39
No.11	0.18	0.21

CHAPTER 8 SEWAGE TREATMENT PLAN

8.1 Quantity of Sewage to be Treated

As has been discussed in the former chapters, the target cities for pollutant reduction are Curitiba M.A. and Cascavel for the Iguaçu River Basin, and Londrina and Ponta Grossa for the Tibagi River Basin. As long as the pollutant loads from these cities can be reduced according to the targets of pollutant reduction, the water quality at each of the control points along the main rivers will meet the prescribed standard value. Therefore, sewage treatment facilities have to be implemented in these large municipalities. Table-8.1 shows the quantity of sewage to be treated by the years of 2005 and 2015, based on the results of pollution analysis in Chapter 6.

Table-8.1 Quantity of Sewage to be Treated

Unit: m^3/day

Year	Curitiba M.A.	Cascavel	Londrina	Ponta Grossa
2005	260,000	25,000	42,000	15,000
2015	420,000	45,000	70,000	30,000

8.2 Project Implementation Plan

Table-8.2 shows the implementation plan of sewage treatment project for Curitiba M.A. and Cascavel in the Iguaçu River Basin, and Londrina and Ponta Grossa in the Tibagi River Basin. The work will start in 1996 and through 4 stages to the target year of 2015.

Table-8.2 Project Implementation Plan

Unit: m^3/day

Implementation Period	Curitiba M.A.		Cascavel		Londrina		Ponta Grossa	
	Treatment Capacity	Treatment method	Treatment Capacity	Treatment method	Treatment Capacity	Treatment method	Treatment Capacity	Treatment method
1996~2000	100,000	a	-	-	-	-	-	-
2001~2005	100,000	a	20,000	b	40,000	a	30,000	b
2006~2010	100,000	a	-	-	-	-	-	-
2011~2015	120,000	a	25,000	b	30,000	a	-	-
Total		420,000		45,000		70,000		30,000

Note:

Treatment Method	BOD Removal (%)
a: Standard Activated Sludge Process	95
b: Anaerobic Digestion + Aerobic Treatment	80

8.3 Project Cost Estimation

The project cost is estimated based on the SANEPAR's "Plano Director de Esgotamento Santario de Curitiba de Regao Metropolitana (Sept., 1993)" which provides the standard unit cost for sewerage system construction. Table-8.3 shows the total costs including the additional cost for the construction of sewer pipelines and other accessory facilities.

Table-8.3 Total Construction Cost

(Unit: US$ x 1,000, Year 1994)

Period	Curitiba M.A.	Cascavel	Londrina	Ponta Grossa
1996~2000	70,300	-	-	-
2001~2005	70,300	23,400	32,800	29,200
2006~2010	70,000	-	-	-
2011~2015	82,700	26,100	26,600	-
Total	293,600	49,500	59,400	29,200

Note) The cost includes those for sewage treatment facilities, sewer pipelines and other accessory facilities.

CHAPTER 9 RECOMMENDATION

(1) In the 11 river basins in Paraná State, IAP established 152 water quality monitoring stations. However, water quality observation was conducted at only 28 stations in 1992 and 23 stations in 1993. In order to provide more detailed information about water quality in all the river basins in the future, it is recommendable that a systematic water quality observation plan be implemented by IAP.

(2) The quality and quantity of industrial wastewater discharge are found to vary widely according to the type of industry and production volume, etc. Although most of the industries are conducting wastewater treatment with a high BOD removal efficiency on average, there are still some factories where discharge BOD loads are very high. Therefore, further improvement in industrial wastewater treatment is still necessary, and IAP should monitor industrial effluent quality, advice some industries to improve their wastewater treatment schemes, and take emergency actions to prevent industrial pollution.

(3) Public awareness of water quality conservation should be expanded and activities of pollutant load reduction should be promoted in each household. This needs IAP to implement educational program in the whole Paraná State.

(4) In areas where it is difficult to implement public sewer systems and sewage treatment facilities, efforts should be made for a reduction of domestic pollutant loads by utilizing soil septic tanks or constructing community waste disposal facilities.

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