3.5 Surface Water Potential

3.5.1 Zoning for Surface Water Potential

In order to compare required water supply with surface water potential, Iguaçu river basin was divided into 22 blocks as shown in Figure-3.3.

In order to compare required water supply with surface water potential, Tibagi river basin was divided into 18 blocks as shown in Figure-3.4.

Discharge reference point was determined downstream of each block. Each reference point is the same as the point of water quality study. Surface water potential was calculated at each discharge reference point.

3.5.2 Surface Water Potential

Surface water potential was calculated by deducting maintenance discharge (50%$Q_{10,7}$) from the low water flow ($Q_{10,7}$) at each reference point. Low water flow was applied as follows:

(1) Curitiba metropolitan area ------ HG64 (CEHPAR,1990)

(2) catchment area < 5,000km² ----- HG52 (CEHPAR,1982)

(3) catchment area ≥ 5,000km² ----- MINIMUM DISCHARGE VALUES FOR THE STATIONS STUDIED BY JICA IN PARANÁ STATE (COPEL,1995)

The result are shown in Table-3.19 and Table-3.20.

The surface water potential of the Iguana main river from its upstream until the junction with Negro river does not satisfy the water demand due to the Curitiba Metropolitan area located the upstream end of Iguaçu river. In the downstream after the junction with Negro river, the surface water potential of Iguaçu main river exceeds the demand and at the downstream end, Foz do Iguaçu, the surface water potential is 4 times more than the demand. However, the surface water potential of tributaries which the large urban area is located at the upstream end, such as Cascavel, tends to be insufficient for the demand.

The surface water potential of Tibagi main river is enough to the demand throughout the river. However, there is a lack of the surface water potential in tributaries around Londrina where large urban areas are concentrated.

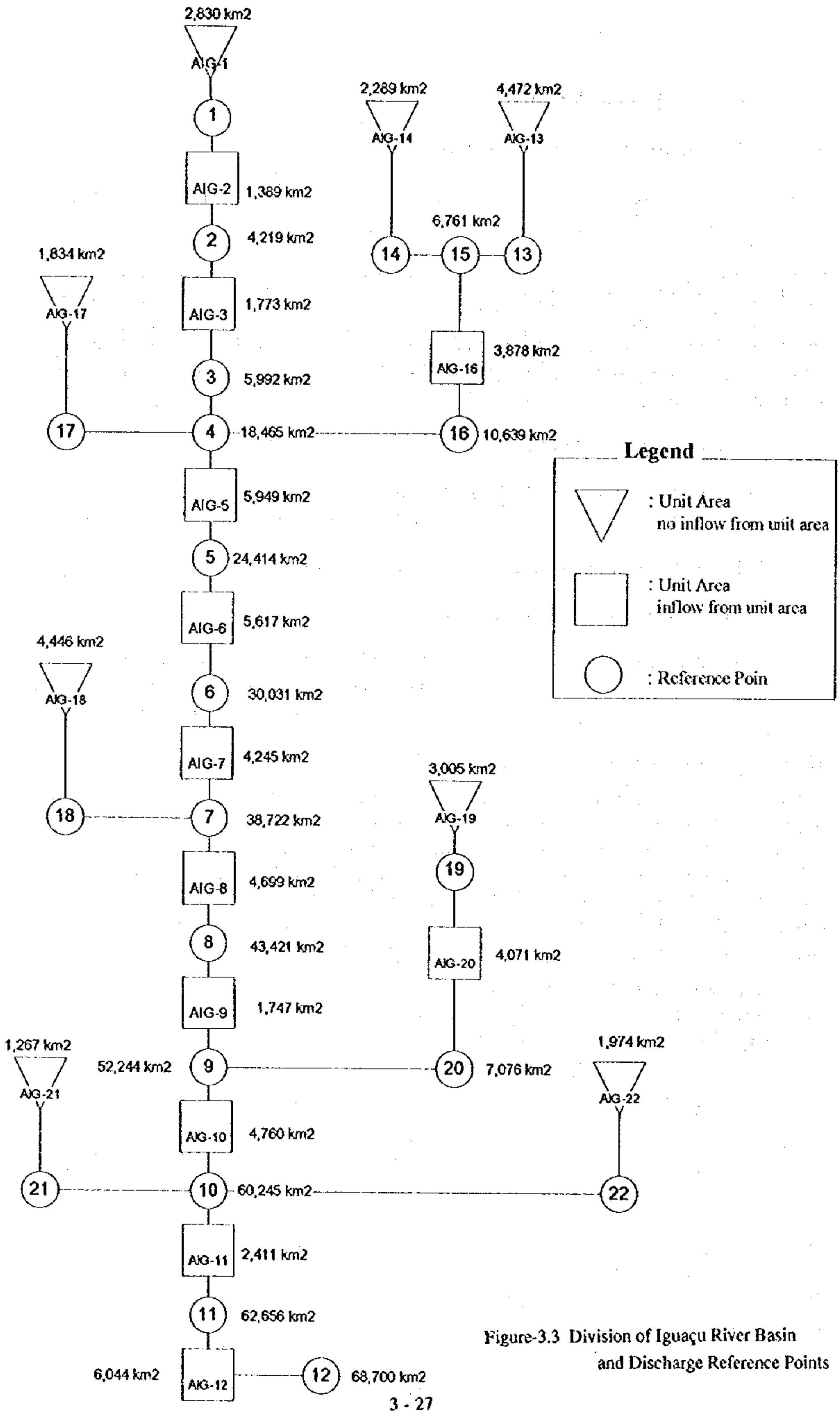


Figure-3.3 Division of Iguaçu River Basin and Discharge Reference Points

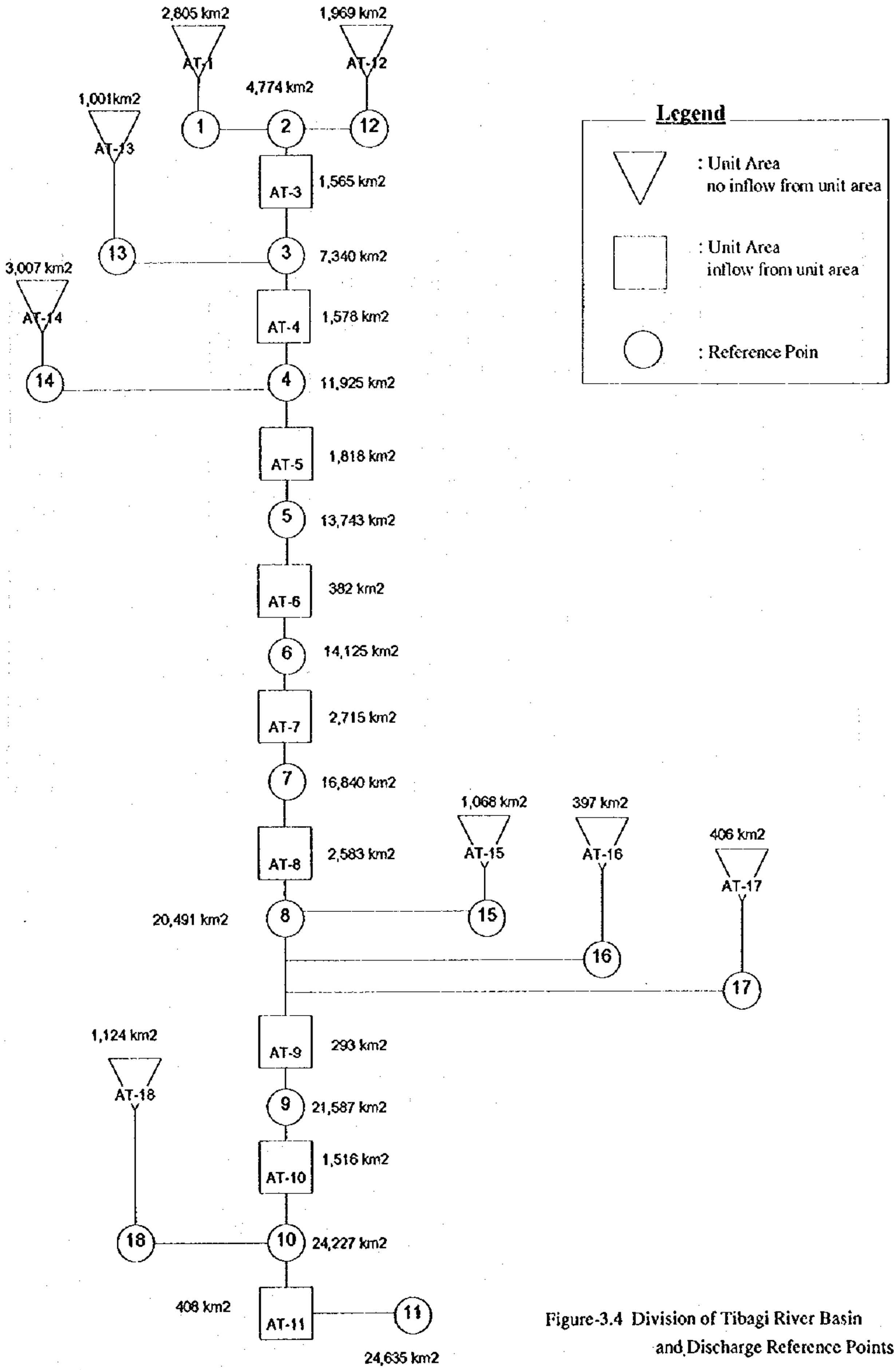


Figure-3.4 Division of Tibagi River Basin
and Discharge Reference Points

Table-3.17 Results of Draught Discharge Computation by Reference Point in Iguaçu River Basin

Basin	Point No.	Catchment Area An : (km²)	Applied Method	$Q_{10,7}$ (m³/sec)	$q_{10,7}$ (m³/sec/100km2)
Iguacu	AIG-1	2,830	HG-64	6.53	0.231
	IG-2	4,219	HG-52	8.36	0.198
	IG-3	5,992	COPEL	13.75	0.229
	IG-4	18,465	IG3 + IG16 + IG17	41.14	0.223
	IG-5	24,414	COPEL	66.61	0.273
	IG-6	30,031	COPEL	85.43	0.284
	IG-7	38,722	COPEL	115.37	0.298
	IG-8	43,421	COPEL	131.50	0.303
	IG-9	52,244	COPEL	160.57	0.307
	IG-10	60,245	COPEL	184.40	0.306
	IG-11	62,656	COPEL	190.91	0.305
	IG-12	68,700	COPEL	205.52	0.299
	AIG-13	4,472	HG-52	11.25	0.251
	AIG-14	2,289	HG-52	5.76	0.251
	IG-15	6,761	AIG13 + AIG14	17.00	0.251
	IG-16	10,639	COPEL	25.30	0.238
	AIG-17	1,834	HG-52	2.09	0.114
	AIG-18	4,446	HG-52	12.20	0.274
	AIG-19	3,005	HG-52	8.69	0.289
	IG-20	7,076	COPEL	16.31	0.230
	AIG-21	1,267	HG-52	2.42	0.191
	AIG-22	1,974	HG-52	4.41	0.223

Table-3.18 Results of Draught Discharge Computation by Reference Pointin Tibagi River Basin

Basin	Point No.	Catchment Area An : (km²)	Applied Method	$Q_{10,7}$ (m³/sec)	$q_{10,7}$ (m³/sec/100km2)
Tibagi	AT-1	2,805	HG-52	5.31	0.189
	AT-2	4,774	AT1 + AT12	9.04	0.189
	AT-3	7,340	COPEL	18.38	0.250
	AT-4	11,925	COPEL	30.51	0.256
	AT-5	13,743	COPEL	34.60	0.252
	AT-6	14,125	COPEL	35.41	0.251
	AT-7	16,840	COPEL	40.64	0.241
	AT-8	20,491	COPEL	46.24	0.226
	AT-9	21,587	COPEL	47.60	0.221
	AT-10	24,227	COPEL	50.27	0.207
	AT-11	24,635	COPEL	50.61	0.205
	AT-12	1,969	HG-52	3.73	0.189
	AT-13	1,001	HG-52	1.67	0.166
	AT-14	3,007	HG-52	4.83	0.160
	AT-15	1,068	HG-52	1.11	0.104
	AT-16	397	HG-52	0.32	0.080
	AT-17	406	HG-52	0.31	0.077
	AT-18	1,124	HG-52	1.25	0.111

Table-3.19 Surface Water Potential and Quality in Iguaçu River Basin

Reference Point	River Name	Location	Catchment Area (km2)	Surface Water Quality in 1993 BOD(mg/l)	Surface Water Potential (m3/sec)	Required Water Supply (m3/sec) * 1993 Urban	2005 Urban	2015 Urban
1	Rio Iguacu	Guajuvira (downstream Curitiba metropolitan Area)	2,830	13.7	3.27	8.04 -4.77 0.41	11.12 -7.85 0.29	15.01 -11.74 0.22
2	Rio Iguacu	south of Porto Amazonas	4,219	1.37	4.18	8.31 -4.13 0.50	11.53 -7.35 0.36	15.56 -11.38 0.27
3	Rio Iguacu	upstream confluence of Rio Negro	5,992	0.39	6.88	8.40 -1.52 0.82	11.65 -4.77 0.59	15.72 -8.84 0.44
4	Rio Iguacu	downstream confluence of Rio Potinga	18,465	0.30	20.57	8.78 11.79 2.34	12.12 8.45 1.70	16.33 4.24 1.26
5	Rio Iguacu	upstream Uniao da Vitoria	24,414	0.06	33.31	8.94 24.37 3.73	12.32 20.99 2.70	16.54 16.77 2.01
6	Rio Iguacu	Foz do Areia Dam	30,031	0.00	42.72	9.13 33.59 4.68	12.56 30.16 3.40	16.84 25.88 2.54
7	Rio Iguacu	downstream confluence of Rio Jordao	38,722	0.00	57.69	9.61 48.08 6.00	13.20 44.49 4.37	17.66 40.03 3.27
8	Rio Iguacu	Salto Santiago Dam	43,421	0.00	65.75	9.82 55.93 6.70	13.44 52.29 4.89	17.99 47.76 3.65
9	Rio Iguacu	downstream confluence of Rio Chopim	52,244	0.00	80.29	10.84 69.45 7.41	14.80 65.49 5.43	19.74 60.55 4.07
10	Rio Iguacu	downstream confluence of Rio Capanema	60,245	0.18	92.20	11.77 80.43 7.83	16.04 76.16 5.75	21.32 70.88 4.32
11	Rio Iguacu	route 163	62,656	0.05	95.46	11.87 83.59 8.04	16.16 79.30 5.91	21.46 74.00 4.45
12	Rio Iguacu	river mouth (Foz do Iguacu)	68,700	0.10	102.76	12.71 90.05 8.08	17.58 85.18 5.85	23.48 79.28 4.38
13	Rio Negro	upstream confluence of Rio da Varzea (include Rio Negro)	4,472	0.18	5.63	0.17 5.46 33.12	0.22 5.41 25.59	0.29 5.35 19.41
14	Rio da Varzea	river mouth	2,289	0.85	2.88	0.13 2.75 22.15	0.15 2.73 19.20	0.19 2.69 15.16
15	Rio Negro	downstream confluence of Rio da Varzea	6,761	0.41	8.50	0.30 8.20 28.33	0.37 8.13 22.97	0.48 8.02 17.71
16	Rio Negro	river mouth	10,639	0.07	12.65	0.31 12.34 40.81	0.38 12.27 33.29	0.49 12.16 25.82
17	Rio Potinga	river mouth	1,834	2.61	1.05	0.08 0.97 13.13	0.10 0.95 10.50	0.12 0.93 8.75
18	Rio Jordao	river mouth (include Guarapuava)	4,446	0.00	6.10	0.44 5.66 13.86	0.58 5.52 10.52	0.76 5.34 8.03
19	Rio Chopim	Sao Luiz (include Palmas)	3,005	0.87	4.35	0.19 4.16 22.89	0.24 4.11 18.13	0.29 4.06 15.00
20	Rio Chopim	river mouth (include Pato Branco, Francisco Beltrao and Dois Vizinhos)	7,076	0.00	8.16	0.93 7.23 8.77	1.25 6.91 6.53	1.62 6.54 5.04
21	Rio Andrade	river mouth (include Cascavel)	1,267	11.4	1.21	0.56 0.65 2.16	0.81 0.40 1.49	1.10 0.11 1.10
22	Rio Capanema	river mouth	1,974	2.38	2.21	0.11 2.10 20.09	0.13 2.08 17.00	0.14 2.07 15.79

*Remark

first step
Required Water Supply
second step
Surface Water Potential - Required Water Supply
third step
Possible Development Water / Required Water Supply

Table-3.20 Surface Water Potential and Quality in Tibagi River Basin

Reference Point	River Name	Location	Catchment Area (km2)	Surface Water Quality in 1993 BOD(mg/l)	Surface Water Potential (m3/sec)	Required Water Supply (m3/sec) * 1993 Urban	2005 Urban	2015 Urban
1	Rio Tibagi	upstream confluence of Rio Imbituva (include Ponta Grossa)	2,805	3.17	2.66	0.78 1.88 3.39	1.01 1.65 2.62	1.27 1.39 2.10
2	Rio Tibagi	downstream confluence of Rio Imbituva	4,774	2.62	4.52	0.94 3.58 4.79	1.22 3.30 3.70	1.53 2.99 2.95
3	Rio Tibagi	downstream confluence of Rio Pitangui	7,340	0.53	9.19	0.97 8.22 9.51	1.25 7.94 7.37	1.56 7.63 5.88
4	Rio Tibagi	downstream confluence of Rio Fortaleza	11,925	0.79	15.26	1.25 14.01 12.21	1.70 13.57 9.00	2.18 13.08 7.00
5	Rio Tibagi	downstream confluence of Rio Imbau (upstream Telemaco Borba)	13,743	0.42	17.30	1.27 16.03 13.58	1.73 15.57 10.02	2.22 15.08 7.80
6	Rio Tibagi	upstream confluence of Rio Imbauzinho (down-stream Telemaco Borba)	14,125	1.29	17.71	1.52 16.19 11.65	2.08 15.63 8.50	2.68 15.03 6.61
7	Rio Tibagi	between Terra Nova and Natingui	16,840	0.00	20.32	1.58 18.74 12.84	2.15 18.17 9.45	2.76 17.57 7.38
8	Rio Tibagi	downstream confluence of Rio Taquara	20,491	0.00	23.12	1.94 21.18 11.94	2.64 20.49 8.77	3.39 19.73 6.82
9	Rio Tibagi	downstream confluence of Rio Tres Bocas	21,587	0.92	23.80	2.13 21.67 11.16	2.89 20.91 8.23	3.73 20.07 6.38
10	Rio Tibagi	downstream confluence of Rio Congonhas	24,227	0.31	25.14	4.15 20.99 6.05	5.57 19.57 4.51	7.24 17.90 3.47
11	Rio Tibagi	river mouth	24,635	0.17	25.31	4.18 21.13 6.06	5.60 19.71 4.52	7.28 18.04 3.48
12	Rio Imbituva	river mouth (include Irati)	1,969	1.83	1.87	0.16 1.71 11.69	0.21 1.66 9.08	0.26 1.61 7.11
13	Rio Pitangui	river mouth (include Ponta Grossa)	1,001	1.67	0.84	0.00 0.84 -	0.00 0.84 -	0.00 0.84 -
14	Rio Fortaleza Rio Iapo	river mouth (include Castro)	3,007	4.33	2.42	0.28 2.14 8.52	0.45 1.97 5.40	0.62 1.80 3.92
15	Rio Taquara	river mouth (include Apucarana)	1,068	10.7	0.56	0.28 0.28 1.99	0.40 0.16 1.40	0.52 0.04 1.07
16	Rio dos Apertados	river mouth (include Arapongas)	397	31.7	0.16	0.20 -0.04 0.81	0.26 -0.10 0.62	0.34 -0.18 0.47
17	Rio Tres Bocas	river mouth (include Londrina)	406	339	0.16	0.00 0.16 -	0.00 0.16 -	0.00 0.16 -
18	Rio Congonhas	river mouth (include Cornelio Procopio)	1,124	6.34	0.63	0.22 0.41 2.89	0.27 0.36 2.35	0.33 0.30 1.89

*Remark

first step
  Required Water Supply
second step
  Surface Water Potential - Required Water Supply
third step
  Possible Development Water / Required Water Supply

The lower water flow ($Q_{10,7}$) is calculated by flowing method.

(1) HG64 (CEHPAR, 1990) ; Curitiba metropolitan area

HG64 is analyzed for the low water flow in Curitiba metropolitan area by CEHPAR. Three figures and two tables are used to calculate the $Q_{TR,t}$.

- TR : return period
- t : continuous days
- Q_t : annual minimum of average discharge of continuous "t" days
- $Q_{TR,t}$: Q_t discharge with occurrence probability of once in "TR" years

The low water flow by HG64 is calculated by following process.

1) α (DIA^{-1}) ; obtained from Table-3.22 and/or Figure-3.5

2) $\frac{Q}{\overline{\overline{Q}}}$; obtained from Figure-3.6 to input TR

3) K(α, t) ; obtained from Table-3.23 to input t and α

4) $\bar{q}t = \frac{Q}{\overline{\overline{Q}}} \times K(\alpha, t)$

5) $\bar{q}_{LP}$; obtained from Figure-3.7

6) $\bar{Q} = \bar{q}_{LP} \times A/1000$

   A; catchment area

7) $Q_{TR,t} = \bar{q}t \cdot \bar{Q}$

(2) HG52 (CEHPAR, 1989); whole Paraná state for catchment area < 5000 km^2

HG52 is analyzed for the low water blow in whole Paraná state by CEHPAR. Six figures are used to calculate the $Q_{TR,t}$. The low water flow by HG52 is calculated by following process.

1) six coefficients (a, b, c, α, β, γ) are obtained by six iso-coefficient map at optional point. (Figure-3.8 ~ Figure-3.13)

2) $\bar{q}t = \exp[a + b \cdot \ell n\, t + c(\ell n\, t)^2]$

3) $\bar{U}_{TR} = \alpha + (\beta + \alpha)[-\ell n(1 - \frac{1}{TR})]^{1/\gamma}$

4) $Q_{TR,t} = \frac{A}{1000} \cdot \bar{U} \cdot \bar{q}t$

(3) Minimum Discharge Values for the stations Studied by JICA in Paraná state (COPEL, 1995); catchment area ≥ 5,000 km^2.

The low water flow ($Q_{10.7}$) for main rivers in Paraná state is analyzed by COPEL. $Q_{10.7}$ by COPEL's study is obtained to input only catchment area at optional point. The equation to calculate Q10.7 is shown as follows.

$$Q_{10.7} = a + b_1 \cdot A + b_2 \cdot A^2 + b_3 \cdot A^3$$

where A; catchment area (km^2)

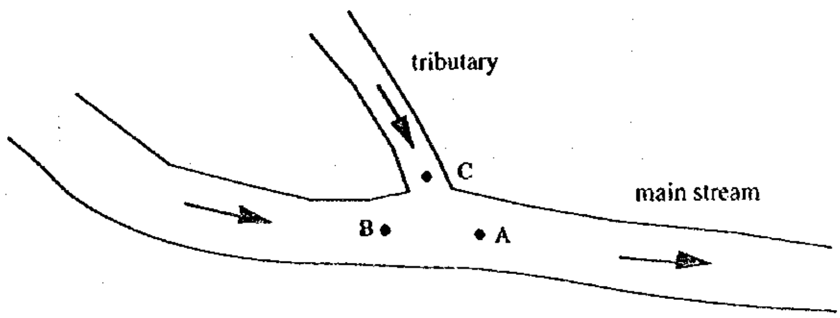
The coefficients (a, b_1, b_2, b_3) are shown in Table-3.21.

Table-3.21 Coefficients of Equation for $Q_{10.7}$

Basin	Coefficient			
	a	b_1	b_2	b_3
Iguaçu	1.27	1.83×10^{-3}	4.46×10^{-8}	-4.07×10^{-13}
Ivai	-9.61	5.10×10^{-3}	-3.61×10^{-7}	9.89×10^{-12}
Piquiri	-5.45	1.35×10^{-3}	1.54×10^{-7}	---
Tibagi	-6.42	3.83×10^{-3}	-6.15×10^{-8}	---
Todas	1.18	2.08×10^{-3}	4.76×10^{-7}	-5.07×10^{-13}

(4) Recommendation for the low water flow calculation method

There are several calculation method to obtain the low water flow in Paraná state. HG52 and HG64 are analyzed considering probability and continuous days and it is able to use at optional point. However, generally, the low water flow at main stream and at tributary are different due to difference of catchment area, time lag of flow and characteristic of basin, etc. For example, at the situation shown in following figure, the specific discharge of the low water flow at each point is different each other. According to HG52, each specific discharge is almost same.



A: downstream of tributary
B: upstream of tributary confluence
C: river mouth of tributary

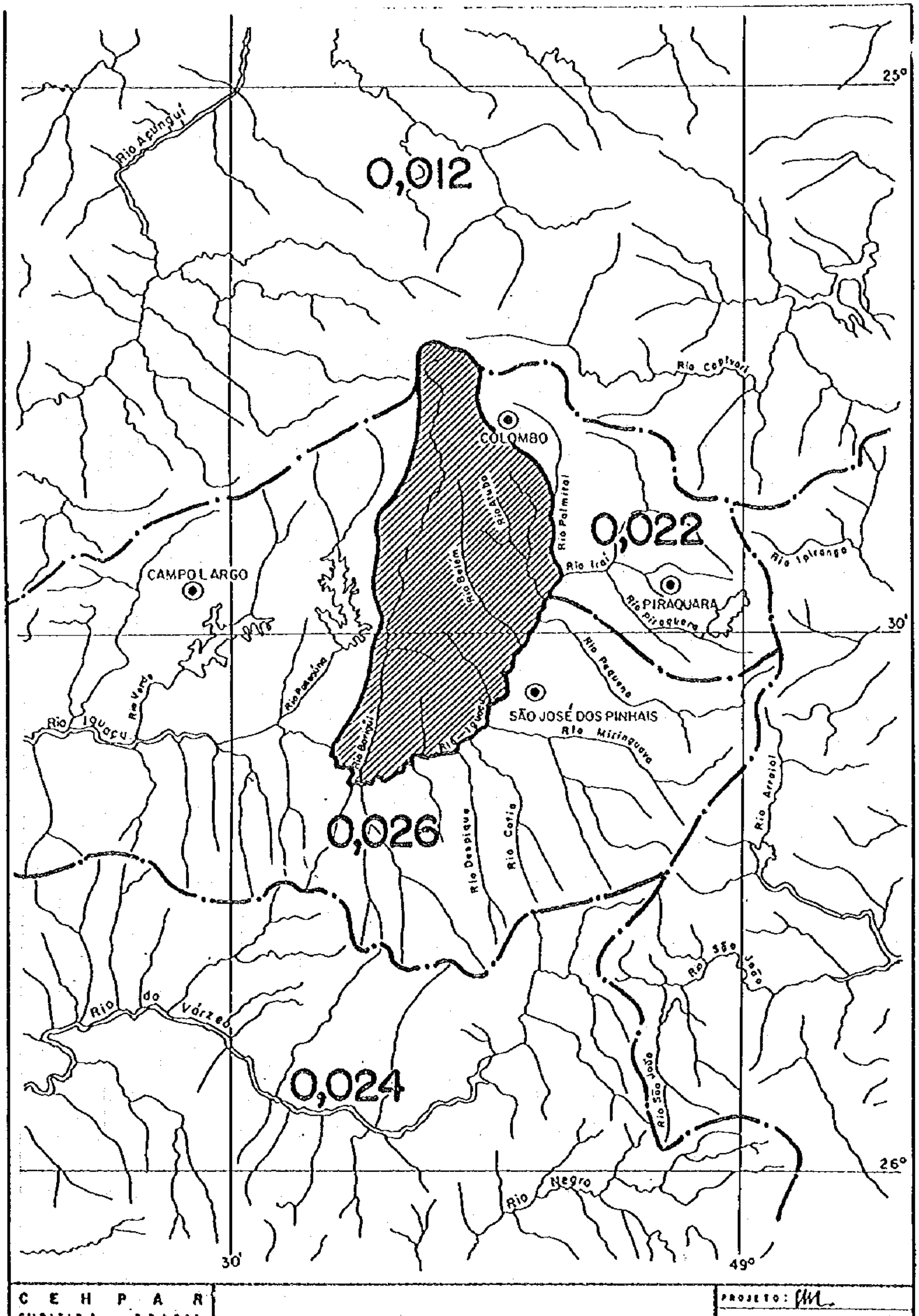
According to the low water calculation method by COPEL for main stream, the condition mentioned above is not given. It seems that the method studied by COPEL is appropriate to calculate the low water flow at main stream.

Table-3.22 Value of α (DIA^{-1})

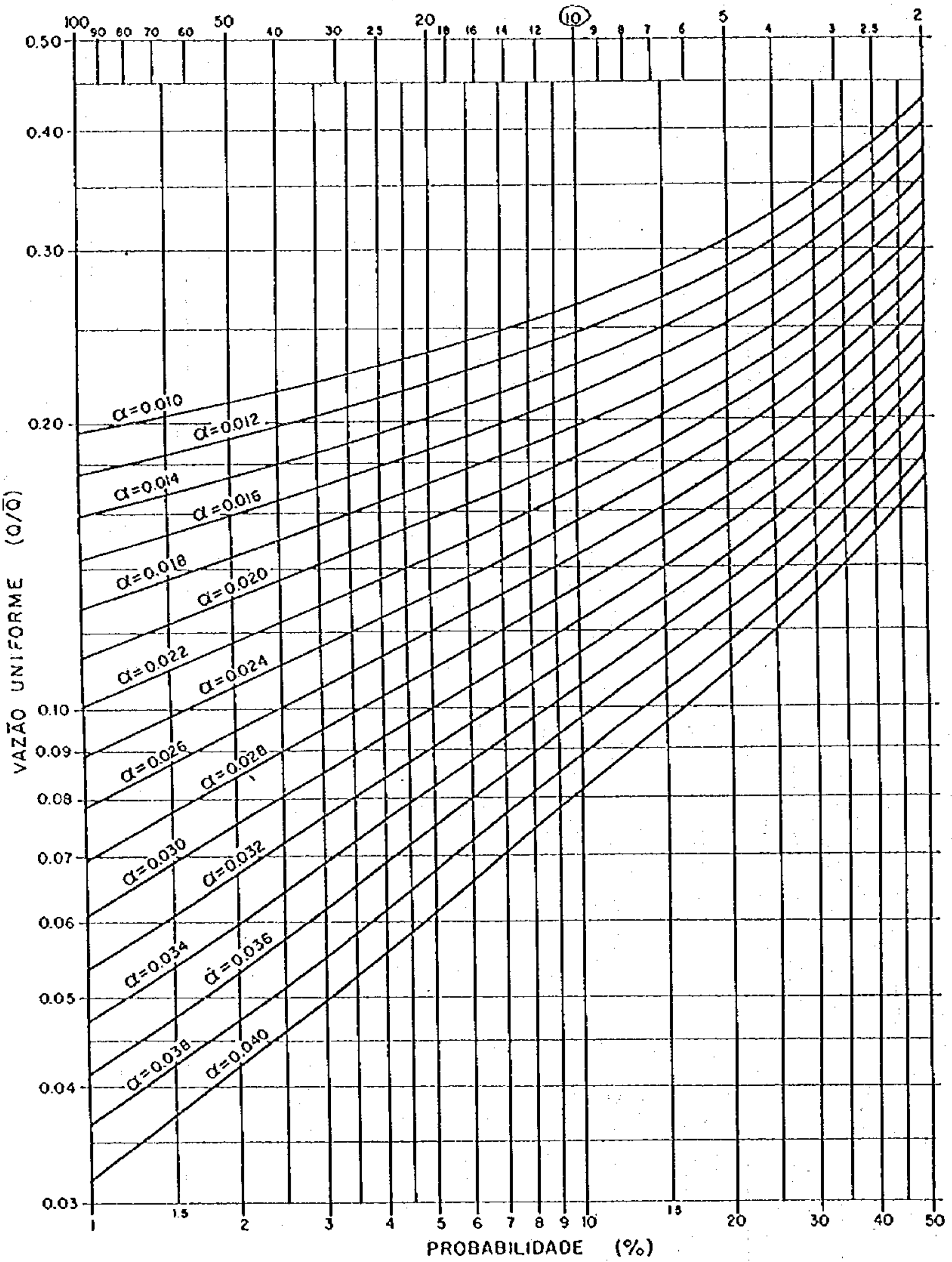
RIO	NOME DO POSTO	α (DIA^{-1})
Iraí	Olaria do Estado	0,014
Iraí	Pinhais	0,022
Palmital	Vargem Grande	0,026
Atuba	Terminal Afonso Camargo	0,022
Iguaçu	Ponte BR-277	0,017
Pequeno	Fazendinha	0,026
Miringuava	Miringuava	0,034
Miringuava	Campina do Taquaral	0,027
Miringuava	Cachoeira	0,027
Cotia	Ponte do Cotia	0,023
Despique	Serraria Baldan	0,023
Iguaçu	Araucária	0,033
Passaúna	Campina das Pedras	0,026
Verde	Rodeio	0,026
Iguaçu	Porto Amazonas	0,036
Negro	Bateias de Baixo	0,019
Negro	Fragosos	0,020
Negro	Rio Preto do Sul	0,029
Negro	Rio Negro	0,023
Várzea	Salto Baraçã	0,040
Várzea	Rio da Várzea dos Lima	0,029
Várzea	São Bento	0,024
Açungui	Passo do Açungui	0,013
Açungui	Balsa do Jacaré	0,012
Turvo	Turvo	0,012
Ribeira	Balsa do Cerro Azul	0,013
Ponta Grossa	Cerro Azul	0,011
Capivari	Praia Grande	0,012

Table-3.23 Value of K (α, t)

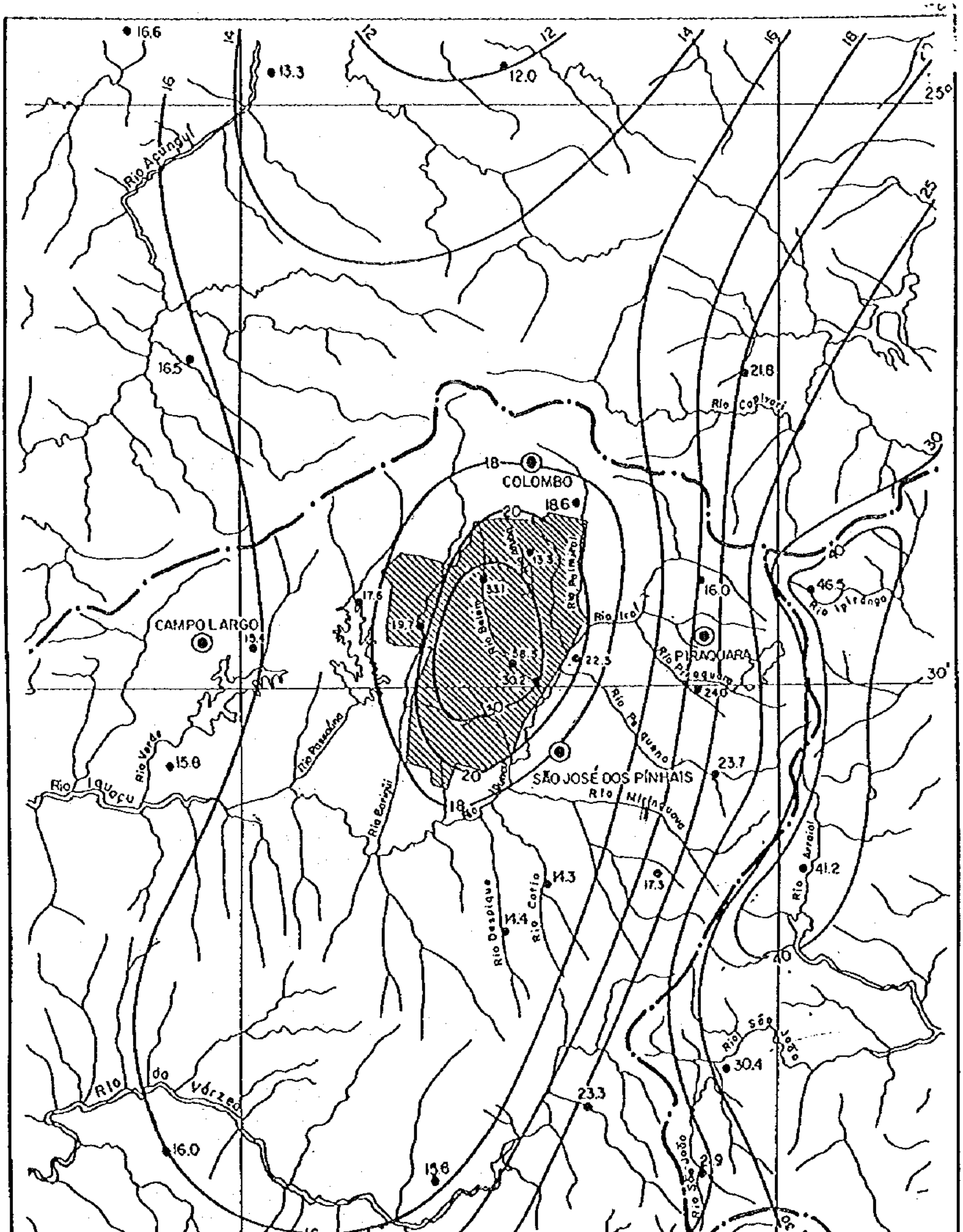
α \ t	3	7	10	15	20
0,010	1,015	1,036	1,052	1,079	1,107
0,015	1,023	1,054	1,079	1,121	1,166
0,020	1,031	1,073	1,107	1,166	1,230
0,025	1,038	1,093	1,136	1,213	1,297
0,030	1,046	1,113	1,166	1,263	1,370
0,035	1,054	1,133	1,197	1,315	1,448
0,040	1,062	1,154	1,230	1,370	1,532



C E H P A R CURITIBA — BRASIL			PROJETO:
REF.: HG-64	F-3.4	Figure-3.5 Value of α (DIA-1)	DESENHO: antolido gutierrez
ÚTIL.:			DATA: 20 de novembro de 1989
ARQUIVO:	CLIENTE: S A N E P A R	NÚMERO: 0 3 2	VISTO:
			APROVADO:



C E H P A R CURITIBA — BRASIL			PROJETO:
REF.: HG-64	F-3.5	Figure-3.6 α Value Distribution	DESENHO:
UTIL.:			DATA: 10 de novembro de 1989
ARQUIVO:		CLIENTE: S A N E P A R — NÚMERO: 032	VISTO:
			APROVADO:



CENPAR CURITIBA — BRASIL		PROJETO:
REF.: HG-64	F-3.8	DESENHO:
UTIL.:	Figure-3.7 Medium Discharge for Long Period	DATA: 17 de julho de
ARQUIVO:		VISTO:
	CLIENTE: SANEPAR	NÚMERO: 032	APROVADO:

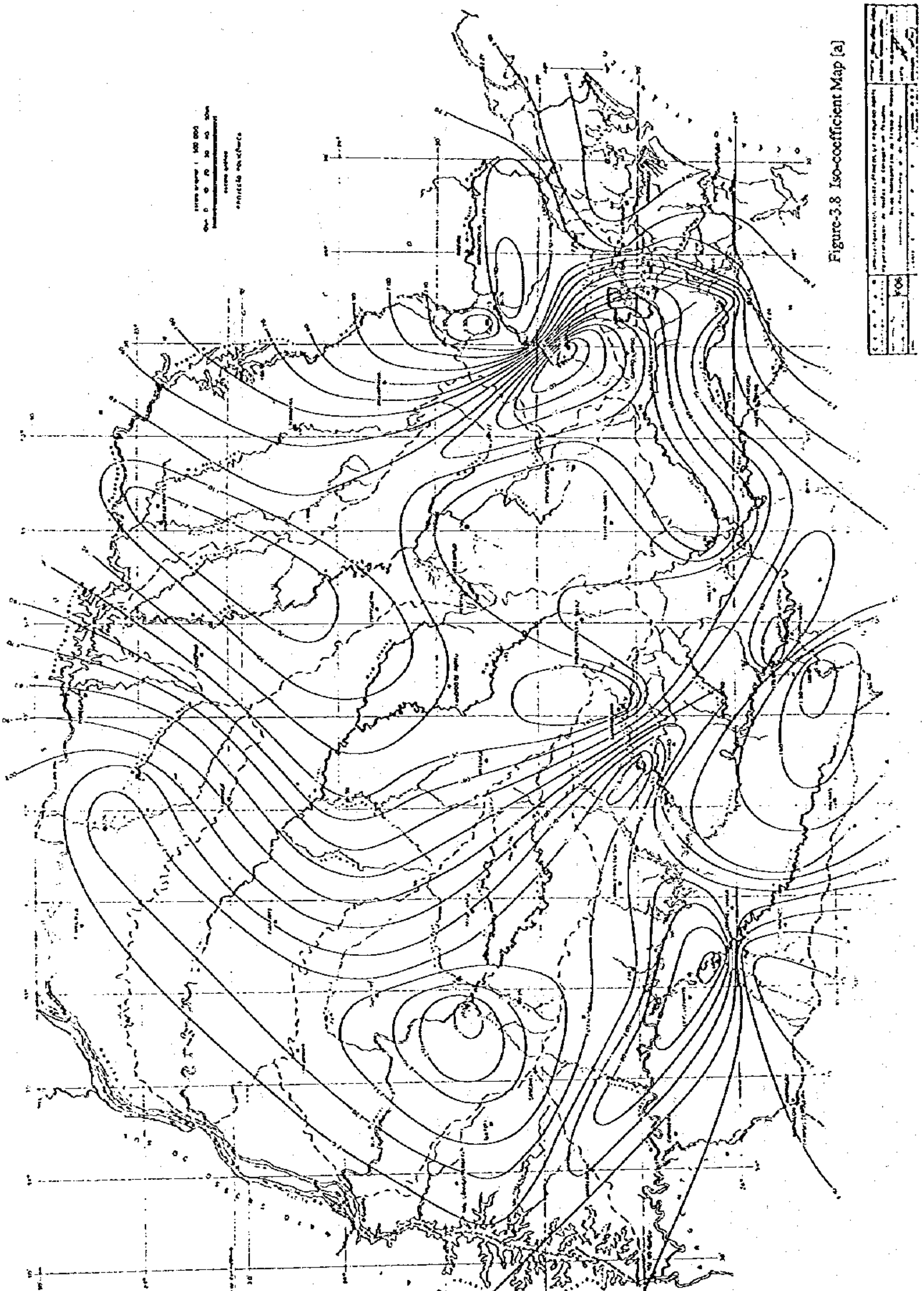


Figure-3.8 Iso-coefficient Map [a]

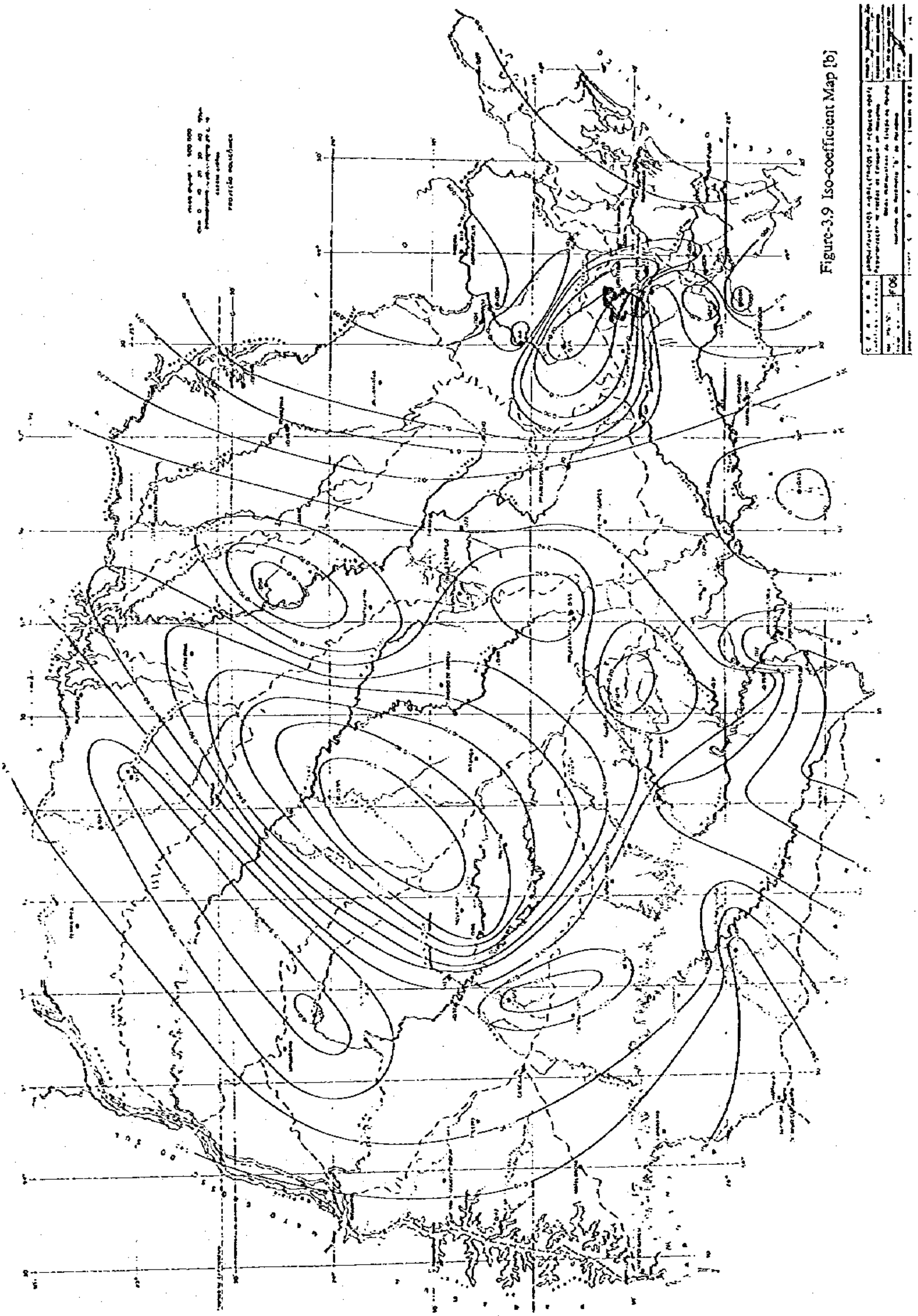


Figure-3.9 Iso-coefficient Map [b]

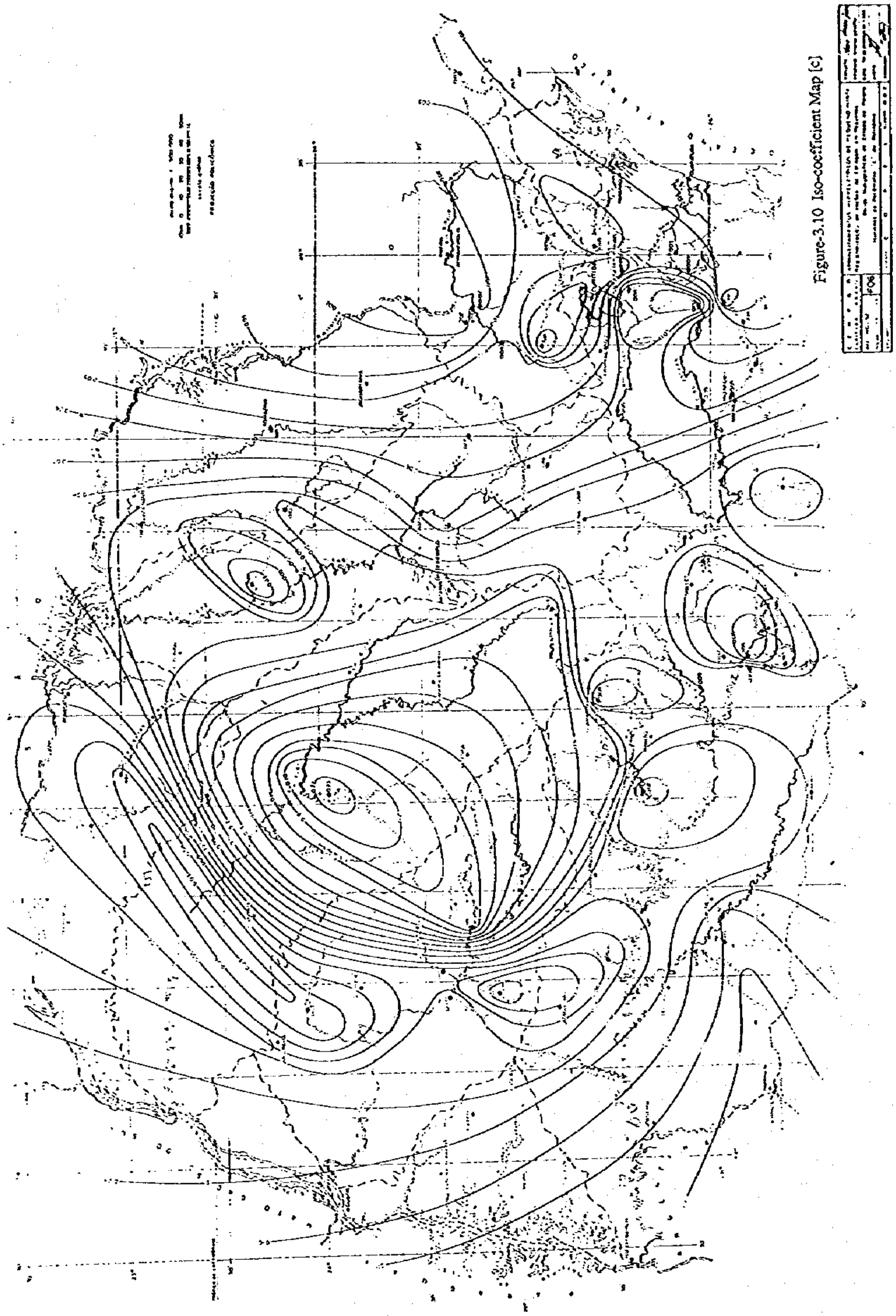


Figure-3.10 Iso-coefficient Map [c]

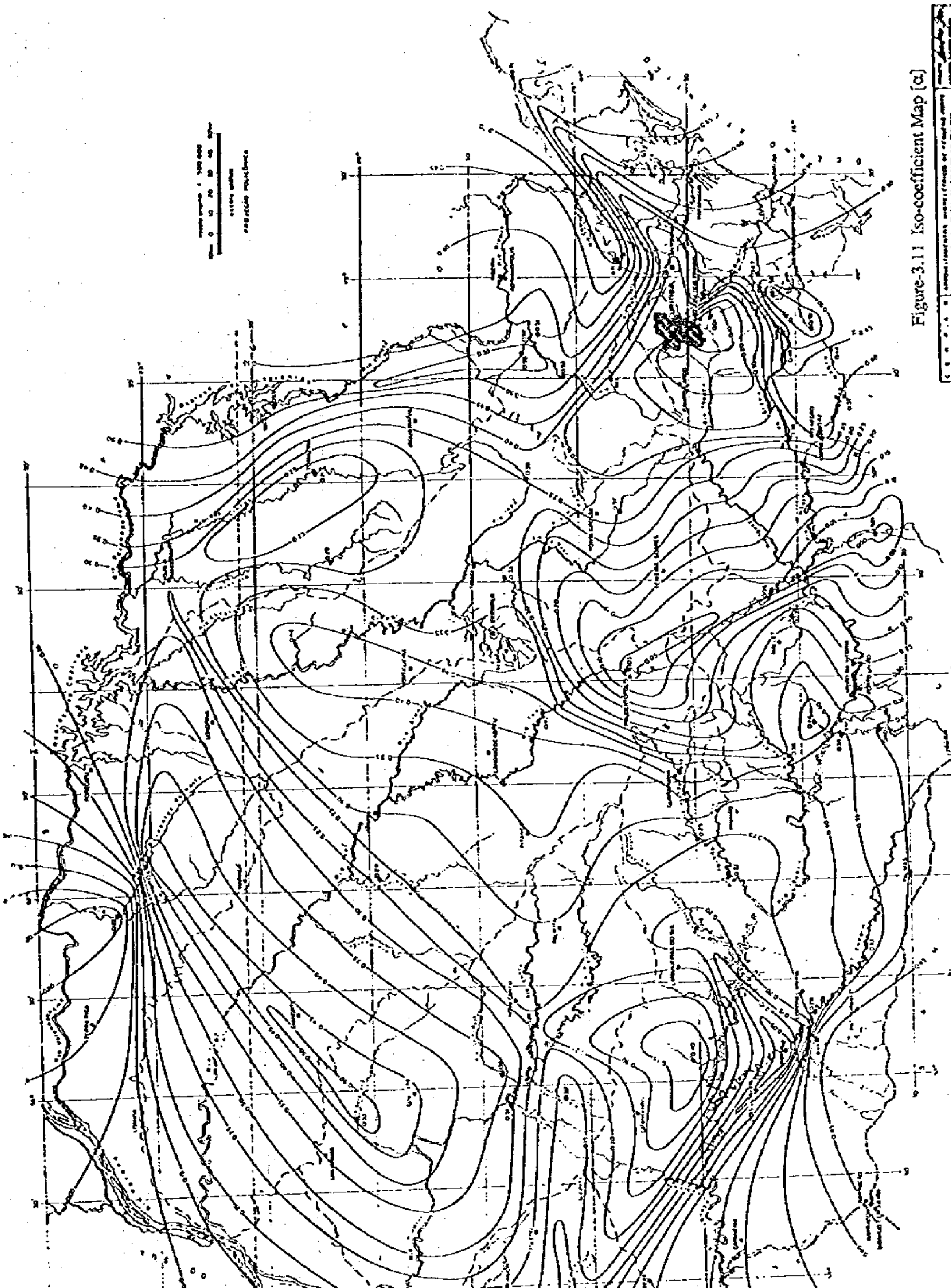


Figure-3.11 Iso-coefficient Map [c]

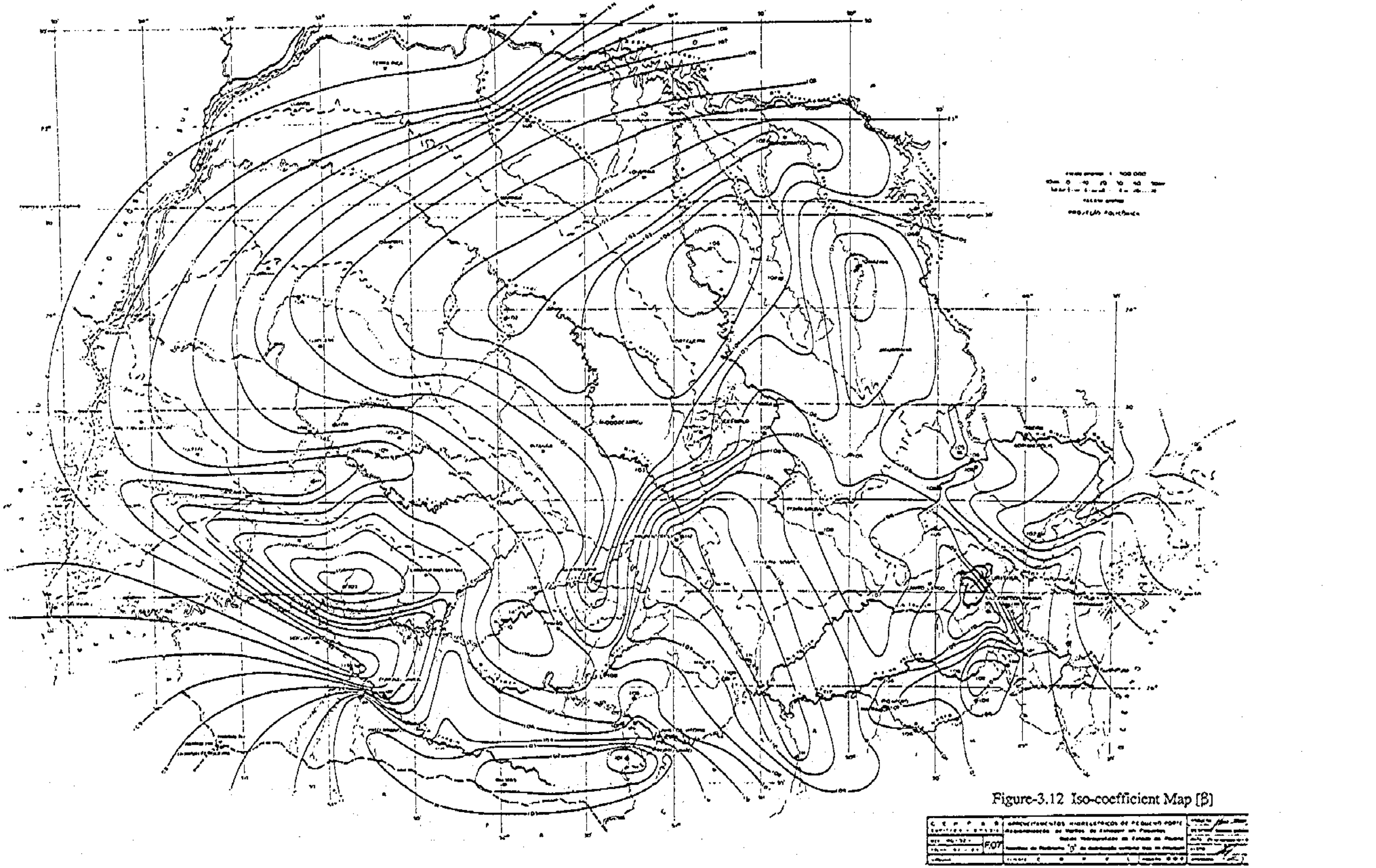


Figure-3.12 Iso-coefficient Map [β]

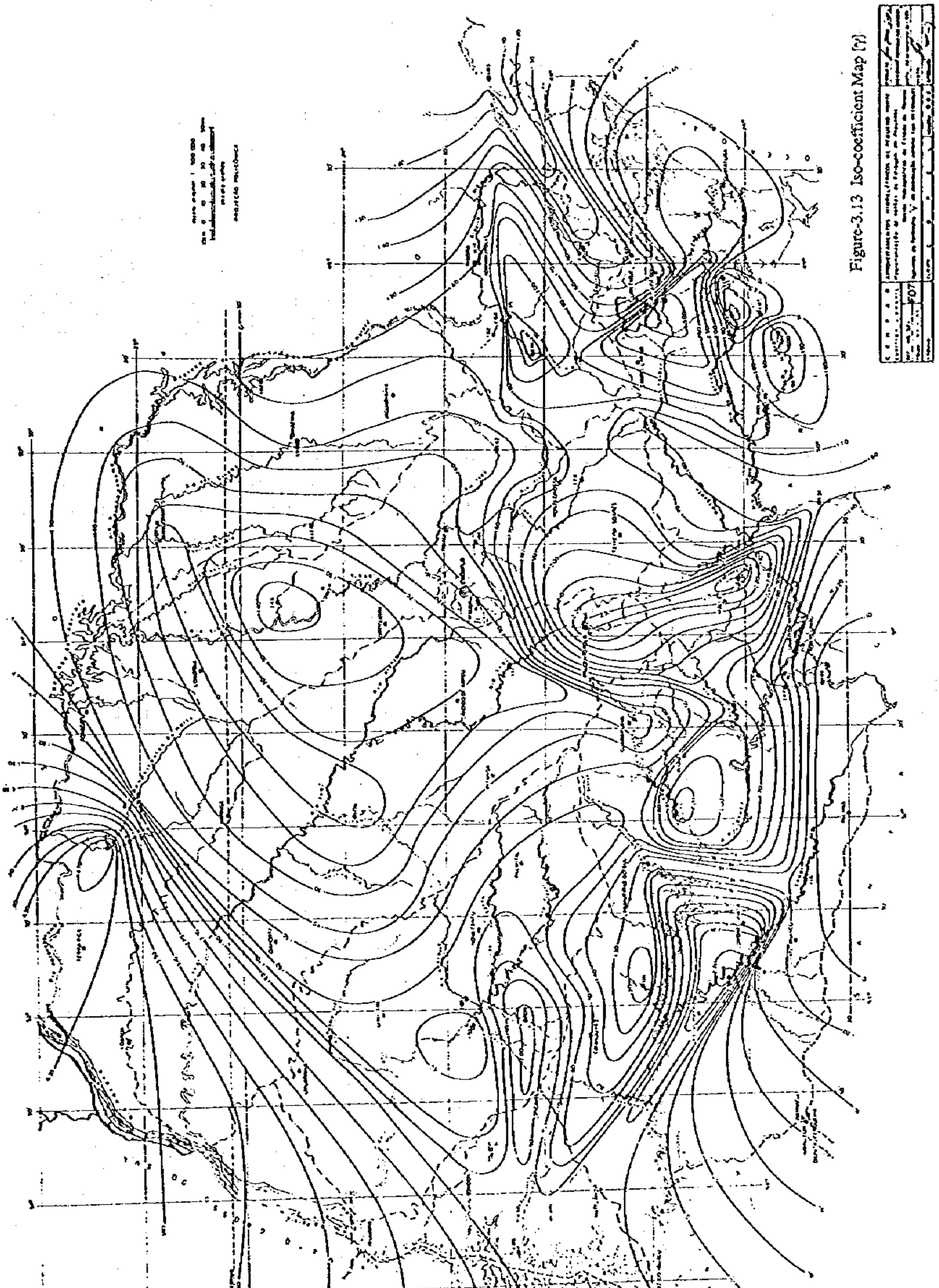


Figure-3.13 Iso-coefficient Map (γ)

3.6 Groundwater Potential

3.6.1 Definition of Boundary of Area for Groundwater Study

(1) Iguaçu River Basin

The major municipal urban areas located in the Iguaçu river basin straddles over the boundary of other river basins. Therefore, the Iguaçu river basin for the study of the groundwater resources is composed of such areas as Iguaçu river basin, Karst basin on the right bank of Ribeira river, a part of the left bank of Piquiri river, and a part of Paraná III river basin including a part of the neighboring groundwater basins related to the major urban demand centers.

(2) Tibagi River Basin

The major municipal urban areas located in the Tibagi River Basins straddle over the boundary of other river basins. Therefore, the Tibagi river basins for the study of the groundwater resources is composed of such areas as Tibagi river, a part of the left bank of the Cinzas River, and upstream of Pirapo River including a part of the neighboring groundwater basins related to the major urban demand centers.

3.6.2 Assessment of Groundwater Potential in Iguaçu River Basin

(1) Iguaçu River Basin

The Iguaçu River Basin is composed of the following aquifers in order of older age:

Karst, Crystalline Rocks (including Granitic Rocks), Furnas Formation, Upper-Middle Paleozoic, Upper Paleozoic, Botucatu Formation, Serra Geral Formation north, Serra Geral Formation south, Guabirotuba Formation.

The specific mean discharge which is defined as the specific mean of the annual minimum of average discharge of continuous 7 days (mQ_7) is used for the key data for the assessment of groundwater potential in this study. The result of the assessment of aquifers in the Iguaçu River Basin is shown in Table-3.24. Assessment of Furnas Formation and Guabirotuba Formation are not able to be done by limitation of the data conditions.

Table-3.24 Spatial Groundwater Potential of Iguaçu River Basin Estimated by Water Circulation in Iguaçu River Basin

[1] Aquifer	[2] Location in River Basin	[3] Study Area	[4] Spatial mQ7	[5] Permissive Yield		[6] Required Recharge	[7] Total Permissive Yield	[8] Productivity of Borehole
		km²	x 10^{-3} m^3/km^2	%	x $10^{-3}m^3$ /s/km²	$km^2/s/m^3$	m^3/s	x10^{-3} m^3/s
Karst	mainly Ribeira nad Upper Iguaçu	3,500	8.29	30	2.49	400	8.750	44.40
Cristalline Rocks	Upper Iguaçu	4,500	6.37	10	0.64	1600	2.880	5.56
Furnas Formation	Upper Iguaçu	350	-	15	-	-	-	11.10
Middle-Upper Paleozoic	Upper Iguaçu	3,900	4.69	10	0.47	2,100	1.830	2.78
Upper Paleozoic	Upper to Middle Iguaçu	3,100	4.90	10	0.49	2,000	1.520	2.78
Botucatu Formation	Middle to Lower Iguaçu	3,2000	-	-	-	-	-	124.00
Serra Geral Formation north	Lower Iguaçu	1,900	5.32	20	1.10	610	3.120	19.20
Serra Geral Formation south	Middle to Lower Iguaçu	32,000	5.26	15	0.79	1,300	11.900	3.33
Guabirotuba Formation	Upper Iguaçu	920	3.53	20	0.76	1,300	0.699	3.33

Note
[4]: Spatial and specific mQ,
[6]: Required Rechargeing Area by $1m^3/s$ of groundwater yield
[7] : Total Permissive Yield of Aquifer in Study Area

The characteristics of each aquifer are described as follows:

1) Karst

Groundwater potential of Karst is evaluated to be high. The Karst area included in the Iguaçu River basin has a drainage area of about 3,500 km^2, and about $8.75m^3/s$ can be developed within the permissible yield. This groundwater resource is appropriate for large scale development since its borehole productivity (borehole yield) is extremely large as 44 l/s/borehole.

The water quality of this aquifer is adequate for drinking water such as Mineral Water for Curitiba City, but not adequate for hydro-thermal and steam resources of industrial water resources because of its chemical characteristics.

2) Botucatu Formation

The permissible yield of Botucatu Formation can not be estimated in this study, and it is difficult to apply the concept of permissible yield to this formation at present. It's permissible yield can be technically estimated by use of the drawdown data of groundwater table, but the drawdown data are not available. The specific mean discharge also cannot be applied to this formation because of the nature of its geologic structure.

However, the amount of its groundwater is assessed to be very large based on its extraordinarily large borehole productivity (124 l/s; in average of 9 boreholes) and storage volume. It's storage volume is assessed to be more than 20 times larger than that of Karst and a little less than 10 times of that of Serra Geral Formation.

This aquifer forms layering, and its water temperature becomes 40-70 °C at the depth of deeper than 800 m. This groundwater resource, therefore, is assessed to have high potential of industrial water use with appropriate control of pH and Na by mixing with other fresh water resources in consideration of confined water pressure, pH level and content of natrium.

3) Serra Geral Formation north

This aquifer is broadly distributed from near Cascavel to the north, but the study area within the Iguaçu River basin is limited to the area of 1,900 km^2 near Cascavel. Though the spatial permissive yield and mean productivity of borehole of this formation is less than a half of those of Karst, its potential is relatively large and is assessed to be an adequate groundwater resource for medium scale development.

The water quality of this aquifer is appropriate for both domestic and industrial water supply.

4) Serra Geral Formation south

The aquifer of Serra Geral Formation is broadly distributed with a basin area of 32,000 km^2 in the area middle reach to downstream of the Iguaçu River Basin. The groundwater resource of this aquifer is assessed to be appropriate for small to medium scale development based on its spatial permissive yield and productivity.

5) Guabirotuba Formation

This aquifer is distributed in Curitiba metropolitan area (CMA) with a basin area of 900 km^2, and its groundwater resource is widely used for the domestic and industrial water in CMA. Monitoring of groundwater of this formation is required with high maneuverability because it is distributed in the urban area. It will be required to measure promptly chemical contents in response to necessity not limiting to the standard observation items for drinking water because there is a possibility of contamination of groundwater.

The total permissive yield of the whole aquifer is estimated to be about 0.7 m^3/s (average of CMA). Various kind of adverse effects on the use of wells will be expected in the central urban area of Curitiba city in the near future because present groundwater use for industries is estimated to be very high in this area.

6) Furnas Formation

The aquifer of Furnas Formation is assessed to be appropriate for small scale development based on its productivity of borehole.

7) Other Aquifers

Groundwater development of other aquifers not aforementioned is assessed to be infeasible except for the rural areas facing shortage or lack of other fresh water sources because of its low permissive yield and productivity.

(2) Tibagi River Basin

Tibagi River Basin is composed of Crystalline Rocks, Furnas Formation, Upper-Middle Paleozoic, Upper Paleozoic, Botsucatu Formation, Serra Geral Formation north.

The result of potential analysis is shown in Table-3.25 and is summarized as set out below.

1) Botucatu Formation

The aquifer of Botucatu Formation is exposed on the ground surface in a limited area, but it lies broadly under Serra Geral Formation in the northern part of the Tibagi River Basin.

The development potential of groundwater of this aquifer is assessed to be high as well as that in the Iguaçu River Basin. Its groundwater is used as hot water in a coffee production factories in Londrina, and is anticipated to be widely used in the future.

2) Serra Geral Formation north

The aquifer of Serra Geral Formation north is distributed broadly in the north of the Tibagi River Basin. It's development potential of groundwater is assessed to be high and appropriate for medium to large scale because its permissive yield and productivity is higher than those of the Iguaçu River Basin.

3) Furnas Formation

The aquifer of Furnas Formation is assessed to be appropriate for small scale groundwater development based on productivity of borehole as well as that in the Iguaçu River Basin.

4) Other Aquifers

Groundwater development of other aquifers not aforementioned is assessed to be unfeasible except for the rural areas facing shortage or lack of other fresh water sources because of its low permissive yield and productivity as well as those in the Iguaçu River Basin.

Table-3.25 Spatial Groundwater Potential of Tibagi River Basin Estimated by Water Circulation in Tibagi River Basin

[1] Aquifer	[2] Location in River Basin	[3] Study Area	[4] Spatial mQ7	[5] Permissive Yield	[6]	[7] Require Recharge	[8] Total Permissive Yield	[9] Productivity of Borehole
		km^2	m^3/km^2 *1	%	x $10^{-3}m^3/skm^2$	$km^2/s/3$	m^3/s	x $10^{-3}m^3/s$
Cristalline Rocks	Upper Tibagi	7,500	6.00	10	0.64	1,600	4.8	5.56
Lower Paleozoic	Middle Tibagi	900	3.61	10	0.36	2,800	0.32	2.78
Furnas Formation	Middle to Upper Tibagi	3,500	-	15	-	-	-	8.33
Lower-Middle Paleozoic	Middle to Upper Tibagi	2,500	6.37	10	0.64	1,600	1.6	2.78
Middle-Upper Paleozoic	Middle to Upper Tibagi	12,000	4.6	10	0.46	2,200	5.5	2.78
Upper Paleozoic	Upper to Middle Iguaçu	11,000	4.6	10	0.46	2,200	5.1	2.78
Botucatu Formation	Middle Tibagi and mainly L. Tibagi in underground	11,000	-	-	-	-	-	124
Serra Geral Formation north	Lower Tibagi	10,800	7.7	20	1.5	670	16.2	11.1

*1 same meaning as transitory Recharge of Groundwater

[4] - Spatial Specific mQ_7

[7] - Total Permissive Yield of Aquifer in Study Area

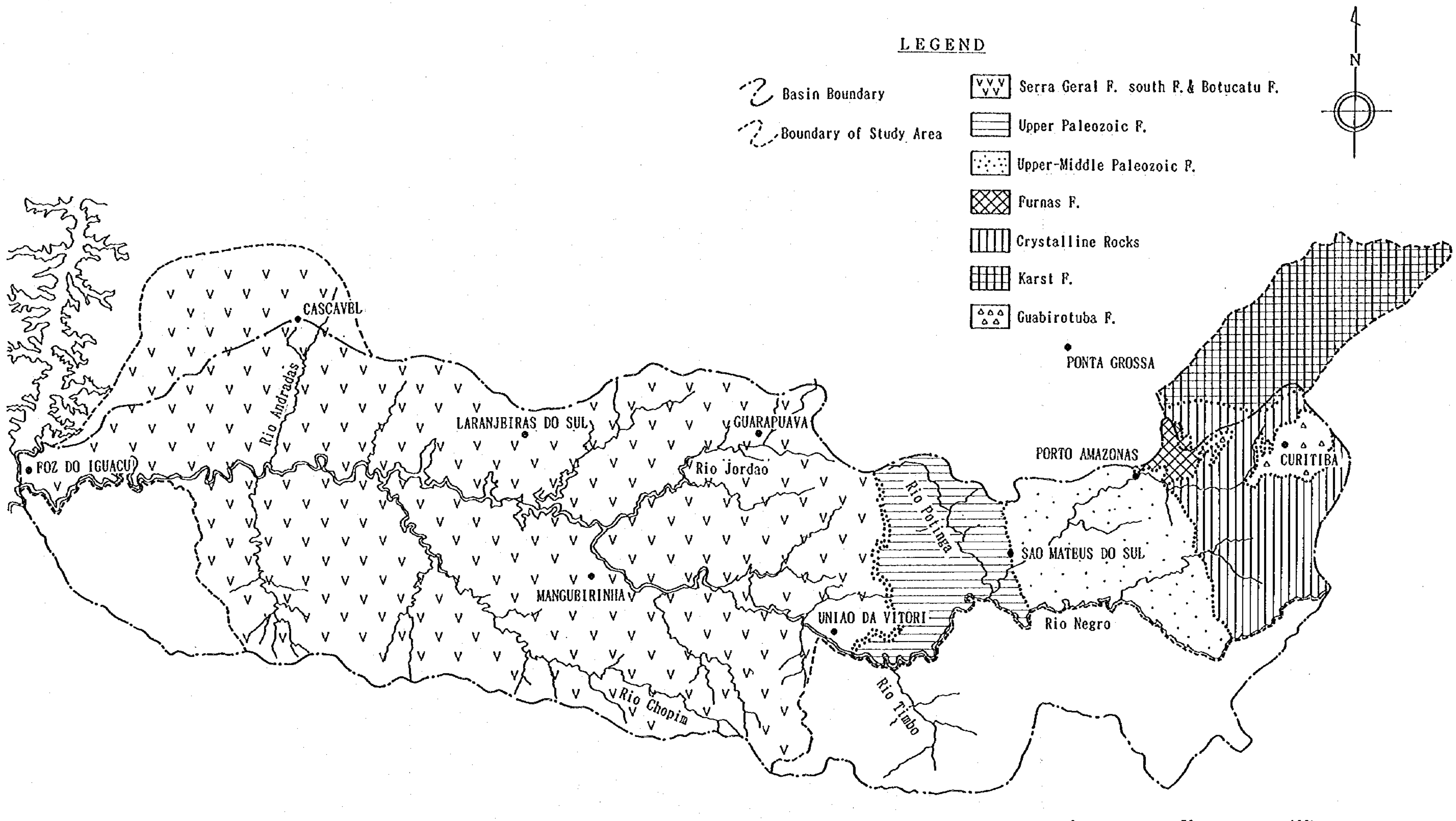


Figure-3.14 Aquifer in Iguaçu River Basin

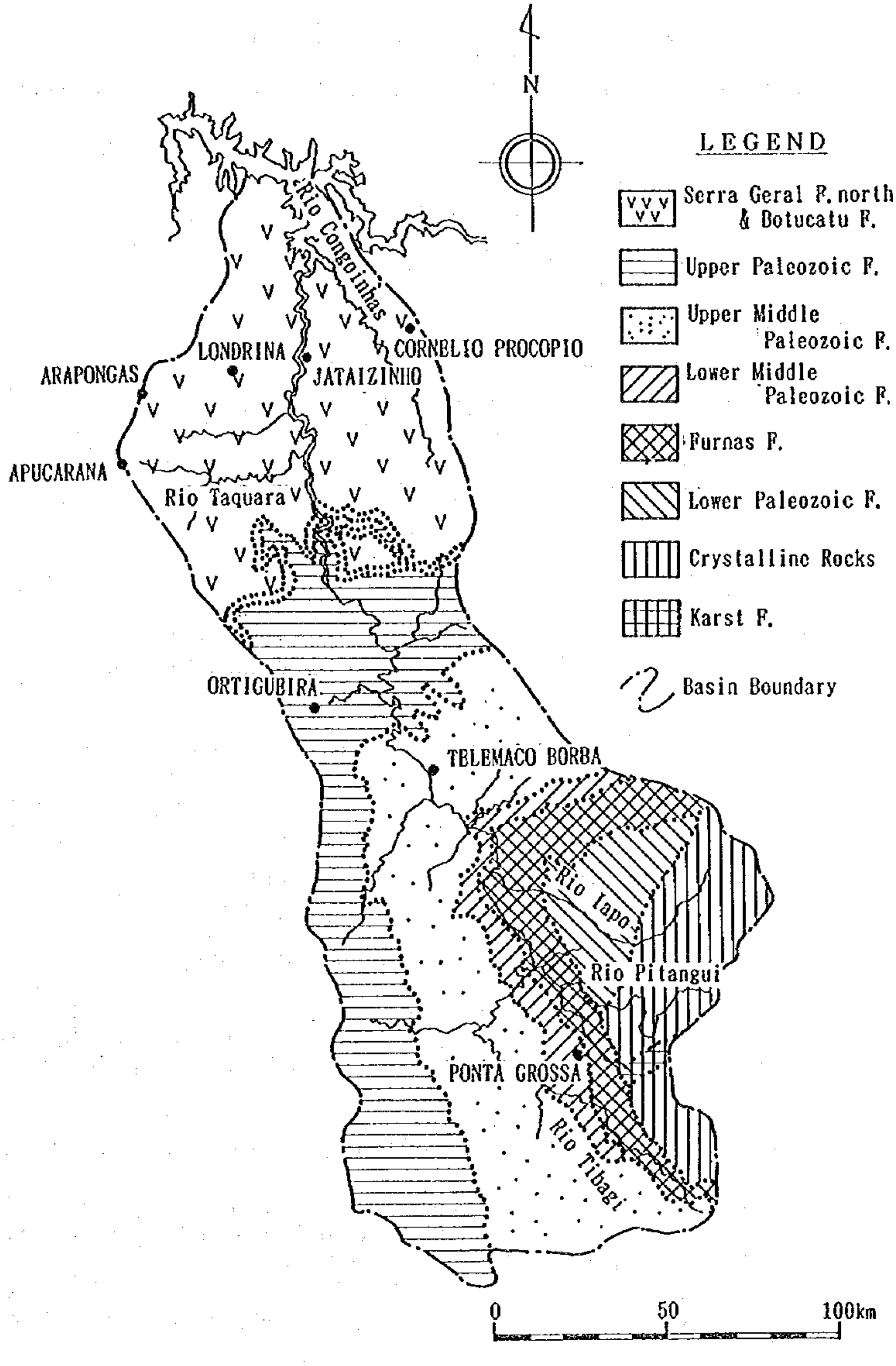


Figure-3.15 Aquifer in Tibagi River Basin

3.7 Water Development in Curitiba Metropolitan Area

The large urban areas included in Curitiba Metropolitan Area are as shown below:

1) Curitiba
2) Almirante Tamandare
3) Colombo
4) Piraquara
5) Sao Jose dos Pinhais
6) Araucaria
7) Campo Largo
8) Pinhais
9) Fazenda Rio Grande
10) Quatro Barras
11) Campina Grande do Sul
12) Balsa Nova
13) Contenda
14) Mandirituba

3.7.1 Water Requirement

Water requirement for urban area is mainly composed of urban domestic water and industrial water. Required water supply in Curitiba Metropolitan Area is shown in Table-3.26.

Table-3.26 Required Water Supply in Curitiba Metropolitan Area (m^3/s)

Case	Required Water	Year		
		1993	2005	2015
Base Case	Required Water Supply	8.190	11.401	15.425
	Water to be newly developed		3.211	7.235

3.7.2 Process of Water Resources Development Study

As studied in the Section-6.1, there is no room for direct intake from river due to shortage of natural discharge in the upstream of Iguaçu river until confluence of Negro river. Therefore, development of new water resources has to depend on the combination of dam-reservoir and groundwater.

Process of water resources development in Curitiba Metropolitan Area was as shown below:

(1) Water supply in Curitiba Metropolitan Areas was studied for surface water development by dams. Water development in proposed 10 dams, planned by SANEPAR around Curitiba at the upstream of Iguaçu river was studied.

(2) Water supply in Curitiba Metropolitan Area was studied for groundwater development by wells.

(3) The combination of dams and wells was optimized for the water supply.

3.7.3 Surface Water Development by Dam

The water development calculation was made based on the following conditions.

a) Assuming the daily discharge at proposed dam sites are inflow to the reservoir, daily water balance in the reservoir is simulated for 20 years.

b) Maintenance discharge from the reservoir and downstream of intake point is assumed to be 50% of $Q_{10,7}$ and the daily discharge is to be more than the maintenance discharge so that the catchment area in upstream of dam and the residual catchment area between dam and intake point are fully utilized for water development.

c) i) When inflow is less than the sum of proposed development water and maintenance discharge, deference is supplied from reservoir water.

ii) When inflow is more than the sum of proposed development water and maintenance discharge, excess of inflow is recharged to the reservoir. If the reservoir is full at that time, excess water is discharge to the downstream of dam.

d) Evaporation from reservoir is also counted by applying average monthly evaporation data for 20 years at Piraquara observation station.

e) Seepage or infiltration from reservoir is neglected.

f) Period of recovery is about 5 years.

The computation of storage capacity is given as the following procedure.

a) Dam Inflow (Q dam)

b) Discharge at intake point (Q intake)

c) Development Volume (Q dev)

d) Maintenance Discharge (Q maint)

Q maint, dam = $0.5 \times Q_{10,7}$ dam

Q maint, intake = $0.5 \times Q_{10,7}$ (intake)

e) Balance at Dam Site

Q_B dam = Q dam – Q maint, dam

f) Balance at Intake Point

Q_B intake = Q intake – Q maint, intake – Q dev

g) Developed Water Development Volume (Q dev)

5 alternative cases are employed.

h) Evaporation (Qevp)

Q evp = E_R x reservoir area

i) Required Replenishment Volume / Possible Recovery Volume (dQ), Outflow (Qout) and Required Storage Volume (Vres)

$dQ = \min(Q_{B.}\ \text{dam}, Q_{B.}\ \text{intake})$

if $dQ < 0$ then $dQ = 0$

j) Outflow from Dam (Qout)

$Q\ out = Q\ in - dQ$

k) Required Storage Volume (Vres)

$V\ res, t = V\ res, t\text{-}1 - (dQ - Q\ evp) \times 86.4$

,where

V res, t : storage volume at t day ($10^3 \times m^3$)

V res, t-1 : storage volume the previous day ($10^3 \times m^3$)

The proposed 10 dams planned by SANEPAR are shown in Table-3.27 and Figure-3.16.

Table-3.27 Proposed 10 dams planned by SANEPAR

Name of Dam (River)	Dam Site				Intake Point				Treat -ment Station	Supply Reser -voir
	Catch -ment Area (km^2)	$q_{10,7}$ [$m^3/s/$ 100km^2]	$Q_{10,7}$ 50% [m^3/s]	Correc -tion Coeffi -cient	Catch -ment Area (km^2)	$q_{10,7}$ [$m^3/s/$ 100km^2]	$Q_{10,7}$ 50% [m^3/s]	Correc -tion Coeffi -Cient		
1 Irai	112.6	0.355	0.200	0.781	226.6	0.408	0.460	1.807	ETA Irai	Cajura
2 Piraquara 2	58.0	0.397	0.115	0.450						
3 pequeno	62.3	0.465	0.145	0.566	110.0	0.465	0.255	1.000	ETA Iguaçu	
4 Alto Miringuava	71.9	0.417	0.150	0.586	97.1	0.402	0.195	0.768	ETA BARRO PRETO	Xaxim
5 Cotia Despique	154.7	0.271	0.210	0.820	same as dam site				ETA COCHOENE	
6 Alto Mauricio	36.0	0.277	0.050	0.195	ditto					Ceasa
7 Das Oncas (Mandirituba)	29.0	0.276	0.040	0.156	ditto					
8 Faxinal	63.3	0.269	0.085	0.333	ditto					Araucaria
9 Das Onces (Coutenda)	75.6	0.265	0.100	0.392	ditto					
10 Piunduva	25.4	0.276	0.035	0.137	ditto					

[Note] : daily discharge at each dam site is calculated by multiplying daily discharge at Fazendinha station by correction coefficient.

Correction Coeffivient : α =C.A./110.0 x $q_{10,7}$/0.465

110.0 : C.A. of Fazendinha

$q_{10,7}$ value was calculated by HG64

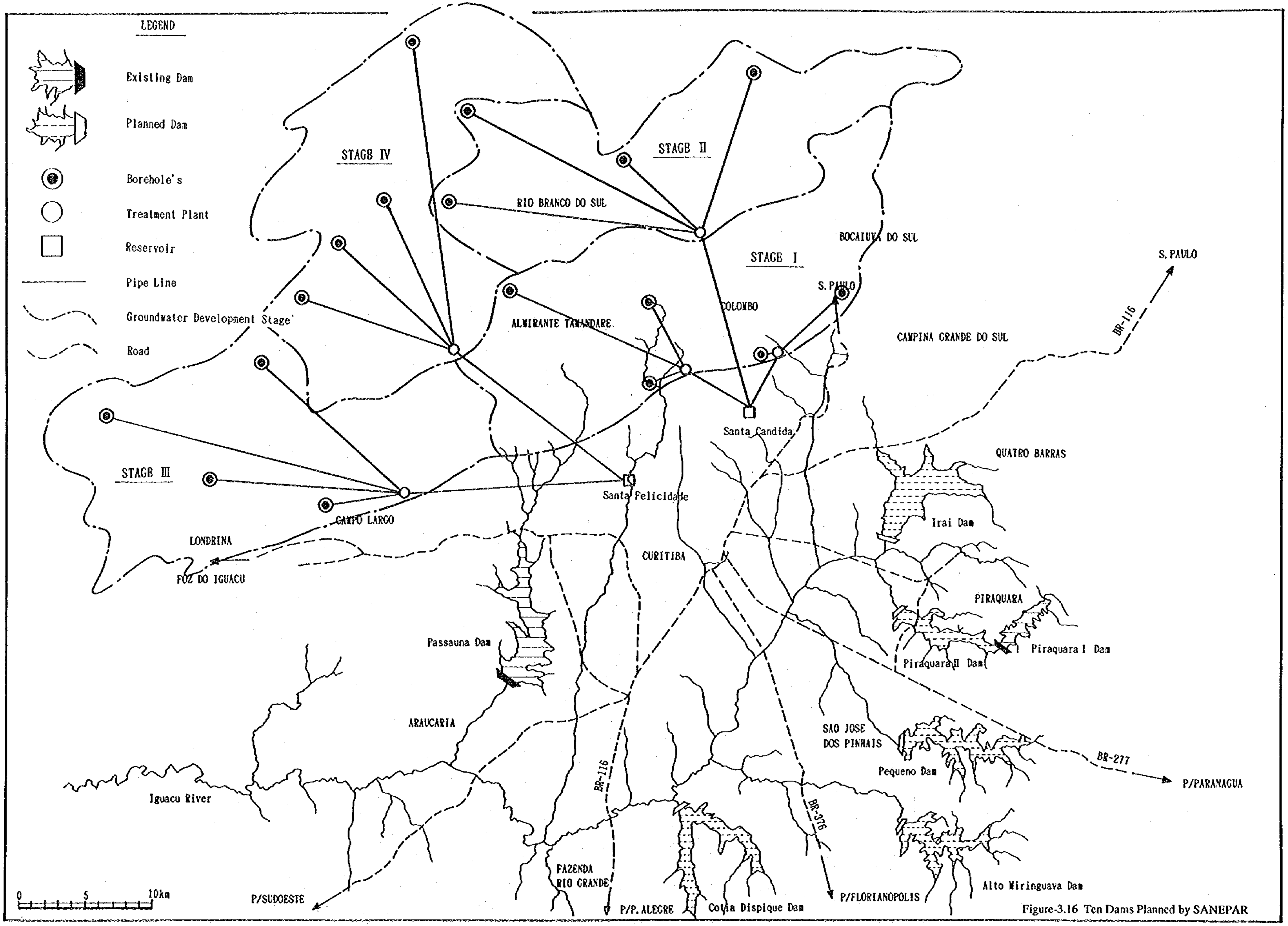


Figure-3.16 Ten Dams Planned by SANEPAR

Several cases of proposed water development volume range from 0.10 m³/sec to 1.40 m³/sec were assumed at each proposed dam. Simulation of daily water balance in reservoir was carried out for 20 years. The result of simulation are shown in Table-3.28.

For example, judging from required recovery period of reservoir capacity, an appropriate water development volume by Pequeno dam (No.3) seems to be 0.8m³/sec.

The water development volume by dams around Curitiba is as shown in Table-3.28.

The results of simulation for dams which intakes are located in the downstream of the dam are shown in Figure-3.17 (1) ~ (4), while ones for dams which intakes are at dam site are same as the results in Chapter 2.

Table-3.28 DevelopedWater and Required Reservoir Capacity by Planned Dam

Name of Dam		Develop-ment Water (m³/sec)	Reservoir Capacity (x 10⁶m³)	Period of Recovery (Year)
1	Irai	1.30	47.9	2.0
		1.40	52.4	5.5
		1.50	57.9	9.0
		1.60	63.6	-
2	Piraquara II	0.70	15.3	4.5
		0.75	21.9	5.5
		0.80	36.7	10.0
		0.85	47.7	-
3	Pequeno	0.60	15.5	2.0
		0.70	20.1	4.0
		0.80	25.4	5.5
		0.90	33.0	-
		1.00	48.2	-
4	Alto Miringuava	0.40	5.2	2.0
		0.50	14.4	3.0
		0.60	19.4	5.5
		0.70	27.6	-
		0.80	46.4	-
5	Cotia Despique	1.00	27.6	3.0
		1.10	32.9	4.5
		1.20	38.9	5.5
		1.30	47.2	-
		1.40		-
6	Alto Mauricio	0.15	3.0	1.5
		0.20	5.3	2.0
		0.25	7.8	5.0
		0.30	11.6	-
		0.36		-
7	Das Onças (Mandirituba)	0.10	1.7	1.5
		0.15	3.5	2.0
		0.20	5.8	4.5
		0.25	9.7	-
		0.30		-
8	Faxinal	0.30	5.2	1.5
		0.40	9.8	2.0
		0.50	14.9	5.5
		0.60	25.0	-
		0.70		-
9	Das Onças (Contenda)	0.40	7.2	2.0
		0.50	11.8	2.5
		0.60	16.8	5.0
		0.70	25.3	-
		0.80		-
10	Piunduva	0.10	1.8	1.5
		0.15	4.0	2.0
		0.20	6.7	5.5
		0.25		
		0.30		
Total		6.50	210.0	

[Note] "-": It means that capacity is not recovery.

Figure-3.17 (1) Result of Simulation of Irai Dam

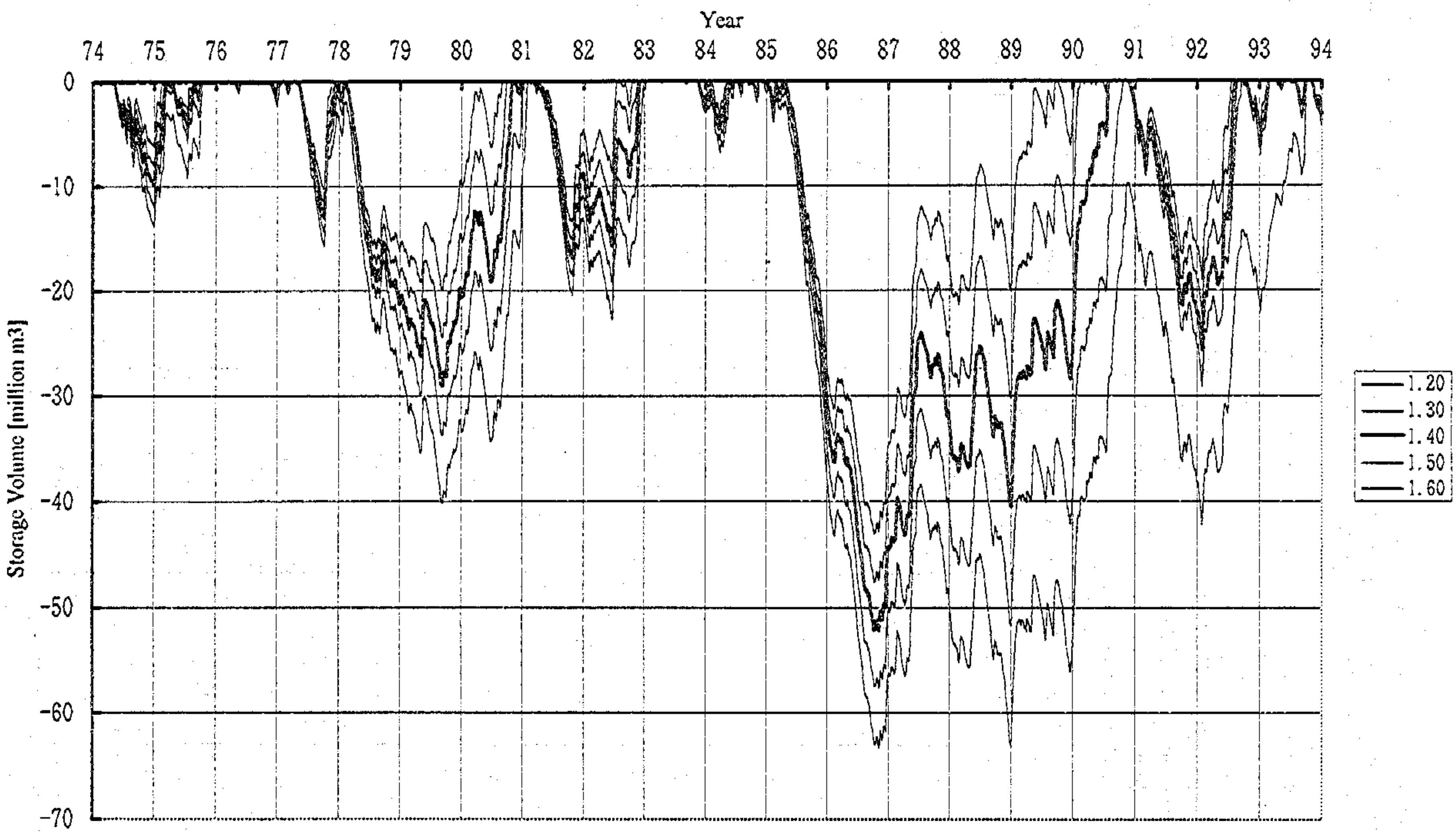


Figure-3.17 (2) Result of Simulation of Piraquara II Dam

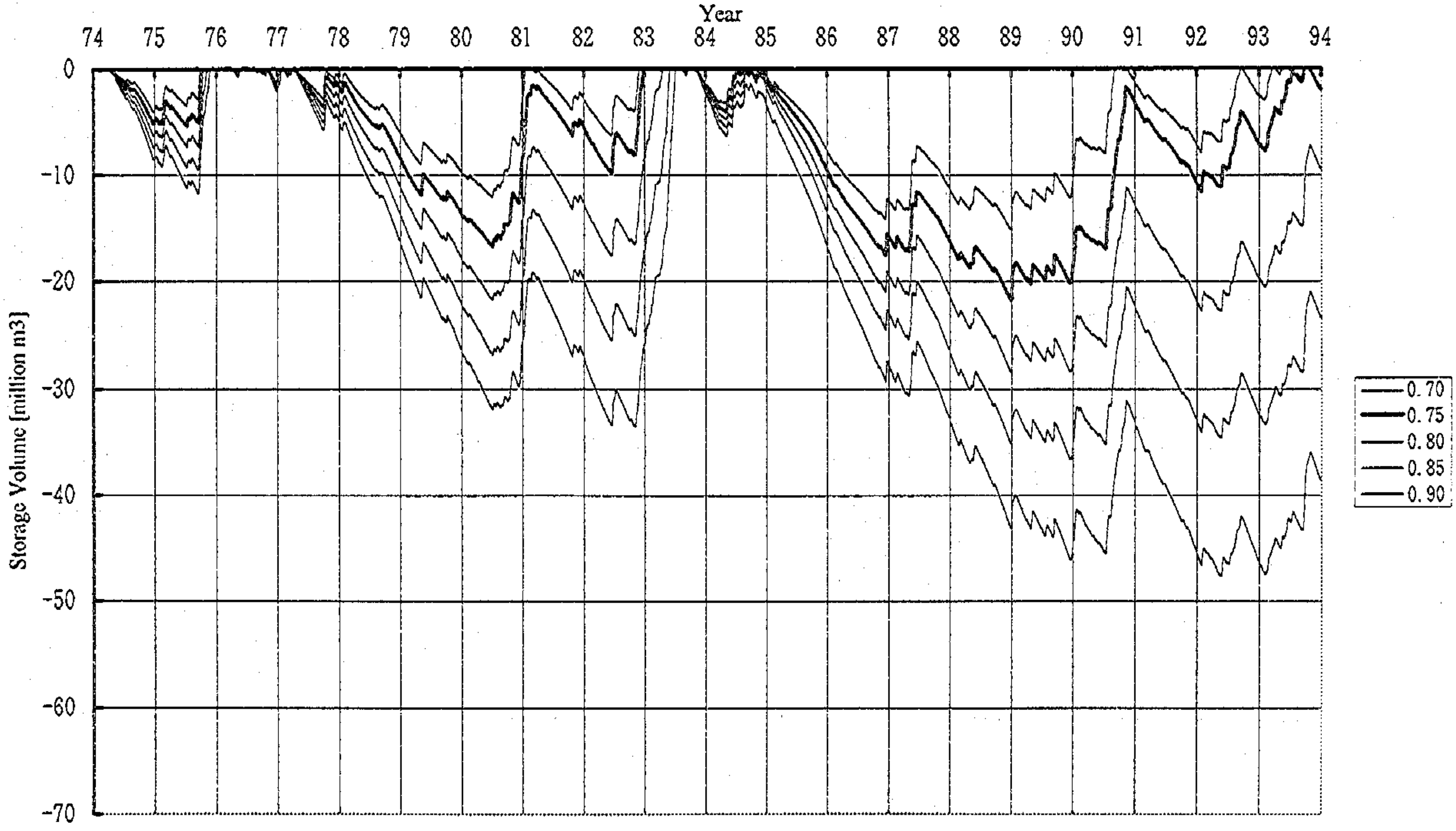


Figure-3.17 (3) Result of Simulation of Pequeno Dam

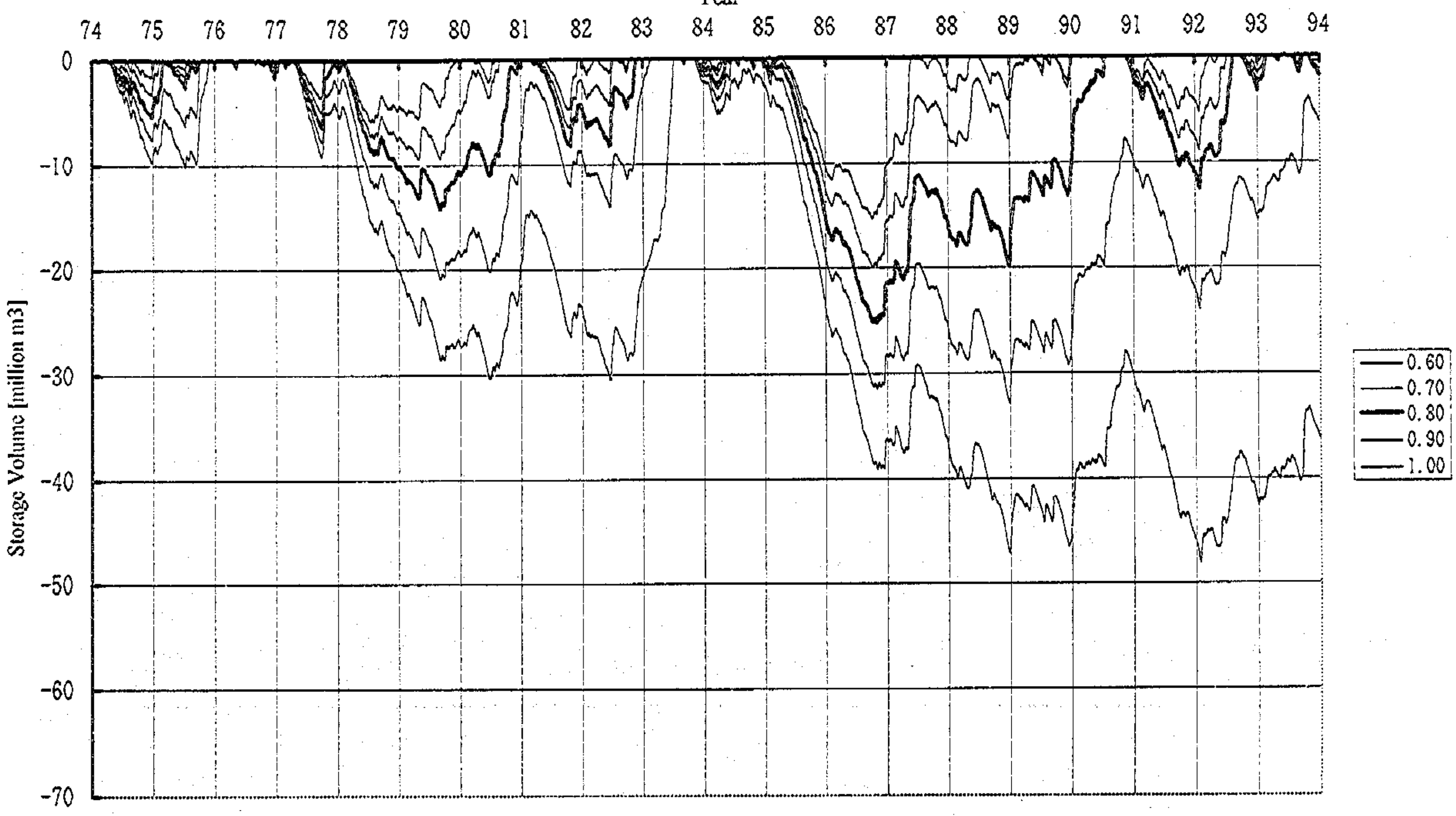
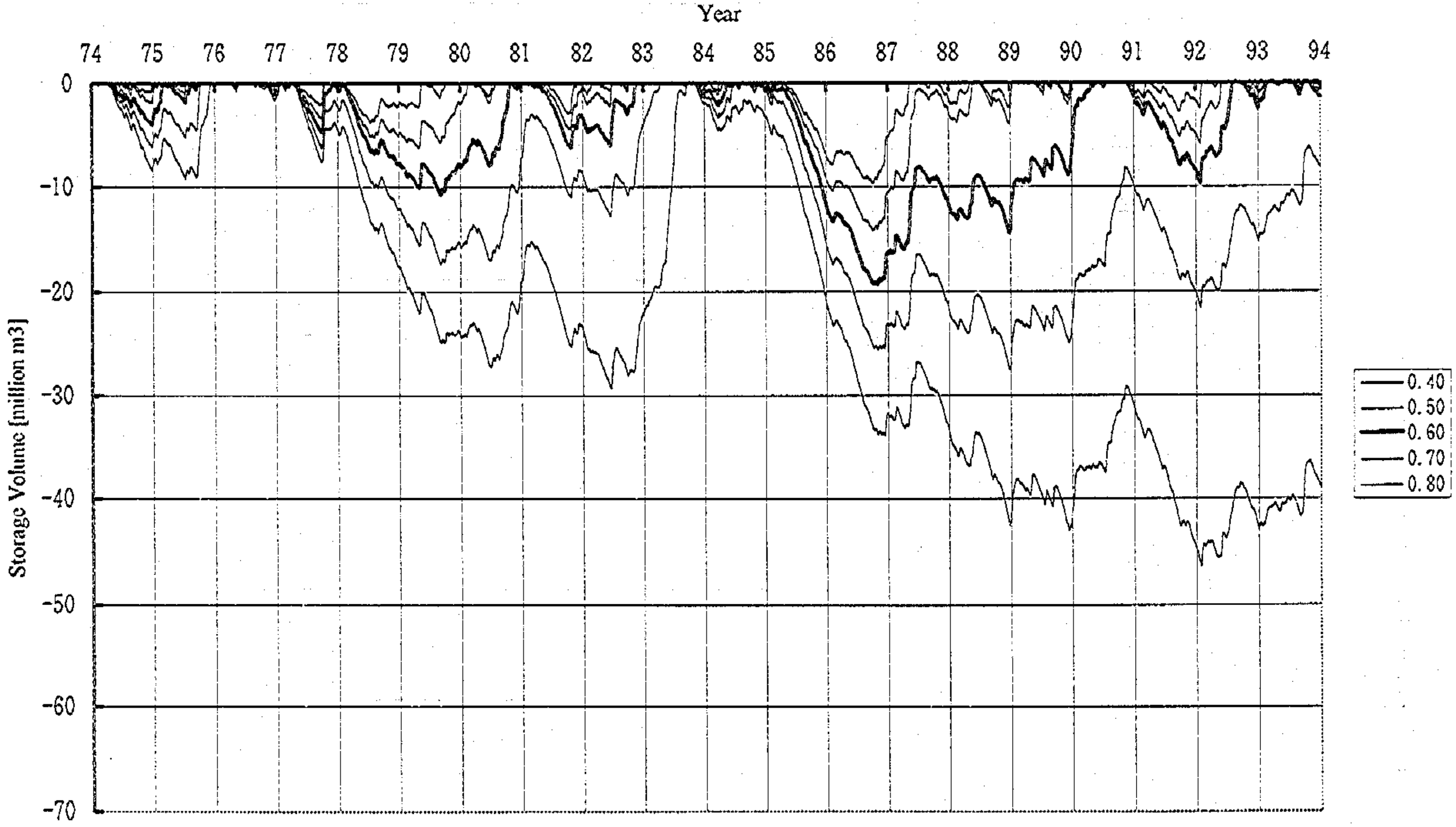


Figure-3.17 (4) Result of Simulation of Alto Miringuava Dam



3.7.4 Groundwater Development by Wells

The aquifers in and around the Curitiba Metropolitan Area are Crystalline Rock, Guabirotuba Formation and Karst. The aquifer being targeted for groundwater development is the Karst aquifer, which is the most productive of the three.

The Karst aquifer is located some 10 to 50 km to the north of Curitiba, its influence area is 400 $km^2/m^3/s$ and its permissive yield per well is 0.044 m^3/s/well.

The survey for the groundwater development of the Karst aquifer was carried out over four stages using the development of approximately 1 m^3/s as one unit. The four stages have been numbered 1 to 4 in order starting from the easiest one to develop. Table-3.29 and Figure-3.18 provide production data and indicate the locations of the wells in the aquifer respectively.

Table-3.29 Productivity of Karst aquifer

No.	Number of Productive Boreheles	Productivity (m^3/s)	Stage	Number of Productive Boreheles	Productivity (m^3/s)	Influence Area (km^2)
1	9	0.40	1	29	1.20	480
2	5	0.20				
3	5	0.20				
4	3	0.10				
5	7	0.30				
6	6	0.25	2	24	1.00	400
7	6	0.25				
8	6	0.25				
9	6	0.25				
10	6	0.25	3	24	1.00	400
11	6	0.25				
12	6	0.25				
13	6	0.25				
14	6	0.25	4	24	1.00	400
15	6	0.25				
16	6	0.25				
17	6	0.25				
Total				101	4.20	1680

[Note] borehile depth is 60 m
permissive yield is 0.044m^3/s
infruence area is 400 $km^2/m^3/s$

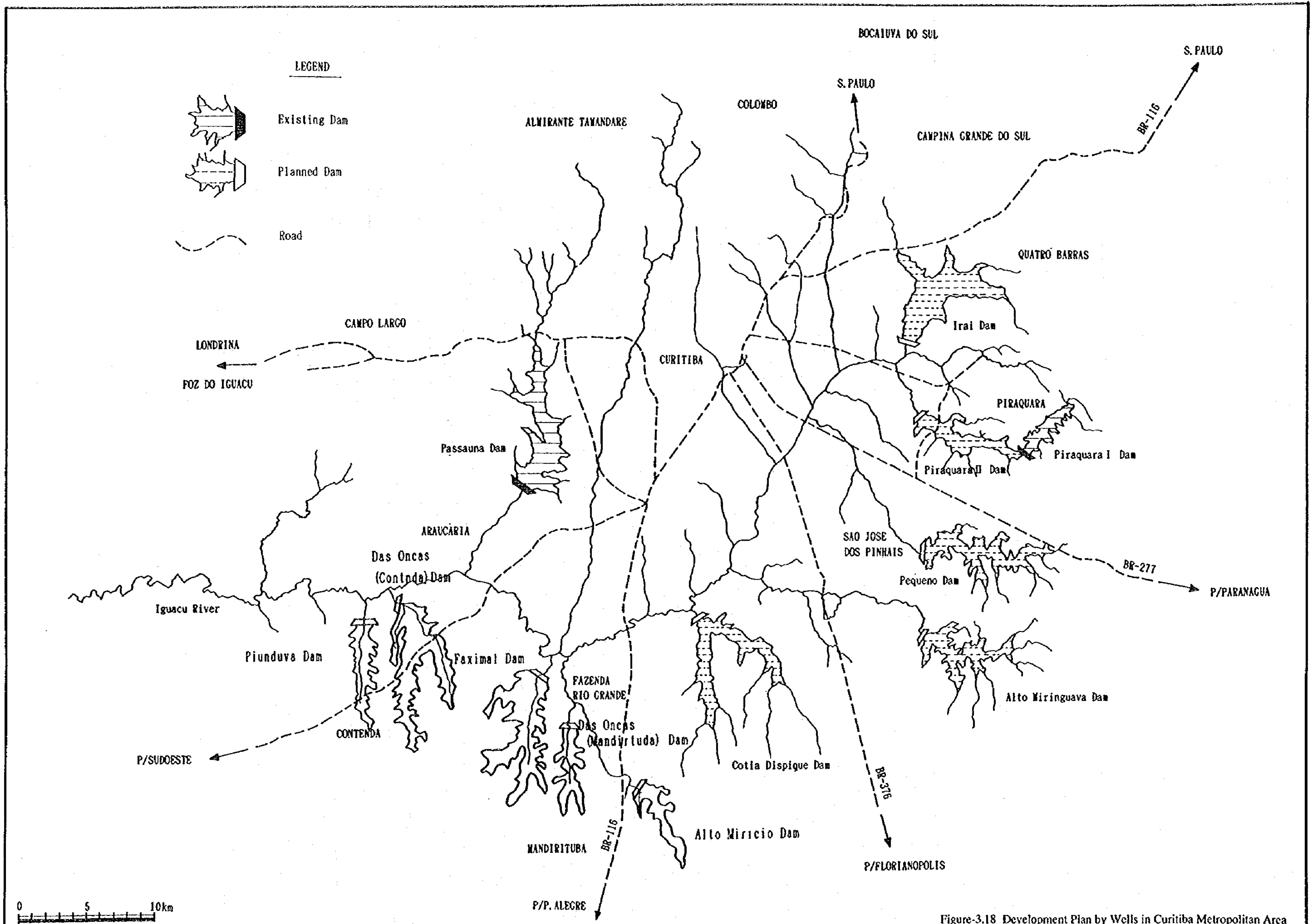


Figure-3.18 Development Plan by Wells in Curitiba Metropolitan Area

3.7.5 Optimization of the Water Supply System

As was mentioned earlier, whereas the required water supply in the Curitiba Metropolitan Area is 7.235 m^3/s, the maximum available amount that can be developed from the ten dams is just 6.50 m^3/s, meaning that it will be difficult to meet the demand through surface water alone. Moreover, as the amounts of water developed from the groundwater of the Karst aquifer increase, the feeding of water over long distances will lead to an increase in the unit water costs (rates) of development. For these reasons, it is necessary to ensure the water supply in the Curitiba Metropolitan Area through a combination of both surface water development by dams and groundwater development by Karst aquifer.

The features of surface water development by dam in contrast to groundwater development are as described below in Table-3.30.

Table-3.30 Comparison of Surface Water Development by Dam and Groundwater Development

Item	Surface Water Development by Dam	Groundwater Development
① Stable water intake (certainty of available water)	As the development plan has been formulated based on the results of statistically processing materials relating to water, which have been collected over a long period, and performing simulations using actual daily flow rates, the degree of certainty regarding the design water intake is high.	The monitoring of groundwater has been implemented in recent times, however, compared to the data on surface water, that relating to groundwater is lacking in terms of the length of period and size of area. Moreover, it cannot be said that a full understanding has been gained of the potentially available groundwater quantities and of the effects of development on surrounding ground and surface water quantities. It is therefore less certain that the design water intake can be secured, compared to the case of surface water development.
② Water quality	In order to preserve the quality of the water in the dam reservoirs, development and improvement of the sewerage systems in upstream towns and the taking of measures to counter eutrophication in the reservoirs will be necessary.	As the Karst aquifer contains hard water, careful thought will need to be given to its specific uses in the case where it is used as industrial water.
③ Construction period	As large-scale works will be necessary, the construction period will be relatively long.	The boring of wells will not take such a long time, however, the laying of pipe lines will be slightly more time consuming than the construction of dams.
④ Environmental impact	As reservoirs will be constructed artificially, it will be necessary to formulate a detailed plan upon first understanding the effects on ecological systems, the surrounding residents and water quality, etc.	Little direct effect on the surface environment can be expected, however, planning will have to take into consideration ground subsidence and the effects on other wells. As groundwater also acts as a source of surface water, it will also be necessary to amply consider the effects the development will have on the flows of downstream rivers.
⑤ Development cost	In the case of dam development, the cost will vary depending on the topographical conditions of the dam sites and the flow conditions of the rivers. Similarly, in the case of groundwater development, cost will vary depending on the distances between the development sites and supply areas, and also on the topographical conditions in the surrounding areas. It is therefore difficult to make sweeping statements about which form of development is the cheaper.	

Regarding the optimal combination of surface water development by dams and groundwater development in order to fulfill the water requirement of Curitiba Metropolitan Area, setting will be done upon conducting the following examinations based on the characteristics described in Table-3.30.

(1) Development costs will be calculated for each stage of both the dam development and the groundwater development, and the cheapest combination in the case where both are combined will be adopted.

(2) The order of priority of the development will be decided in consideration of the required construction periods and the exploitable water quantities, etc.

The costs involved in the development of each dam and wells in each stage are as indicated in Table-3.31. The relationship between development costs when dam development and groundwater development are combined in order to develop the required water supply of 7.235 m^3/s is as shown in Figure-3.19.

Table-3.31 Development Cost

Water Source	Supply Reservoir / Well Field Zone	Name of Dam / Number of Wells	Develpment Volume (m^3/s)	Cost (10^6US$)	Unit Cost (10^6US$/$m^3/s$)
Surface Water	Cajura	Irai	1.400	49.3	49.3
		Piraquara 2	0.750	22.0	22.0
		Pequeno	0.800	28.6	35.8
	Xaxim	Alto Mirinquava	0.600	35.3	58.8
		Cotia Despique	1.200	43.8	36.5
	Ceasa	Alto Mauricio	0.250	20.0	80.0
		Das Oncas (Mandirituba)	0.200	25.4	127.0
	Araucaria	Faxinal	0.500	25.5	51.0
		Dos Oncas (Contenda)	0.600	23.1	38.5
		Piunoluva	0.200	17.4	87.0
Groundwater	Stage 1	29	1.290	40.3	31.2
	Stage 2	24	1.066	51.3	48.1
	Stage 3	24	1.066	53.7	50.4
	Stage 4	24	1.066	54.9	51.5

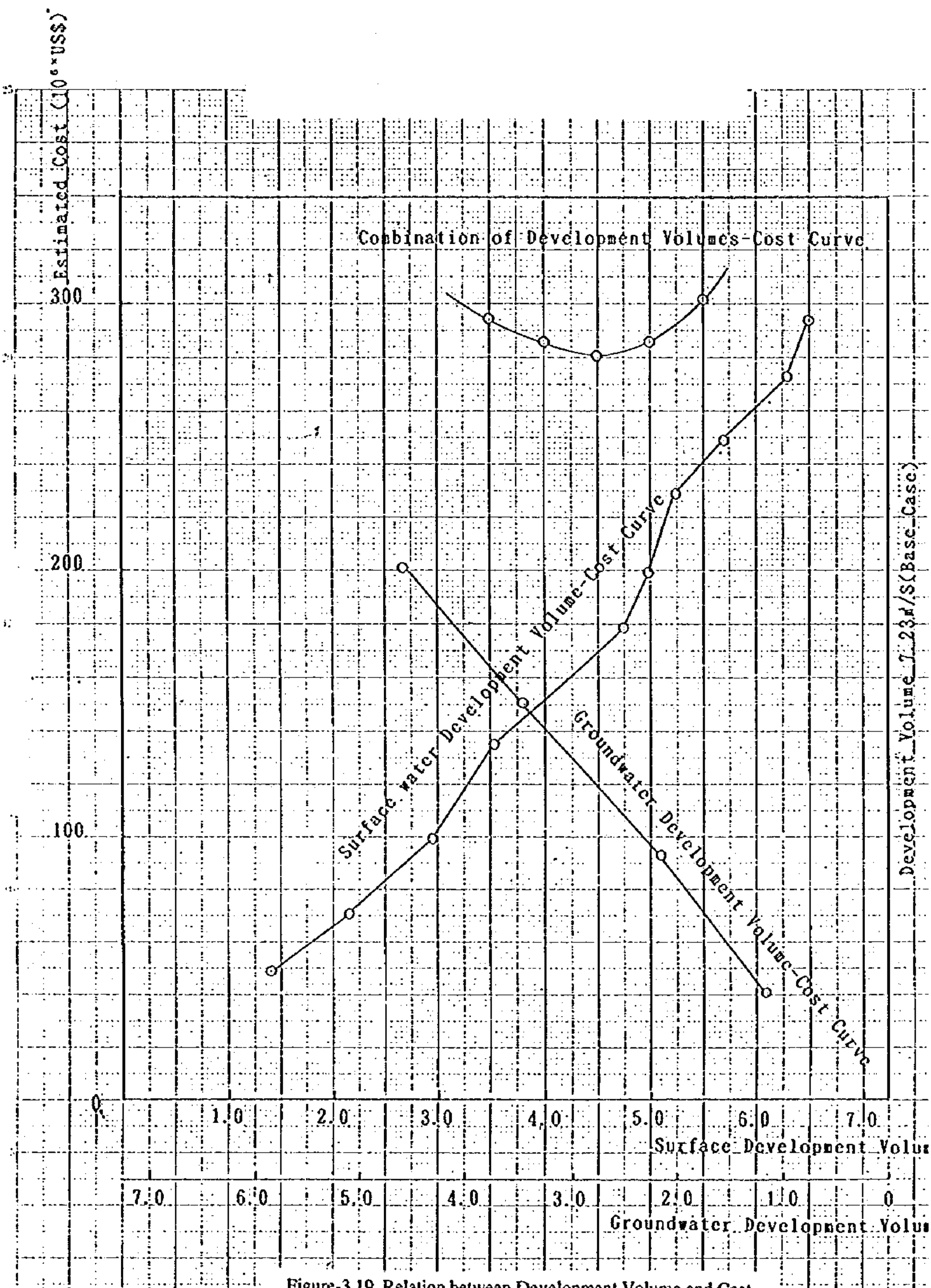


Figure-3.19 Relation between Development Volume and Cost

Based on Table-3.31 and Figure-3.19, the optimum use of dams and groundwater in terms of development cost is shown in Table-3.32. The water supply system in Curitiba metropolitan area is shown in Figure-3.20.

Table-3.22 Optimization Water Supply

Name of Water Resource	Constructions	Development Volume (m^3/s)	Cost (10^6US$)
Irai Dam	dam, pipeline (Ø 1,200 x 15,000 m)	1.400	49.3
Piraquara II Dam	dam, pipeline (do.)	0.750	22.0
Pequeno Dam	dam, pipclin (Ø 800 x 8,000 m)	0.800	28.6
Alto Miringuava Dam	dam, pipeline (Ø 900 x 23,500 m)	0.600	35.3
Cotio Despique	dam, pipeline (Ø 900 x 17,000 m)	1.200	43.8
wells (stage 1)	29 wells, pipeline	1.290	40.3
wells (stage 2)	27 wells, pipeline	1.195	57.5
Total		7.235	276.8

3.7.6 Implementation Schedule of Water Development

The development schedule in the case of the combination of dam development and groundwater development shown in Table-3.32 is as illustrated below.

Dam construction will take a relatively long time until completion, however, once completed it will be possible to obtain large amounts of water. The development of groundwater will take less time compared to dam. As 5 dams will be constructed over 20 years, one dam will be built every 4 years. Groundwater development will be implemented in the period during dam construction in order to supplement the water supply. Figure-3.21 gives a detailed representation of the implementation schedule of the development.

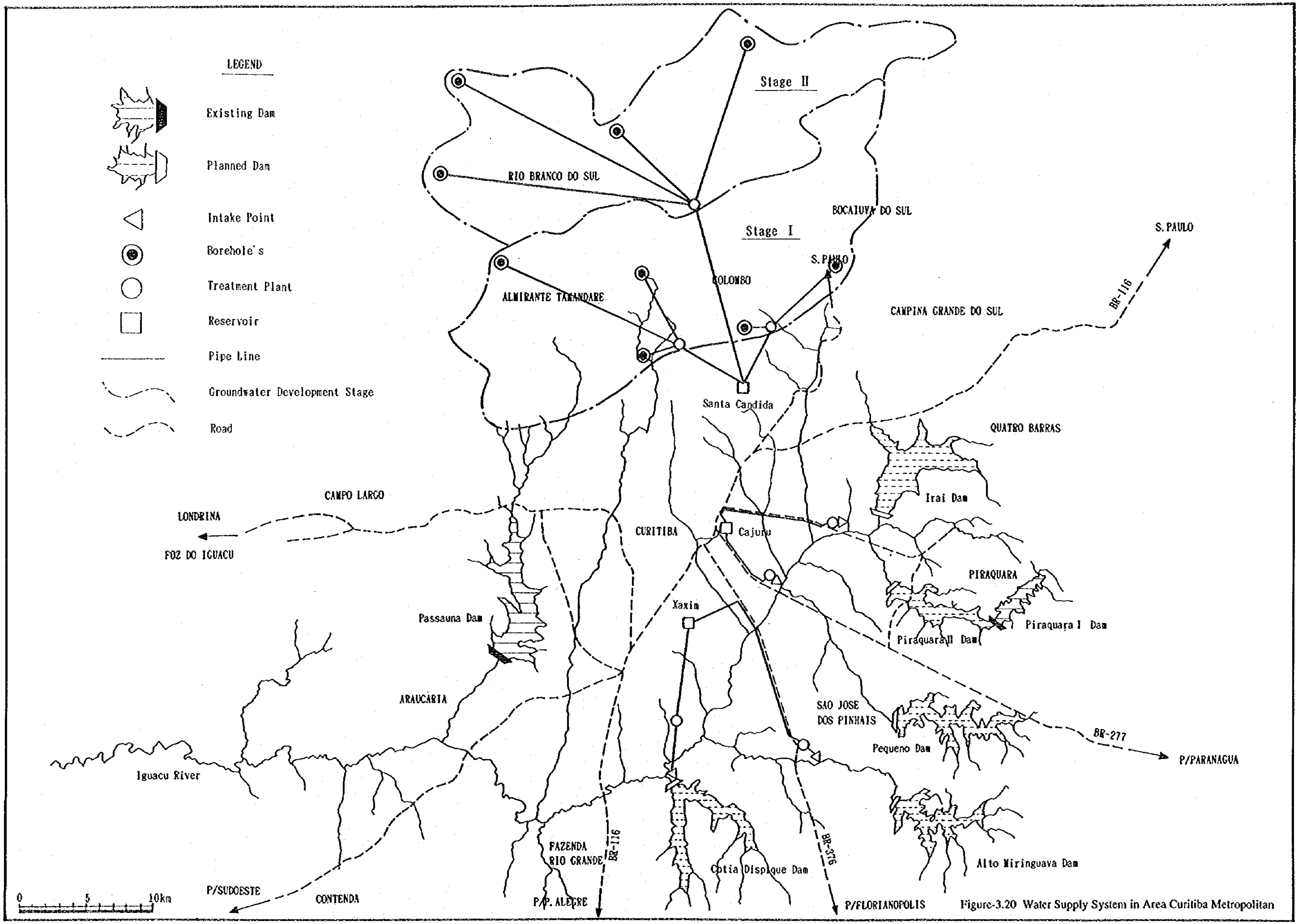
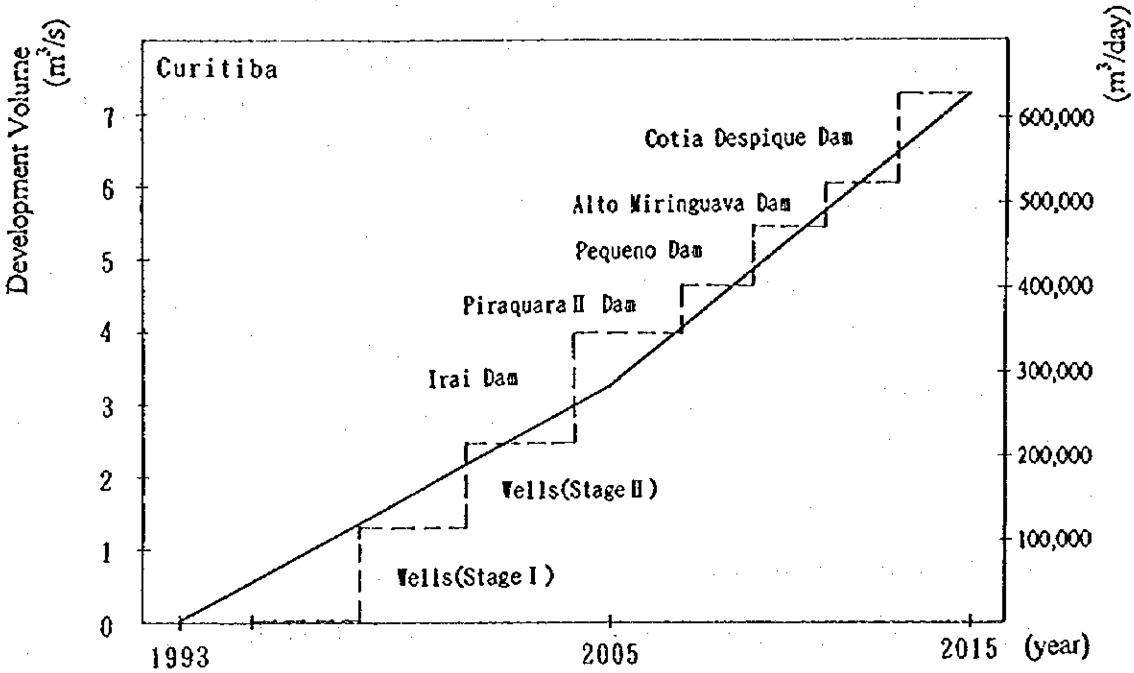


Figure-3.20 Water Supply System in Area Curitiba Metropolitan



Wells (StageI)	110.6			
Wells (StageII)	157.9			
Irai Dam		135.4		
Piraquara II Dam			60.4	
Pequeno Dam			78.5	
Alto Miringuava Dam			96.9	
Cotia Despique Dam				120.3
Total : 760.0 million us$	215.9 [28%]	218.2 [29%]	211.4 [28%]	114.5 [15%]

Figure-3.21 Implementation Schedule of Critiba Metropolitan Area

3.8 Water Development in Large Urban Areas (Type-A)

The urban areas were defined that their population will be more than approximately 100,000 in 2015. The following urban areas belong to Type-A as large urban areas in Iguaçu river basin except for Curitiba Metropolitan Area and in Tibagi river basin.

(1) Iguaçu river basin
- Cascavel
- Foz do Iguaçu
- Guarapuava

(2) Tibagi river basin
- Ponta Grossa
- Londrina
- Apucarana

3.8.1 Water Requirement

Required water supply in large urban areas was shown in Table-3.33.

Table-3.33 Required Water Supply in Large Urban Areas (m^3/s)

River Basin	Municipality	Year	
		2005	2015
Iguaçe	Cascavel	0.268	0.542
	Foz do Iguaçu	0.504	1.043
	Guarapuava	0.127	0.292
Tibagi	Ponta Grossa	0.205	0.433
	Londrina and Cambe	0.549	1.223
	Apucarana	0.114	0.232

(Note) Water requirement for urban area is mainly composed of urban domestic water and industrial water.

3.8.2 Process of Water Resources Development Study

The process of water resources development in large urban areas is as shown below.

(1) In cities where main rivers are nearby and direct intake is easy, water supply shall be secured through surface water development.

(2) In cases where development by means of direct intake is difficult, careful consideration shall be given to the case of development to the development capacity and the development cost, etc. for both surface water and groundwater.

(3) Regarding the development of surface water, more detailed examination shall be made on the promising alternatives stated in the Strategy (Main Report I) upon consideration of the local survey results and the state of existing facilities.

(4) Examination shall be given to the case where the whole water supply is provided by groundwater development.

(5) Based upon the examination results of (3) and (4), the optimal development plan shall be formulated upon first giving careful consideration to the conditions stated in (2).

3.8.3 Water Resources Development Policies

Based upon consideration of the topographical conditions in Type-A cities and the surface water and groundwater conditions in the target areas, the water resources development policies as shown in Table-3.34 were decided upon.

Table-3.34 (1) Water Resources Development Policies for Large Urban Areas (Iguaçu River Basin)

City	Topographical Condition	State of Water Resources		Water Resource Development
		Surface Water	Groundwater	
Cascavel	Cascavel is situated in the mountains within the basins of the Iguaçu, Piquiri and Paranâ3.	As the water resources are the rivers that flow down from the mountains, the water intake points must be placed downstream in order to expand their catchment area, meaning that the pipe lines will become very long. As the catchment area is small, the construction of a dam will be necessary.	The town is surrounded by the Serra Geral Formation north aquifer and below that the Botucatu Formation aquifer, and the productivity levels in both of these are high.	As the city has a large water requirement and the development of surface water is not easy, the development plan shall be formulated upon first examining the potential of both surface water development and groundwater development.
Foz de Iquacu	This city is situated at the mouth of the Iguaçu river next to the reservoir of the Itaipu Dam.	The city currently obtains its water from the Itaipu Dam reservoir. The city currently obtains its water from the reservoir of Itaipu Dam. Compared to the water quantity of Parama river, the necessary water requirement is very small.	Same as above (however, change north to south)	Development will involve improving the intake facilities from Itaipu Dam andthe pipe line facilities for taking water from Paraná river.
Guaraperava	This city is situated in the upper reaches of the Jardao river, which is a right bank tributary of the Iguaçu river. It is situated 20-30 km from the mountain tops.	A river with a catchment area of 700 km^2 runs nearby the city and direct intake development is feasible.	The Serra Geral Formation south aquifer is located around the town, however, the productivity of the existing wells is low.	In view of the fact that direct intake development is easy and the groundwater productivity is low, the development will be performed on the surface water resources.

Table-3.34 (2) Water Resources Development Policies for Large Urban Areas (Tibagi River Basin)

City	Topographical Conditions	State of Water Resources		Water Resources Development Policies
		Surface Water	Groundwater	
Ponta Grossa	Ponta Grossa is situated in the ridge area of the basin boundaries of the Tibagi river and Pitangui river.	If development that utilizes the tributaries is carried out, the small catchment areas mean that a dam will have to be built in order to store water. If the Tibagi river mainstream is utilized, direct intake development will be feasible.	The Middle Paleozoic aquifer is located around the town, however, the productivity of existing wells is low and the permissive yield is small.	As the direct intake development of surface water is feasible and the surrounding aquifer is not suited to groundwater development, development will be carried out to exploit the surface water resources.
Londrina	Londrina is situated in the midstream to upstream area of a tributary of the Tibagi river.	If development that utilizes the tributaries is carried out, the large demand for water means that dams will have to be built in order to store water. Even if two dams are built, however, it will still not be possible to obtain the required amount of water. Although a pipe line in excess of 10 km would be required, it would be possible to achieve the direct intake development of the mainstream waters of Tibagi river.	The Serra Geral Formation north aquifer and below that the Botucatu Formation aquifer are located around the town, and the productivity levels in each are high.	As both surface water development and groundwater development are feasible, the development plan shall be formulated upon examining both possibilities.
Apucarana	Apucarana is situated in the mountains and within the three river basins of the Tibagi, Pirapo and Ivai.	As the ratio of surface water that can be developed is low (50% $q_{10,7}$ or less) compared to the unit catchment area in this district, it would not be possible to supply the whole water demand through surface water development alone, even if direct intake from nearby rivers and dam construction was carried out.	Same as above	As the city is located in a region where surface water development is difficult and where suitable aquifers are situated, a water supply plan of groundwater development will be formulated.

3.8.4 Water Supply System in Large Urban Areas

The water supply system proposed for each municipality was examined and the result is shown in Table-3.35.

Table-3.35 (1) Proposed Water Supply System in Iguaçu River Basin (Type-A)

Item		Name	Location	Possibility of Development	Catchment Area	$q_{10,7}$	Total Project cost		
				m^3/s	km^2	$m^3/s/100km^2$	10^6us$	10^6us$/$m^3/s$	
Cascavel	S-C_1	Rio Sao Jose	Cascavel	0.300	145.0	0.420	14.18	47.3	○
0.542m^3/s	G-C_1	Stage1(B.F.×1, S.G.F.n×5)	Cascavel	0.220			17.74	80.6	○
	G-C_2	Stage2(S.G.F.n×4)	Cascavel	0.080			6.97	87.1	○
	D-C_3	Antos	Cascavel	0.690	68.9	0.369	42.0	60.9	
Foz do Iguacu	S-FI_1	Itaipu Reservoir	Foz do Iguacu	1.042		0.299	11.12	10.7	○
1.043m^3/s									
Guarapuava	S-G_1	Rio Bananas	Guarapuava	0.292	704.0	0.180	9.12	31.2	○
0.292m^3/s	G-G_1	Stage1(S.G.F.s×7)	Guarapuava	0.040			7.33	183.3	
	G-G_2	Stage2(S.G.F.s×7)	Guarapuava	0.040			7.33	183.3	
	G-G_3	Stage3(S.G.F.s×7, B.F.×1)	Guarapuava	0.124			17.74	143.1	

[Note] ○ is the recommended water supply system.
B.F. means Botucatu Formation aquifer.
S.G.F. n means Serra Geral Formation north aquifer.
S.G.F. s means Serra Geral Formation south aquifer.

Table-3.35 (2) Proposed Water Supply System in Tibagi River Basin (Type-A)

Item		Name	Location	Possibility of Development	Catchment Area	$q_{10,7}$	Total Project cost		
				m³/s	km²	m³/s/100km²	10^6us $	10^6us $ / m³/s	
Londrina	$S-L_1$	Rio Tibagi	Londrina	1.223	21,955.0	0.088	46.51	38.0	○
Cambe	$G-L_1$	Stage1(S.G.F.n×6, B.F.×1)	Londrina	0.223			14.33	64.3	
1.223m³/s	$G-L_2$	Stage2(S.G.F.n×6, B.F.×1)	Londrina	0.223			16.15	72.4	
	$G-L_3$	Stage3(S.G.F.n×6, B.F.×1)	Londrina	0.223			16.65	74.7	
Ponta Grossa	$S-P_1$	Rio Tibagi	Ponta Grossa	0.433	1,520.0	0.221	13.47	31.1	○
0.433m³/s									
Apucarana	$S-A_1$	Ribeirao do Cerne	Apucarana	0.041	20.9	0.056	9.83	239.8	
0.232m³/s	$S-A_2$	Ribeirao do Cerne	Apucarana	0.009	15.6	0.056	7.65	850.0	
	$G-A_1$	Stage1(S.G.F.n×4)	Apucarana	0.132			7.65	58.0	○
	$G-A_2$	Stage2(S.G.F.n×4)	Apucarana	0.132			7.27	55.1	○

[Note] ○ is the recommended water supply system.
B.F. means Botucatu Formation aquifer.
S.G.F. n means Serra Geral Formation north aquifer.

The water supply systems that should be promoted in large urban areas are as shown in Table-3.36 below.

Table-3.36 Water Supply System Recommended in Large Urban Area

River Basin	City	Water Supply System	Constructions	Catchment Area or Well Number	Development Volume (m^3/s)	Cost (10^6US$)
Iguaçu	Cascavel	direct intake from Sao Jose river	pumps, pipeline (Ø 300 x 13,000 m x 2)	145.0km²	0.300	14.2
		wells (Serra Geral F. aquifer	wells, pipeline (Ø 400 x 11,000 m)	9 boreholes	0.180	
		and (Botucatu F. aquifer)	wells, pipeline (Ø 300 x 8,000 m)	1 boreholes	0.120	24.7
	Foz do Iguaçu	direct intake from Paraná river	pumps, pipeline (Ø 500 x 1,900 m x 3)	-	1.043	11.1
	Guarapuava	direct intake from Bananas river	pumps, pipeline (Ø 300 x 4,800 m x 2)	704.0km²	0.292	9.1
Tibagi	Ponta Grossa	direct intake from Tibagi river	pumps, pipeline (Ø 400 x 6,000 m x 2)	1520km²	0.433	13.5
	Londrina	direct intake from Tibagi river	pumps, pipeline (Ø 500 x 13,400 m x 3)	21955km²	1.223	46.5
	and	(Alternative) wells (Serra Geral F.aquifer)	wells pipeline (Ø 400 x 5,000 m, Ø 400 x 7,500 m)	30 bereholes	(0.494*)	(47.1)
	Cambe	and (Botucatu aquifer)		4 bereholes	(0.496*)	
	Apucarana	wells(Serra Geral F. aquifer)	wells, pipeline (Ø 300 x 9,000 m, Ø 300 x 8,000 m)	8 bereholes	0.260	14.9

Note: * is development volume for only Londrina

The intake points and pipe lines for each city are as illustrated in Figure-3.22 - Figure-3.27.

3.8.5 Implementation Schedule of Water Development

The implementation schedules for each city are as shown in Figure-3.28 and Figure-3.29.

Since the water demands of all municipalities are expected to exceed the current water supply soon, the water development is necessary to be implemented as early as possible. In the case that the development is composed of several phases, the investment can be split. On the other hand, in the case that the volume of the water development is small, the construction has to be implemented at once. The water development is assumed to be implemented with the following manner.

1) If the water development consists of surface water and groundwater, the development will be split in several phases.

2) The minimum diameter of pipeline is assumed to be Ø 200. The number of pipe lines depends on the volume of water to be developed.

   volume of water to be developed < 0.2 m^3/sec one pipe line

   volume of water to be developed ≥ 0.2m^3/sec 2 or 3 pipe lines

   Construction is composed of several phases.

No. S-C1			Scale : 1 / 50,000
(Location)	X =257	Y =7224	
Basin Iguacu	River Rio Sao Jose	Municipality Cascavel	Others

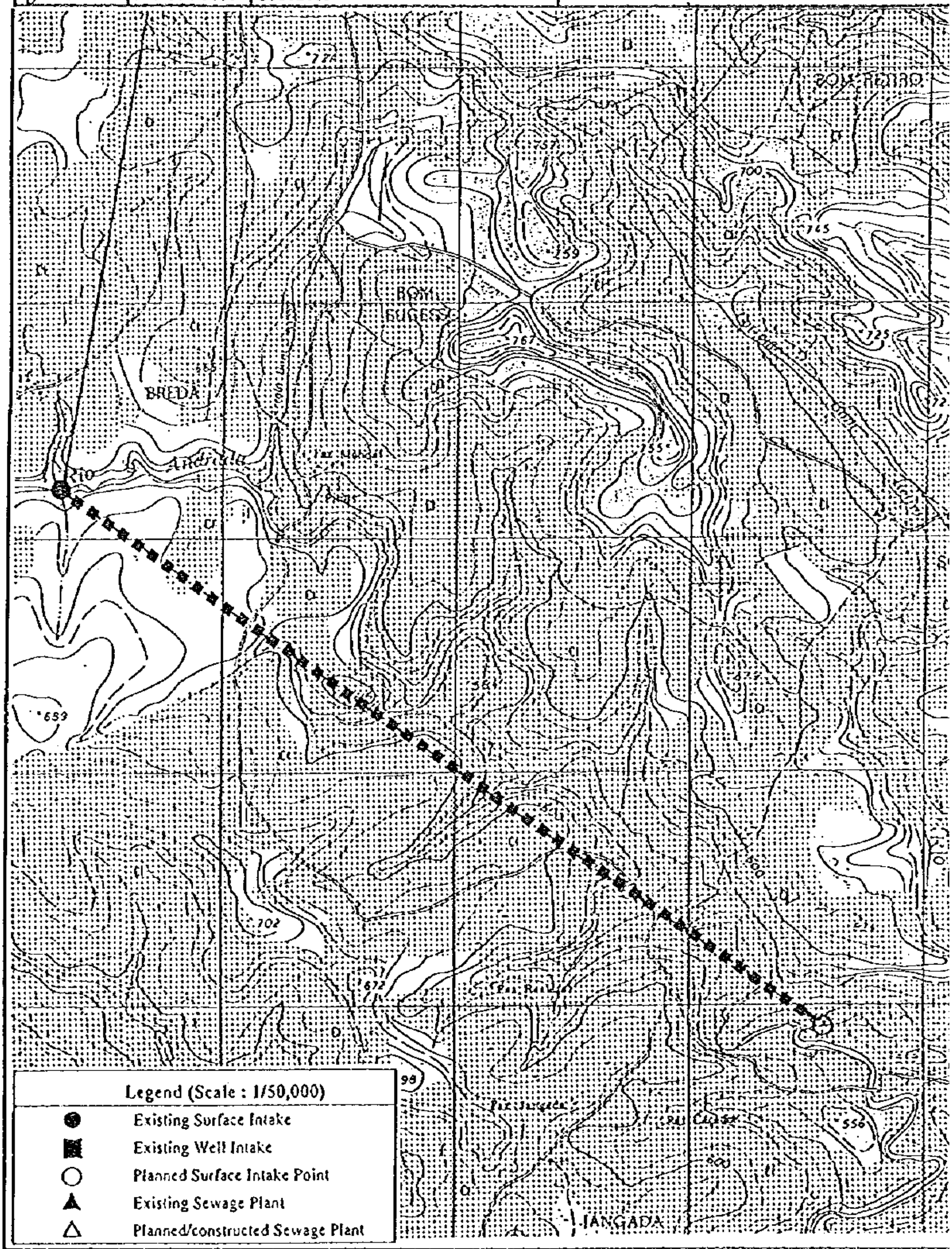


Figure-3.22 (1) Water Supply System by Surface Water in Cascavel

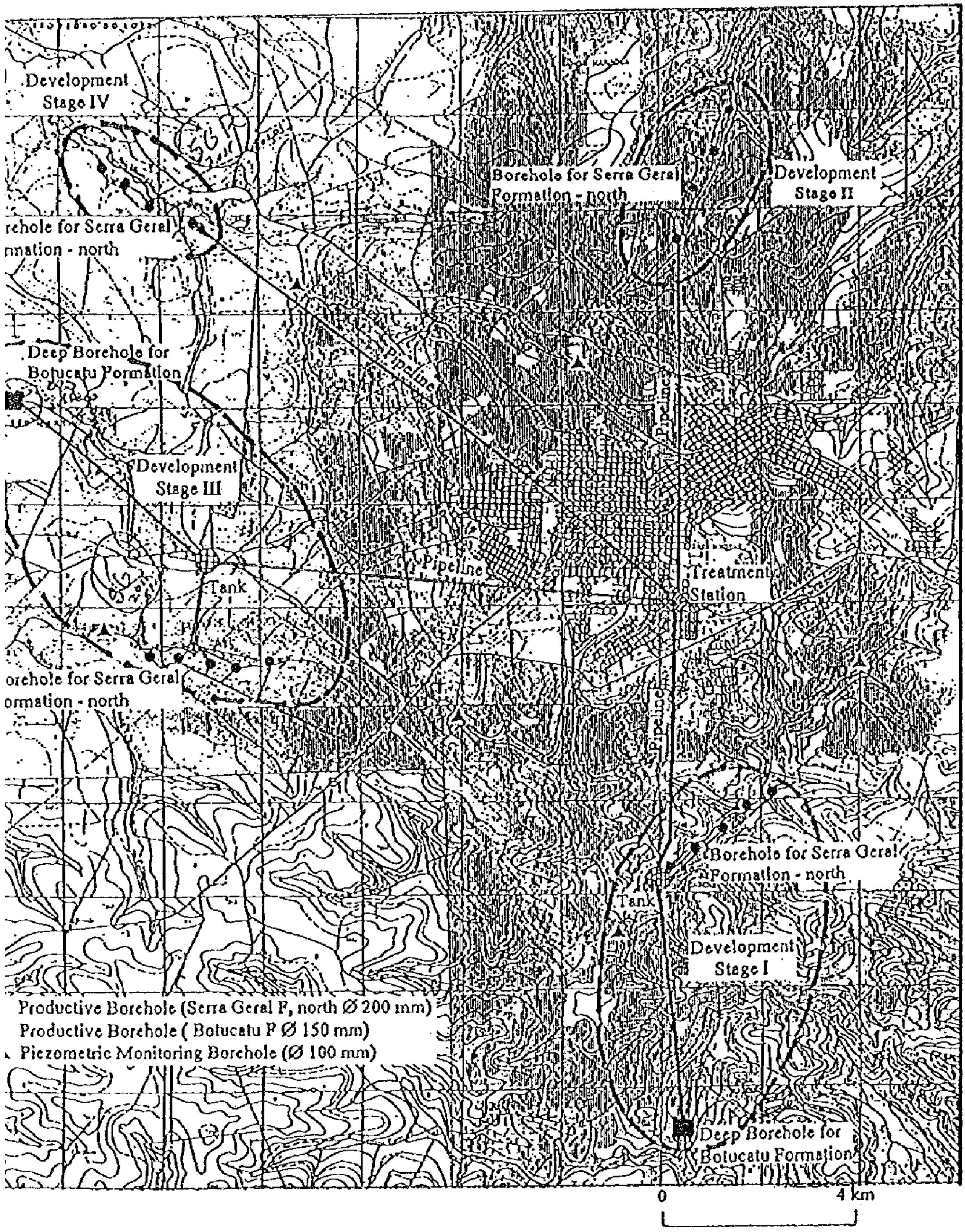


Figure-3.22 (2) Water Supply System by Groundwater in Cascavel (using stage I and II)

No. S-FII			Scale : 1 / 50,000
(Location)	X =746	Y =7185	
Basin	River	Municipality	Others
Iguacu	Itaipu Reser.	Foz do Iguacu	

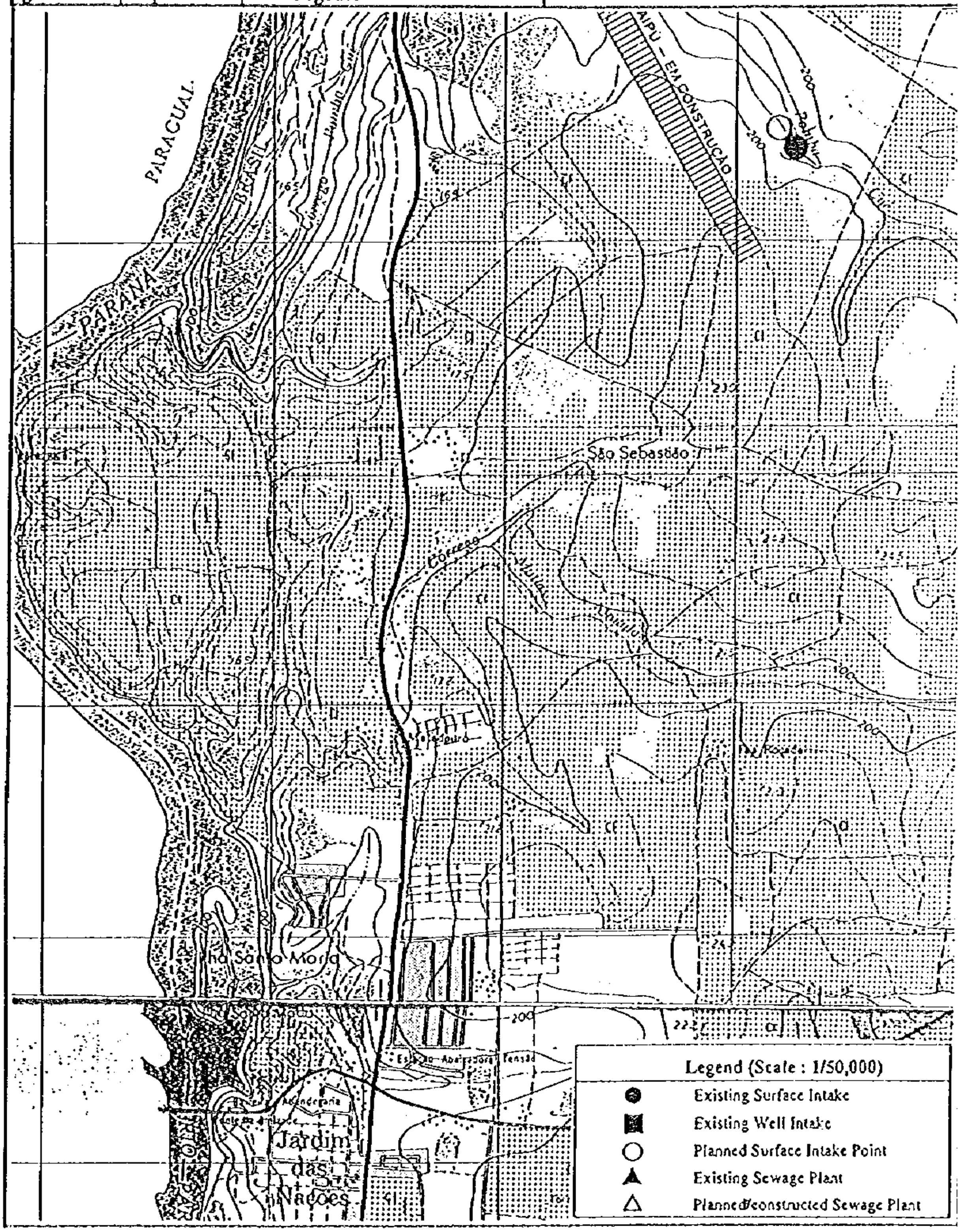


Figure-3.23 Water Supply System in Foz do Iguaçu

No. S-G1			Scale : 1 / 50,000
(Location)	X =454	Y =7186	
Basin Iguacu	River Rio Bananas	Municipality Guarapuava	Others

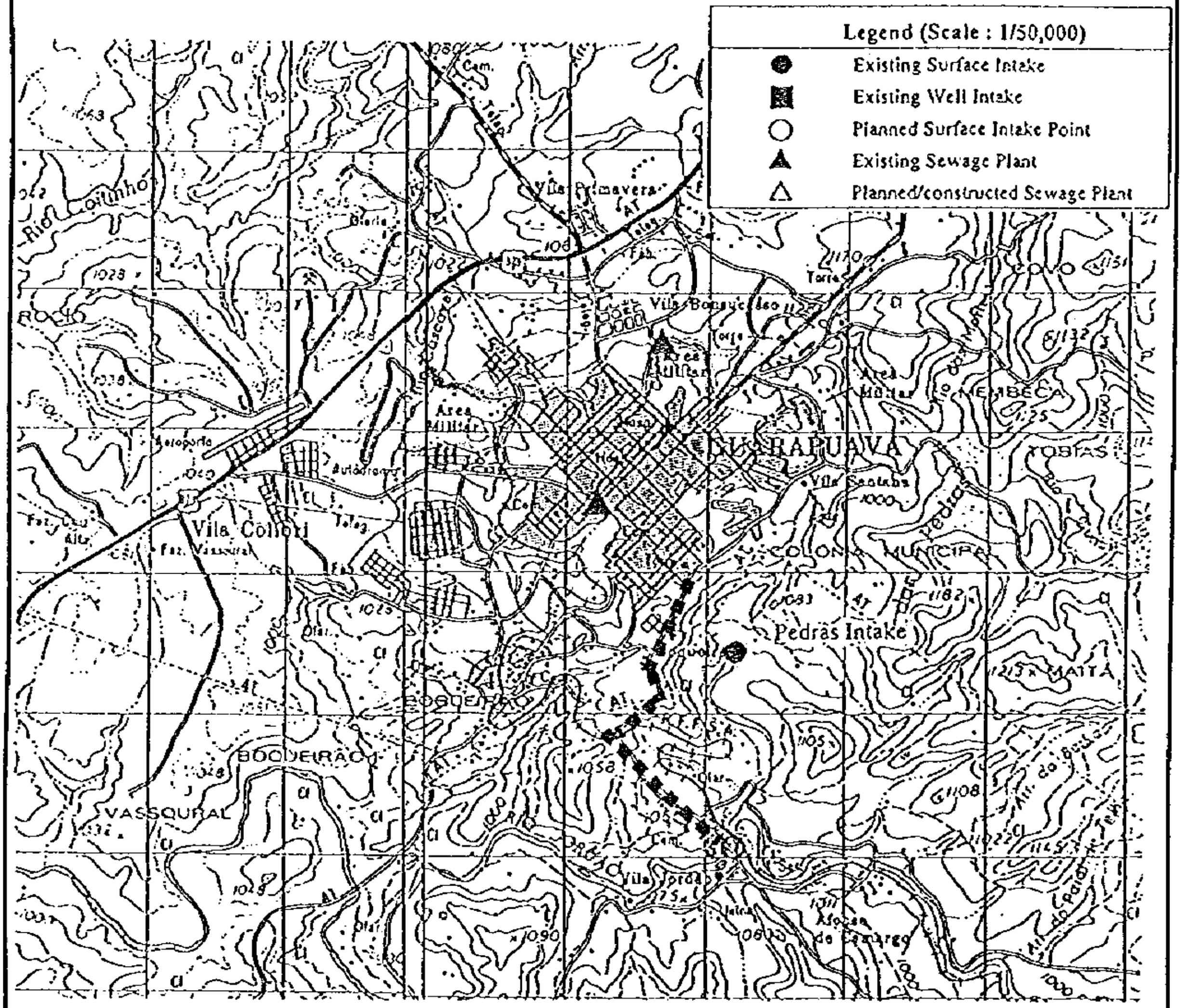


Figure-3.24 Water Supply System in Guarapuava

No.				Scale : 1 / 50,000
(Location)	X =580	Y =7216		
Basin	River	Municipality	Others	
Iguacu	Rio Tibagi	Ponta Grossa		

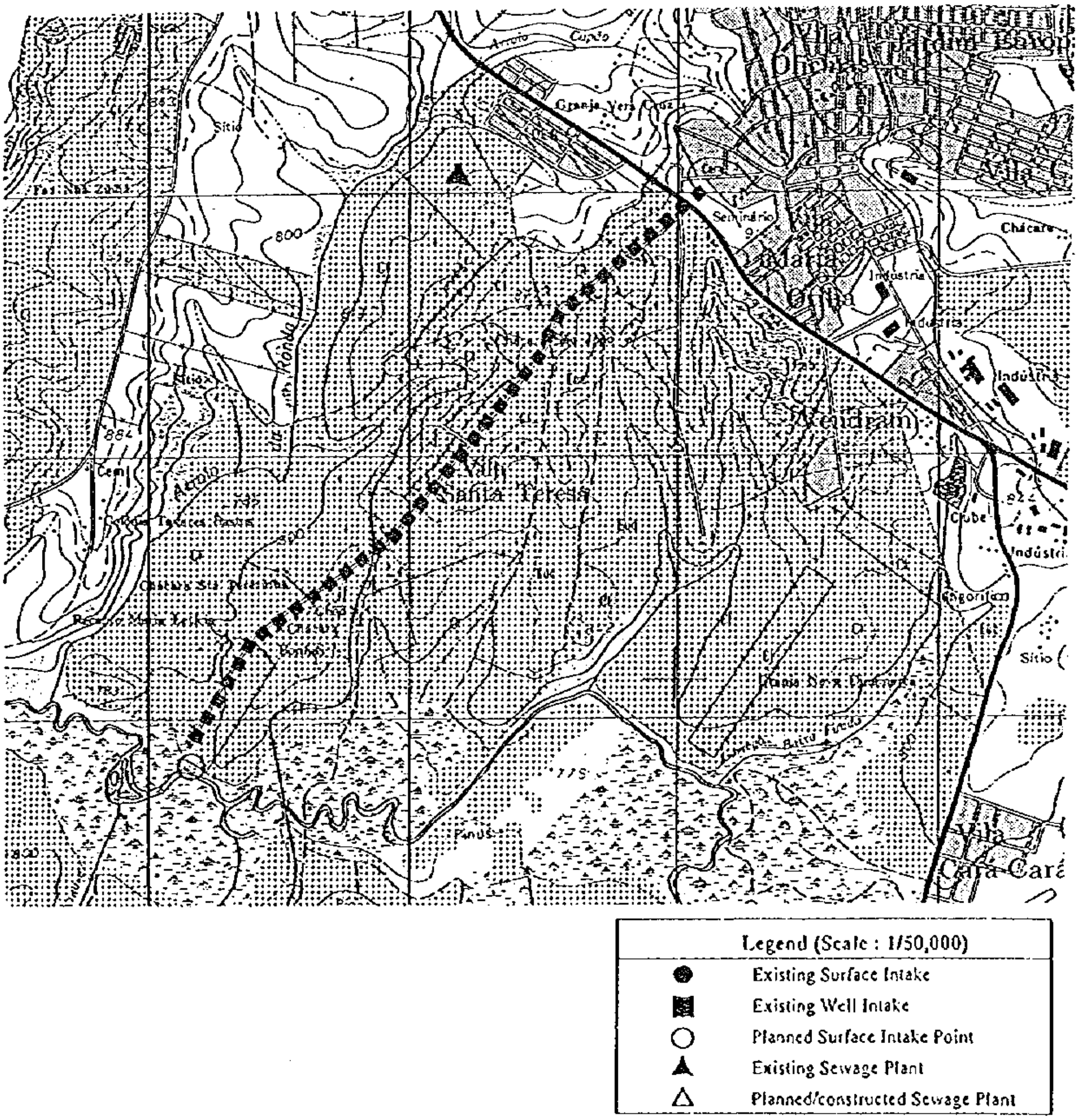


Figure-3.25 Water Supply System in Ponta Grossa

No.			Scale : 1 / 100,000
(Location) X =510	Y =7416		
Basin	River	Municipality	Others
Tibagi	Rio Tibagi	Londrina and Cambe	

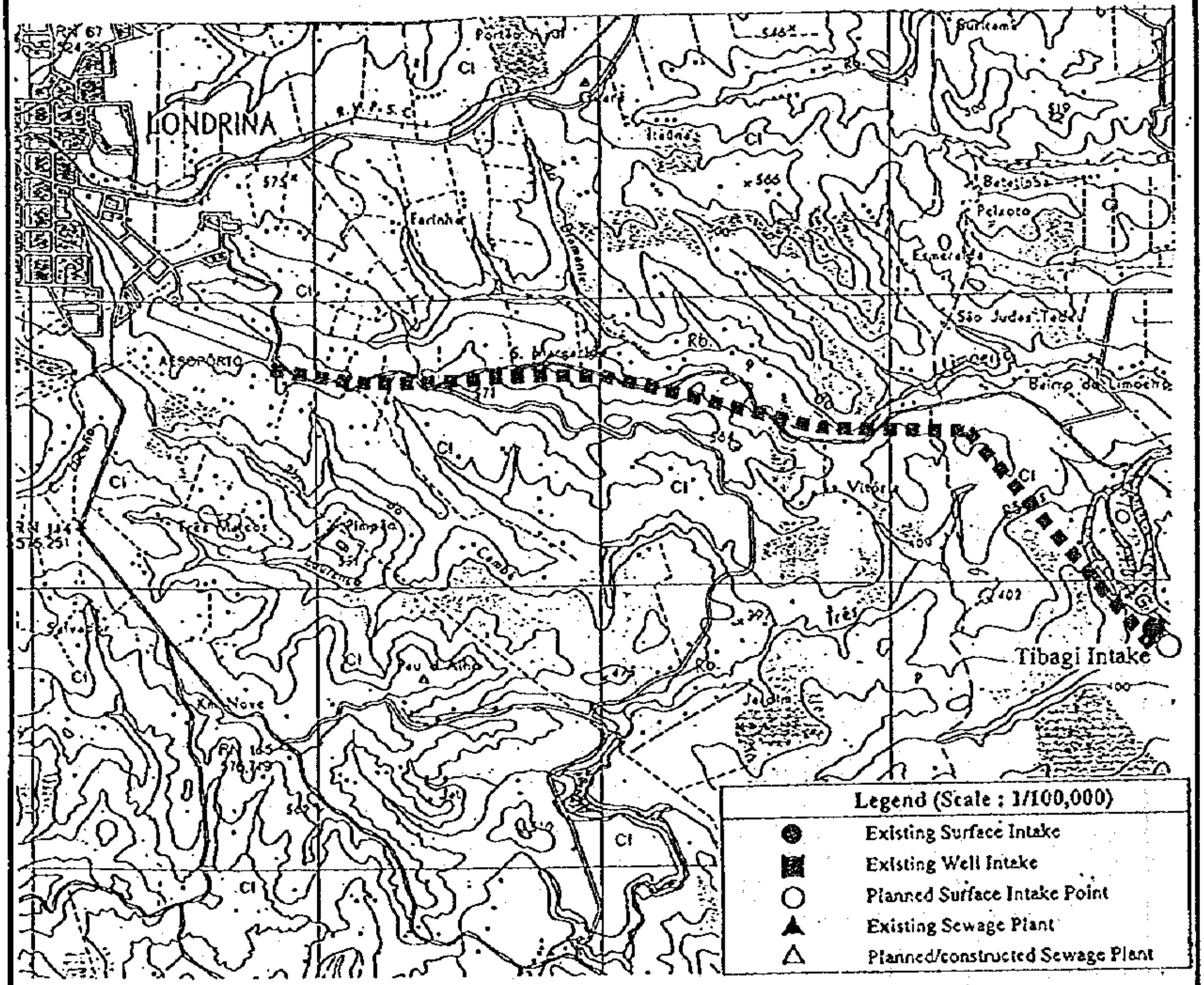


Figure-3.26 Water Supply System in Londrina and Cambe

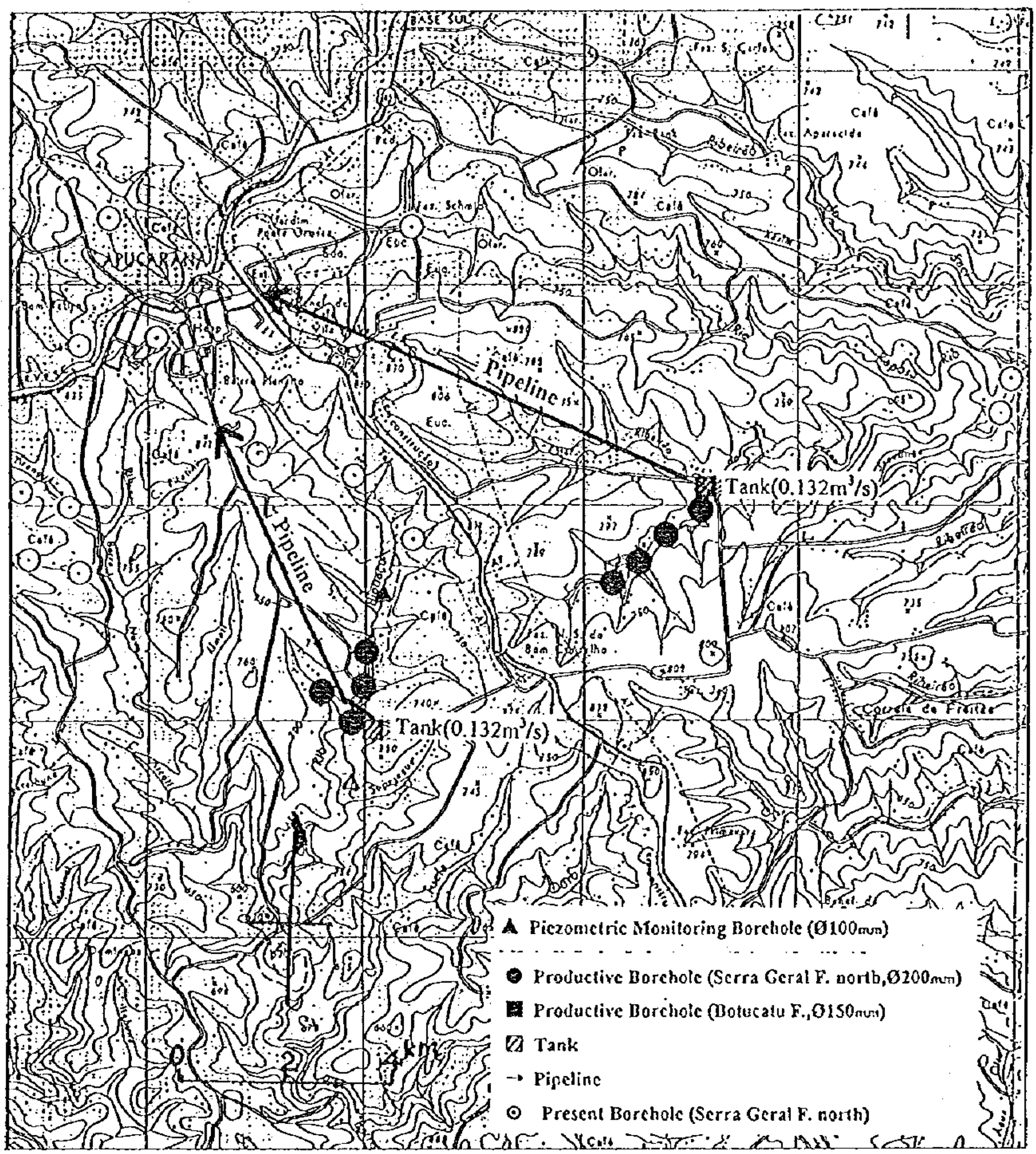


Figure-3.27 Water Supply System in Apucarana

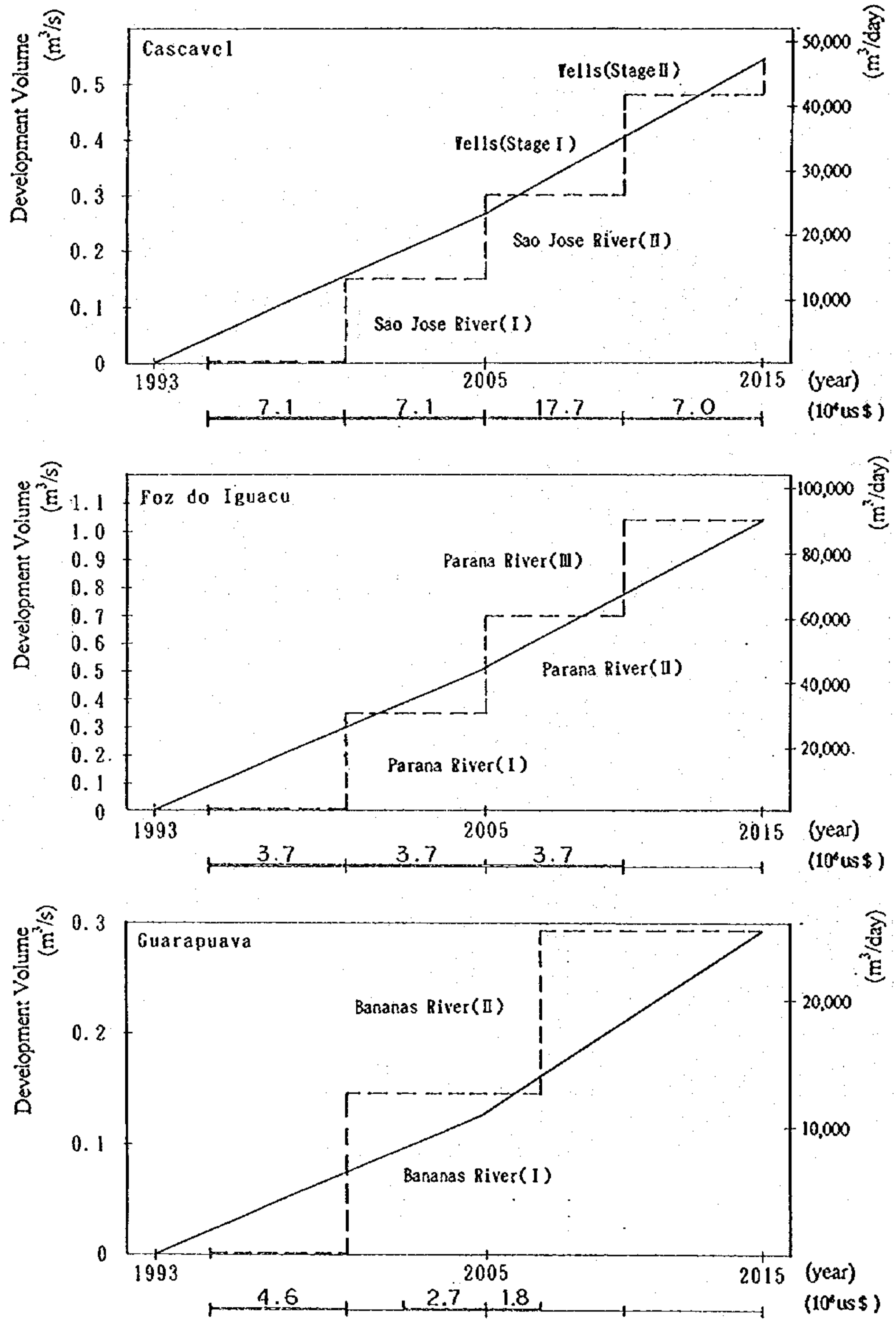


Figure-3.28 Implementation Schedule of Large Urban Area in Iguaçu River Basin

Figure-3.29 Implementation Schedule of Large Urban Area in Tibagi River Basin

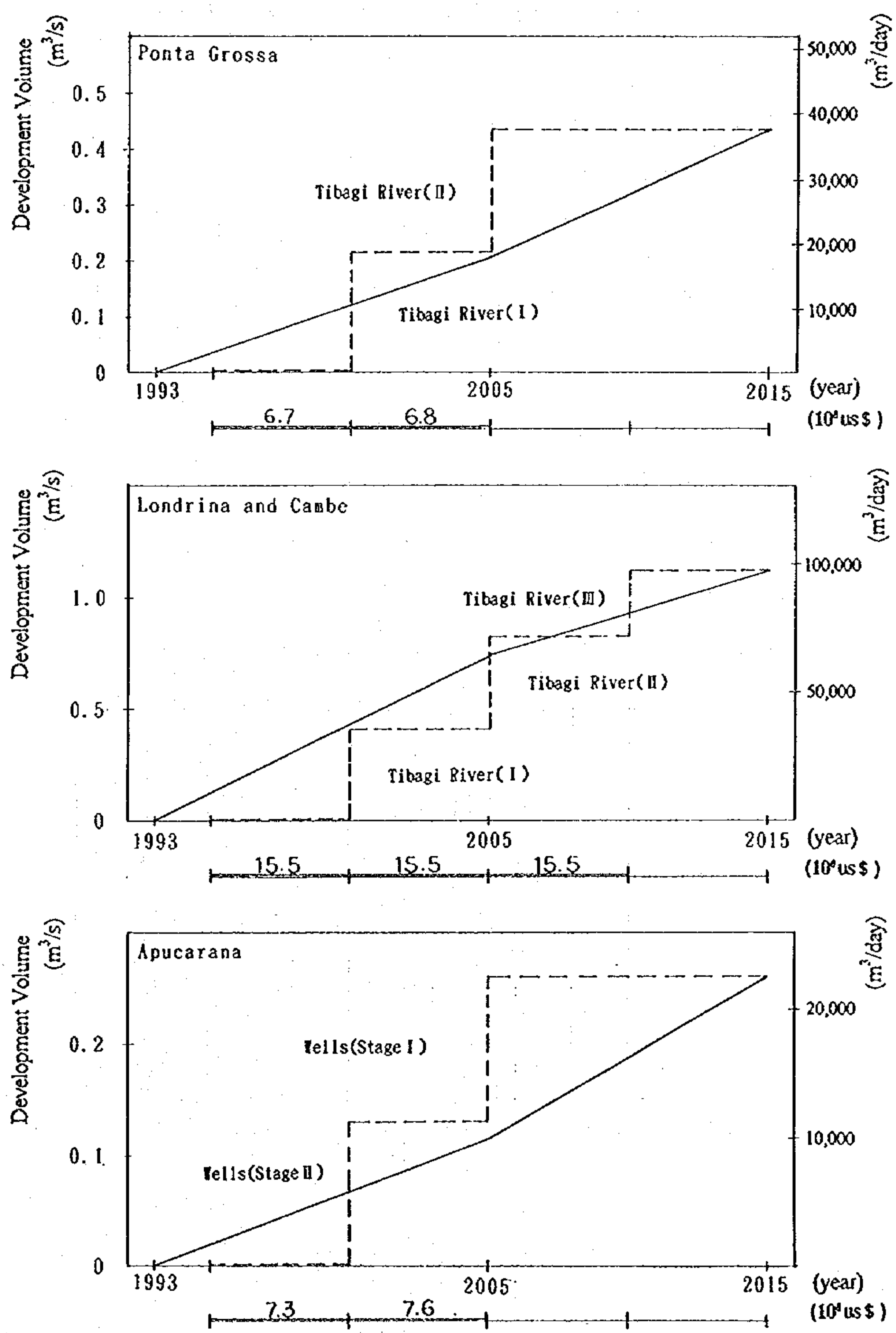


Figure-3.29 Implementation Schedule of Large Urban Area in Tibagi River Basin

3.9 Water Development in Medium Urban Areas (Type-B)

The urban areas were defined that their population will be more than approximately 50,000 in 2015. The following urban areas belong to Type-B as medium urban areas in Iguaçu river basin and Tibagi river basin.

(1) Iguaçu river basin

- Francisco Beltrao
- Pato Branco
- Medianeira
- Dois Vizinhos
- Palmas
- Uniao da Vitoria

(2) Tibagi river basin

- Castro
- Telemaco Borba
- Cornelio Procopio
- Arapongas
- Cambe (be mentioned with Londrina in sector 3.8)
- Ibipora
- Irati

3.9.1 Water Requirement

Required water supply in medium urban areas was shown in Table-3.37.

Table-3.37 Required Water Supply in Medium Urban Areas [m^3/s]

River Basin	Municipality	Year	
		2005	2015
Iguaçu	Francisco Bertrao	0.098	0.231
	Pato Branco	0.053	0.112
	Medianeira	0.038	0.066
	Dois Vizinhos	0.061	0.164
	Palmas	0.028	0.065
	Uniao da Vitoria	0.025	0.035
Tibagi	Castro	0.124	0.250
	Telemaco Borba	0.112	0.215
	Cornelio Procopio	0.027	0.069
	Arapongas	0.061	0.142
	Ibipora	0.044	0.105
	Irati	0.033	0.075

[Note] Water requirement for urban area is mainly composed of urban domestic water and industrial water.

3.9.2 Process of Water Resources Development Study

The process of water resources development in large urban areas is as shown below.

(1) In cities where main rivers are nearby and direct intake is simple, water supply shall be secured through surface water development.

(2) In cases where development by means of direct intake is difficult, careful consideration shall be given to the case of development, the development capacity and the development cost, etc. for both surface water and groundwater.

(3) Regarding the development of surface water, examination shall be made based on the topographical conditions and water resource materials.

(4) Examination shall be given to the case where the whole water supply is provided by groundwater development.

(5) Based upon the examination results of (3) and (4), the optimal development plan shall be formulated upon first giving careful consideration to the conditions stated in (2).

3.9.3 Water Resources Development Policies

Based upon consideration of the topographical conditions in Type-B cities and the surface water and groundwater conditions in the target area, the water resources development policies as shown in Table-3.38 are decided upon.

Table-3.38 (1) Water Resources Development Policies for Medium Urban Areas (Iguaçu River Basin)

City	Topographical Condition	State of Water Resources		Water Resources Development
		Surface Water	Groundwater	
Francisco Beltrao	This city is situated in the mid-stream of a tributary to the Iguaçu river and 30-40 km downstream from the mountain tops.	A river with a catchment area of 400 km^2 runs nearby the city and direct intake development is feasible.	The Serra Geral Formation south aquifer is located around the town, however, the productivity of the existing wells is low.	In view of the fact that direct intake development is easy, the development will be performed on the surface water resources.
Pato Branco	This city is situated in the upper reaches (near the mountain tops) of a tributary to the Iguaçu river.	Development through the direct intake of water from the river running nearby the town is feasible.	The Serra Geral Formation south aquifer is located around the town, and the productivity of the existing wells is high.	As the development of both surface water and groundwater is easy, the development plan will be formulated upon first examining both possibilities.
Medianeira	This city is situated on the ridge that separates the Iguaçu river and the Paraná river.	As the city is situated on a ridge, it is difficult to obtain large amounts of water from just one intake point, so intake will need to be performed at a number of locations.	Same as above	The water supply plan that combines both surface water development and groundwater development will be formulated.
Dois Vizinhos	This city is situated in the mid-stream of a tributary to the Iguaçu river. The catchment area of the nearby river is small at less than 100 km^2.	The water demand cannot be satisfied solely through the intake of water from the city's surrounding small rivers. If water was taken from Chopim river, the demand for water would be satisfied, however, the pipe line length would be 210 km.	Same as above	If taking water from Chopim river is effective, the water supply can be secured through development of surface water alone, however, if this turns out to be unrealistic a supply plan that combines both surface water development and groundwater development
Palmas	This city is situated in the upper reaches (near the mountain tops) of a tributary to the Iguaçu river.	Development through the direct intake of water from the river running nearby the city is feasible.	Same as above	As the direct intake development of surface water is easy, the river running nearby the city will be developed as the water supply source.
Uniao Vitoria	This city is situated in the mid-stream of the mainstream Iguaçu river.	The direct intake of water from the Iguaçu river mainstream is possible.	The Upper Paleozoic aquifer is located around the town, however, the productivity of existing wells is low and the permissive yield is small.	As the direct intake of surface water is easy and the nearby aquifer is not suited to groundwater development, surface water will be developed as the water supply source.

Table-3.38 (2) Water Resources Development Policies for Medium Urban Areas (Tibagi River Basin)

City	Topographical Condition	State of Water Resources		Water Resources Development Policies
		Surface Water	Groundwater	
Castro	Castro is situated in the midstream of a tributary to the Tibagi river.	A river with a catchment area of 1,000 km^2 runs nearby the city and direct intake development is possible.	The Lower Paleozoic aquifer is located around the town, however, the productivity of existing wells is low and the permissive yield is small.	As the direct intake development of surface water is easy and no suitable aquifers are located nearby, development that utilizes surface water as the supply source will be carried out.
Telemaco Borba	This city is situated in the midstream area of the mainstream Tibagi river.	The direct intake of water from Tibagi river is possible.	The Middle-Upper Paleozoic aquifer is located around the town, however, the productivity of existing wells is low and the permissive yield is small.	Same as above
Cornelio Procopio	This city is situated in the upper reaches (near the mountain tops) of a tributary to Tibagi river.	The water intake from the nearby small rivers is not enough to satisfy the total water demand. If water was taken from Congonhas river, it would be possible to meet the supply, however, the pipe line would stretch for more than 128 km.	The Serra Geral Formation north aquifer and below that the Botucatu Formation aquifer are located around the town, and the productivity levels of existing wells are relatively high.	As both surface water and groundwater development are possible, the development plan will be formed upon examining both cases.
Arapongas	Arapongas is situated on the ridge of the border between the Tibagi river and Pirapo river basins.	The amount of water that can be taken from the nearby small rivers is not enough to satisfy demand and, even if water is taken from the Pirapo river (200 km^2) more than 10 km away, the amount will still not be enough.	The Serra Geral Formation north aquifer is located around the town, and the productivity of existing wells is high.	As surface water development is difficult, either a combination of surface water development with groundwater development or groundwater development alone will be implemented.
Ibipora	Ibipora is situated in the downstream area of a tributary that runs into the lower reaches of the Tibagi river.	The amount of water that can be taken from the nearby small rivers is not enough to satisfy demand. If water is taken from Tibagi river, the required supply will be secured, however, the pipe lines will extend for approximately 10 km.	Same as above	As both surface water and groundwater development are possible, the development plan will be formed upon examining both cases.
Irati	Irati is situated in the upper reaches (near the mountain tops) of a tributary running into the upper reaches of the Tibagi river.	The amount of water that can be taken from the nearby small rivers is not enough to satisfy demand. If water is taken from Invitavinha river, the required supply will be secured, however, the pipe lines will extend for in excess of 10 km.	The Upper Paleozoic aquifer is located around the town, however, the productivity levels of existing wells is low and the permissive yield is small.	As the nearby aquifer is not suited to groundwater development, surface water shall be developed to provide the water supply.

3.9.4 Water Supply System in Medium Urban Areas

The water supply system proposed for each municipality was examined and the result is shown in Table-3.39.

Table-3.39 (1) Proposed Water Supply System in Iguaçu River Basin (Type-B)

Item		Name	Location	Possibility of Development	Catchment Area	$q_{10,7}$	Total Project cost		
				m³/s	km²	m³/s/100km²	10^6us $	10^6us $/m³/s	
Francisco	S-F₁	Rio Marnccas	Francisco	0.237	437.0	0.341	4.65	19.6	○
Beltrao	G-F₁	Stage1(S.G.F.s×5)	Francisco	0.011			5.80	527.3	
0.231m³/s	G-F₂	Stage2(B.F.×1)	Francisco	0.124			6.24	50.3	
Medianeira	S-M₁	Rio Represa Grande	Medianeira	0.013	14.2	0.026	5.38	413.8	
0.066m³/s	S-M₂	Corrego Sanga Funda	Medianeira	0.017	18.9	0.034	5.09	299.4	
	S-M₃	Corrego Solde Ouro	Medianeira	0.010	10.8	0.019	5.65	565.0	
	G-M₁	Stage1(S.G.F.s×5)	Medianeira	0.020			6.50	325.0	
	G-M₂	Stage2(B.F.×1)	Medianeira	0.124			4.30	34.7	○
Palmas	S-PA₁	Riodas Caldeiras	Palmas	0.065	83.7	0.028	4.94	76.0	○
0.065m³/s	G-PA₁	Stage1(S.G.F.s×10)	Palmas	0.033			10.12	306.7	
	G-PA₁	Stage2(S.G.F.s×10)	Palmas	0.033			11.89	360.3	
Dois Vizinhos	S-D₃	Rio Chopim	Dois Vizinhos	0.134	4,050.0	0.125	9.12	68.1	○
0.134m³/s	G-D₃	Stage1(S.G.F.s×4)	Dois Vizinhos	0.018			3.71	206.1	
	G-D₄	Stage2(S.G.F.s×3, B.F.×1)	Dois Vizinhos	0.138			10.30	74.6	
Pato Branco	S-PB₁	Rio Chopim	Pato Branco	0.112	2,816.7	0.363	9.12	81.4	○
0.112m³/s	G-PB₁	Stage1(S.G.F.s×6)	Pato Branco	0.025			8.09	325.6	
	G-PB₂	Stage2(B.F.×1)	Pato Branco	0.124			7.30	58.9	
Uniao da Vitoria	S-U₁	Iguacu	Uniao da Vitoria	0.035	24,414.0	0.273	3.71	106.0	○
0.035m³/s									

[Note] ○ is the recommended water supply system.
B.F. means Botucatu Formation aquifer.
S.G.F. s means Serra Geral Formation south aquifer.

Table-3.39 (2) Proposed Water Supply System in Tibagi River Basin (Type-B)

Item		Name	Location	Possibility of Development	Catchment Area	$q_{10,7}$	Total Project cost		
				m³/s	km²	m³/s/100km²	10^6us S	10^6us S / m³/s	
Cornelio Procopio 0.069 m³/s	S-CP₁	Congonhas	Cornelio Procopio	0.069	913.3	0.086	7.44	107.8	○
	G-CP₁	Stage1(S.G.F.n×4)	Cornelio Procopio	0.029			5.53	190.7	
	G-CP₂	Stage2(B.F.×1)	Cornelio Procopio	0.129			9.68	75.0	
Arapongas 0.142 m³/s	S-AR₁	Rio Pirapo	Arapongas	0.101	200.0	0.101	8.65	85.6	○
	G-AR₁	Stage1(S.G.F.n×5)	Arapongas	0.066			11.41	172.9	
	G-AR₂	Stage2(B.F.×1)	Arapongas	0.124			7.21	58.1	○
Ibipora 0.105 m³/s	S-IB₁	Rio Tibagi	Ibipora	0.105	21,955.0	0.091	7.44	70.9	○
	G-IB₁	Stage1(S.G.F.s×3)	Ibipora	0.050			3.97	79.4	
	G-IB₂	Stage2(S.G.F.s×3)	Ibipora	0.050			4.71	94.2	
Castro 0.250 m³/s	S-CA₁	Rio Lapo	Castro	0.250	1,183.3	0.179	5.53	22.1	○
Telemaco Borba 0.215 m³/s	S-T₁	Rio Tibagi	Telemaco Borba	0.215	13,743.0	0.252	6.77	31.5	○
Irati 0.075 m³/s	S-IR₁	Rio Imbituvinba	Irati	0.075	220.0	0.151	9.00	120.0	○

[Note] ○ is the recommended water supply system.
B.F. means Botucatu Formation aquifer.
S.G.F. n means Serra Geral Formation north aquifer.
S.G.F. s means Serra Geral Formation south aquifer.

The Water supply systems proposed for medium urban areas are shown in Table-3.40.

Table-3.40 Proposed Water Supply System

River Basin	City	Water Supply System	Constructions	Catchment Area or Well Number	Development Volume (m^3/s)	Cost (10^6US$)
Iguaçu	Francisco Beltrao	direct intake from Marrecas river	pumps, pipeline (Ø 300 x 700 m x 2)	437.0km²	0.231	4.7
	Pato Branco	direct intake from Chopim river	pump, pipeline (Ø 300 x 12,500 m)	2817.0km²	0.112	9.1
		(Alternative) Wells (Botucatu F.aquifer)	wells, pipeline (Ø 300 x 6,000 m)	1 borehole	0.124	(8.1)
	Medianeira	Wells(Botucatu F.aquifer)	well, pipeline (Ø 300 x 4,000 m)	1 borehole	0.124	4.3
	Dois Vizinhos	direct intake from Chopim river	pump, pipeline (Ø 300 x 7,500 m)	4050.0km²	0.134	9.1
		(Alternative) Wells (Serra Geral F.aquifer) and (Botucatu F.aquifer)	wells, pipeline (Ø 300 x 6,000 m)	3 boleholes 1 boleholes	0.012 0.124	(10.3)
	Palmas	direct intake from Caldeiras river	pump, pipeline (Ø 200 x 3,400 m)	83.7km²	0.065	4.9
	Uniao da Vitoria	direct intake from Iguaçu river	pump, pipeline (Ø 200 x 200 m)	24.414km²	0.035	3.7
Tibagi	Castro	direct intake from Iapo river	pumps, pipeline (Ø 300 x 1,200 m x 2)	1,183 km²	0.250	5.5
	Telemaco Borba	direct intake from Tibagi river	pumps, pipeline (Ø 300 x 2,700 m x 2)	13,743 km²	0.215	6.8
	Cornelio Procopio	direct intake from Congonhas river	pump, pipeline (Ø 300 x 8,500 m)	413.3 km²	0.069	7.4
		(Alternative) wells (Botucatu aquifer)	well, pipe line (Ø 300 x 14,000 m)	1 boreholl	(0.129)	(9.7)
	Arapongas	wells (Botucatu aquifer)	well, pipeline (Ø 400 x 9,000 m)	1 boreholl	0.124	7.2
		direct intake from Pirapo river	pump, pipeline (Ø 300 x 11,000 m)	200.0km²	0.101	8.7
	Ibipora	direct intake from Tibagi river	pump, pipelin (Ø 300 x m)	21,955 km²	0.105	7.4
		(Alternative) wells (Sella Geral F. aquifer)	wells, pipeline (Ø 200 x 3,500 m, Ø 200 x 6,000 m)	6 boreholls	(0.100)	(8.7)
	Irati	direct intake from Imbituvinha river	pump, pipeline (Ø 300 x 13,200 m)	220.0 km²	0.075	9.0

The intake point and pipelines for each city are as illustrated in Annex 6 and Annex 7.

3.9.5 Implementation Schedule of Water Development

Implementation schedule of water development is shown in Figure-3.30 and Figure-3.31.

Since the water demands of all municipalities are expected to exceed the current water supply soon, the water development is necessary to be implemented as early as possible. In the case that the development is composed of several phases, the investment can be split. On the other hand, in the case that the volume of the water development is small, the construction has to be implemented at once. The water development is assumed to be implemented with the following manner.

1) If the water development consists of surface water and groundwater, the development will be split in several phases.
2) The minimum diameter of pipeline is assumed to be Ø 200. The number of pipe lines depends on the volume of water to be developed.

   volume of water to be developed < 0.2 m^3/sec one pipe line

   volume of water to be developed ≥ 0.2m^3/sec 2 or 3 pipe lines

   Construction is composed of several phases.

As a result, in the Medium Urban Area, whose water development will be finished in the first phase, the investment will be concentrated in the first 5 years; however, this investment is small compared to the total investment of the water development in the whole river basin.

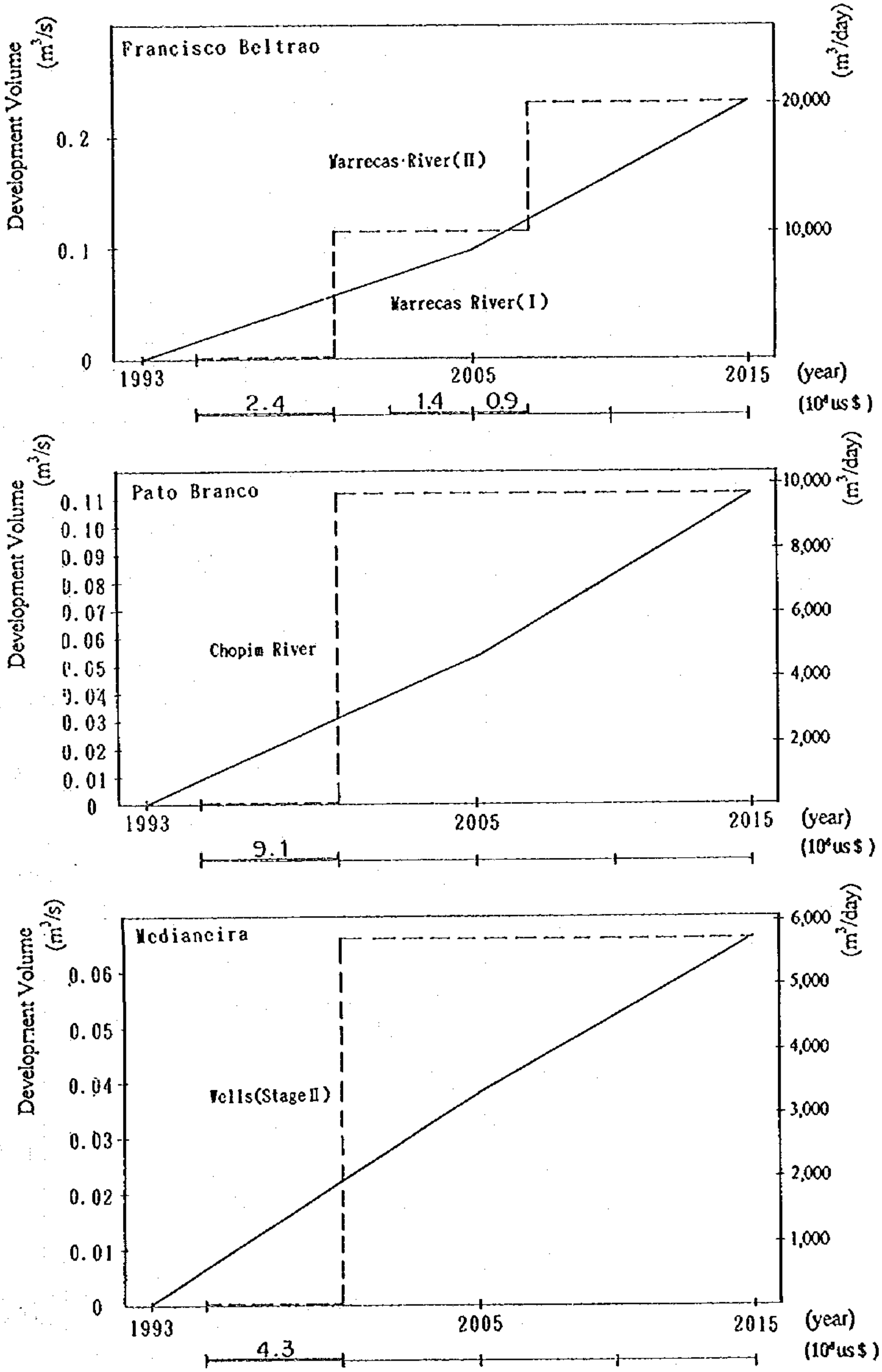


Figure-3.30 (1) Implementation Schedule of Medium Urban Area in Iguaçu River Basin

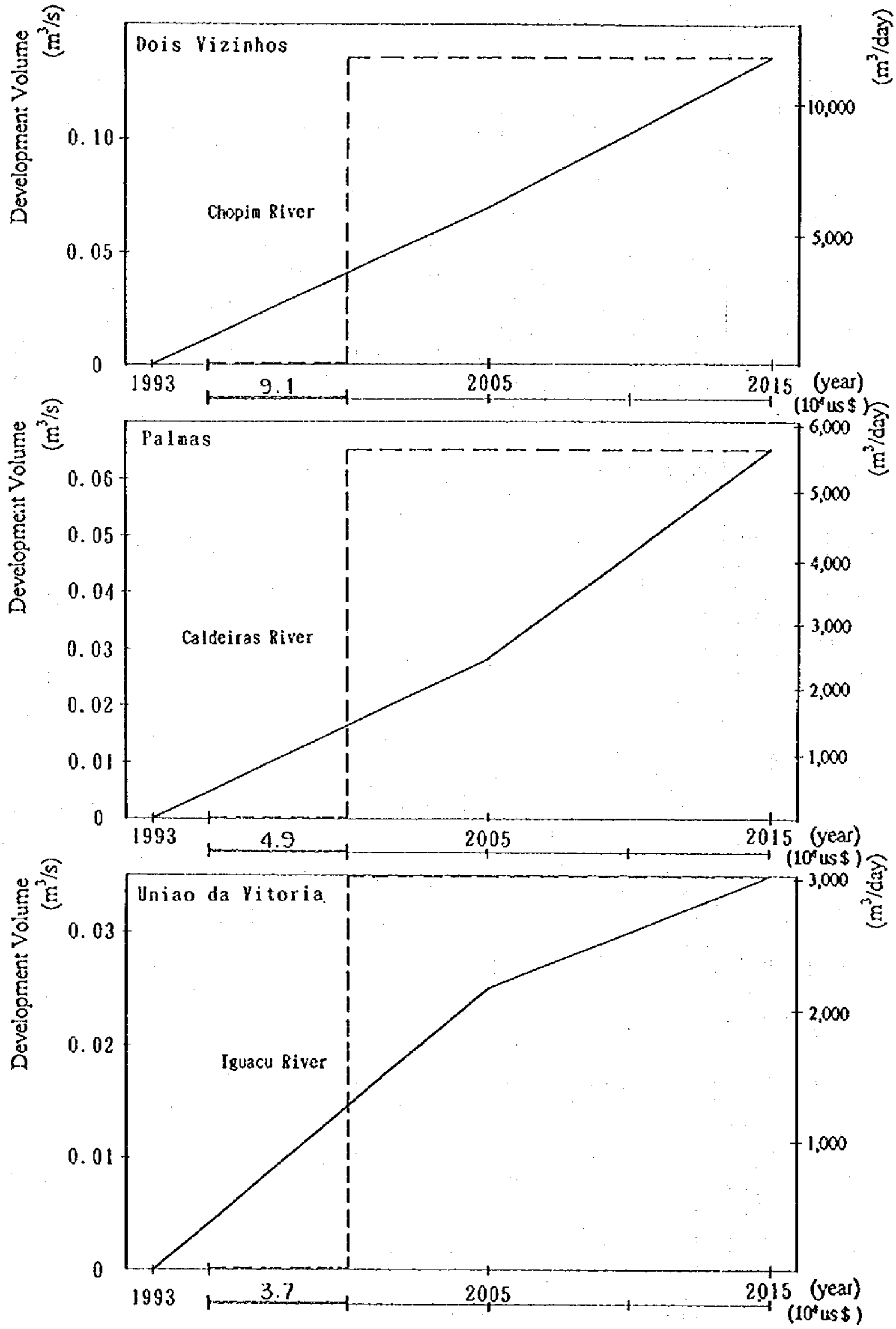


Figure-3.30 (2) Implementation Schedule of Medium Urban Area in Iguaçu River Basin

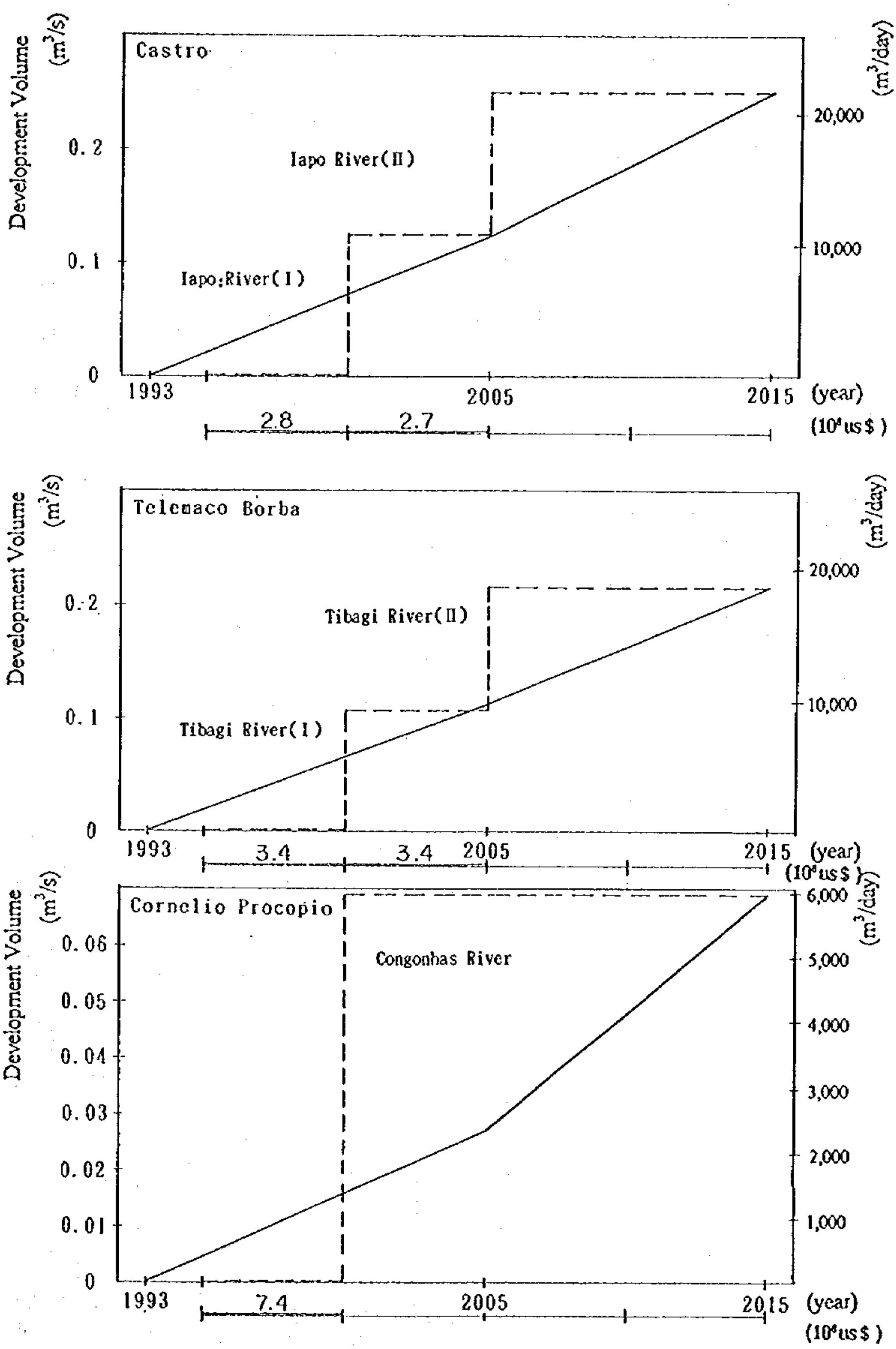
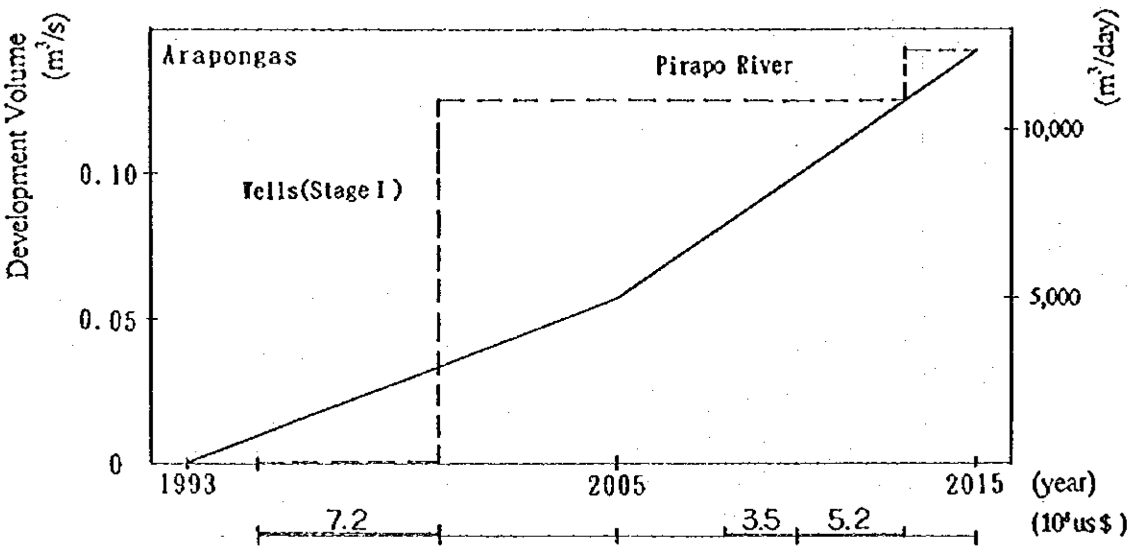
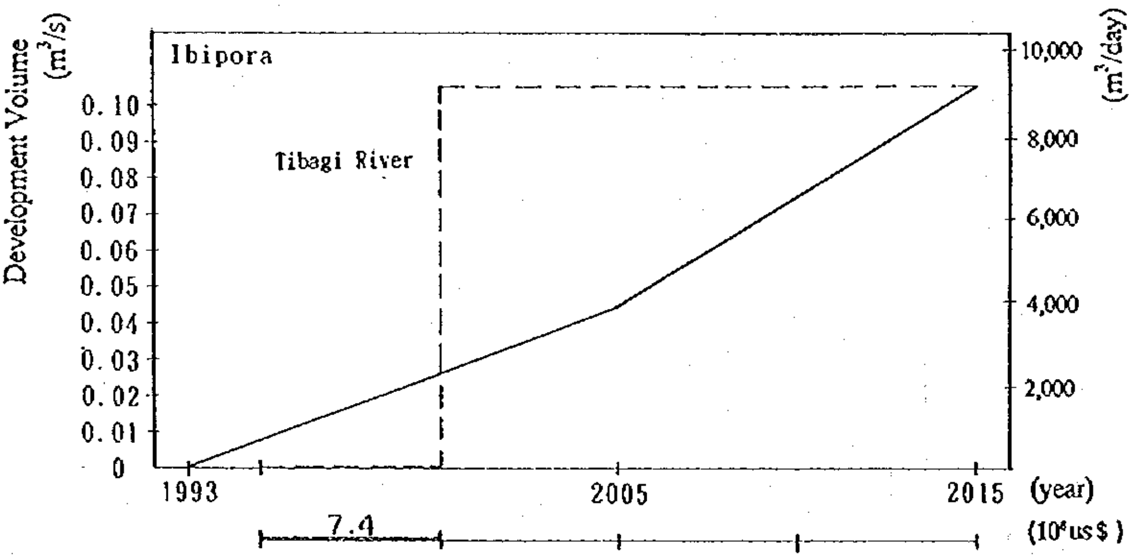


Figure-3.31 (1) Implementation Schedule of Medium Urban Area in Tibagi River Basin





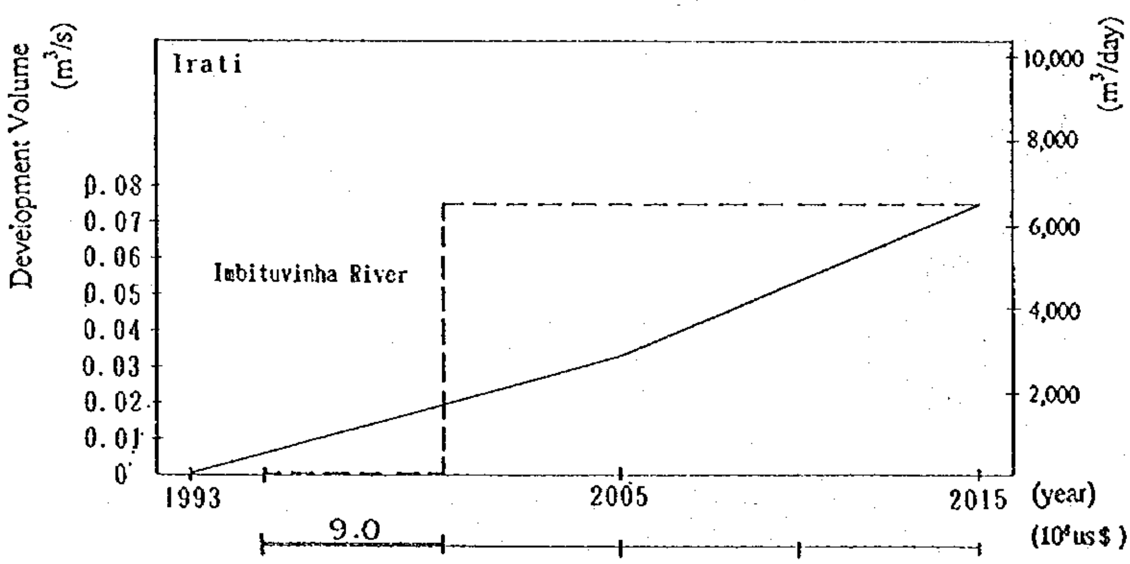


Figure-3.31 (2) Implementation Schedule of Medium Urban Area in Tibagi River Basin

3.10 Water Development in Other Urban Areas (Type-C)

Water development study of other urban areas was done for each zone as zone-a, zone-b and zone-c.

3.10.1 Water Requirement

Required water supply in other urban areas was shown in Table-3.41.

Table-3.41 Required Water Supply in Other Urban Areas (m^3/s)

	Zone	Year	
		2005	2015
Iguaçu	Zone-a	0.143	0.322
	Zone-b	0.142	0.326
	Zone-c	0.091	0.180
Tibagi	Zone-a	0.055	0.123
	Zone-b	0.056	0.119
	Zone-c	0.045	0.105

[Note] Water requirement for urban area is mainly composed of urban domestic water and industrial water.

3.10.2 Process of Water Resources Development Study

Process of water resources development in other urban areas was as shown below:

(1) Determination of water resource for each zone evaluating surface water potential and groundwater potential.

(2) Identification of the relationship between the water requirement and its development cost based on the cost estimation of several municipalities selected from each zone.

(3) Cost estimation of all municipalities applying the above relationship to the water requirement of each municipalities.

3.10.3 Water Resources Development Policies

The water resources development policies for Type-C cities, based upon consideration of the topographical conditions and surface water and groundwater conditions in each zone, are as indicated in Table-3.42.

Table-3.42 (1) Water Resources Development Policies for Other Urban Areas (Iguaçu River Basin)

City	Topographical Condition	State of WaterResources		Water Resources Development Policies
		Surface Water	Groundwater	
Zone-a	These areas are situated nearby mainstream or downstream of tributaries.	As these areas are located nearby rivers with ample catchment areas, direct intake development is easy to achieve.	Of the aquifers located within the Iquacu River basin, those suited to groundwater development are the Karst, Farnas Formation, Guabirotuba Formation, Botucatu Formation and the Serra Geral Formation north and south aquifers. Of these, the first three are located in the Curitiba metropolitan area. Regarding the supply of groundwater to Type-C cities, the Botucatu Formation and Serra Geral Formation aquifers are situated in usable locations. The former of these possesses greater productivity potential, however, deep drilling would be necessary. As the Type-C cities do not have such a high water requirement, development of the latter (Serra Geral Formation) aquifer is more appropriate.	As the direct intake development of surface water is easy, the nearby rivers will be developed as water supply sources.
Zone-b	These areas are situated of second or third tributaries	The catchment areas of the nearby rivers are too small for performing the direct intake of water. The development of surface water would be possible if the intake points are placed further downstream, although the pipe line lengths would become long.		For those cities, which are located on the Serra Geral Formation south aquifer and where the required water supply can be met by one well (0.003 m^3/s or less), groundwater will be developed in order to provide the water supply. For those cities requiring a bigger water supply or which are not located on the said aquifer, direct intake development of surface water will be implemented.
Zone-c	These areas are situated on top of ridges of mountains.	Surface water resources are not sufficient to provide the required water in those cities with a large water demand.		For those cities which are located on the Serra Geral Formation south aquifer and where the required water supply can be met by three wells (0.010 m^3/s or less), groundwater will be developed in order to provide the water supply. For those cities requiring a bigger water supply, or which are not located on the said aquifer, direct intake development of surface water will be implemented to meet the supply requirement.

Table-3.42 (2) Water Resources Development Policies for Other Urban Areas (Tibagi River Basin)

City	Topographical Condition	State of Water Resources		Water Resources Development Policies
		Surface Water	Groundwater	
Zone-a	These areas are situated nearby mainstream or downstream of tributaries.	As these areas are located nearby rivers with ample catchment areas, direct intake development is easy to achieve.	Of the aquifers located within the Tibagi river basin, those suited to groundwater development are the Farnas Formation,Botucatu Formation and the Serra Geral Formation north aquifers. Of these, the Farnas Formation aquifer is located in a narrow zone in the upper reaches of Tibagi river and does not lie close to Type-C cities. Regarding the supply of groundwater to Type-C cities, the Botucatu Formation and Serra Geral Formation aquifers, which are limited to the lower reaches of Tibagi river, can be utilized. The former of these possesses greater productivity potential, however, deep drilling would be necessary. As the Type-C cities do not have such a high water requirement, development of the latter (Serra Geral Formation) aquifer is more appropriate	As the direct intake development of surface water is easy, the nearby rivers will be developed as water supply sources.
Zone-b	These areas are situated upstream of second or third tributaries	The catchment areas of the nearby rivers are too small for performing the direct intake of water. The development of surface water would be possible if the intake points are placed further downstream, although the pipe line lengths would become long.		For those cities, which are located on the Serra Geral Formation north aquifer and where the required water supply can be met by three wells (0.033 m^3/s or less), groundwater will be developed in order to provide the water supply. For those cities requiring a bigger water supply or which are not located on the said aquifer, direct intake development of surface water will be implemented.
Zone-c	These areas are situated on top of ridges of mountains.	Surface water resources are not sufficient to provide the required water in those cities with a large water demand.		For those cities, which are located on the Serra Geral Formation north aquifer will be developed in order to provide the water supply. For those cities requiring a bigger water supply, the remaining water will be obtained from surface water development. In those cities not located on the Serra Geral Formation south aquifer, direct intake development of surface water will be implemented to meet the supply requirement.

3.10.4 Water Supply System in Other Urban Areas

Water supply system in other urban areas are shown in Table-3.42 by each zone.

For municipalities belonged to Type-C, the relationship between the development volume and cost of surface water and groundwater for each Zone (a - c) is shown in Figure-3.32. Water resources (surface water or groundwater) for each municipality are shown in Data Book.

Table-3.43 (1) Water Supply System in Other Urban Areas (Iguaçu River Basin)

Zone	Number of Municipalities	Water Supply System	Development Volume		Cost
			Surface Water (m^3/s)	Groundwater (m^3/s)	(10^6US$)
C-a	23	direct intake from river	0.322	-	9.7
C-b	22	direct intake from river	0.298	-	42.5
	16	wells	-	0.028	14.8
C-c	9	direct intake from river	0.157	-	28.4
	8	wells	-	0.023	7.5
Total			0.777	0.051	102.9

Table-3.43 (2) Water Supply System in Other Urban Areas (Tibagi River Basin)

Zone	Number of Municipalities	Water Supply System	Development Volume		Cost
			Surface Water (m^3/s)	Groundwater (m^3/s)	(10^6US$)
C-a	9	direct intake from river	0.123	-	4.0
C-b	2	direct intake from river	0.057	-	5.1
	6	wells	-	0.062	7.8
C-c	3	direct intake from river	0.034	-	8.5
	6	wells	-	0.071	7.5
Total			0.214	0.133	32.9

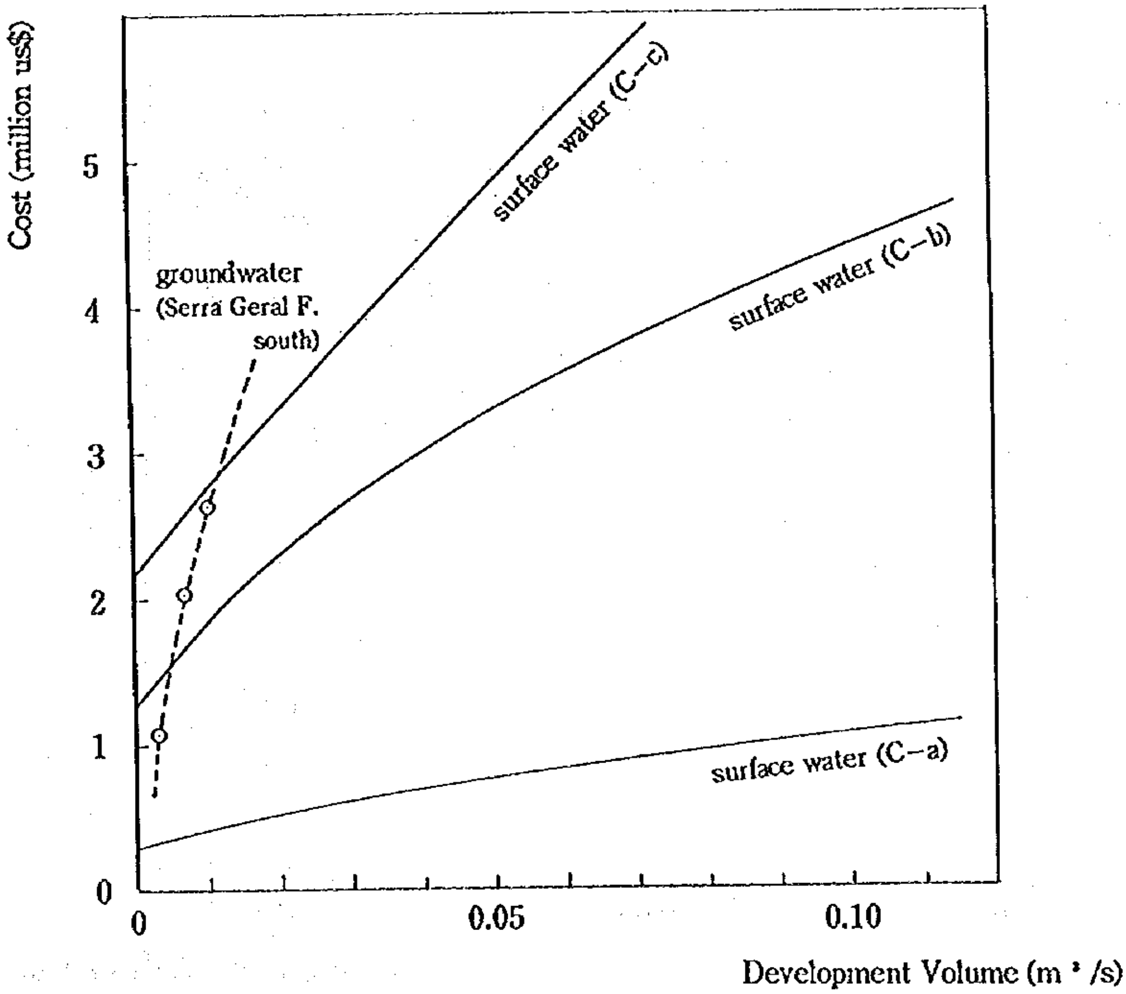


Figure-3.32 (1) Relationship between Development Volume and Cost (Iguaçu River Basin)

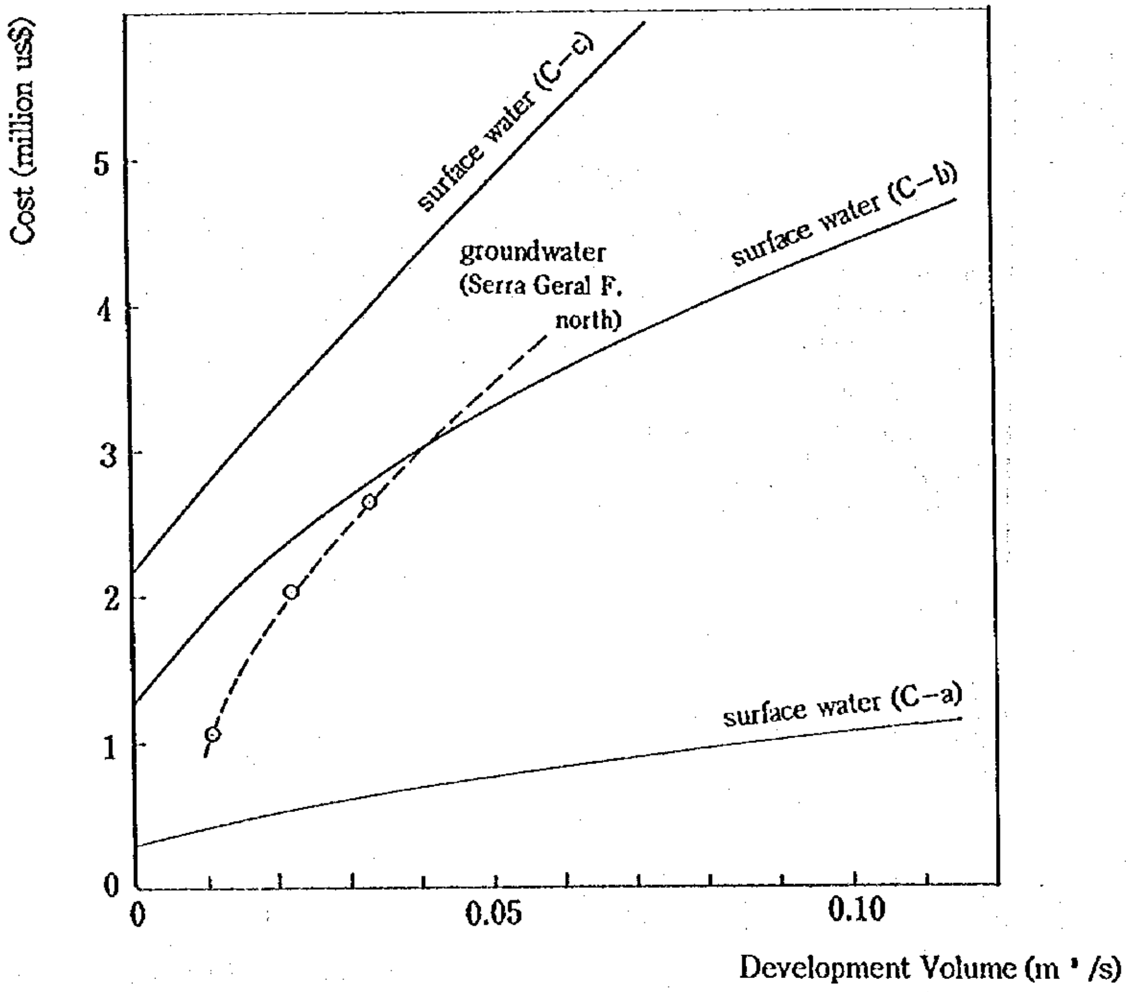


Figure-3.32 (2) Relationship between Development Volume and Cost (Tibagi River Basin)

3.10.5 Implementation Schedule of Water Development

Implementation schedule of water development is shown in Figure-3.33.

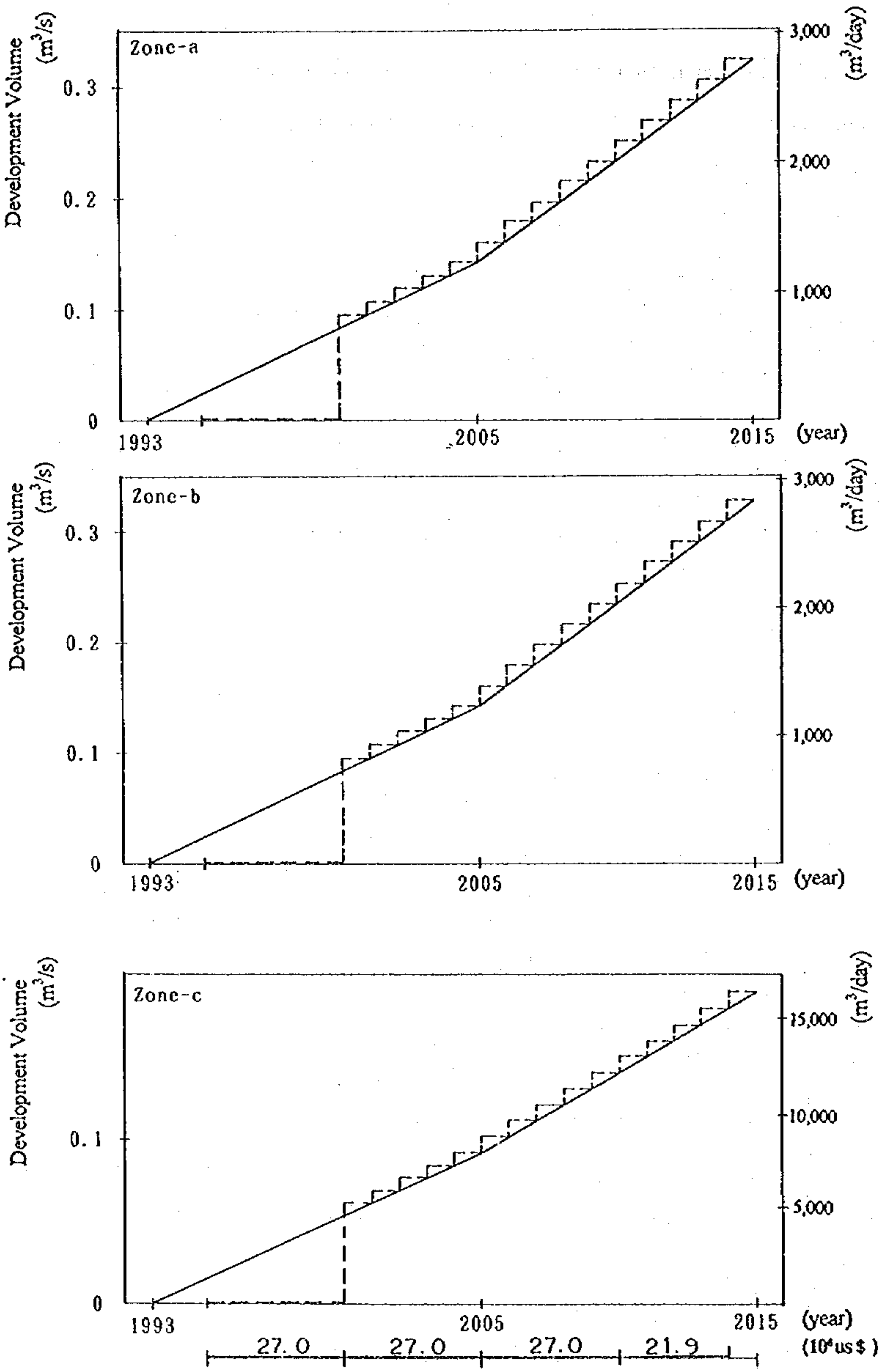


Figure-3.33 (1) Implementation Schedule of Other Urban Area in Iguaçu River Basin

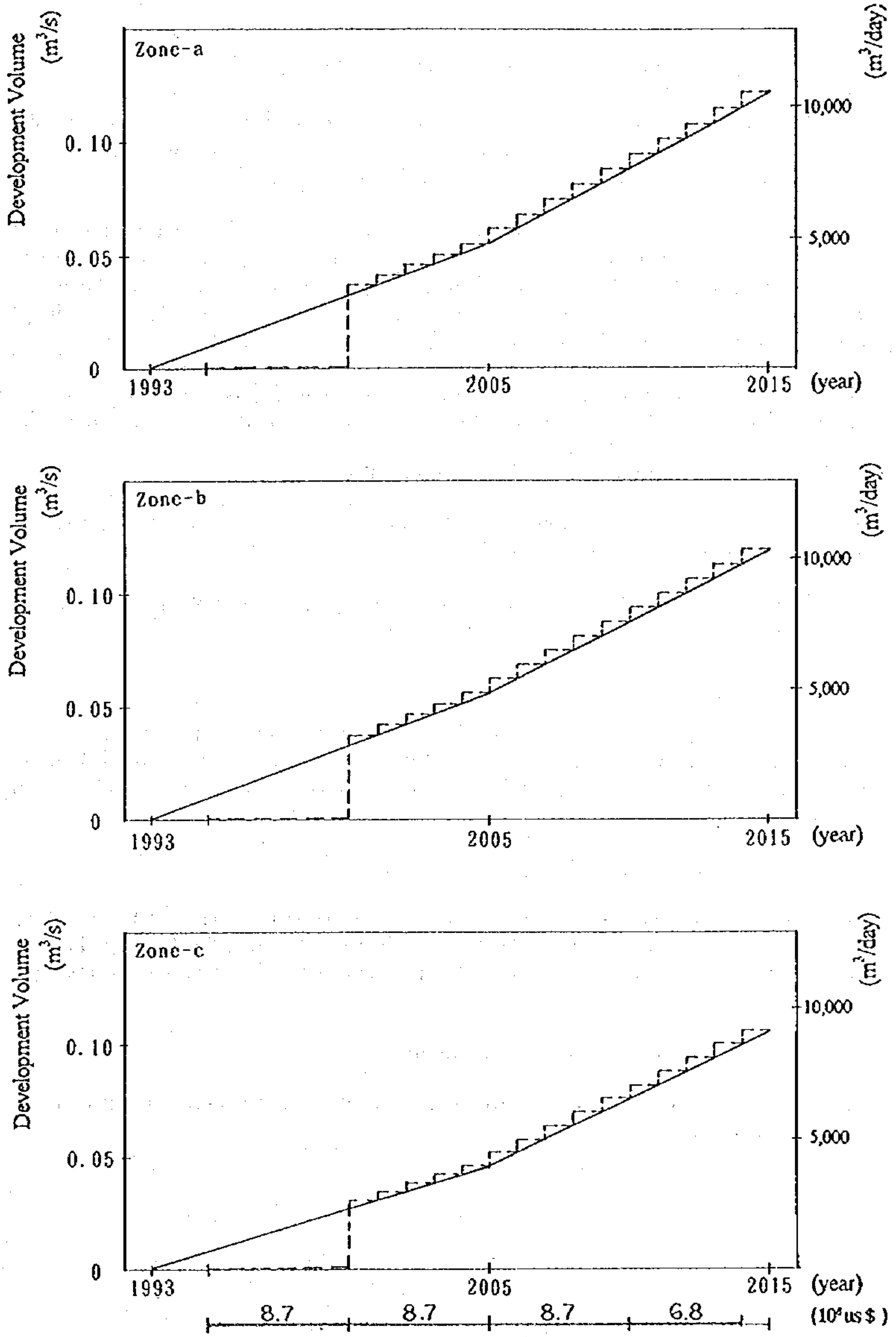


Figure-3.33 (2) Implementation Schedule of Other Urban Area in Tibagi River Basin

3.11 Water Development for Rural Domestic Water

In rural areas, it is difficult to supply the water requirement by surface water systematically, because demand of domestic water is scattered due to topographic condition. Therefore, supply for domestic water will be done by groundwater development.

The demand of domestic water in rural areas tends to decrease from the point of view of the whole Iguaçu river basin and Tibagi river basin. Although there is an increase in some municipalities if the demand is examined with municipality wise, the volume of demand is very little. The maximum volume to be newly development is about 0.004 m^3/s in Iguaçu river basin and about 0.02 m^3/s in Tibagi river basin.

As a result, the development of rural domestic water will not be necessary and only improvement or maintenance of existing wells is enough to satisfy the future water demand.

3.12 Water Development for Agricultural Water

Supply method of agricultural water at rural areas is generally a pipeline method with a direct intake using a pipeline and headworks.

According to hearing and field reconnaissance, an average of intake volume was less than 0.001 m^3/s, and average length of pipeline was 3 km.

(1) Iguaçu River Basin

The total water requirement for agricultural sector is 0.381 m^3/s. The total cost of its development was estimated applying the cost of unit water development determined during the cost estimation for large and medium urban areas and thus the total cost is US$4.6 million.

(2) Tibagi River Basin

The total water requirement for agricultural sector is 0.083m^3/s. The total cost of its development was estimated applying the cost of unit water development determined during the cost estimation for large and medium urban areas and thus the total cost is US$ 1.0 million.

3.13 Total Cost for Water Development

The total cost for water development covering from intake to water-service installation was summarized in Table-3.44.

Table-3.44 Total Cost for Water Development

River Basin	Development Volume (m^3/s)		Cost (10^6us$)
	(1) Domestic and Industrial Water Development (Urban Area)		
Iguaçu	1)Curitiba Metropolitan Area	7.235 (2.638)	760.0
	2) Large Urban Areas	1.877 (0.090)	59.1
	3) Medium Urban Areas	0.643 (0.192)	35.8
	4) Other Urban Areas	0.828 (0.243)	102.9
	Sub-total	10.583 (3.163)	957.8
	(2) Agricultural Water Development (Rural Area)		
		0.381	4.6
	Total	10.964 (3.163)	962.4
Tibagi	(1) Domestic and Industrial Water Development (Urban Area)		
	1) Large Urban Areas	1.629 (0.324)	74.9
	2) Medium Urban Areas	1.115 (0.441)	52.0
	3) Other Urban Areas	0.347 (0.102)	32.9
	Sub-total	3.091 (0.867)	159.8
	(2) Agricultural Water Development (Rural Area)		
		0.088	1.0
	Total	3.179 (0.867)	160.8

Note: ( )shows industrial water

The implementation schedule of water supply project is shown in Table-3.45.

Table-3.45 Implementation Schedule of Water Supply Project for Iguaçu River Basin

Area	Project	Water Resource	Development Volume (m3/s)	Project Cost (million us$)	Construction Schedule 96 97 98 99 00	01 02 03 04 05	06 07 08 09 10	11 12 13 14 15
<Curitiba Metropolitan Area>								
		Wells (StageI)	111,000	110.6				
		Wells (StageII)	103,000	157.9				
		Irai Dam	121,000	135.4				
		Piraquara II Dam	65,000	60.4				
		Pequeno Dam	69,000	78.5				
		Alto Miringuava Dam	52,000	96.9				
		Cotia Despique Dam	104,000	120.3				
(5 year Progress Rate)			625,000	760.0	215.9 [29%]	207.2 [27%]	222.4 [29%]	114.5 [15%]
<Large Urban Area>								
	Cascavel	Sao Jose River (I)	13,000	7.1				
		Sao Jose River (II)	13,000	7.1				
		Wells (StageI)	16,000	17.7				
		Wells (StageII)	10,000	7.0				
	Foz do Iguacu	Parana River (I)	30,000	3.7				
		Parana River (II)	30,000	3.7				
		Parana River (III)	30,000	3.7				
	Guarapuava	Bananas River (I)	13,000	4.6				
		Bananas River (II)	12,000	4.5				
(5 year Progress Rate)			167,000	59.1	15.4 [26%]	13.5 [23%]	23.2 [39%]	7.0 [12%]
<Medium Urban Area>								
	Francisco Beltrao	Marrecas River (I)	10,000	2.4				
		Marrecas River (II)	10,000	2.3				
	Pato Branco	Chopim River	10,000	9.1				
	Medianeira	Wells (Stage II)	11,000	4.3				
	Dois Vizinhos	Chopim River	12,000	9.1				
	Palmas	Caldeiras River	6,000	4.9				
	Uniao da Vitoria	Iguacu River	3,000	3.7				
(5 year Progress Rate)			62,000	35.8	33.5 [94%]	1.4 [4%]	0.9 [2%]	0 [0%]
<Other Urban Area>		Surfacewater & Wells						
(5 year Progress Rate)			72,000	102.9	27.0 [26%]	27.0 [26%]	27.0 [26%]	21.9 [22%]
<Agricultural Water>		Surfacewater						
(5 year Progress Rate)			33,000	4.6	1.1 [24%]	1.2 [26%]	1.1 [24%]	1.2 [26%]
Total			959,000	962.4	292.9 [31%]	250.3 [26%]	274.6 [28%]	144.6 [15%]

Table-3.46 Implementation Schedule of Water Supply Project for Tibagi River Basin

Area	Project	Water Resource	Development Volume (m3/s)	Project Cost (million us$)	Construction Schedule 96–00	01–05	06–10	11–15
<Large Urban Area>								
	Ponta Grossa	Tibagi River (I)	18,000	6.7				
		Tibagi River (II)	19,000	6.8				
	Londrina & Canbe	Tibagi River (I)	35,000	15.5				
		Tibagi River (II)	35,000	15.5				
		Tibagi River (III)	36,000	15.5				
	Apucarana	Wells (Stage II)	22,000	7.3				
		Wells (Stage I)	23,000	7.6				
	(5 year Progress Rate)		188,000	74.9	29.5 [39%]	29.9 [40%]	15.5 [21%]	0 [0%]
<Medium Urban Area>								
	Castro	Iapo River (I)	11,000	2.8				
		Iapo River (II)	11,000	2.7				
	Telemaco Borba	Tibagi River (I)	9,000	3.4				
		Tibagi River (II)	9,000	3.4				
	Cornelio Procopio	Congonhas River	6,000	7.4				
	Arapongas	Wells (Stage I)	11,000	7.2				
		Pirapo River	9,000	8.7				
	Ibipora	Tibagi River	9,000	7.4				
	Irati	Imbituvinha River	6,000	9.0				
	(5 year Progress Rate)		81,000	52.0	37.2 [71%]	6.1 [12%]	3.5 [7%]	5.2 [10%]
<Other Urban Area>		Surfacewater & Wells						
	(5 year Progress Rate)		30,000	32.9	8.7 [26%]	8.7 [26%]	8.7 [26%]	6.8 [22%]
<Agricultural Water>		Surfacewater						
	(5 year Progress Rate)		8,000	1.0	0.2 [20%]	0.3 [30%]	0.2 [20%]	0.3 [30%]
Total			307,000	160.8	75.6 [47%]	45.0 [28%]	27.9 [17%]	12.3 [8%]

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