Part – B

Tables

Table B-1 MEAN MONTHLY DISCHARGE FOR THE REPRESENTATIVE 5-YEAR DRAUGHT YEAR

No.	Name of Major River Basin	Name of Representative Stream Gauging Station	Catchment Area at S.G. (km2)	Annual Runoff Cycle	Representative Drought Year (1)	Mean Monthly Discharge for Representative 5-Year Draught Year in m³/sec (1)												
						1	2	3	4	5	6	7	8	9	10	11	12	Mean
1	Laoag	Laoag R. @ Laoag City	1355	Aug-July	1989	259.1	98.7	118.3	25.6	13.3	11.7	7.1	4.8	4.3	5.3	39.9	269.4	71.5
2	Abra	Abra R. @ Bumagcat	2575	Aug-July	1975	187.3	103.6	354.3	192.1	20.6	17.7	17.5	17.4	17.7	21.8	30.2	32.1	84.4
3	Cagayan	Pinacanauan R. @ Tuguegarao	646	Jan-Dec	1964	32.1	27.3	17.0	10.5	9.9	19.0	18.7	50.7	60.9	106.5	467.3	101.1	76.8
4	Abulog	Abulog R. @ Bulu	1609	Oct-Sept	1977	97.7	276.3	171.6	135.2	95.6	66.77	55.4	65.0	49.0	196.1	139.6	305.5	137.8
5	Agno	Ambayoan R. @ Sta. Maria	281	Aug-July	1964	39.4	60.7	15.2	11.3	6.7	6.4	5.4	3.7	3.4	7.0	10.7	9.8	15.0
6	Pampanga	Pampanga R. @ Arayat, Camba	6487	Aug-July	1960	285.3	474.7	239.9	263.5	132.5	75.3	62.2	36.4	23.7	29.0	183.2	260.8	172.2
7	Pasig-Laguna	Panaysayan R. @ Gen. Trias	30	Aug-July	1986	1.3	0.6	1.6	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	1.6	0.6
8	Amnay-Patrick	Caguray R. @ Otoyan, San Jose	136	Aug-July	1967	13.9	12.8	7.1	9.0	8.7	8.6	6.1	4.9	4.4	4.2	9.6	13.8	8.6
9	Bicol	Bicol R. @ Sto. Domingo	905	Oct-Sept	1970	18.5	15.9	51.2	39.5	17.7	12.3	10.0	6.7	4.9	23.8	59.6	57.2	26.4
10	Catanduanes Island	Payo R. @ San Miguel	29	Jan-Dec	1983	1.5	1.0	0.5	0.3	0.3	0.2	0.6	0.9	1.0	1.9	9.9	7.5	2.1
11	Panay	Panay R. @ Tacas Cuartero	880	Jan-Dec	1987	38.6	26.0	6.4	3.0	3.2	10.9	27.5	42.0	36.1	33.6	85.8	61.5	31.2
12	Jalaur	Jalaur R. @ Calyan, Potatan	1499	Oct-Sept	1995	43.9	2.9	12.3	6.7	1.3	0.8	0.2	5.1	10.1	16.6	53.7	53.6	17.3
13	Ilog-Hilanbangan	Ilog R. @ Pandan Orong	346	Aug-July	1978	244.2	208.7	16.0	19.7	6.4	6.7	5.8	5.3	5.3	10.1	20.2	47.8	49.7
14	Cebu Island	Carcar R. @ Carcar	31	Nov-Oct	1990	0.4	0.3	0.3	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
15	Bohol Island	Wahig-Pamacsalan R. @ Pilar	141	Jan-Dec	1988	1.2	1.9	0.8	1.1	0.6	1.9	1.9	3.5	2.6	5.3	12.7	10.2	3.6
16	Leyte Island	Daguitan R. @ Burauen	135	Jan-Dec	1975	7.5	13.5	7.3	6.6	7.3	7.3	6.5	7.0	5.9	5.3	10.4	14.8	8.3
17	Samar Island	Tenane R. @ Wright	346	Jan-Dec	1972	67.5	11.9	9.0	6.6	4.0	11.2	6.3	4.5	18.0	4.9	25.9	31.8	16.8
18	Agusan	Agusan R. @ Kalaw Bridge	1355	Jan-Dec	1960	59.7	75.1	38.5	42.8	37.4	49.3	62.8	57.5	52.7	55.2	97.3	215.0	70.3
19	Tagaloan	Tagaloan R. @ Pina-auan	533	Oct-Sept	1988	34.7	35.7	26.2	10.2	11.3	8.6	15.9	16.6	16.6	26.6	25.2	38.6	22.2
20	Cagayan De Oro	Cagayan R. @ Uguiaban	532	Oct-Sept	1987	61.2	54.4	41.1	38.1	43.9	28.0	28.7	37.5	42.4	61.2	72.9	38.4	45.7
21	WRR 11 (3)	Padada R. @ Lapulabao	821	Aug-July	1956	14.5	19.9	27.2	12.5	12.7	8.5	4.6	4.7	14.6	23.4	17.2	14.1	14.5
22	Agus	Lake Lanao Inflow	1681	June-May	1986	93.0	45.0	48.0	79.0	149.0	99.0	109.0	62.0	106.0	43.0	46.0	44.0	76.9
23	Mindanao	Pulangi R. No. 4	3100	Jan-Dec	1973	65.6	63.2	52.0	74.0	57.8	81.0	154.7	141.8	262.0	105.7	206.9	94.8	113.3

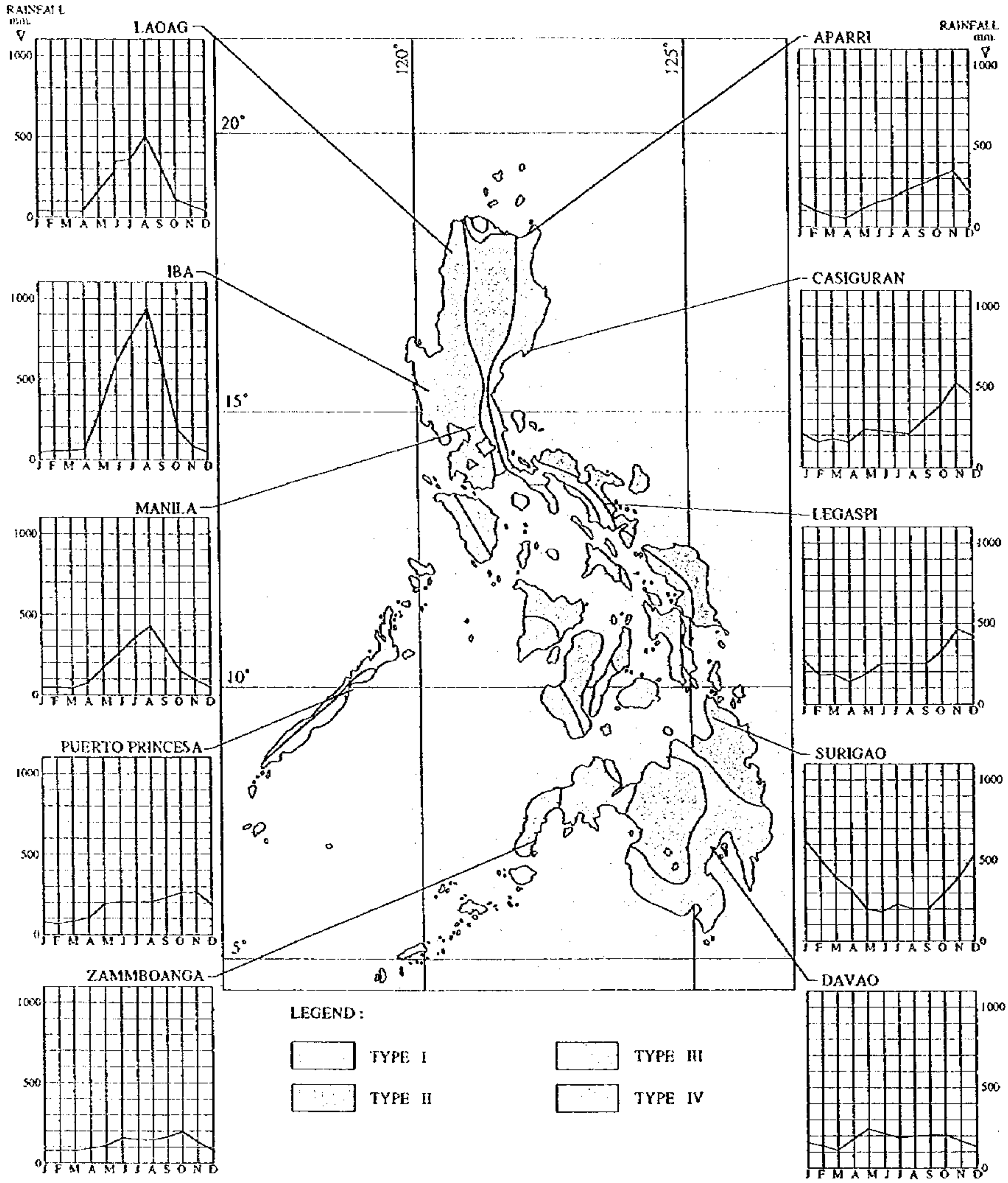
Notes: (1) The annual cycle used to perform the frequency analysis for each station was adjusted to begin at the typical peak runoff period. The draught year designation corresponds to the *year in which the cycle ends.*
(2) No runoff data were available for Masbate Island. The runoff data used for the Panay river basin are considered to be representative of Masbate Island.
(3) WRR XI includes the Davao, Tagum-Limbuganon and Buayan-Malungun River basins. The Padada River data were used for all of these basins due to lack other long term data.

Table B-2 PMF AND 10,000-YEAR FLOW DATA

Location			Discharge of PMF/10000 (m^3/sec)	Drainage Area (km^2)	Specific Discharge ($m^3/sec/km^2$)	Source of Information
Project Name/River Basin	WRR	Climate Type				
Binongan	1	I	5,200	377	13.79	F.S. Binongan H.E. Project Vol. 1 Main Report, 1985
San Rougue	1	I	15,130	1,250	12.10	Re-Study of the San Rogue Multi-Purpose Project, 1985
Balincaguin	3	I	5,756	145	39.70	Pre-F.S. Mini Hydropower Projects Pangasinan Province, 1993
Pila River	3	I	1,344	126	10.67	Pre-F.S. Mini Hydropower Projects Pangasinan Province, 1993
Ambayoan R. @ Sta. Rita	3	I	1,473	281	5.24	Pre-F.S. Mini Hydropower Projects Pangasinan Province, 1993
Mutano R. @ Bante	2	I	10,300	558	18.46	F.S. Maturo River Development Project, 1984
Balintigon Reservoir	2	III	4,015	228	17.61	F.S. Balintingon Reservoir Multi-purpose Project, 1983
Abaca	2	III	6,600	590	11.19	F.S. Casecnan Project - Phased Transbasin Scheme, 1994
Addalam A	2	III	12,000	684	17.54	F.S. Addalam A Project, Luzon
Patabangan	2	III	17,040	1,657	10.28	F.S. Casecnan Project - Phased Transbasin Scheme, 1994
Agbulu	2	IV	8,504	773	11.00	F.S. Abulu Hydroelectric Project, 1992
Abuan	2	IV	7,300	487	14.99	F.S. on the Abuan Hydropower Project, 1996
Agos	3	IV	16,900	867	19.49	F.S. Agos Project, 1991
Conwap	3	IV	13,500	1,150	11.74	F.S. Casecnan Project - Phased Transbasin Scheme, 1994
Kanan B1 Scheme	3	IV	8,020	355	22.59	F.S. Small Hydropower Projects, Luzon, Vol IV Kanan B1 Scheme, 1993
Bago	6	III	6,000	402	14.93	F.S. Bago Hydroelectric Project, 1982
Bactot-Balongbong	6	II	1,045	10	104.50	F.S. of Boctot-Balongbong Rivers Diversion Projects
Pulangi 3	12	III	7,000	1,340	5.22	F.S. Pulangi III Multi-Purpose Project, May 1982
Maramag H.E.	12	III	13,000	3,100	4.19	Pulangi River Development - Maramag Development Project Interim Report, 1978
Tagoloan River	10	III	7,100	530	13.40	F.S. Tagaloan II hydro Electric Project
Bulanog Batang	10	III	1,936	75	25.81	F.S. Bulanog-Batang Project
Kabacan River	12	IV	2,700	698	3.87	Pre-F.S. of Hydropower Potential of Kabacan River, 1993
Polondak River	9	IV	850	52	16.35	Pre-F.S. of Hydropower Potential of Polandok River, 1993
Suwawan/Tumugan	11	IV	2,602	152	17.12	F.S. Davao River Projects, 1992
Asiga	10	II	2,432	65	37.19	F.S. Small Hydro in Mindanao / Asiga R., 1992

Part – B

Figures



SOURCE : PAGASA

Figure B-1 CLLIMATE REGIONS OF THE PHILIPPINES

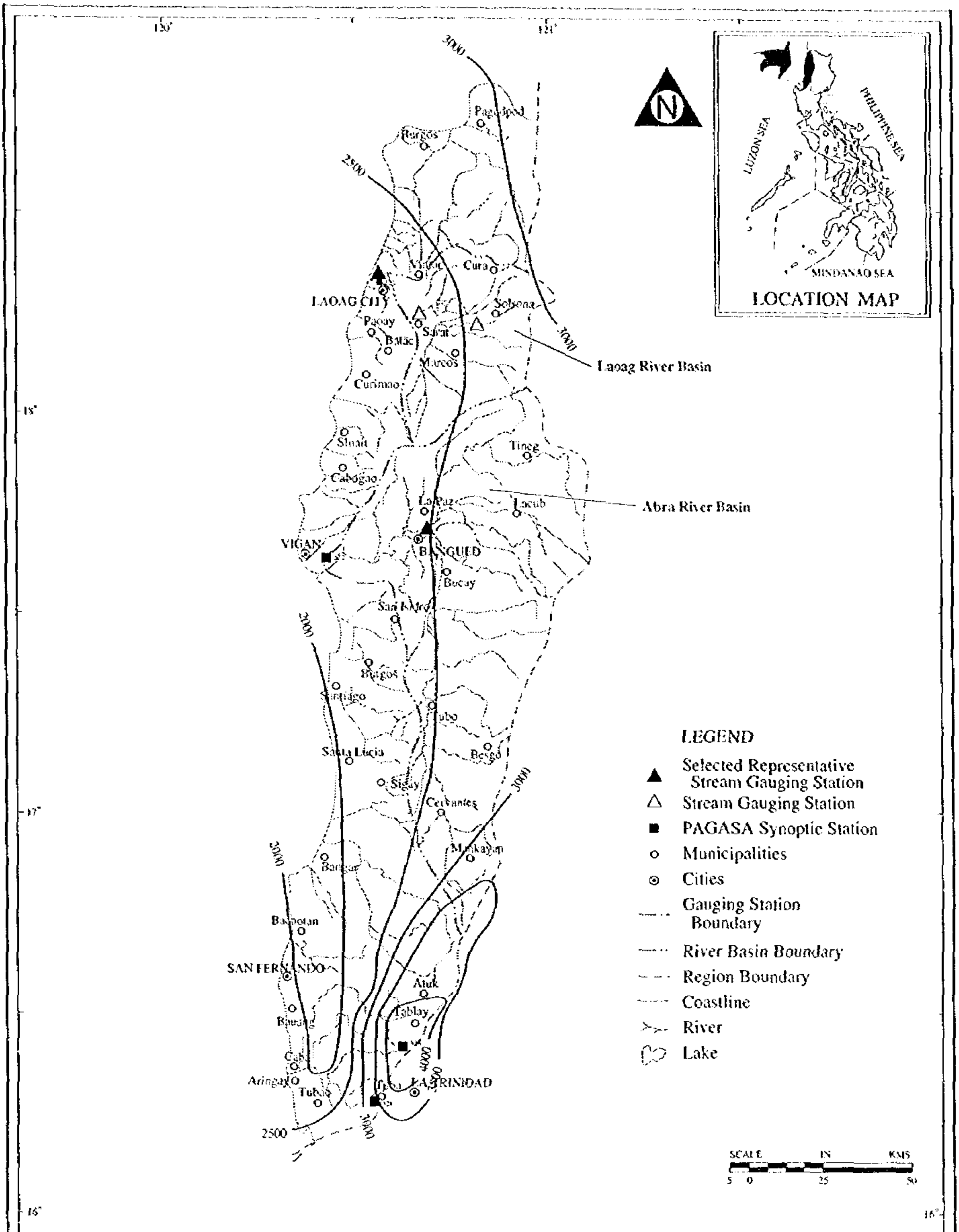


Figure B-2 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION I

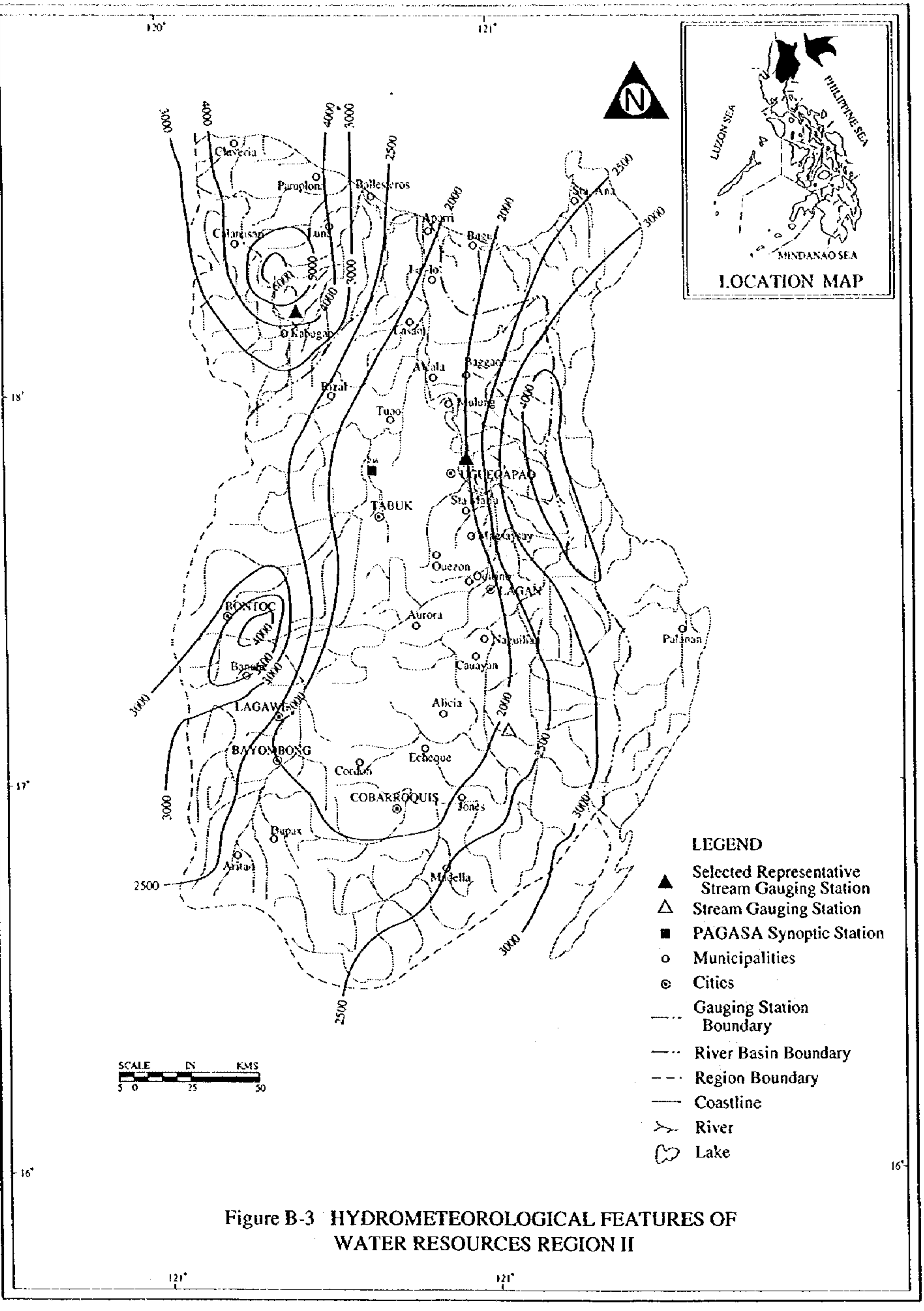


Figure B-3 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION II

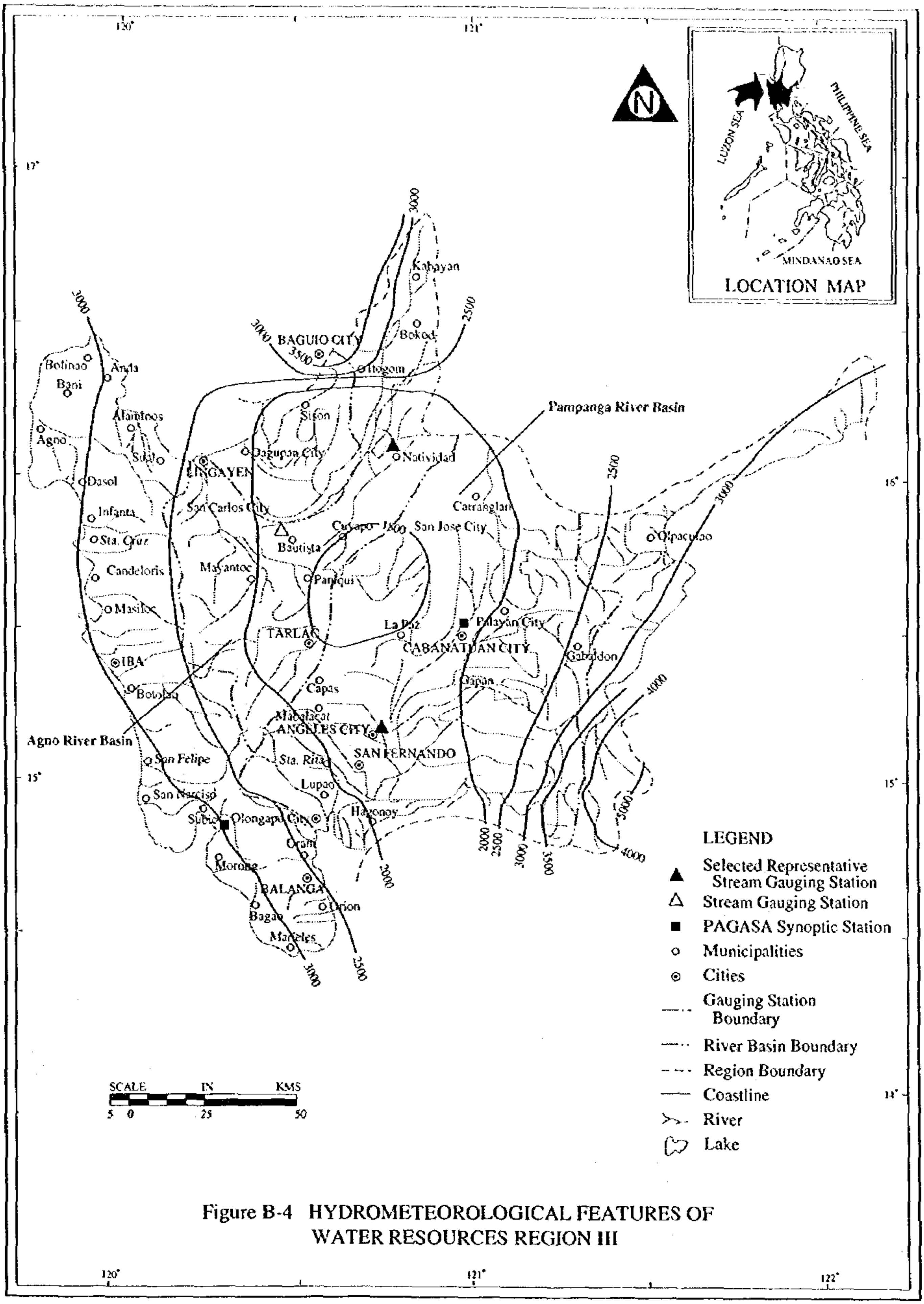


Figure B-4 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION III

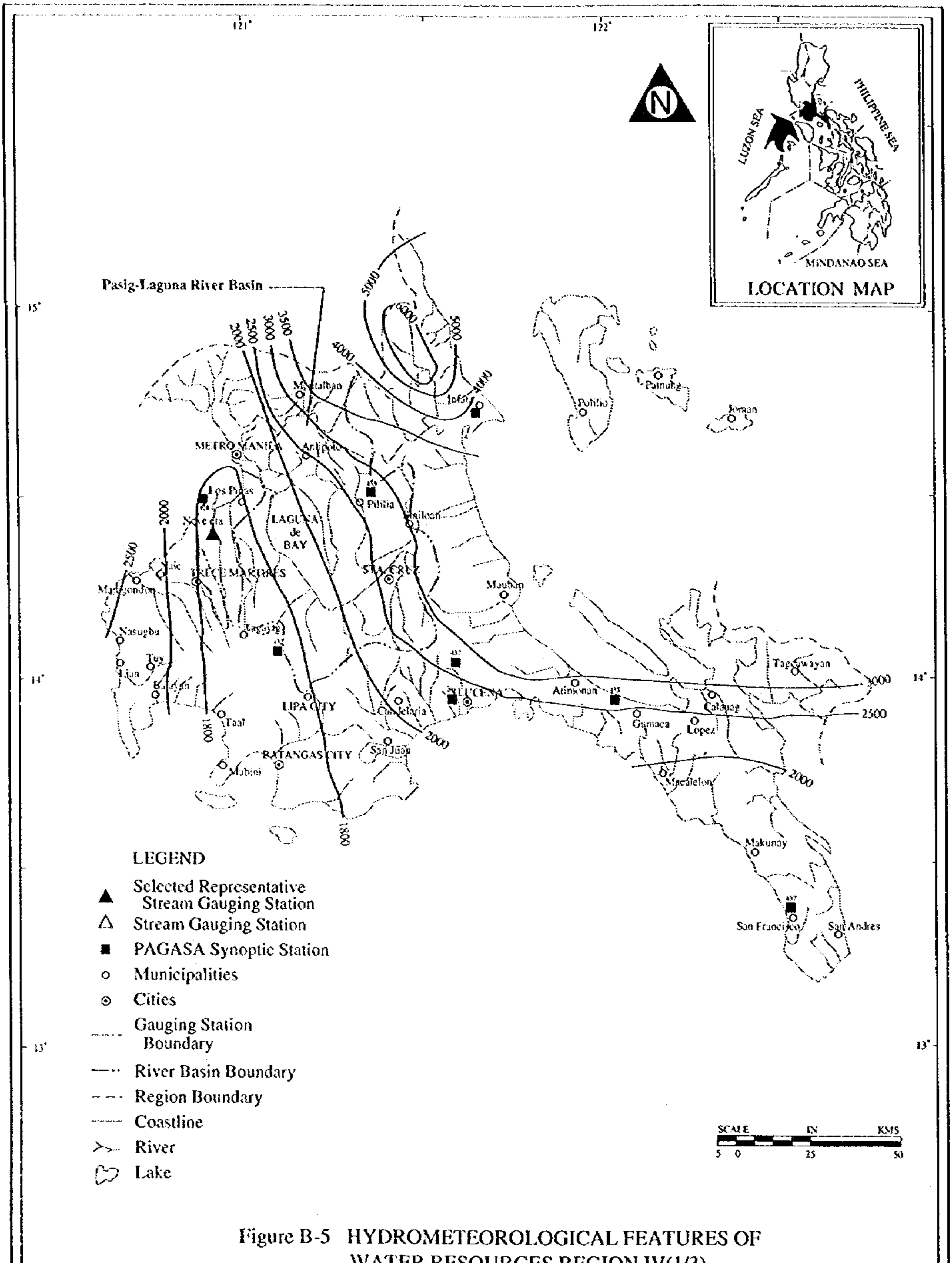


Figure B-5 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION IV(1/3)

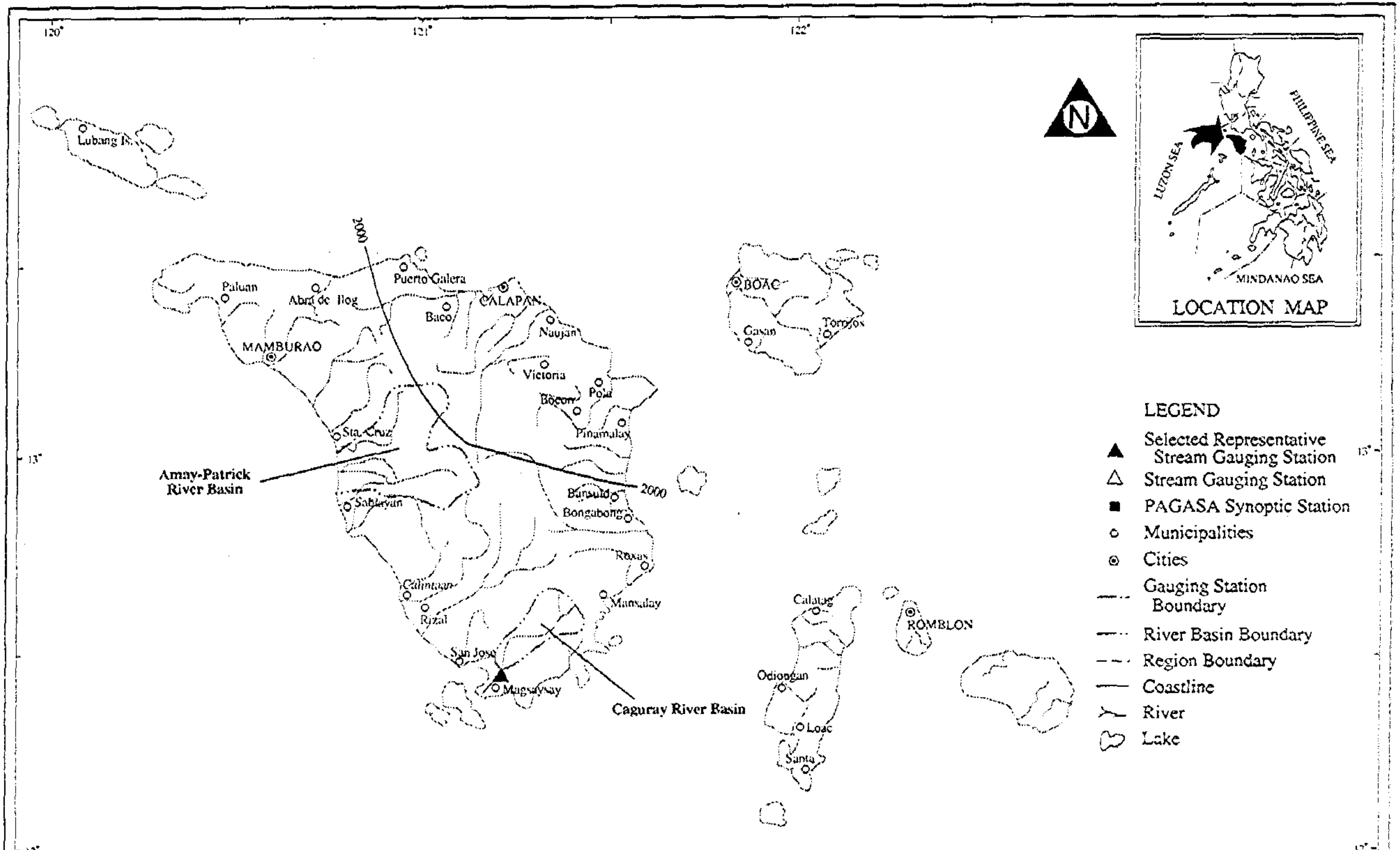


Figure B-5 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION IV (2/3)

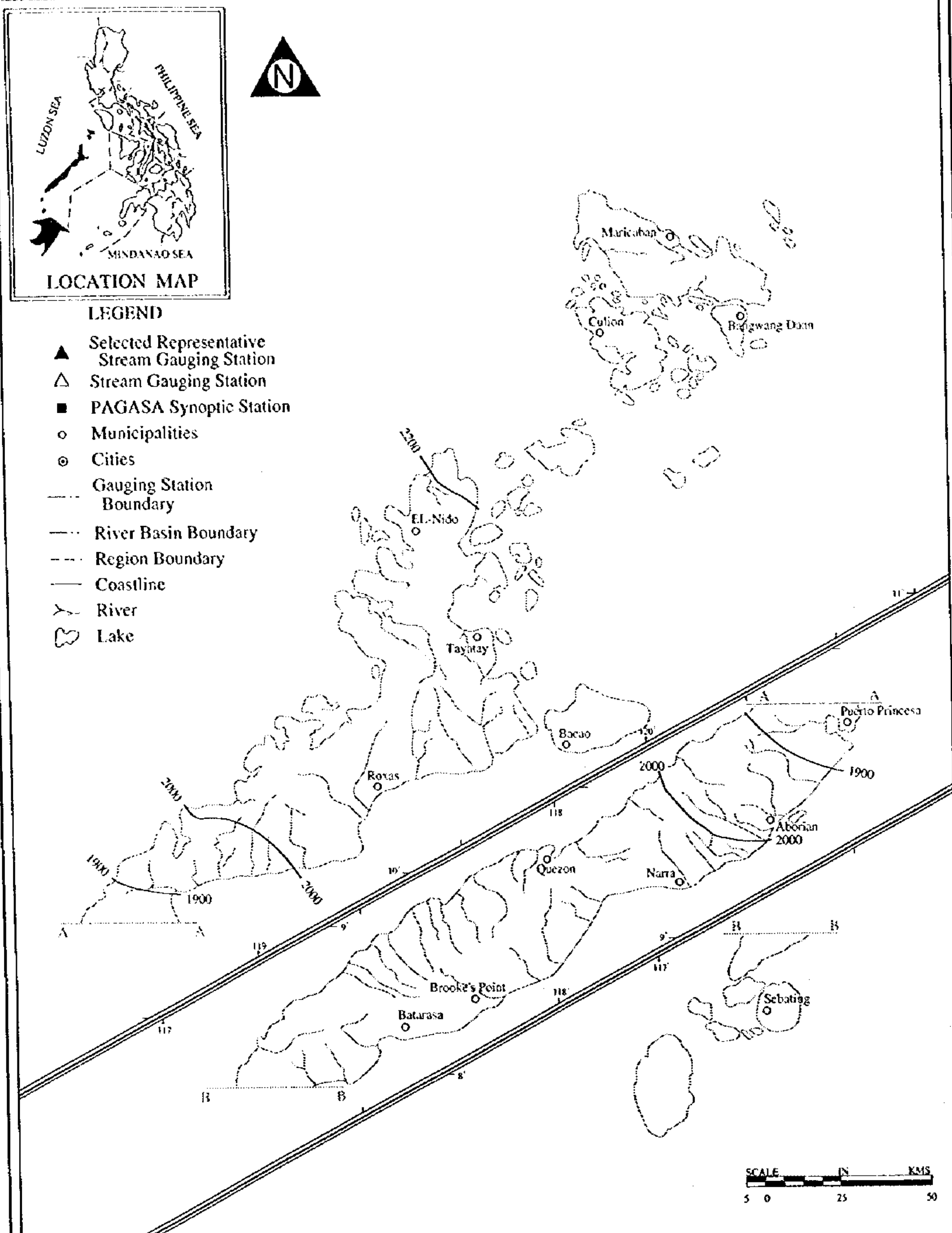


Figure B-5 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION IV (3/3)

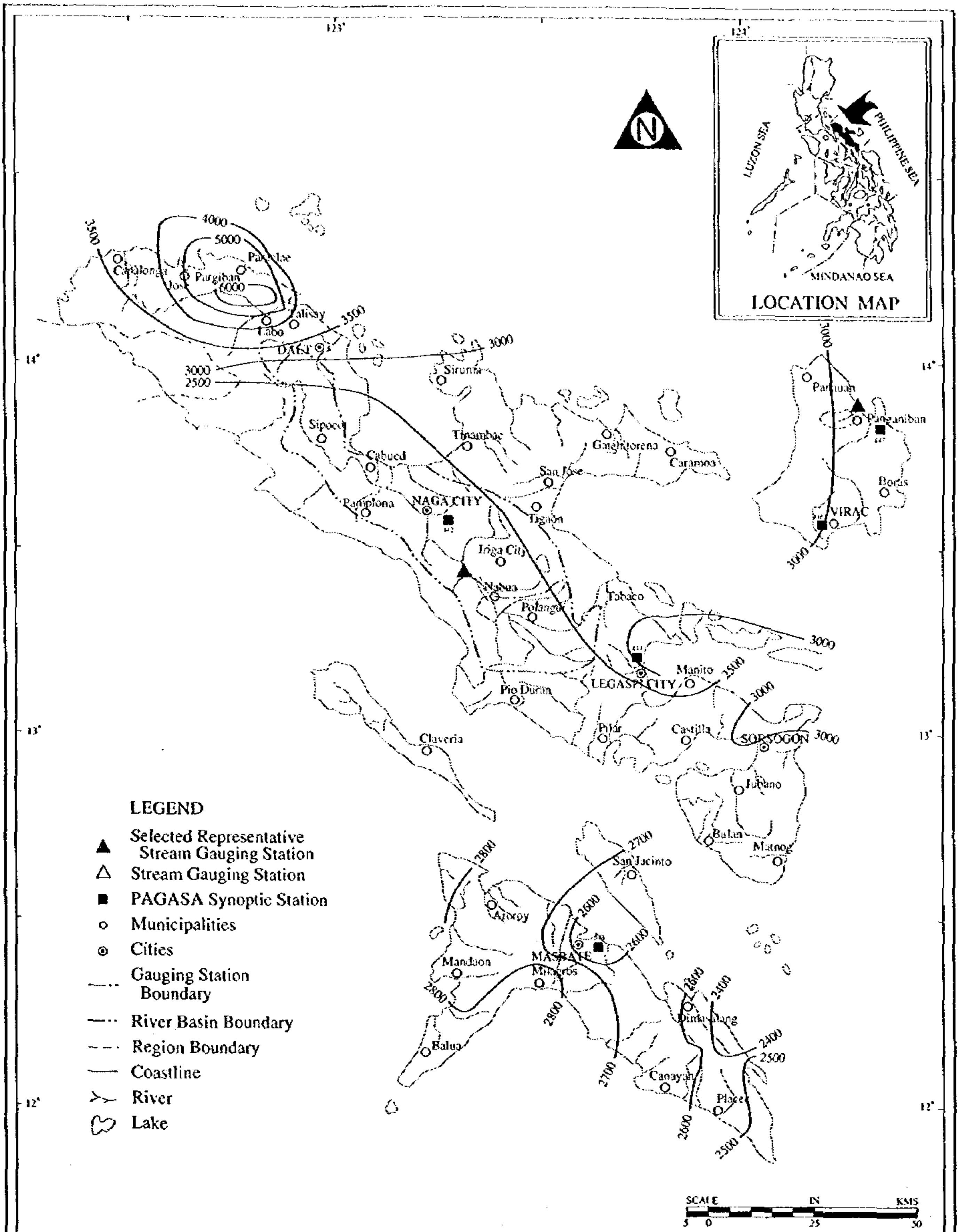


Figure B-6 HYDROMETEOROGICAL FEATURES OF WATER RESOURCES REGION V

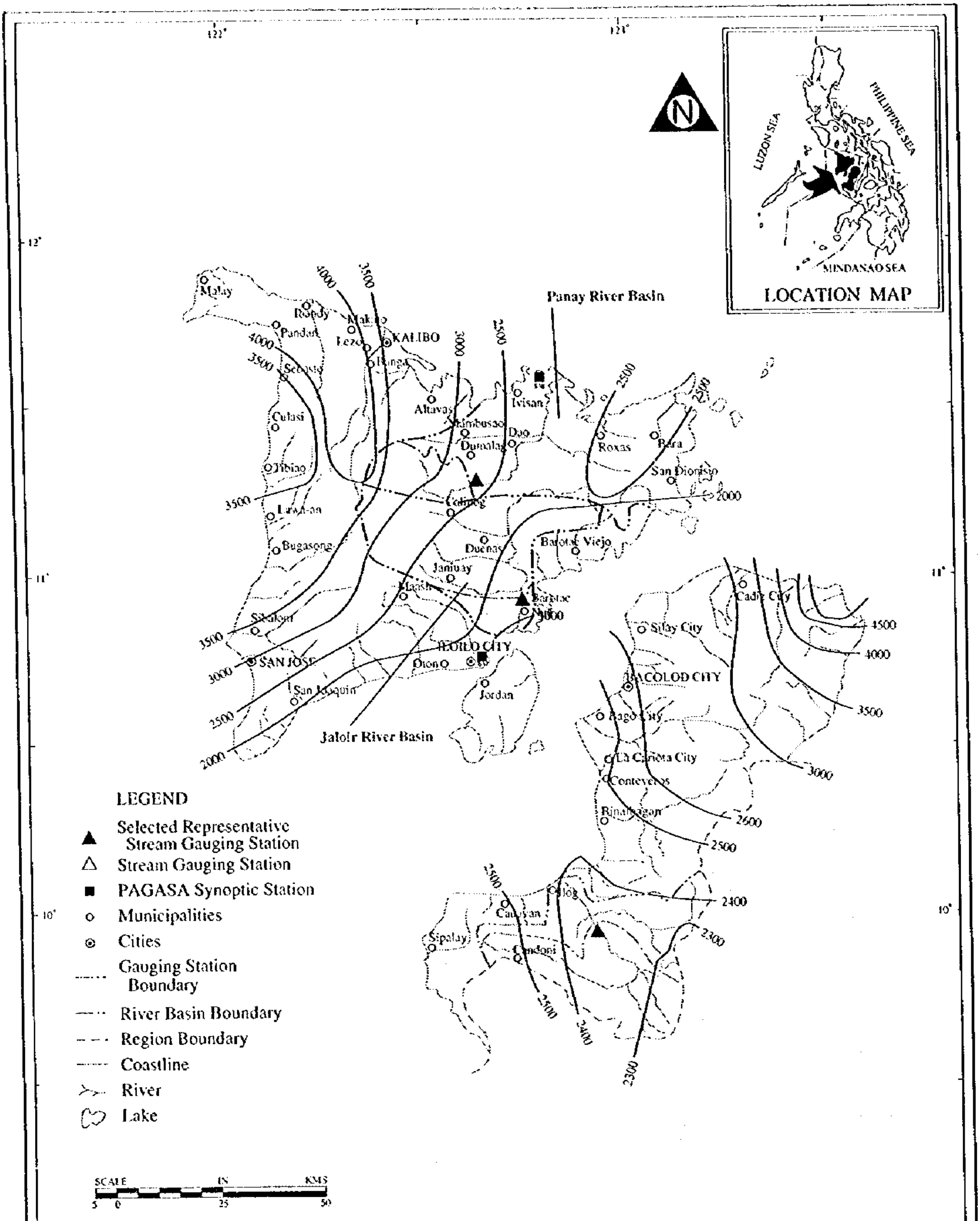


Figure B-7 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION VI

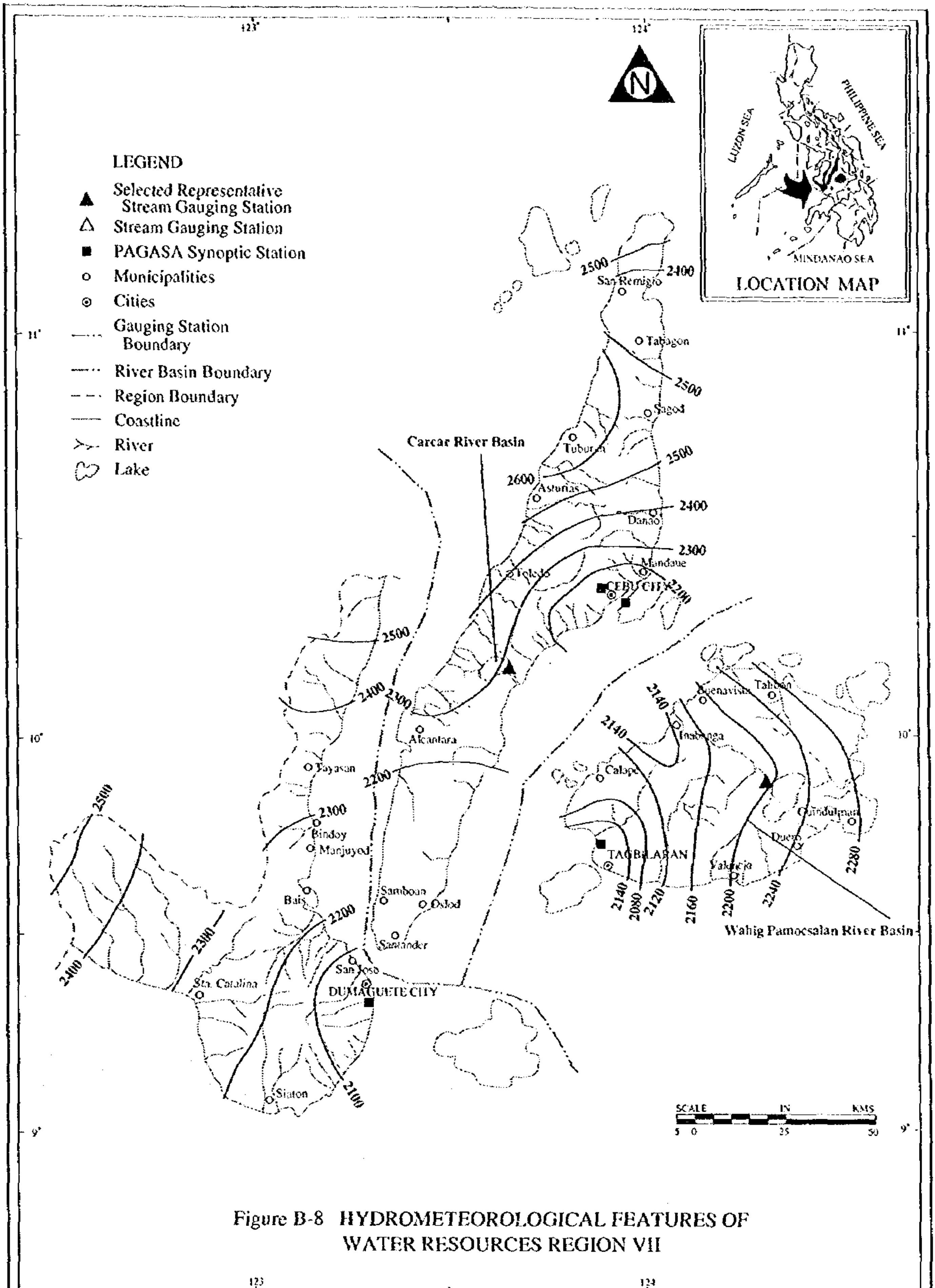


Figure B-8 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION VII

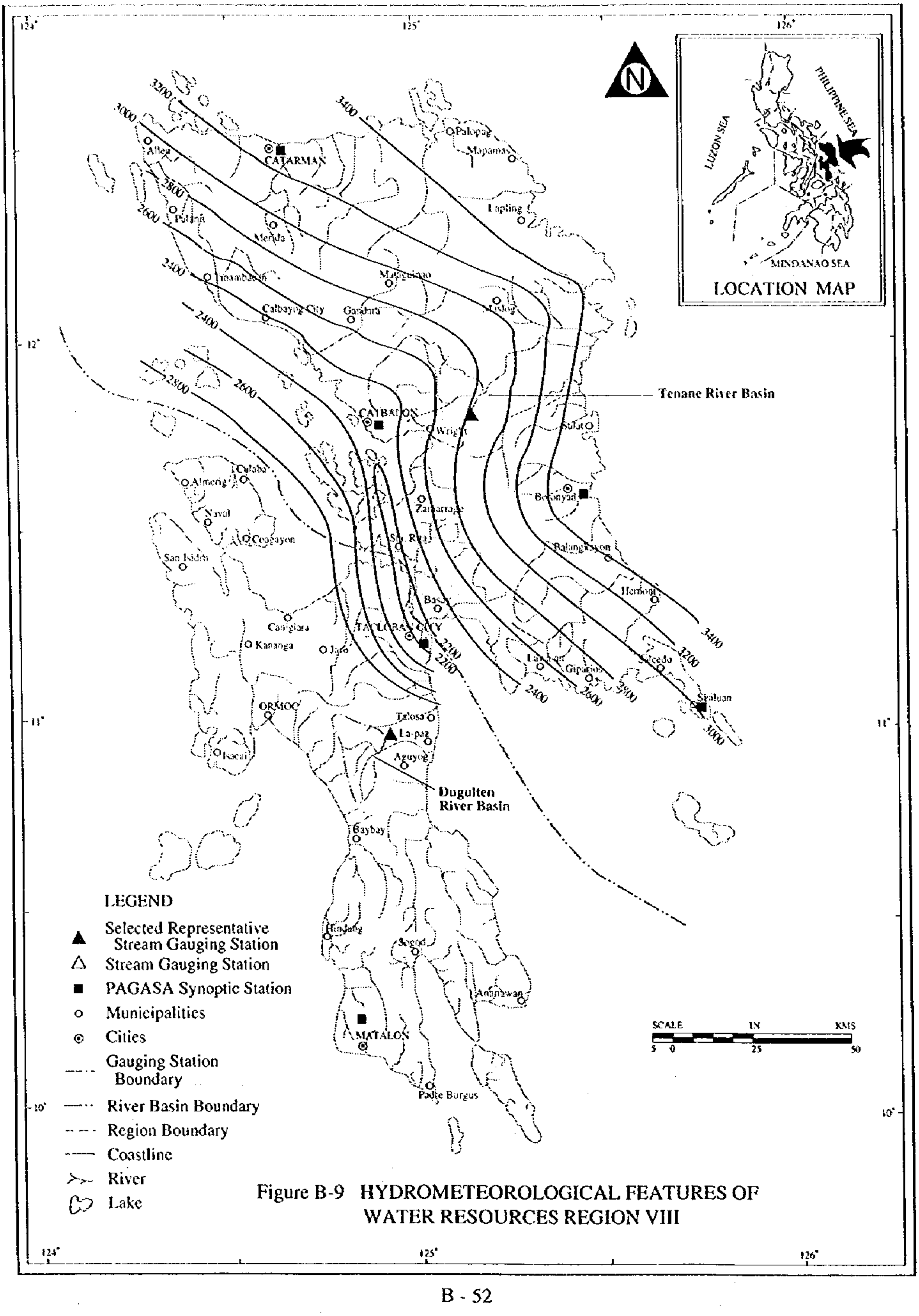


Figure B-9 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION VIII

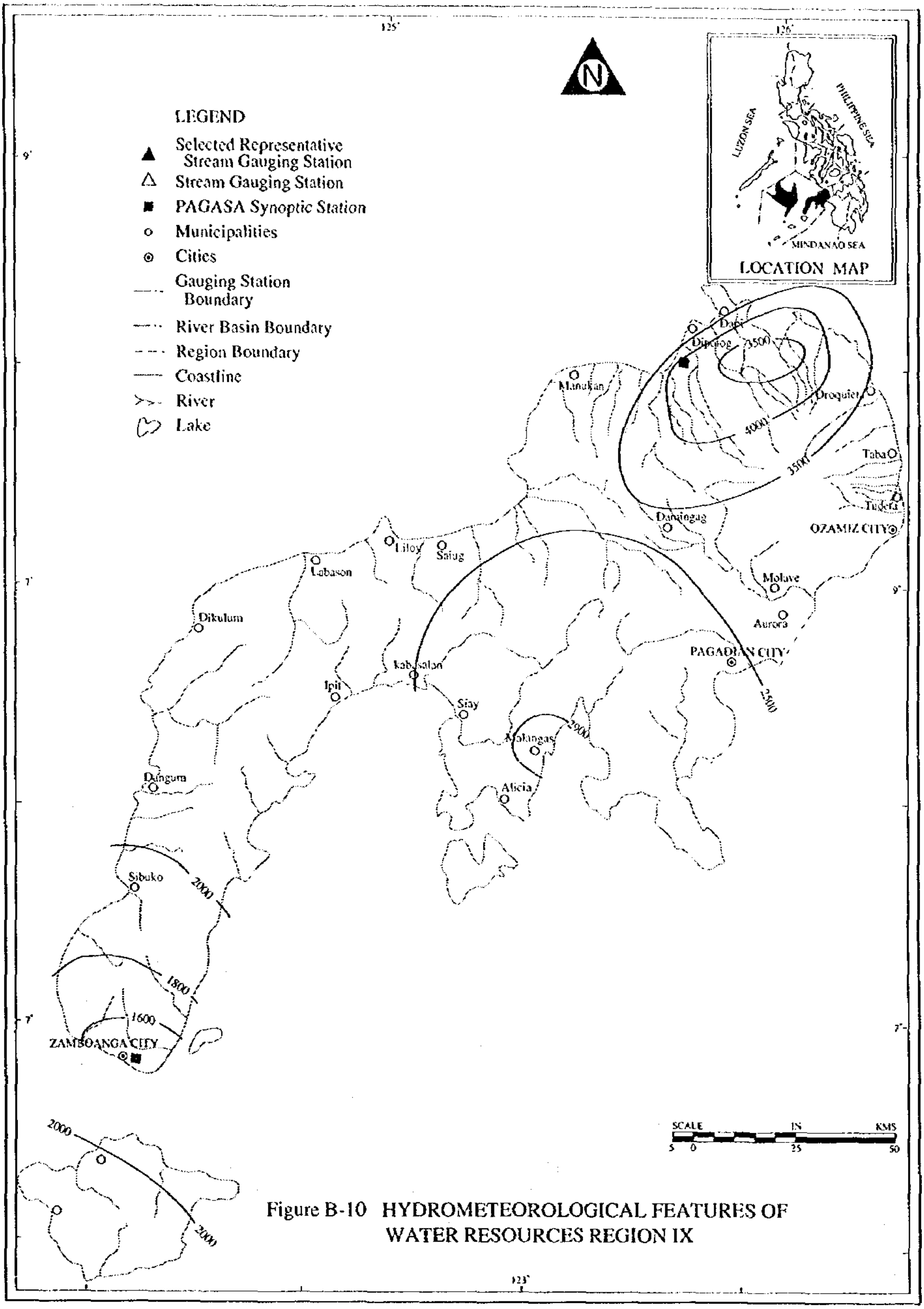


Figure B-10 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION IX

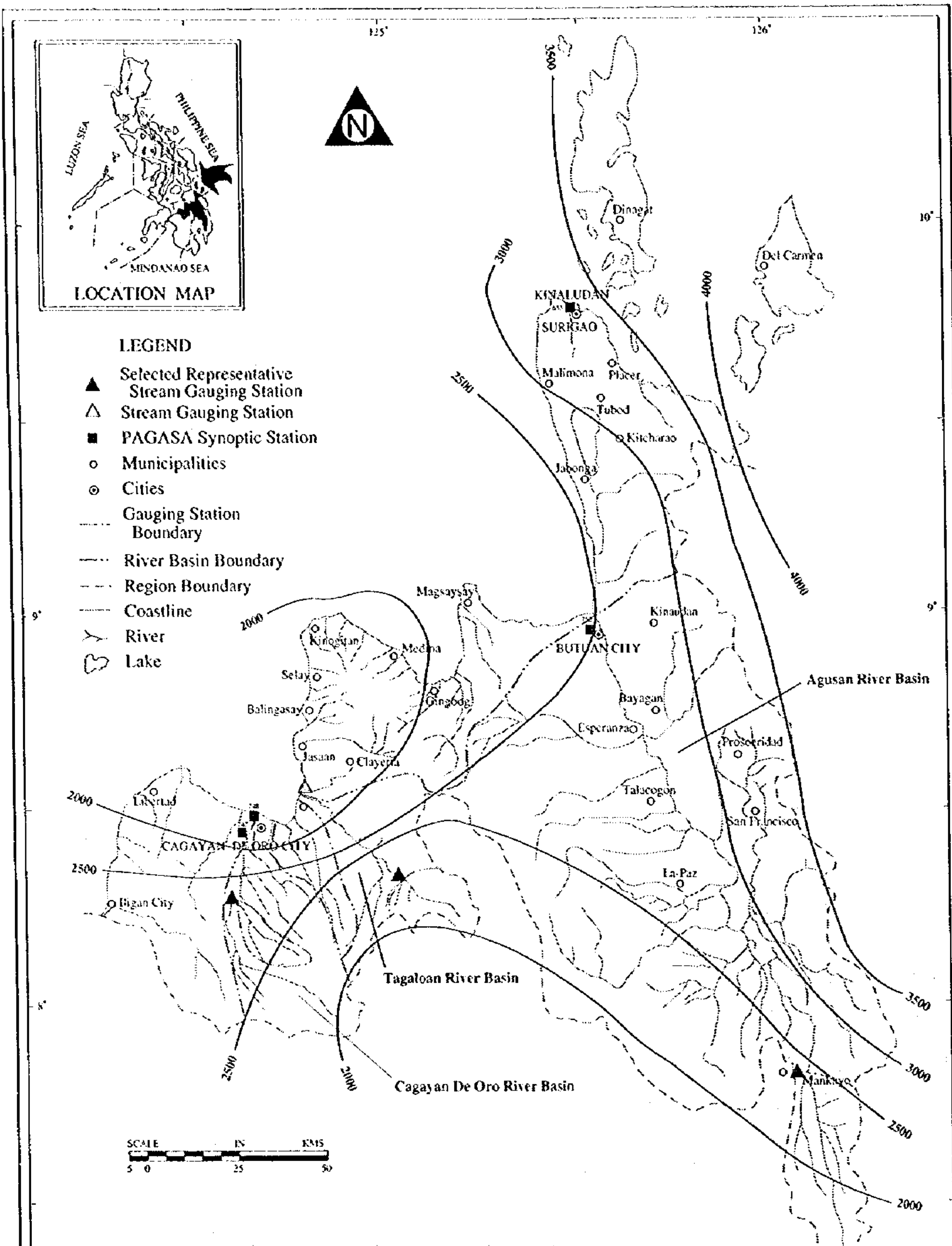


Figure B-11 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION X

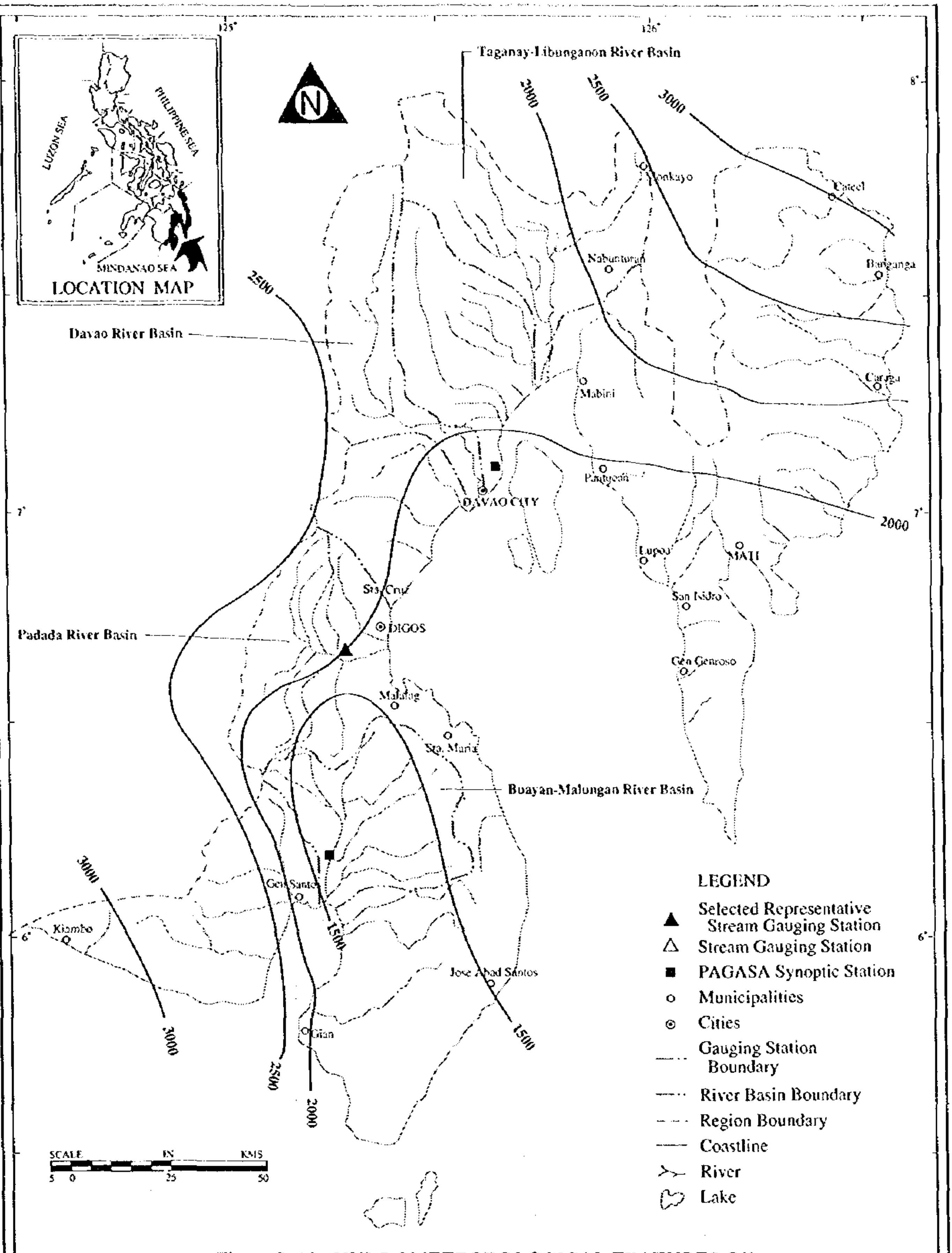


Figure B-12 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION XI

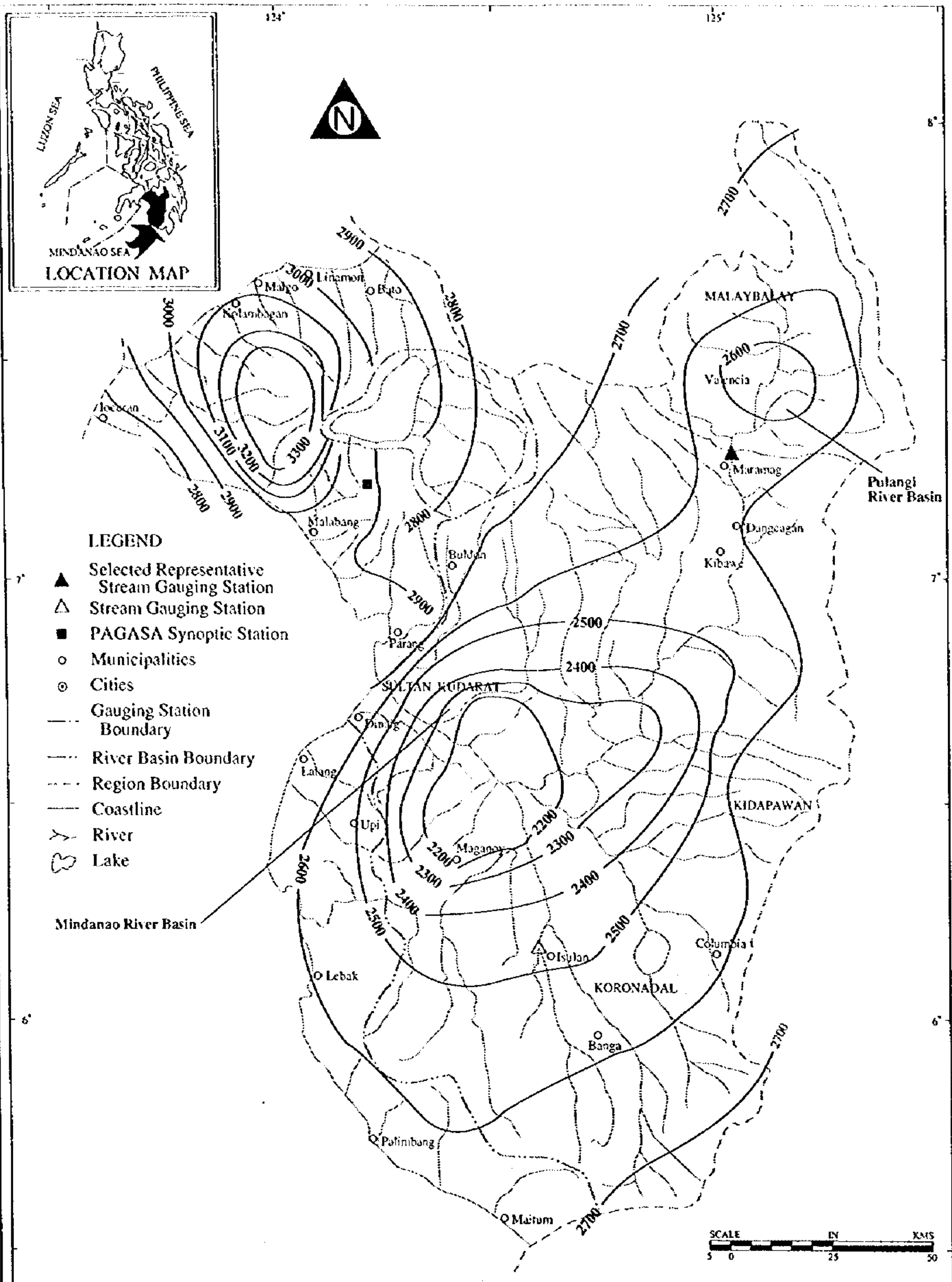
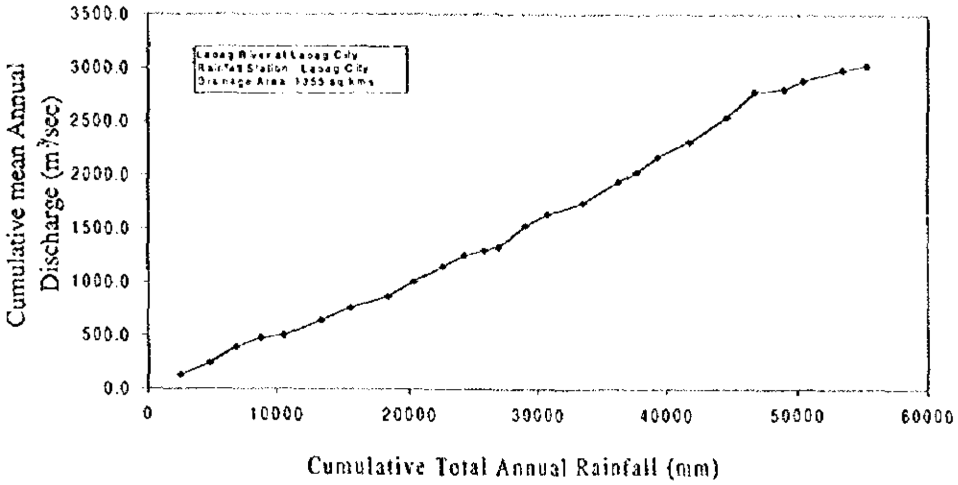
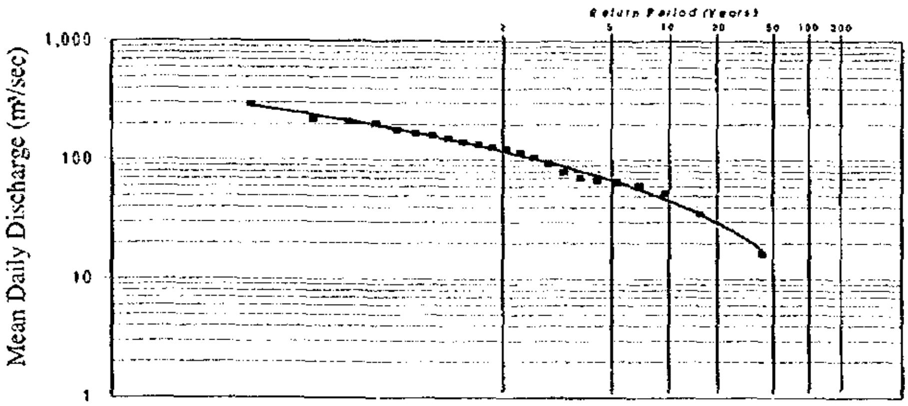


Figure B-13 HYDROMETEOROLOGICAL FEATURES OF WATER RESOURCES REGION XII

Double Mass Curve



Frequency Analysis for Annual Mean Discharge



Drought Year Hydrographs

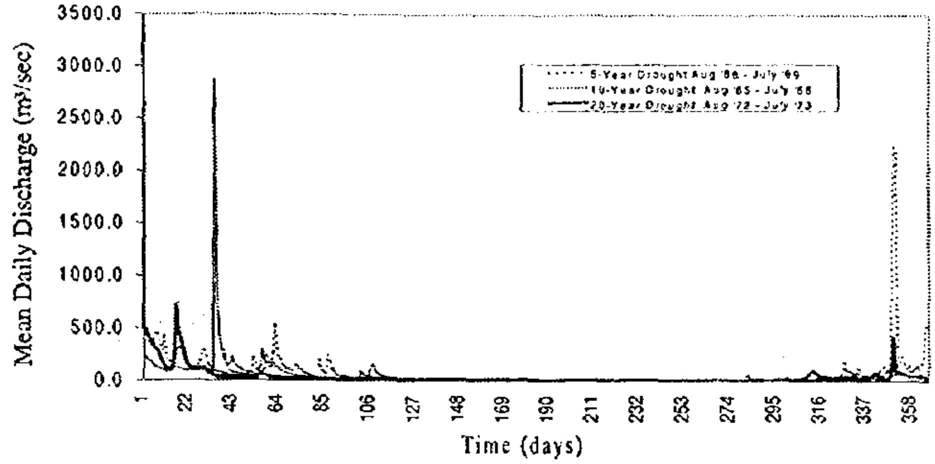
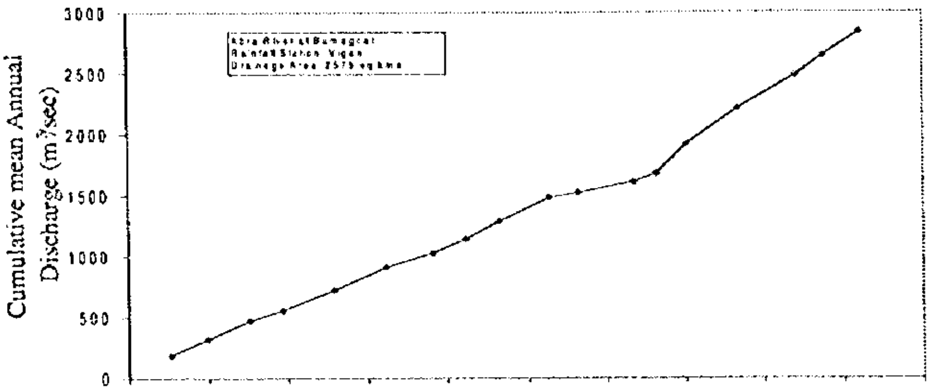


Figure B-14 HYDROLOGICAL OUTCOMES IN LAOAG RIVER BASIN

Double Mass Curve



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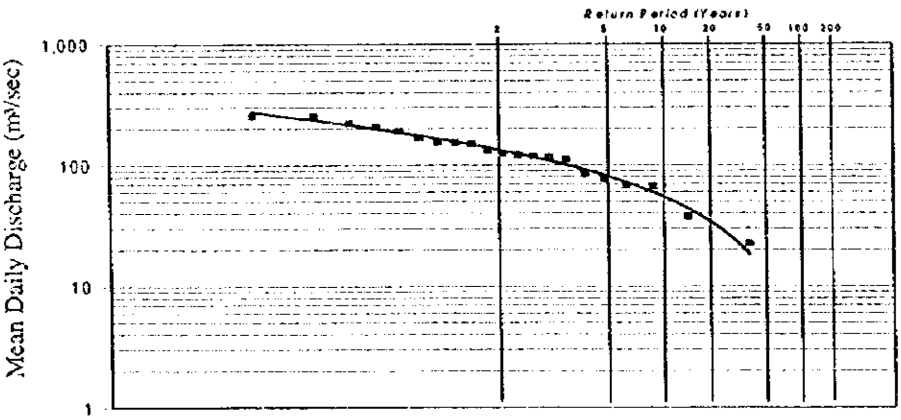

Drought Year Hydrographs

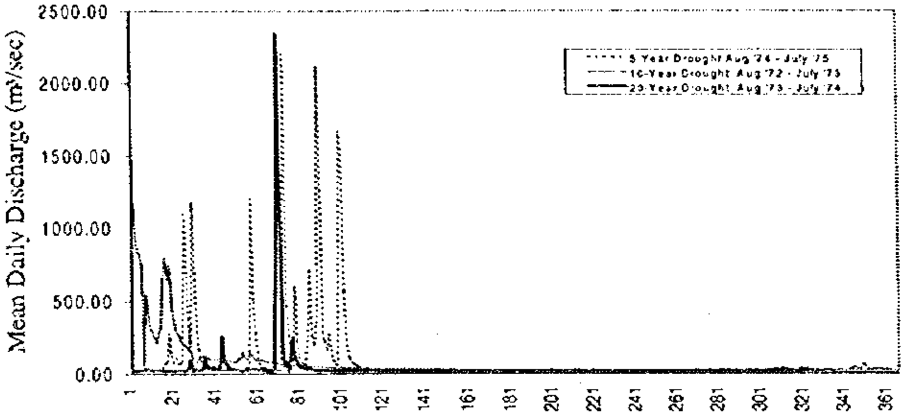

Figure B-15 HYDROLOGICAL OUTCOMES IN ABRA RIVER BASIN

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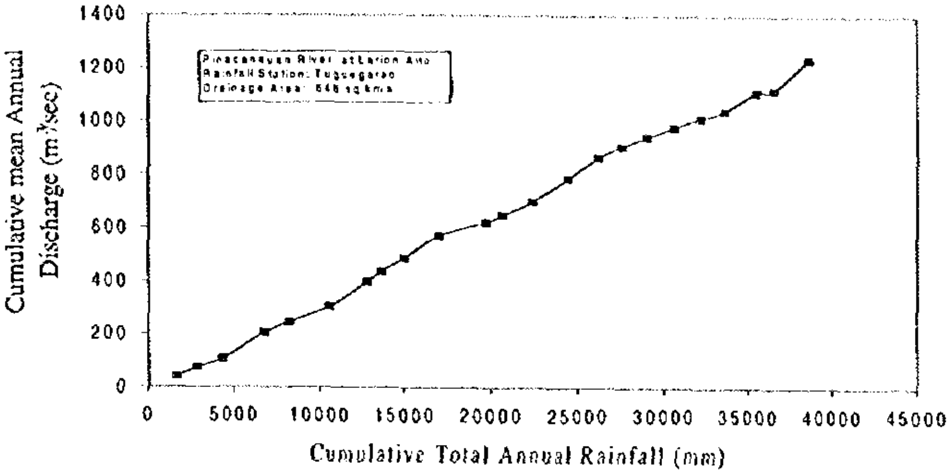

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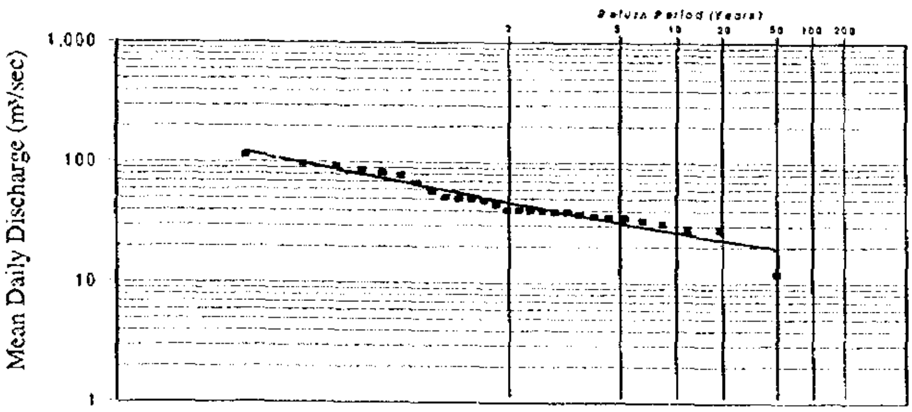


Drought Year Hydrographs

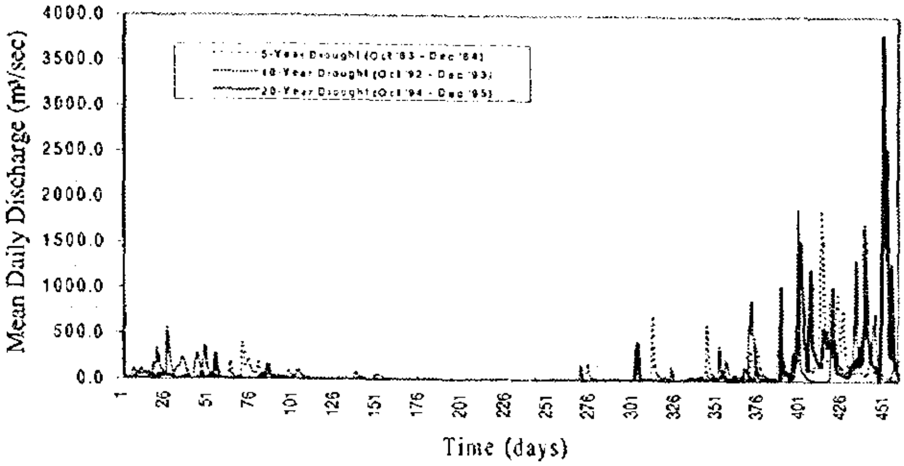
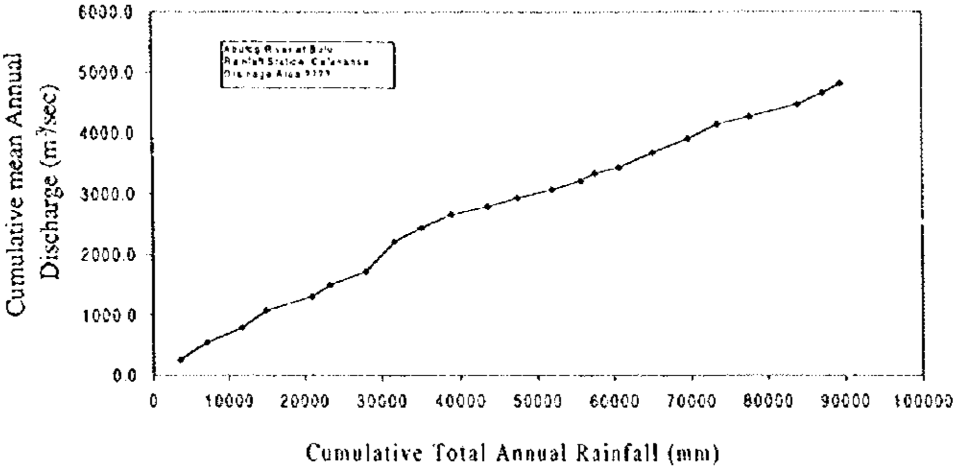
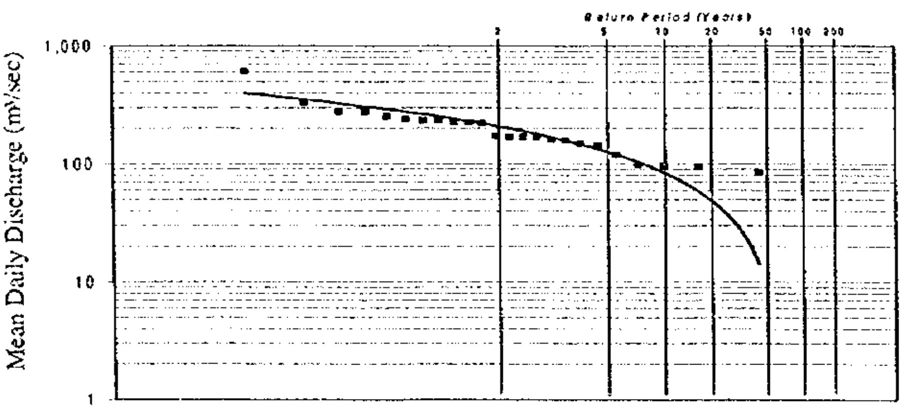


Figure B-16 HYDROLOGICAL OUTCOMES IN PINACANAUAN RIVER BASIN (CAGAYAN)

Double Mass Curve



Frequency Analysis for Annual Mean Discharge



Drought Year Hydrographs

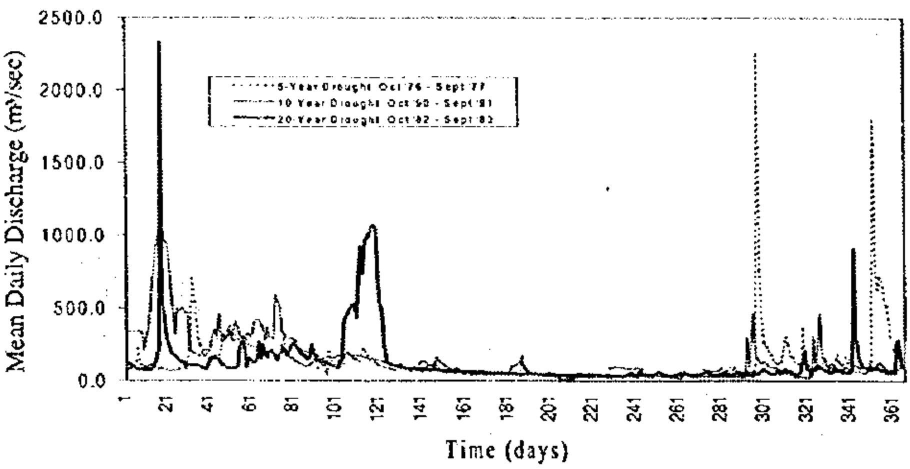


Figure B-17 HYDROLOGICAL OUTCOMES IN ABULUG RIVER BASIN

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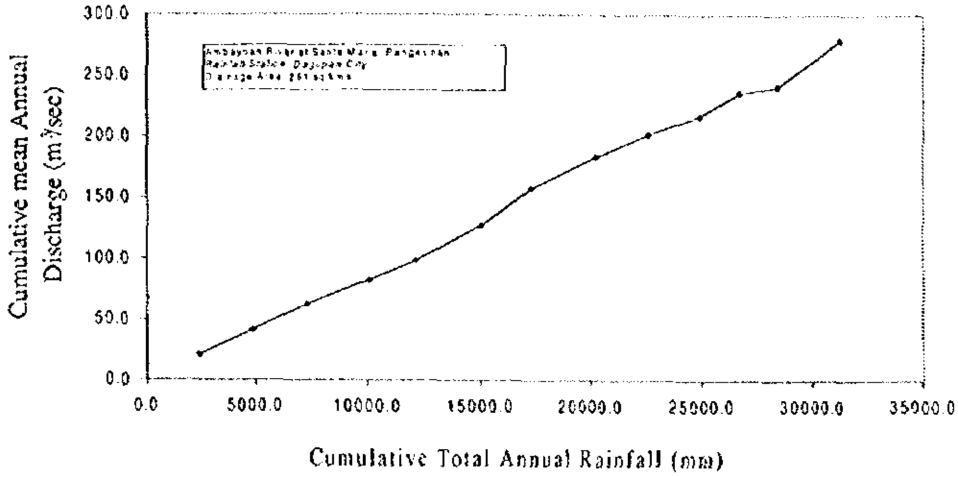
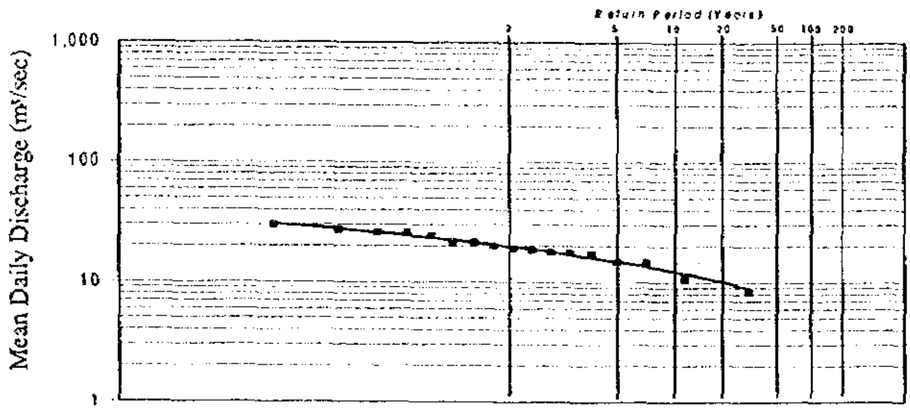


Frequency Analysis for Annual Mean Discharge



Drought Year Hydrographs

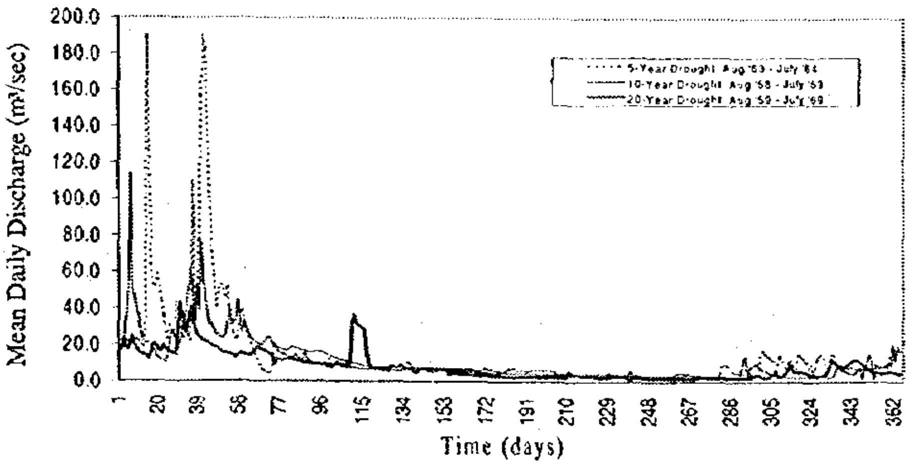
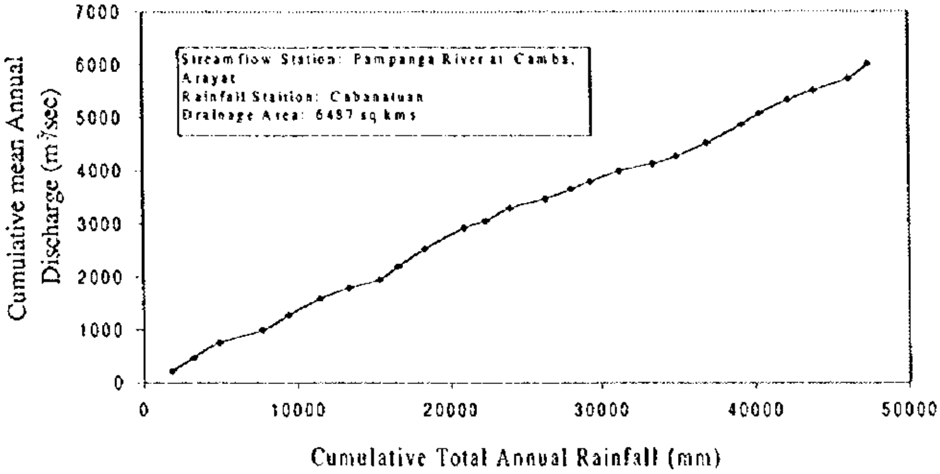
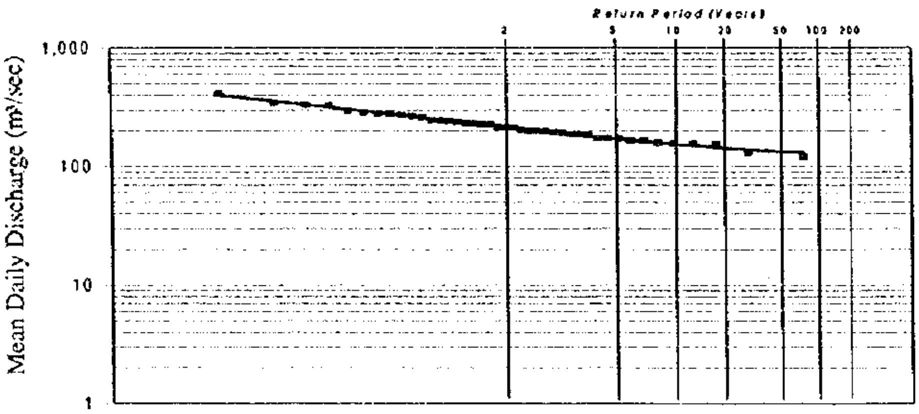


Figure B-18 HYDROLOGICAL OUTCOMES IN AGNO RIVER BASIN

Double Mass Curve



Frequency Analysis for Annual Mean Discharge



Drought Year Hydrographs

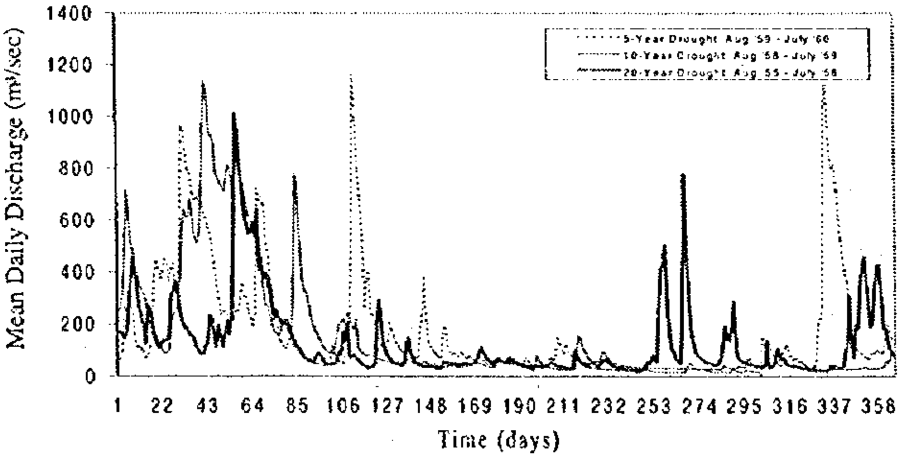
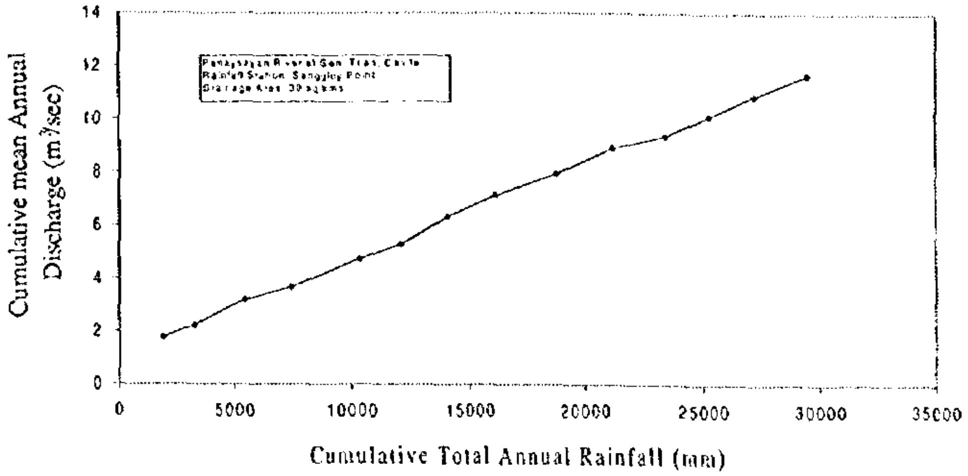
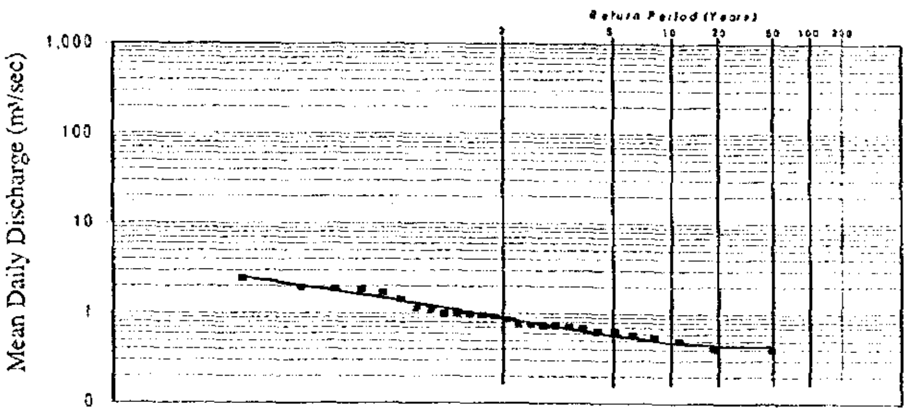


Figure B-19 HYDROLOGICAL OUTCOMES IN PAMPANGA RIVER BASIN

Double Mass Curve



Frequency Analysis for Annual Mean Discharge



Drought Year Hydrographs

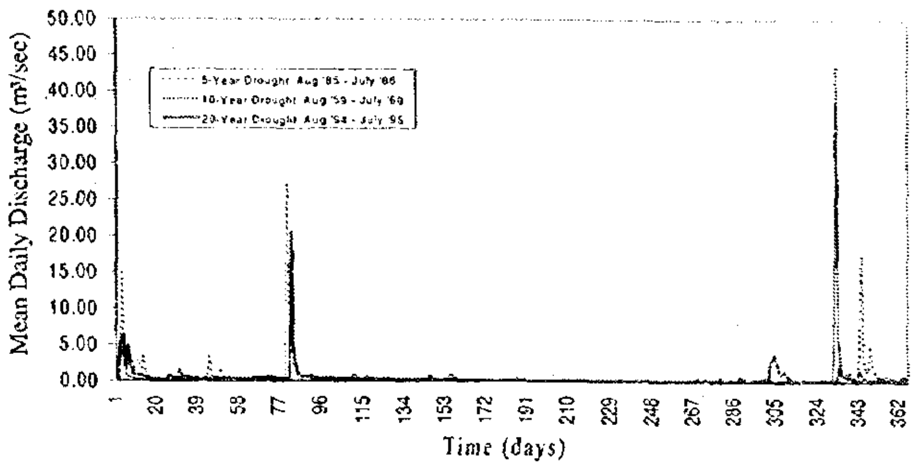
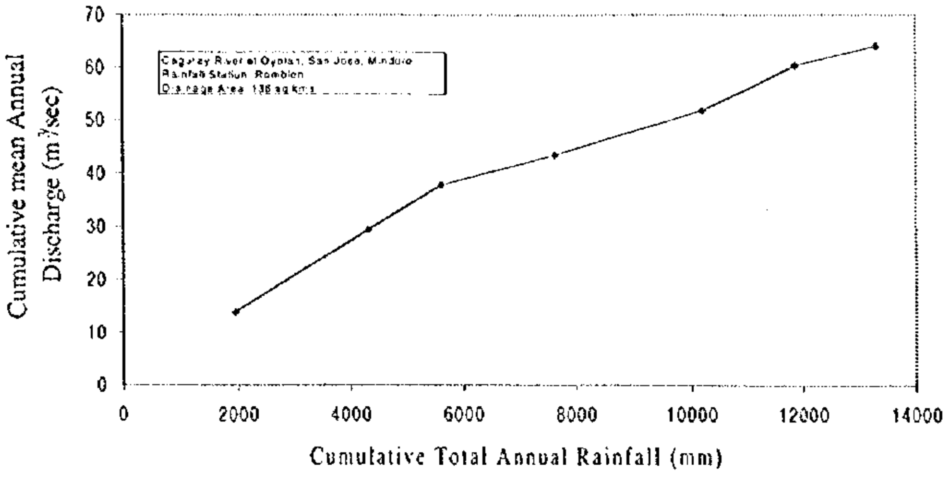
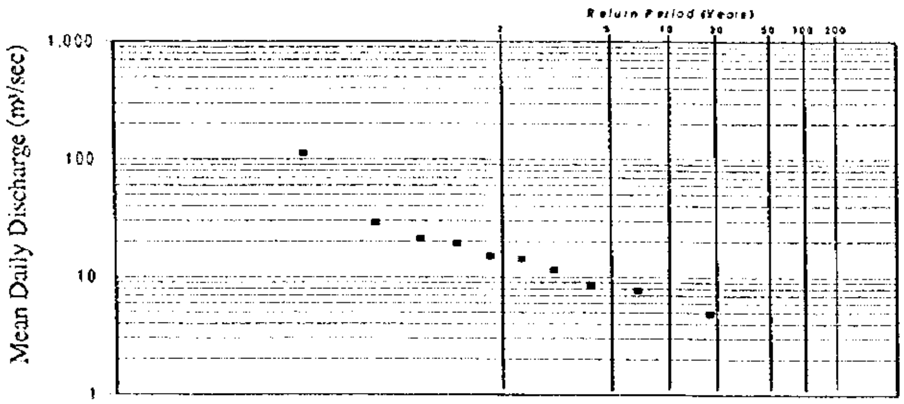


Figure B-20 HYDROLOGICAL OUTCOMES IN PASIG RIVER BASIN

Double Mass Curve



Frequency Analysis for Annual Mean Discharge



Drought Year Hydrographs

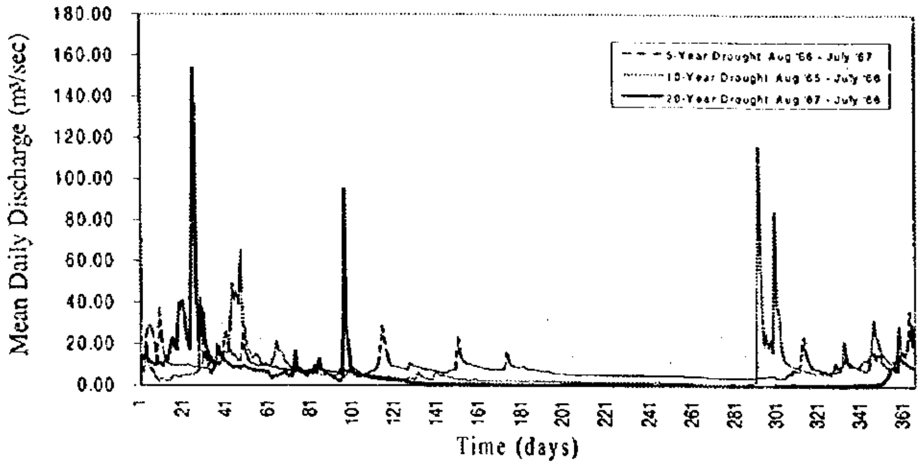
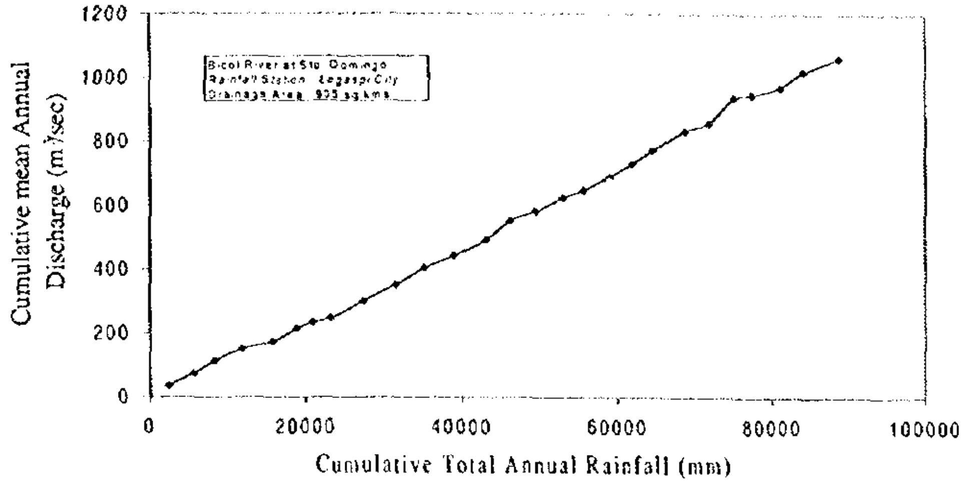
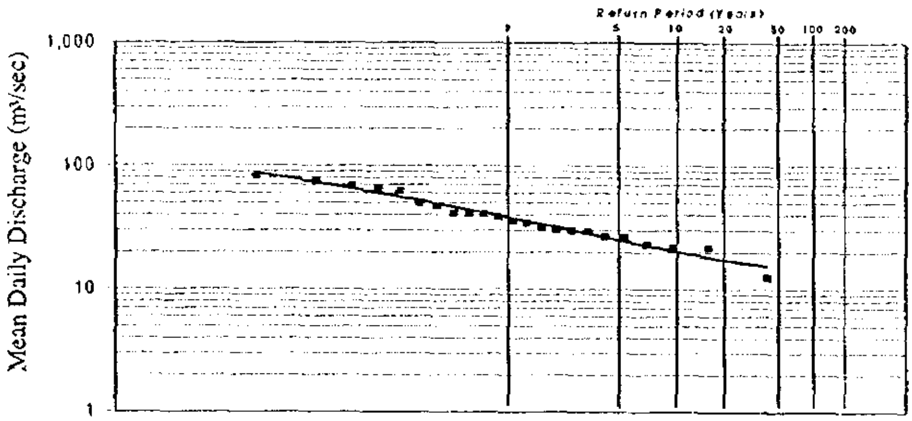


Figure B-21 HYDROLOGICAL OUTCOMES IN CAGURAY RIVER BASIN (MINDORO)

Double Mass Curve



Frequency Analysis for Annual Mean Discharge



Drought Year Hydrographs

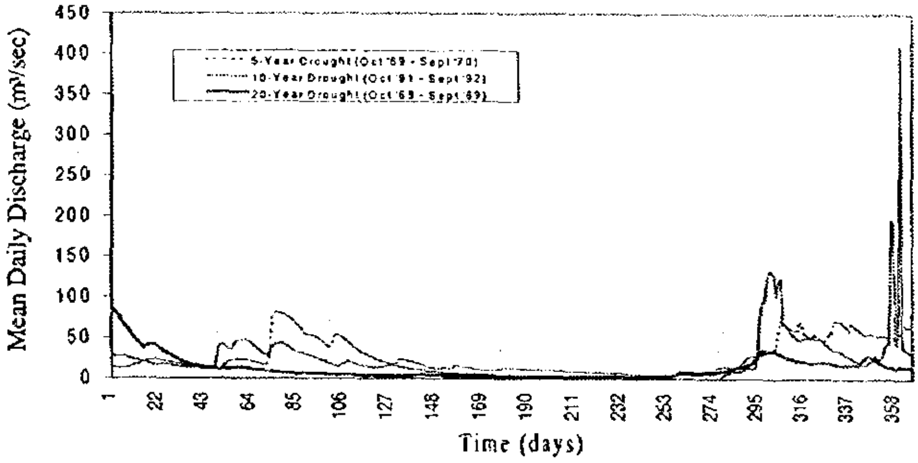
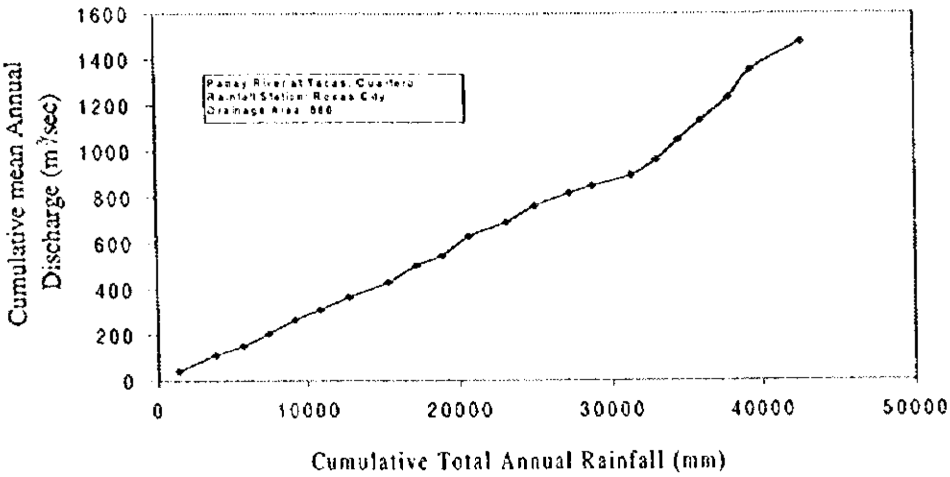
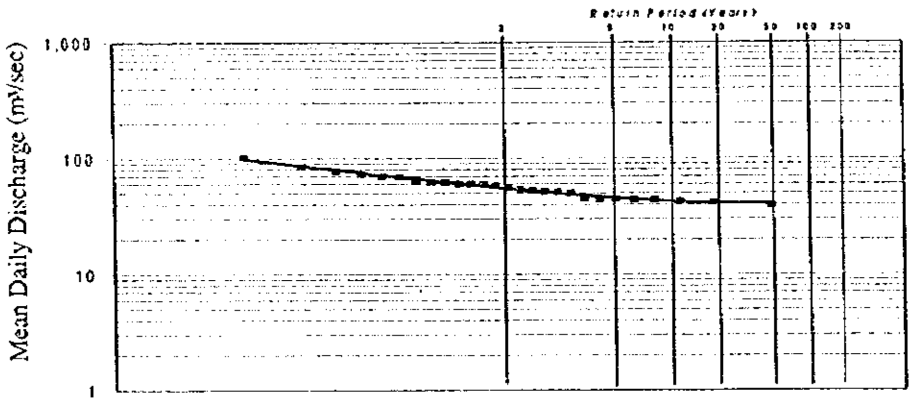


Figure B-22 HYDROLOGICAL OUTCOMES IN BICOL RIVER BASIN

Double Mass Curve



Frequency Analysis for Annual Mean Discharge



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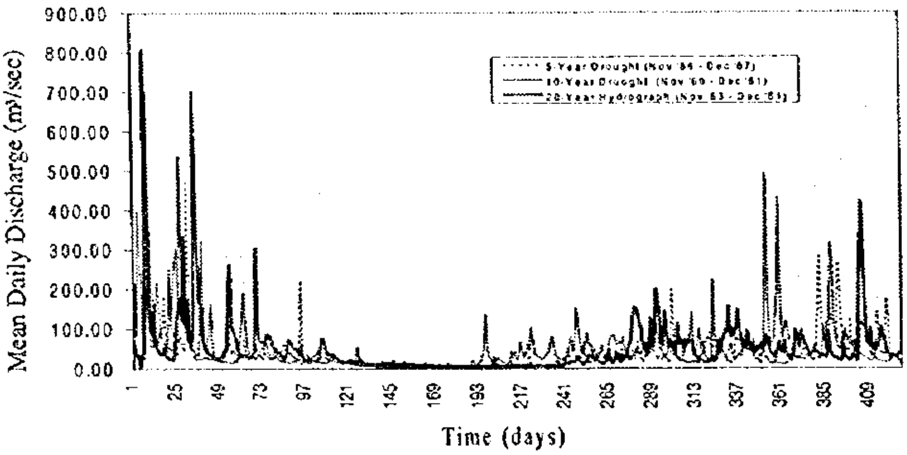

Figure B-23 HYDROLOGICAL OUTCOMES IN PANAY RIVER BASIN

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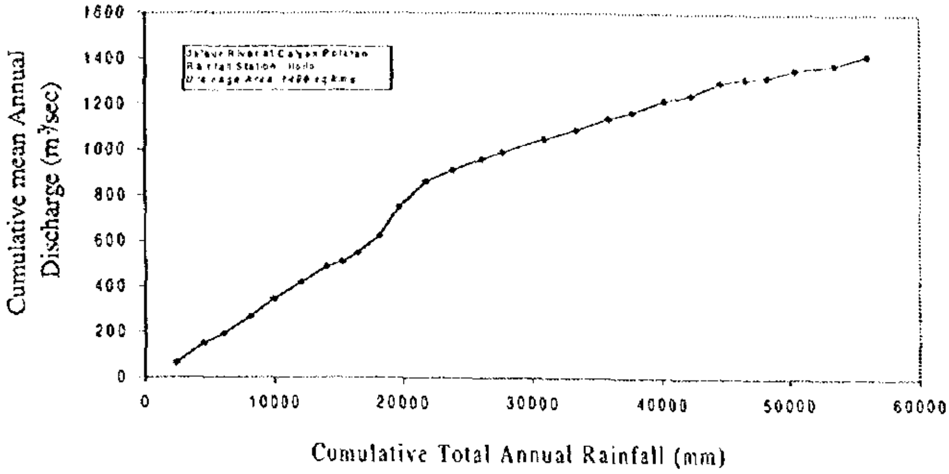

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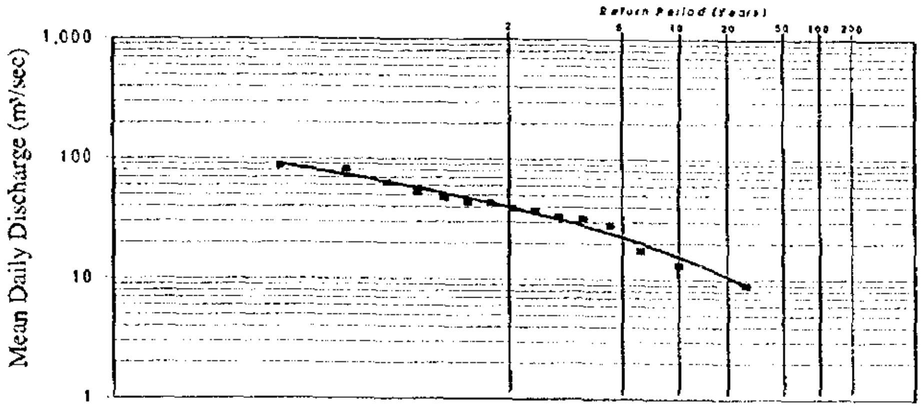

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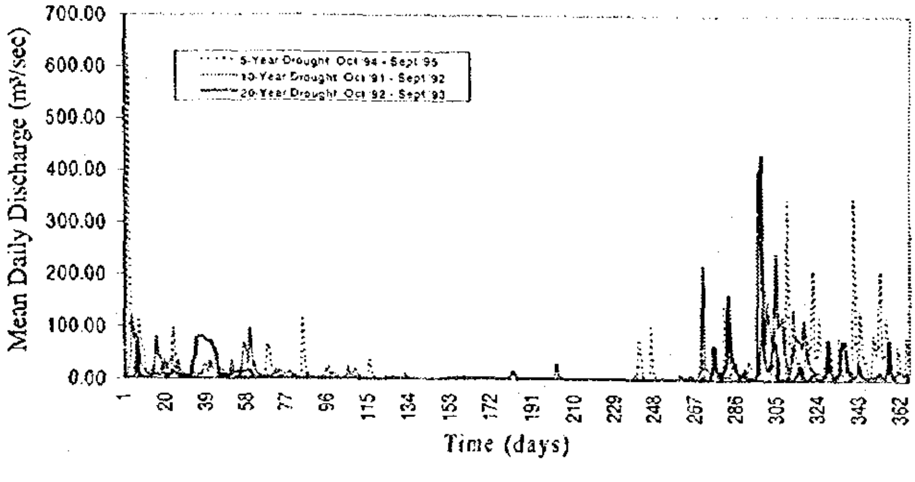

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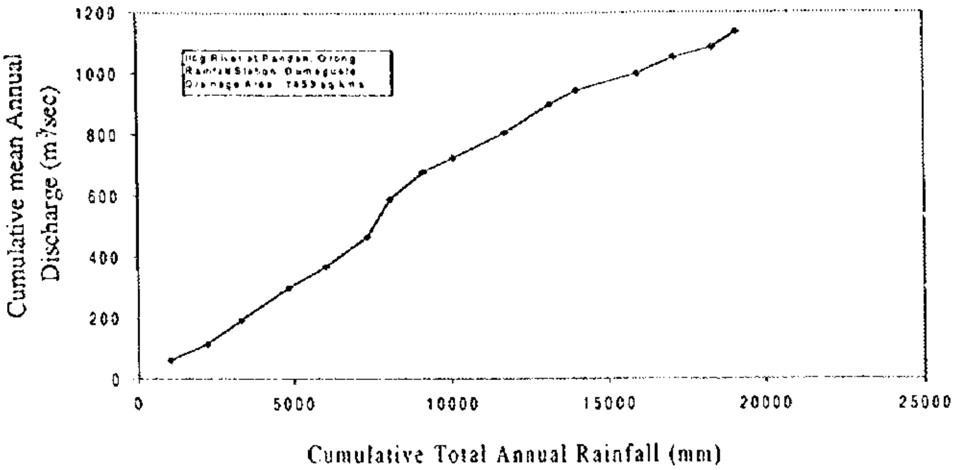
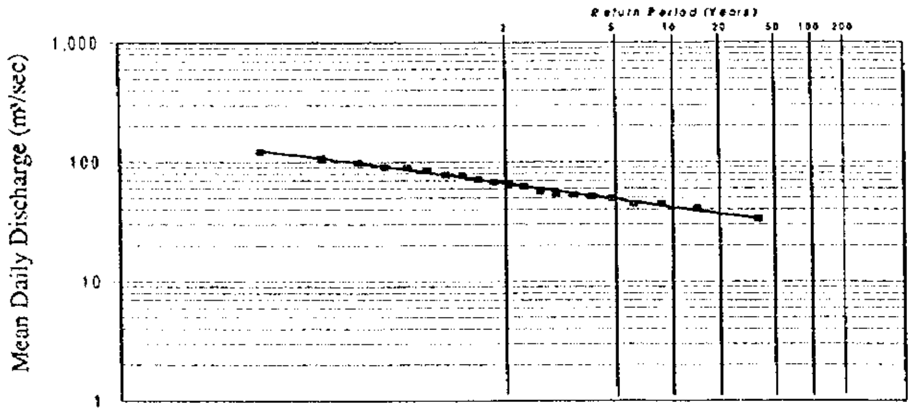


Frequency Analysis for Annual Mean Discharge



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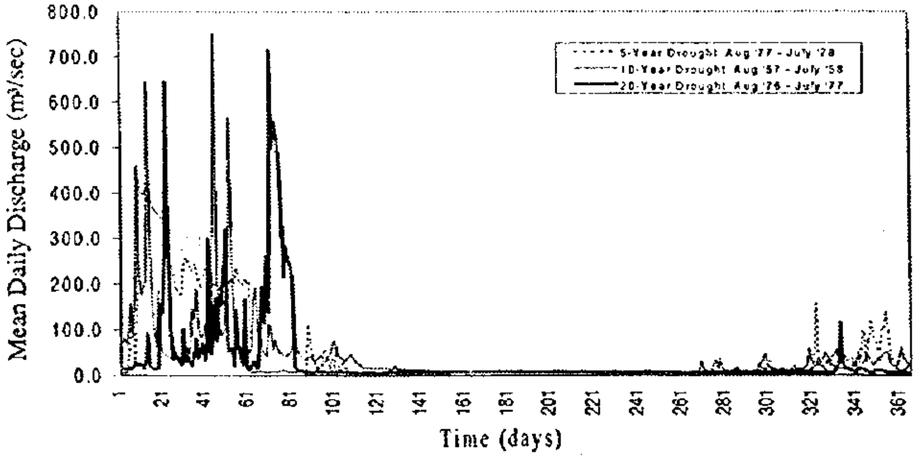

Figure B-25 HYDROLOGICAL OUTCOMES IN ILOG-HILABANGAN RIVER BASIN

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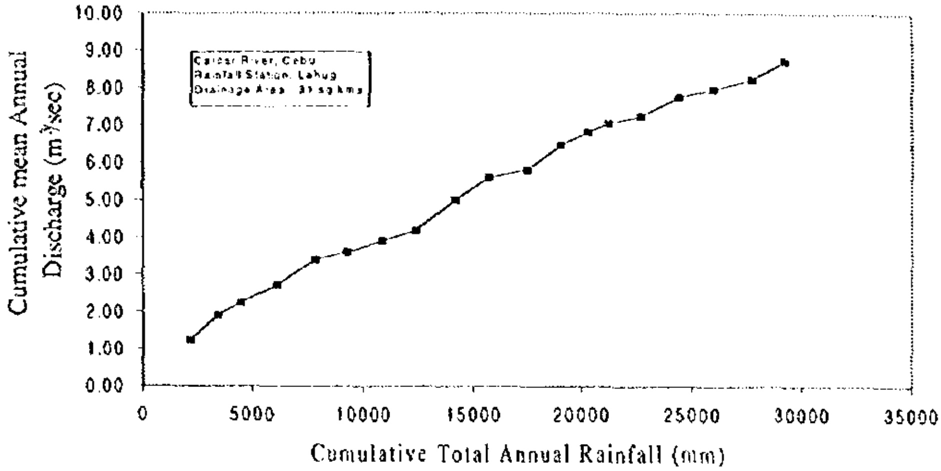

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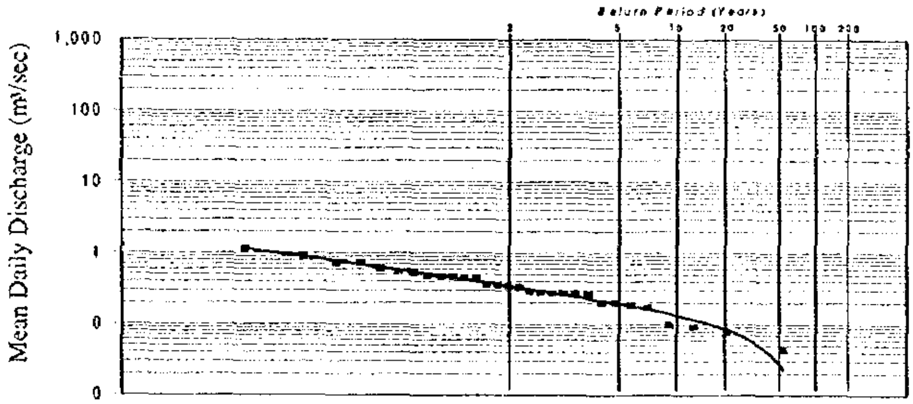

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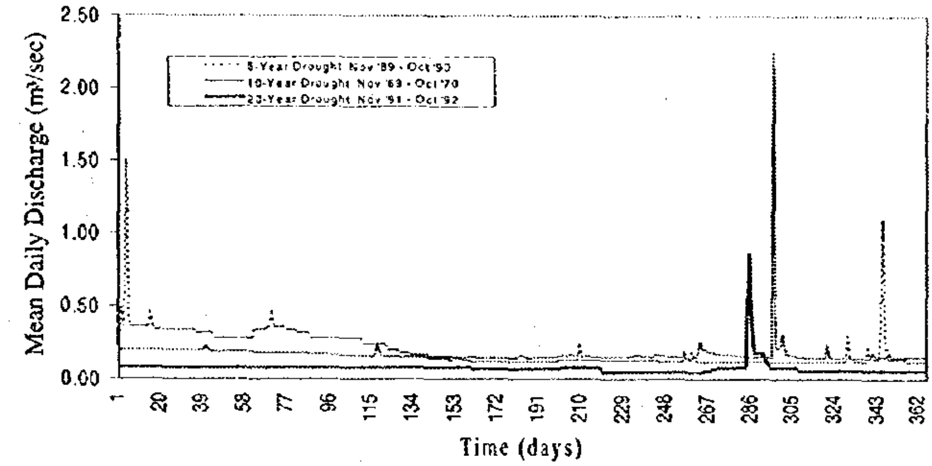
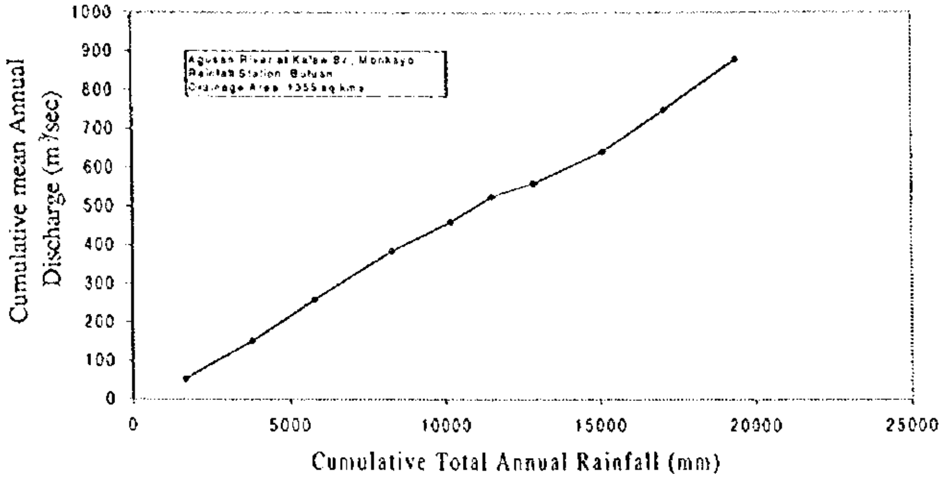
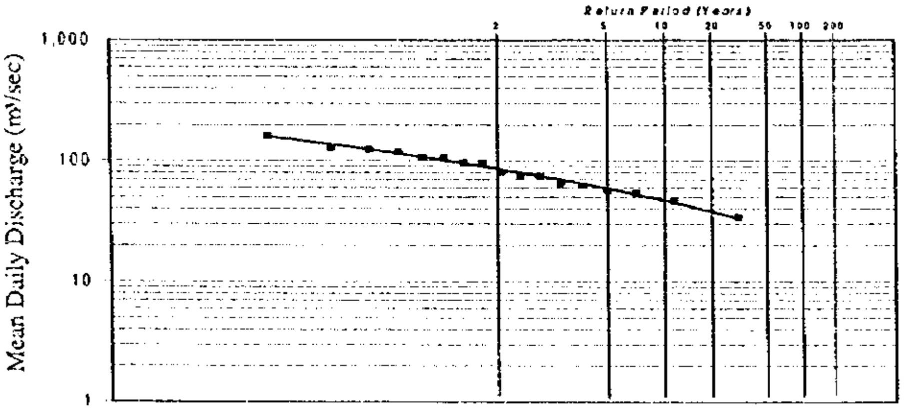


Figure B-26 HYDROLOGICAL OUTCOMES IN CARCAR RIVER BASIN (CEBU)

Double Mass Curve



Frequency Analysis for Annual Mean Discharge



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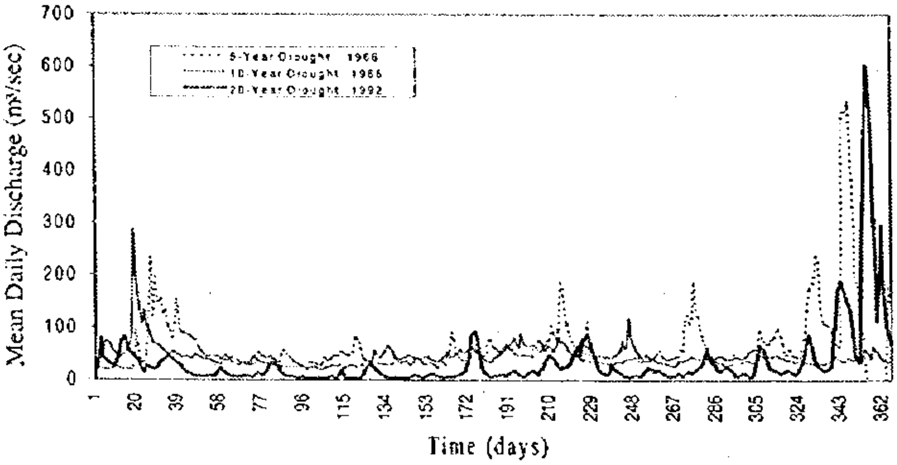

Figure B-27 HYDROLOGICAL OUTCOMES IN AGUSAN RIVER BASIN

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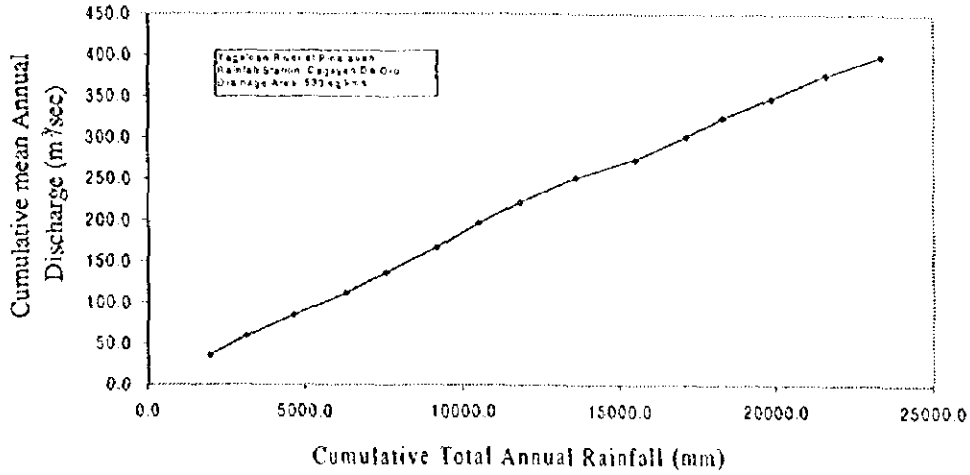

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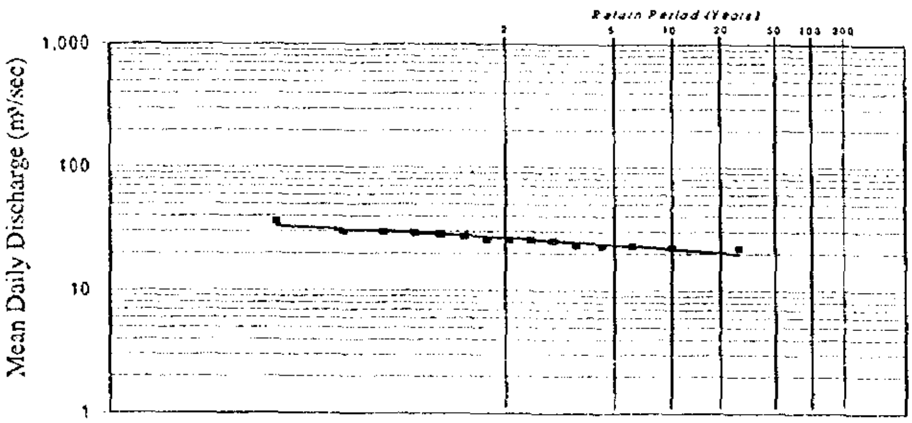

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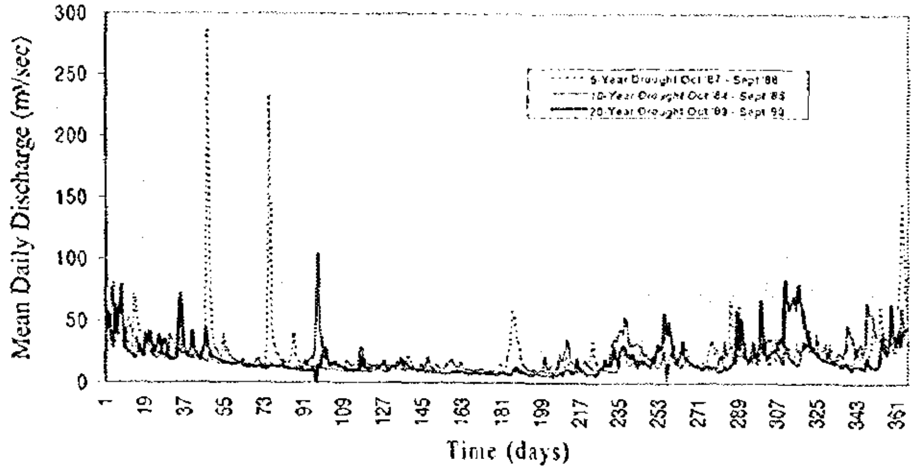
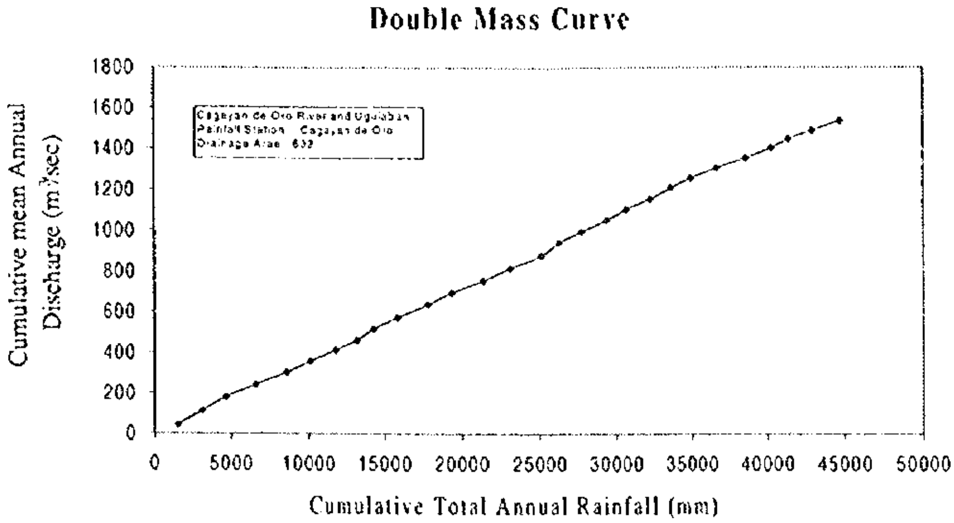
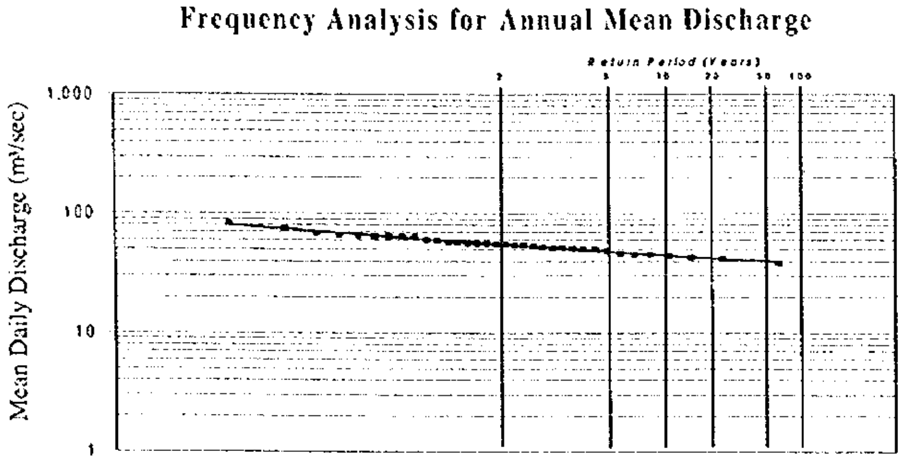
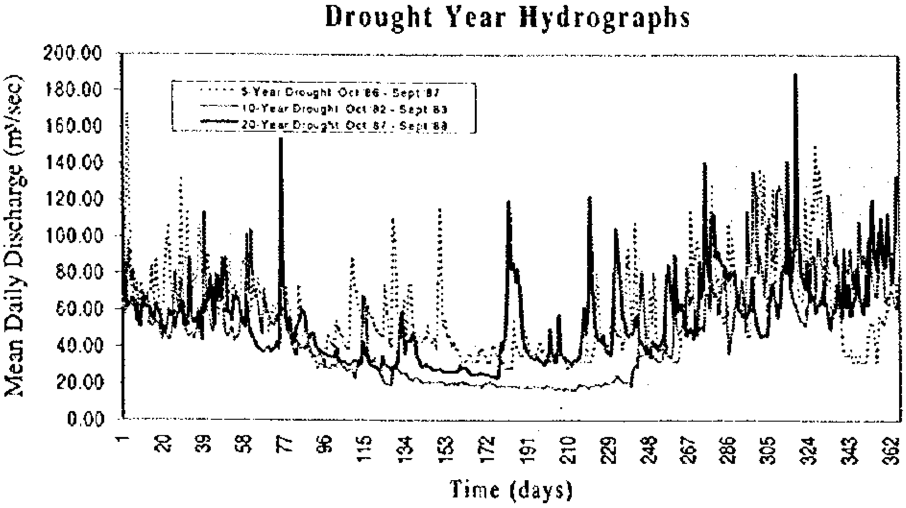


Figure B-28 HYDROLOGICAL OUTCOMES IN TAGOLOAN RIVER BASIN







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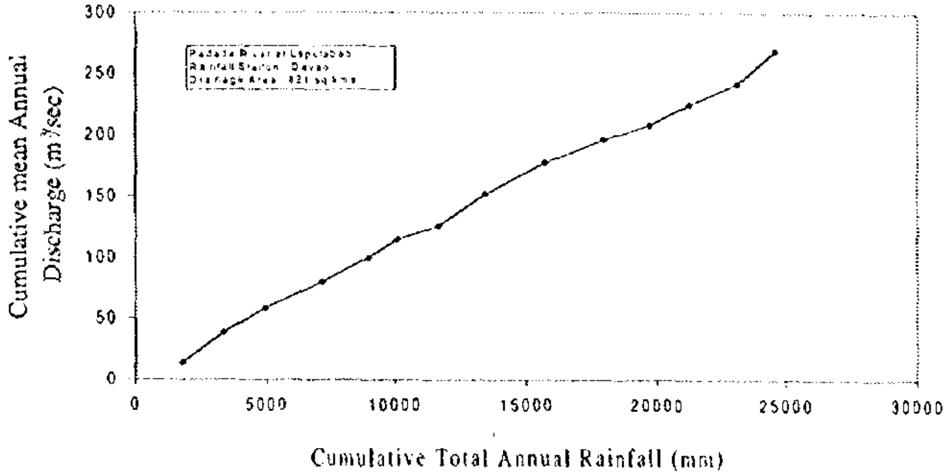
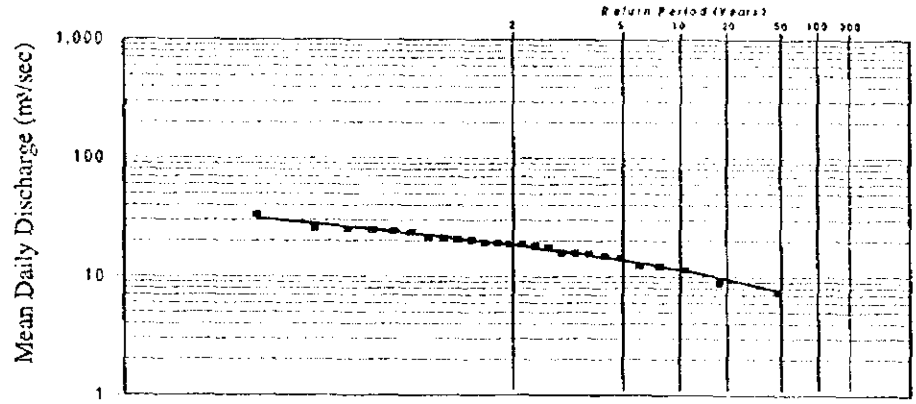
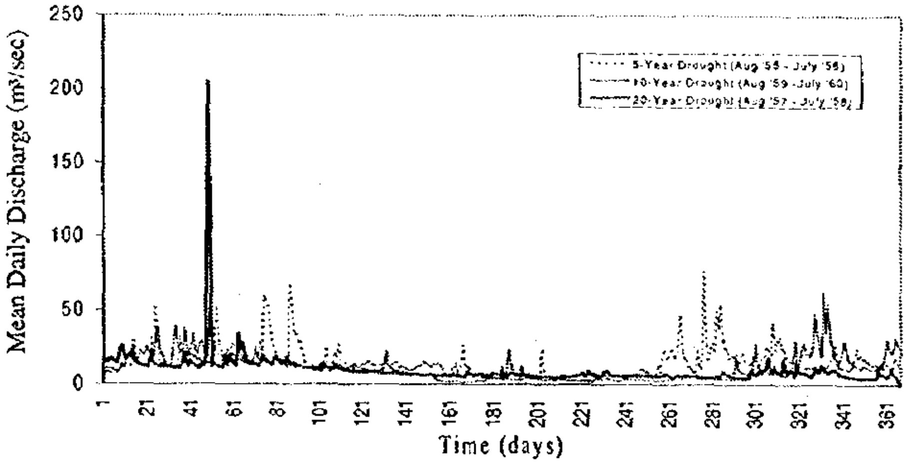


Frequency Analysis for Annual Mean Discharge



Drought Year Hydrographs



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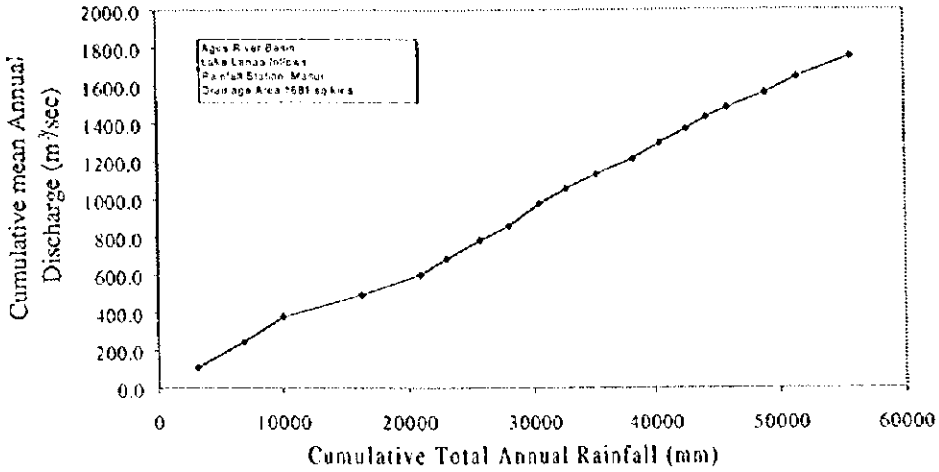
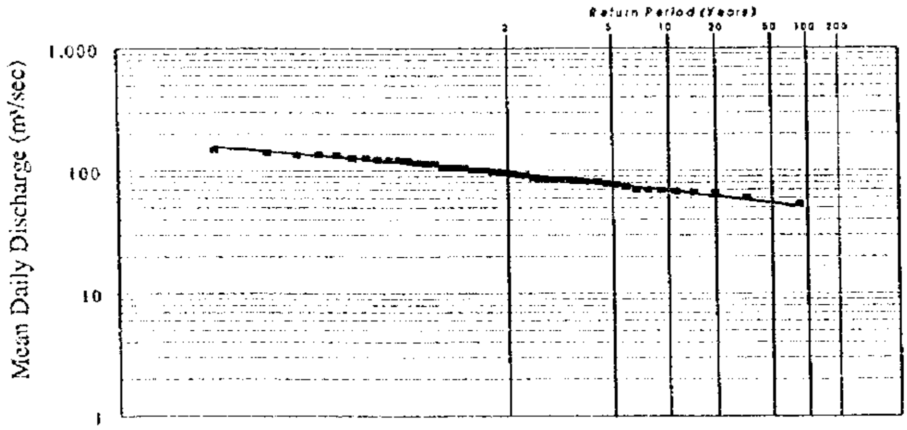


Frequency Analysis for Annual Mean Discharge



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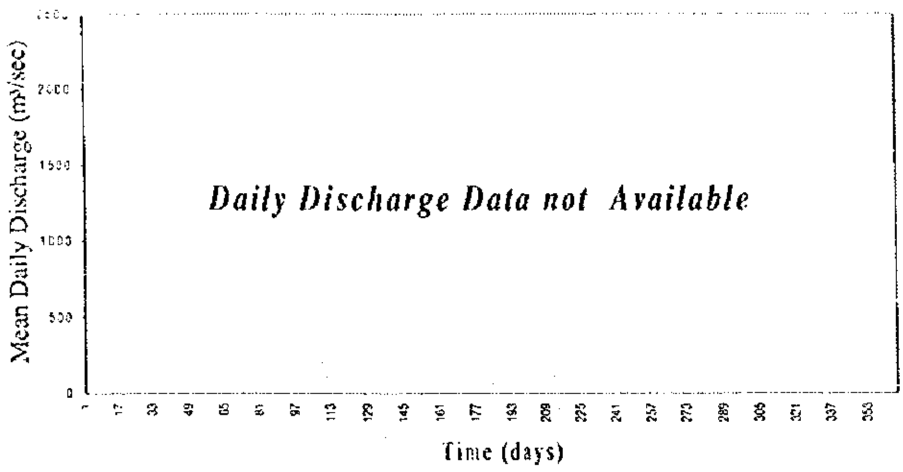

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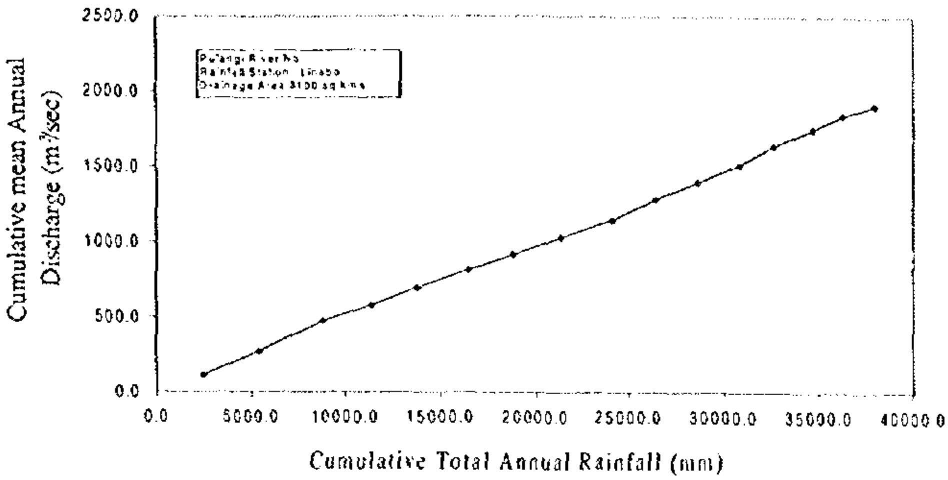
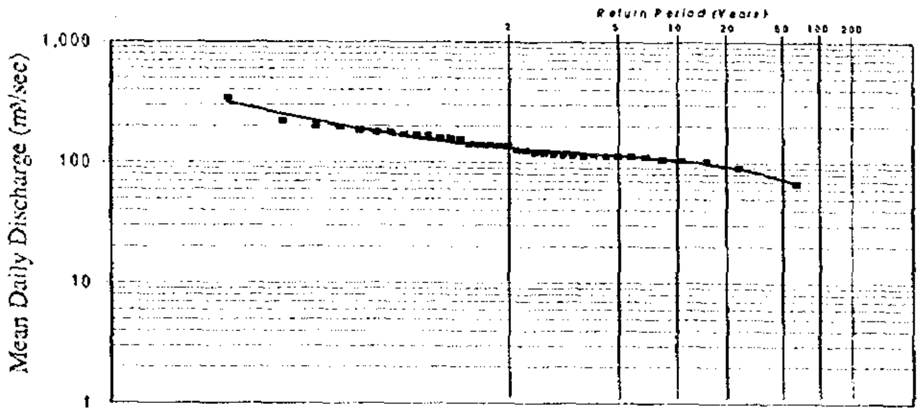


Frequency Analysis for Annual Mean Discharge



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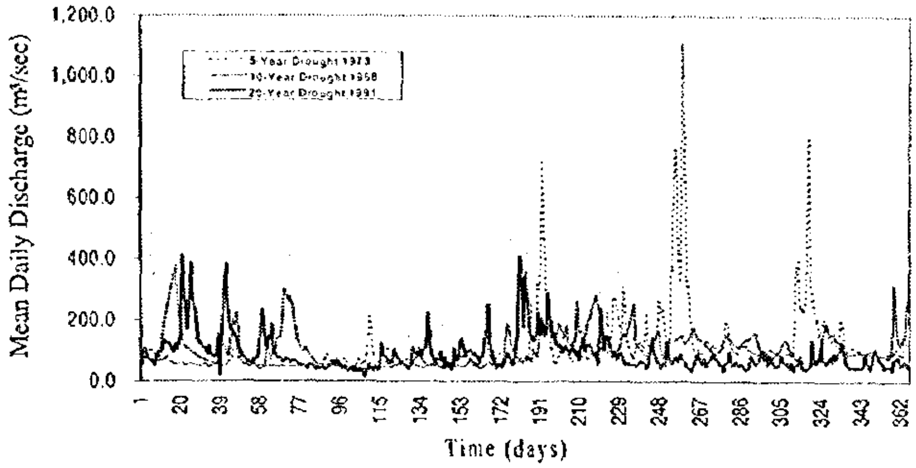

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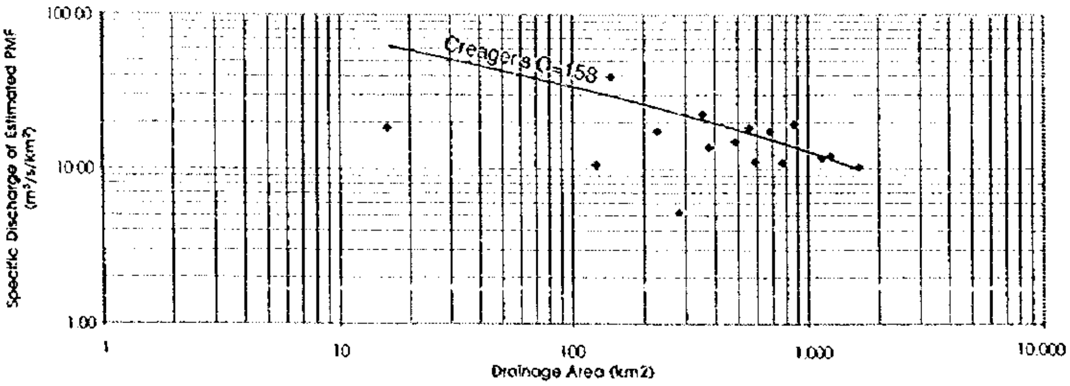
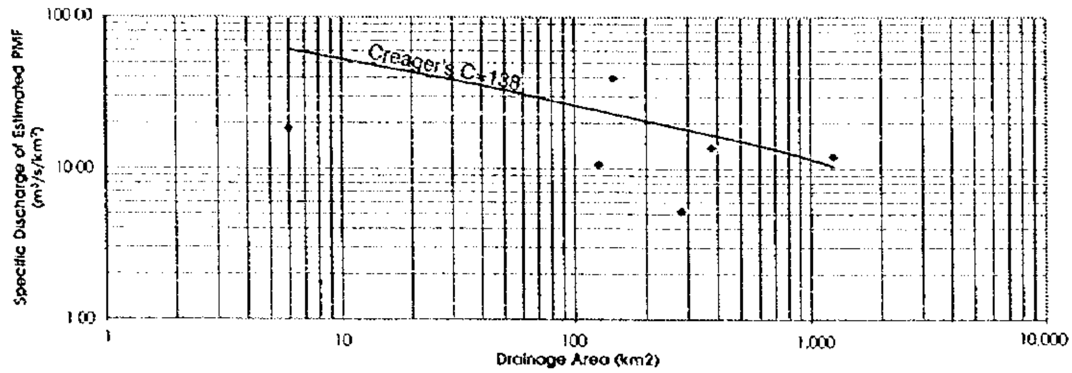
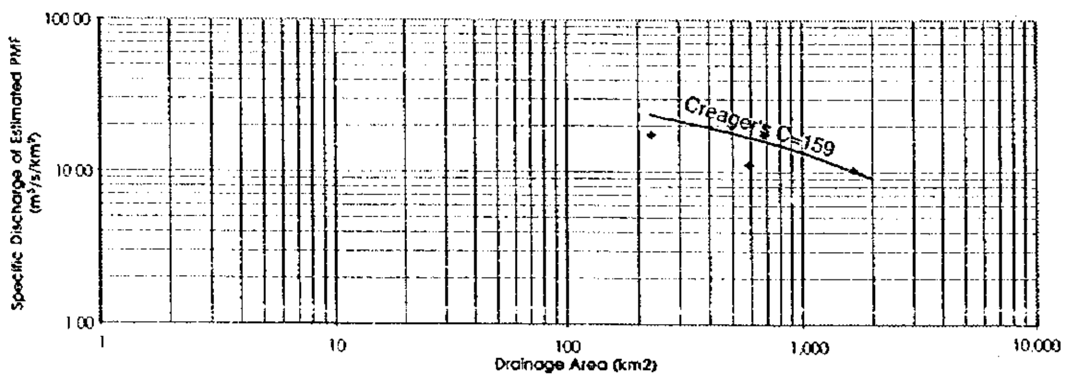


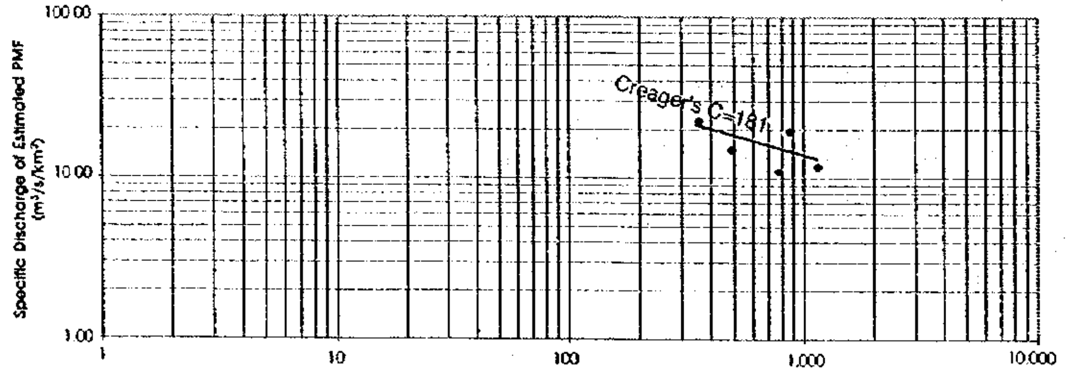
Luzon Island (All)



Luzon Island Type I Climate Region

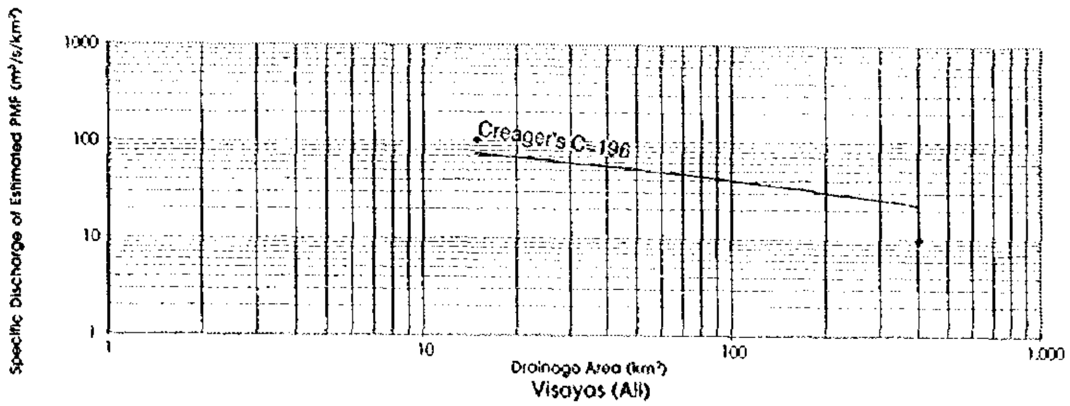


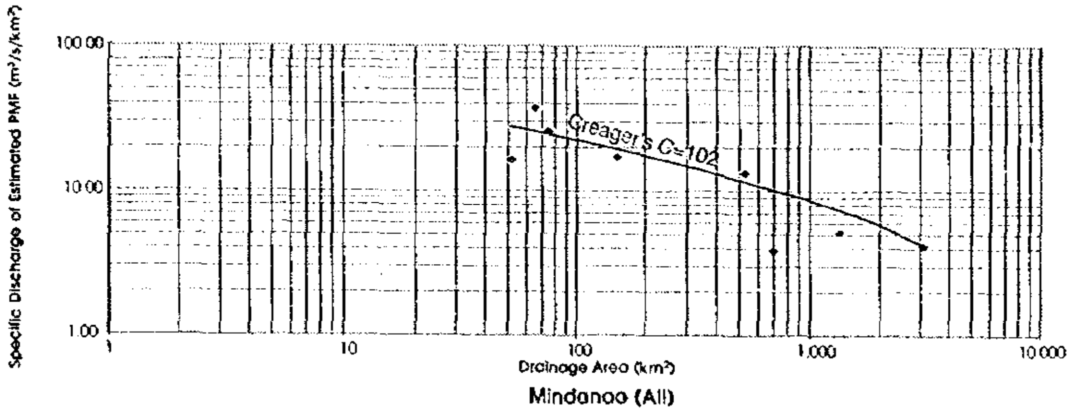
Luzon Island Type III Climate Region

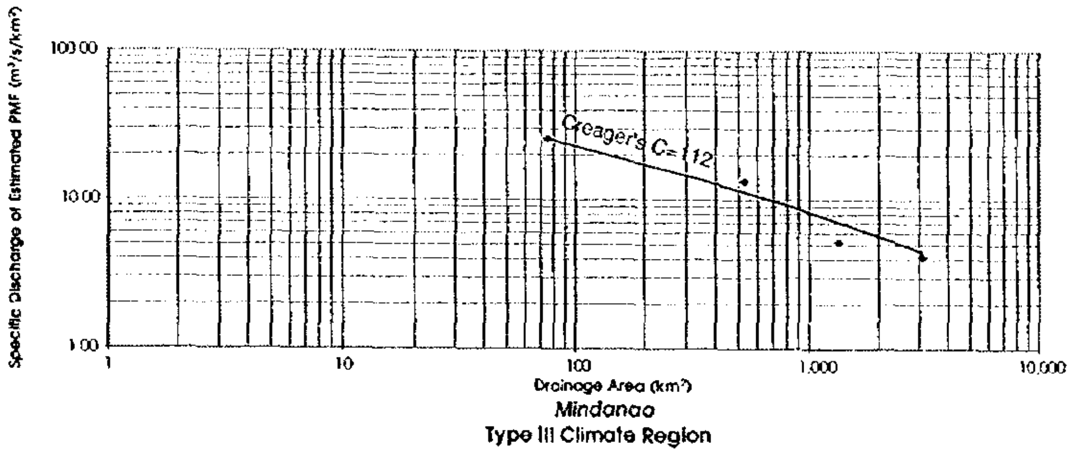


Luzon Island Type IV Climate Region

Figure B-33 SPECIFIC DISCHARGE OF ESTIMATED PMF -VS- DRAINAGE AREA (1/2)







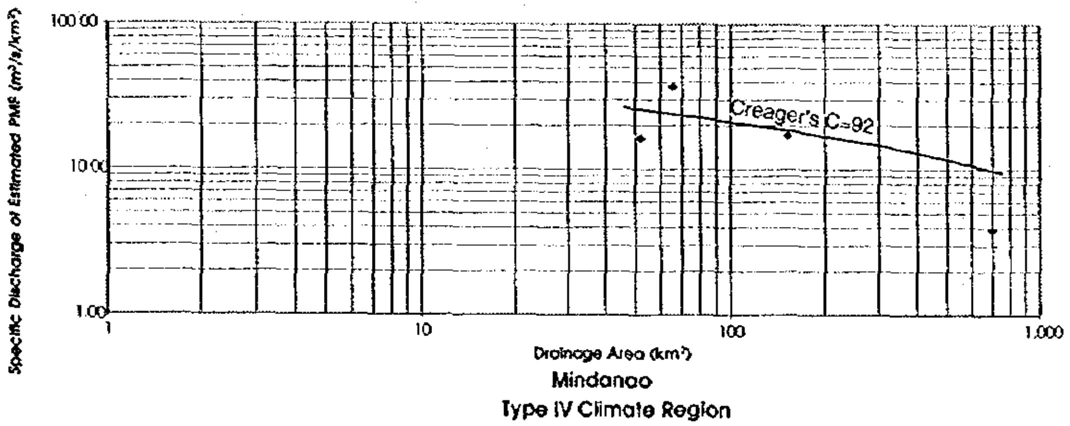
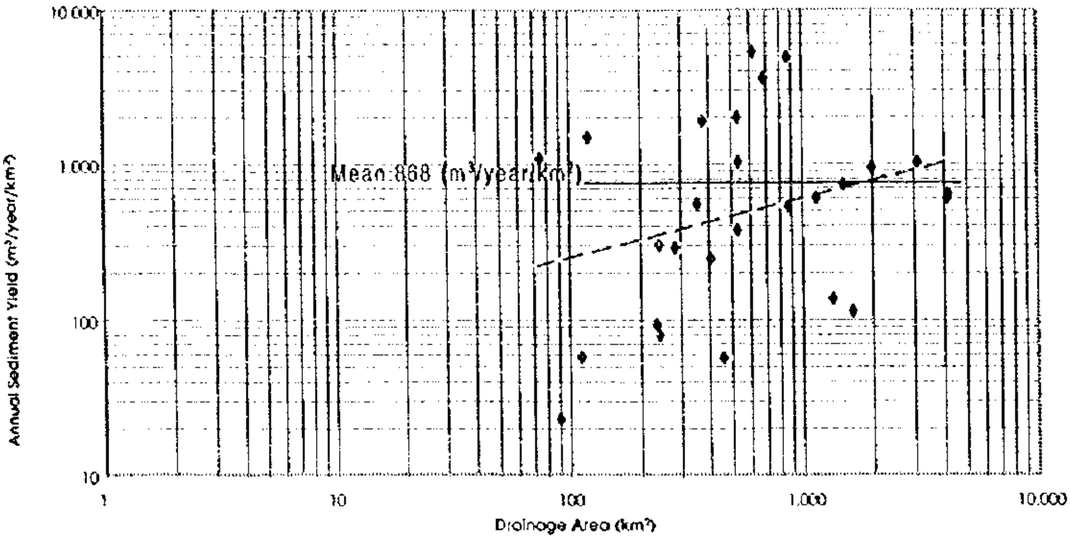
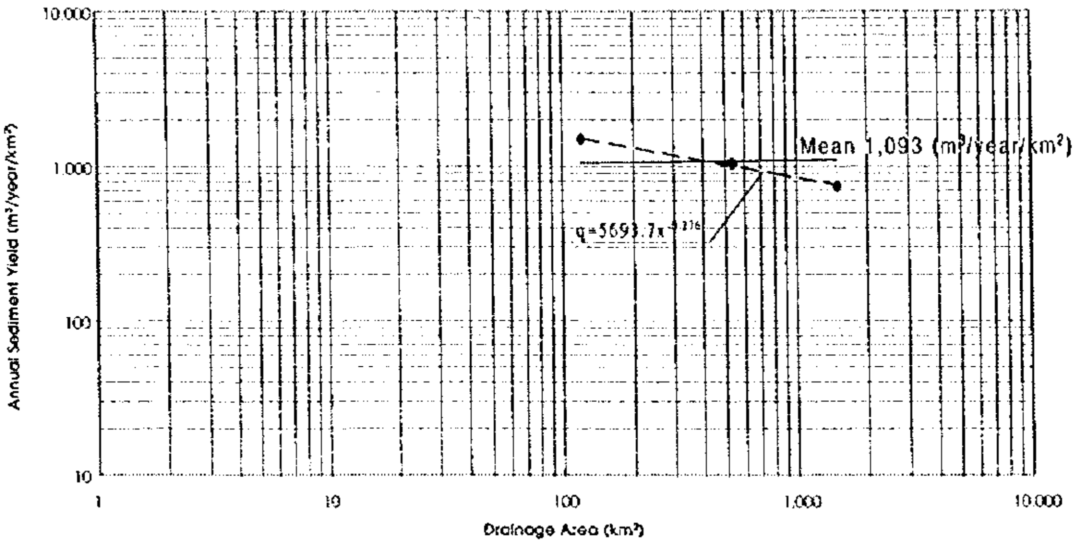


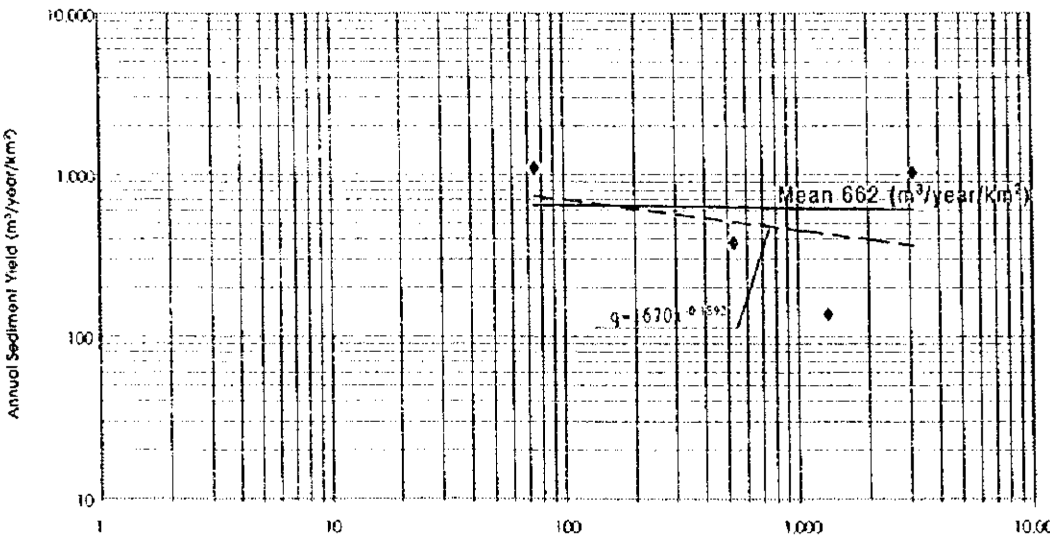
Figure B-33 SPECIFIC DISCHARGE OF ESTIMATED PMF -VS- DRAINAGE AREA (2/2)



Luzon



Visayas



Mindanao

Figure B-34 ANNUAL SEDIMENT YIELD VERSUS DRAINAGE AREA

Part – C

GROUNDWATER RESOURCES

Part – C GROUNDWATER RESOURCES

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Part - C GROUNDWATER RESOURCES

C1 Groundwater Development Potential

The groundwater development potential of each Water Resources Region (WRR) was roughly estimated in this study. In general, the total groundwater development potential of the WRRs is considered equal to their groundwater recharge. The future groundwater development potential of each WRR corresponds to the groundwater amount which is not currently used.

C1.1 Methodology

The groundwater recharge is defined to be the inflow flux to a groundwater basin. There are two basic methods which are used to estimate groundwater recharge. One is the water balance method and the other is the empirical method based on annual precipitation. In case of the water balance method, in general, the following equation is applied:

$$P = Rr + Et + Gr +/- Sm$$

Where,

P : Precipitation	Rr : River Run-off	Sm : Soil Moisture
Et : Evapotranspiration	Gr : Groundwater Recharge	

In this case, it is reasonable to ignore soil moisture in the water balance equation if the water cycle period is taken to be one year or longer. The meteor-hydrological data indicate that for most basins the sum of Rr and Et exceeds P. It was therefore concluded that the water balance method is not applicable to estimate the groundwater recharge due to the unreliability of the data which constitute the above equation. Thus, the groundwater development potential was estimated using the empirical method which was previously used by the NWRC.

C1.1.1 Groundwater Recharge

The water resources development studies carried out by the NWRC are (i) Groundwater of the Philippines (1980), and (ii) Framework Plans of 41 Major River Basins (1979-1983). These previous studies concluded that groundwater recharge value is approximately 10% of the basin rainfall. The estimated recharge values from the previous studies are shown in Tables C-1 and C-2. The results from the two studies are similar. The difference in the values reflects the difference in the time frames of the rainfall records used for each study. The groundwater recharge values for the Jalaur river basin and the Panay river basin of the Western Visayas were not included in the previous study reports. Thus, these values were estimated using the rainfall data and isohyetal maps from previous reports. According to the Framework Plans, the yearly groundwater recharge of the country was estimated at 49,315 MCM/year, which was broken down into those of the respective regions as follows:

Groundwater Recharge (Gr) by WRR (Unit; MCM/year)

WRR	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Gr	2,635	10,055	5,900	5,550	3,384	4,004	519	4,826	654	5,744	3,568	2,458

In the two recent studies on groundwater development in Metro Manila (1992) and in Cavite Province (1996), both of which were conducted under JICA, the groundwater recharge was estimated based on the results of the detailed field investigation using computer simulation. According to the study done in Metro Manila, it was estimated that the direct recharge of the study area was about 153.6 mm which was equivalent to 6.1% of the annual rainfall of 2,498.8 mm/year for the northern part of Metro Manila. For the southern part of Metro Manila, it was estimated at 114.7 mm which is equivalent to 5.0% of annual rainfall of 2,308.2 mm. In the latter study, the groundwater recharge was estimated to be only 3.9% of the annual rainfall. Thus, the groundwater recharge rates to annual rainfall in the previous detailed studies on groundwater are in a range of 3.9% to 6.1%, averaging approximately 5%.

In this study, 5% is adopted as the rate of groundwater recharge to annual rainfall to make the estimate conservative, taking into account the limited number of data and information available for the estimate thereof. The groundwater recharge was estimated by using the isohyetal maps based on recent rainfall data and applying the adopted groundwater recharge. The groundwater recharges for the respective water resources regions which were newly estimated through the aforesaid procedures are indicated in Table C-3.

C1.1.2 Groundwater Availability and Storage

The groundwater storage was roughly estimated dividing the exploitable areas of groundwater into two areas, namely shallow and deep well (alluvial) area and deep well (diluvium and tertiary) area. These features are categorized on the groundwater availability map of each WRR as described in the succeeding Section "C.2 Hydrogeology".

The land area was divided into three areas from the hydrogeological conditions, namely Quaternary formation area (shallow and deep well area), Tertiary formation area (deep well area) and other area (difficult area of groundwater exploitation). The first two formations generally have the groundwater development potential. These areas were then delineated on the hydrogeologic maps based on the relevant data and information. The groundwater storage of each area was then calculated using the following formula:

GW Storage = Area x Avg. well depth x Storage rate

The effective storage rates were roughly estimated at 15% in alluvial plains and 10% in diluvium and tertiary formations based on the general information. The results are shown in Table C-3. The groundwater storage represents the scale of a groundwater basin. As seen in the Table, the shallow and deep well area is one third that of the deep well areas. However, the total storage volume of the former is about 60% of that of the latter. This indicates that, although the alluvial areas are smaller than that of the diluvium and tertiary areas, the groundwater storage volume is fairly larger than that of the diluvium and tertiary area.

C1.2 WRR and Province-wide Groundwater Potential

The groundwater potential of the WRRs and provinces is dependent on their land area, their hydrogeological conditions and the amount of precipitation. Using this basic data, it was possible to roughly determine the groundwater potential of each WRR and province as discussed below.

The available recharge for the WRR/province was taken to be 5% of average annual precipitation depth as aforesaid. These calculation results are shown in Table C-4.

The data on land use patterns of each WRR and province were provided by the NWRB and were used to determine the land which would yield recharge to the groundwater of the area. The ratio of the different land types was then applied to calculate the rechargeable land ratio as shown in Table C-5. Based on the possible irrigable area as well as the presently irrigated area, the additional groundwater recharge amount other than that estimated above based on annual rainfall was calculated at a five-year interval was calculated as shown in Table C-6.

On the other hand, the urbanization reduces the amount of groundwater recharge in an area due to the covering of the land with concrete, asphalt and other non-porous materials. To determine the amount of groundwater recharge reduction taking place in the urban areas, the population and area therein were projected for each province based on the results of the socio-economic projection made in this study. The estimated urban population and land area are shown in Table C-7.

As a result, it is estimated that the groundwater recharge will increase from 1995 to 2005 in taking into consideration the expansion of irrigation areas and urbanized areas in the future as shown in the Table C-8. On the other hand, it is forecast that he increase ratio is as small as 2.5% as seen in the Table.

C2 Hydrogeology

In groundwater development, the groundwater conditions are predominantly controlled by geology, topography and structure of the groundwater basin. The structure of the basin includes the distribution and other hydrogeological conditions such as the aquifer structure and aquiclude, physical characteristics of geological formations as per transmissibility and storage coefficient and chemical characteristics of groundwater. These factors are directly related to the possible development depth and overall development potential.

The hydrogeological conditions were roughly evaluated on a region-wide basis. The groundwater availability maps for each WRR were produced as shown in Figures C-1 to C-12. From the view point of groundwater development, each area was divided into the following three categories:

(1) Shallow & deep well area: equivalent to the alluvial plain area which has a groundwater basin consisting of several aquifers and aquicludes. The aquifers consist of sand and gravel layers as well as impervious layers of clay and/or silt. In these areas, shallow and deep groundwater is available. The aquifers in these areas generally have enough magnitude, scale and permeability to produce large quantity of groundwater. Especially, it is reported in Groundwater Resources Investigation (NWRC) that high yielding areas distributed in the alluvial plains are formed by good aquifers mostly consisting of sand and gravel, and others.

(2) Deep well area: corresponds to Diluvium and/or Tertiary sediments consisting mainly of the Neogene age, which have low groundwater potential as compared with that of shallow and deep well area. This type of area is best suited to the development by handpump deep well which require small pumping rates.

(3) Difficult area: corresponds to area that is difficult in terms of groundwater development. The geology of this type of area is mainly formed of intrusive rocks, metamorphosed rocks and volcanic rocks.

In the evaluation, the reference materials utilized were previous studies such as the "Rapid Assessment of Water Supply Sources in the Philippines (NWRC, 1982)" which was published by province in a total of 73 volumes province, the "Study on the Provincial Water Supply, Sewerage and Sanitation Sector Plan (JICA-DILG, 1996)", the "Geological Map of the Philippines (Bureau of Mines, 1963)", etc.

The groundwater development in the Philippines has progressed greatly during the past 16 years since the completion of the "Rapid Assessment" in 1982. As a result, the information on deep groundwater and aquifers in alluvial plains has been rapidly accumulated with the construction of the numerous deep wells. Based on these achievements, the categorization of the groundwater development areas in the Rapid Assessment was partially modified in term of quantity in working out the groundwater availability maps in this Study. Moreover, the saline water intrusion areas were additionally illustrated on those maps based on the available information.

This study reassesses the groundwater availability maps for each water resources region. In the process of making new groundwater availability maps, this Study Team took efforts to incorporate into the maps the results of recent studies as well as new information as much as possible.

C2.1 Present Problems

C2.1.1 Saline Water Intrusion

The saline water intrusion can be observed along any seashore. This phenomenon is attributed to the insufficient and/or declining groundwater recharge rate, geological conditions and difference of density between saline and freshwater. This problem usually has been induced by the over-exploitation of groundwater.

The Study Team collected the white paper (1995) on the Philippines environment from DENR in the field investigation so as to clarify the present problems of groundwater use. However, there is no description on the environmental problems related to groundwater in the white paper. Accordingly, based on the available data and information on hydrogeology, the major saline water intrusion areas were attempted to be identified. As a result, it was found that in particular Metro Manila and Cebu City have serious saline water intrusion problems.

C2.1.2 Groundwater Pollution and Subsidence

The aforesaid DENR's white paper (1995) doesn't deal with the environmental problems on groundwater such as pollution of groundwater and subsidence of ground by groundwater over-exploitation. In consideration of the situation in the Philippines, the major pollutants might be sewage, factory wastes and agricultural chemicals (fertilizer). Accordingly, all populated, industrial and agricultural areas have a possibility for groundwater pollution.

The ground subsidence is observed mainly in wide plain areas, although the scale of subsidence isn't too serious. The ground subsidence is caused by the drainage of groundwater from clayey sediments. The artificial subsidence usually takes place in case that the excessive amount of groundwater has been extracted emphatically through artificial structures such as wells, etc. On the other hand, the densely populated areas such as Metro Manila, Cebu City, Davao City, etc. are located on consolidated sediments or on firm ground with thin unconsolidated sediments. Therefore, the subsidence hasn't been reported to the DENR as an environmental problem yet.

C2.2 Groundwater Availability

C2.2.1 Water Resources Region I

The Water Resources Region I (WRR I) covers the northwestern area of Luzon Island, comprising Ilocos Norte, Abra, Ilocos Sur, and a part of La Union and Benquet provinces. The eastern part of the area is occupied by the Cordillera Central Mountains stretching in a N-S direction, with the higher elevations ranging from 1,000 m to 2,400 m and a length of about 270 km . The area faces the South China Sea on the western side and has a width of 60 km in a E-W direction and 260 km in a N-S direction. The topography of the mountain is highly dissected by weathering with the formation of numerous small valleys. The mountain ranges are composed of the following:

(1) Metamorphosed volcanic in the geological age of probably Cretaceous and Paleocene
(2) Intrusive igneous rocks of Neogene geological age.

The metamorphosed volcanic rock consists of submarine volcanic flows, largely basalts, and some andesites. The intrusive igneous rocks are formed by largely intra-Miocene quartz diorite (mostly batholiths and stocks), and some laccoliths.

The hilly ranges with fairly smooth slopes are located on the western side of the mountain range. The elevation of the hilly ranges are from about 200 m to 100 m. The major fault lines often run in a N-S direction and sometimes form the hills along the alluvial plain as distributed in the Laoag City area. Many small streams directly flow down to the sea with short stream length. Most of the alluvial plains are of small area and sand dunes near the seashore are sometimes formed along the shoreline.

The groundwater availability map of the WRR I is indicated in Figure C-1. From the view point of groundwater development, the 14,103 km^2 area is divided into three categories. Of these three areas, the shallow and deep well area accounts for 12.3% of the total land area, the deep well area 49.2%, and difficult area 38.5%. Most of the area is composed of the deep well area.

The shallow and deep well area is formed by the alluvial plain. The alluvial area generally has a groundwater basin, formed by the accumulation of several aquifers and impervious layers. The aquifers consist of sand and gravel layers, and impervious layers of clay and/or silt layers. In these areas, shallow and deep groundwater is available. The aquifer in the area generally has enough magnitude and scale and permeability to produce a sufficient amount of groundwater. Thus, deep wells with casing diameters of 6 inches or more could mostly produce water rate of more than 1,000 m^3/day.

The deep well area is equivalent to sedimentary rock area of the Pleistocene to Miocene ages. These area have a topography consisting of hills and lower mountainous areas. The slope of the topography is moderate and gentle 25 compared with that of the Cordillera Central Mountains distributed on the eastern side and stretching from north to south.

The difficult area for groundwater development is occupied by the Cordillera Central Mountains. The geology is composed mainly of intrusive rocks, quartz diorite, including granodiorite and dacite of the Neogene age and old volcanic rocks such as basalt and andesite of the Cretaceous and Paleocene ages.

Groundwater Characteristics

In Ilocos Norte province, the Paoay plain often has saline fossil groundwater in its deeper portions. Ilocos Mountain, located north of the municipality of Pasquin, has large springs which are used as water sources for the water supply system of the Laoag Water District.

C2.2.2 Water Resources Region II

The WRR II covers the eastern area of Luzon Island, comprising Cagayan, Isabela, Kalinga, Apayao, Mountain Province, Ifugao, Nueva Vizcaya and a part of Benquet and Quirino and Aurora. The western parts of the area is occupied by the Cordillera Central Mountains which stretch in a N-S direction with the higher elevations ranging from 100 m to 2,800 m and with a length of about 270 km.

The topography of the Cordillera Central Mountains is highly dissected by weathering with the formation of numerous small valleys. The eastern side is also occupied by the Sierra Madre Mountains which run in a N-S direction along the eastern seashore with the higher elevations ranging from 100 m to 1,900 m and with a length of about 300 km. The height of the mountain range is generally lower than those of the Cordillera Central Mountains and its scale is smaller. The topography is strongly dissected with small complex and dendritic drainage networks. The vast Cagayan valley, formed by the Cagayan River, extends with a width of about 50 km and a length of about 200 km in a N-S direction. The valley has vast flat terraces ranging from about 10 m to less than 80 m on both sides of the Cagayan River. The WRR II faces the Philippine Sea on the eastern side and has a width of 170 km in a E-W direction and length of 260 km in a N-W direction.

The groundwater availability map of the WRR II is indicated in Figure C-2. From the view point of groundwater development, the 37,986km^2 area is divided into three categories. Of these three categories, the shallow and deep well area accounts for 14.3 % of the total land area, the deep well area 49.2%, and the difficult area 36.5%. Most parts of the area are occupied by the deep well area.

The shallow and deep well area is formed by the alluvial plain. The alluvium is distributed in the midstream and the downstream areas of the Cagayan River. The scale of the alluvium with an average width of 15 km and a length of 35 km is relatively small. The alluvial plain is suitable for groundwater development and forms a groundwater basin with several aquifers and impervious layers.

The deep well area is composed of marine and terrestrial sediments of the Pliocene to Pleistocene ages (the major part) consisting of plateau red earth and/or laterite, marine clastic sediments, locally transgressive pyroclastics (chiefly tuff and tuffaceous) and tuffaceous sedimentary rocks of the Upper Miocene to Pliocene ages as well as thick, extensive, transgressive mixed shelf marine deposits, largely greywakes, shales, and reef limestone of the Oligocene to Miocene ages.

The difficult area for groundwater development is covered by the Cordillera Central Mountain range in the western part of the region and the Sierra Madre Mountains on its eastern part. The Cordillera Central Mountain range is made up of metamorphosed volcanic rocks of the geologic age of probably Cretaceous and Paleocene and intrusive igneous rocks of the Neogene age. The metamorphosed volcanic rock consists of submarine volcanic flows, largely basalts and some andesites. Intrusive igneous rocks are formed by mostly intra-Miocene quartz diorite, batholiths, stocks and some laccoliths. The Sierra Madre Mountains are formed by old sedimentary rocks, largely greywacke and metamorphosed shale and/or pyroclastics, probably of the Cretaceous and Paleocene ages.

Groundwater Characteristics

The deep well area in the municipality of Ilagan is widely distributed with high cliffs on both sides of the Cagayan River. The alluvium areas are distributed in a very narrow area along the river. The groundwater level is fairly deep. Thus, the developmentment of deep groundwater is possible.

C2.2.3 Water Resources Region III

The WRR III covers the central part of Luzon Island and consists of Pangasinan, Zambales, Tarlac, Pampanga, Nueva Ecija, Bulacan, Bataan, and a part of the Quirino and Nueva Vizcaya and Aurora provinces. There exists the vast Central Luzon Plain, which has a width of 70 km and a length of 150 km extending in a NW-SE direction. The plain is located between the Zambales Mountains on the western side and the Sierra Madre Mountains on the eastern side. The plain is used for cultivation of paddy. It has many large alluvium fans formed by small streams flowing out of and near the mountains. There are some major rivers on the plain, where the Agno River empties into Lingayen Gulf and the Pampanga River flows into Manila Bay.

The Zambales Mountains stretch in a NNW-SSE direction and have high peaks ranging from 1,300 m to 2,037 m. The mountains have highly dissected topography in their northern portion and are volcanically active (Mt. Pinatubo erupted in July 1991). Inactive volcanoes, with cone shapes, are in the mountain range's southern portion. The Sierra Madre Mountains have lower elevations ranging from about 1,000 m to 1,400 m and they are highly dissected.

The groundwater availability map of the WRR III is indicated in Figure C-3. From the view point of groundwater development, the 23,545km^2 area is divided into three categories. Of these three categories, the shallow and deep well area accounts for 39.2% of the total land area, the deep well area 19.5%, and the difficult area 41.3%. Most part of the area is occupied by the difficult area.

The shallow and deep well area is formed by the alluvial plain. The Central Luzon Plain has a vast area of about 11,000 km^2, forming large groundwater basins with the complex structures consisting of several aquifers and impervious layers. The aquifer is generally composed of sand and gravel. The impervious layers are made up of silt and clay layers. The deep groundwater aquifers are in confined conditions. The groundwater development potential of the plains is considered very high because of the huge scale of the groundwater basins. The aquifers in the area generally have enough magnitude, scale and permeability to produce a sufficient amount of groundwater. Thus, deep wells with casing diameters of 6 inches or more could produce water at a rate of more than 1,000 cum/day.

The deep well area occupies only a small portion of the region along narrow belts between the plain and the mountain ranges. The area consists of several different sediment formation including the following:

(1) marine and terrestrial sediments of the Pliocene to Pleistocene ages (the major part) consisting of plateau red earth and/or laterite,
(2) marine clastic sediments, locally transgressive pyroclastics (chiefly tuff and tuffaceous) and tuffaceous sedimentary rocks of the Upper Miocene to Pliocene ages and
(3) thick, extensive, transgressive mixed shelf marine deposits (largely wackes, shales, and

reef limestone) of the Oligocene to Miocene ages.

The difficult area for groundwater development covers the Zambales Mountains and the Sierra Madre Mountains. The Zambales Mountains are formed by ultramafic and mafic plutonic rocks, predominantly peridotite associated with late gabbro and/or diabase dikes of the Cretaceous to Paleocene ages in its northern portion, and the volcanic rocks of the active or inactive volcanoes, consisting of dacite, basalt rocks, volcanic debris and pyroclastics in its southern portion. The Sierra Madre Mountains are made up of very complex geological formations including:

(1) very old basement complex of the Pre-Jurassic age consisting of amphibolite, quartzofeldspathic and mica schist, and phillites-slate, frequently associated with marble and quartzite,
(2) igneous rocks of the Paleocene age, consisting of mostly quartz diorite,
(3) old sedimentary rocks of greywacke and metamorphosed shale interbedded with base and intermediate flows and/or pyroclastics,
(4) old sediments rocks consisting of andesite flow rocks, wackes and shales of the Oligocene age and
(5) intrusive rocks of the Neogene age consisting of largely intra-Miocene quartz diorite.

The each geological formation occupies and is divided into the small sections by several major fault lines running in a NNW-SSE direction.

Groundwater Characteristics

Near the seashore areas such as Lingayen Gulf and Pampanga Delta, salt water intrusion is often observed in deep wells. In these areas, groundwater development should be conducted based on the results of the adequate underground survey. In the provinces of Tarlac and Bulacan, deep groundwater often has high levels of iron and manganese. Thus, the water quality of the groundwater needs to be checked prior to any groundwater development. A simple treatment system may be necessary.

C2.2.4 Water Resources Region IV

The WRR IV covers the southern central part of Luzon Island, comprising of the provinces of Rizal, Cavite, Batangas, Laguna, Marinduque, Occidental Mindoro, Oriental Mindoro, Romblon, Palawan, and a part of Quezon. The region is mainly divided into three areas as follows:

(1) Luzon Island

The Sierra Madre Mountains run along the eastern seashore in a NNW-SSE direction from the northern part to Tayabas Bay. Laguna Lake and the Taal Volcano in the southeast part of the mountains occupy a large area. Laguna Lake has a large surface area of about 5,080 km^2 and a depth 5 m on average, connecting to Manila Bay through the Pasig River. The lake has a tide and brackish water. The Taal Volcano is of a huge caldera type with a volcano scale of 55 km in a NW-SE direction and 30 km in a NE-SW direction. The volcano's highest peak is about 640 m. The Luzon Island portion stretches in SE direction, forming narrow belts with mostly flat plains and low hills ranging from 300 m to 400 m.

(2) Southern Islands

The southern islands are composed mainly of three islands, nammly Mindoro Island, Marinduque Island and Romblon Island. They are surrounded by coral reefs. Of these islands Mindoro is the largest. On Mindoro the steeply sloped mountain range runs in a NNW-SSE direction. The highest peak is 2,600 m. Alluvial plains are distributed on the northeastern and southwestern sides of the mountain range with a width from 10 km to 24 km and a length of about 60 km. Other small islands are mostly occupied by mountainous areas.

(3) Palawan Island

Palawan Island is isolated in the southwest and has a long and narrow shape extending in a NE-SW direction. The width of the island is 20 km to 35 km and its length is about 410 km. A mountain range runs along the central portion of the island with an elevation ranging from 900 m to 2,800 m. Alluvial plains are distributed in a narrow belt area on both sides of the mountains.

The groundwater availability map of the WRR IV is indicated in Figure C-4. From the viewpoint of groundwater development, the 47,475km^2 area is divided into three categories. Of these three categories, the shallow and deep well area accounts for 13.8% of the total land area, the deep area 25.1%, and difficult area 61.1%. Manila, the capitol city of the Philippines with a population of about eight million, is located in the shallow and deep well area. The WRR IV has a very large water demand and the overpumping of groundwater has caused the serious problems.

The shallow and deep well area is formed by the alluvial plain, which is not large. The plain is scattered in narrow belts of isolated islands or part of Luzon Island. The plain has a groundwater basin consisting of several pervious and impervious layers. In these areas, shallow and deep groundwater is available. The aquifer generally has high permeability and can produce a large amount of groundwater. Thus, deep wells with casing diameters of 6 inches or more could produce water at a rate of more than 1,000 m^3/day.

Metro Manila is located in the northwestern portion of the region. The municipal water for Metro Manila is supplied by MWSS using treated river water. However, the water supply volume is not enough even for domestic use because of its huge water demand. In addition, the area has numerous private firms, commercial centers, and public facilities which require a large quantity of water. These consumers independently have numerous deep wells and those wells are pumping groundwater in excess of the groundwater recharge. The overpumping causes severe problems such as the lowering of groundwater levels (to 120 m below sea level) and large-scale salt water intrusion over a fairly large area.

The deep well area is distributed over most areas of the southern part of Luzon Island, as well as the southern part of Palawan Island and the mountain sides of Mindoro Island. The area consists of several different sedimentary formations:

(1) marine and terrestrial sediments of the Pliocene to Pleistocene ages (major part) consisting of plateau of red earth and/or laterite,
(2) marine clastic sediments, locally transgressive pyroclastics (chiefly tuff and tuffaceous) and tuffaceous sedimentary rocks of the Upper Miocene to Pliocene ages and
(3) thick, extensive, transgressive mixed shelf marine deposits (largely wackes, shales, and reef limestone) of the Oligocene to Miocene ages.

The difficult area for groundwater development is distributed over most of the southern range of the Sierra Madre Mountains, the central mountain range of Mindoro Island and the northern part of Palawan Island. The area is made up of the following:

(1) volcanic rocks of the Pliocene to Quaternary age, consisting of pyroclastics and volcanic debris,
(2) igneous rocks of the Cretaceous to Paleocene age, consisting of ultramafic and mafic rocks, and
(3) old sedimentation rocks of the Pre-Jurassic age, forming basement complex such as amphibolite and quartzfeldspathic and mica schist and phillite-slate frequency associated with marble and quartzite.

Groundwater Characteristics

In the northern area of Laguna Lake, deep wells with depth of 300 m or more often hit fossil water with high concentration of chloride. The northern mountain slope of the caldera of Taal Volcano has a large amount of groundwater production with many aquifers.

C2.2.5 Water Resources Region V

The WRR V covers the most southern part of Luzon Island and the isolated islands of Catanduanes Island and Masbate Island. It comprises the provinces of Camarines Norte, Camarines Sur, Albay, Sorsogon, Catanduanes and Masbate. The area is characterized by conical shaped active and inactive volcanoes. It has complex seashore lines formed by the distribution of the volcanoes. The alluvial plains are distributed over narrow and flat areas among the volcanoes.

Masbate Island is an isolated and fairly large island with the area of 4,048 km^2. The island has mountains covering a small area in the central part of the island and a plateau with elevations ranging from 50 m to 100 m, covering most of the island.

The groundwater availability map of the WRR V is indicated in Figure C-5. From the view point of groundwater development, the 17,631km^2 area is divided into three categories. Of these three categories, the shallow and deep well area accounts for 11.3% of the total area, the deep area 34.1% and the difficult area 54.6%.

The shallow and deep well area is formed by the alluvial plain. On Luzon Island, the plain is distributed in a narrow belt among the small mountains, extending in a NW-SE direction. In these areas, shallow and deep groundwater is available. The aquifer generally has high permeability and can produce a large amount of groundwater. Thus, deep wells with casing diameters of 6 inches or more could produce water at a rate of more than 1,000 m^3/day. Masbate Island has a very limited alluvial plain.

The deep well area occupies the largest area in the region, covering most of Camarines Norte, Albay, Sorsogon and Masbate provinces. The area consists of the following different sedimentary formations:

(1) marine and terrestrial sediments of the Pliocene to Pleistocene ages (major part) consisting of plateau of red earth and/or laterite,
(2) marine clastic sediments, locally transgressive pyroclastics (chiefly tuff and tuffaceous) and tuffaceous sedimentary rocks of the Upper Miocene to Pliocene ages, and

(3) thick, extensive, transgressive mixed shelf marine deposits (largely wackes, shales, and reef limestone) of the Oligocene to Miocene ages.

The difficult area for groundwater development is occupied by volcanic rocks of the Paleocene-Quaternary ages, consisting of pyroclastic or volcanic debris and a basement complex of the Pre-Jurassic age, as well as amphibolite, qurtzofeldspathic, mica schists, and phillites-slates frequently associated with marble and quartzite. Those of Masbate Island are made up of andesitic pyroclastics of the Oligocene age.

Groundwater Characteristics
The volcanic area has abundant groundwater sources with many springs and many flowing wells are often observed at the foot of the volcanoes. Salt water intrusion in deep wells near the seashore is sometimes experienced.

C2.2.6 Water Resources Region VI

The WRR VI covers two large islands, Visayas Island and Panay Island with an area of 12,902 km^2 and a part of Negros Island with an area of 7,926 km^2. The region comprises of the provinces of Aklan, Antique, and Capits on Panay Island and Negros Occidental province on Negros Island, as well as the sub-province of Guimaras Island.

The western half of Panay Island is occupied by a mountainous area, with elevations ranging from 1,000 m to 1,400 m and steep slopes. The topography is strongly dissected with small complex and dendritic drainage networks. The eastern part of the island is also covered by a mountainous area with elevations of about 400 m to 500 m. Most parts of the central island are sandwiched between both mountainous areas and are occupied by a plateau with an elevation of about 300 m. Alluvial plains are only located on the north and southeast sides with most occurring on Panay Island.

Negros Island is occupied by inactive volcanoes and mountainous areas. The volcanoes range from 1,400 m to 2,500 m in elevation and are located in the northern portion of the island. A mountain range is distributed in a southeasterly direction, with elevations ranging of from 400 m to 500 m. Alluvial plains are only distributed in limited locations with small areas facing the sea.

The groundwater availability map of the WRR VI is indicated in Figure C-6. From the view point of groundwater development, the 20,223km^2 area of is divided into three categories. Of these three categories, the shallow and deep well area accounts for 14.0% of the total area, the deep well area 29.4% and the difficult area 56.6%.

The shallow and deep well area is formed by the alluvial plain. The distribution of the plain is limited to the area near the seashore, with an average extension of about 5 km by 25 km. The aquifer generally has high permeability and can produce much groundwater. Thus, deep wells with casing diameters of 6 inches or more could produce water at a rate of more than 1,000 m^3/day. The deep well area consists of the following different sedimentary formations:

(1) marine and terrestrial sediments of the Pliocene to Pleistocene ages (major part) consisting of plateau of red earth and/or laterite,
(2) marine clastic sediments, locally transgressive pyroclastics (chiefly tuff and tuffaceous)

and tuffaceous sedimentary rocks of the Upper Miocene to Pliocene ages, and
(3) thick, extensive, transgressive mixed shelf marine deposits (largely wackes, shales, and reef limestone) of the Oligocene to Miocene ages.

The difficult area for groundwater development is distributed in the central range, extending in a N-S direction as well as the eastern side of Panay Island and in the northern and the southwestern parts of Negros Island. The area is composed of the following:

(1) intrusive rocks of the Neogene age consisting of quartz diorite,
(2) old volcanic rocks such as andesite flow, pyroclastic formations of the Paleocene-Eocene and Oligocene ages and
(3) new basaltic volcanic rocks covering the volcanic plain and volcanic piedmont area of the Pliocene-Quaternary age.

Groundwater Characteristics
Near the seashore area of Panay Island, salt water intrusion is often observed.

C2.2.7 Water Resources Region VII

The WRR VII area covers the central Visayas region, comprizing the provinces of Negros Oriental, Cebu and Bohol. Negros, Cebu and Bohol Islands have land areas of 13,329 km^2 5,088 km^2 and 4,117 km^2, respectively. Negros Oriental province occupies eastern part of Negros Island and is formed by a low mountainous area ranging from 400 m to 500 m in elevation.

Cebu Island is mostly formed by mountainous areas except for a flat land area in a narrow belt of 100 m to 250 m along the seashore. The mountainous area has an elevation of 400 m to 900 m. The flat land area is connected by fairy steep slopes to the mountainous area. The topography of the mountainous area is highly dissected with numerous small peaks and many small valleys.

Bohol Island is characterized by karst topography, which is formed by weathered limestone. This topography is widely distributed in the northeastern area of the island. A low mountainous area is distributed in the western and southeastern sides of the island.

The groundwater availability map of the WRR VII is indicated in Figure C-7. From the view point of groundwater development, the 14,951km^2 area is divided into three categories. Of these three categories, the shallow and deep well area accounts for 7.6% of the total land area, the deep well area 70.2%, and the difficult area 22.2%.

The shallow and deep well area is formed by the alluvial plain. The alluvial plains are only distributed in limited areas on the three islands. The alluvial areas in the islands of Cebu and Bohol are mostly formed by younger soft limestone which is quite porous. The limestone is not a strong retention capacity of groundwater. Thus, the groundwater level is low and the pumping of groundwater in wells is likely to lead to salt water intrusion.

The deep well area is also in the same condition as that of the shallow and deep well area in Cebu and Bohol Islands. The area has a higher elevation than that of the alluvial area. However, the geology is also composed of porous younger limestone and similarly the groundwater level is low and salt water intrusion is a hazard.

The difficult area for groundwater development is distributed across the eastern volcanoes of Negros Island, the central part of Cebu Island and the northern and eastern sides of Bohol Island. The eastern volcanoes of Negros Island consist of volcanic rocks such as pyroxene andesite, dacite of the Pliocene to Quaternary ages. The difficult area of Cebu and Bohol Islands is formed by the following:

(1) volcanic rocks of the Cretaceous-Paleocene age, consisting of basic flows, usually intercalated with greywacke, and
(2) old sedimentation rocks formed by basement complex of the Pre-Jurassic age, consisting of amphibolite, quartzofeldspathic and mica schist, and phillite-slate frequently associated with marble and quartzite.

Groundwater Characteristics
Cebu and Bohol Islands are mostly made up of porous, younger and unconsolidated limestone. The limestone is not a good medium for the retention of groundwater. Thus, intensive groundwater pumping will often cause salt water intrusion into groundwater due to the lowering of groundwater table. Thus, it appears that the large-scale groundwater development is not appropriate in both "shallow and deep well" area and "deep well" area.

C2.2.8 Water Resources Region VIII

The WRR VIII covers the islands of Samar and Leyte in the Visayas region and consists of Northern Samar, Eastern Samar, Samar, Leyte, and Southern Leyte provinces and Biliran sub-province.

Samar Island has an area of 13,429 km^2 and the area of Leyte Island is 8,003 km^2. Samar Island is mostly covered by low mountains ranging from 400 m to 900 m in elevation, which extend to the seashore. The alluvial plain is only distributed in a very narrow area near the seashore.

Leyte Island has mountains higher than those of Samar Island and their elevation ranges from 1,000 m to 1,300 m. The mountain range extends in a NW-SE direction from the central part of northern Leyte to southern Leyte. A low mountainous area with an elevation of about 500 m is also distributed in the eastern part of Leyte Island. The mountains have a very high dissected topography. A vast alluvial plain with a width of 3 km and a length of 50 km is distributed between both mountain ranges and extends in a NW-SE direction. In other places, the alluvial plain is distributed in limited areas. A plateau near the mountain ranges with an elevation of about 100 m also exists.

The groundwater availability map of the WRR VIII is indicated in Figure C-8. From the view point of groundwater development, the 21,531km^2 area is divided into three categories. Of these three categories, the shallow and deep well area accounts for 3.8% of the total land area, the deep well area 80.5%, and difficult area15.7%.

The shallow and deep well area is formed by the alluvial plain. The vast plain distributing in the eastern part of Leyte Island is considered to have a high groundwater development potential due to the scale and magnitude of the plain. The plain is composed of recent sediments which were conveyed by streams for a long time. The plain has a groundwater basin with alternating layers of aquifers and impervious layers. Shallow groundwater is in an unconfined condition and the deep groundwater is in a confined condition. The aquifer consists of sand and gravel layers and the impervious layers are formed by clay and silt layers.

The deep well area is distributed over most parts of Samar Island and in the mountain foothill areas of Leyte Island. The area consists of the following different sediments formations:

(1) marine and terrestrial sediments of the Pliocene to Pleistocene ages (major part) consisting of plateau of red earth and/or laterite,
(2) marine clastic sediments, locally transgressive pyroclastics (chiefly tuff and tuffaceous) and tuffaceous sedimentary rocks of the Upper Miocene to Pliocene ages, and
(3) thick, extensive, transgressive mixed shelf marine deposits (largely wackes, shales, and reef limestone) of the Oligocene to Miocene ages.

The difficult area is distributed in the central and the southern central parts of Samar Island and in the eastern part of and a part of central mountains of Leyte Island. In Samar Island, the geology is composed of

(1) old volcanic rocks of the Cretaceous-Paleocene age,
(2) igneous rocks of the Cretaceous-Paleocene age, consisting of ultramafic and mafic plutonic rocks, predominately peridotite associated with gabbro and diabase. The eastern part of Leyte Island consists of old sediment rocks of the Pre-Jurassic age (forming a basement complex) and
(3) igneous rocks of the Cretaceous-Paleocene age, consisting of ultramafic and mafic plutonic rocks.

A part of the central mountains of Leyte Island is made up of inactive volcanoes of the Pliocene-Quaternary ages, consisting of dacite and/or andesite.

Groundwater Characteristics
The plateau areas of Samar and Leyte Islands generally have fairly deep groundwater.

C2.2.9 Water Resources Region IX

The WRR IX covers the western part of Mindanao Island and some small southwestern islands. It consists of the provinces of Zamboanga del Norte, Zamboanga del Sur, Misamis Occidental, Basilan, Sulu and Tawi-Tawi.

The area extends to the southwest like a long arm with a width of about 30 km and a length of 270 km. There exists a large and inactive volcano with an elevation of 2,500 m located at the elbow of the long arm and between the arm and the main Mindanao Island. Another high mountain block with an elevation of about 1,400 m is found at the southwestern end of the arm. The arm is covered by low mountainous areas with elevations ranging from 400 m to 900 m near the seashore. An alluvial plain is distributed fairly widely over portion of Misamis Occidental province. The other areas have very limited areas along their seashores.

The groundwater availability map of the WRR IX is indicated in Figure C-9. From the view point of groundwater development, the 18,740km^2 area is divided into three categories. Of these three categories, the shallow and deep well area accounts for 6.7% of the total land area, the deep well area 56.7%, and the difficult area 36.6%.

The shallow and deep well area is formed by the alluvial plain. The plain is composed of recent sediments which have been conveyed by streams and rivers. The sediments have complex structures with fair depth, with aquifers and impervious layers piled on top of each other. The aquifer consists of sand and gravel layers and impervious layers formed by clay and silt layers. Shallow groundwater is in the unconfined condition, while deep groundwater is in the artesian condition. The deep well area is distributed over a major part of the region and it is formed by lower mountains and hills. The area consists of the following different sedimentary formations:

(1) marine and terrestrial sediments of the Pliocene to Pleistocene ages (major part) consisting of plateau of red earth and/or laterite,
(2) marine clastic sediments, locally transgressive pyroclastics (chiefly tuff and tuffaceous) and tuffaceous sedimentary rocks of the Upper Miocene to Pliocene ages, and
(3) thick, extensive, transgressive mixed shelf marine deposits (largely wackes, shales, and reef limestone) of the Oligocene to Miocene ages.

The difficult area for groundwater development is formed by:

(1) volcanic rocks of the Pliocene-Quaternary ages, consisting of andesite and/or dacite and forming pyroclastic flow and volcanic debris,
(2) old volcanic rocks of the Cretaceous-Paleocene ages,
(3) old sediments of the Pre-Jurassic ages forming a basement complex, and
(4) igneous rocks of the Cretaceous-Paleocene ages consisting of ultramafic and mafic plutonic rocks, predominately periodite associated with gabbro and diabase.

<u>Groundwater Characteristics</u>
The deep well area generally requires fairly deep drilling in order to enable groundwater production.

C2.2.10 Water Resources Region X

The WRR X covers the northern part of Mindanao Island. The area consists of the provinces of Misamis Oriental, Agusan del Norte, Surigao del Norte and the part of Lanao del Norte province facing the Bohol Sea, as well as Agusan del Sur province and a part of Bukidnon province in the inland areas.

The WRR X area is characterized by large volcanic areas in the western side and deep well areas in the eastern side, as well as fairly large alluvial plains. Bukidnon province is characterized by mountainous areas, including an old and large volcano, Mt. Katanglad, with a peak of 2,370 m. Misamis Oriental province also has several old volcanoes (Mt. Balatocan and Mt. Kaluayan) reaching an elevation of about 2,600 m. On the front side of the mountains, several river terraces have been upthrust with elevations ranging from 50 m to 100 m. The eastern side of the WRR X is covered by a high plateau ranging from 50 m to 200 m. An alluvial plain is distributed with a width of 20 km and the length of 60 km in the inland area, extending in a NW-SE direction and with a somewhat wide area along the seashore area of Butuan City. This alluvial plain was formed by the Agusan River.

The groundwater availability map of the WRR X is indicated in Figure C-10. From the viewpoint of groundwater development, the 28,018km^2 area is divided into three categories. Of these three categories, the shallow and deep well area accounts for 11.6% of the total land area, the deep well area 53% and the difficult area 35.4%.

The shallow and deep well area is formed by the alluvial plain. The alluvial areas generally have groundwater basins formed by the accumulation of several aquifers and impervious layers. The aquifers consist of sand and gravel layers and the impervious layers of clay and/or silt layers. In these areas, shallow and deep groundwater is available. The aquifer in the areas generally have the necessary magnitude, scale and permeability to produce a large amount of groundwater. Thus, deep wells with casing diameters of 6 inches or more can produce water at a rate of more than 1,000 m^3/day.

The deep well area is distributed in the western part of Misamis Oriental province and Agusan del Sur province and the plateau or the upthrust terraces with elevations of about 60 m to 200 m. The area is formed by old sediments consisting of the following:

(1) largely marine clastics (molasse) overlain by extensive, locally transgressive pyroclastics (chiefly tuff) and fuffaceous sedimentary rocks of the Upper Miocene-Pliocene ages, and
(2) marine and terrestrial sediments of the Pliocene-Pleistocene ages.

The difficult area for groundwater development is distributed in the western part of the WRR X. The geology is made up of the following:

(1) volcanic rocks of the Pliocene-Quaternary ages, consisting of andesite and/or dacite and forming pyroclastic flow and volcanic debris,
(2) old volcanic rocks of the Cretaceous-Paleocene ages, and
(3) igneous rocks of the Cretaceous-Paleocene ages, consisting of ultramafic and mafic plutonic rocks, predominately peridotite associated with gabbro and diabase.

Groundwater Characteristics
Cagayan de Oro City is located in a small alluvial plain formed by the Iponan River. The plain has a good aquifer at the depth of 200 m or more. The thickness of this aquifer is unknown. Wells are difficult to be plugged due to very high water pressures and yield a large amount of groundwater of more than 2,000 m^3/day.

C2.2.11 Water Resources Region XI

The WRR XI covers the eastern and the southeastern parts of Mindanao Island and consists of the provinces of Surgao del Sur, Davao Oriental, Davao, Davao del Sur and parts of North Cotabato and South Cotabato and Sarangani provinces.

The WRR XI area has a long seashore which extends from the northern part to the southern part of Mindanao Island and faces the Philippine sea. A mountain range covers most of the area with elevations ranging from about 1,000 m to 1,500 m with the exception of the Apo Volcano, which has a peak of 2,500 m. This volcano is located in the western part of Davao City. The mountains come close to the seashore lines. A few plains with fairly wide areas are distributed among the mountains in the areas of Tandag, Tagum, Digos, and Gen. Santos

Municipalities. These plains are sometimes constituted by younger limestone materials, surrounded by hilly areas consisting of old limestone sediments.

The groundwater availability map of the WRR XI is indicated in Figure C-11. From the viewpoint of groundwater development, the 24,224km^2 area is divided into three categories. Of these three categories, the shallow and deep well area accounts for 10.5% of the total land area, the deep area 61.6% and the difficult area 27.9%.

The shallow and deep well area is formed by the alluvial plain. The plain is distributed in limited locations with a fairly wide area. Some of the plains located in the southern parts are made up of younger limestone. These areas have the possibility of being developed for groundwater, but the previous development often experienced salt water intrusion. The plains near the inactive volcanoes have the piled structures resulting from volcanic eruptions and they mostly form good groundwater basins and produce a significant amount of groundwater. Other plains consisting such as weathered materials of sand and gravel, silt, and clay layers produce much groundwater because the aquifer in these areas generally have adequate magnitude and scale. In these plains, shallow groundwater is in the unconfined condition and deep groundwater is in the artesian condition.

The deep well area covers fairly wide areas of the eastern, southern and central parts of the WRR XI. These areas have a hilly and wide topography with elevations of about 20 m to 60 m behind the plains and low mountain ranges with elevations of about 1,000 m. The hilly areas are often formed by old limestone sediments of the Pliocene-Pleistocene ages. The limestone areas sometime have dorine and ubare structures.

The difficult area for groundwater development is distributed across the northern, southeastern and the southwestern parts of the region as well as the western area of Davao City. The area is composed of the following:

(1) volcanic rocks of the Pliocene-Quaternary ages,
(2) old volcanic rocks of the Cretaceous-Paleocene ages,
(3) old sedimentary rocks of the Pre-Jurassic ages forming a basement complex, and
(4) old sedimentary rocks, probably of the Cretaceous and Paleocene ages, consisting of largely greywacke and metamorphosed shale interbeded and/or intercalated with basic and intermediate flows and/or pyroclastics.

Groundwater Characteristics

Davao City is located east of the inactive Apo Volcano range which extends in a N-S direction and has elevations of about 2,500 m to 2,900 m. Thus, the geology of the mountain foothills area is composed by alternating layers of volcanic eruptions and lava flows. This area is blessed with high groundwater potential.

The municipality of Tagum is characterized by alluvial deposits consisting of younger limestone with a porous medium. The limestone does not form a good aquifer and this causes salt water intrusion near the seashore. The municipality of General Santos also is in the same condition with Tagum.

C2.2.12 Water Resources Region XII

The WRR XII covers the central part of Mindanao Island and consists of the provinces of

Lanao del Sur, Magindano, Sultan Kudarat, a part of the provinces of Lanao del Norte and Bukidnon and North Cotabato and South Cotabato and Sarangani provinces.

The area is mostly occupied by hills and mountain ranges. The vast plains are spread in the central portion of the inland. The plain has a width of 60 km and a length of 110 km, extending in a SSE-NW direction and reaches to the seashore of Cotabato City. In the drainage basin, the Mindanao River empties into the sea collecting many branch streams. Other plains have small and limited areas. The Apo Volcano is located on the eastern side of the plain with a peak of more than 2,900 m. There exist high and old volcanoes with elevations of about 2,800 m in the northern part of the WRR XII. Lanao Lake with a surface area of 360 km^2 is also surrounded by old volcanoes. Low mountain ranges ranging from 1,000 m to 2,000 m in elevation are distributed along the southwestern side of the region, adjacent to the southwest of the vast central plain.

The groundwater availability map of the WRR XII is indicated in Figure C-12. From the viewpoint of groundwater development, the 29,962km^2 area is divided into three categories. Of these three categories, the shallow and deep well area accounts for 24.9% of the total land area the deep area 40.6% and the difficult area 34.5%.

The shallow and deep well area is formed by the alluvial plain, which is distributed over a vast area in the central part and in other limited areas of the WRR XII. The area is formed by recent sediments with a fair thickness and width, consisting of sand, gravel, silt, and clay layers. The sediments form groundwater basins which consist of aquifer and impervious layers and produce much groundwater.

The deep well area is distributed in the central and southwest parts of the WRR XII and along the front of the mountains. The area is formed by hilly mounds and low mountains. The area consists of the following different sedimentary formations:

(1) marine and terrestrial sediments of the Pliocene to Pleistocene ages (major part) consisting of plateau of red earth and/or laterite,
(2) marine clastic sediments, locally transgressive pyroclastics (chiefly tuff and tuffaceous) and tuffaceous sedimentary rocks of the Upper Miocene to Pliocene ages, and
(3) thick, extensive, transgressive mixed shelf marine deposits (largely wackes, shales, and reef limestone) of the Oligocene to Miocene ages.

The difficult area is formed by the following:

(1) volcanic rocks of the Pliocene-Quaternary ages, forming volcanic plain and volcanic piedmont deposits, chiefly pyroclastics and/or volcanic debris,
(2) igneous rocks of largely quartz-diorite of the Neogene age,
(3) igneous rocks of the Cretaceous-Paleocene ages, consisting of ultramafic and mafic plutonic rocks and
(4) old sedimentation rocks of greywacke and metamorphosed shale and/or pyroclastics, probably of the Cretaceous and Paleocene age.

Groundwater Characteristics

The vast alluvial plain distributed across the central area of the region has significant groundwater development potential considering the scale of the area.