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 B

METEOROLOGY, HYDROLOGY AND SURFACE WATER RESOURCES

December, 1995

Yachiyo Engineering Co., Ltd.
Tokyo, Japan

and

Nippon Koei Co., Ltd.
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COMPOSITION OF FINAL REPORT

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THE MASTER PLAN STUDY ON
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List of Abbreviation

CEHPAR : Center of Hydraulics and Hydrology, Professor Parigot de Souza
Centro and Hidraulica e Hodrologia Professor Parigot de Souza

CONAMA : National Envirnmental Council
Conselho Nacional do Meio Ambiente

COPEL : Energy Company of the State of Parana
Companhia Pananaense de Energia

DEFAM : Department of Diffusion of Environmental Information
Departamento Difusao Informacoes Ambien

DELAM : Department of Environmental Statistics
Departamento Estatistica Ambiental

DIFLA : Directorate of Inspection and Licensing
Diretoria Fiscalizacao Licenciamento

DNAEE : National Department of Water and Electric Energy
Departamento Nacional de Águas e Energia Elétrica

EMATER : Parana State Technical Assistance and Rural Extension Company
Empresa Paranaense de Assistência Técnica e Extensão Rural

FAO : Food and Agriculture Organizationulture Organization
Fundo das Nações Unidas para Aliment

IAP : Environmental Institute of Parana
Instituto Ambiental do Paraná

JICA : Japan International Cooperation Agency
Agência de Cooperação Internacional do Japão

SANEPAR : Sanitation Company of the State of Parana
Companhia de Saneamento do Paraná

CHAPTER 1 METEOROLOGICAL ANALYSIS

1.1 Data Collection

In the Study Area, there are 51 main meteorological stations and 844 rain-gauge stations (as of March, 1995). The Team selected 33 meteorological stations (See Figure-1.1), and additional three rainfall stations by considering their data availability as listed in Table-1.1 and collected data at all selected stations.

According to accuracy and availability of observed data, simulation period adapted for the last 20 years (1974-1993).

1.2 Results of Analysis

1.2.1 General Meteorological Condition

The climate and meteorological conditions of a region are mainly determined by atmospheric circulation that acts on the various scales where the region is inserted. The south of Brazil as a result of localization in the middle latitudes, is subject to the following basic atmospheric actions; (Source : Sugai et al, 1993)

- the Subtropical anticyclone of the South Atlantic
- the Migratory Polar Anticyclone
- the Chaco Center of Low Pressure
- the Amazon Tropical High Pressure
- the Pacific Anticyclone

Along the year, these centers of atmospheric action change position and vary their intensities, and they cause the so called air mass. These air masses have almost uniform physical properties at the same level, such as temperature ,humidity, air pressure and wind, and can be classified as tropical and polar and subclassified as continental and maritime. The influence of air masses in Parana state is characterized as follows;

<From October to March>

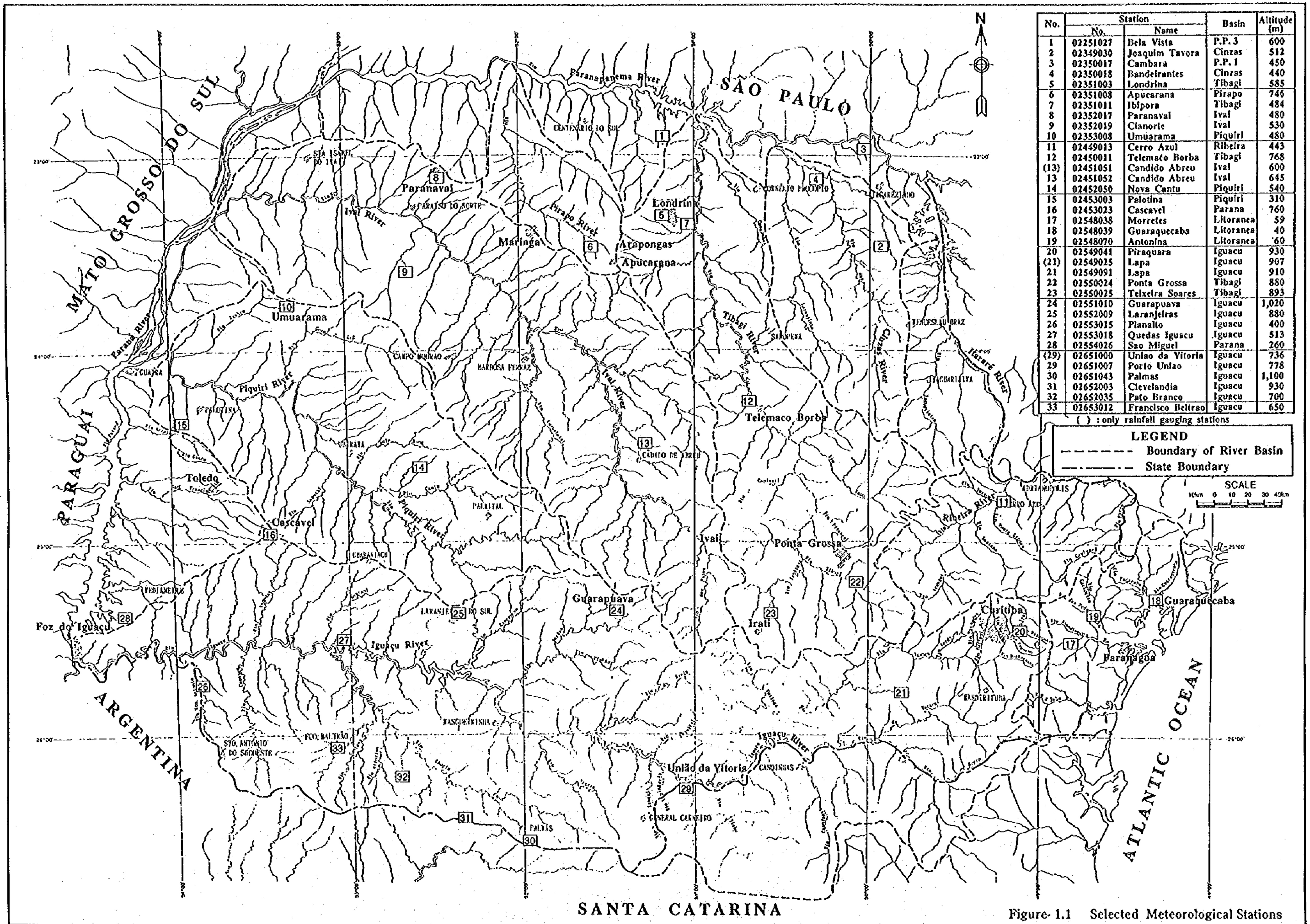
A predominance of the Atlantic Tropical air mass of low pressure occurs in the direction of the south of Brazil bringing good dry weather with few clouds.

<From April to September>

An Atlantic Polar air mass occurs more intense in this period, and infiltration occurs north provoking good weather and few clouds, as well as cold nights and droughts.

<Whole Season>

When the tropical air mass goes over the polar one, there are the formation of warm fronts and shorter duration rainfall. When the opposite occurs, there is a formation of cold fronts which provoke instability of great extension and long duration rains, it is called frontal rains.



No.	Station		Basin	Altitude (m)
	No.	Name		
1	02251027	Bela Vista	P.P. 3	600
2	02349030	Joaquim Tavora	Cinzas	512
3	02350017	Cambara	P.P. 1	450
4	02350018	Bandeirantes	Cinzas	440
5	02351003	Londrina	Tibagi	585
6	02351008	Apucarana	Pirapo	746
7	02351011	Ibipora	Tibagi	484
8	02352017	Paranavai	Ival	480
9	02352019	Cianorte	Ival	530
10	02353008	Umuarama	Piquiri	480
11	02449013	Cerro Azul	Ribeira	443
12	02450011	Telemaco Borba	Tibagi	768
(13)	02451051	Candido Abreu	Ival	600
13	02451052	Candido Abreu	Ival	645
14	02452050	Nova Cantu	Piquiri	540
15	02453003	Palotina	Piquiri	310
16	02453023	Cascavel	Parana	760
17	02548038	Morretes	Litoranea	59
18	02548039	Guaraquecaba	Litoranea	40
19	02548070	Antonina	Litoranea	60
20	02549041	Piraquara	Iguacu	930
(21)	02549025	Lapa	Iguacu	907
21	02549091	Lapa	Iguacu	910
22	02550024	Ponta Grossa	Tibagi	880
23	02550025	Teixeira Soares	Tibagi	893
24	02551010	Guarapuava	Iguacu	1,020
25	02552009	Laranjeiras	Iguacu	880
26	02553015	Planalto	Iguacu	400
27	02553018	Quedas Iguacu	Iguacu	513
28	02554026	Sao Miguel	Parana	260
(29)	02651000	Uniao da Vitoria	Iguacu	736
29	02651007	Porto Uniao	Iguacu	778
30	02651043	Palmas	Iguacu	1,100
31	02652003	Clevelandia	Iguacu	930
32	02652035	Pato Branco	Iguacu	700
33	02653012	Francisco Beltrao	Iguacu	650

( ) : only rainfall gauging stations

LEGEND

- - - - - - - Boundary of River Basin

—·——·— State Boundary

Figure- 1.1 Selected Meteorological Stations

Table-1.1 Meteorological Data Availability

Station			Basin	Location			Data Availability Year																																												
	No.	Name		Lat.	Log.	Altitude	'50					'55					'60					'65					'70					'75					'80					'85					'90			
1	02251027	Bela Vista	P.P.3	22°57'S	51°12'W	600																						O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
2	02349030	Joaquim Tavora	Cinzas	23°30'S	49°57'W	512																						O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
3	02350017	Cambara	P.P.1	23°00'S	50°02'W	450								O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
4	02350018	Bandeirantes	Cinzas	23°06'S	50°21'W	440																									O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
5	02351003	Londrina	Tibagi	23°22'S	51°10'W	585																											O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
6	02351008	Apucarana	Pirapo	23°30'S	51°32'W	746																				O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
7	02351011	Ibipora	Tibagi	23°16'S	51°01'W	484																						O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
8	02352017	Paranavai	Ivai	23°05'S	52°26'W	480																									O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
9	02352019	Cianorte	Ivai	23°40'S	52°35'W	530																						O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
10	02353008	Umuarama	Piquiri	23°44'S	53°17'W	480																						O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
11	02449013	Cerro Azul	Ribeira	24°49'S	49°15'W	443																							O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
12	02450011	Telemaco Borba	Tibagi	24°20'S	50°37'W	768																						O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
(13)	02451051	Candido Abreu	Ivai	24°34'S	51°19'W	600																																							O	O	O	O	O	O
13	02451052	Candido Abreu	Ivai	24°33'S	51°15'W	645																																							O	O	O	O	O	O
14	02452050	Nova Cantu	Piquiri	24°40'S	52°34'W	540																											O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
15	02453003	Palotina	Piquiri	24°18'S	53°55'W	310																							O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
16	02453023	Cascavel	Parana 3	24°56'S	53°26'W	760																							O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
17	02548038	Morretes	Litoranea	25°30'S	48°49'W	59																					O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
18	02548039	Guaraquecaba	Litoranea	25°16'S	48°32'W	40																												O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
19	02548070	Antonina	Litoranea	25°13'S	48°48'W	60																												O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
20	02549041	Piraquara	Iguacu	25°25'S	49°08'W	930																					O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
(21)	02549025	Lapa	Iguacu	25°47'S	49°43'S	907																																							O	O	O	O	O	O
21	02549091	Lapa	Iguacu	25°47'S	49°46'S	910																																							O	O	O	O	O	O
22	02550024	Ponta Grossa	Tibagi	25°13'S	50°01'W	880					O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
23	02550025	Teixeira Soares	Tibagi	25°27'S	50°35'W	893														O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
24	02551010	Guarapuava	Iguacu	25°21'S	51°30'W	1,020																								O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
25	02552009	Laranjeiras	Iguacu	25°25'S	52°25'W	880																								O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
26	02553015	Planalto	Iguacu	25°42'S	53°47'W	400																								O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
27	02553018	Quedas Iguacu	Iguacu	25°31'S	53°01'W	513																							O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
28	02554026	Sao Miguel	Parana 3	25°26'S	54°22'W	260																																	O	O	O	O	O	O	O	O	O	O	O	O
(29)	02651000	Uniao da Vitoria	Iguacu	26°14'S	51°04'W	736												O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O														
29	02651007	Porto Uniao	Iguacu	26°13'S	51°04'W	778																								O	O	O	O	O	O															
30	02651043	Palmas	Iguacu	26°29'S	51°59'W	1,100																														O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
31	02652003	Clevelandia	Iguacu	26°25'S	52°21'W	930																							O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
32	02652035	Pato Branco	Iguacu	26°07'S	52°41'W	700																														O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
33	02653012	Francisco Beltrao	Iguacu	26°05'S	53°04'W	650																								O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O

(Note) O : Data is available, (...) : only rainfall data was used.

1.2.2 Rainfall

The rainfall data in Parana has been measured with different agencies and different observation periods by stations. At present, about 900 rain gauge stations are registered.

(1) Monthly Rainfall Distribution

The last 20 years mean monthly rainfall data was summarized as shown in both Table-1.2 and Figure-1.2. The missing monthly rainfall data were determined by applying the correlation equations by station (refer to the section 1.2.9).

Seasonal variations of monthly totals are similar in different parts of the Parana. Fluctuation of monthly rainfall by regions are summarized as follows;

Two different fluctuation pattern exists between Litoranea and Northern region, Southern region. Litoranea and Northern region rainfall pattern only fluctuates once a year on December or January, but at the Southern region has two times a year on both May and October.

(2) Annual Rainfall Distribution

Using the last 20 years annual mean rainfall data as shown in Table-1.2, an Iso-hyetal map was developed as shown in Figure-1.3. In Parana, the following rain characteristics can be observed;

a) Litoranea at the eastern side of the coast mountains range has the highest annual rainfall volume.

b) The region including Curitiba at the western side of the coast mountains range has the lowest annual rainfall.

c) The south-western region has second highest annual rainfall volume because of high altitude between 1100 m and 1200 m, and rainfall volume decrease toward the eastern side.

(3) Long-Term Rainfall Variation

To determine the long term variation of rainfall, 10 typical rainfall stations were selected. And analysis of long period annual rainfall was computed by using 5-years running annual mean and average of 5-years running annual mean rainfall as shown in Figure-1.4.

According to Figure-1.4, rainfall fluctuation cycles of 5-years running annual mean repeat the range from 8 to 12 years in Parana.

In this Study, meteorological simulation period adapted from 1974 to 1993, there are two fluctuations exist in 1983 and 1990, especially central region and Iguacu basin. It was found that the simulation period adapted last 20 years is sufficient to study of meteorological factor such as rainfall, evaporation and others.

Table-1.2 Annual and Monthly Mean Rainfall
(Simulation Period 1974 - 1993, 20 Years)

Station			Basin	Location			Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean	Total
No.	St.No.	Name		Lat.	Long.	Altitude														
1	02251027	Bela Vista	P.P.3	22°57'S	51°12'W	600	206.5	136.6	143.6	116.4	118.3	86.5	51.1	48.1	112.9	145.1	161.9	217.7	128.7	1544.7
2	02349030	Joaquim Tavora	Cinzas	23°30'S	49°52'W	512	179.3	141.0	141.2	87.5	128.2	80.2	54.5	52.3	100.2	122.8	123.2	189.6	116.7	1400.0
3	02350017	Cambara	P.P.1	23°00'S	50°02'W	450	168.4	174.8	175.8	92.6	94.8	75.8	47.0	43.3	84.3	113.4	154.3	194.9	118.3	1419.4
4	02350018	Bandeirantes	Cinzas	23°06'S	50°21'W	440	179.9	160.1	160.2	90.4	110.9	79.7	49.6	46.3	105.3	122.7	166.3	211.4	123.6	1482.8
5	02351003	Londrina	Tibagi	23°18'S	51°09'W	585	189.5	165.5	157.7	120.9	117.8	90.5	62.5	53.1	118.9	136.8	179.1	242.4	136.2	1634.7
6	02351008	Apucarana	Pirapo	23°30'S	51°32'W	746	190.3	154.6	151.5	112.7	151.0	112.2	69.2	66.2	128.6	153.6	159.1	211.3	138.4	1660.3
7	02351011	Ibipora	Tibagi	23°16'S	51°01'W	484	199.9	160.7	155.4	111.6	115.3	90.2	55.8	50.8	117.0	131.2	173.6	225.7	132.3	1587.2
8	02352017	Paranavai	Ivai	23°05'S	52°26'W	480	184.1	145.0	130.2	110.0	123.7	101.4	54.5	54.8	127.2	163.1	122.0	185.3	125.1	1501.3
9	02352019	Cianorte	Ivai	23°40'S	52°35'W	530	189.1	142.0	139.5	134.4	162.7	110.7	66.6	75.8	134.1	143.7	136.8	211.1	137.2	1646.5
10	02353008	Umuarama	Piquiri	23°44'S	53°17'W	480	165.0	126.7	125.0	136.0	157.2	106.0	68.5	76.4	141.3	153.3	168.8	191.2	134.8	1617.4
11	02449013	Cerro Azul	Ribeira	24°49'S	49°15'W	443	156.1	135.1	120.0	73.0	116.2	80.8	75.6	66.6	101.0	120.3	105.8	157.1	109.0	1307.6
12	02450011	Telemaco Borba	Tibagi	24°20'S	50°37'W	768	181.0	155.3	139.1	102.6	150.8	98.5	87.3	74.1	131.7	150.6	151.4	205.4	135.7	1627.8
(13)	02451051	Candido Abreu	Ivai	24°34'S	51°19'W	600	178.0	149.9	118.6	100.1	157.5	102.1	98.8	77.7	131.8	155.9	129.4	159.1	129.9	1558.9
14	02452050	Nova Cantu	Piquiri	24°40'S	52°34'W	540	166.5	178.1	144.2	167.8	195.8	136.1	109.4	99.1	145.1	196.8	185.3	220.0	162.0	1944.2
15	02453003	Palotina	Piquiri	24°18'S	53°55'W	310	153.1	141.4	117.1	148.4	177.7	114.2	90.3	81.5	135.8	169.4	165.1	178.3	139.4	1672.3
16	02453023	Cascavel	Parana 3	24°56'S	53°26'W	760	177.2	173.0	137.1	163.7	218.2	128.9	114.4	109.8	147.8	205.3	197.8	177.9	162.6	1951.1
17	02548038	Morretes	Litoranea	25°30'S	48°49'W	59	276.4	242.7	242.8	113.5	118.4	93.5	101.4	82.6	140.2	153.3	147.1	183.2	157.9	1895.1
18	02548039	Guaraquecaba	Litoranea	25°18'S	48°20'W	40	349.0	309.0	326.8	157.1	145.3	107.1	111.2	82.0	149.6	166.1	171.9	235.9	192.6	2311.0
19	02548070	Antonina	Litoranea	25°13'S	48°48'W	60	355.5	343.8	355.3	152.1	150.4	110.0	115.6	87.1	165.0	186.9	204.7	264.5	207.6	2490.9
20	02549041	Piraquara	Iguacu	25°25'S	49°08'W	930	161.3	135.8	125.3	86.4	119.5	88.5	92.8	73.2	109.7	127.2	122.4	146.2	115.7	1388.3
(21)	02549025	Lapa	Iguacu	25°47'S	49°43'S	907	159.0	138.0	120.8	86.4	142.5	107.2	109.4	98.3	119.9	146.1	127.7	158.6	126.2	1513.9
22	02550024	Ponta Grossa	Tibagi	25°13'S	50°01'W	880	163.2	133.7	140.3	105.0	157.4	98.1	105.1	85.0	128.4	136.3	126.5	151.7	127.6	1530.7
23	02550025	Teixeira Soares	Tibagi	25°27'S	50°35'W	893	174.7	126.0	132.0	99.0	168.3	113.7	111.1	89.9	133.6	147.0	152.5	146.9	132.9	1594.7
24	02551010	Guarapuava	Iguacu	25°21'S	51°30'W	1,020	182.0	147.1	146.8	143.7	196.1	141.4	128.6	107.8	156.4	183.9	174.4	184.2	157.7	1892.4
25	02552009	Laranjeiras	Iguacu	25°25'S	52°25'W	880	167.1	175.4	120.0	154.8	188.3	150.6	140.4	115.6	152.7	209.6	180.1	181.7	161.4	1936.3
26	02553015	Planalto	Iguacu	25°42'S	53°47'W	400	179.8	143.2	123.3	163.8	181.4	157.4	117.2	124.0	144.4	188.3	182.8	173.1	156.6	1878.7
27	02553018	Quedas Iguacu	Iguacu	25°31'S	53°01'W	513	172.5	174.7	138.0	168.1	181.4	153.0	142.4	117.0	159.3	204.4	202.8	176.8	165.9	1990.4
28	02554026	Sao Miguel	Parana 3	25°11'S	54°08'W	307	162.0	152.6	130.5	143.1	166.4	136.0	111.6	112.8	131.5	189.7	178.2	149.9	147.0	1764.3
(29)	02651000	Uniao da Vitoria	Iguacu	26°14'S	51°04'W	736	184.9	158.6	125.8	110.8	171.0	116.9	144.2	116.3	139.6	162.0	149.6	159.1	144.9	1738.8
30	02651043	Palmas	Iguacu	26°29'S	51°59'W	1,100	187.2	169.5	131.7	161.8	199.3	171.0	161.2	128.3	157.1	208.6	179.5	161.9	168.1	2017.1
31	02652003	Clevelandia	Iguacu	26°25'S	52°21'W	930	186.2	152.4	123.1	162.2	213.8	167.6	154.6	126.8	151.1	195.5	199.1	165.6	166.5	1998.0
32	02652035	Pato Branco	Iguacu	26°07'S	52°41'W	700	193.7	163.7	123.9	168.8	204.6	166.2	155.7	123.5	163.7	208.5	197.5	175.2	170.4	2045.0
33	02653012	Francisco Beltrao	Iguacu	26°05'S	53°04'W	650	171.6	166.9	127.2	157.8	197.9	154.1	143.1	117.1	153.5	209.7	194.1	163.8	163.1	1956.8

Data Source : COPEL

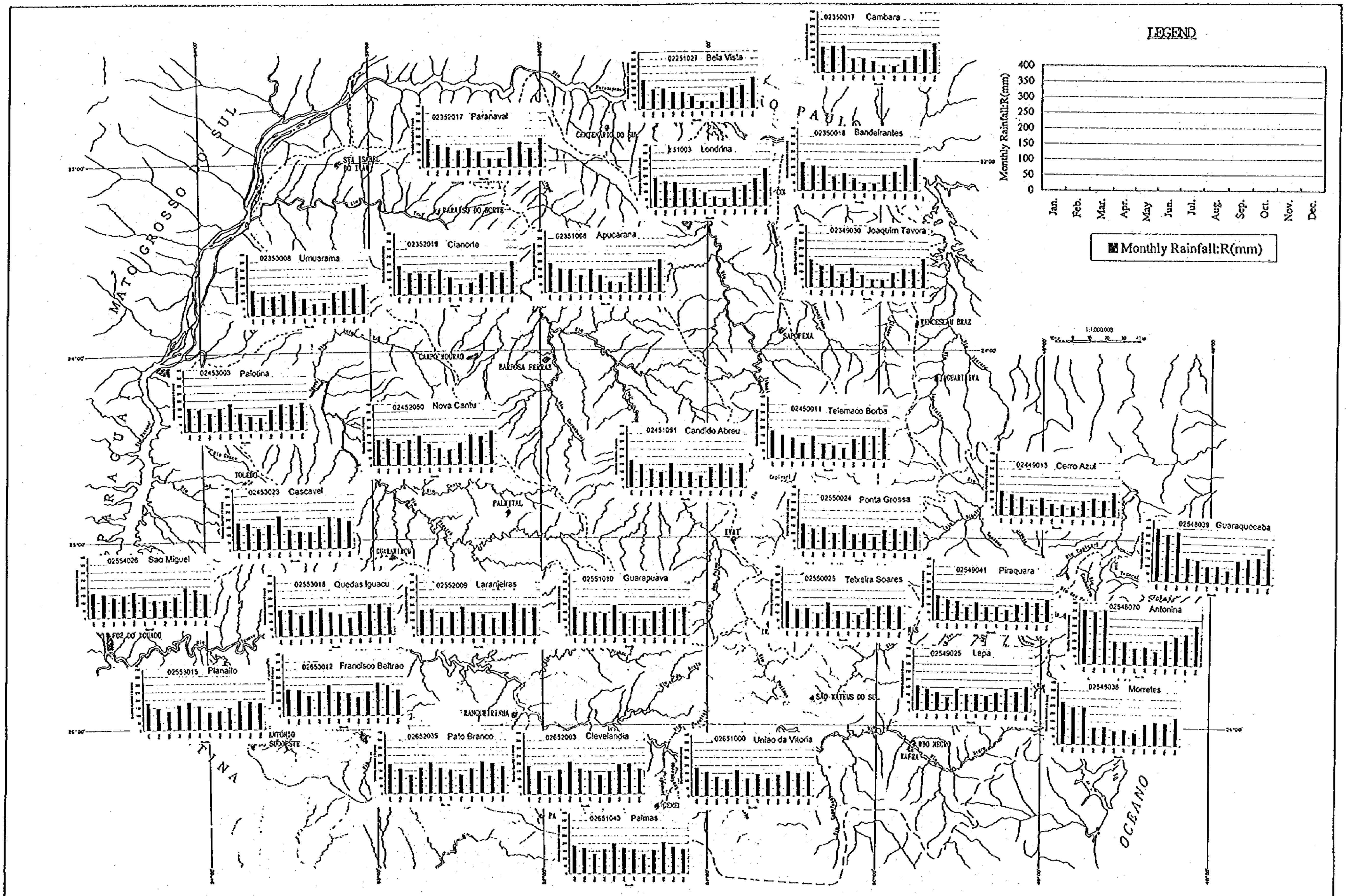


Figure-1.2 Monthly Rainfall Distribution by Stations

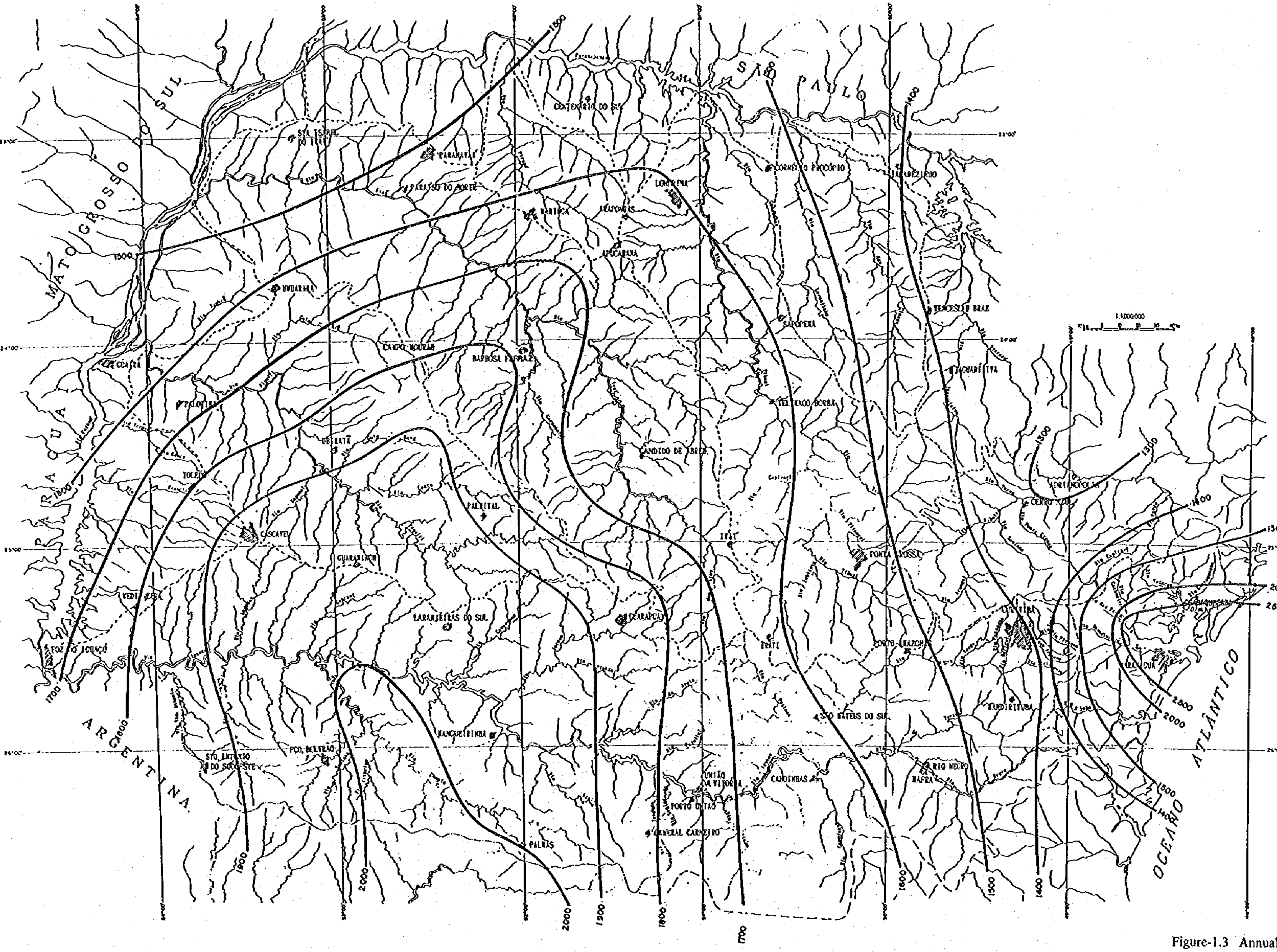


Figure-1.3 Annual Iso-hyetal Map

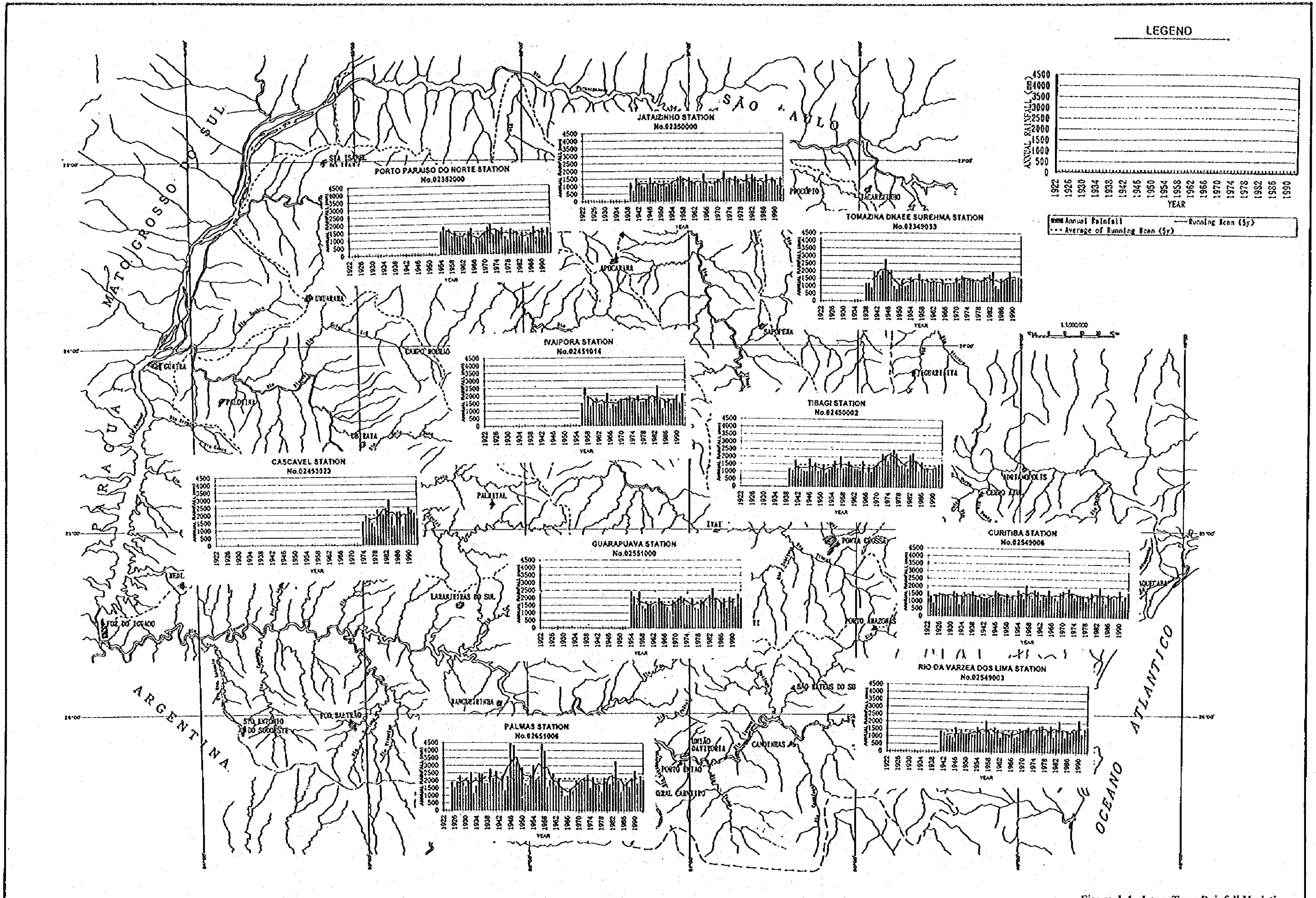


Figure-1.4 Long-Term Rainfall Variation

1.2.3 Temperature

The observation of temperature is normally made by three times a day (9:00, 15:00 and 21:00 hr). Annual mean temperature in Parana has generally range between 16°C and 22°C throughout the year. According to collected data, maximum temperature 41.5°C at Paranavai in the north-west area and minimum temperature -6.8°C both at Palmas and Guarapuava in the south highland area were recorded respectively during the recent 20 years.

The monthly and annual mean temperature were summarized in Table-1.3, and also plotted as an Iso-thermal map (Figure-1.6). The missing monthly mean temperature data were obtained by employing the correlation equation by station. (refer to the section 1.2.9)

The annual mean temperature by the station except for Litoranea area is closely related to its elevation as shown in Figure-1.5. The relation between them can be described as the following equation ;

$$Tm = 24.6 - 0.0077 \times EL$$

where Tm : annual mean air temperature (°C)

EL : elevation (m)

correlation coefficient = 0.91

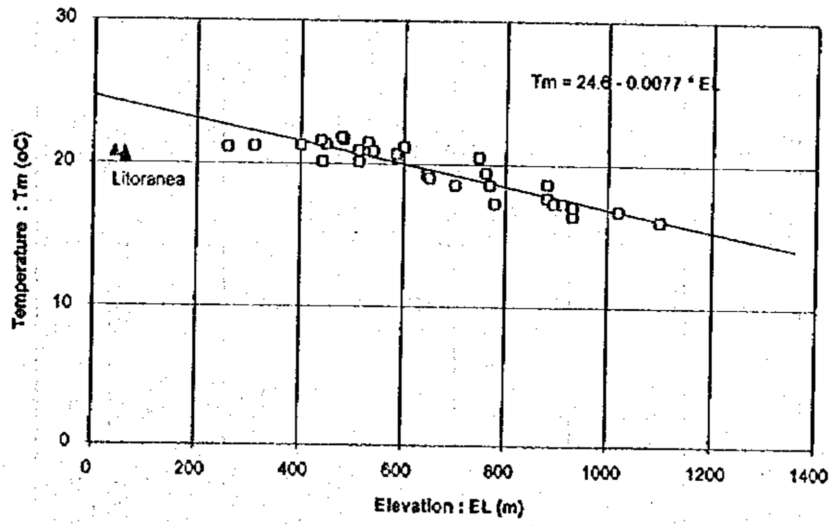


Figure-1.5 Relation between Air Temperature and Elevation

Table-1.3 Annual and Monthly Mean Temperature
(Simulation Period 1974 - 1993, 20years)

Station			Basin	Location			Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
No.	St.No.	Name		Lat.	Long.	Altitude													
1	02251027	Bela Vista	P.P.3	22°57'S	51°12'W	600	23.8	24.0	23.6	21.7	18.9	17.4	17.5	19.1	19.8	22.0	23.2	23.3	21.2
2	02349030	Joaquim Tavora	Cinzas	23°30'S	49°52'W	512	24.4	24.5	23.7	21.4	18.4	16.5	16.6	18.2	19.4	21.6	23.0	23.7	20.9
3	02350017	Cambara	P.P.1	23°00'S	50°02'W	450	24.4	24.4	23.8	21.8	18.8	17.0	16.9	18.8	20.2	22.6	23.8	23.9	21.4
4	02350018	Bandeirantes	Cinzas	23°06'S	50°21'W	440	24.6	24.7	24.0	22.1	19.1	17.4	17.5	19.3	20.4	22.7	23.8	24.1	21.6
5	02351003	Londrina	Tibagi	23°18'S	51°09'W	585	23.7	23.7	23.1	21.1	18.2	16.5	16.6	18.3	19.5	21.8	23.0	23.2	20.7
6	02351008	Apucarana	Pirapo	23°30'S	51°32'W	746	23.1	23.1	22.8	20.9	18.4	17.0	17.0	18.6	19.3	21.3	22.2	22.5	20.5
7	02351011	Ibipora	Tibagi	23°16'S	51°01'W	484	24.5	24.6	24.1	22.2	19.4	17.6	17.7	19.4	20.5	22.7	23.9	24.0	21.7
8	02352017	Paranavai	Ivai	23°05'S	52°26'W	480	24.9	24.7	24.3	22.2	19.4	17.7	17.9	19.5	20.4	22.8	24.1	24.6	21.9
9	02352019	Cianorte	Ivai	23°40'S	52°35'W	530	24.6	24.5	24.1	21.9	19.0	17.2	17.3	19.0	20.0	22.4	23.7	24.2	21.5
10	02353008	Umuarama	Piquiri	23°44'S	53°17'W	480	25.0	24.8	24.4	22.3	19.3	17.6	17.7	19.4	20.2	22.6	23.9	24.6	21.8
11	02449013	Cerro Azul	Ribeira	24°49'S	49°15'W	443	24.4	24.3	23.4	20.9	17.5	15.3	15.1	16.5	18.1	20.6	22.6	23.8	20.2
12	02450011	Telemaco Borba	Tibagi	24°20'S	50°37'W	768	22.8	22.6	21.7	19.1	15.8	13.9	13.7	15.1	16.7	19.3	20.8	21.9	18.6
13	02451052	Candido Abreu	Ivai	24°38'S	51°15'W	645	22.7	22.8	22.3	19.8	16.7	14.8	14.9	16.7	17.7	20.3	21.5	22.0	19.3
14	02452050	Nova Cantu	Piquiri	24°40'S	52°34'W	540	24.5	24.0	23.5	21.1	18.2	16.4	16.6	18.3	19.4	21.8	23.0	24.0	20.9
15	02453003	Palotina	Piquiri	24°18'S	53°55'W	310	25.2	24.9	24.3	21.8	18.5	16.4	15.9	17.5	19.4	22.3	23.9	24.8	21.2
16	02453023	Cascavel	Parana 3	24°56'S	53°26'W	760	23.0	22.6	22.2	19.8	16.8	15.0	14.9	16.5	17.8	20.3	21.6	22.7	19.4
17	02548038	Morretes	Litoranea	25°30'S	48°49'W	59	24.4	24.7	23.8	21.7	19.1	16.8	16.4	17.1	18.0	20.2	22.3	23.6	20.7
18	02548039	Guaraquecaba	Litoranea	25°18'S	48°20'W	40	24.6	24.9	23.9	21.8	19.1	16.7	16.3	17.1	18.1	20.4	22.3	23.7	20.7
19	02548070	Antonina	Litoranea	25°13'S	48°48'W	60	24.2	24.3	23.6	21.2	18.5	16.4	16.1	16.7	17.9	20.0	22.0	23.4	20.4
20	02549041	Piraquara	Iguacu	25°25'S	49°08'W	930	19.9	20.3	19.4	16.9	14.5	13.0	12.7	13.6	14.3	16.2	17.9	19.0	16.5
21	02549091	Lapa	Iguacu	25°47'S	49°46'S	910	20.8	20.7	19.9	17.7	15.1	13.6	13.6	14.6	15.3	17.4	19.1	20.0	17.3
22	02550024	Ponta Grossa	Tibagi	25°13'S	50°01'W	880	21.3	21.2	20.4	18.1	15.4	13.8	13.8	14.9	15.8	17.9	19.6	20.5	17.7
23	02550025	Teixeira Soares	Tibagi	25°27'S	50°35'W	893	21.2	21.1	20.1	17.6	14.8	13.1	13.0	14.4	15.4	17.8	19.4	20.4	17.4
24	02551010	Guarapuava	Iguacu	25°21'S	51°30'W	1,020	20.6	19.8	19.6	17.1	14.2	12.7	12.6	14.0	15.1	17.4	18.9	19.9	16.8
25	02552009	Laranjeiras	Iguacu	25°25'S	52°25'W	880	22.3	22.0	21.3	18.8	16.0	14.4	14.6	16.1	17.0	19.3	20.7	21.9	18.7
26	02553015	Planalto	Iguacu	25°42'S	53°47'W	400	25.3	24.8	24.2	21.4	18.3	16.3	16.6	18.3	19.5	22.0	23.5	25.0	21.3
27	02553018	Quedas Iguacu	Iguacu	25°31'S	53°01'W	513	24.3	23.7	23.0	20.3	17.2	15.4	15.5	17.1	18.5	21.0	22.5	23.8	20.2
28	02554026	Sao Miguel	Parana 3	25°11'S	54°08'W	307	25.6	25.1	24.4	21.4	18.0	15.8	15.9	17.6	19.2	22.1	23.7	25.1	21.2
29	02651007	Porto Uniao	Iguacu	26°13'S	51°04'W	778	22.0	21.5	20.6	17.5	14.1	12.2	12.0	13.9	15.0	18.0	19.8	21.3	17.3
30	02651043	Palmas	Iguacu	26°29'S	51°59'W	1,100	20.2	20.0	19.0	16.3	13.2	11.8	11.6	13.0	14.1	16.7	18.1	19.5	16.1
31	02652003	Clevelandia	Iguacu	26°25'S	52°21'W	930	21.0	20.7	19.9	17.3	14.3	12.6	12.7	14.2	15.1	17.6	19.1	20.5	17.1
32	02652035	Pato Branco	Iguacu	26°07'S	52°41'W	700	22.5	22.2	21.4	18.7	15.7	13.9	14.1	15.7	16.8	19.3	20.7	22.0	18.6
33	02653012	Francisco Beltrao	Iguacu	26°05'S	53°04'W	650	23.5	23.0	22.2	19.1	15.8	13.9	14.1	15.8	17.2	20.0	21.4	23.0	19.1

Data Source : COPEL

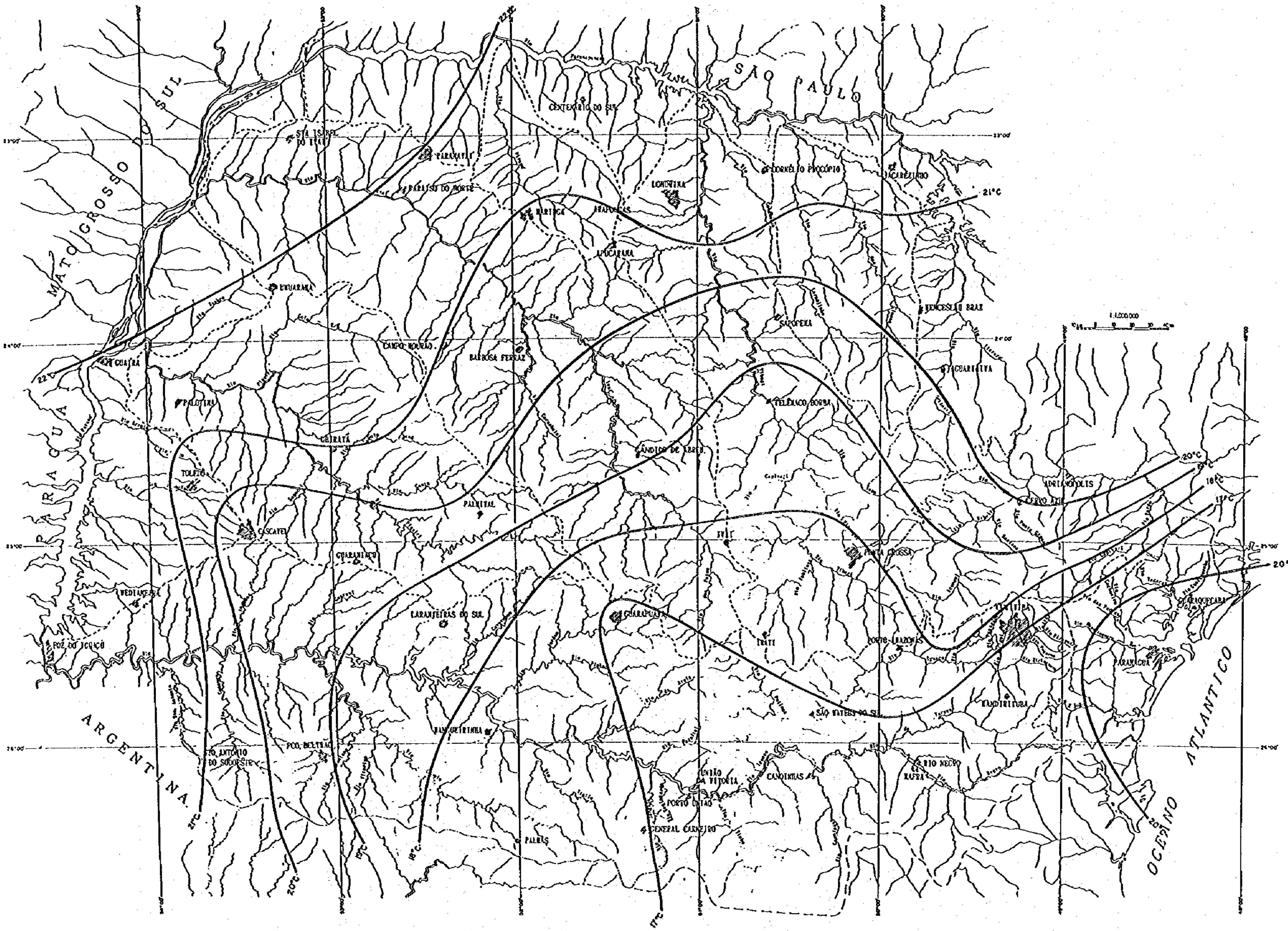


Figure-1.6 Iso-thermal Map of Annual Mean Temperature

1.2.4 Evaporation

1) Direct Measurement Data

Evaporation pan data after converted by using a pan coefficient (0.6 - 0.8) is useful for estimating the value for lakes or reservoirs. The observation of evaporation pan data is mainly carried out at main meteorological stations in Parana, and is observed by IAPAR (at main meteorological Stations) and DNAEE (at 12 main meteorological stations). But data is not sufficiently available. The Team collected row evaporation pan data at some stations to compare the evaporation data by Penman's equation.

2) Penman's Evaporation

COPEL, IAP and other related agencies are commonly computed an evaporation rate by using Penman's equation. The Team determined the relation between evaporation pan data after converting by using a mean of pan coefficient 0.7 (: Evpan) and evaporation data by Penman's equation (: Evp) at several stations. Using both annual evaporation data, the ratio of Evpan / Evp ranges from 0.7 to 0.9, with a mean of 0.8. The mean value of 0.8 will be employed to estimate the evaporation value for planned dam reservoirs in surface water development study.

The annual mean evaporation results calculated by COPEL using Penman's equation (by Frere, 1979) in the selected 33 stations is summarized as shown in Table-1.4. The missing monthly evaporation data were determined to employ the correlation equation by station. (refer to the section 1.2.9)

One of the factor affecting evaporation is usually known as air temperature. Figure-1.7 shows the relationship between the monthly mean air temperature and the monthly mean evaporation. It obviously indicates that monthly mean evaporation for months having the same monthly mean air temperature of the same month is higher between October and March (hot season) than between April and September (cold season).

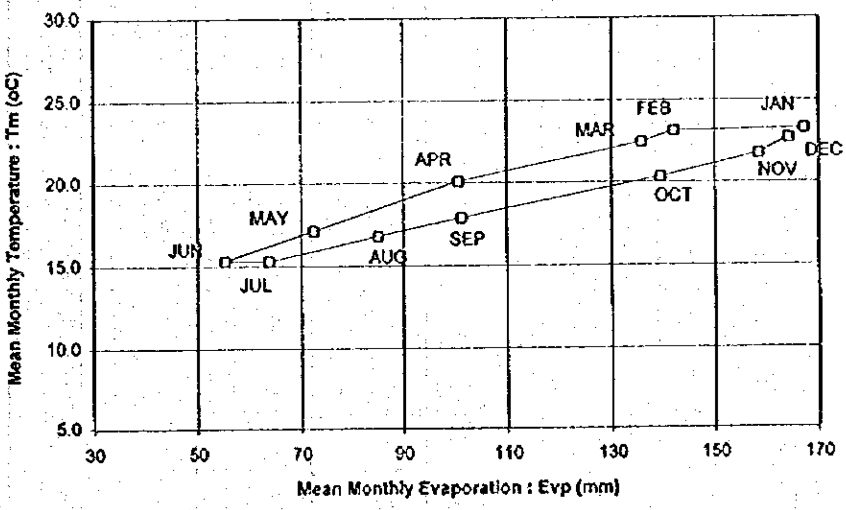


Figure-1.7 Relation between Penman's Evaporation and Air Temperature (using mean monthly data at 33 selected stations)

Table-1.4 Annual and Monthly Mean Evaporation by Penman's Equation

(Simulation Period 1974 - 1993, 20 years)

Station			Basin	Location			Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean	Total
No.	St.No.	Name		Lat.	Long.	Altitude														
1	02251027	Bela Vista	P.P.3	22°57'S	51°12'W	600	173.4	152.5	146.8	119.3	87.3	67.0	78.9	105.0	116.8	159.2	174.3	169.3	129.2	1549.8
2	02349030	Joaquim Tavora	Cinzas	23°30'S	49°52'W	512	173.4	152.1	144.6	114.2	80.0	61.5	71.5	99.3	112.3	155.5	173.4	167.7	125.5	1505.5
3	02350017	Cambara	P.P.1	23°00'S	50°02'W	450	183.2	149.7	148.0	120.3	88.2	70.1	84.9	116.1	133.3	174.9	188.5	166.9	135.3	1624.1
4	02350018	Bandeirantes	Cinzas	23°06'S	50°21'W	440	180.6	155.5	148.1	118.4	84.8	68.2	78.6	108.4	124.8	165.0	180.1	172.8	132.1	1585.3
5	02351003	Londrina	Tibagi	23°18'S	51°09'W	585	175.0	151.8	146.1	118.3	85.0	65.8	76.7	102.1	118.1	160.0	175.0	170.6	128.7	1544.5
6	02351008	Apucarana	Pirapo	23°30'S	51°32'W	746	164.1	139.3	138.5	111.5	78.5	58.5	70.0	92.3	106.7	151.0	164.6	165.9	120.1	1440.9
7	02351011	Ibipora	Tibagi	23°16'S	51°01'W	484	175.6	153.5	148.6	120.2	87.3	67.7	77.8	103.4	117.3	160.0	174.8	170.6	129.7	1556.8
8	02352017	Paranavai	Ivai	23°05'S	52°26'W	480	185.1	157.0	156.7	118.0	85.0	68.0	78.8	103.3	115.4	160.9	179.6	179.8	132.3	1587.6
9	02352019	Cianorte	Ivai	23°40'S	52°35'W	530	181.7	154.6	154.9	114.5	80.8	63.6	73.6	96.5	113.3	157.4	175.6	178.8	128.8	1545.3
10	02353008	Umuarama	Piquiri	23°44'S	53°17'W	480	185.0	158.9	157.1	119.4	84.9	65.9	74.9	99.2	113.6	157.6	178.5	185.4	131.7	1580.4
11	02449013	Cerro Azul	Ribeira	24°49'S	49°15'W	443	158.7	134.2	130.7	90.6	61.5	51.2	53.7	73.8	87.2	130.0	154.8	155.6	106.8	1282.0
12	02450011	Telemaco Borba	Tibagi	24°20'S	50°37'W	768	167.3	144.4	135.9	101.6	71.3	54.7	64.0	84.1	100.5	139.8	158.1	163.6	115.4	1385.3
13	02451052	Candido Abreu	Ivai	24°38'S	51°15'W	645	187.0	159.2	153.8	113.2	77.9	57.6	66.0	87.2	108.7	152.7	173.5	186.4	126.9	1523.2
14	02452050	Nova Cantu	Piquiri	24°40'S	52°34'W	540	176.3	147.6	144.0	103.8	74.2	56.4	65.7	87.1	105.4	144.6	162.8	176.5	120.4	1444.4
15	02453003	Palotina	Piquiri	24°18'S	53°55'W	310	147.0	129.3	119.0	85.4	64.1	48.9	51.8	64.9	75.2	105.2	127.8	138.4	96.4	1157.0
16	02453023	Cascavel	Parana 3	24°56'S	53°26'W	760	175.5	147.6	144.0	103.8	74.2	56.2	65.5	86.7	105.4	144.6	161.2	175.6	120.0	1440.3
17	02548038	Morretes	Litoranea	25°30'S	48°49'W	59	147.7	129.7	119.0	85.4	65.1	48.9	51.6	64.9	75.2	105.2	127.8	138.4	96.6	1158.9
18	02548039	Guaraquecaba	Litoranea	25°18'S	48°20'W	40	142.7	127.6	115.4	84.0	64.0	47.9	51.3	63.8	74.4	102.6	124.8	134.8	94.4	1133.3
19	02548070	Antonina	Litoranea	25°13'S	48°48'W	60	141.9	125.8	115.8	84.3	64.7	49.4	52.4	65.0	75.1	103.3	123.4	132.9	94.5	1134.0
20	02549041	Piraquara	Iguacu	25°25'S	49°08'W	930	146.1	123.4	111.6	85.3	62.7	48.7	56.4	72.9	84.2	116.6	134.7	138.3	98.4	1180.9
21	02549091	Lapa	Iguacu	25°47'S	49°46'S	910	155.8	131.9	124.8	92.4	67.1	53.1	62.8	84.2	96.8	131.7	150.9	152.4	108.7	1303.9
22	02550024	Ponta Grossa	Tibagi	25°13'S	50°01'W	880	162.6	138.3	132.3	101.4	76.3	61.9	72.0	92.9	106.6	142.1	159.0	160.4	117.2	1405.8
23	02550025	Teixeira Soares	Tibagi	25°27'S	50°35'W	893	148.9	127.1	116.9	82.6	58.7	46.0	51.2	71.0	87.0	120.4	139.9	140.8	99.2	1190.5
24	02551010	Guarapuava	Iguacu	25°21'S	51°30'W	1,020	164.2	137.5	132.8	98.1	70.8	55.7	66.3	88.7	105.1	140.3	154.4	160.8	114.6	1374.7
25	02552009	Laranjeiras	Iguacu	25°25'S	52°25'W	880	168.1	140.5	136.8	96.5	70.4	53.3	62.7	84.8	101.4	138.2	153.2	166.8	114.4	1372.7
26	02553015	Planalto	Iguacu	25°42'S	53°47'W	400	190.5	155.8	152.5	106.1	75.1	55.4	61.8	89.1	109.8	153.8	177.4	196.3	127.0	1523.6
27	02553018	Quedas Iguacu	Iguacu	25°31'S	53°01'W	513	178.0	144.9	141.2	99.2	70.8	49.3	59.1	74.6	105.0	142.8	166.2	181.9	117.8	1413.0
28	02554026	Sao Miguel	Parana 3	25°11'S	54°08'W	307	186.5	155.0	149.3	104.3	72.0	51.4	60.5	78.9	106.8	149.7	175.3	191.4	123.4	1481.1
29	02651007	Porto Uniao	Iguacu	26°13'S	51°04'W	778	150.3	120.7	116.0	79.6	56.9	40.8	48.3	67.1	83.8	116.8	136.8	147.9	97.1	1165.0
30	02651043	Palmas	Iguacu	26°29'S	51°59'W	1,100	124.2	107.3	97.4	69.6	49.9	37.9	45.1	62.2	78.0	107.9	125.4	132.1	86.4	1037.0
31	02652003	Clevelandia	Iguacu	26°25'S	52°21'W	930	166.4	135.8	126.8	89.8	63.9	46.9	55.7	75.7	94.1	130.8	152.9	165.1	108.7	1303.9
32	02652035	Pato Branco	Iguacu	26°07'S	52°41'W	700	178.3	150.4	139.6	98.8	69.0	51.3	59.4	82.3	102.6	142.3	164.7	178.5	118.1	1417.2
33	02653012	Francisco Beltrao	Iguacu	26°05'S	53°04'W	650	177.9	148.1	138.5	94.3	65.0	47.8	56.7	77.7	99.9	140.3	162.6	177.9	115.6	1386.7

Data Source : COPEL

As considering relation between evaporation and air temperature at a certain place, annual mean relation of both parameters can be described as following equation; (Refer to Figure-1.8)

$$Evp = 91.6 + 67.9 * Tm$$

where Evp : annual mean evaporation by Penman's equation (mm)
Tm : annual mean air temperature (°C)
correlation coefficient = 0.87

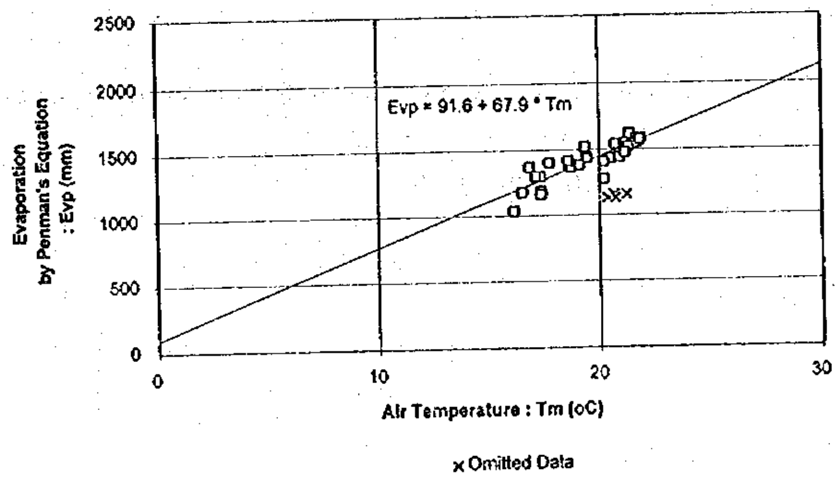


Figure-1.8 Relation between Annual Evaporation and Air Temperature

1.2.5 Potential Evapotranspiration

Evapotranspiration is the evaporation from all water, soil, vegetative, and other surfaces, plus transpiration. COPEL computed the value of potential evapotranspiration by using Penman's equation (by Frere, 1979) which is commonly used in Brazil.

The calculated results were summarized in Table-1.5 and was plotted as an Iso-potential evapotranspiration map (Figure-1.10).

The annual potential evapotranspiration at a certain place except for Litoranea area is related to its elevation, it can be described as following equation; (Refer to Figure-1.9)

$$Evt = 1320 - 0.37 * EL$$

where, Evt : annual potential evapotranspiration by Penman's equation (mm)
EL : elevation (m)
correlation coefficient = 0.70

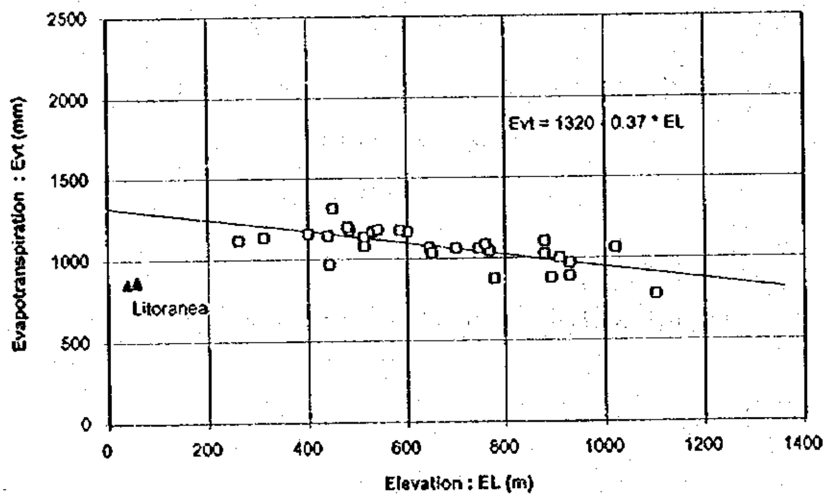


Figure-1.9 Relation between Annual Potential Evapotranspiration and Elevation

Table-1.5 Annual and Monthly Mean Potential Evapotranspiration
(Simulation Period 1974 - 1993, 20 years)

Station			Basin	Location			Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean	Total
No.	St.No.	Name		Lat.	Long.	Altitude														
1	02251027	Bela Vista	P.P.3	22°57'S	51°12'W	600	133.3	117.0	111.7	88.9	62.9	46.5	56.0	77.7	88.6	120.8	134.1	130.4	97.3	1167.9
2	02349030	Joaquim Tavora	Cinzas	23°30'S	49°52'W	512	133.3	117.2	110.4	84.9	57.6	42.8	50.4	73.8	84.7	118.9	133.6	129.9	94.8	1137.5
3	02350017	Cambara	P.P.1	23°00'S	50°02'W	450	144.7	123.5	122.2	100.0	70.2	55.4	65.6	92.8	108.7	141.8	151.7	139.5	109.7	1316.1
4	02350018	Bandeirantes	Cinzas	23°06'S	50°21'W	440	135.4	115.0	111.1	84.4	60.0	44.9	53.0	74.1	85.3	118.1	134.0	131.0	95.5	1146.3
5	02351003	Londrina	Tibagi	23°18'S	51°09'W	585	135.2	116.8	112.1	88.4	61.4	46.3	54.9	76.3	91.1	124.2	136.4	132.7	98.0	1175.8
6	02351008	Apucarana	Pirapo	23°30'S	51°32'W	746	124.3	104.8	103.4	80.7	54.0	37.7	46.9	66.3	79.0	113.4	125.5	126.3	88.5	1062.3
7	02351011	Ibipora	Tibagi	23°16'S	51°01'W	484	135.3	118.3	114.5	89.8	62.9	47.3	55.0	76.4	89.4	123.1	135.2	131.9	98.3	1179.1
8	02352017	Paranavai	Ivai	23°05'S	52°26'W	480	142.9	120.9	119.6	88.3	61.6	47.9	56.3	76.9	87.7	123.3	138.6	138.9	100.2	1202.9
9	02352019	Cianorte	Ivai	23°40'S	52°35'W	530	139.9	118.7	118.1	85.4	58.3	44.5	52.3	71.5	85.8	120.5	135.5	138.0	97.4	1168.5
10	02353008	Umuarama	Piquiri	23°44'S	53°17'W	480	142.6	122.0	120.0	89.2	61.4	46.3	53.9	74.0	86.3	120.8	137.7	143.0	99.8	1197.2
11	02449013	Cerro Azul	Ribeira	24°49'S	49°15'W	443	121.5	103.2	100.2	67.5	44.2	36.6	38.3	54.5	65.4	99.6	119.7	120.2	80.9	970.9
12	02450011	Telemaco Borba	Tibagi	24°20'S	50°37'W	768	128.1	109.6	102.0	76.0	50.7	37.4	45.2	63.0	77.3	109.1	122.6	125.2	87.2	1046.2
13	02451052	Candido Abreu	Ivai	24°38'S	51°15'W	645	132.9	111.9	107.5	77.3	47.5	31.0	40.3	63.7	80.1	117.1	131.4	129.3	89.2	1070.0
14	02452050	Nova Cantu	Piquiri	24°40'S	52°34'W	540	146.7	119.9	115.7	87.0	57.1	42.2	52.3	69.6	86.6	121.6	135.4	146.4	98.4	1180.5
15	02453003	Palotina	Piquiri	24°18'S	53°55'W	310	142.7	122.3	117.3	82.6	53.5	38.8	45.9	63.6	82.0	114.5	130.9	143.8	94.8	1137.9
16	02453023	Cascavel	Parana 3	24°56'S	53°26'W	760	136.9	112.3	108.7	76.5	52.4	38.9	46.0	64.0	79.1	110.1	124.4	137.2	90.5	1086.5
17	02548038	Morretes	Litoranea	25°30'S	48°49'W	59	114.1	99.8	90.7	63.9	46.6	33.8	36.0	47.1	56.3	80.1	98.4	106.9	72.8	873.7
18	02548039	Guaraquecaba	Litoranea	25°18'S	48°20'W	40	110.3	98.4	88.2	63.2	46.0	33.2	35.9	46.5	55.8	78.2	96.0	104.1	71.3	855.8
19	02548070	Antonina	Litoranea	25°13'S	48°48'W	60	110.0	97.3	88.7	63.7	46.7	34.7	36.9	47.6	56.6	78.9	95.2	102.9	71.6	859.2
20	02549041	Piraquara	Iguacu	25°25'S	49°08'W	930	112.7	94.8	84.7	63.5	44.9	33.9	40.3	53.8	63.5	89.3	103.5	106.5	74.3	891.4
21	02549091	Lapa	Iguacu	25°47'S	49°46'S	910	121.6	101.8	95.4	69.8	49.2	38.4	46.4	64.5	74.9	103.1	118.9	119.7	83.6	1003.7
22	02550024	Ponta Grossa	Tibagi	25°13'S	50°01'W	880	128.7	108.5	103.2	78.8	58.2	47.2	55.6	73.2	84.5	113.1	127.1	127.9	92.2	1106.0
23	02550025	Teixeira Soares	Tibagi	25°27'S	50°35'W	893	113.3	96.1	87.2	60.1	40.6	30.7	34.7	50.6	64.3	90.4	106.4	107.5	73.5	881.9
24	02551010	Guarapuava	Iguacu	25°21'S	51°30'W	1,020	128.3	106.7	102.4	74.6	52.6	41.2	49.7	68.4	82.6	109.9	121.5	126.2	88.7	1064.1
25	02552009	Laranjeiras	Iguacu	25°25'S	52°25'W	880	129.0	107.0	103.1	70.6	49.3	36.1	43.5	61.7	76.0	105.1	117.8	128.1	85.6	1027.3
26	02553015	Planalto	Iguacu	25°42'S	53°47'W	400	147.4	119.7	116.7	79.5	54.5	39.1	46.2	66.1	82.9	117.8	136.9	152.5	96.6	1159.3
27	02553018	Quedas Iguacu	Iguacu	25°31'S	53°01'W	513	137.5	111.3	107.6	73.9	51.1	36.3	44.2	62.8	79.7	109.1	128.1	140.2	90.2	1081.8
28	02554026	Sao Miguel	Parana 3	25°11'S	54°08'W	307	143.0	118.5	113.5	77.4	51.2	35.6	42.4	62.2	79.9	113.7	134.8	146.9	93.3	1119.1
29	02651007	Porto Uniao	Iguacu	26°13'S	51°04'W	778	115.4	92.3	87.6	58.6	40.1	27.3	33.6	49.7	62.9	89.2	105.5	113.9	73.0	876.1
30	02651043	Palmas	Iguacu	26°29'S	51°59'W	1,100	95.7	82.3	74.2	51.7	35.4	26.1	31.3	45.0	58.0	81.7	96.3	101.7	65.0	779.4
31	02652003	Clevelandia	Iguacu	26°25'S	52°21'W	930	126.9	103.0	95.1	65.4	44.3	31.2	38.6	55.2	70.1	98.8	116.9	126.3	81.0	971.8
32	02652035	Pato Branco	Iguacu	26°07'S	52°41'W	700	136.9	115.0	105.8	72.9	48.8	35.3	41.5	60.5	77.0	108.4	126.7	137.3	88.8	1066.1
33	02653012	Francisco Beltrao	Iguacu	26°05'S	53°04'W	650	136.4	113.1	104.6	69.0	45.2	32.1	39.0	56.3	74.5	106.1	124.3	136.4	86.4	1037.0

Data Soure : COPEL

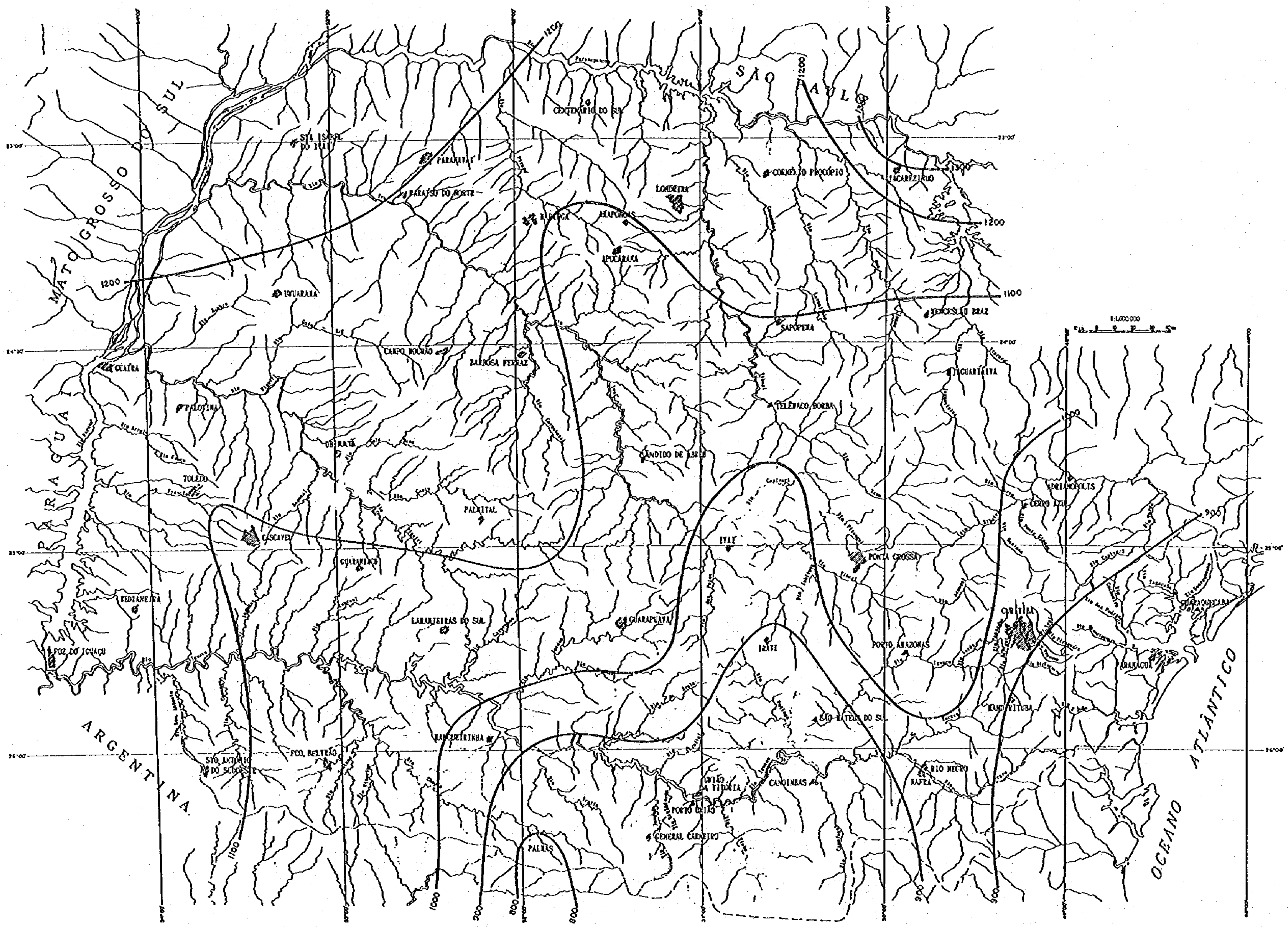


Figure-1.10 Annual Iso-potential Evapotranspiration Map

1.2.6 Wind Speed and Direction

The wind speed and direction are observed by 3 methods in Parana, such as using automatic anemometer recorder, manual observation with anemometer (10 minutes duration) and visual observation. The wind condition in Parana depends on the air mass movement of the whole Brazil.

In January equatorial air mass is moderately humid and has entered from the north. In July the tropical air mass which brings easterly or northeasterly winds to near all area. According to collected data, wind speed is stable at range between 2.0 and 5.0 m/sec throughout the year. The annual mean and monthly wind speed at the each selected stations are summarized in Table-1.6.

Table-1.6 Annual and Monthly Mean Wind Speed and Direction
(Available Period between 1974 and 1993)

Station			Basin	Location			Jan.	Feb	Mar.	Apr.	May	Jun.	Jul.	Aug	Sep.	Oct	Nov.	Dec.	Mean
No	St.No	Name		Lat.	Long	Altitude													
1	02251027	Bela Vista	P.P.3	22°67'S	51°12'W	600	2.4 SE	2.4 SE	2.4 SE	2.5 SE	2.4 SE	2.4 SE	2.8 SE	2.8 SE	3.1 SE	2.8 SE	2.7 SE	2.4 SE	2.6 SE
2	02349030	Joaquim Tavora	Cinzas	23°30'S	49°52'W	512	2.6 E	2.6 E	2.8 E	3.0 E	2.4 E	2.4 E	3.0 E	3.2 E	3.7 E	3.4 E	3.2 E	2.9 E	2.9 E
3	02350017	Cambara	P.P.1	23°00'S	50°02'W	450	2.3 E	2.0 E	2.1 E	2.4 SE	2.0 E	2.1 E	2.4 E	2.8 E	3.3 SE	3.5 E	3.2 E	2.8 E	2.5 E
4	02350018	Bandeirantes	Cinzas	23°06'S	50°21'W	440	2.8 SE	2.9 SE	2.9 SE	3.1 SE	2.8 SE	2.6 E	3.0 SE	3.5 SE	4.2 SE	4.0 SE	3.7 SE	3.2 SE	3.2 SE
5	02351003	Londrina	Tibagi	23°18'S	51°09'W	585	2.7 E	2.5 E	2.4 E	2.5 E	2.3 E	2.3 E	2.6 E	2.7 E	3.0 E	3.1 E	3.0 E	2.8 E	2.6 E
6	02351008	Apucarana	Pirapo	23°30'S	51°32'W	745	4.3 E	4.2 E	4.3 E	4.4 E	4.4 E	4.4 E	4.7 E	4.8 E	5.0 E	4.7 E	4.5 E	4.3 E	4.5 E
7	02351011	Ibipora	Tibagi	23°16'S	51°01'W	454	2.6 SE	2.4 SE	2.4 SE	2.5 SE	2.2 SE	2.4 S	2.5 SE	2.7 SE	3.1 SE	3.2 SE	3.1 SE	2.8 SE	2.7 SE
8	02352017	Paranavai	Ivai	23°05'S	52°26'W	480	2.4 NE	2.3 NE	2.3 NE	2.3 NE	2.3 NE	2.6 NE	3.0 NE	2.9 NE	2.9 NE	2.7 NE	2.7 NE	2.6 NE	2.6 NE
9	02352019	Cianorte	Ivai	23°40'S	52°35'W	530	2.5 E	2.4 E	2.3 E	2.4 E	2.2 E	2.3 E	2.8 E	2.7 E	2.8 E	2.7 E	2.6 E	2.4 E	2.5 E
10	02353008	Umuarama	Piquiri	23°44'S	53°17'W	480	2.5 NE	2.4 NE	2.4 NE	2.5 NE	2.7 NE	2.8 NE	3.2 NE	3.3 NE	3.2 NE	2.9 NE	2.7 NE	2.6 NE	2.8 NE
11	02449013	Cerro Azul	Ribeira	24°49'S	49°15'W	443	1.8 NE	2.0 NE	1.9 NE	1.9 NE	1.7 NE	1.7 NE	1.8 NE	1.9 NE	2.1 NE	2.1 NE	2.1 NE	1.8 NE	1.9 NE
12	02450011	Telemaco Borba	Tibagi	24°20'S	50°37'W	768	2.0 SE	2.0 SE	1.8 SE	1.8 SE	1.6 SE	1.7 SE	1.9 SE	1.8 SE	2.0 SE	2.1 SE	2.2 SE	2.2 SE	1.9 SE
13	02451052	Candido Abreu	Ivai	24°38'S	51°15'W	645	2.1 SE	2.0 E	1.9 SE	1.8 E	2.0 SE	1.9 SE	2.1 SE	2.3 SE	2.4 SE	2.3 SE	2.3 SE	2.2 SE	2.2 SE
14	02452050	Nova Cantu	Piquiri	24°40'S	52°34'W	540	1.8 E	1.7 SE	1.7 E	1.8 SE	1.8 SE	1.6 E	1.9 E	1.8 E	2.0 E	1.9 E	2.0 E	1.8 E	1.8 E
15	02453003	Palotina	Piquiri	24°18'S	53°55'W	310	2.1 NE	2.2 NE	2.2 NE	2.2 NE	2.1 NE	2.0 NE	2.2 NE	2.3 NE	2.8 NE	3.0 NE	2.8 NE	2.4 NE	2.4 NE
16	02453023	Cascavel	Parana	24°56'S	53°26'W	760	3.0 NE	3.0 NE	3.0 NE	3.1 NE	3.3 NE	3.4 NE	3.9 NE	3.8 NE	3.8 NE	3.7 NE	3.5 NE	3.2 NE	3.4 NE
17	02548038	Morretes	Litorane	25°30'S	48°49'W	59	1.7 NE	1.5 NE	1.3 NE	1.1 NE	1.1 NE	1.2 NE	1.2 NE	1.2 NE	1.4 NE	1.6 NE	1.8 NE	1.7 NE	1.4 NE
18	02548039	Guaraquecaba	Litorane	25°10'S	48°20'W	40	2.3 SE	2.1 SE	1.9 SE	1.7 SE	1.5 SE	1.5 SE	1.8 SW	1.7 SE	2.1 SE	2.4 SE	2.5 SE	2.4 SE	2.0 SE
19	02548070	Antonina	Litorane	25°13'S	48°48'W	60	2.3 S	2.4 S	2.1 S	2.1 S	2.1 S	2.2 S	2.3 S	2.1 S	2.2 S	2.3 S	2.5 S	2.4 S	2.2 S
20	02549041	Piraquara	Iguacu	25°25'S	49°06'W	930	2.8 E	2.5 E	2.3 E	2.4 E	2.3 N	2.3 N	2.7 N	2.7 N	2.9 E	3.0 E	3.1 E	2.9 E	2.6 E
21	02549091	Lapa	Iguacu	25°47'S	49°46'S	910	3.4 E	2.9 E	2.9 E	2.8 E	2.8 E	2.8 NE	3.1 NE	3.0 E	3.5 E	3.5 E	3.8 E	3.6 E	3.2 E
22	02550024	Ponta Grossa	Tibagi	25°13'S	50°01'W	880	3.5 NE	3.2 NE	3.1 NE	3.3 NE	3.3 NE	3.3 NE	3.9 NE	3.8 NE	4.0 NE	4.0 NE	4.0 NE	3.8 NE	3.6 NE
23	02550025	Teixeira Soares	Tibagi	25°27'S	50°35'W	893	1.6 SE	1.4 SE	1.5 SE	1.7 SE	1.6 SE	1.9 NW	2.0 SE	2.0 SE	2.1 SE	1.9 SE	1.9 SE	1.7 SE	1.8 SE
24	02551010	Guarapuava	Iguacu	25°21'S	51°30'W	1,020	2.6 E	2.6 NE	2.7 E	2.8 NE	2.5 NE	2.5 NE	3.1 NE	3.1 NE	3.4 E	3.3 E	3.1 NE	3.0 E	2.9 NE
25	02552009	Laranjeiras	Iguacu	25°25'S	52°25'W	840	2.4 E	2.3 E	2.2 E	2.3 E	2.4 E	2.5 E	2.9 E	2.9 E	2.9 E	2.8 E	2.8 E	2.5 E	2.6 E
26	02553015	Planalto	Iguacu	25°42'S	53°47'W	400	3.1 NE	2.5 NE	3.0 NE	3.1 NE	3.0 NE	3.0 NE	3.7 NE	3.4 NE	3.4 NE	3.4 NE	3.4 NE	3.7 NE	3.2 NE
27	02553018	Quedas Iguacu	Iguacu	25°31'S	53°01'W	513	2.7 SE	2.6 SE	2.5 SE	2.5 SE	2.6 SE	2.8 SE	2.9 SE	2.8 SE	2.8 SE	2.7 SE	2.8 SE	2.7 SE	2.7 SE
28	02554026	Sao Miguel	Parana	25°11'S	54°08'W	307	2.3 N	2.3 N	2.3 E	2.5 E	2.7 E	2.7 E	2.7 N	2.9 E	3.1 E	3.0 E	2.8 N	2.3 N	2.8 E
29	02651007	Porto Uniao	Iguacu	26°13'S	51°04'W	778	1.6 SE	1.6 SE	1.4 SE	1.3 SE	1.5 SE	1.5 SE	1.3 SE	1.6 SE	1.6 E	1.8 SE	2.0 SE	2.0 SE	1.6 SE
30	02651043	Palmas	Iguacu	26°29'S	51°59'W	1,100	3.2 NE	3.1 N	2.9 NE	3.0 NE	3.0 N	3.0 N	2.8 N	3.5 N	3.9 NE	3.6 N	3.5 NE	3.1 NE	3.3 NE
31	02652003	Clevelandia	Iguacu	26°25'S	52°21'W	930	3.5 NE	3.4 NE	3.2 NE	3.4 NE	3.5 NE	3.8 NE	4.3 NE	4.0 NE	4.2 NE	4.0 NE	4.0 NE	3.7 NE	3.7 NE
32	02652035	Pato Branco	Iguacu	26°07'S	52°41'W	700	3.0 NE	3.0 SE	3.2 SE	3.1 SE	3.0 SE	3.1 SE	3.4 SE	3.4 SE	3.7 SE	3.3 SE	3.3 SE	3.0 N	3.2 SE
33	02653012	Francisco Beltrao	Iguacu	26°05'S	53°04'W	650	2.3 NE	2.2 NE	2.0 NE	1.9 NE	1.8 SW	2.1 SW	2.5 NE	2.4 NE	2.8 NE	2.6 NE	2.6 NE	2.5 NE	2.3 NE

Data Source : COPEL

1.2.7 Sunshine Hours

It is generally known that sunshine hours relates to the latitude of observation point. The state of Parana locates between latitude 22°30' and 26°40' and the tropic of Capricorn passes through the north area (Londrina, Maringa city). According to the collected data, mean annual sunshine hours has about 7 hours/day at the regions except for Litoranea area. Litoranea area has about 4 hours sunshine hours almost through the year, because Litoranea area locates to nearby Serra do Mar high mountain range and the fog gathers, especially in the morning. (Refer to Table-1.7)

Table-1.7 Annual and Monthly Daily Mean Sunshine Hours
(Available Period between 1974 and 1993)

Station			Basin	Location			Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean	Annual
No.	St.No.	Name		Lat.	Long.	Altitude														
1	02251027	Bela Vista	P.P.3	22°57'S	51°12'W	600	6.9	7.0	6.9	7.4	6.9	6.7	7.5	7.4	6.4	7.2	7.7	6.6	7.1	2,575
2	02349030	Joaquim Tavora	Cinzas	23°30'S	49°52'W	512	6.8	6.7	6.9	7.1	6.3	6.2	6.9	7.1	6.2	7.3	7.7	6.3	6.8	2,472
3	02350017	Cambara	P.P.1	23°00'S	50°02'W	450	7.0	6.9	6.9	7.4	6.9	6.8	7.5	7.5	6.4	7.2	7.6	6.1	7.0	2,560
4	02350018	Bandeirantes	Cinzas	23°06'S	50°21'W	440	7.1	6.9	7.0	7.3	6.6	6.6	7.3	7.3	6.3	7.4	7.7	6.7	7.0	2,563
5	02351003	Londrina	Tibagi	23°18'S	51°09'W	585	6.9	7.0	7.0	7.4	6.8	6.8	7.4	7.3	6.3	7.4	7.6	6.7	7.0	2,569
6	02351008	Apucarana	Pirapo	23°30'S	51°32'W	746	7.0	6.8	7.4	7.5	6.8	7.1	7.7	7.5	6.6	7.3	7.3	6.6	7.1	2,598
7	02351011	Ibipora	Tibagi	23°16'S	51°01'W	484	6.8	6.9	6.9	7.4	6.9	6.8	7.5	7.3	6.3	7.3	7.5	6.5	7.0	2,560
8	02352017	Paranavai	Ivai	23°05'S	52°26'W	480	7.4	7.2	7.4	7.5	6.8	6.6	7.4	7.2	6.2	7.5	7.9	7.0	7.2	2,619
9	02352019	Cianorte	Ival	23°40'S	52°35'W	530	7.2	7.1	7.4	7.3	6.5	6.6	7.3	7.0	6.1	7.3	7.7	7.1	7.0	2,572
10	02353008	Umuarama	Piquiri	23°44'S	53°17'W	480	7.4	7.4	7.4	7.4	6.7	6.5	7.1	6.8	6.1	7.2	7.9	7.5	7.1	2,596
11	02449013	Cerro Azul	Ribeira	24°49'S	49°15'W	443	5.6	5.5	5.2	4.9	4.2	3.7	4.2	4.4	4.2	5.1	5.7	5.4	4.8	1,737
12	02450011	Telemaco Borba	Tibagi	24°20'S	50°37'W	768	6.5	6.5	6.3	6.3	6.0	5.7	6.4	6.4	5.6	6.5	6.7	6.2	6.3	2,285
13	02451052	Candido Abreu	Ivai	24°38'S	51°15'W	645	6.5	7.3	6.6	7.2	6.9	5.8	6.7	6.8	5.8	7.0	8.0	7.6	6.9	2,531
14	02452050	Nova Cantu	Piquiri	24°40'S	52°34'W	540	7.4	7.0	7.0	6.8	6.4	6.0	6.6	6.7	6.2	6.9	7.2	7.1	6.8	2,470
15	02453003	Palotina	Piquiri	24°18'S	53°55'W	310	7.7	7.5	7.4	7.1	6.4	6.0	6.7	6.5	6.0	7.0	7.6	7.6	6.9	2,537
16	02453023	Cascavel	Parana 3	24°56'S	53°26'W	760	7.3	7.1	7.1	6.7	6.3	6.1	6.7	6.5	5.9	6.7	7.3	7.3	6.8	2,465
17	02548038	Morretes	Litoranea	25°30'S	48°49'W	59	4.9	5.1	4.7	4.3	4.6	4.5	4.2	3.8	3.1	3.7	4.5	4.5	4.3	1,584
18	02548039	Guaraquecaba	Litoranea	25°18'S	48°20'W	40	4.8	4.8	4.5	4.3	4.5	4.4	4.2	3.8	3.1	3.5	4.5	4.4	4.2	1,538
19	02548070	Antonina	Litoranea	25°13'S	48°48'W	60	4.7	4.6	4.5	4.4	4.7	4.6	4.3	4.0	3.2	3.6	4.5	4.4	4.3	1,567
20	02549041	Piraquara	Iguacu	25°25'S	49°08'W	930	5.6	5.6	5.1	4.9	5.0	5.1	5.6	5.3	4.5	5.1	5.6	5.1	5.2	1,901
21	02549091	Lapa	Iguacu	25°47'S	49°46'S	910	5.5	6.4	5.2	5.7	5.4	4.9	5.6	5.5	4.5	5.3	6.6	6.3	5.6	2,032
22	02550024	Ponta Grossa	Tibagi	25°13'S	50°01'W	880	5.8	6.0	5.9	5.9	5.9	5.8	6.3	6.2	5.5	6.1	6.3	5.6	6.0	2,173
23	02550025	Teixeira Soares	Tibagi	25°27'S	50°35'W	893	5.8	5.9	5.4	5.1	5.0	5.1	5.3	5.5	5.0	5.6	6.1	5.2	5.4	1,973
24	02551010	Guarapuava	Iguacu	25°21'S	51°30'W	1,020	6.6	6.4	6.5	6.3	6.0	5.7	6.4	6.6	5.9	6.6	6.6	6.6	6.3	2,316
25	02552009	Laranjeiras	Iguacu	25°25'S	52°25'W	880	6.8	6.7	6.8	6.7	6.3	6.0	6.6	6.5	5.9	6.7	6.9	6.7	6.6	2,392
26	02553015	Planalto	Iguacu	25°42'S	53°47'W	400	6.8	6.7	6.8	6.7	6.3	6.0	6.6	6.5	5.9	6.7	6.9	6.7	6.6	2,392
27	02553018	Quedas Iguacu	Iguacu	25°31'S	53°01'W	513	7.3	6.9	7.0	6.4	5.9	5.4	6.1	6.3	5.9	6.6	7.4	7.5	6.6	2,402
28	02554026	Sao Miguel	Parana 3	25°11'S	54°08'W	307	7.9	7.6	7.2	8.0	5.7	5.2	5.9	6.1	5.9	7.1	7.8	8.2	6.7	2,444
29	02651007	Porto Uniao	Iguacu	26°13'S	51°04'W	778	6.9	7.5	6.8	7.4	6.5	5.9	6.3	6.2	5.7	6.7	7.4	7.3	6.7	2,461
30	02651043	Palmas	Iguacu	26°29'S	51°59'W	1,100	6.9	6.5	6.5	5.3	5.7	5.7	5.8	6.2	5.7	6.8	7.4	6.9	6.3	2,282
31	02652003	Clevelandia	Iguacu	26°25'S	52°21'W	930	7.4	6.9	7.1	6.4	6.1	5.8	6.3	6.2	6.0	6.9	7.5	7.4	6.6	2,426
32	02652035	Pato Branco	Iguacu	26°07'S	52°41'W	700	7.8	7.2	7.5	6.4	6.1	5.6	6.2	6.4	6.3	6.9	7.5	7.6	6.8	2,456
33	02653012	Francisco Beltrao	Iguacu	26°05'S	53°04'W	650	7.3	7.1	7.2	6.3	6.0	5.4	6.1	6.1	6.1	6.9	7.5	7.5	6.6	2,410

Data Source : COPEL

1.2.8 Relative Humidity

Relative humidity in Parana is almost constant, range between 70 and 80 % throughout the year. Monthly relative humidity by the selected stations is summarized in Table-1.8.

The annual mean relative humidity is closely related to air temperature, it can be described as the following equation;(Also see Figure-1.11)

$$RH = 111.5 - 1.9 * Tm$$

where, RH : annual mean relative humidity (%)

Tm : annual mean air temperature (°C)

correlation coefficient = 0.81

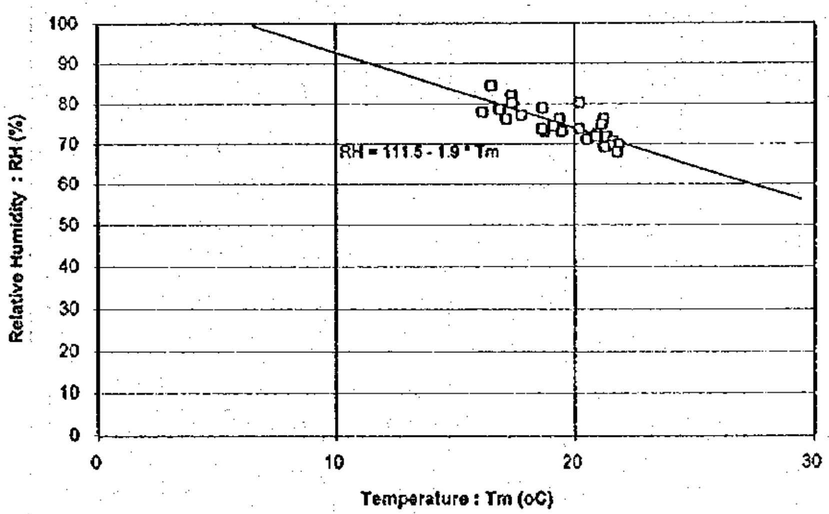


Figure-1.11 Relation between Relative Humidity and Air Temperature

Table-1.8 Annual and Monthly Mean Relative Humidity
(Available Period between 1974 and 1993)

Station			Basin	Location			Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
No.	St.No.	Name		Lat.	Long.	Altitude													
1	02251027	Bela Vista	P.P.3	22°57'S	51°12'W	600	75.9	74.9	73.5	71.7	73.5	73.0	66.5	61.8	65.3	65.9	67.2	74.7	70.3
2	02349030	Joaquim Tavora	Cinzas	23°30'S	49°52'W	512	74.2	74.3	74.8	74.3	77.3	76.8	71.7	67.5	68.4	68.8	69.5	73.4	72.6
3	02350017	Cambara	P.P.1	23°00'S	50°02'W	450	76.7	77.0	75.5	74.1	76.4	75.6	71.0	64.5	65.5	64.6	67.5	74.3	71.9
4	02350018	Bandeirantes	Cinzas	23°06'S	50°21'W	440	75.7	74.8	73.9	72.8	74.6	73.8	68.1	62.7	65.1	64.9	67.6	74.0	70.8
5	02351003	Londrina	Tibagi	23°18'S	51°09'W	585	76.1	76.0	75.3	73.8	75.7	75.9	70.5	65.1	66.6	66.0	67.2	73.9	71.8
6	02351008	Apucarana	Pirapo	23°30'S	51°32'W	746	76.7	76.8	75.3	73.3	73.3	72.6	66.8	62.1	65.3	67.0	68.1	75.3	71.2
7	02351011	Ibipora	Tibagi	23°16'S	51°01'W	484	75.0	74.0	72.8	70.8	72.3	73.4	67.6	62.6	64.5	64.0	65.7	73.3	69.7
8	02352017	Paranavai	Ivai	23°05'S	52°26'W	480	73.4	74.4	73.7	72.9	74.6	73.0	66.4	62.2	66.1	66.0	66.3	72.3	70.0
9	02352019	Cianorte	Ivai	23°40'S	52°35'W	530	73.8	74.6	71.9	71.2	73.2	74.1	67.4	63.2	65.2	65.2	65.2	72.0	69.7
10	02353008	Umuarama	Piquiri	23°44'S	53°17'W	480	71.5	72.0	70.8	69.7	71.2	71.2	64.7	61.3	64.4	65.0	64.8	70.1	68.0
11	02449013	Cerro Azul	Ribeira	24°49'S	49°15'W	443	78.1	79.5	81.2	82.8	85.5	85.7	84.3	80.9	79.2	76.3	74.8	76.2	80.4
12	02450011	Telemaco Borba	Tibagi	24°20'S	50°37'W	768	76.8	79.1	80.4	81.3	84.3	84.4	81.1	78.4	76.5	75.1	74.1	76.7	79.0
13	02451052	Candido Abreu	Ivai	24°38'S	51°15'W	645	77.8	75.8	79.4	80.4	81.0	82.6	79.0	73.3	73.7	73.0	70.0	73.8	76.4
14	02452050	Nova Cantu	Piquiri	24°40'S	52°34'W	540	73.9	76.1	75.0	75.3	76.0	75.6	70.4	65.9	66.5	67.3	68.6	72.7	71.9
15	02453003	Palotina	Piquiri	24°18'S	53°55'W	310	78.6	78.8	76.9	76.7	80.2	81.5	78.8	75.0	71.8	71.5	71.1	76.1	76.4
16	02453023	Cascavel	Parana 3	24°56'S	53°26'W	760	75.6	77.8	75.6	74.7	76.5	77.3	72.9	69.0	68.5	68.8	68.4	73.3	73.2
17	02548038	Morretes	Litoranea	25°30'S	48°49'W	59	84.5	85.3	87.2	87.3	86.5	86.2	86.6	86.8	87.0	85.5	82.7	83.0	85.7
18	02548039	Guaraquecaba	Litoranea	25°18'S	48°20'W	40	83.5	85.1	86.6	87.4	88.4	88.1	87.7	87.8	86.9	85.1	82.2	82.9	86.0
19	02548070	Antonina	Litoranea	25°13'S	48°43'W	60	84.3	85.6	87.0	87.6	87.4	87.1	87.4	86.9	86.7	84.9	82.6	83.4	85.9
20	02549041	Piraquara	Iguacu	25°25'S	49°08'W	930	85.0	85.4	86.5	87.5	86.5	84.7	82.1	81.9	84.1	84.3	83.4	84.4	84.6
21	02549091	Lapa	Iguacu	25°47'S	49°46'S	910	82.8	81.2	85.2	85.0	84.8	85.0	83.3	80.6	82.4	80.8	76.4	77.6	82.1
22	02550024	Ponta Grossa	Tibagi	25°13'S	50°01'W	880	77.5	79.3	80.1	79.8	80.0	79.2	76.4	74.6	75.5	75.4	73.2	75.8	77.2
23	02550025	Teixeira Soares	Tibagi	25°27'S	50°35'W	893	80.1	81.6	83.3	83.5	84.3	83.6	80.4	77.5	78.2	77.8	76.6	78.6	80.4
24	02551010	Guarapuava	Iguacu	25°21'S	51°30'W	1,020	79.1	80.9	81.1	81.6	82.3	81.3	78.9	74.8	75.4	76.0	74.9	77.7	78.7
25	02552009	Laranjeiras	Iguacu	25°25'S	52°25'W	880	74.5	77.0	76.3	76.5	76.8	76.1	71.9	67.9	68.7	70.1	70.1	73.2	73.2
26	02553015	Planalto	Iguacu	25°42'S	53°47'W	400	69.2	72.2	71.5	72.6	73.8	74.7	68.6	65.5	65.3	66.0	65.9	66.6	69.3
27	02553018	Quedas Iguacu	Iguacu	25°31'S	53°01'W	513	74.0	76.8	77.1	77.5	78.7	79.5	73.0	70.1	69.2	69.6	69.3	71.6	73.9
28	02554026	Sao Miguel	Parana 3	25°11'S	54°08'W	307	74.0	76.2	75.5	79.8	81.6	81.6	78.1	73.2	69.9	69.5	68.7	70.8	74.9
29	02651007	Porto Uniao	Iguacu	26°13'S	51°04'W	778	79.8	79.2	83.8	82.2	83.8	85.0	85.0	80.4	79.4	74.6	73.8	77.0	80.3
30	02651043	Palmas	Iguacu	26°29'S	51°59'W	1,100	76.5	79.9	79.3	82.6	82.9	81.7	78.1	75.3	74.9	74.9	74.1	75.5	78.0
31	02652003	Clevelandia	Iguacu	26°25'S	52°21'W	930	76.7	80.0	79.1	79.3	79.7	79.1	75.6	72.8	73.5	72.8	71.9	74.3	76.2
32	02652035	Pato Branco	Iguacu	26°07'S	52°41'W	700	73.8	77.7	75.0	78.3	78.9	77.7	73.5	70.3	69.2	69.5	69.4	72.3	73.8
33	02653012	Francisco Beltrao	Iguacu	26°05'S	53°04'W	650	73.5	77.1	76.6	77.6	79.9	79.8	75.9	72.1	70.4	69.9	69.7	71.5	74.5

Data Source : COPEL

1.2.9 Correlation Analysis

The missing data of the following meteorological items were determined to employ correlation equation by station. The simulation period were adapted for the last 20 years (1974-1993). The employed correlation equations were summarized as shown in Table-1.9 - Table-1.11.

- Monthly Rainfall
- Monthly Temperature
- Monthly Evaporation

Table-1.9 Correlation Equations for Monthly Rainfall

No.	X Station	Y Station	Y = a + b x X		X = a'+ b' x Y		Correlation Coefficient
			a	b	a'	b'	
3-4	02350017 Cambara	02350018 Bandeirantes	15.40	0.93	-16.63	1.08	0.85
5-7	02351003 Londrina	02351011 Ibipora	12.89	0.88	-14.64	1.14	0.91
8-6	02352017 Paranaval	02351008 Apucarana	30.32	0.87	-34.94	1.15	0.81
12-7	02450011 Telemaco Borba	02351011 Ibipora	28.48	0.77	-36.87	1.29	0.73
12-13	02450011 Telemaco Borba	02451052 Candido Abreu	33.64	0.85	-39.39	1.17	0.79
13-6	02451052 Candido Abreu	02351008 Apucarana	27.12	0.73	-36.92	1.36	0.74
13-7	02451052 Candido Abreu	02351011 Ibipora	33.64	0.66	-51.12	1.52	0.67
13-14	02451052 Candido Abreu	02452050 Nova Cantu	59.97	0.81	-73.69	1.23	0.78
14-16	02452050 Nova Cantu	02453023 Cascavel	22.08	0.86	-25.69	1.16	0.79
15-16	02453003 Palotina	02453023 Cascavel	43.36	0.66	-50.61	1.17	0.77
17-18	02548038 Morretes	02548039 Guaraquecaba	13.74	1.13	-12.20	0.89	0.85
19-17	02548070 Antonina	02548038 Morretes	17.76	0.68	-26.11	1.47	0.88
20-11	02549041 Piraquara	02449013 Cerro Azul	19.51	0.78	-25.16	1.29	0.78
21-22	02549091 Lapa	02550024 Ponta Grossa	28.79	0.85	-34.05	1.18	0.86
22-23	02550024 Ponta Grossa	02550025 Teixeira Soares	21.02	0.87	-24.10	1.15	0.82
24-25	02551010 Guarapuava	02552009 Laranjeiras	22.49	0.88	-25.56	1.14	0.84
26-27	02553015 Planalto	02553018 Quedas Iguacu	28.59	0.88	-32.65	1.14	0.86
27-28	02553018 Quedas Iguacu	02554026 Sao Miguel	21.82	0.75	-28.96	1.33	0.85
30-31	02651043 Palmas	02652003 Clevelandia	9.49	0.94	-10.11	1.07	0.90
31-32	02652003 Clevelandia	02652035 Pato Branco	13.30	0.94	-14.10	1.06	0.88

Table-1.10 Correlation Equations for Monthly Temperature

No.	X Station		Y Station		Y = a + b x X		X = a'+ b' x Y		Correlation Coefficient
					a	b	a'	b'	
3-4	02350017	Cambara	02350018	Bandeirantes	1.07	0.96	-1.11	1.04	0.99
5-7	02351003	Londrina	02351011	Ibipora	1.56	0.97	-1.61	1.03	1.00
8-6	02352017	Paranaval	02351008	Apucarana	1.79	0.85	-2.09	1.17	0.99
9-10	02352019	Cianorte	02353008	Umuarama	0.29	1.00	-0.29	1.00	1.00
11-12	02449013	Cerro Azul	02450011	Telemaco Borba	-0.79	0.95	0.84	1.06	0.99
13-6	02451052	Candido Abreu	02351008	Apucarana	5.35	0.78	-6.81	1.27	0.98
14-15	02452050	Nova Cantu	02453003	Palotina	-2.61	1.14	2.29	0.88	0.98
15-16	02453003	Palotina	02453023	Cascavel	0.83	0.88	-0.95	1.14	0.99
17-18	02548038	Morretes	02548039	Guaraquecaba	-0.37	1.02	0.36	0.98	1.00
19-20	02548070	Antonina	02549041	Piraquara	-1.51	0.88	1.71	1.13	0.98
21-22	02549091	Lapa	02550024	Ponta Grossa	-1.09	1.07	1.01	0.93	0.99
22-23	02550024	Ponta Grossa	02550025	Teixeira Soares	-1.38	1.06	1.31	0.95	0.99
22-24	02550024	Ponta Grossa	02551010	Guarapuava	-1.36	1.03	1.32	0.97	0.96
25-27	02552009	Laranjeiras	02553018	Quedas Iguacu	-0.31	1.10	0.28	0.91	0.99
26-27	02553015	Planalto	02553018	Quedas Iguacu	-0.74	0.98	0.75	1.02	0.99
27-28	02553018	Quedas Iguacu	02554026	Sao Miguel	-1.21	1.11	1.10	0.90	0.99
29-31	02651007	Porto Uniao	02652003	Clevelandia	2.25	0.86	-2.62	1.17	0.99
30-31	02651043	Palmas	02652003	Clevelandia	1.31	0.98	-1.34	1.02	0.99
32-33	02652035	Pato Branco	02653012	Francisco Beltrao	-1.39	1.10	1.26	0.91	1.00

Table-1.11 Correlation Equations for Monthly Evaporation

No.	X Station		Y Station		Y = a + b x X		X = a' + b' + Y		Correlation Coefficient
					a	b	a'	b'	
1-6	02251027	Bela Vista	02351008	Apucarana	-4.17	0.96	4.33	1.04	0.90
2-3	02349030	Joaquim	02350017	Cambara	21.42	0.93	-22.96	1.07	0.95
3-4	02350017	Cambara	02350018	Bandeirantes	-5.25	0.98	5.35	1.02	0.96
5-7	02351003	Londrina	02351011	Ibipora	4.29	0.97	-4.41	1.03	0.99
6-7	02351008	Apucarana	02351011	Ibipora	27.28	0.65	-31.98	1.17	0.88
8-9	02352017	Paranavai	02352019	Cianorte	-5.85	1.02	5.75	0.98	0.99
9-10	02352019	Cianorte	02353008	Umuarama	4.24	0.99	-4.28	1.01	0.99
10-11	02353008	Umuarama	02449013	Cerro Azul	13.53	0.99	-13.73	1.01	0.98
12-13	02450011	Telemaco Borba	02451052	Candido Abreu	-4.51	1.14	3.96	0.88	0.98
13-5	02451052	Candido Abreu	02351003	Londrina	21.74	0.85	-25.66	1.18	0.96
14-15	02452050	Nova Cantu	02453003	Palotina	4.72	0.77	-6.16	1.31	0.93
15-16	02453003	Palotina	02453023	Cascavel	9.94	1.14	-8.72	0.88	0.93
17-18	02548038	Morretes	02548039	Guaraquecaba	2.04	0.96	-2.14	1.05	0.99
17-19	02548038	Morretes	02548070	Antonina	4.47	0.93	-4.79	1.07	0.99
17-20	02548038	Morretes	02549041	Piraquara	14.25	0.86	-16.54	1.16	0.91
17-21	02548038	Morretes	02549091	Lapa	4.47	1.02	-4.38	0.98	0.97
20-21	02549041	Piraquara	02549091	Lapa	-3.87	1.09	3.54	0.91	0.99
21-22	02549091	Lapa	02550024	Ponta Grossa	10.22	0.98	-10.39	1.02	0.99
22-23	02550024	Ponta Grossa	02550025	Teixeira Soares	-17.08	0.99	17.22	1.01	0.98
23-24	02550025	Teixeira Soares	02551010	Guarapuava	13.39	1.02	-13.12	0.99	0.98
25-27	02552009	Laranjeiras	02553018	Quedas Iguacu	-5.19	1.09	4.78	0.92	0.97
26-27	02553015	Planalto	02553018	Quedas Iguacu	4.10	0.90	-4.54	1.11	0.99
27-28	02553018	Quedas Iguacu	02554026	Sao Miguel	-3.56	1.07	3.32	0.93	0.99
29-31	02651007	Porto Uniao	02652003	Clevelandia	2.92	1.09	-2.67	0.91	0.97
30-33	02651043	Palmas	02653012	Francisco Beltrao	41.30	0.85	-48.31	1.17	0.78
31-32	02652003	Clevelandia	02652035	Pato Branco	12.68	0.98	-12.94	1.02	0.95
32-33	02652035	Pato Branco	02653012	Francisco Beltrao	-3.06	1.00	3.05	1.00	0.99
33-27	02653012	Francisco Beltrao	02553018	Quedas Iguacu	6.76	0.97	-6.96	1.03	0.98

CHAPTER 2 HYDROLOGICAL ANALYSIS

2.1 Review of Hydrological Measurement Data

2.1.1 Present Discharge Measurement

There are 217 hydrological stations (as of March, 1995) operated by mainly DNAEE, COPEL, IAP, of which 69 stations are provided with automatic level recorder. The actual field works such as discharge measurement, water quality sampling and sediment sampling by each hydrological station are carried out by 11 observation teams of IAP. The frequency of field measurements is either once a month or once in two months, and at times when the floods occur.

2.1.2 Confirmation of Discharge Measurement

The Study Team visited several operating hydrological stations accompanied with an observation team from IAP to confirm the accuracy of field measurement in terms of instrumental and methodological. The comments are described as follows;

< Instrument >

IAP has been using enough number of sounding current meters, the instrument is well maintained as annual calibration.

< Methodology >

The methodology is enough skilled in executing the discharge measurement and sampling by two observers.

2.1.3 Review of Discharge Rating Curve

To convert the observed data of water level to discharge, the discharge rating curve is essential. The discharge rating curve generally prepared from relation between water level and discharge as determined by the discharge measurements. It is usually expressed as the following equations;

1) Second-degree curve

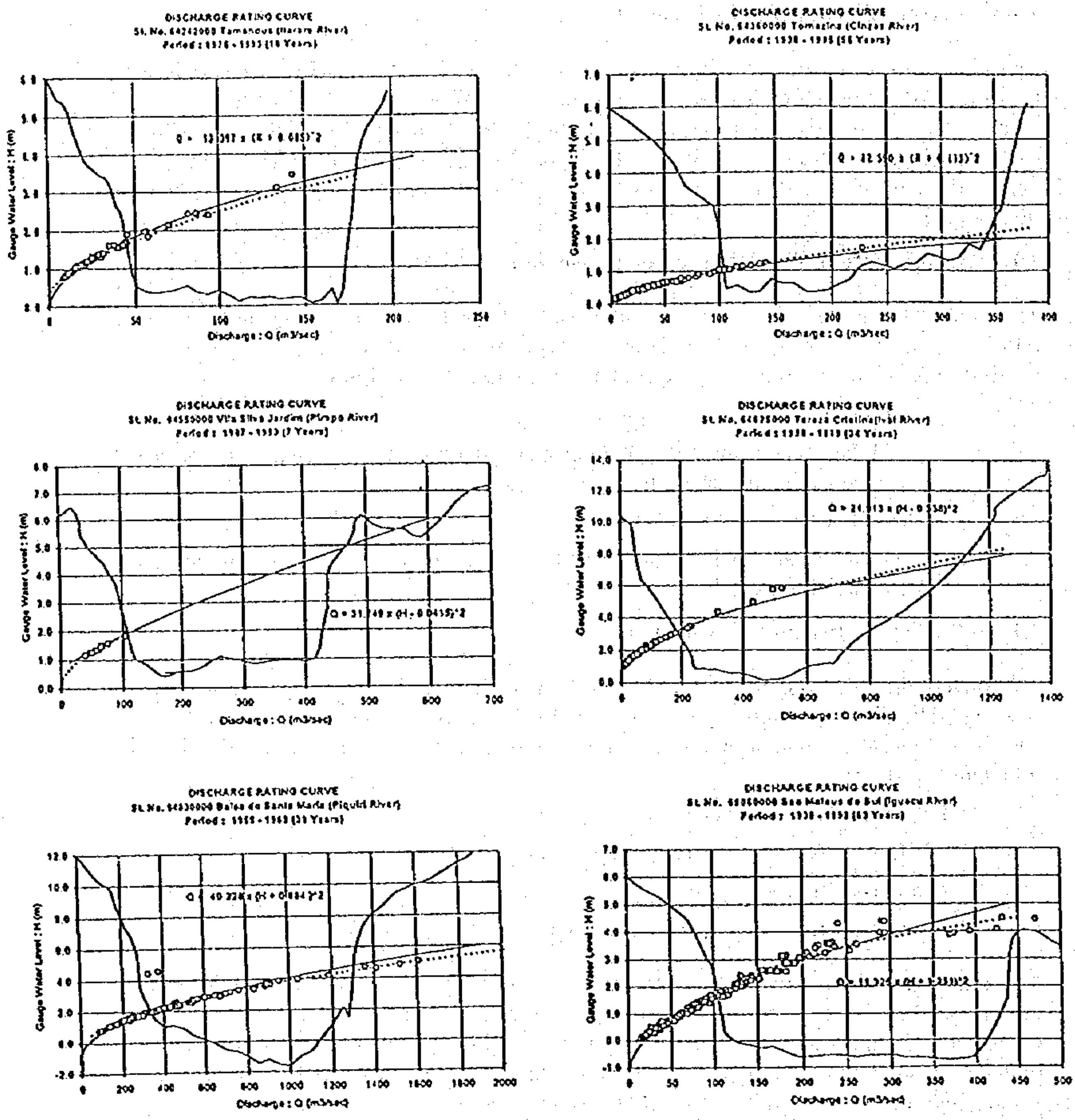
$Q = a \times (H + b)^2$ where, a, b : constant

2) n-degree curve

$Q = a \times (H + b)^n$ where, a, b, n : constant, $n = 1.5 - 2.5$

The established discharge rating tables and curves in Parana are determined by manual plotting method. To confirm that the established discharge rating curves in Parana are exact curve with flow measurement data, the Team employed the second-degree curve determined by the least square method. Figure-2.1 shows both discharge rating curves at some selected station, and there are not much different between two curves.

Therefore, the discharge rating curves /or tables established by Counterparts were employed to determined discharge by selected station in this Study.



Legend : □ Measured Data, ———— JICA, ... Counterparts

Figure-2.1 Discharge Rating Curves

2.1.4 Hydrological Database

At present, the following three database systems are used by the different public agencies in Parana;

1) MSDHD (DNAEE)
2) SISTEMA DAD (COPEL)
3) CADASTRO-PLU-FLU (IAP)

The database system developed in this Study are composed of the following components and described in Figure-2.2. The database prepared by JICA Study Team is covered all registered stations except for the closed stations in Parana State.

1) Filling System
   - H-Q Table by Station
   - Cross Section Data by Station
   - Flow Measurement Data by Station
   - Daily River Water Level
2) Analyzing System
   - Discharge Rating Curve by using Manning's Formula
   - Discharge Rating Curve by using Least Square Method
   - Daily Discharge
   - Monthly Discharge
   - Correlation Analysis between Stations
   - Flow Regime Table and Graph

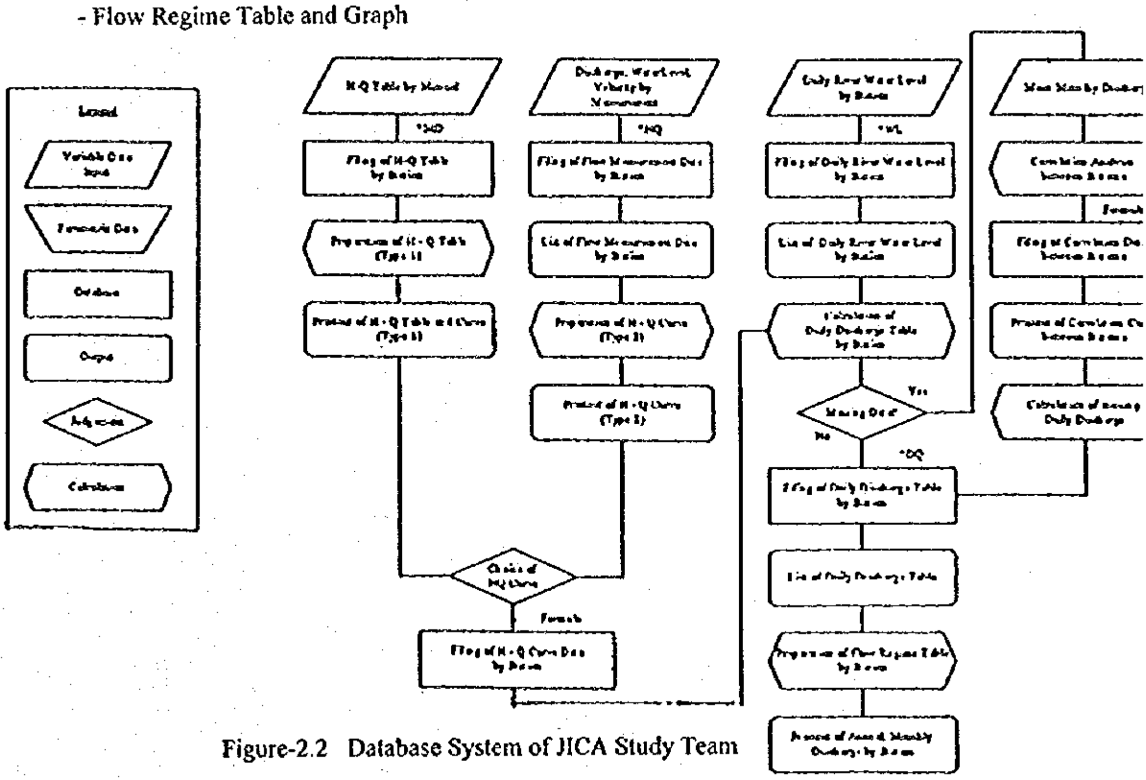


Figure-2.2 Database System of JICA Study Team

2.2 Runoff Analysis

2.2.1 Discharge Reference Point

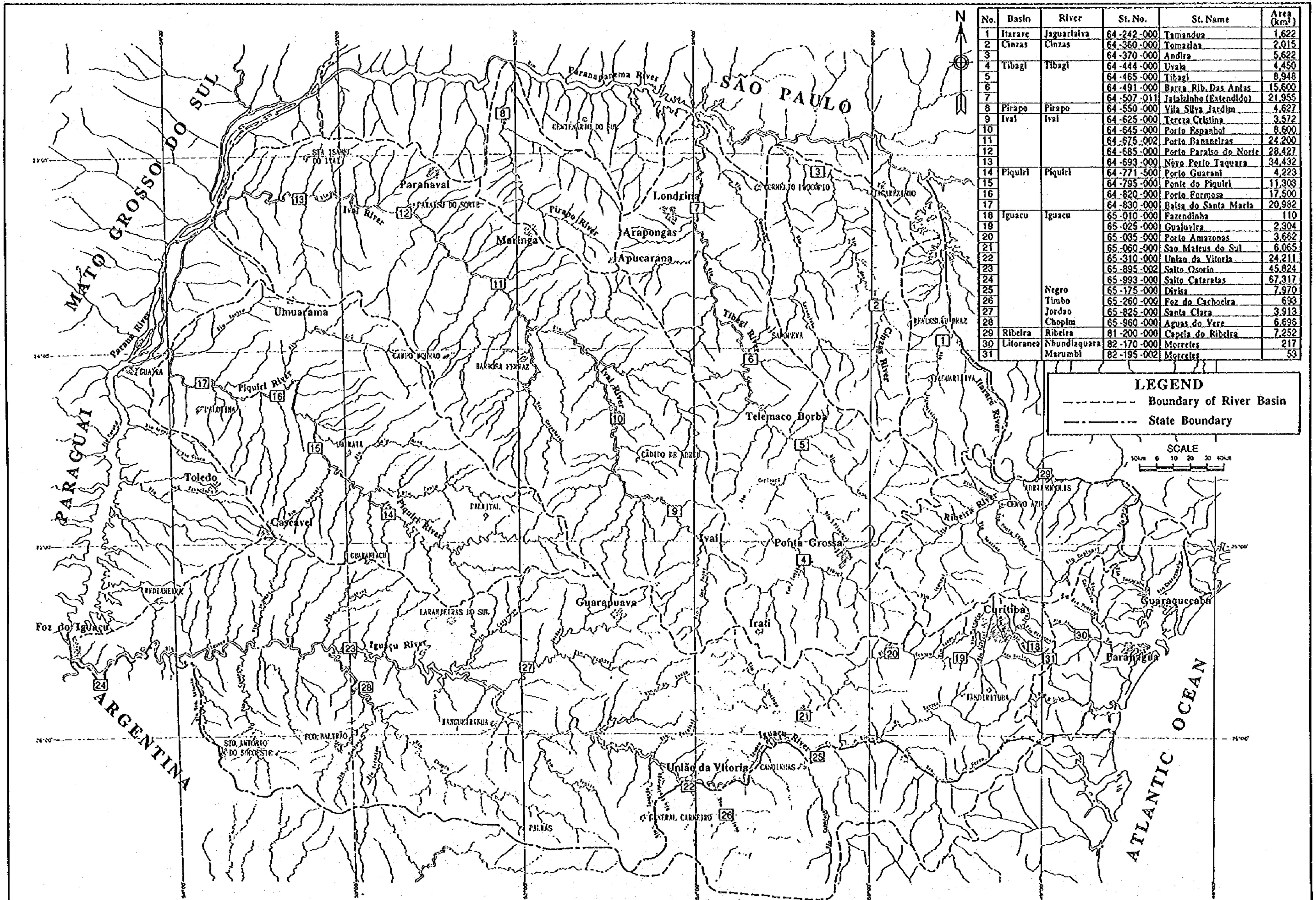
To clarify the flow characteristics of each river basin, 31 hydrological stations were selected as discharge reference points by considering the following conditions; (See Figure-2.3)

- data availability
- balance of catchment area
- accuracy of existing data

Considering the discharge measurement data availability and other collected data as shown in Table-2.1, the simulation period was applied to the last 20 years (1974 to 1993).

2.2.2 Discharge Correlation Analysis

In case that the missing or not-available discharge data were found at each selected station, the correlation equations as shown in Table-2.2 was employed. The simulation period was adapted for the last 20 years (1974 - 1993).



No.	Basin	River	St. No.	St. Name	Area (km²)
1	Itarare	Jaguarlaiva	64-242-000	Tamandua	1,622
2	Cinzas	Cinzas	64-360-000	Tomazina	2,015
3			64-370-000	Andira	5,622
4	Tibagi	Tibagi	64-444-000	Uvala	4,450
5			64-465-000	Tibagi	8,948
6			64-491-000	Barra Rib. Das Antas	15,600
7			64-507-011	Jataizinho (Extendido)	21,955
8	Pirapo	Pirapo	64-550-000	Vila Silva Jardim	4,627
9	Ival	Ival	64-625-000	Tereza Cristina	3,572
10			64-645-000	Porto Espanhol	8,600
11			64-675-002	Porto Bananeiras	24,200
12			64-685-000	Porto Paralso do Norte	28,427
13			64-693-000	Novo Porto Taquara	34,432
14	Piquiri	Piquiri	64-771-500	Porto Guarani	4,223
15			64-795-000	Ponte do Piquiri	11,303
16			64-820-000	Porto Formosa	17,500
17			64-830-000	Balsa do Santa Maria	20,982
18	Iguacu	Iguacu	65-010-000	Fazendinha	110
19			65-025-000	Guajuvira	2,304
20			65-035-000	Porto Amazonas	3,662
21			65-060-000	Sao Mateus do Sul	6,065
22			65-310-000	Uniao da Vitoria	24,211
23			65-895-002	Salto Osorio	45,824
24			65-993-000	Salto Cataratas	67,317
25		Negro	65-175-000	Divisa	7,970
26		Timbo	65-260-000	Foz do Cachoeira	693
27		Jordao	65-825-000	Santa Clara	3,913
28		Chopim	65-960-000	Aguas do Vere	6,696
29	Ribeira	Ribeira	81-200-000	Capela do Ribeira	7,252
30	Litoranea	Nhundiaquara	82-170-000	Morretes	217
31		Marumbi	82-195-002	Morretes	53

Figure - 2.3 Selected Hydrological Stations (Discharge Reference Points)

Table-2.1 Hydrological Data Availability at Each Selected Stations

Basin	River	No	St. No.	St. Name	Area (km2)	Operate by	Opened
Itarare	Jaguariaiva	1	64-242-000	Tamandua	1,622	D	Aug-76
Cinzas	Cinzas	2	64-360-000	Tomazina	2,015	D	Jun-28
		3	64-370-000	Andira	5,622	D	Jun-31
Tibagi	Tibagi	4	64-444-000	Uvaia	4,450	I/C	Jan-74
		5	64-465-000	Tibagi	8,946	D/I/C	Nov-31
		6	64-491-000	Barra Rib. das Antas	15,600	I/C	Feb-74
		7	64-507-011	Jataizinho (Extendido)	21,955	D/CESP	Jul-31
Pirapo	Pirapo	8	64-550-000	Vila Silva Jardim	4,627	D	Oct-67
Ivai	Ivai	9	64-625-000	Tereza Cristina	3,572	D	Aug-56
		10	64-645-000	Porto Espanhol	8,600	I/C	Aug-65
		11	64-675-002	Porto Bananeiras	24,200	I/C	Feb-74
		12	64-685-000	Porto Paraiso do Norte	28,427	D/I/C	Mar-53
		13	64-693-000	Novo Porto Taquara	34,432	D	Jul-74
Piquiri	Piquiri	14	64-771-500	Porto Guarani	4,223	D/I/C	Jul-76
		15	64-795-000	Ponte do Piquiri	11,303	D/I/C	Apr-70
		16	64-820-000	Porto Formoso	17,500	I/C	Jun-66
		17	64-830-000	Balsa do Santa Maria	20,962	D	Sep-69
Iguacu	Iguacu	18	65-010-000	Fazendinha	110	I	Jan-55
		19	65-025-000	Guajuvira	2,304	D	Aug-73
		20	65-035-000	Porto Amazonas	3,662	D	Aug-35
		21	65-060-000	Sao Mateus do Sul	6,065	D	May-30
		22	65-310-000	Uniao da Vitoria	24,211	D/I/C	May-30
		23	65-895-002	Salto Osorio	45,824	D	Oct-40
		24	65-993-000	Salto Cataratas	67,317	D/I/C	Apr-42
	Negro	25	65-175-000	Divisa	7,970	I/C	Dec-63
	Timbo	26	65-260-000	Foz do Cachoeira	693	D	Nov-85
	Jordao	27	65-825-000	Santa Clara	3,913	D/I/C	Aug-49
	Chopim	28	65-960-000	Aguas do Vere	6,696	D/I/C	Jul-56
Ribeira	Ribeira	29	81-200-000	Capela da Ribeira	7,252	D	Oct-38
Litoran.	Nhundiaquara	30	82-170-000	Morretes	217	D	Aug-38
	Marumbi	31	82-195-002	Morretes	53	D	Feb-48

No	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939
1										
2	■	■	■	■	■	■	■	■	■	■
3		■	■	■	■	■	■	■	■	■
4										
5		■	■	■	■	■	■	■	■	■
6										
7		■	W	■	■	■	■	■	■	■
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20						■	■	■	■	■
21	■	■	■	■	■	■	■	■	■	■
22	■	■	■	■	■	■	■	■	■	■
23										
24										
25										
26										
27										
28										
29							O	■	■	■
30									■	■
31										

No	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
1										
2	■	■	■	■	■	■	■	■	■	■
3	■	■	■	■	■	■	■	■	■	■
4										
5	■	■	■	■	■	■	■	■	■	■
6										
7	■	■	■	■	■	■	■	■	■	■
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20	■	■	■	■	■	■	■	■	■	■
21	■	■	W	■	■	■	W	W	■	■
22	■	■	■	■	■	■	■	■	■	W
23	■	W	W	■	W	■	W	W	W	W
24			W	W	W	W	W	W	W	W
25										
26										
27										■
28										
29	■	■	■	■	■	■	■	■	■	■
30	■	■	■	W	■	■	■	■	■	■
31										

No	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
1										
2	■	■	■	■	■	■	■	■	W	■
3	■	■	■	■	■	■	■	■	■	■
4										
5	■	■	■	■	■	■	■	■	■	■
6										
7	■	■	■	■	■	■	■	■	■	■
8										
9							■	W	■	■
10										
11										
12			■	■	■	■	■	■	■	■
13										
14										
15										
16										
17										
18						■	■	■	■	■
19										
20	■	■	■	■	■	■	■	■	■	■
21	■	■	■	■	■	■	W	W	■	■
22	■	■	W	■	■	■	W	■	W	■
23	W	W	■	■	W	W	W	W	■	W
24	W	W	W	■	W	W	W	W	W	W
25										
26										
27	W	■	■	W	W	■	■	W	■	■
28							■	■	■	■
29	■	W	■	■	■	■	■	■	■	■
30	■	W	■	■	■	■	■	■	■	■
31										

No	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1										
2	■	W	W	■	W	■	W	■	W	■
3	■	W	■	■	■	■	■	■	■	■
4										
5	■	■	■	■	W	■	■	■	■	■
6										
7	■	■	■	■	■	W	■	■	■	■
8								W	W	W
9	W	■	■	■	W	■	W	■	W	■
10						■	■	W	■	■
11										
12	■	■	■	■	■	■	■	■	■	■
13										
14										
15										
16							■	W	■	■
17										■
18	■	O	O	■	■	■	■	■	■	■
19										
20	■	■	■	■	■	■	■	■	■	■
21	■	W	W	■	■	W	■	■	■	■
22	■	■	■	■	■	■	■	■	■	■
23	■	W	■	■	W	W	W	■	W	■
24	W	W	W	W	W	W	W	W	W	W
25				O	■	■	W	■	■	■
26										
27	■	■	■	■	W	■	■	■	W	■
28	■	■	■	W	■	■	■	■	■	W
29	■	■	■	■	■	■	W	■	■	■
30	■	■	■	W	■	■	■	■	■	W
31										

No	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1							■	■	■	■
2	■	■	■	■	■	■	■	■	■	■
3	■	■	■	■	■	■	■	■	■	■
4					■	■	■	■	■	■
5	■	■	■	■	■	■	■	■	■	■
6					■	■	■	■	■	■
7	■	■	■	■	■	■	■	■	■	■
8	W	W	W	W	W	W	W	W	W	W
9	■	■	■	■	■	■	■	■	■	■
10	■	W	■	■	■	■	■	■	■	■
11					■	■	■	■	■	■
12	■	■	■	■	■	■	■	■	■	■
13					■	■	■	■	■	■
14							■	■	■	■
15	■	■	■	■	■	■	■	■	■	■
16	■	W	■	■	■	■	■	■	■	■
17	■	■	■	■	■	■	■	■	■	■
18	■	■	■	■	■	■	■	■	■	■
19				O			■	■	■	W
20	■	■	■	■	■	■	■	■	■	■
21	■	■	■	■	■	■	■	■	■	■
22	■	■	■	■	■	■	■	■	■	W
23	■	■	■	■	■	■				
24	W	W	W	W	W	W	W	W	W	W
25	■	■	■	■	■	■	■	■	■	■
26										
27	■	■	■	■	■	■	■	■	■	■
28	■	■	■	■	■	■	■	■	■	■
29	■	■	■	■	■	■	■	■	■	■
30	■	■	■	■	■	■	■	■	■	■
31					O	■	■	■	■	■

No	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
1	■	■	■	■	■	■	■	■	■	W
2	■	■	■	■	■	■	W	W	W	W
3	■	■	■	■	■	■	W	W	W	W
4	■	■	■	■	■	■	■	■	■	■
5	■	■	■	■	■	■	■	■	■	■
6	■	■	■	■	■	■	■	■	■	■
7	■	■	■	■	■	■	■	■	■	■
8	W	W	W	W	W	W	W	■	■	■
9	■	■	■	■	■	■	■	■	■	■
10	■	■	■	■	■	■	■	■	■	■
11	■	■	■	■	■	■	■	■	■	■
12	■	■	■	■	■	■	■	■	■	■
13	■	■	■	■	■	■	■	■	■	■
14	■	■	■	■	■	■	■	■	■	■
15	■	■	■	■	■	■	■	■	■	■
16	■	■	■	■	■	■	■	■	■	■
17	■	■	■	■	■	■	■	■	■	■
18	■	■	■	■	■	■	■	■	■	■
19	W	W	W	W	■	■	■	■	■	■
20	■	■	■	■	■	■	■	■	■	■
21	■	■	■	■	■	■	■	■	■	■
22	■	■	■	■	W	■	■	■	■	■
23			O			W	W	■	■	W
24	■	■	■	■	■	■	■	■	■	■
25	■	■	■	■	■	■	■	■	■	■
26						■	■	■	■	■
27	■	■	■	■	■	■	■	■	■	■
28	■	■	■	■	■	■	■	■	W	■
29	■	■	■	■	■	■	■	■	■	■
30	■	■	■	■	■	■	■	■	■	■
31	■	W	■	■	■	W	W	W	W	■

No	1990	1991	1992	1993
1	■	■	■	■
2	W	W	W	W
3	W	W	W	W
4	■	■	■	■
5	■	■	■	■
6	■	■	■	■
7	■	■	■	■
8	■	■	■	■
9	W	W	W	
10	■	■	■	■
11	■	■	■	■
12	■	■	■	■
13	W	■	W	■
14	■	■	■	■
15	■	■	■	■
16	■	■	■	■
17	■	■	W	■
18	■	■	■	■
19	■	■	■	■
20	■	■	■	■
21	■	■	■	W
22	■	■	■	■
23	W	W	W	W
24	■	■	■	■
25	■	■	■	■
26	■	■	■	■
27	■	■	■	■
28	■	■	■	■
29	■	■	■	W
30	■	■	■	■
31	■	■	■	■

(Note) O :Flow Measurement Data only W : Water Level only, ■ : both water level and FM data are available. D : DNAEE, I : IAP, C: COPEL, CESP: CESP

Table-2.2 Monthly Specific Discharge Correlation Results

Unit ($m^3/sec/100\ km^2$)

No.	River	X Station	Y Station	Y = a + b x X		X = a'+ b' x Y		Correlation Coefficient
				a	b	a'	b'	
1-2	Itarare-Cinzas	64242000, 1622 km2 Tamandua (Itarare)	64360000, 2015 km2 Tomazina (Cinzas)	0.00037	0.84961	-0.00044	1.17701	0.95217
2-3	Cinzas-Cinzas	64360000, 2015 km2 Tomazina (Cinzas)	64370000, 5622 km2 Andira (Cinzas)	-0.00292	1.01074	0.00289	0.98938	0.96013
4-5	Tibagi-Tibagi	64444000, 4450 km2 Uvaia (Tibagi)	64465000, 8948 km2 Tibagi (Tibagi)	0.00157	0.92193	-0.00170	1.08468	0.97371
5-6	Tibagi-Tibagi	64465000, 8948 km2 Tibagi (Tibagi)	64491000, 15600 km2 Barra Rib. das Antas (Tibagi)	0.00131	0.90742	-0.00144	1.10203	0.98892
6-7	Tibagi-Tibagi	64491000, 15600 km2 Barra Rib. das Antas (Tibagi)	64507011, 21955 km2 Jataizinho (Tibagi)	0.00030	0.98994	-0.00031	1.01016	0.98554
7-8	Tibagi-Pirapo	64507011, 21955 km2 Jataizinho (Tibagi)	64550000, 4627 km2 Vila Silva Jardim (Pirapo)	0.00796	0.38490	-0.02068	2.59805	0.73835
9-10	Ivai-Ivai	64625000, 3572 km2 Tereza Cristina (Ivai)	64645000, 8600 km2 Porto Espanhol (Ivai)	0.00366	0.86109	-0.00426	1.16132	0.97828
10-11	Ivai-Ivai	64645000, 8600 km2 Porto Espanhol (Ivai)	64675002, 24200 km2 Porto Bananeiras (Ivai)	0.00363	0.73018	-0.00497	1.36952	0.96137
11-12	Ivai-Ivai	64675002, 24200 km2 Porto Bananeiras (Ivai)	64685000, 28427 km2 Porto Paraiso do Norte (Ivai)	0.00086	0.95612	-0.00090	1.04589	0.98907
12-13	Ivai-Ivai	64685000, 28247 km2 Porto Paraiso do Norte (Ivai)	64693000, 34437 km2 Novo Porto Taquara (Ivai)	0.00206	0.88949	-0.00232	1.12424	0.92718
14-15	Piquiri-Piquiri	64771500, 4223 km2 Porto Guarani (Piquiri)	64795000, 11303 km2 Ponte do Piquiri (Piquiri)	0.00115	1.04025	-0.00110	0.96130	0.97424
15-16	Piquiri-Piquiri	64795000, 11303 km2 Ponte do Piquiri (Piquiri)	64820000, 17500 km2 Porto Formosa (Piquiri)	0.00549	0.70210	-0.00782	1.42430	0.98123
16-17	Piquiri-Piquiri	64820000, 17500 km2 Porto Formosa (Piquiri)	64830000, 20982 km2 Balsa do Santa Maria (Piquiri)	0.00203	0.84994	-0.00239	1.17655	0.97651
18-19	Iguacu-Iguacu	65010000, 110 km2 Fazendinha (Iguacu)	65025000, 2304 km2 Guajuvira (Iguacu)	-0.00119	0.92679	0.00128	1.07899	0.82588
19-20	Iguacu-Iguacu	65025000, 2304 km2 Guajuvira (Iguacu)	65035000, 3662 km2 Porto Amazonas (Iguacu)	-0.00011	0.93787	0.00012	1.06625	0.87600
20-21	Iguacu-Iguacu	65035000, 3662 km2 Porto Amazonas (Iguacu)	65060000, 6065 km2 Sao Mateus do Sul (Iguacu)	0.00044	0.94833	-0.00047	1.05448	0.94533
21-22	Iguacu-Iguacu	65060000, 6065 km2 Sao Mateus do Sul (Iguacu)	65310000, 24211 km2 Uniao da Vitoria (Iguacu)	0.00073	1.11026	-0.00066	0.90069	0.92934
23-24	Iguacu-Iguacu	65895002, 45824 km2 Salto Osorio (Iguacu)	65993000, 67317 km2 Salto Cataratas (Iguacu)	0.00359	0.80064	-0.00449	1.24900	0.96305
21-25	Iguacu-Negro	65060000, 6065 km2 Sao Mateus do Sul (Iguacu)	65175000, 7970 km2 Divisa (Negro, Iguacu)	0.00394	0.86862	-0.00453	1.15125	0.86180
22-25	Iguacu-Negro	65310000, 24211 km2 Uniao da Vitoria (Iguacu)	65175000, 7970 km2 Divisa (Negro, Iguacu)	0.00390	0.76368	-0.00511	1.30946	0.88779
26-22	Timbo-Iguacu	65260000, 693 km2 Foz do Cachoeira (Timbo)	65310000, 24211 km2 Uniao da Vitoria (Iguacu)	0.00362	0.61317	-0.00590	1.63088	0.84700
27-28	Jordao-Chopim	65825000, 3913 km2 Santa Clara (Jordao, Iguacu)	65960000, 6696 km2 Aguas do Vere (Chopim, Iguacu)	-0.00313	1.18238	0.00265	0.84575	0.89169
23-28	Iguacu-Chopim	65895002, 45824 km2 Salto Osorio (Iguacu)	65960000, 6696 km2 Aguas do Vere (Chopim, Iguacu)	0.00499	1.09337	-0.00457	0.91460	0.81493
31-1	Ribeira-Itarare	81200000, 7252 km2 Capela do Ribeira (Ribeira)	64242000, 1622 km2 Tamandua (Itarare)	-0.00542	1.50814	0.00359	0.66307	0.85131
32-33	Litoranea	82170000, 217 km2 Morretes	82195002, 53 km2 Morretes	-0.00205	1.55160	0.00132	0.64450	0.84590

2.2.3 River Flow Simulation

Based on the river flow data for the last 20 years period (1974-1993), daily discharge at each discharge reference point were determined, and the missing daily discharge were determined by monthly discharge correlation analysis among the stations.

The flow regime shows the annual condition using the calculated daily discharge at a certain hydrological station and shall be indicated by the daily discharge and number of exceeded days. The annual flow regime of each selected stations in the Study area shows as follows;

- High Discharge (95th daily discharge from the greatest)
- Normal Discharge (185th daily discharge from the greatest)
- Low Discharge (275th daily discharge from the greatest)
- Drought Discharge (355th daily discharge from the greatest)

The flow regime is commonly used to find the fluctuation in the daily discharge, and utilized for determining the potential water characteristics in Japan.

The flow regime computed by station was adapted for 20 years period (1974-1993), and mean value of the 95th, 185th, 275th and 355th daily discharge for the last 20 years period were calculated. The results of mean flow regime for the last 20 years period are summarized in Table-2.3, and Figure-2.4 shows flow regime curves at the typical selected hydrological stations.

Table-2.3 Flow Regime (mean values for the last 20 years period (1974 - 1993))

Basin	River	No	St. No.	St Name	Area	Daily Discharge (m3/sec)			
					(km2)	95 day	185 day	275 day	355 day
Itarare	Jaguariaiva	1	64-242-000	Tamandua	1,622	33.86	23.56	18.13	13.04
Cinzas	Cinzas	2	64-360-000	Tomazina	2,015	38.19	25.11	18.09	12.20
		3	64-370-000	Andira	5,622	88.26	50.03	34.18	22.32
Tibagi	Tibagi	4	64-444-000	Uvaia	4,450	116.02	64.61	40.56	24.83
		5	64-465-000	Tibagi	8,948	229.39	132.92	87.08	51.69
		6	64-491-000	Barra Rib das Antas	15,600	381.96	230.94	153.34	95.24
		7	64-507-011	Jataizinho (Extendido)	21,955	502.08	312.46	211.73	128.70
Pirapo	Pirapo	8	64-550-000	Vila Silva Jardim	4,627	79.54	61.38	49.43	37.74
Ivai	Ivai	9	64-625-000	Tereza Cristina	3,572	80.26	38.23	21.57	10.98
		10	64-645-000	Porto Espanhol	8,600	220.04	115.48	67.89	37.24
		11	64-675-002	Porto Bananeiras	24,200	561.65	311.55	199.13	120.84
		12	64-685-000	Porto Paraiso do Norte	28,427	650.69	381.95	262.71	173.59
		13	64-693-000	Novo Porto Taquara	34,432	777.78	491.69	355.97	246.35
Piquiri	Piquiri	14	64-771-500	Porto Guarani	4,223	120.83	60.39	33.58	16.61
		15	64-795-000	Ponte do Piquiri	11,303	345.65	186.73	111.87	65.20
		16	64-820-000	Porto Formosa	17,500	498.85	315.78	219.41	143.22
		17	64-830-000	Balsa do Santa Maria	20,982	551.77	368.49	262.97	172.25
Iguacu	Iguacu	18	65-010-000	Fazendinha	110	3.13	1.86	1.29	0.85
		19	65-025-000	Guajuvira	2,304	58.29	35.78	22.03	12.53
		20	65-035-000	Porto Amazonas	3,662	84.96	49.48	30.73	17.17
		21	65-060-000	Sao Mateus do Sul	6,065	136.44	78.47	50.85	30.30
		22	65-310-000	Uniao da Vitoria	24,211	656.67	365.42	232.03	131.34
		23	65-895-002	Salto Osorio	45,624	1310.22	829.86	532.17	262.67
		24	65-993-000	Salto Cataratas	67,317	1690.20	1126.20	792.05	436.76
	Negro	25	65-175-000	Divisa	7,970	195.67	112.64	76.21	49.50
	Timbo	26	65-260-000	Foz do Cachoeira	693	22.90	12.47	7.92	4.52
	Jordao	27	65-825-000	Santa Clara	3,913	126.17	77.18	49.67	28.19
	Chopim	28	65-960-000	Aguas do Vere	6,696	224.80	131.11	78.13	40.14
Ribeira	Ribeira	29	81-200-000	Capela do Ribeira	7,252	130.63	101.75	86.87	72.80
Litoranea	Nhundiaquara	30	82-170-000	Morretes	217	14.43	8.04	4.86	2.56
	Marumbi	31	82-195-002	Morretes	53	5.02	2.77	1.61	0.77

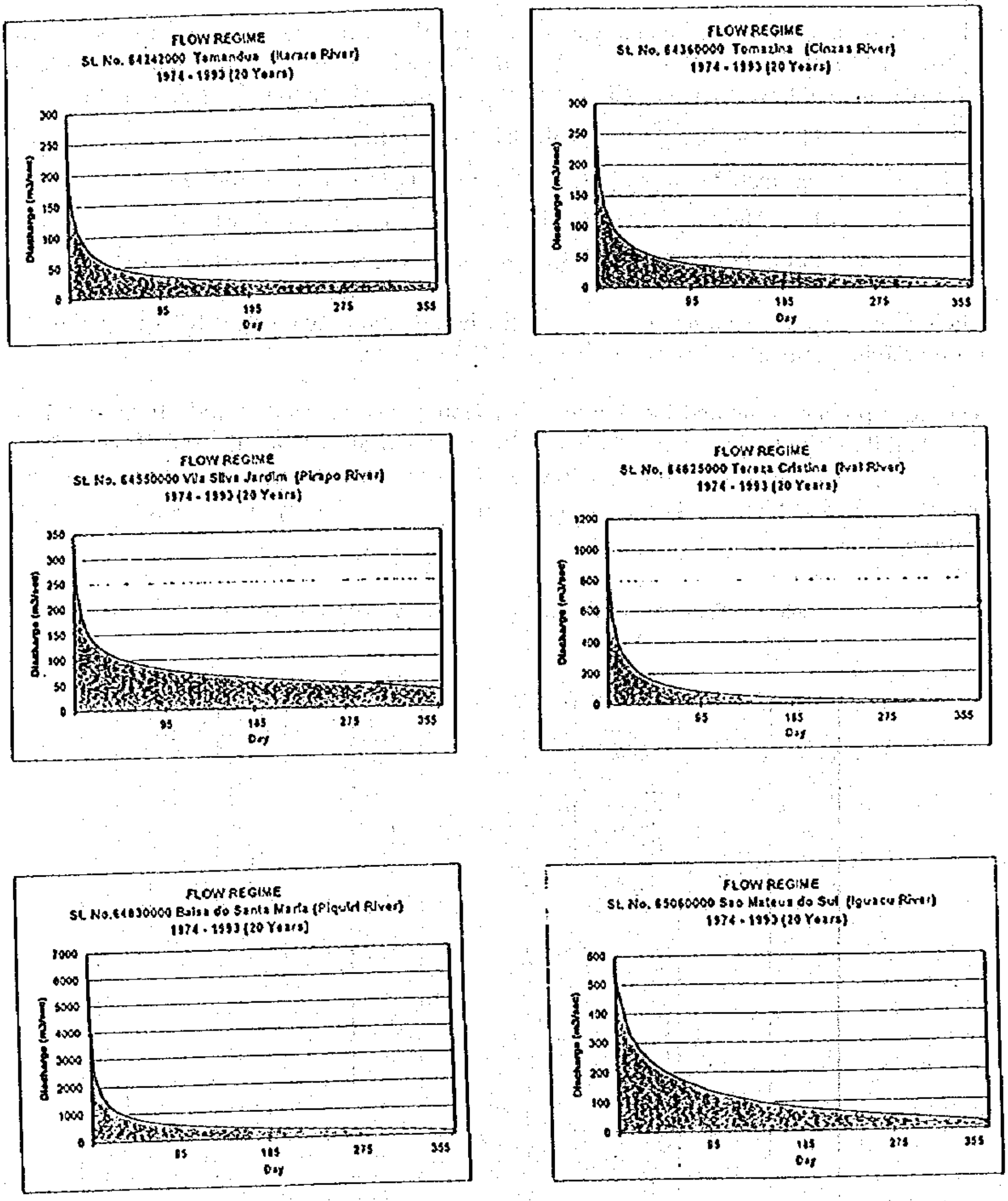


Figure-2.4 Flow Regime (Typical Selected Stations)

2.2.4 Characteristics of River Flow

(1) Monthly Discharge

Using the last 20 years period (1974-1993), the average monthly flow patterns at each discharge reference points were given as Table-2.4.

(2) Monthly Specific Discharge

Based on the monthly mean discharge at each station, monthly mean specific discharge were determined as shown in Table-2.5, and Figure-2.5 shows distribution of monthly mean specific discharge by discharge reference point. Based on Figure-2.5, characteristics of monthly specific discharge are summarized as follows;

<Upper Iguacu>

Monthly specific discharge at the region including Curitiba at the western side of the coast mountain range, Ribeira river basin and Negro river basin ranges from 1.3 to 2.9 m^3/sec/100km^2, with a mean of 2.0 m^3/sec/100km^2. The monthly fluctuation is not clearly existed as compared with other regions.

<North Eastern Region>

Monthly specific discharge at the region including Itarare, Cinzas, Tibagi and Pirapo river basins ranges from 1.1 to 2.7 m^3/sec/100km^2, with a mean of 1.9 m^3/sec/100km^2. The runoff peak exists twice a year from December to February and from May to July.

<Central, Western and Middle and Lower Iguacu Region>

Monthly specific discharge at the region including Ivai, Piquiri, Middle Iguacu and Lower Iguacu river basins ranges from 1.2 to 4.3 m^3/sec/100km^2, with a mean of 2.5 m^3/sec/100km^2. This region has a biggest value in Parana, and especially fluctuation pattern is clearly occurred from May to July.

<Litoranea Region>

The region of coast area has highest value in Parana ranges from 2.6 to 12.3 m^3/sec/100km^2, with a mean of 7.0 m^3/sec/100km^2, and fluctuation of peak runoff occurs on between October and March with different from the patterns of other regions.

Table-2.4 Mean Monthly Flow Pattern

Unit : m3/sec

No.	St. No.	St.Name	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Mean
1	64-242-000	Tamandua	45.99	40.58	34.81	25.35	33.18	37.30	28.05	23.81	27.51	28.32	27.10	38.24	32.53
2	64-360-000	Tomazina	52.65	45.59	37.09	27.11	38.47	40.43	32.06	25.53	30.78	31.13	31.06	43.95	36.15
3	64-370-000	Andira	138.23	102.41	97.54	64.30	85.94	99.06	64.07	51.05	69.25	70.48	73.24	111.35	85.66
4	64-444-000	Uvaia	82.08	75.00	65.94	54.03	96.18	120.68	110.16	88.71	95.95	114.38	92.59	89.25	90.41
5	64-465-000	Tibagi	182.43	163.47	140.72	111.55	198.58	238.47	213.79	163.61	191.69	215.13	180.77	180.37	181.55
6	64-491-000	Barra Rib das Antas	327.14	302.20	257.61	201.20	338.32	394.13	338.93	283.82	311.56	346.62	305.30	310.84	307.81
7	64-507-011	Jataizinho (Extendido)	488.63	430.84	379.40	290.27	457.11	528.12	435.63	335.14	401.53	443.03	400.88	462.21	421.16
8	64-550-000	Vila Silva Jardim	81.47	82.42	79.47	87.93	75.25	78.50	82.64	56.52	58.54	66.78	65.71	81.31	72.29
9	64-625-000	Tereza Cristina	77.04	62.83	52.88	48.32	121.13	108.02	95.06	63.40	98.47	101.19	71.07	73.75	81.08
10	64-645-000	Porto Espanhol	190.83	174.14	140.26	121.24	278.28	248.07	224.57	162.66	225.86	242.70	181.35	199.80	198.98
11	64-675-002	Porto Bananeiras	543.58	489.96	390.28	335.08	631.71	609.57	479.40	381.75	517.65	574.15	489.63	552.41	497.93
12	64-685-000	Porto Paraiso do Norte	653.04	565.38	478.60	404.67	733.08	698.59	585.57	448.66	598.05	659.30	539.50	652.59	583.10
13	64-693-000	Novo Porto Taquara	785.56	726.99	577.55	514.64	868.26	756.70	652.80	523.91	821.86	790.66	651.59	783.11	704.30
14	64-771-500	Porto Guarani	97.35	100.22	82.69	75.04	167.44	141.84	124.49	83.75	120.84	134.39	119.29	137.58	114.58
15	64-795-000	Ponte do Piquiri	300.91	278.30	195.98	220.90	508.62	406.74	336.73	262.26	338.48	387.57	330.28	409.71	331.96
16	64-820-000	Porto Formosa	430.10	409.96	312.43	333.41	649.41	540.12	463.67	376.25	455.60	506.74	466.36	541.19	457.10
17	64-830-000	Balsa do Santa Maria	472.57	450.43	387.95	365.61	655.76	601.71	516.69	432.25	496.95	577.35	532.07	597.53	508.07
18	65-010-000	Fazendinha	3.19	3.07	2.61	2.15	2.68	2.35	2.49	2.02	2.57	2.84	2.52	2.54	2.59
19	65-025-000	Guajuvira	48.82	47.67	44.98	34.92	45.39	48.06	52.10	47.28	47.26	54.58	42.03	45.42	46.38
20	65-035-000	Porto Amazonas	68.69	68.41	64.51	48.35	75.15	76.47	61.53	64.65	72.41	77.89	64.26	67.35	68.72
21	65-060-000	Sao Mateus do Sul	112.98	102.22	93.53	74.29	113.58	133.35	126.44	111.09	114.97	133.59	102.18	108.29	110.54
22	65-310-000	Uniao da Vitoria	467.10	452.99	413.22	325.20	499.24	646.35	624.43	545.11	527.63	622.39	502.15	489.66	509.62
23	65-895-002	Salto Osorio	834.80	788.66	745.53	652.79	1432.93	1436.19	1562.36	1074.56	1164.26	1274.95	1301.89	1104.30	1112.08
24	65-993-000	Salto Cataratas	1221.31	1159.48	1103.50	1020.03	1896.84	1980.93	2007.44	1485.45	1643.48	1773.19	1748.53	1518.51	1546.89
25	65-175-000	Divisa	156.59	145.65	135.47	105.44	147.24	176.70	175.68	170.82	165.32	184.76	148.95	158.27	155.91
26	65-260-000	Foz do Cachoeira	18.69	17.05	14.66	11.31	21.35	21.15	25.22	21.16	19.88	24.34	19.51	19.71	19.45
27	65-825-000	Santa Clara	92.87	85.28	71.61	72.10	155.48	134.79	141.32	94.51	114.08	135.21	121.26	115.84	111.15
28	65-960-000	Aguas do Vere	141.38	132.04	111.42	128.25	287.06	283.57	309.19	181.74	210.62	238.87	243.34	171.52	203.58
29	81-200-000	Capela do Ribeira	140.47	136.04	128.81	102.45	134.17	139.15	125.97	108.62	124.07	122.74	118.60	128.97	125.50
30	82-170-000	Morreles	17.41	17.07	18.19	11.73	10.39	8.81	7.24	5.74	10.07	13.39	13.93	14.15	12.01
31	82-195-002	Morreles	6.55	5.82	5.24	3.83	3.79	2.48	2.68	2.44	3.96	5.86	5.02	5.68	4.45

Data Source : COPEL

Table-2.5 Mean Monthly Specific Discharge

Unit : m3 / sec / 100km2

No.	St. No.	St.Name	Catchment Area (km2)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Mean
1	64-242-000	Tamandua	1,622	2.835	2.502	2.146	1.563	2.046	2.305	1.729	1.468	1.696	1.746	1.871	2.358	2.005
2	64-360-000	Tomazina	2,015	2.813	2.263	1.841	1.346	1.810	2.007	1.591	1.267	1.527	1.545	1.541	2.161	1.794
3	64-370-000	Andira	5,622	2.459	1.822	1.735	1.144	1.547	1.762	1.140	0.908	1.232	1.254	1.303	1.951	1.524
4	64-444-000	Uvaia	4,450	1.844	1.685	1.482	1.214	2.161	2.712	2.475	1.993	2.156	2.570	2.081	2.006	2.032
5	64-465-000	Tibagi	8,948	2.039	1.827	1.573	1.247	2.219	2.643	2.389	1.626	2.142	2.404	2.020	2.016	2.029
6	64-491-000	Barra Rib.das Antas	15,600	2.097	1.937	1.651	1.290	2.156	2.526	2.160	1.691	1.997	2.222	1.957	1.993	1.973
7	64-507-011	Jataizinho (Extendido)	21,955	2.230	1.963	1.726	1.322	2.082	2.405	1.954	1.527	1.829	2.018	1.826	2.105	1.918
8	64-550-000	Vila Silva Jardim	4,627	1.977	1.781	1.717	1.468	1.626	1.896	1.354	1.221	1.267	1.443	1.420	1.757	1.562
9	64-625-000	Tereza Cristina	3,572	2.157	1.759	1.480	1.353	3.391	3.024	2.661	1.775	2.757	2.833	1.990	2.065	2.270
10	64-645-000	Porto Espanhol	8,600	2.219	2.025	1.831	1.410	3.236	2.881	2.611	1.891	2.826	2.822	2.109	2.323	2.314
11	64-675-002	Porto Bananeiras	24,200	2.246	2.025	1.613	1.385	2.610	2.519	1.981	1.577	2.139	2.373	1.941	2.283	2.058
12	64-685-000	Porto Paraiso do Norte	28,427	2.297	1.989	1.684	1.424	2.579	2.458	1.990	1.578	2.104	2.319	1.898	2.296	2.051
13	64-693-000	Novo Porto Taquara	34,432	2.281	2.111	1.877	1.495	2.516	2.198	1.896	1.522	2.387	2.296	1.892	2.274	2.045
14	64-771-500	Porto Guarani	4,223	2.305	2.373	1.485	1.777	3.965	3.359	2.948	2.220	2.862	3.182	2.825	3.258	2.713
15	64-795-000	Ponte do Piquiri	11,303	2.662	2.482	1.734	1.954	4.500	3.599	2.979	2.320	2.977	3.429	3.002	3.625	2.937
16	64-820-000	Porto Formosa	17,500	2.458	2.343	1.785	1.805	3.711	3.086	2.650	2.150	2.603	2.896	2.665	3.093	2.612
17	64-830-000	Balsa do Santa Maria	26,952	2.252	2.194	1.849	1.742	3.125	2.868	2.493	2.080	2.368	2.752	2.536	2.849	2.421
18	65-010-000	Fazendinha	110	2.904	2.790	2.373	1.955	2.435	2.139	2.262	1.634	2.337	2.581	2.289	2.305	2.350
19	65-025-000	Guajuvira	2,304	2.032	2.069	1.952	1.516	1.970	2.066	2.261	2.052	2.051	2.369	1.824	1.971	2.013
20	65-035-000	Porto Amazonas	3,662	1.876	1.613	1.762	1.320	2.052	2.068	2.226	1.766	1.977	2.127	1.673	1.639	1.877
21	65-060-000	Sao Mateus do Sul	6,065	1.863	1.685	1.542	1.225	1.873	2.199	2.085	1.832	1.896	2.203	1.665	1.785	1.823
22	65-310-000	Uniao da Vitoria	24,211	1.929	1.871	1.707	1.343	2.062	2.870	2.579	2.251	2.179	2.571	2.074	2.023	2.105
23	65-895-002	Salto Osorio	45,824	1.822	1.721	1.627	1.425	3.127	3.139	3.453	2.345	2.541	2.782	2.841	2.410	2.427
24	65-993-000	Salto Cataratas	67,317	1.814	1.722	1.639	1.515	2.818	2.952	2.982	2.207	2.441	2.634	2.597	2.253	2.298
25	65-175-000	Divisa	7,970	1.965	1.827	1.700	1.323	1.847	2.217	2.204	2.143	2.074	2.318	1.869	1.986	1.956
26	65-260-000	Foz do Cachoeira	693	2.687	2.450	2.115	1.632	3.081	3.052	3.640	3.054	2.869	3.512	2.815	2.644	2.806
27	65-825-000	Santa Clara	3,913	2.368	2.179	1.830	1.843	3.973	3.445	3.811	2.405	2.815	3.455	3.099	2.960	2.840
28	65-960-000	Aguas do Vere	6,696	2.111	1.972	1.684	1.865	4.287	4.235	4.618	2.714	3.145	3.567	3.724	2.562	3.040
29	81-200-000	Capela do Ribeira	7,252	1.937	1.876	1.778	1.413	1.850	1.919	1.737	1.490	1.711	1.692	1.608	1.751	1.731
30	82-170-000	Morreles	217	8.025	7.868	7.480	5.406	4.789	3.140	3.337	2.644	4.838	8.173	6.419	6.519	5.535
31	82-195-002	Morretes	53	12.359	10.986	9.891	7.313	7.149	4.651	5.064	4.807	7.467	11.058	9.465	10.710	8.393

Data Source : COPEL

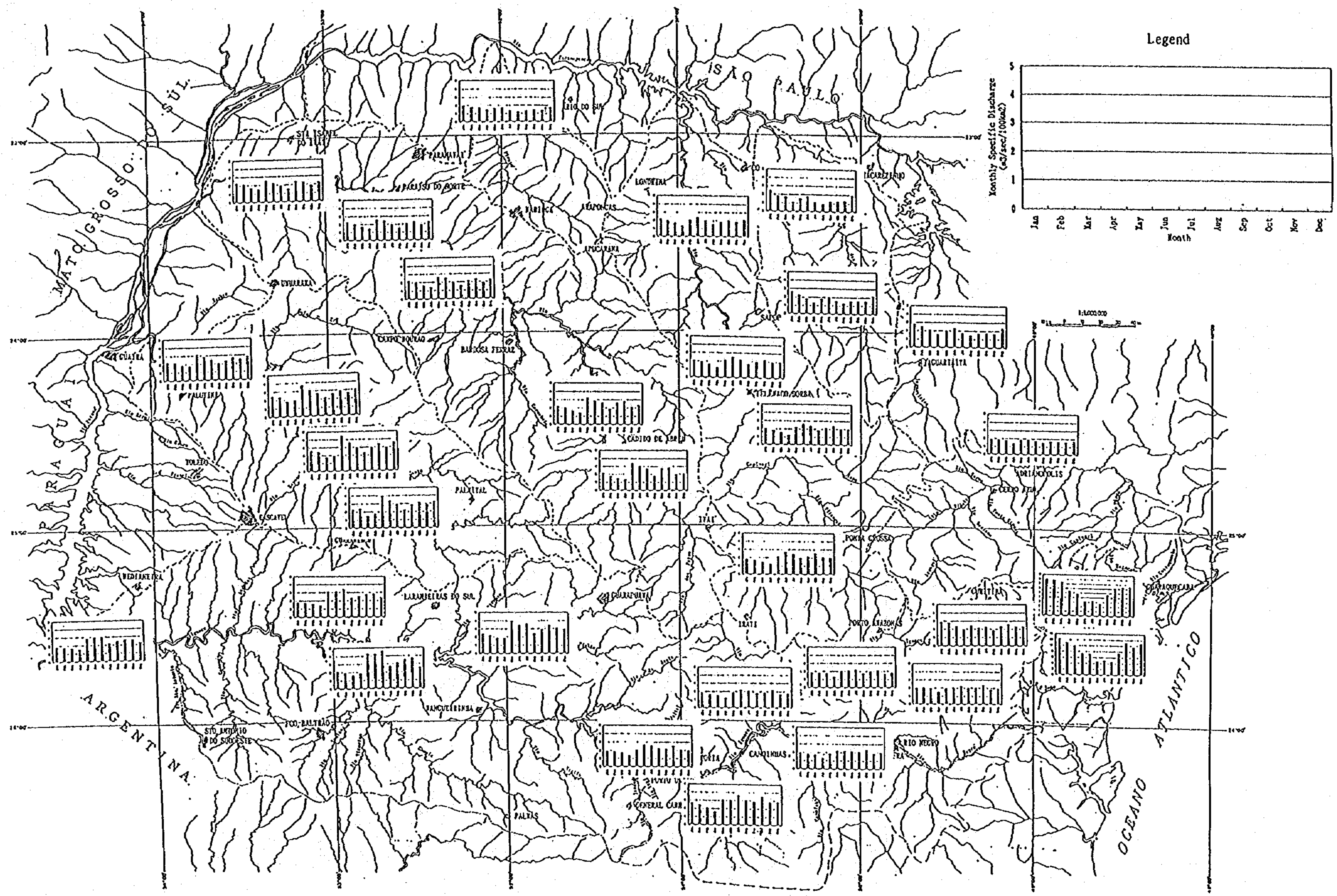


Figure-2.5 Mean Monthly Specific Discharge Distribution

2.2.5 Probable Discharge Analysis

Using annual maximum daily discharge data by each discharge reference point, probable discharge by discharge reference point were computed using plotting position method.

The simulation period were adapted available period by the selected station in order to determine an general tendency of peak flood discharge in this section.

(1) Plotting Position Method (Source:Ministry of Construction in Japan)

Probability papers can be used for a brief estimation of the probability or random hydrological quantities. Typical methods for giving the plotting position of samples are widely known as Weibull (1939) (or Tomas plot, 1948) and Hazen (1930) plotting position methods.

Weibull plot can give the expected value of plotting position of order statistics, when samples are regarded as a set of order statistics. On the other hand, Hazen plot corresponds to the median of each interval of each sample value represented by a histogram and is a simple method. Weibull plot is rational for empirically presuming the distribution and gives a slightly larger hydrological quantity compared to Hazen plot at the upper tail of distribution for the same probability of exceedance or non-exceedance, which means at the safe side in planning point of view. Thus, the use of Weibull plot is very reasonable when making simplified estimations based on probability paper.

Weibull Plot $$P(xj) = \frac{J}{N+1} \text{ or } F(xi) = \frac{i}{N+1}$$ ....(Equation 2.1)

Hazen Plot $$P(xj) = \frac{2j-1}{2N} \text{ or } F(xi) = \frac{2i-1}{2N}$$ ....(Equation 2.2)

where, P(xj) : probability of exceedance of a certain value of a hydrological quantity xj

F(xi) : probability of non-exceedance of a certain value of a hydrological quantity xi

j : order of xj from the greatest value of sample

i : order of xi from the lowest value of sample

N : size of samples

Using annual maximum daily discharge data by each discharge reference point, probable discharge by discharge reference point were computed using both Weibull (1939) (or Tomas plot,1948) and Hazen (1930) plotting position methods.

(2) Distribution Function Formula (Source:Ministry of Construction in Japan)

Shape of frequency distribution of hydrological quantities varies depending on the kind of hydrological elements and method of drawing samples and thus precautions should be taken. In this study, two distribution types were applied as follows;

1) Logarithmic Normal Type Distribution

Although hydrological quantities can be approximated to normal distribution as they are, or by means of logarithmic conversion or the conversion of square root or cubit root, the logarithmic normal distribution is often used since a widely applicable method of analysis has been established for the logarithmic normal distribution. Basic formula for logarithmic normal distribution is shown as below,

$$P(x) = 1 - F(x) = \frac{1}{\sqrt{2\pi}}\int_u^{\infty} e^{-u^2/2}du = \frac{1}{\sqrt{\pi}}\int_{\xi}^{\infty} e^{-\xi^2}d\xi \quad \text{......(Equation 2.3)}$$

$$u = a'\log\frac{x+b}{xo+b} \quad \text{or} \quad \xi = a\cdot\log\frac{x+b}{xo+b}$$

$$\log(x+b) = \log(xo+b) + \frac{1}{a'}\cdot u = \log(xo+b) + \frac{1}{a}\cdot\xi \quad \text{......(Equation 2.4)}$$

$$a, a' > 0, \quad xo > -b, \quad -b < x < \infty$$

where, x : random hydrological quantity

u & ξ : values converted from x, standard normal variables

F(x) : probability of non-exceedance of x

P(x) : probability of exceedance of x

xo, a, a', b : constant values

$a' = a\cdot\sqrt{2}\cdot, u = \xi\cdot\sqrt{2}$,

Constant values in the functions are normally estimated based on samples and they can be estimated by Iwai's method, moment method, least square method and others.

<Least Square Method>

This method computed a regression line to fit the plotted data.

<Iwai's Method>

This method considers that the technique of normal distribution and empirical distribution for estimating three parameters xo, a' and b in logarithmic normal distribution given by (Equation 2.3) and (Equation 2.4).

- Estimation of b :

When a sample size (number of years of data) for hydrological quantity x is N, a median value xg (first approximate value of xo) should first determined.

$$b = \frac{1}{m}\sum_{s=1}^{m} bs \quad \text{......(Equation 2.5)}$$

where, $bs = \frac{xl\,xs - xg^2}{2xg - (xl + xs)}, (l = N - s - 1)$

with $m \approx N/10$, bs should be calculated for s=1,2,...m and then b should be determined. bs should be determined based on the s-th value xs, l-th values or (N-s+1)-th values xl and xg.

$$xg : \log xg = \frac{1}{N}\sum_{i=1}^{N} \log xi$$

xg is a median value (first approximate value of xo)

- Estimation of xo and 1/a'

$$\log (xo + b) = \frac{1}{N}\sum_{i=1}^{N} \log (xi + b) \quad \text{.....(Equation 2.6)}$$

$$\frac{1}{a'} = \sqrt{V} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N} \{\log (xi + b) - \log (xo + b)\}^2}$$

$$= \sqrt{\frac{1}{N-1}\sum_{i=1}^{N} \{\log (xi + b)\}^2 - \frac{N}{N-1}\{\log (xo + b)\}^2} \quad \text{...(Equation 2.7)}$$

The procedure for estimating constants shown above and (Equation 2.4) is normally applied for examining the maximum-value-side of distribution but can also be applied to the minimum-value-side as long as the value of b is carefully handled. That is, if the minimum value of x as characteristics of hydrological quantity to be applied has to be zero or larger, then b = 0 or b < 0. Therfore, if b > 0 in (Equation 2.5) to (Equation 2.7), the remaining constants xo and 1/a' should be determined using b = 0. If b =0, the distribution curve shows a straight line on logarithmic normal probability paper. For this purpose, if the sample distribution shows a curve and the adaptability of distribition applied is not good, it is desired to apply the logarithmic normal distribution with the upper side bounded, that is suitable for the minimum-value-side of distribution.

<Estimating Constants by Moment Method (Ishihara and Takase's Method)>

This method can determined the constant values based on the moment.

- Estimation of 1/a'

$$\frac{1}{a'} = \frac{\log e}{\sqrt{2}} \cdot \frac{1}{k} = 0.30709 \cdot \frac{1}{k} \quad \text{.....(Equation 2.8)}$$

1/k should be determined by the following procedure: First, find the skew coefficient of samples, Csl

$$Csl = \frac{\sum_{i=1}^{N}(xi - \bar{x})^3}{(N-1)\sigma x^3} = \sqrt{\frac{N-1}{N}} \cdot \frac{\overline{x^3} - 3(\overline{x^2}) \cdot \bar{x} + 2(\bar{x})^3}{\{\overline{x^2} - (\bar{x})^2\}^{\frac{3}{2}}} \quad \text{.....(Equation 2.9)}$$

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} xi, \overline{x^2} = \frac{1}{N}\sum_{i=1}^{N} xi^2, \overline{x^3} = \frac{1}{N}\sum_{i=1}^{N} xi^3$$

Then, find the skew coefficient of population, Cs

$$Cs = Csl(1 + \beta s) \quad \text{.....(Equation 2.10)}$$

βs is correction coefficient of the skew coefficient of samples as shown in Figure-2.6, and 1/k should be determined from this coefficient.

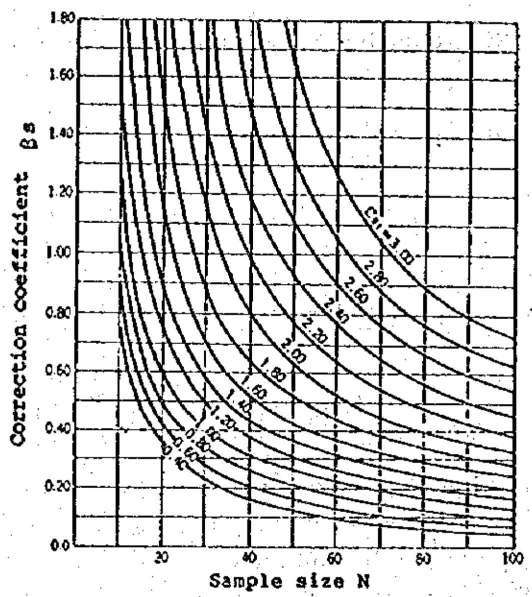


Figure-2.6 Correction Coefficient βs for Skew Coefficient of Samples, Csl
(Logarithmic normal distribution : by Ishihara and Takase's method and Hazen plot)

$$Cs = \frac{e^{9/4k^2} - 3e^{5/4k^2} + 2e^{3/4k^2}}{(e^{1/k^2} - e^{1/2k^2})^{3/2}}$$

$$\therefore \frac{1}{k} = \left[2\ln\left\{\sqrt[3]{1 + \frac{1}{2}Cs^2 + \frac{1}{2}Cs\sqrt{4 + Cs^2}} + \sqrt[3]{1 + \frac{1}{2}Cs^2 - \frac{1}{2}Cs\sqrt{4 + Cs^2}} - 1\right\}\right]^{1/2}$$

.....(Equation 2.11)

- Estimation of b, xo

$$b = \frac{1}{\sqrt{\lambda^2 - 1}}\sigma x - mx \equiv A_3\sigma x - mx$$

$$xo - mx - \frac{\lambda - 1}{\lambda(\lambda^2 - 1)}\sigma x \equiv mx - B_3\sigma x$$ .....(Equation 2.12)

$$xo + b = \frac{\lambda}{\lambda\sqrt{\lambda^2 - 1}}\sigma x \equiv C_3\sigma x$$

where, $\lambda = \exp\left(\frac{1}{4k^2}\right)$

$$mx \equiv \bar{x} = \frac{1}{N}\sum_{i=1}^{N} xi, \qquad \sigma x \equiv \sqrt{Vx} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(xi - \bar{x})^2}$$

Method of solution by moments stated above is based on the empirical correration method utilizing sample distribution (based on Hazen plot) in (Equation

2.10).The results of this method can approximate relatively well the theoretical solutions of distribution functions.

2) Extreme Value Distribution (Type I)

This distribution is derived as the distribution of the maximum values of data in a group taken from a population having exponential type distribution, and the data of maximum values of hydrological quantities of each year can be suited to this distribution in many cases. This distribution shows a straight line on the extreme value probability paper. Basic formula for extreme value distribution is shown as below;

$$P(x) = 1 - \exp(-e^{-y}) \qquad \text{............(Equation 2.13)}$$

$$y = a(x - xo) \text{ or } x = xo + \frac{1}{a}y \qquad \text{............(Equation 2.14)}$$

$$a, xo > 0, \quad -\infty < x < \infty$$

where, x : random hydrological quantity (annual maximum value)
y : standard extreme variable transformation of x
P(x) : probability of exceedance
xo, a : constant values

Constant values xo, and a in the above formulae are normally estimated based on samples, and various methods of estimation are available such as Gumbel's method (moment method), Kimball's method.

<Estimating Constants by Gumbel's Method>

$$\frac{1}{a} = \frac{Sx}{Sy}$$

$$xo = \bar{x} - \frac{1}{a}\bar{y} \qquad \text{.....(Equation 2.15)}$$

where, $\bar{x} = \frac{1}{N}\sum_{i=1}^{N} xi \quad S_x = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(xi - \bar{x})^2} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} xi^2 - (\bar{x})^2}$

.........(Equation 2.16)

For y, (Equation 2.13) can be rewritten as shown below with respect to sample No. i = 1, 2,.., N.

Using Weibull plotting method,

$$yi = -\ln\{-\ln(1 - P(x))\} = -\ln(-\ln\frac{i}{N+1}) \qquad \text{....(Equation 2.17)}$$

Then, $\bar{y}$ and S_y should be determined from the following formula;

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} yi, \qquad Sy = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(yi - \bar{y})^2} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} yi^2 - \bar{y}^2} \qquad \text{....(Equation 2.18)}$$

$\bar{y}$ and Sy are determined only by N and also can be obtained from the table proposed by Gumbel. In the above method of solution, the plotting position samples is utilized together with the Weibull plot as shown in (Equation 2.17).

(2) Results of Probable Discharge Analysis

The results of probable discharge calculation were applied the above methods, and Table-2.6 shows only results of Gumbel's method and Figure-2.6 shows results of four methods such as least square method, moment method, Iwai method and Gumbel's method at typical discharge reference points in this Study.

Table-2.6 Summary of Probable Discharge at Typical Discharge Reference Points (Gumbel's Method)

Unit : (m3/sec)

Basin	River	No.	St. No.	St.Name	Period	Catchment Area (km²)	Probable Year 2	5	10	30	50	100
Itarare	Jaguariaiva	1	64-242-000	Tamandua	1976-1993	1,622	243.7	485.7	646.0	888.1	998.6	1,147
Cinzas	Cinzas	2	64-360-000	Tomazina	1931-1993	2,015	231.5	379.4	477.3	625.2	692.8	783
		3	64-370-000	Andira	1931-1993	5,622	588.0	917.0	1,134.8	1,464.0	1,614.2	1,816
Tibagi	Tibagi	4	64-444-000	Uvaia	1974-1993	4,450	328.8	500.6	614.4	786.4	864.8	970
		5	64-465-000	Tibagi	1931-1993	8,948	652.7	1,056.6	1,317.4	1,711.5	1,891.5	2,134
		6	64-491-000	*1) Barra Rib.das Antas	1941-1993	15,600	1,222.8	1,878.8	2,313.1	2,969.3	3,268.9	3,673
		7	64-507-011	Jataizinho (Extendido)	1931-1993	21,955	1,921.4	3,172.5	4,000.9	5,252.7	5,824.1	6,594
Pirapo	Pirapo	8	64-550-000	Vila Silva Jardim	1967-1993	4,627	310.8	437.4	521.2	647.8	705.6	783
Ivai	Ivai	9	64-625-000	Tereza Cristina	1957-1992	3,572	979.7	1,445.0	1,753.0	2,218.5	2,431.0	2,717
		10	64-645-000	Porto Espanhol	1965-1993	8,600	1,716.7	2,495.0	3,010.2	3,788.8	4,144.2	4,623
		11	64-675-002	Porto Bananeiras	1974-1993	24,200	3,552.7	4,681.0	5,428.1	6,556.9	7,072.2	7,767
		12	64-685-000	Porto Paraiso do Norte	1953-1993	28,427	3,610.7	4,820.4	5,621.3	6,831.4	7,383.9	8,129
		13	64-693-000	Novo Porto Taquara	1974-1993	34,432	4,120.6	5,324.2	6,121.1	7,325.2	7,874.8	8,616
Piquiri	Piquiri	14	64-771-500	Porto Guarani	1976-1993	4,223	1,513.2	1,996.4	2,316.4	2,799.8	3,020.5	3,318
		15	64-795-000	*2) Ponte do Piquiri	1970-1993	11,303	3,493.3	4,938.2	5,894.9	7,340.5	8,000.4	8,890
		16	64-820-000	Porto Formosa	1966-1993	17,500	3,061.4	4,470.4	5,403.3	6,812.9	7,456.4	8,324
		17	64-830-000	*2) Balsa do Santa Maria	1969-1993	20,982	3,331.3	4,519.1	5,305.5	6,493.8	7,036.2	7,767
Iguacu	Iguacu	18	65-010-000	Fazendinha	1955-1993	110	11.2	14.8	17.1	20.7	22.3	24
		19	65-025-000	Guajuvira	1976-1993	2,304	200.2	375.4	491.4	666.7	746.7	854
		20	65-035-000	Porto Amazonas	1935-1993	3,662	291.1	452.1	558.7	719.7	793.2	892
		21	65-060-000	Sao Mateus do Sul	1930-1993	6,065	380.9	587.5	724.3	930.9	1,025.3	1,152
		22	65-310-000	Uniao da Vitoria	1930-1993	24,211	1,460.4	2,182.1	2,659.9	3,381.9	3,711.5	4,156
		23	65-895-002	Salto Osorio	1940-1993	45,824	4,289.7	7,989.2	10,438.5	14,139.6	15,829.2	18,108
		24	65-993-000	Salto Cataratas	1926-1993	67,317	8,065.4	14,095.9	18,088.6	24,121.8	26,876.0	30,590
	Negro	25	65-175-000	Divisa	1964-1993	7,970	491.9	644.8	746.0	899.0	968.8	1,063
	Timbo	26	65-260-000	Foz do Cachoeira	1974-1993	693	124.0	219.3	283.1	378.9	422.6	481
	Jordao	27	65-825-000	Santa Clara	1949-1993	3,913	615.0	1,092.3	1,408.3	1,885.8	2,103.8	2,397
	Chopim	28	65-960-000	Aguas do Vere	1956-1993	6,696	1,394.6	2,343.6	2,971.8	3,921.2	4,354.6	4,939
Ribeira	Ribeira	29	81-200-000	Capela do Ribeira	1936-1993	7,252	655.9	993.0	1,216.2	1,553.5	1,707.4	1,915
Litoranea	Nhundiaquara	30	82-170-000	Morretes	1938-1993	217	111.5	153.0	180.4	221.9	240.8	266
	Marumbi	31	82-195-002	Morretes	1975-1993	53	55.1	78.2	93.4	116.5	127.0	141

Note : *1) : The data period from 1947 to 1973 are not available.
*2) : These results are not accurate enough, because of the data source

Figure-2.7 Results of Probable Discharge at Typical Discharge Reference Points
(Weibull Plotting Position Method