ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC

ASSESSMENT OF WATER RESOURCES AND WATER DEMAND BY USER SECTORS IN THAILAND

UNITED NATIONS

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FOREWORD

There are still serious inadequacies in the availability of data on the quantity and quality of water resources in most countries of the region. Furthermore, data on water withdrawals for various uses are even scarcer and less reliable than the data on water resources. It is for these reasons that a study on assessment of water resources of member countries and demands by user sectors has been initiated by the Natural Resources Division of the United Nations Economic and Social Commission for Asia and the Pacific with a view to promoting more efficient management for sustainable development of water resources. Greater knowledge about water resources and their use is needed in order to improve the management of water resources by determining the sources, potential and quality of surface and groundwater resources, on which to base an evaluation of the possibilities for their utilization.

This report, which constitutes a part of the study, on assessment of water resources and water demand by users sectors in Thailand has been prepared by Prof. Tawatchai Tingsanchali of the Asian Institute of Technology for the Natural Resources Division of ESCAP. The opinions, figures and estimates set forth in this publication are the responsibility of the author, and should not necessarily be considered as reflecting the views or carrying the endorsement of the United Nations.

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ABBREVIATIONS

General abbreviations

AIT	=	Asian Institute of Technology
ADB	=	Asian Development Bank
ALRO	=	Agricultural Land Reform Office, Ministry of Agriculture and Cooperatives
ARD	=	Accelerated Rural Development Office, Ministry of Interior
BMA	=	Bangkok Metropolitan Administration
BMR	=	Bangkok Metropolitan Region
CPD	=	Cooperatives Promotion Department, Ministry of Agriculture and Cooperatives
DCD	=	Department of Community Development, Ministry of Interior
DOH	=	Department of Health, Ministry of Public Health
DOLA	=	Department of Local Administration, Ministry of Interior
DMR	=	Department of Mineral Resources, Ministry of Industry
DPW	=	Department of Public Works, Ministry of Interior
EGAT	=	Electricity Generating Authority of Thailand
ESCAP	=	Economic and Social Commission for Asia and the Pacific
FAO	=	Food and Agriculture Organization of the United Nations
HD	=	Harbour Department, Ministry of Communications
IEAT	=	Industrial Estate Authority of Thailand
JICA	=	Japan International Cooperation Agency
LDD	=	Land Development Department, Ministry of Communications
MD	=	Meteorological Department, Ministry of Communications
MWA	=	Metropolitan Water Works Authority
NEA	=	National Energy Administration
NEB	=	National Environmental Board
NESDB	=	National Economic and Social Development Board of Thailand
NRC	=	National Research Council
NSC	=	National Security Council
NWRC	=	National Water Resources Committee
PWA	=	Provincial Water Works Authority
PWD	=	Public Welfare Department, Ministry of Interior
RID	=	Royal Irrigation Department, Ministry of Agriculture and Cooperatives
RAPA/FAO	=	Regional Office for Asia and the Pacific, FAO
TDRI	=	Thailand Development Research Institute

UNESCO	=	United Nations Educational, Scientific and Cultural Organization
UNIDO	=	United Nations Industrial Development Organization

Technical abbreviations

BOD	=	biochemical oxygen demand
d	=	day
DO	=	dissolved oxygen
DW	=	deep wells
GWh	=	gigawatt-hour
h	=	hour
ha	=	hectare
kg	=	kilogram
km	=	kilometre
kW	=	kilowatt
kWh	=	kilowatt hour
lpcd	=	litre per capita per day
m	=	metre
mm	=	millimetre
mcm	=	million cubic metres
mg/l	=	milligram per litre
NRW	=	non-revenue water
ppt	=	parts per thousand
s	=	second
yr	=	year

Exchange rate
(approx.)

25 baht	=	$US 1.00

INTRODUCTION

This report presents the results of the assessment of water resources, water uses and demand by various user sectors in Thailand. It is the first time that this type of study has been carried out in Thailand.

Data on water resources availability and water use in the different hydrological regions of Thailand were analysed for the period 1980 to 1989 and demand-supply situations for 1990 to 2000 were predicted. Observed data on rainfall, evaporation and streamflow were generally available for the period 1980 to 1989, therefore, water resources availability could be accurately determined. However, the observed data on water uses were not fully documented, therefore, estimates of the amount of water used for some activities had to be made.

This report consists of five chapters, the first chapter provides an overview and the observed data on the water resources availability in the different hydrological regions as well as in the whole country. The second chapter provides the observed data and an overview of the various types of water use activities and their analysis. The third chapter provides an overview of the estimated future amount of water uses. The fourth chapter presents the method of computation and the computed results of water resources availability and water use for the period 1980-1989 and the predictions for the period 1990-2000. The fifth chapter provides the main conclusions on water resources availability and water uses in the past from 1980 to 1989 and for the future from 1990 to 2000. Chapter V is followed by an annex which contains additional data to supplement the information in Chapters I to V.

The consultant wishes to express his sincere thanks to the Thai Government agencies, international organizations and private organizations concerned for providing their full cooperation including the data and information necessary for this study, namely, in alphabetical order:

1. Asian Institute of Technology (AIT)
2. Department of Mineral Resources (DMR), Ministry of Industry
3. Electricity Generating Authority of Thailand (EGAT)
4. Department of Fisheries, Ministry of Agriculture and Cooperatives
5. Harbour Department, Ministry of Communications
6. Industrial Estate Authority of Thailand (IEAT)
7. Interim Committee for Co-ordination of Investigations of the Lower Mekong Basin
8. Meteorological Department (MD), Ministry of Communications
9. Metropolitan Water Works Authority (MWA)
10. Ministry of Industry
11. National Energy Administration (NEA)
12. National Water Resources Committee (NWRC), Office of the Prime Minister
13. National Economic and Social Development Board (NESDB), Office of the Prime Minister
14. Provincial Water Works Authority (PWA), Ministry of the Interior
15. Royal Irrigation Department (RID), Ministry of Agriculture and Cooperatives
16. Thailand Development and Research Institute (TDRI)

I. WATER RESOURCES AVAILABILITY

Thailand is located in South-east Asia in the centre of the Indo-Chinese peninsula between latitude 6°-21°N and longitude 98°-106°E. The total country area is about 513,115 km^2. Thailand is bounded on the north by Myanmar and the Lao People's Democratic Republic, on the east by the Lao People's Democratic Republic and Cambodia, on the south by the Gulf of Thailand and Malaysia and on the west by Myanmar and the Andaman Sea. The length of Thailand from north to south is about 1,648 km and the widest part from east to west is about 780 km.

The hydrological characteristics of Thailand vary from region to region depending on various factors such as the geographical and climatic conditions of each region. Further, the country area can be divided into 25 river basins according to the topography as described by the National Water Resources Committee (NWRC 1990) and as shown in figure 1. Table 1 indicates the drainage area and annual run-off volume of each river basin.

In view of the difference in the climatic and hydrological conditions in the different parts of Thailand, the 25 river basins are grouped into 5 hydrological regions namely : northern, central, north-eastern, eastern and southern regions (figure 2). Table 2 indicates the areal extent of each region including the river basins covered by each region.

The purpose of this study is to carry out an investigation on the water resources availability and the water uses including non-consumptive use in Thailand for the past period 1980-1989 and for the future period 1990-2000.

The following sections describe the physiographical conditions, climate, rainfall, temperature, humidity, surface water and groundwater resources of Thailand.

A. Physiographical conditions

Thailand can be divided into several physiographical regions as shown in figure 3. These physiographical regions are used in classifying ground-water aquifers as explained later in this chapter. These physiographical regions can be described as follows:

The Central Plain : Most parts of this region are in the Lower Chao Phraya basin. The sediment transported from the Ping, Wang, Yom and Nan river basins in the north, and from the watersheds in the east and west results in siltation in this plain. Deposition forms the largest plain of the country. The width and length of the Central Plain are about 175 km and 450 km, respectively.

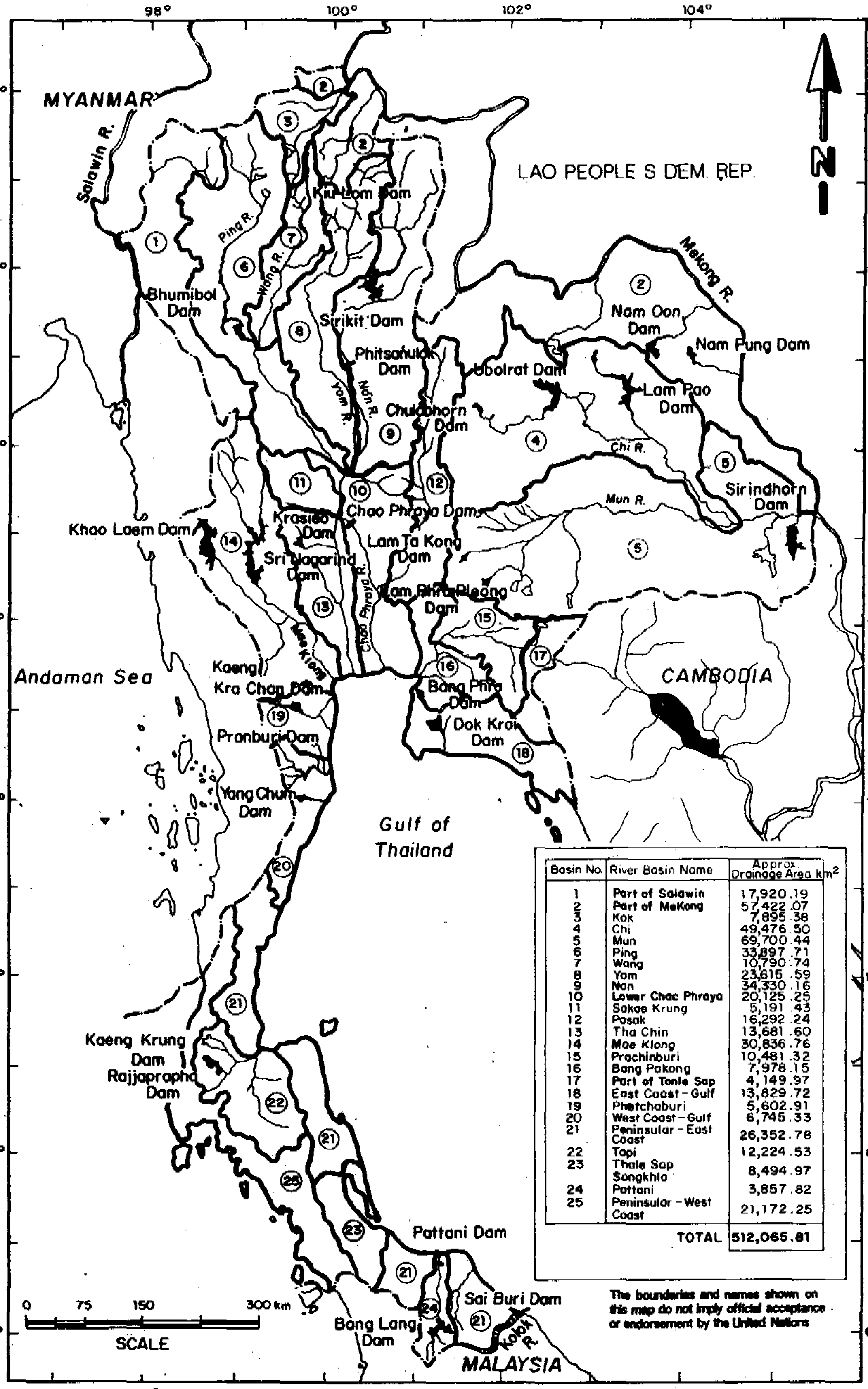
The south-east Coast : The main landform of this region is a marine terrace which can be affected by the coastal climate. Topography shows micro landform of the undulating terrain. Watersheds could not play important role due to their small areas and low potentials of water yield for irrigation and hydro power electricity generation. The coastal watershed area provides a favourable zone of brackish water for mangrove forest.

The north-east Plateau : The undulating or rolling landforms in the north-east Plateau comprise of several small watersheds which drain into the two principal rivers Chi and Mun, flowing into the Mekong river. The physiographic pattern of high plateau is typical in this region.

The Central Highlands : The Central Highlands are connected in the east by the north-east Plateau and on the west by the Central Plain. Various landforms including hill, plateau and a number of valleys are physiographically involved in the region. Among the valleys, the most important one is the Pasak river valley which divides the region longitudinally. Its catchment area in the north, east, and west is composed mainly of hills and more or less strongly incised plateaux of various heights ranging from 1,200 m to 300 m above MSL. Deforestation in the catchment area causes very serious environmental problems in the region.

The north and west continental Highlands : The region can be subdivided into the two main subregions which are the western mountain range and the northern hill and valleys. The northern hill and valleys subregion starts from 18° N latitude up to the northern border of the country. The western mountain range originates the Ping, Wang, Yom and Nan rivers. Their lower reaches join together to form the Chao Phraya river, flowing through the Central Plain toward the Gulf of Thailand.

Peninsular Thailand : The peninsula runs in the south direction starting from 11.5° N latitude to Malaysia. The western coast is adjacent to the Indian Ocean. The eastern coast adjoins to the Gulf of Thailand with many small watersheds of flat or undulating terrains.



Basin No.	River Basin Name	Approx. Drainage Area km²
1	Part of Salawin	17,920.19
2	Part of MeKong	57,422.07
3	Kok	7,895.38
4	Chi	49,476.50
5	Mun	69,700.44
6	Ping	33,897.71
7	Wang	10,790.74
8	Yom	23,615.59
9	Nan	34,330.16
10	Lower Chao Phraya	20,125.25
11	Sakae Krung	5,191.43
12	Pasak	16,292.24
13	Tha Chin	13,681.60
14	Mae Klong	30,836.76
15	Prachinburi	10,481.32
16	Bang Pakong	7,978.15
17	Part of Tonle Sap	4,149.97
18	East Coast - Gulf	13,829.72
19	Phetchaburi	5,602.91
20	West Coast - Gulf	6,745.33
21	Peninsular - East Coast	26,352.78
22	Tapi	12,224.53
23	Thale Sap Songkhla	8,494.97
24	Pattani	3,857.82
25	Peninsular - West Coast	21,172.25
	TOTAL	512,065.81

Figure 1. Map of river basins in Thailand

Source: NWRC (1990)

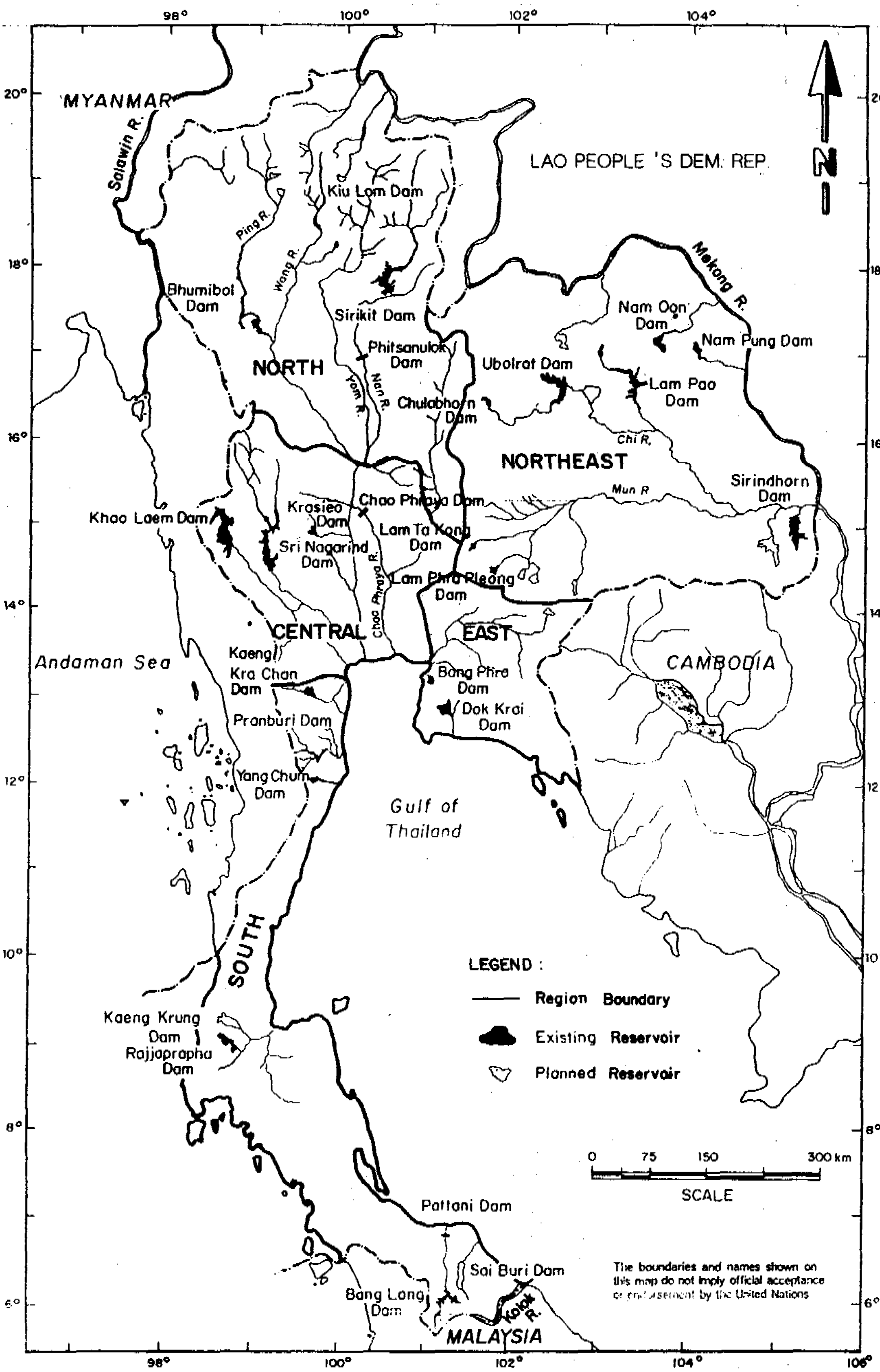


Figure 2. Extent of the different hydrological regions of Thailand

Table 1. River basins, drainage areas and long-term average run-off volumes

No.	*River Basin*	*Region*	*Drainage Area, (km^2.)*	*Main River*	*Annual Runoff, (mcm/yr+)*
1	Part of Salawin	North	17,920	Salawin	8,156
2	Part of Mekong	North	57,422	Mekong	15,800
3	Kok	North	7,895	Kok	5,119
4	Chi	North-east	49,476	Chi	8,035
5	Mun	North-east	69,700	Mun	21,767
6	Ping	North	33,898	Ping	6,686
7	Wang	North	10,791	Wang	1,429
8	Yom	North	23,615	Yom	1,430
9	Nan	North	34,330	Nan	9,581
10	Lower Chao Phraya	Central	20,125	Chao Phraya	4,925
11	Sakae Krung	Central	5,191	Sakae Krung	519
12	Pasak	North-Central	16,292	Pasak	2,708
13	Tha Chin	Central	13,681	Tha Chin	2,815
14	Mae Klong	Central	30,837	Mae Klong	12,943
15	Prachinburi	East	10,481	Prachinburi	4,502
16	Bang Pakong	East	7,978	Bang Pakong	4,900
17	Part of Tonle Sap	East	4,150		1,193
18	East Coast-Gulf	East	13,830	Rayong	10,623
19	Phetchaburi	South	5,603	Phetchaburi	1,410
20	West Coast-Gulf	South	6,745		1,013
21	Peninsular-East Coast	South	26,353	Chumporn	35,614
22	Tapi	South	12,224	Tapi	17,380
23	Thale Sap Songkhla	South	8,495		7,301
24	Pattani	South	3,858	Pattani	3,024
25	Peninsular-West Coast	South	21,172	Trang	9,918
	Total		512,066		198,791

(mcm/yr = million m^3/yr)

Source: National Water Resources Committee, Office of the Prime Minister (1990)

Table 2. Coverage areas of the different hydrological regions of Thailand

NORTH REGION

Basin No./Name*		Coverage Area (in km2 and %**)	
1.	Part of Salawin	17,920	100
2.	Part of Mekong	7,752	13.5
3.	Kok	7,895	100
6.	Ping	33,898	100
7.	Wang	10,791	100
8.	Yom	23,615	100
9.	Nan	34,330	100
12.	Pasak	12,667	77.75
	Total	148,868	

CENTRAL REGION

Basin No./Name*		Coverage Area (in km2 and %**)	
10.	Lower Chao Phraya	20,125	100
11.	Sakae Krung	5,191	100
12.	Pasak	3,625	22.25
13.	Tha Chin	13,681	100
14.	Mae Klong	30,837	100
	Total	73,459	

NORTH-EAST REGION

Basin No./Name*		Coverage Area (in km2 and %**)	
2.	Part of Mekong	49,670	86.5
4.	Chi	49,476	100
6.	Mun	69,700	100
	Total	168,846	

EASTERN REGION

Basin No./Name*		Coverage Area (in km2 and %**)	
15.	Prachin Buri	10,481	100
16.	Bang Pakong	7,987	100
17.	Part of Tonle Sap	4,150	100
18.	East Coast - Gulf	13,830	100
	Total	36,448	

SOUTHERN REGION

Basin No./Name*		Coverage Area (in km2 and %**)	
19.	Phetchaburi	5,603	100
20.	West Coast-Gulf	6,745	100
21.	Peninsular-East Coast	26,353	100
22.	Tapi	12,224	100
23.	Thale Sap Songkhla	8,495	100
24.	Pattani	3,858	100
25.	Peninsular-West Coast	21,172	100
	Total	84,450	

* According to figure 1

** Percentage of a basin area within the hydrological region

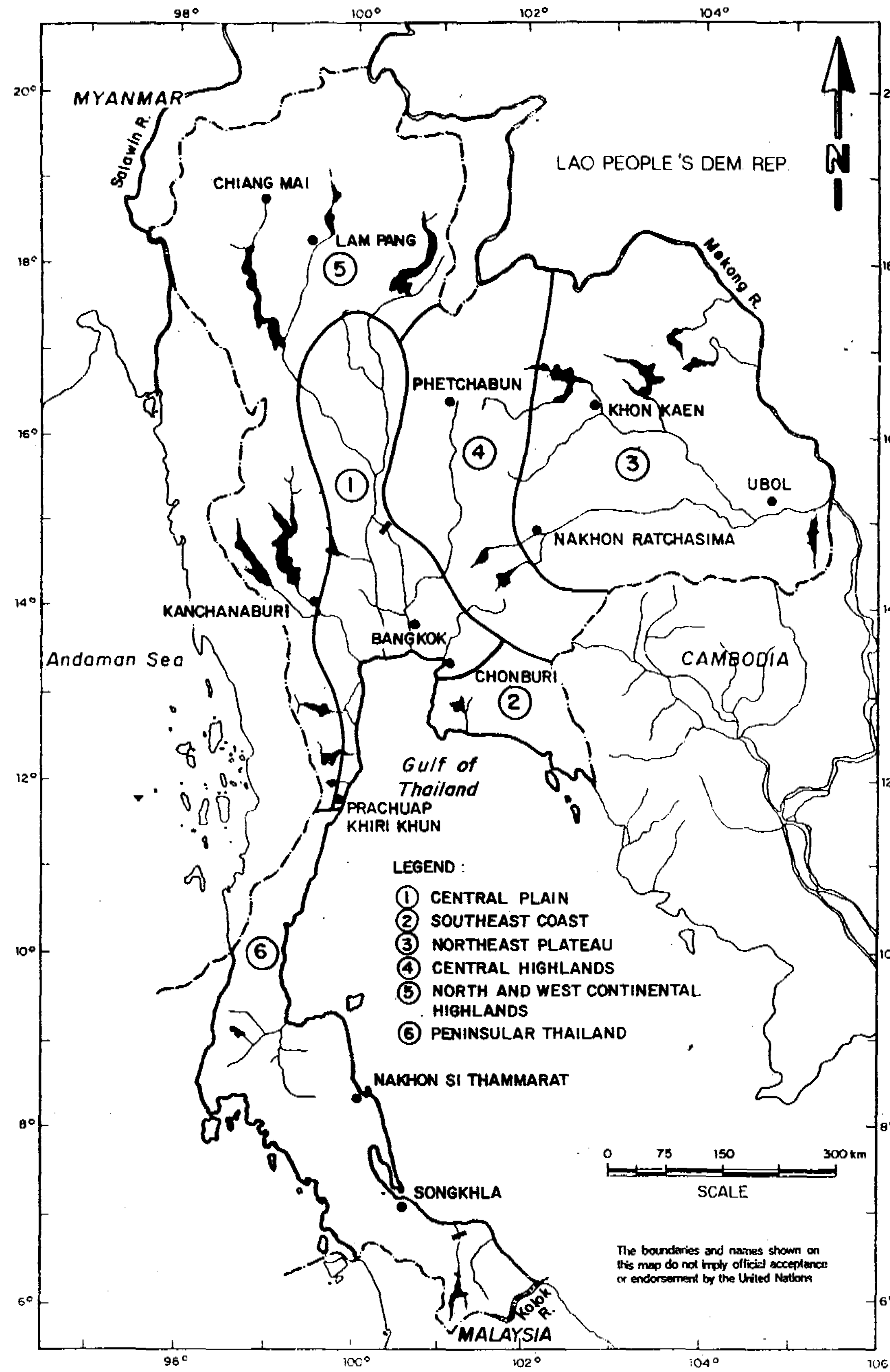


Figure 3. Physiographical regions of Thailand

Source: National Research Council, Thailand (1989)

B. Climate

The climate of Thailand is mainly governed by two monsoons namely: the south-west monsoon and the north-east monsoon (figure 4). The south-west monsoon, in which heavy rainfalls occur, begins from mid-May and lasts until mid-October. The north-east monsoon which is comparatively dry and cool occurs from mid-October to mid-February. The transition period from mid-February to mid-May is the period in which the north-east monsoon changes to the south-west monsoon with uncertain wind directions and heavy thunder storms. The two monsoon currents are closely associated with atmospheric pressure conditions over the whole of Asia. The boundary zone between these two monsoonal flows called the Equatorial Trough Zone (ETZ) passes back and forth over the country several times during the lulls and surges of the monsoons.

C. Rainfall

Heavy rainfalls occur due to tropical depression storms originating in the South Pacific or the South China Sea during the period from June to October. On the regional scale, the rainfall in Thailand can be described as follows:

In the north, rain is brought by the south-west monsoon. Orographic rains also occur due to hilly areas. This region is far from the influence of the sea. In the upland area, heavy rainfall could occur due to orographical effects.

The central region is flat and surrounded by mountain ranges except in the south where it is connected to the Gulf of Thailand. The rainfall amount is about the same as in the north and is mainly brought by the south-west monsoon and occasionally by depression storms.

The north-eastern region has an average annual amount of rainfall more than those in the north and in the central region.

The eastern part is connected to the sea and has a tropic-coastal climate. It has heavier rainfall than in the northern, north-eastern and central regions.

The southern peninsula has its western part influenced directly by the south-west monsoon from May to August with more rainfall than in the east. The south-west monsoon provides very heavy rainfall along the west coast of the southern peninsula. It has rainfall almost all year round. During the north-east monsoon, the eastern part of the southern peninsula has more rainfall than in the west. The average annual rainfall of the southern east coast is less than that of the southern west coast.

The average annual rainfalls in the northern, north-eastern, central, eastern and southern (east coast and west coast) regions for the 30-year period 1960 - 1989 are shown in table 3. It can be seen that the rainfall in the north and central regions has approximately the same annual volume i.e., 1,250 mm and 1,240 mm, respectively, while in the north-east the annual rainfall is 1,417 mm. The annual rainfall of 2,719 mm in the west coast of the southern peninsula is the highest of the country, while the second and third ranks of 2,047 mm and 1,742 mm are in the eastern region and the southern east coast region, respectively. The areal distribution of mean annual rainfall is shown by an isohyetal map in figure 5. From the figure, it can be seen that the highest local annual rainfall as much as 4,000 mm occurs at Ranong province in the south and Chantaburi province in the east.

The distribution of average monthly rainfall in various regions of Thailand based on the 30-year period 1960-1989 of observations is given in table 4.

D. Temperature and humidity

The Upper Thailand, i.e., the northern, north-eastern and central regions, experiences a long period of hot weather. Except along the coastal areas, the maximum temperatures during the rainy and summer seasons generally range from about 33 °C to 38 °C in the afternoon. At the nights the temperature drops and the minimum temperatures are about 21°C over the northern region, 23°C in the north-eastern region and 24°C in the central region.

During the north-east monsoon or cool season, the temperatures over the Upper Thailand are milder. The daily temperature difference during this period is about 13°-20°C and a minimum of about 15°C. However, outbreaks of cold air from Siberia and China occasionally bring down temperatures even lower.

In the south, temperatures are generally mild throughout the year, because of the maritime exposure of the region with a maximum temperature of 33°C and a minimum of about 22°C.

The annual mean relative humidity of the whole country lies between 70-80 per cent. During the south-west monsoon season or the rainy season, the mean monthly relative humidity is the highest about 80-85 per cent. During the northeast monsoon or cool season, the mean relative humidity falls to its lowest of about 65-70 per cent.

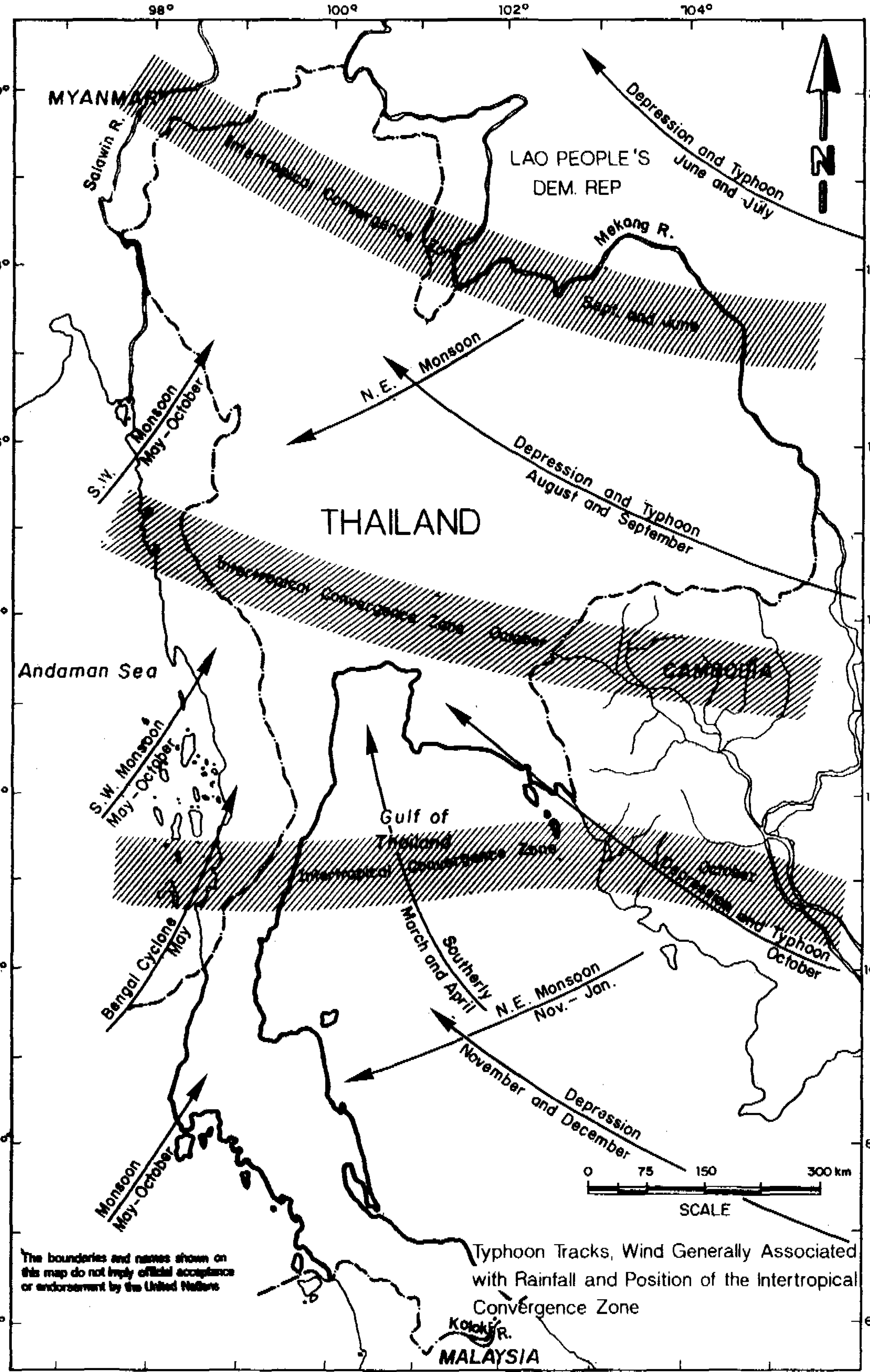


Figure 4. Direction of monsoons, depressions and typhoons in Thailand

Source: Meteorological Department, Thailand (1986)

Table 3. Annual distribution of rainfall in the hydrological regions of Thailand (1960-1989)

Year	*Average annual rainfall*					
	North *mm*	*North-east* *mm*	*Central* *mm*	*East* *mm*	*South*	
					East Coast *mm*	*West Coast* *mm*
1960	1,250.6	1,477.9	1,186.0	2,357.3	1,678.4	2,936.2
1961	1,467.2	1,617.0	1,250.5	2,306.2	1,995.4	2,685.3
1962	1,150.6	1,670.2	1,214.5	2,034.2	1,771.7	2,710.8
1963	1,375.9	1,496.1	1,272.9	2,141.7	1,773.0	2,547.0
1964	1,279.6	1,493.1	1,435.6	2,248.6	1,591.8	2,905.6
1965	1,202.8	1,327.5	1,315.0	2,037.6	2,104.9	2,988.1
1966	1,192.7	1,632.7	1,387.4	2,499.5	2,413.7	3,165.4
1967	1,243.5	1,311.8	1,046.4	1,854.5	1,832.5	2,804.7
1968	1,146.0	1,398.2	1,019.9	1,875.8	1,498.5	2,792.4
1969	1,305.5	1,507.3	1,221.5	2,087.8	2,067.0	2,853.4
1970	1,497.5	1,530.2	1,579.2	2,446.6	2,254.4	3,201.5
1971	1,369.9	1,407.7	1,210.6	1,971.5	1,857.4	3,083.1
1972	1,224.5	1,450.8	1,426.9	1,826.9	1,751.3	2,337.3
1973	1,293.1	1,179.1	1,133.3	1,928.8	2,209.5	3,387.0
1974	1,317.0	1,395.1	1,463.6	2,182.1	1,843.4	2,971.4
1975	1,434.7	1,542.3	1,287.0	2,061.4	2,272.1	3,242.4
1976	1,276.2	1,402.6	1,310.1	2,207.1	1,916.4	2,679.2
1977	1,231.7	1,138.3	984.6	1,829.1	1,668.2	2,283.4
1978	1,318.4	1,618.0	1,265.4	2,077.2	1,503.2	2,510.8
1979	984.7	1,243.9	882.0	1,781.6	1,512.3	2,439.0
1980	1,331.8	1,523.4	1,221.0	2,185.2	1,548.4	2,901.2
1981	1,269.0	1,312.6	1,302.9	2,010.8	1,728.7	2,222.1
1982	1,090.8	1,365.0	1,209.2	1,875.9	1,541.3	2,575.9
1983	1,200.9	1,388.1	1,404.4	2,398.2	1,558.6	2,949.3
1984	1,172.7	1,414.5	1,041.2	1,712.4	1,621.0	2,597.1
1985	1,279.9	1,338.1	1,197.4	1,888.0	1,757.5	2,668.7
1986	1,063.9	1,330.9	1,183.4	1,843.2	1,662.9	3,204.1
1987	1,136.2	1,348.9	1,141.0	1,782.4	1,580.7	2,593.3
1988	1,289.5	1,373.4	1,468.3	2,257.7	1,978.7	3,123.9
1989	1,100.1	1,280.7	1,121.9	1,709.6	1,410.0	2,485.5
Average	1,249.9	1,417.2	1,239.4	2,047.3	1,742.4	2,718.8

Source: Meteorological Department of Thailand (1990)

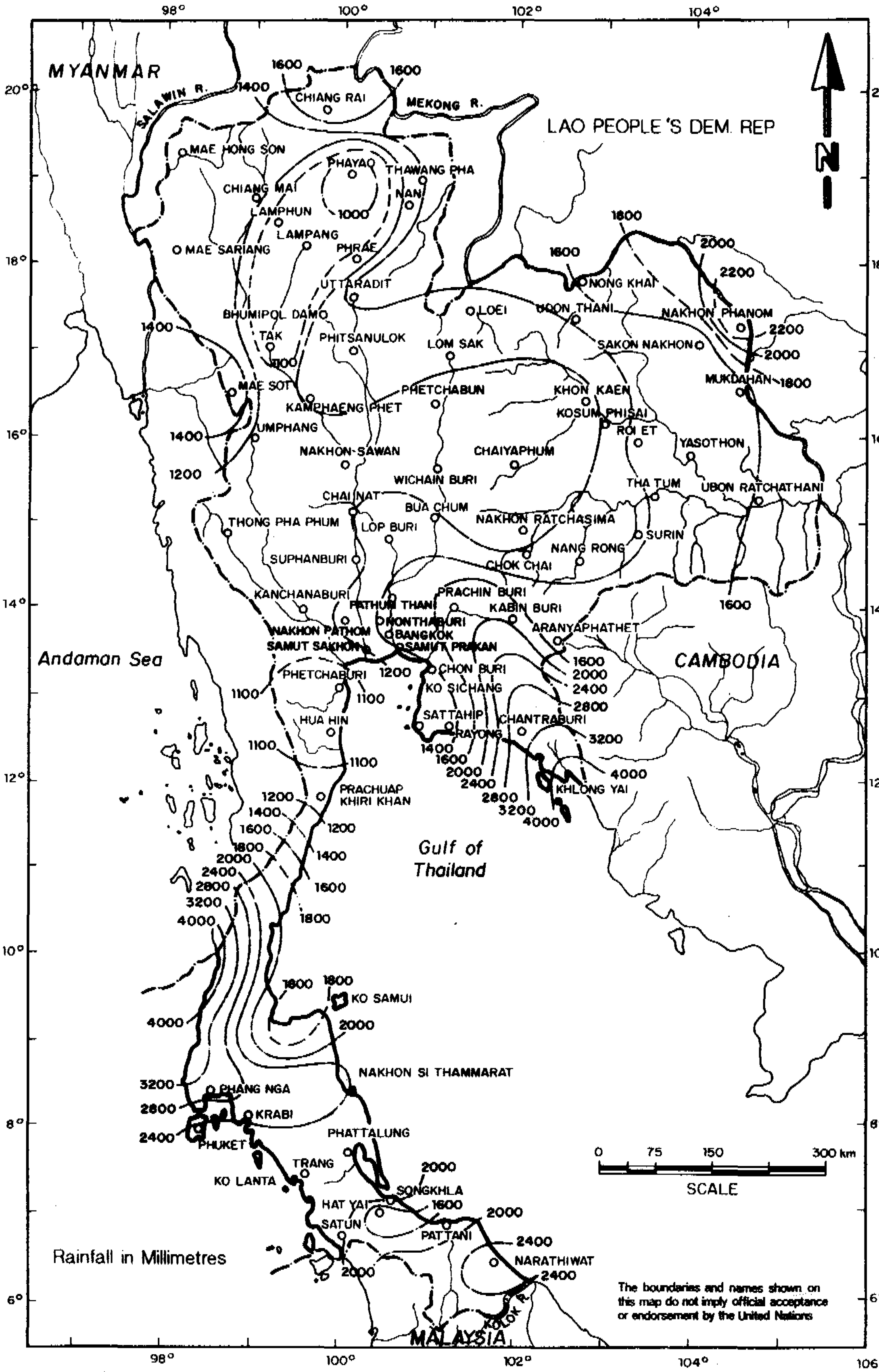


Figure 5. Isohyetal map of average annual rainfall in Thailand (1951-1985)

Source: Meteorological Department, Thailand 1990.

Table 4. Monthly distribution of average rainfall in the hydrological regions of Thailand (1960-1989)

Month	*Average monthly rainfall*					
	North mm	*North-east mm*	*Central mm*	*East mm*	*South*	
					East Coast mm	*West Coast mm*
January	7.0	4.1	7.7	14.5	75.0	26.7
February	8.7	14.3	19.3	34.4	29.8	23.0
March	19.9	35.6	30.1	52.3	39.6	51.4
April	65.1	85.6	69.4	88.7	67.0	152.2
May	177.2	186.8	159.7	226.4	149.0	360.7
June	158.9	214.4	134.7	272.5	108.3	330.1
July	175.6	203.5	143.6	261.5	119.1	359.7
August	225.3	259.2	176.8	314.4	123.2	383.4
September	220.0	258.2	265.6	335.6	144.8	452.0
October	131.6	114.3	174.3	238.4	249.0	352.6
November	36.1	17.6	45.8	75.2	396.0	201.5
December	7.6	2,6	8.0	10.3	214.0	61.3
Total *	1,233.0	1,396.2	1,234.4	1,924.2	1,715.1	2,754.6

Source: Meteorological Department of Thailand (1990)

* The total (annual rainfall) values are slightly different from the average annual rainfalls given in table 3 due to the roundoff error in calculating the average rainfall of each month.

E. Surface water

1. *Run-off*

Generally, most rivers in Thailand have flow highly concentrated during the south-west monsoon period which contributed about 80 to 90 per cent of the annual flow. For a smaller stream, the flow volume during the south-west monsoon season may be as high as 95 per cent of annual flow volume. The maximum annual flow of major rivers varies from 3 to 8 times greater than the minimum annual flow.

From the country's average annual rainfall of about 1,485 mm or 761,700 million m^3 equivalent, the resulting surface run-off after subtracting losses such as evaporation, transpiration and infiltration is about 198,791 million m^3 or about 26 per cent of rainfall. The surface run-off is drained mostly into the Gulf of Thailand, however there is some run-off to the Mekong river in the north-east, the Salawin river in the west and to the Andaman sea on the west coast of the country. Table 1 shows the drainage area and the mean annual run-off volume of each river basin. This run-off volume is calculated based on the specific yield determined from the measured streamflow data at the gaging station nearest to the basin outlet and the total drainage area of the river basin.

There are many major multipurpose dam projects in Thailand. Those which are under the Electricity Generating Authority of Thailand (EGAT) can produce hydro power, while those under the Royal Irrigation Department of Thailand (RID) mainly store water for irrigation, domestic or industrial water supply. Figure 6 shows the existing and planned major dam projects in Thailand.

As described earlier, there are a total of 25 river basins in Thailand. The boundaries of these river basins, their drainage areas and annual run-off volumes are shown in figure 1 and table 1. The drainage areas and average run-off volumes of each hydrological region are given in table 2 and can be described as follows:

a) Northern region : The total drainage area is about 148,868 km^2 with an average annual run-off volume of about 36,440 million m^3/yr. The region consists of the following river basins:

   (i) Ping, Wang, Yom and Nan river basins which conform the Upper Chao Phraya river basin and the Upper Pasak river basin. The Ping river basin has a different pattern of seasonal run-off fluctuation from that of the Nan basin. The annual run-off from the Ping basin is about 1.4 times less than that of the Nan basin.

   (ii) Pai and Khun-Yuam river basins which conform a part of the Salawin basin.

   (iii) Kok and Chan river basins which conform a part of the Mekong basin.

b) North-eastern region : The total river basin area is about 168,846 km^2 with an average annual run-off volume of 43,469 million m^3/yr. The plateau in the north-east of the country is a part of the Mekong river basin. The rolling ranges of hills constitute a number of small watersheds draining constitutively into the Chi, Mun and Mekong rivers. This causes the river basin pattern in the North-east Plateau being similar to the fish-bone shape. Moreover, the basins are underlaid with impermeable layers of latterite causing intense surface run-off. This results in rapid rises and falls of the streamflow following the rain storms. Consequently, during the period of rainy season the streams give rises to widespread floods which are sometimes disastrous to crops, while shortage of water may occur in dry seasons. Another important characteristic is the series of short droughts during the beginning and ending of the rainy season. The period of short drought might be as much as 3 to 5 weeks occurring with moderate frequency. This of course affects the growth and yields of crops adversely, since the period without rainfall in excess of two weeks is stated to be damaging. The measures of utilizing the available water resources have, therefore, to be planned. Schemes aiming at impounding water during the wet seasons for use during dry seasons have been considered the most beneficial to this region. Small reservoirs or tank projects have proved to be suitable in order to impound the excess water in the rainy season to be used during the dry months, and also to minimize flooding.

   The north-eastern region consists mostly of the Chi river basin and the Mun river basin. The Chi river joins the Mun river at Ubon Ratchathani to become the Lower Mun river flowing eastward into the Mekong river. The total drainage area of the Chi and Mun river basins is 119,176 km^2 and the average annual run-off is 29,802 million m^3/yr. The run-off from the Chi and Mun river basins have the same pattern of distribution but the run-off from the Mun basin is 2.7 times more than the run-off from the Chi basin.

   A part of the Mekong river basin, not including the Chi and Mun river basins, is also situated in this region.

c) Central region : This region has an area of about 73,459 km^2 and an annual run-off volume formed within the region of about 21,804 million m^3/yr. The region comprises 6 river basins, namely:

   (i) Lower Chao Phraya river basin,

   (ii) Sakae Krung river basin,

   (iii) Lower Pasak river basin,

   (iv) Tha Chin river basin,

   (v) Mae Klong river basin comprising the Quae Yai and Quae Noi river basins in the upstream part and the Lower Mae Klong river basin in the downstream part.

   The joining of the Ping, Wang, Yom and Nan rivers originates the Chao Phraya river at Nakhon Sawan about 200 km north of Bangkok. From Nakhon Sawan, the river flows down through the central plain passing Bangkok to the Gulf of Thailand. The Chao Phraya river has its slope of 1: 7,000 at Nakhon Sawan and flattens out to 1:50,000 or more while entering the Gulf of Thailand. Flood plains which are fertile for rice cultivation exist on the both sides of the Chao Phraya river in the central plain covering an area of 1 million hectares.

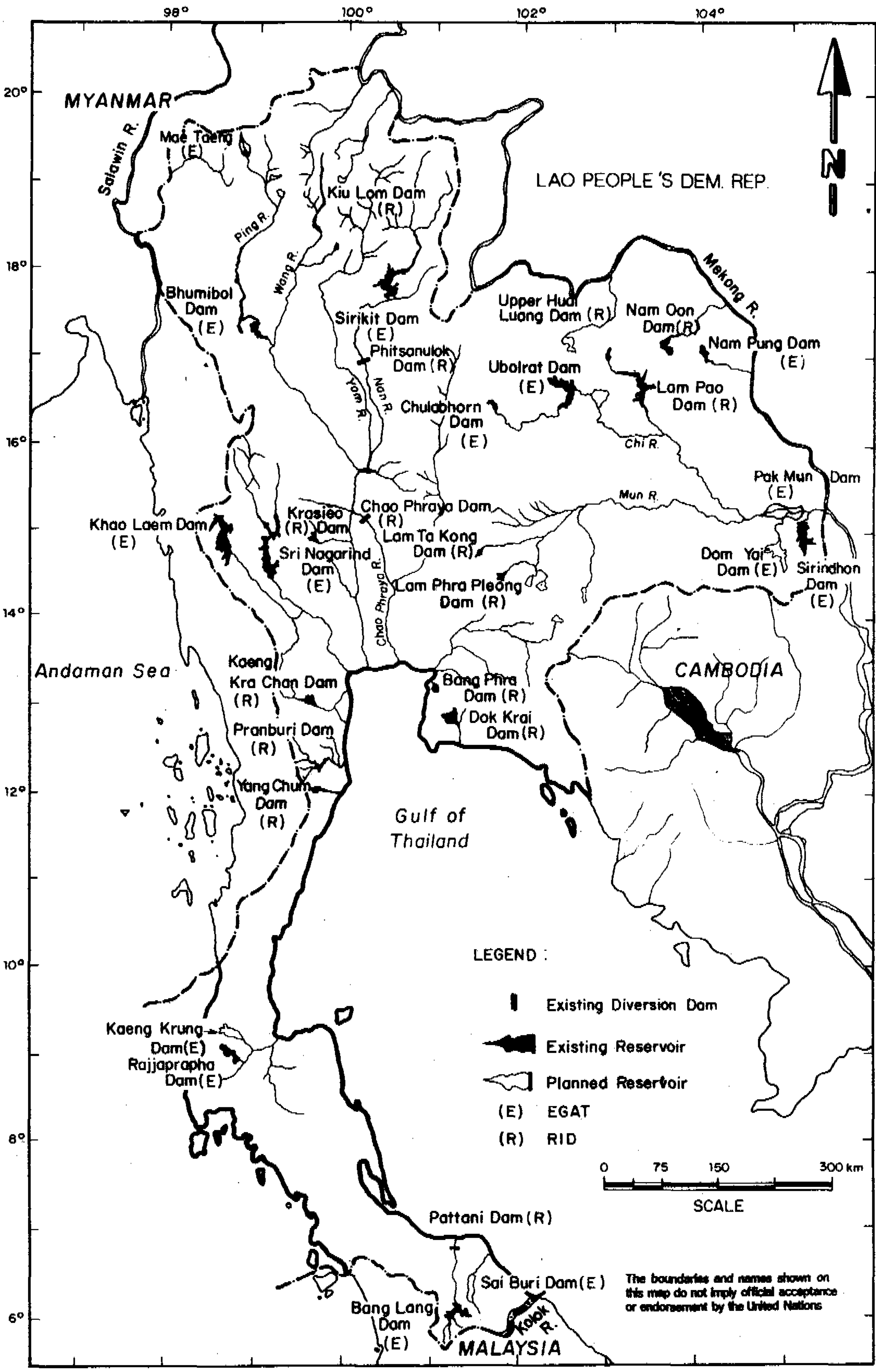


Figure 6. Existing and planned major dam projects in Thailand

Source: EGAT, Hydroelectric Project (1990). Data from RID (1990)

At Ayutthaya about 55 km north of Bangkok, the Chao Phraya river is joined by the Pasak river which rises in the divide between the central alluvial plain and the *North-east plateau*. The Lower Chao Phraya river basin starts from Nakhon Sawan and has a drainage area of 20,125 km^2 and an average annual run-off volume of 4,925 million m^3/yr.

The Mae Klong river rises from two tributaries Quae Yai and Quae Noi about 80 km from the Gulf of Thailand. The two rivers originate in the mountain ranges in the west near the Thailand-Myanmar border. The Mae Klong basin has a drainage area of 30,837 km^2 and the annual run-off volume of 12,943 million m^3/yr. This basin has the highest potential in water resources development, since it has much more water than would ever be needed by the land resources in the basin.

The Lower Chao Phraya river basin has a more lagging pattern of discharge hydrograph and a lower peak than that of the Mae Klong basin. The annual run-off volume from the Lower Chao Phraya river basin is only 0.38 times of that of the Mae Klong basin.

d) Eastern region : This region has a total watershed area of 36,448 km^2 with an annual run-off volume of about 21,218 million m^3/yr. This region comprises the river basins along the coastal areas (Rayong, Prasae, Chonburi, Khlung and Weru) and the Bang Pakong river basin which is located further inland. The upstream part of the Tonle Sap river basin is also located in the region.

e) South region : Traversing down south, the mountain ranges extending from the north as a backbone of the Peninsula form continuous small watersheds in which rivers flow eastward to the Gulf of Thailand and westward to the Bay of Bengal.

This region starts from the Phetchaburi river basin (figure 1) toward the Thai – Malaysian border. The total drainage area is about 84,450 km^2 with an average annual run-off volume of about 75,660 million m^3/yr.

The Upper Southern region consists of the Phetchaburi and West Coast Gulf river basins. The lower southern region can be divided into the east coast and west coast river basins. The annual run-off from the east coast is much larger than the west coast. The east coast river basins are namely: Peninsular-East Coast, Tapi, Thale Sap Songkhla and Pattani. The west coast river basin is the Peninsular-West Coast river basin. The Tapi river basin has a much more fluctuating pattern compared to that of the Pattani river basin and its annual run-off volume 5.7 times greater than that of the Pattani river basin.

2. *River sediment transport*

In 1978, it was estimated that due to land erosion sediments entered the river system of Thailand at an amount of 47 million m^3 (TDRI, 1990). At present, due to deforestation, more land erosion occurs and thus more sediment enters the river system.

The estimated amounts of suspended sediment transport by regions based on field measurements in 1989 are shown in table 5.

It can be seen that the suspended sediment transport per unit of the drainage area is the highest in the northern region, followed by those in the southern, north-eastern and eastern regions respectively. The total sum of the suspended sediment transport in all the regions of Thailand is 1,243 million tons per year. It is noted that due to flat slope, the amount of sediment from the central region that enter the river system is almost negligible and therefore is not shown in table 5.

Table 5. Estimated annual suspended sediment transport in the hydrological regions based on field measurements (1989)

Region	*Drainage Area (km^2)*	*Suspended Sediment (million ton)*
Northern	148,868	1,210.2
Central	73,459	-
North-eastern	168,846	5.4
Eastern	36,448	1.8
Southern	84,450	25.7
Whole Country	512,066	1,243.1

Source: National Research Council (1989)

F. Surface water quality

The quality of water in rivers, estuaries and coastal waters in Thailand is deteriorating due to discharges of pollutants from populated areas and industrial plants. The most serious conditions of water quality are in the Lower Chao Phraya river.

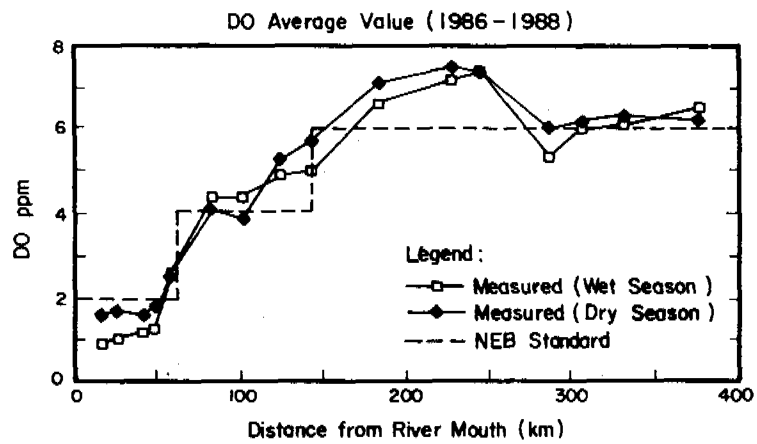
The Chao Phraya river is the largest river in Thailand. Its discharge varies from 50 m^3/s in dry seasons to more than 4,000 m^3/s in wet seasons. Due to discharges of sewage and industrial effluents into the river especially in the Bangkok Metropolitan Area, the lower reach of the Chao Phraya river is heavily polluted. From the results of field measurements by the Japan International Cooperation Agency (1990), the water quality of the Chao Phraya river in terms of dissolved oxygen (DO) and biochemical oxygen demand (BOD) along the Chao Phraya river is shown in figure 7. The quality of water in the Chao Phraya river is gradually but consistently deteriorating. The level of contamination has already reached the maximum limit set up by the National Environmental Board (NEB).

JICA (1990) forecasts that the Chao Phraya river between the Rama VI bridge (Km 58 from the river mouth) to Samut Prakarn province (Km 28) could become anaerobic in low flows by the year 2000 (figure 8).

It was estimated that in the Lower Chao Phraya river basin about 365 ton/day of BOD loading is discharged into the river. Of this, 355 ton/day is from untreated domestic sewage and 10 ton/day is from treated industrial wastes. The detail of BOD loadings in three areas of the Chao Phraya river basin is shown in table 6.

Although toxic substances from agricultural chemicals have affected river sediments, the damage to water is so far not significant. However, farming and livestock raising and fish ponds are beginning to be additional sources of water pollution.

In the Lower Chao Phraya river, within the 100 km distance from the river mouth, the maximum concentrations of heavy metals such as copper, nickel, etc. in the water and sediment are within the acceptable limits.



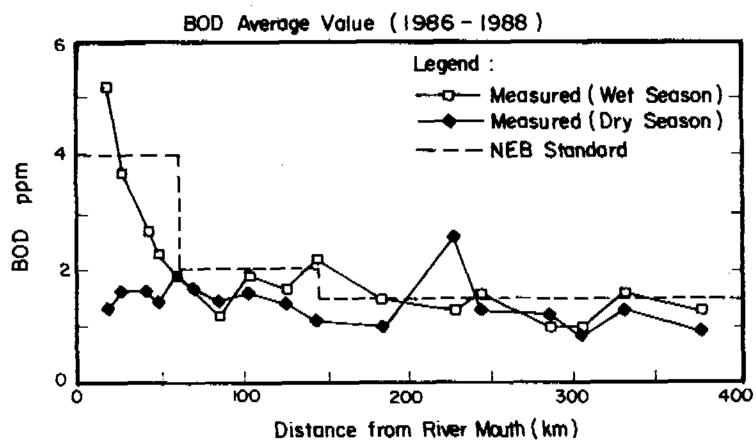


Figure 7. Measured water quality in the Chao Phraya River

Source: JICA (1990)

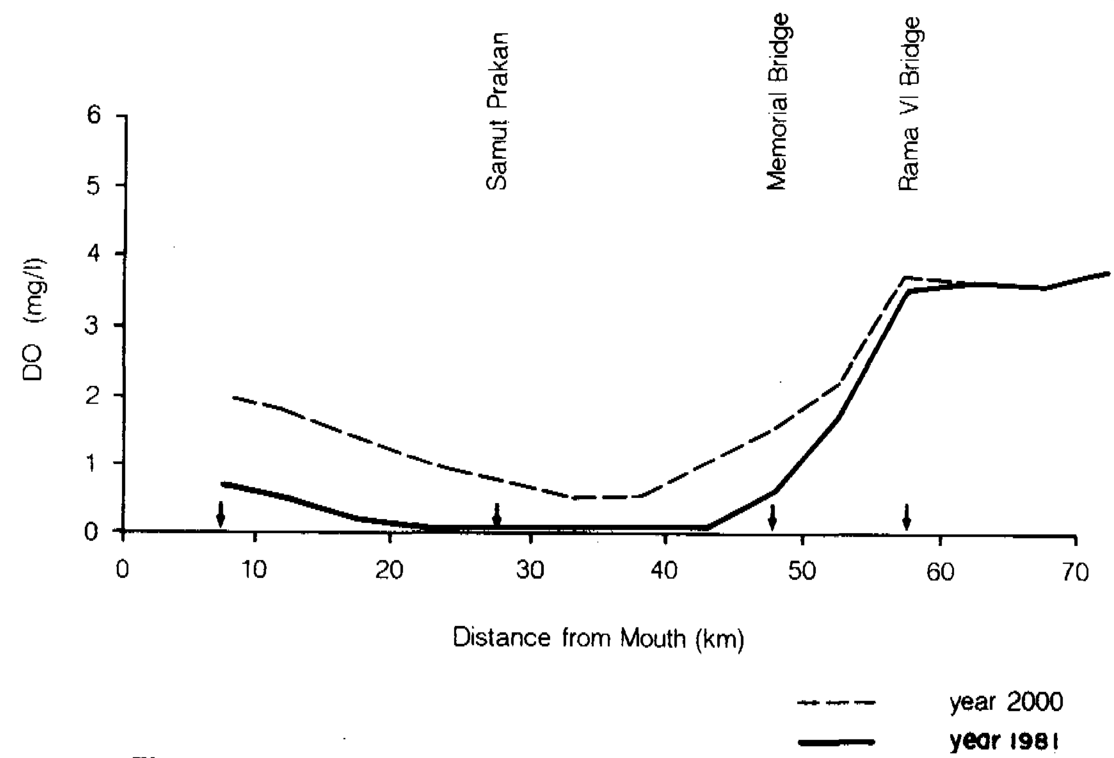


Figure 8. Forecast DO level in the Chao Phraya River in the year 2000

Source: JICA (1990).

Table 6. Sources of high BOD loadings in several areas of the northern region and the Chao Phraya river basin (1984-1985)

Region/ (Provinces)	*River Basin*	*No. of Factories Surveyed*	*Total Waste Flow Rate (m3 /day)*	*Total Influent BOD_5 Loading (kg/day)*	*Total Effluent BOD_5 Loading (kg/day)*	*Total BOD_5 Removal by Waste Treatment (kg/day)*	*Treatment Efficiency (%)*	*Estimated Domestic Sewage Loading (kg/day)*
Northern (14)	Ping, Wang, Yom, Nan, Pasak, Mae Kok	76	766,945	99,119	18,087	81,032	82	485,203
Northern (8)	Lopburi and Pasak	84	97,739	78,217	11,005	67,213	86	197,281
Central (Bangkok, Thonburi, Samut Prakarn, Nonthaburi Pathum Thani)	Lower Chao Phraya	205	96,639	136,879	9,960	126,919	93	335,090
		365	961,323	314,215	39,052	275,164		1,037,574

Source: Thailand Development Research Institute (1987)

Table 7. Groundwater yields in the different hydrological regions of Thailand

Hydrological Regions	*Physiographical Regions*	*Major Aquifers*	*Yield**		*Water Quality*	*Groundwater Use*
			m^3/hr	*mcm/yr*		
Northern	A. Northern Continental Highland	- Alluvium Deposits	25	0.219	Good	Drinking
		- Old Terrace Deposits	50	0.438	Good	Domestic Agriculuture
	B. Upper Central Plain	- Alluvium Deposits	40	0.350	Potable	Industry
		- Old Terrace Deposits	250	2.190	Good	
North-eastern	A. North-east Plateau	- Upper Khorat	27.5	0.241	Saline and sulphate	Drinking Domestic
		- Lower Khorat	115.0	1.007	Good but saline at some locations	Agriculture
Central	A. Lower Central Plain	- Alluvium Deposits	350	3.066	Good but saline at some locations	Domestic
	B. West Continental Highland	- Shallow Alluvium	40	0.350	-	Industry
Eastern	A. South-east Coast	- Alluvium and Terrace Deposits	8.5	0.074	Potable	Drinking Domestic
		- Limestone	15	0.131	Potable	
Southern	A. Peninsular Thailand	- Coastal Aquifers	105	0.920	-	Drinking Domestic
		TOTAL	1,026	8.988		

Source: Data from Department of Mineral Resources (1982)

* average values

Other rivers which are facing water quality problems are the Tha Chin, Mae Klong and Bang Pakong as well as coastal waters in the Gulf of Thailand and in the Andaman Sea.

G. Groundwater

1. Groundwater resources :

According to a report of the United Nations (1986), the groundwater system in Thailand is mainly recharged by rainfall and seepage from rivers. Previous preliminary hydrological balance studies of different regions of Thailand indicate that only about 12.5 per cent to 18 per cent of rainfall infiltrates the soils and only about 8.75 per cent of rainfall reaches the aquifers. This estimate is however valid only for the basins under favourable geologic conditions such as those in the Northern Highlands, the Upper Central Plain and along the Gulf Coastal Plain. For the basins under unfavourable geologic conditions such as in the Lower Central Plain where Bangkok Metropolitan Area is situated, about half of the area is covered by a thick marine clay, and in the Khorat plateau where its central part is covered by impervious soft shales, it is estimated that only about 5 per cent to 6 per cent of rainfall reaches the aquifers. These recharges are regarded as the safe yield of the aquifers.

The quantity and quality of groundwater vary according to local hydrogeological conditions. Usually, large and high yielding aquifers occur in alluvium and terrace deposits. To a lesser extent, groundwater also exists within crack formations in limestone, sand stones and some types of shales.

According to the Department of Mineral Resources (1982), the main aquifers in Thailand are shown in figure 9. The groundwater yields, quality and their uses are summarized by the hydrological regions in table 7 and by the physiographical regions in table 43 in the annex. The major groundwater resources in Thailand are shown in figure 10. The largest sources of groundwater in Thailand are found in the Lower Central Plain, especially in Bangkok and surrounding provinces (figure 8). Besides the Chao Phraya basin, groundwater is also found in the north in Chiangmai and Lampang provinces. Groundwater is also found along the Mekong river bank in the north-east such as Nongkhai and Nakhon Phanom provinces. In the southern part, groundwater can be found along the east coast adjacent to the Gulf of

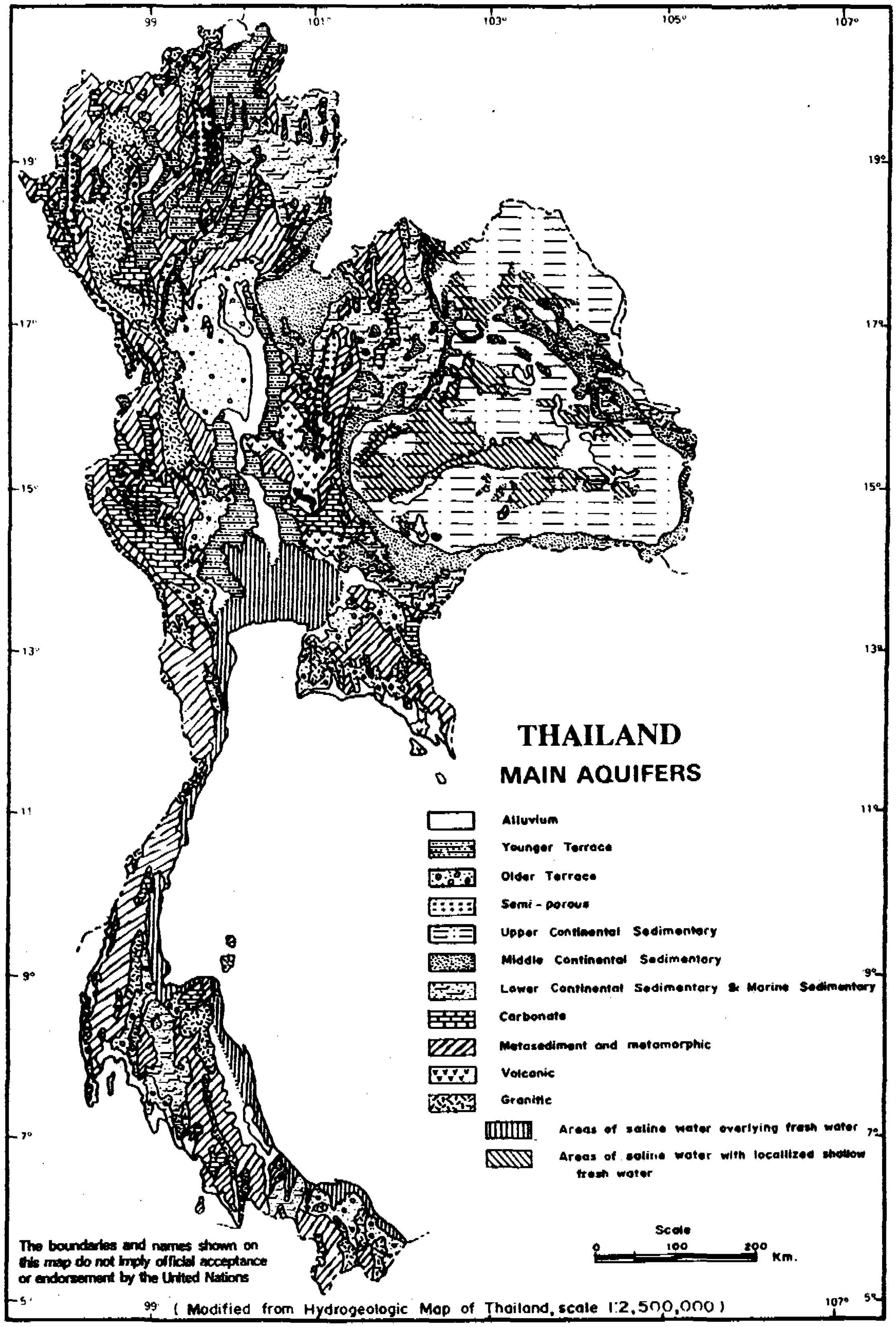


Figure 9. Main aquifers of Thailand

Source: Department of Mineral Resources (1982).

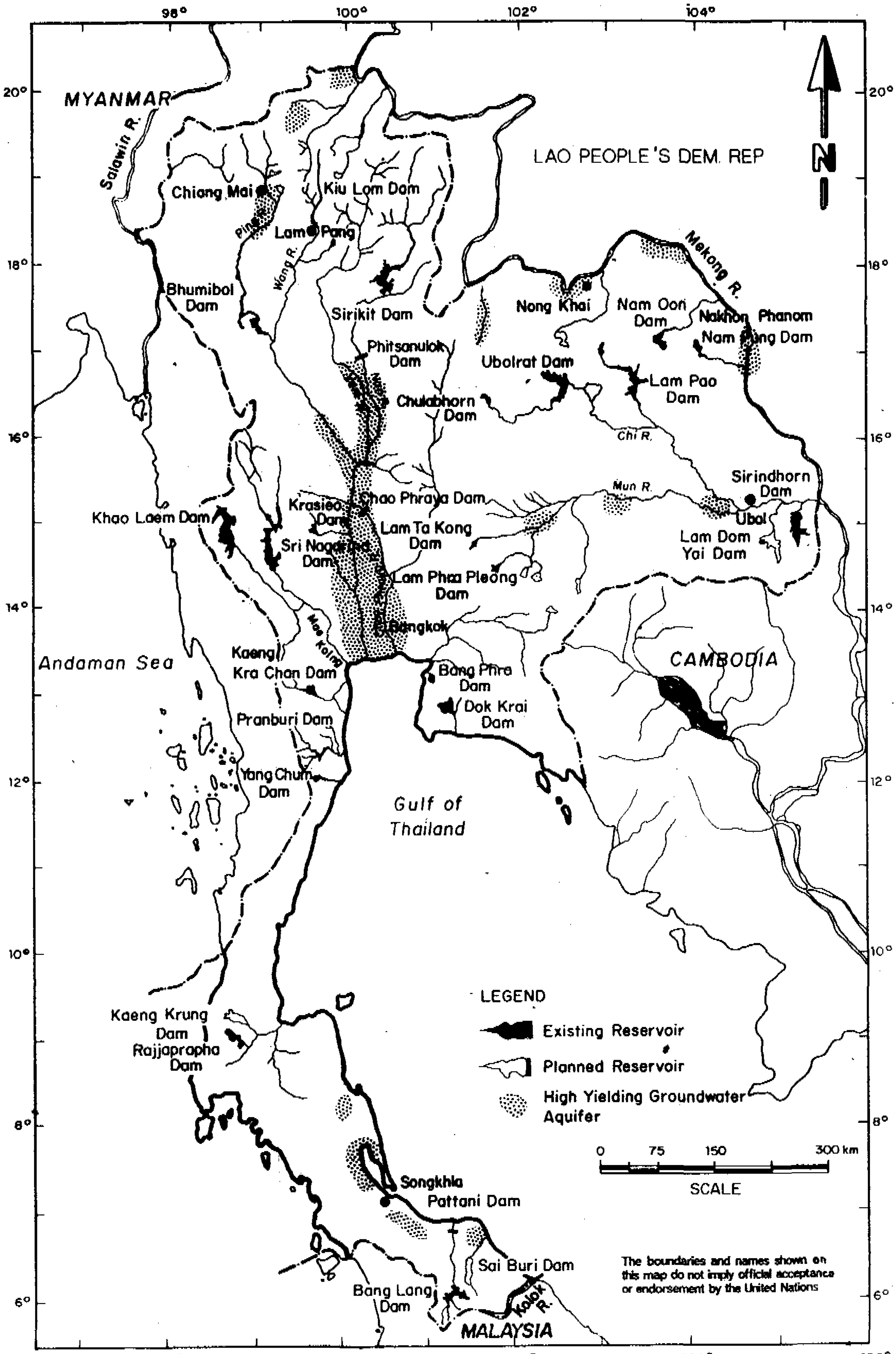


Figure 10. Major surface and groundwater resources in Thailand

Source: Ghooprasert, W. (1990)

Thailand. In Thailand, groundwater is widely used for urban and rural domestic water supply and also for agricultural and industrial purposes. Groundwater investigation and development for village water supply has been extended to all over the country since 1964. Starting from 1982 up to the present, more than 26,000 wells have been drilled for rural domestic water supply. The Thai Government has formulated a master plan for providing safe drinking water to the rural population under the United Nations Water Decade up to 1991.

The hydrogeological north - south aquifer profile of the Lower Chao Phraya basin is shown in figure 11. The safe yield of the aquifers in the Bangkok Metropolitan Area is estimated to be 600,000 m^3/d (219 million m^3/yr). The actual extraction in the same area by far exceeds the safe yield by more than twice causing a rapid decline in the peizometric head of more than 50 m. This results in a land subsidence of about 10-14 cm/yr in the eastern and southern suburban areas of Bangkok. At the Hua Mak District in the east of Bangkok, the land subsidence of more than 1 m has occurred since 1970 and the present ground level is nearly at the mean sea level. The actual groundwater consumption in the Bangkok Metropolitan Area during the period 1978-1988 is shown in table 8.

To control groundwater activities, the Ground Water Act of Thailand was enacted in 1977 concerning drilling for groundwater and its use as well as disposal of wastewater into the aquifers through wells. Under the provisions of the Act, no one may utilize groundwater from designated groundwater areas without an official permit. At present, the Ground Water Act is implemented in specific areas where groundwater resources are critical with respect to water quality or overexploitation.

2. *Groundwater quality problems*

In general the quality of groundwater in Thailand depends largely on the type of alluvial deposits, and rocks where it originates. The main problems in groundwater quality are high concentrations of chloride, sulfate, iron, nitrate and fluoride (Ramnarong 1985). The majority of deep groundwater in the Korat Plateau in the North-east of Thailand is highly saline due to the existence of rocksalt.

Table 8. Groundwater use in Bangkok Metropolitan Region (BMR)

(million m^3/yr)

Year	*Private Sector*						*MWA*	*Total*
	Bangkok	*Nontha-buri*	*Samut Prakarn*	*Pathum Thani*	*Samut Sakorn*	*Total*		
1978	123.74	9.49	83.22	21.90	10.22	248.93		
1979	132.50	10.59	89.42	22.26	10.59	265.35		
1980	152.57	12.41	96.36	27.37	12.77	302.22	169.36	471.58
1981	169.73	15.33	104.03	28.10	14.23	331.78	164.25	496.03
1982	182.13	16.42	115.34	30.66	18.98	363.54	156.95	520.49
1983	190.53	19.34	116.43	36.13	21.17	383.98	136.87	520.86
1984	198.19	20.44	128.84	41.61	22.26	411.35	124.10	535.46
1985	182.50	18.98	125.19	40.15	14.23	380.69	102.56	483.26
1986	174.10	16.79	132.86	43.07	28.83	395.66	62.41	458.07
1987	177.02	20.80	139.43	45.99	31.75	415.00	66.79	481.80
1988	178.48	21.53	144.91	56.94	36.50	438.36	62.05	500.41

Source: Based on data in m^3/d (Ramnarong and others 1989)

Note: Use of groundwater in Nakhon Prathom is not included, partly because it is not within the announced critical areas and partly due to the lack of data.

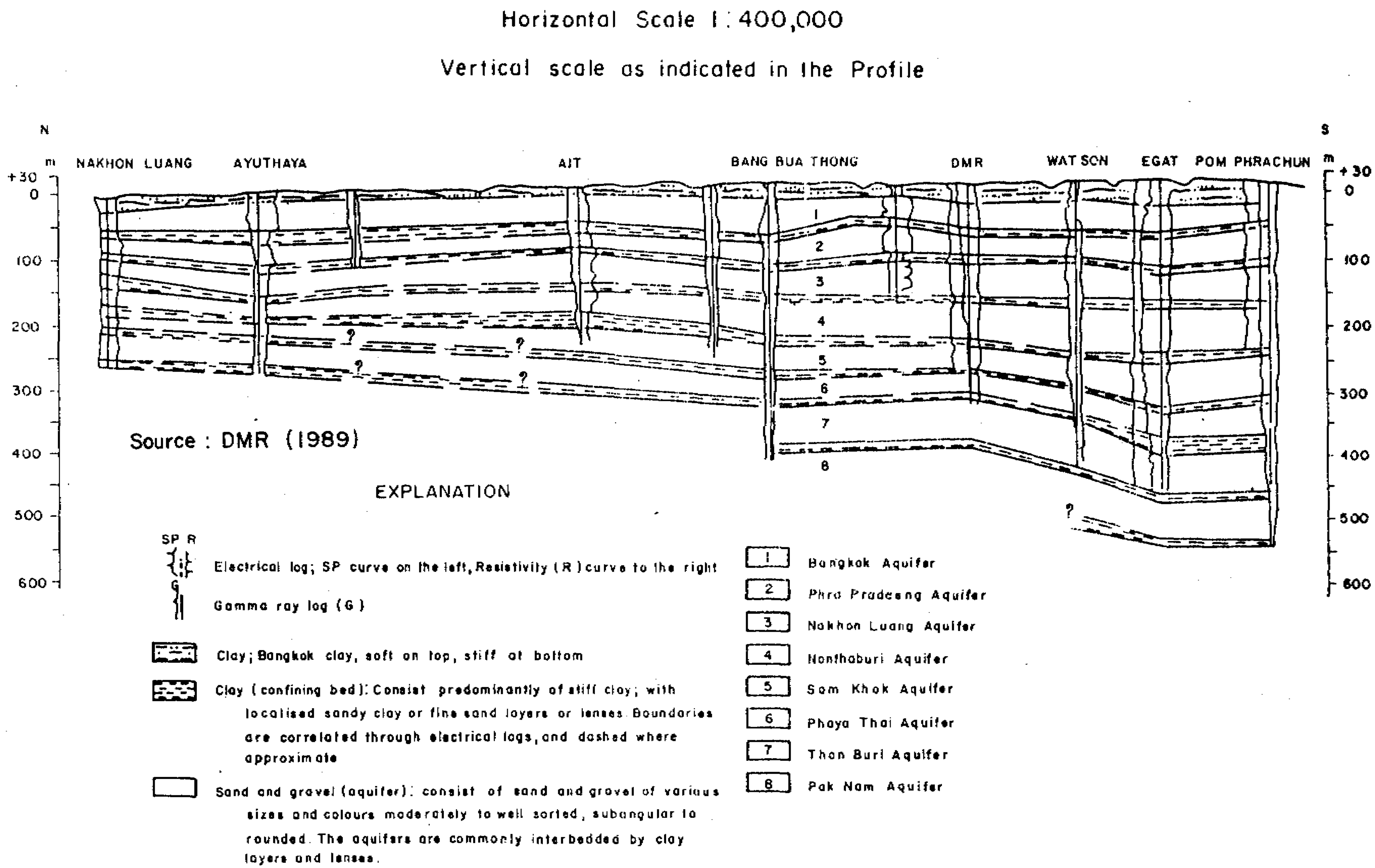


Figure 11. Hydrogeological north-south aquifer profile of the Lower Chao Phraya basin

The *highest* chloride concentrations of sodium chloride water type vary from 2,000-10,000 mg/l. This saline water is generally found in low lying areas in the middle of the southern basin of the Korat Plateau such as Nakhon Ratchasima and Chaiyaphum provinces. However, fresh groundwater is also found in shallow wells at higher elevations.

The concentration of calcium in the groundwater of Korat plateau varies from place to place depending on the distribution of the sources of gypsum and calcium minerals. The concentration of calcium is generally within the limit of drinking water standards.

Dissolved iron in groundwater in consolidated rocks in the North-east and in other parts of the country ranges from 0.3 mg/l to over 100 mg/l. Most of the groundwater especially in the North-east has iron concentrations over the limit of drinking water standard of the World Health Orgnaization (WHO).

High nitrate concentrations in the North-eastern region are mostly found in shallow aquifers due to heavy use of fertilizers. These concentrations range from 10 mg/l to about 1,180 mg/l. Groundwater in the eastern part of Thailand such in Cholburi province has significant concentrations of fluoride contents up to 1.5 mg/l exceeding WHO drinking water standard. Fluoride is considered as an essential constituent of drinking water regarding particularly to the prevention of dental caries in children but excessive concentrations may give dental fluorosis and skeleton damages.

A study of the hydrochemical data pertaining to groundwater of Bangkok deltaic areas and the peninsular coastal aquifers reveals that salt water encroachment could be observed in the heavily pumped aquifers. The heavy pumpage in coastal regions especially in Bangkok and adjacent areas is about 1.3 million m^3/d. Such quantity by far exceeds the natural recharge of the aquifers. The depletion of groundwater due to long-time heavy pumping has caused rapid decline in peizometric heads to more than 50 m. This decline results in salt-water encroachment and saline groundwater supply. The salt water encroachment occurs at an alarming rate of 500 m/yr in the 150 m deep aquifer. The chloride concentrations have risen from 10 mg/l to more than 600 mg/l in the past nine years. This results in the abandonment of hundreds of wells in the southern part of Bangkok and Samut Prakarn provinces.

H. Non-conventional water resources

The non-conventional water resources are generally those created by desalination process or treated sewage. In Thailand the non-conventional water resources are negligible.

II. WATER USE

A. Agricultural water use

Agricultural water use in Thailand is mainly water use for irrigation. Water supply for crops can be obtained from direct rainfall, surface water irrigation or groundwater irrigation. Thailand is predominantly an agricultural country with rice as the main crop. About 80 per cent of its population is engaged in agriculture. Water resources development for irrigation has been mainly undertaken by the Royal Irrigation Department.

Though Thailand has a 6 - 9 month period of rainy season with an average rainfall varying from 1,000 mm to 4,500 mm from one region to another, the country's agricultural crops still suffer from drought periods and sequences of dry spells as well as flood disaster. These varying hydrologic conditions create uncertainties in wet season rice production especially in non-irrigated areas. The irrigation system stabilizes the rice cultivated area and the rice production. The storage dams would secure a stable supply of water and reduce damages due to floods and droughts. Based on the total country area of 51.3 million ha the distribution of land use is comprising about 28 per cent for forest land, 25.9 per cent for unclassified area and 46 per cent for farm holding land (23.65 million ha). Only about 60 per cent of this farm holding land area or 14.2 million ha has been used for paddy farming. Out of this 14.2 million ha, only 20 per cent or 2.8 million ha is under irrigation. The Greater Chao Phraya irrigation project takes a major share of 1.2 million ha, while the Phitsanulok irrigation project and others take the rest. The major irrigation areas are shown in figure 12. Table 9 shows the major irrigation areas and the numbers of irrigation projects in each region of the country up to 1987.

Table 9. Numbers and areas of large-scale irrigation projects in Thailand (1987)

Region	*Number of Projects*	*Irrigation Project Areas* (ha)*
Northern	244	595,618
Central and Eastern	216	1,936,741
North-eastern	309	401,747
Southern	103	283,794
Total: (Whole Country)	872	3,217,900

Source : Ministry of Agriculture (1989)

* Irrigation project areas comprise irrigated areas and areas used for other purposes.

1. *Crop water requirement*

At farm level, experiments on water consumption of high yielding variety rices show a value of 4-6 mm/day for wet seasons and 5-9 mm/day for dry seasons. Even though, water requirement for rice crop varies widely due to the method of cultivation and the growth period after transplanting. The average water requirement for high yielding varieties of rice during 160 days from land preparation to the end of the reproductive period was found to be 9,400 m^3/ha in wet seasons and 12,500 m^3/ha in dry seasons. The wet season cropping is done in a much larger area compared to the dry season cropping. In dry years, the dry season cropping is not done. Based on the data from the Royal Irrigation Department of Thailand, in 1989 the country irrigated area was 3 million ha and the irrigation water use was 30,000 million m^3/yr. This means that the average annual water use for irrigation is 10,000 m^3/ha/yr. Comparing the above average water requirements during the wet and dry seasons with the annual volume of irrigation water use, it is found that the wet season cropping is the main user of water for irrigation, while the irrigation water use during the dry season is much less.

2. *Irrigation water use*

The Royal Irrigation Department of Thailand defines the large, medium and small-scale irrigation projects as follows:

(i) large-scale irrigation projects:
construction cost > \$US 8 million
and storage volume > 100 mcm

(ii) medium-scale irrigation projects :
\$US 8 million $\geq$ construction cost > \$US 0.32 million
and storage volume $\leq$ 100 mcm

(iii) small-scale irrigation projects :
construction cost < \$US 0.32 million
and construction period $\leq$ 1 year

For the large-scale irrigation projects, the average annual volume of water use for irrigation and the annual irrigated areas (wet season + dry season) are given in table 10. In the northern, north-eastern, eastern and central regions, the periods of wet season irrigation and dry season irrigation are from July to December and January to June respectively. In the southern region, the climate is different, the periods of wet season irrigation and dry

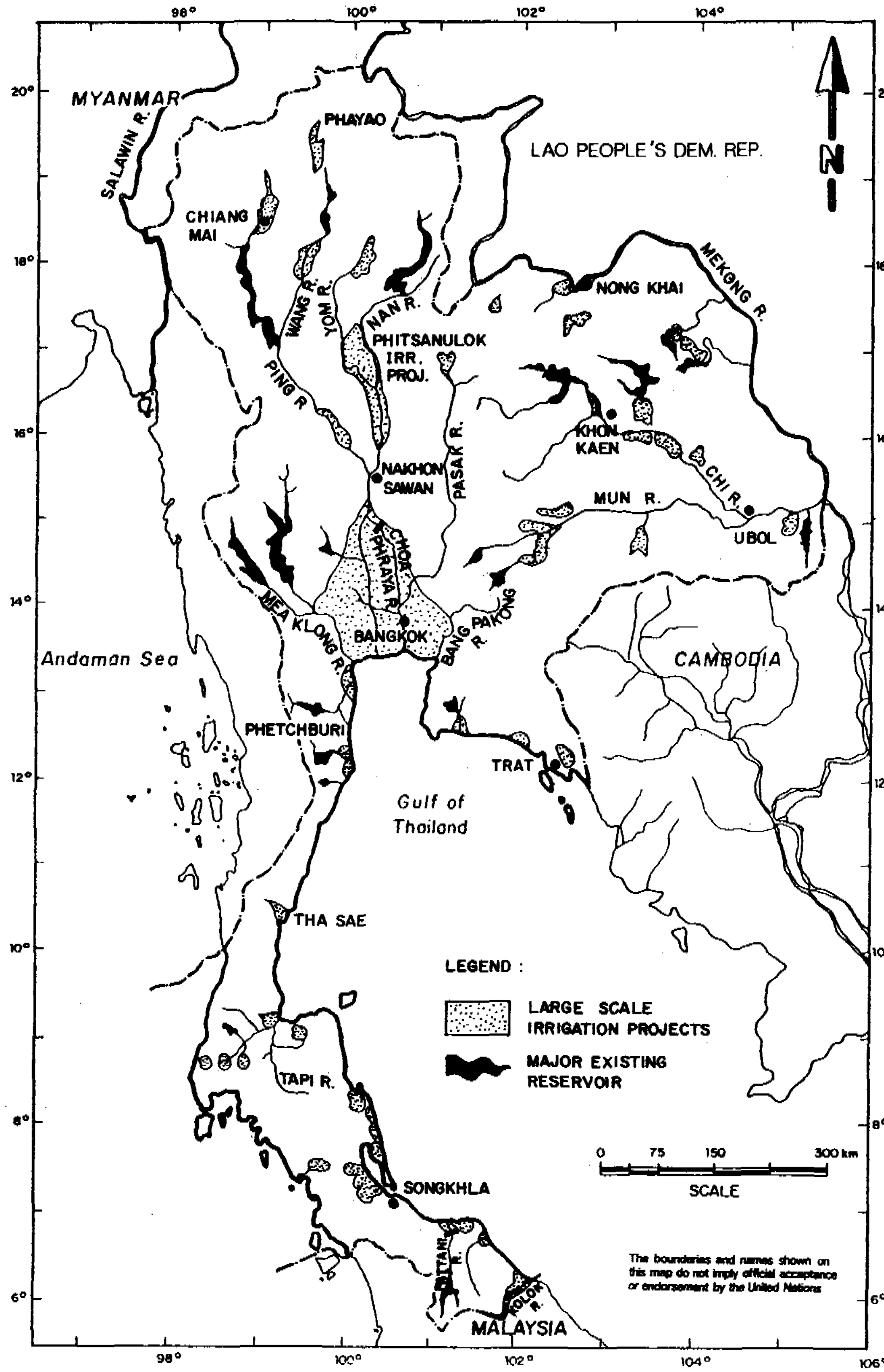


Figure 12. Major irrigation projects in Thailand

Source: Kiravanich, P.(1983)

Table 10. Average seasonal water use and irrigated areas for large-scale irrigation projects in Thailand[x]

Region	Irrigation Project	Dry Season* Water amount (mcm)+	Dry Season* Area (ha)	Wet Season** Water amount (mcm)+	Wet Season** Area (ha)	Years in which data are available
North	Mae Ngat	30.80	108.64	64.60	12,611.60	1987-1989
	Kiu Lom	35.06	1,351.94	93.32	18,383.04	1980-1989
	Phitsanulok	270.77	24,714.33	545.97	74,066.21	1982-1989
	Mae Tang	111.19	722.24	220.92	20,728.20	1980-1989
	Mae Faek	73.18	262.05	113.67	10,888.10	1980-1989
	Sub Total	521.00	27,159.2	1,038.48	136,677.15	
North-east	Nong Wai	206.84	8,740.03	335.81	31,300.39	1980-1989
	Huai Luang	15.10	131.76	42.80	13,051.92	1980-1989
	Lam Pao	144.28	1,270.50	267.42	33,420.36	1980-1989
	Nam Oon	98.22	27.81	173.83	28,981.79	1980-1989
	Lam Pra-pleong	29.29	3,586.18	74.77	11,602.67	1980-1989
	Sirindhorn	53.33	2,549.70	142.50	21,858.29	1980-1989
	Lam Takhong	86.11	4.62	143.64	20,643.96	1980-1989
	Sub Total	633.17	16,312.4	1,180.77	160,859.38	
Central	Chao Phraya	4,816.00	442,105.42	7,622.40	974,650.98	1980-1989
	Mae Kiong	864.70	40,119.89	1,499.20	131,002.83	1980-1989
	Kra Sieo	60.33	6,352.99	71.67	15,552.75	1983-1989
	Sub Total	5,741.03	488,578.30	9,193.27	1,121,206.56	
East	Bang Pra	5.37	375.52	4.8	1,277.79	1984-1989
	Dok Krai	23.69	1,950.60	32.4	4,367.68	1984-1989
	Sub Total	29.06	2,326.12	37.2	5,645.47	
South	Phetchaburi	172.90	4,973.61	526.97	53,633.08	1980-1989
	Pranburi	68.87	836.80	160.88	7,744.26	1980-1989
	Pattani	95.93	587.41	124.42	12,072.67	1984-1989
	Sub Total	337.70	6,397.52	812.27	73,450.01	
	Grand Total:	7,261.96	540,773.54	12,261.99	1,497,838.57	

Source: Data from Water Operation Center, RID (1990)

x The values of irrigation water use and irrigated areas of large, medium and small-scale irrigation projects are shown in figures 13 and 14, respectively.

* In North, North-east and Central regions, dry season is from January to June; in South region, dry season is from February to May.

** In North, North-east and Central regions, wet season is from July to December, in South region, dry season is from June to January.

\+ mcm = million m^3/yr

season irrigation are from June to January and February to May respectively. According to the agricultural statistics of Thailand (Ministry of Agriculture and Cooperatives 1989), the annual volume of water use and the annual irrigated areas of overall irrigation projects in the country as estimated in this study is 1.3 times those of the RID large-scale projects. The factor of 1.3 is calculated from the available data of the annual irrigated areas of the whole country and of RID. This ratio is assumed to be applicable also to the annual volume of water use for irrigation. An average ratio between dry season and wet season irrigated areas from 1984 to 1988 is 0.236. The annual irrigation water use and annual irrigated areas for all irrigation projects of RID and other organizations in different regions of Thailand from 1980 to 1989 are shown in figures 13 and 14. The average annual water use for irrigation during 1980-1989 in the different regions of Thailand specified in terms of surface water and groundwater uses is shown in table 11.

Table 11. Estimated annual average water use for irrigation by region (1980-1989)

Regions	*Average Annual Water Use for Irrigation (million m^3 /yr)*		
	Surface Water	*Ground Water*	*Total*
Northern	1,554.7	202	1,756.7
Central	19,563.8	-	19,563.8
North-eastern	2,367.7	-	2,367.7
Eastern	79.8	-	79.8
Southern	1,501.0	-	1,501.0
Total (Whole Country)	25,067.0	202	25,269.0

Source: Data from RID (1990), Ministry of Agriculture and Cooperatives (1989) and United Nations (1986)

From the data on the annual volume of water use and the annual irrigated areas in each region during 1980-1989 (figures 13 and 14), respective rates of growth is summarized in table 12. From this table, it can be seen that the average increase in volume of water used for irrigation in the central region was 421 million m^3/yr which is about 50 per cent of the annual increase in the whole country equal to 839.5 million m^3/yr and the highest of all the regions. The Chao Phraya irrigation project is the largest water user in the central region, while the Phitsanulok project is the largest water user in the north. The shortage of irrigation water in dry seasons is quite evident in the Greater Chao Phraya project in which the dry season paddy area is only 0.5 million ha compared to that of the wet season of 1.2 million ha. The water deficiency, which prevents dry season irrigation from operating at its full potential, forces farmers to switch from paddy to field crops. The rates of growth of water use for irrigation are in a descending order as follows: north, north-east, south and east. Due to the high annual growth in the northern region equal to 175 million m^3/yr (or 20.85 per cent of the whole country), it is expected that the central region, which receives major run-off contribution from the northern region, will face a problem of water shortage in the near future. The problem of water deficiency will inevitably worsen with increasing population. Transbasin projects such as the diversion of water from the Mae Klong basin to the Chao Phraya basin and the diversion of water from Mae Kok and Mae Ing rivers to the Yom and Nan rivers are under consideration to facilitate the water shortage problem in the Chao Phraya basin.

Regarding the growth in annual irrigated areas from 1980-1989, the northern region has the highest average annual increase of 22,750 ha/yr or 47 per cent of the nationwide increase of 48,430 ha/yr. The other regions, namely, north-eastern, central, southern and eastern, have their growth rates ranks in descending order. Field data indicate that the growth of dry season irrigated areas is very small due to limited water resources available during the dry season.

Table 12. Growth in irrigation water use and actual irrigated area

Region	*Average Annual Increase (1980-1989)*			
	Irrigation Water Use		*Annual Irrigated Area*	
	(million m^3/yr)	*%*	*(10^3ha/yr)*	*%*
Northern	175.0	20.85	22.75	46.97
Central	421.0	50.03	8.50	17.55
North-eastern	132.5	15.78	11.75	24.26
Eastern	12.0	1.43	0.105	0.22
Southern	100.0	11.91	5.325	10.99
Whole Country	839.5	100.0	48.43	100.00

It is noted that the central region has the highest growth rate in irrigation water use but the northern region has the highest growth rate in the annual irrigated area. This could be explained by the fact that the central region has much more intensive agricultural activities compared to the northern region. The high growth in irrigated area in the northern region indicates the large potential for irrigation there compared with the central region.

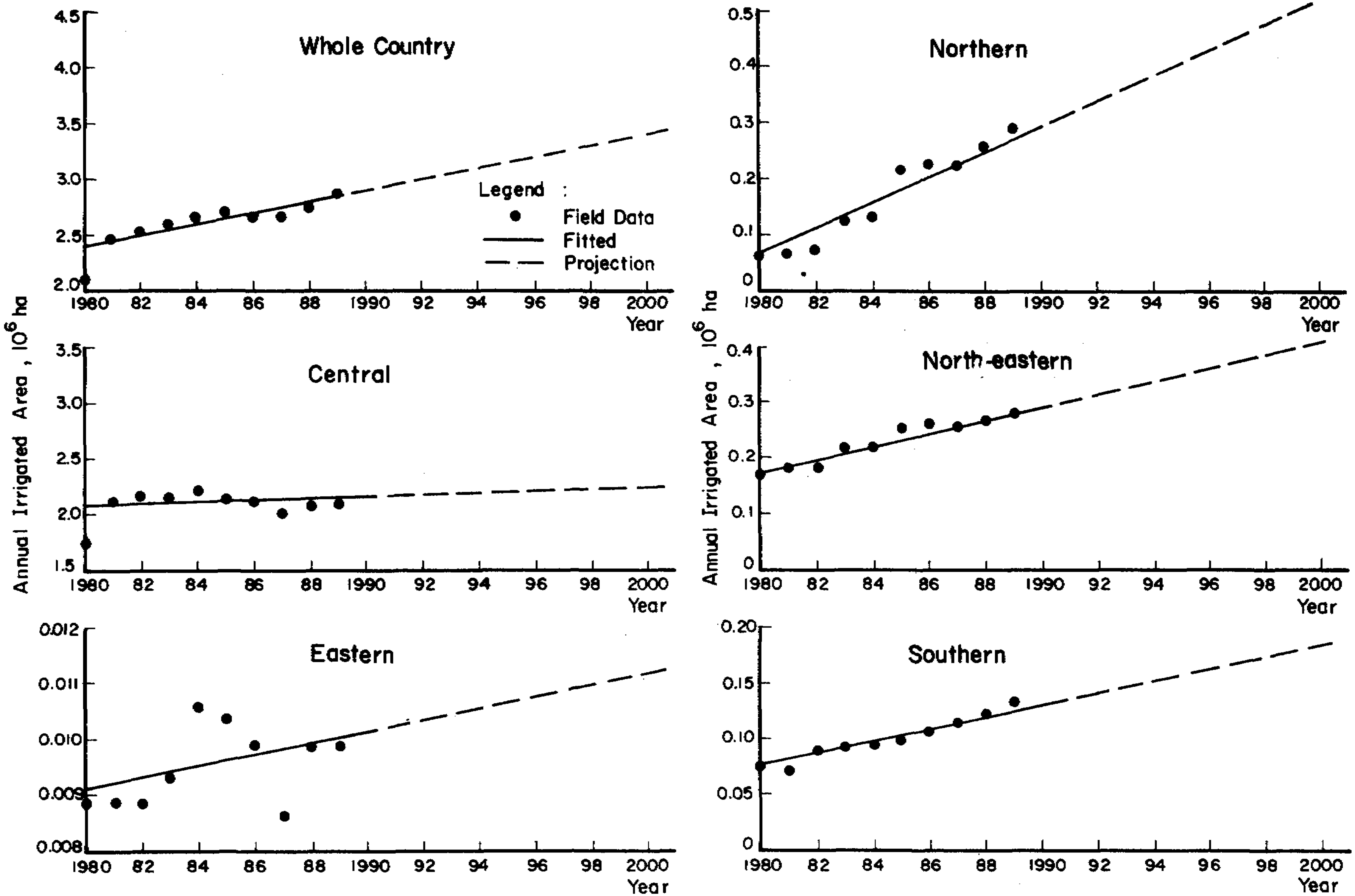


Figure 13. Annual irrigated areas (wet season + dry season) in the different regions of Thailand (1980-1989) and their projections (1990-2000)

Source: RID (1989).

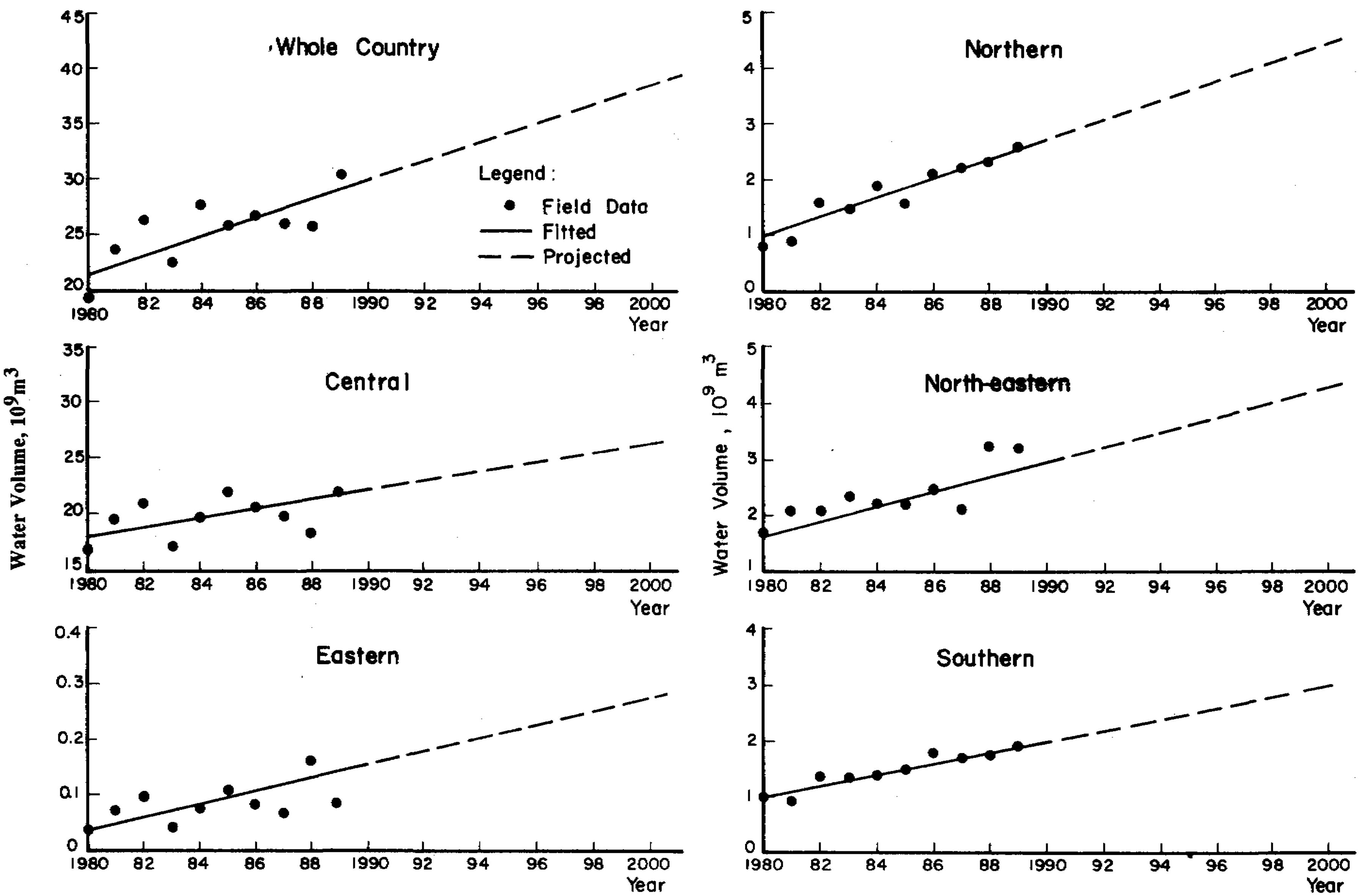


Figure 14. Annual irrigation water use in the different regions of Thailand (1980-1989) and its projections (1990-2000)

Source: RID (1989).

3. *Pump irrigation projects*

Pump irrigation projects are constructed by the Royal Irrigation Department (RID) and the National Energy Administration (NEA). Most of the pump irrigation projects utilize surface water except an area of 6,758 ha in Sukhothai province where groundwater is used for irrigation. As of 1989, there were 833 pumping stations in the total project area of 394,502 ha. Out of these, 679 pumping stations were in operation serving a total area of 161,724 ha. The distribution of these pumping stations, the project areas and served areas in each region are given in table 13. More details are given in tables 44 and 45 of the annex.

Table 13. Summary of pump irrigation projects up to 1989

Regions	*Total No of Stations up to 1989*		*Pump Stations Under Operation*		
	Number of Stations	*Project Area (ha)*	*Number of Stations*	*Project Area (ha)*	*Present Irrigation Area (ha)*
North-eastern	412	201,744	358	185,584	89,653
Northern	241	105,856	195	91,080	47,014
Central and Eastern	101	50,992	75	41,872	15,915
Southern	79	36,000	47	21,392	9,142
Total	833	394,592	679	339,928	161,724

Source: Data from NEA (1990)

For surface water pumping irrigation by NEA, the amounts of pumping increase steadily from year to year. Table 44 in the annex shows the amount of surface water pumping by NEA in different years and different regions during the dry and wet seasons. Also shown in the table are the costs of pumping. In 1989, the annual pumping volumes of surface water were 336 million m^3 in the dry season and 246 million m^3 in the wet season. The corresponding costs of pumping in 1989 were 43.3 and 31.6 million baht, respectively. Pump irrigation is mainly located in the north-eastern and northern regions of the country. The locations of these pumping stations are shown in figures 27 to 30 in the annex. It can be seen that all the pump irrigation stations are located along the river banks. The pump irrigation areas are normally within a 1 km distance from the river. The pumping sites are selected at the locations where there is enough river water throughout the year and the amount of water pumping is designed in such a way that it does not cause water shortage downstream. The farmers have to pay for the cost of water pumping to their land.

4. *Groundwater use for irrigation*

The only large-scale groundwater irrigation project in Thailand is at Sukhothai province. Rice is the main crop during wet seasons. Field crops such as soya beans, cotton are the main crops during dry seasons. Groundwater is used to supplement surface water during wet seasons. In dry seasons, irrigation is mainly done by using groundwater. The amount of groundwater use for irrigation which is mainly in the northern region was about 202 million m^3/yr in 1985 or 22 per cent of the total groundwater use of the whole country for domestic needs, irrigation and industry estimated at 924 million m^3/yr.

5. *Efficient use of water for irrigation*

Much of water brought to the fields of irrigation is wasted. The main effort of irrigation development has been devoted to rice cultivation both in wet and dry seasons. Due to cultivation of more than one rice crop per year, irrigation water requirements soar so high that water becomes scarce in dry seasons.

With increasing demand for water combined with a limited supply, efficient use of water has to be encouraged. The use of water especially for agriculture and industry is the major concern since there is a high potential for saving water. Poor efficiency of irrigation systems is normally resulted from an incomplete system, unregulated flow, inadequate control structures and wasteful use of water for irrigation. One of the most inefficient elements of existing irrigation systems is often the section where water is transferred from canal outlets to farms. Improper design, unsatisfactory operation and maintenance of the canal outlets are the main causes. While much research has been carried out on canal losses, very little has been done to reduce losses from the canal outlets to farms. Some farm turnouts are damaged and some are installed illegally by farmers. These factors make the control of flow impossible and result in irregular supply. Near the head regulator, farmers receive excess of water most of the time, while those at the end of a delivery system face shortages. When new irrigation projects are developed, special efforts should be made to maintain their efficiencies at high levels because they decline with time.

Table 14 shows the main crops, the percentage of irrigable area, the rainfall, the water use and the irrigation efficiency of the major irrigation projects in Thailand during wet and dry seasons. The rice yield and irrigation water use ratio of irrigation projects in central and northern Thailand are shown in figure 15.

6. Water charges

Thailand is among a few countries that provide irrigation water to the people free of charge. Thai farmers have been accustomed to this subsidy for so long that they now think that they are entitled to free water and they use it wastefully. Since, however, the farmer who receives irrigation water also has a larger crop harvest, it is only reasonable that he should pay for the water received. Extensive experiments should be conducted to obtain the requirement of various crops for water for different kinds of soil. Irrigation water should then be released on the basis of these findings. Revenues collected could increase the capacity of RID in maintaining and expanding irrigation systems.

7. Water laws

Thailand has three laws relating to water, namely, the People's Irrigation Act, the Field Dykes and Ditches Act, and the State Irrigation Act. These laws, especially the second, have rarely been exercised or enforced. Everywhere buffaloes can be seen wallowing in irrigation canals and causing destruction. Frequently, embankments are cut by farmers. In some sections, homes are actually constructed on the waterway embankments.

It is imperative that these laws be enforced and more stringent penalties be enacted for infringements.

B. Domestic water supply

1. Service coverage and demand.

In 1985, it was estimated that water supply facilities in Thailand were available to 65 per cent of the urban population, 75 per cent of the rural population, or to 73 per cent of the total population. Many of these facilities, however, produce water of questionable quality. In 1986, it was estimated that as much as 50 per cent of the population still lacked access to a safe and adequate supply of water. Water in Bangkok and other urban areas is supplied predominantly through individual metered connections. In the rural areas, water is obtained from various sources, including piped water supply systems, rainwater harvesting, wells and ponds.

In mid-1989 the population of Thailand was estimated to be 55.44 million, growing at an average annual rate of 1.48 per cent. In 1989 water produced for Bangkok and the two neighboring provinces of Nonthaburi and Samut Prakarn averaged 2.56 million m^3/d. With water demand projected to increase by about 40 per cent in the year 2000, water production capacity

Table 14. Water use and irrigation efficiency for large-scale irrigation projects in Thailand

Projects	*Wet Season*					*Dry Season*				
	Main crop	*Irrigable area (%)*	*Rainfall (mm)*	*Water use thousand (m^3/ha)*	*Efficiency (%)*	*Main crop*	*Irrigable area (%)*	*Rainfall (mm)*	*Water use thousand (m^3/ha)*	*Efficiency (%)*
Northern	Rice	100	760	10.63	37	Field Crop	43	140	9.38	40
Mae Klong	Rice Sugar Cane & Others	55 45	750	10.00	40	Rice Sugar Cane & Others	70 (total)	250	13.13	50
Chao Phraya	Rice	100	620	9.25	46	Rice	54	200	12.22	62
Phitsanulok	Rice	-	-	-	-	Rice	-	232	13.50	70

Source: Tongaram, D. (1985)

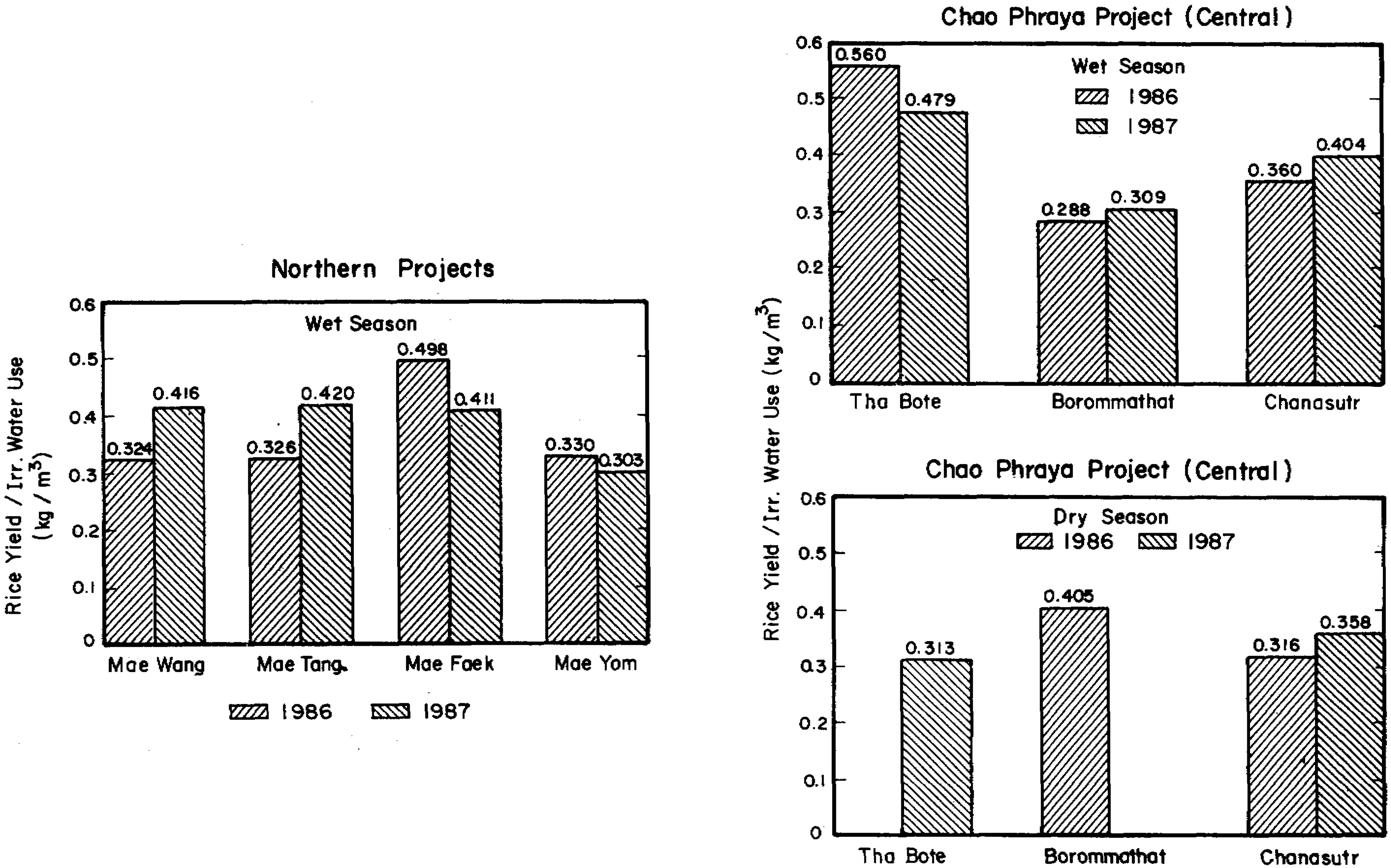


Figure 15. Rice yield and irrigation water use ratio in central and northern irrigation projects, Thailand

would have to be expanded to about 4.62 million m^3/d to serve approximately 90 per cent of the population in this service area. Outside Bangkok, the demand for potable water is more acute, and programmes to narrow the gap between supply and demand have been formulated.

In line with the targets of the International Drinking Water Supply and Sanitation Decade, the Government aimed to achieve a 100 per cent service coverage of water supply and sanitation by the year 1990. Although this target appeared overambitious was not met, policies to promote the development in this sector are continuously being evolved.

The institutional arrangement for water supply in Thailand consists essentially of two major divisions, Bangkok and other than Bangkok. Water supply for Bangkok is the responsibility of the Metropolitan Waterworks Authority (MWA), a corporation under the Ministry of Interior. MWA is responsible for the production, supply and sale of water to a service area comprising Metropolitan Bangkok, and the neighboring provinces of Nonthaburi anu Samut Prakarn, with a total population of 7.3 million in 1989.

Outside the Bangkok area, the principal institution responsible for water supply is the Provincial Waterworks Authority (PWA), a corporation under the Ministry of the Interior. It was established by virtue of the PWA Act of 1979, which declared PWA responsible for all piped water supplies outside the Bangkok area. In urban areas, PWA undertakes commercial operations, while in the rural areas it undertakes the construction of small water supply systems that are financed largely from the Government subsidies. Upon completion of the systems, these are turned over to the community concerned to manage and operate themselves, and thereafter, PWA furnishes technical guidance only. In 1987, PWA was managing 187 waterworks and providing technical assistance to 671 rural water supplies.

Aside from the PWA-managed waterworks, there are 101 concessional waterworks operated by municipalities, sanitary districts and other entities. In order to achieve full integration of provincial water supply, the Government instructed the handover of these systems to PWA within 1991.

Table 15 shows the average annual volumes of urban water supply and rural water supply in the different regions of Thailand during 1980-1989.

Table 15. Average annual volume of urban and rural water supply in the different regions of Thailand (1980-1989)

Regions	*Average Annual Volume (million m^3/yr)*		
	Urban Water Supply	*Rural Water Supply*	*Total Domestic Water Supply*
Northern	71.8	7.5	79.3
Central	797.4	6.0	803.4
North-eastern	77.3	15.0	92.3
Eastern	51.7	1.5	53.2
Southern	59.8	5.0	64.8
Total (Whole Country)	1,058.0	35.0	1,093.0

Source: Data from MWA (1989), PWA (1990) and ADB (1988)

2. *Rural water supply*

Apart from collecting rainwater, the sources of rural water supply are:

a) Shallow wells,

b) Deep wells,

c) Piped water supply system,

d) Surface water supply (village ponds)

Most villages distinguish between two different types of water, i.e., drinking water, which for at least several months is rainwater and water for other purposes. During dry seasons, local shallow wells or ponds are the preferred sources of drinking water, but these sources sometimes dry up, forcing people to travel farther to find water of acceptable quality. In some areas, people rely on hand-dug wells for eight months of the year when there is no rainwater.

The use of rainwater jars is probably the most effective means of providing drinking water to the rural population over a wide geographical area, especially in non-densely populated areas, where piped water systems are not feasible. There are different types of facilities in order to collect and store rainwater: ceramic jars of different sizes; cement jars of 1 $m^3$to 5 m^3 capacity, and family water filters also made from cement. The Nation-wide Rainwater Jar Program for provision of drinking water for the rural community has been an important activity of the Thai Government and also is in line with the United Naitons Drinking Water Supply and Sanitation Decade.

Thailand has met its targets in providing clean and safe drinking water supply for 80 per cent of the rural population by the end of 1987 by constructing 5.8 million jars of 2000 litre capacity. The major successfulness of the programme is that Thailand has been able to partially solve the problem of shortage of drinking water for the rural community by means of simple and economical technology. The meeting of targets results from high level coordination and wide ranging cooperation between relevant agencies and organizations at all levels as well as the private sector. The construction of the 2000 litre rainwater jars is continued up to present with the latest number of 8.87 million jars by the end of 1988. The geographical distribution of jars is the following: 1.07 million in the north, 6.6 million in the north-east, 0.68 million in the central and east regions and 0.52 million in the south.

Shallow wells are found to be the most accessible source of rural water supply both for the public and non-public facilities. The locally made "Korat" handpump has proven to be well suited for most deep wells in the country except in the Northern provinces, where difficulties are still experienced. The number of handpump operation hours vary greatly from one region to another. On average, the operation period is about 2 to 3 hours per day. Maximum utilization of locally made handpumps should be promoted.

Piped water supply systems are the type of a water supply system preferred in rural communities. From various investigations it appears that attempts to introduce standpipes have failed mainly because of operation and maintenance problems aggravated by inefficient collection of water charges and excessive water wastage. Non-revenue water in a piped rural water supply system has been estimated roughly to be 40 to 50 per cent.

Based on the 1983 study by Mahidol University on National Census of Rural Drinking Water Sources and Latrines and the reports of the implementing agencies of the Royal Thai Government, it was concluded that in terms of adequacy of water supply 85 per cent of the rural population in Thailand had been supplied by adequate water resources, however, only 15 per cent of the entire rural population had access to adequate and sanitary water sources. The Asian Institute of Technology (1985) and the Asian Development Bank (1988) carried out the detailed studies of water supply facilities in the rural areas and population coverage in terms of adequate and sanitary sources for the different regions of Thailand. The results of their studies are shown in table 16 and also in tables 46 and 47 of the annex.

The rural water supply in Thailand suffers from institutional fragmentation. The responsibility of providing water supply, usually non-piped, to rural communities not serviced by PWA, is handled by 12 agencies under six different ministries. Among those with substantial involvement are: Department of Mineral Resources (DMR), Accelerated Rural Development Office (ARD), Department of Health (DOH), Department of Public Works (DPW), and Department of Local Administration (DOLA).

This situation complicates sector planning and monitoring and requires greater coordination among the agencies involved. It is advisable to better define specific responsibilities of each agency involved, eliminate duplication of service areas and ensure that all rural areas are adequately taken care of PWA as the organization in charge of all piped water supply needs and to establish its policy and future role in rural water supply development and operation.

3. *Urban water supply*

The main source of urban water supply in Thailand is surface water from rivers and reservoirs. However, in some remote or isolated areas, urban water supply is obtained from groundwater resources. The following agencies are involved in the management of urban water supply in Thailand namely: the Metropolitan Water Works Authority (MWA), the Provincial Water Works Authority (PWA) and the Department of Public Works (DPW). The MWA was established in 1967 and serves the Bangkok Metropolitan Area. The MWA service areas and its major facilities are shown in figure 16. The PWA was established in 1979 and has 10 regional offices that are grouped into two operation areas throughout the country. The locations of PWA waterworks, regional offices and operation areas are shown in figure 17. The DPW provides technical advices to 101 waterwork concessions, 81 of which are in urban areas.

Table 16. Population coverage in terms of adequate and sanitary sources of rural water supply for the different regions of Thailand at the end of 1983, as a percentage

Regions / *Type of Facility*	*NORTHERN*		*NORTH-EASTERN*		*CENTRAL & EASTERN*		*SOUTHERN*		*WHOLE COUNTRY*	
	Adequate	*Adequate and Safe*	*Adequate*	*Adequate and Safe*	*Adequate*	*Adequate and Safe*	*Adequate*	*Adequate and Safe*	*Adequate*	*Adequate and Safe*
Non-Public										
Shallow Well	15.8	3.0	2.0	0.5	6.5	1.6	32.7	4.0	10.4	1.8
Deep Well	2.5	0.9	1.0	0.3	0.4	0.2	0.7	0.2	1.2	0.4
Piped Water Supply	10.0	3.5	6.0	1.9	3.2	1.6	2.2	0.6	5.7	2.0
Public										
Shallow Well	38.2	3.8	27.3	4.3	19.5	2.2	22.2	2.1	27.3	3.4
Deep Well	10.7	3.7	17.4	5.6	14.1	7.1	8.3	2.3	13.9	5.0
Piped Water Supply	5.4	1.9	4.4	1.4	6.9	3.5	5.2	1.5	5.3	2.0
Surface Water	11.9	-	27.1	-	24.6	-	12.4	-	21.1	-
Total	94.5	16.8	85.2	14.0	75.2	16.2	83.7	10.7	84.9	14.6

Source: Asian Institute of Technology (1985)

Note: "Adequate sources" refer to facilities which provide water throughout the year.
"Sanitary sources" refer to such facilities as shallow wells with handpumps and cover; deep wells and piped water supply systems (using deep wells as sources) without iron and manganese problems which are believed to provided water supply of acceptable quality, but not necessarily meeting WHO Drinking Water Standards.

Table 17. Rural water supply activities by agencies of the Government

Agencies Involved	*Facilities for Rural Drinking and Domestic Water Supply*				
	Storage Tanks (Jars included)	*Shallow Wells*	*Deep Wells*	*Ponds*	*Piped Water Systems*
Ministry of Agriculture					
- CPD				x [1]	
- LDD				x [1]	
- ALRO				x [1]	
Ministry of Interior (MOI)					
- DOLA	x	x		x	
- DPW			x		x
- PWD	x	x			
- DCD	x	x		x	
- ARD	x	x	x	x	
- PWA					x
Ministry of Public Health (MOH)					
- DOH	x	x	x		x
Ministry of Industry					
- DMR			x		
Ministry of Defense (MOD)					
- NSC	x	x	x	x	x

Source: Asian Institute of Technology (1985)

[1] Service in specific areas

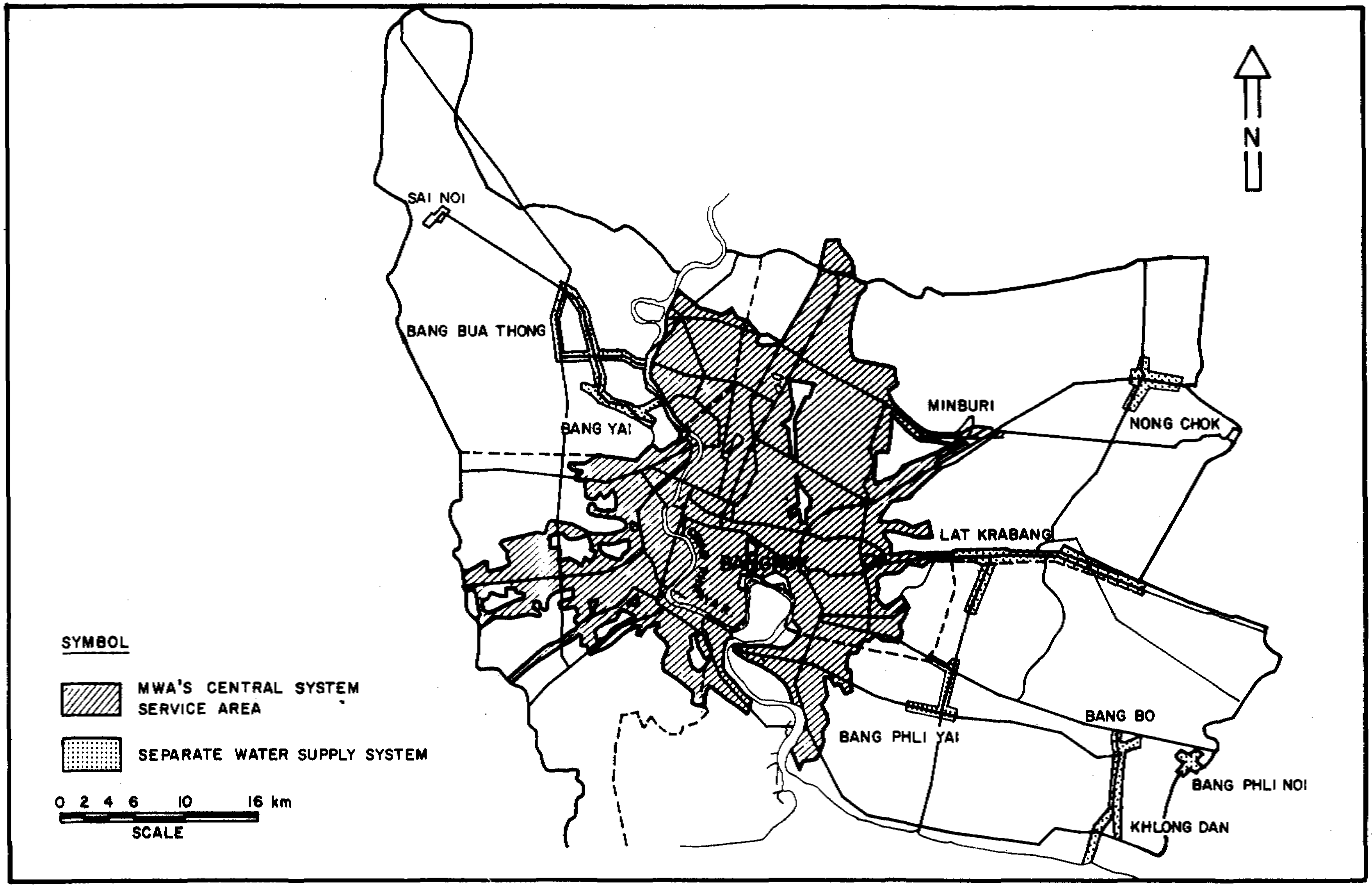


Figure 16. Service boundary of MWA's central system and separate systems in 1989

Source: Yuktananda, T. (1990)

As in most countries, the Thai Government policy on urban water supply calls for full cost recovery from consumers. Tariffs are charged to cover the costs of operation and maintenance, depreciation and debt service requirements and to realize a rate of return not less than that established by the Government.

Table 18 shows typical data for 1986 on urban water supply under the responsibility of MWA, PWA and DPW. It can be seen that MWA has the largest production capacity of 2.320 million m^3/d compared to 1.037 million m^3/d of PWA and 0.269 million m^3/d of DPW. The actual production of water in 1986 was 821 and 256 million m^3/d for MWA and PWA respectively. The number of the population served, and the service coverage percentage (in brackets) of MWA, PWA and DPW was 4,78 Million (67 per cent), 2.625 million (56 per cent) and 0.927 million (56 per cent), respectively.

Bangkok Metropolitan Area: The existing water supply system in the MWA service area comprises the central system which serves 4,300,000 people or about 70 per cent of the population of Bangkok Metropolitan and seven separate systems which serve about 35,000 people in outlying areas. The annual amounts of water production of the central system, and of the separate systems for the period 1982 - 1989 are shown in table 18. Also shown in the same table are the annual amounts of total water sales, the service areas and the average water consumption per capita per month. MWA has implemented two major expansion programmes and is currently implementing the third one.

Upon the completion of the third Bangkok Water Supply programme, it is expected that 5.4 million people or about 73 per cent of the population of MWA service area (80 per cent of the population of Bangkok Metropolitan) will be served. The remaining population will continue to use mainly private wells, but the distribution of wells and the quantity of groundwater abstracted will be within sustainable yield of the aquifers.

Other urban areas: PWA as of 1987 operated 187 waterworks. It has a service area covering 91 municipalities, 159 sanitary districts and 25 districts which are all considered urban. PWA's list of waterworks by regional office is summarized in table 19, indicating design capacity versus actual daily production and

Table 18. Total water production, water sales, service areas and service coverage percentage of MWA, Bangkok Metropolitan Area

	Unit	*Year*							
		1982	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*
Total Water Production	mcm	630.3	626.5	731.2	801.8	820.8	841.3	859.6	934.3
Central System	mcm	623.9	619.9	724.6	794.5	812.0	831.6	849.2	921.6
Separate System	mcm	6.4	6.6	6.6	7.3	8.8	9.7	10.4	12.7
Total Water Sales	mcm	341.8	369.7	423.4	477.4	485.0	523.0	570.4	628.2
Service Area	km^2	330	350	390	430	475	520	580	625
Average Consumption	m^3/capita/month	67.05	68.28	72.65	69.39	63.97	62.98	62.58	62.88
Population in Service Areas *		6,475,998	6,098,429	6,293,197	6,530,414	6,684,021	6,923,128	7,102,220	7,289,922
Number of Customers		445,000	467,675	519,487	602,267	659,660	721,365	790,160	866,673
Population Served **		3,224,470	3,388,773	3,764,202	4,364,121	4,780,000	5,227,124	5,725,623	6,280,050
Service Coverage	%	49.8	55.6	59.8	66.8	71.5	75.5	80.6	86.1

Source: Metropolitan Water Works Authority (1989)

* In 1983 the number of population decreased as a result of a new census under the Project Identification Number Arrangement

** Based on the estimation in 1986 by ADB (1988) of 7.246 people per customer (flowmeter connection)

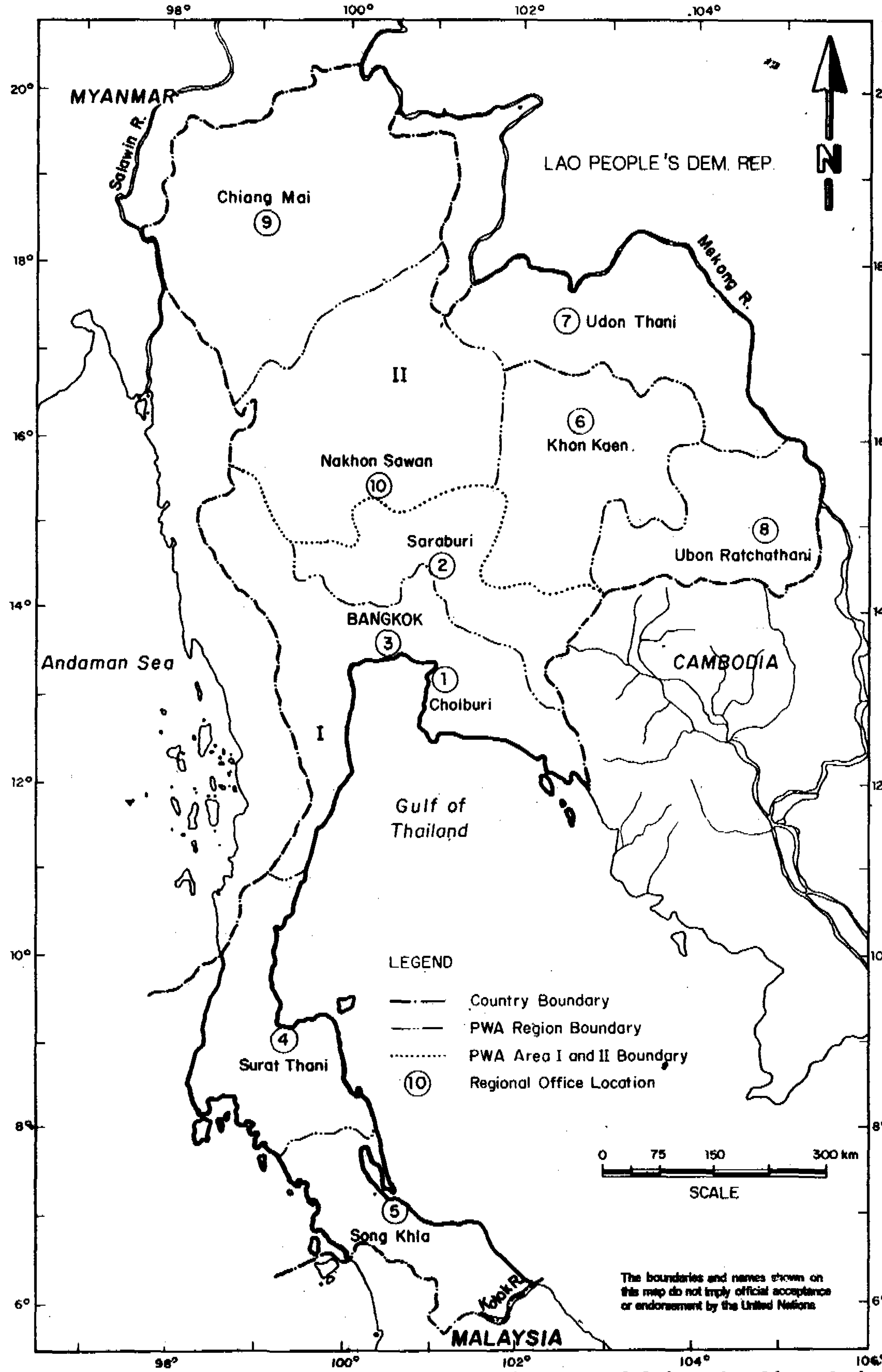


Figure 17. Locations of PWA waterworks regional offices and their regional boundaries

Source: ADB (1988)

population served as of 1986. Table 48 in the annex shows the PWA regional offices, their water production capacities and population served.

Table 19. Urban water supply production capacities and population served, 1986, Thailand

	Production Capacity (m^3/d)	*Water Production in 1986 (mcm)*	*Population in Service Area*	*Population Served*	*Service Coverage (%)*
MWA					
Combined Capacity of 4 water treatment plants	2,320,000[a]	821.0	7,133,000	4,780,000	67
PWA					
Combined Capacity of 187 waterworks in 10 regions outside MWAs' service area	1,037,400	256.2	4,707,260	2,625,230	56
DPW					
Combined Capacity of DPW 101 concessional waterworks outside MWA's service area	269,156	n.a.[b]	1,654,625	927,000	56
TOTAL	3,626,556	1,077.2	13,494,885	8,332,230	62

Sources: Asian Development Bank (1988)

[a] Not including deep wells which are being gradually abandoned

[b] Not available

For PWA systems, present non-revenue water (NRW) ranges from 30 per cent to 50 per cent. While the reduction of NRW has been successfully pursued by MWA, PWA has only recently intensified its campaign to systematically lower NRW in many of its systems. It is expected that PWA will be able to reduce its NRW by 10 per cent which would bring an additional $US 1.5 million in revenues with substantial cost savings. PWA is planning to rehabilitate and expand waterworks to upgrade its facilities and increase service coverage to about 70 per cent of the population in its service area.

A partial listing of the 101 waterworks under concession is given in table 49 in the annex showing their capacity, the population in and size of service area, number of connections and water tariff ranges. In recent years, the Government has recognized the need to improve water supply services not just in major urban centres such as Bangkok, but in other urban areas as well. To encourage the development of alternative growth centres, the Government is carrying out water supply systems expansion in numerous places and has commissioned master plans and/or feasibility studies to facilitate the systematic and efficient development of urban water supply. At present, an immediate improvement project is being undertaken to upgrade 125 municipal systems and improve existing O & M practices. DPW will undertake the expansion of the water treatment plant and pipelines in Nakhon Ratchasima and the pipeline project in the Eastern Seaboard. DPW will also provide technical assistance to rehabilitate and expand concessional waterworks.

C. Industrial water use

Industrial development is one of the most important means for economic development of Thailand. Water is an essential part in the industrial processes, therefore sufficient water resources should be provided to meet the growing demand of the industry.

The Lima Declaration of UNIDO stated that by the year 2000 25 per cent of the global industrial production should take place in developing countries.

Industrial uses of water range from washing raw materials and equipment to cooling and boilers. Industry is a relatively small user of water compared to agriculture, which uses about 30 times the amount of water per unit of GDP than industry does. Industrial water use is normally concentrated in a limited area, while agricultural water use is geographically dispersed and can be met from a variety of sources. The growth in industrial water use is expected to continue with an annual rate of about 10 per cent or more, while the growth in agricultural water use is leveling off. Much of the water required for industries need not to be of a high quality since it is used primarily for cooling. However, enormous discharges of heated water from a thermal power plant could aggravate thermal pollution problems. Nearly 60-80 per cent of water required for industrial processes is for cooling. By extensive recirculation, the total water requirements can be drastically reduced. Industry by its own waste mismanagement reduces the available water not only to itself, but also to other sectors.

The sources of water supply for industries in Thailand are surface water and groundwater. The major industries are located in Bangkok, Samut Prakan, Nonthaburi, Pathumthani and Ayutthaya provinces and in the eastern part of Thailand. The main industries in the eastern region are in the areas of Sattahip and Laem Chabang deep sea ports in Cholburi province, at Bang Pakong industrial estate in Chachoeng Sao province and at Map Ta Put industrial estate in Rayong province.

Due to unreliable and insufficient pipe water supply and the lower cost of groundwater compared with that of piped water as well as the abundance of groundwater resources in Bangkok and the surrounding provinces, groundwater is the main source for industrial water supply in these areas.

In the eastern part of Thailand, the major source of water supply for industries is surface water from reservoirs. RID is planning to construct more reservoirs in the Rayong and Bang Pakong river basins. It is suggested to construct a water supply distribution system to supply water for the industrial areas. It is important to note that the water resources availability in the east is limited. Therefore, it is necessary to develop a master plan for water resources management for various user sectors in the future.

Table 20 shows the average annual water use for industry in the different regions of Thailand during 1980-1989 in terms of surface water and groundwater uses.

Table 20. Estimation of average annual water use for industry by region, Thailand (1980-1989)

Regions	*Average Annual Water Volume (million m^3/yr)*		
	Surface Water	*Groundwater*	*Total*
Northern	-	-	-
Central	-	1,205.7	1,205.7
North-eastern	-	-	-
Eastern	50 *	-	-
Southern	-	-	-
Total (Whole Country)	50	1,205.7	1,255.7

Source: Data from Ramnarong and Buapheng (1989), MWA (1989), TDRI (1990) and IEAT (1990)

* Average annual value in 1988 and 1989

1. Surface water use for industries

Most of the industries in the Bangkok Metropolitan Area have their water supply from private groundwater deep wells. The amount of MWA pipe water supply for industries is about 1 per cent of the total water supply of MWA or 6.28 million m^3/yr in 1989. Due to overpumpage of groundwater and drastic depletion of groundwater resources in the Bangkok Metropolitan Area, the replacement of groundwater by surface water has to be made. In 1987, the groundwater pumping rate from the deep wells in the Bangkok Metropolitan Region for urban, domestic and industrial water supply was 415 million m^3/yr. This by far exceeds the safe yield of the aquifers of 219 million m^3/yr. To maintain sustainable use of groundwater, e.g., in 1987, a surface water of about 200 million m^3/yr would be required to supplement the industrial water demand, which is mainly supplied from groundwater at present. The water supply for the industrial estates in the eastern part of Thailand is mainly from reservoirs, namely: Dok Krai, Mab Prachan, Nong Kho and Bang Phra (Figure 18). These reservoirs have limited capacities for future industrial expansion. The details of some major industrial estates in the eastern region are as follows:

Laem Chabang industrial estate: the Laem Chabang industrial estate is one of the major industrial estates in the eastern part of the country in Cholburi province. It had a total project area of 465 ha in 1990 and will be expanded to 570 ha in the second stage. The Laem Chabang industrial estate receives its water supply from the Nong Kho reservoir which has a maximum capacity of 19 million m^3. The maximum supply capacity of the transmission from the reservoir to the industrial estate is 21.6 million m^3/yr. At present, the actual water demand of this industrial estate is 4.5 million m^3/yr. This water demand can be listed according to the actual data for each group of industries as follows:

1.	Automobile Parts	2,173 m^3/d
2.	Electrical Products	3,795 m^3/d
3.	Engine Products	125 m^3/d
4.	Food Products	285 m^3/d
5.	Glass Products	3,000 m^3/d
6.	Metals and Construction Materials	2,000 m^3/d
7.	Rubber Products	620 m^3/d
8.	Wood Products	335 m^3/d
9.	Other Products	4 m^3/d
	Total	12,337 m^3/d

(or 4.5 million m^3/yr)

Map Ta Put industrial estate: This industrial estate is one of the major industrial estates in the east involved with petrochemical and natural gas related industries. It had a total project area of 735 ha in 1990. The project area will be expanded to 1280 ha during the second stage. The industrial water supply is from the Dok Krai reservoir which has a maximum capacity of 58 million m^3. The actual industrial water demand in 1989 was 42

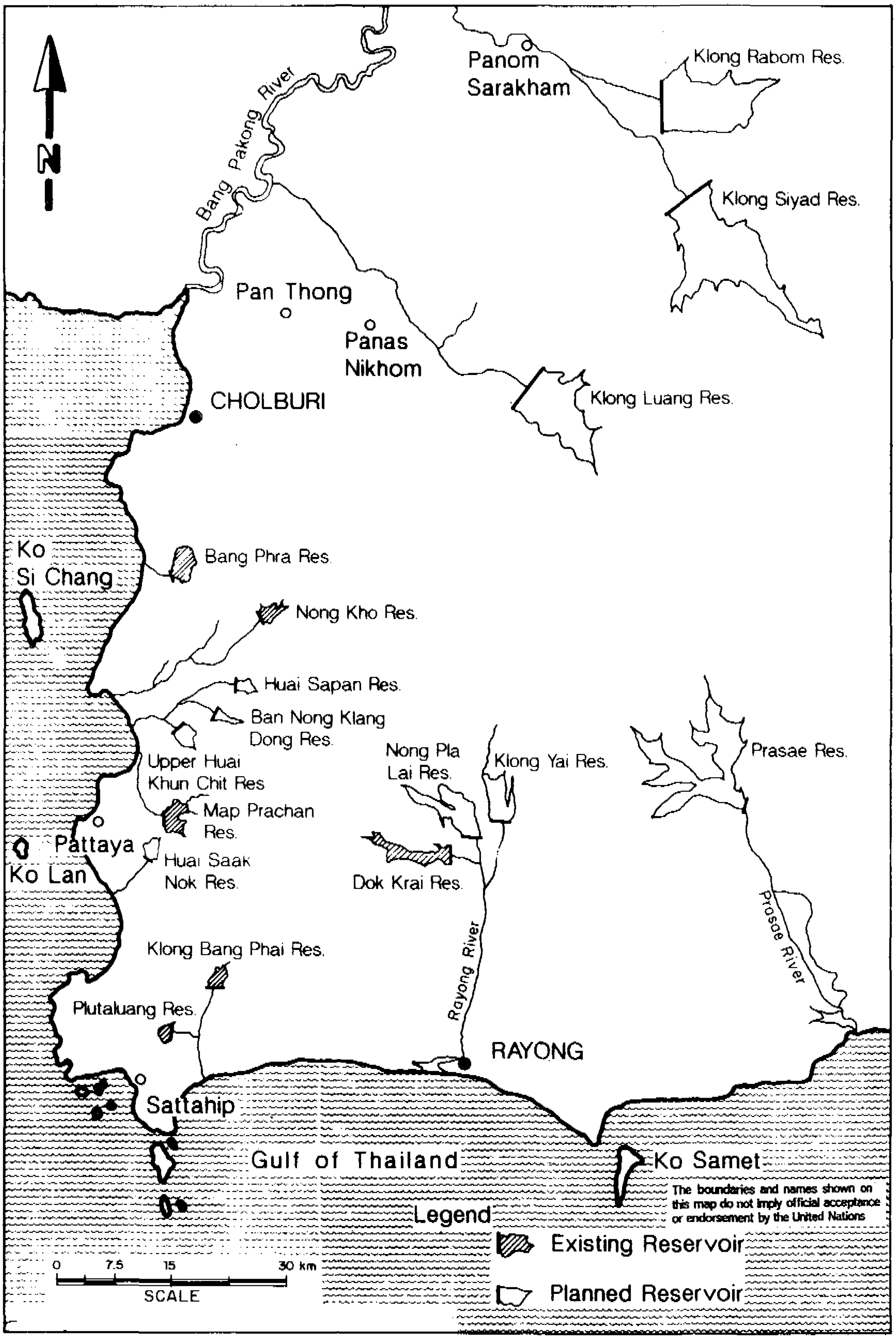


Figure 18. Existing and planned reservoirs in Eastern Thailand

Source: Industrial Estate Authority of Thailand (1989).

million m^3/yr. The water demands of each group of industries in the Map Ta Put industrial estate can be listed as follows:

1.	Chemical Products	34,600 m^3/d
2.	Metals and Construction Materials	18,300 m^3/d
3.	Petroleum Products	30,260 m^3/d
4.	Plastic Products	32,000 m^3/d
	Total	115,160 m^3/d
		(or 42 million m^3/yr)

The existing and planned reservoir systems in the eastern part of the country are shown in figure 18. The water resources development and supply plan in the eastern part in 2001 is shown in figure 19. The active reservoir capacities, average annual water demand, annual pipeline conveyance capacity and the sharing of water for various industrial estates, offices and domestic uses are shown in the same figure.

In the northern part, the industrial estates obtain their water supply mainly from the Ping river and partly from groundwater deep wells in the Chiang Mai area. The data on industrial water supply in the northern industrial estates are very scarce. The industrial development scale in the north is much smaller compared with that in the east.

In the north-east and southern parts of Thailand, there are not so many industries and hence only a small demand of water for industry.

2. *Groundwater use for industries*

In Bangkok Metropolitan Area and the surrounding provinces, the industries heavily rely on groundwater because of the following reasons:

1. lack of access to public pipe water supply,
2. unreliable or insufficient pipe water supply,
3. lower cost of groundwater supply compared to that of pipe water supply.

The average cost of groundwater supply in Thailand, e.g., from a private deep well in Bangkok is 1 Baht/m^3, while that of pipe water supply is about 6 Baht/m^3. In Bangkok Metropolitan Area, most of the industrial factories use groundwater and have their own private deep wells.

Based on the results of surveys of typical industries in the Bangkok Metropolitan Area and surrounding provinces the amounts of water use by various types of industries are given in table 21. It can be seen from this table that most of water supply for industries in this region is from private deep wells.

The present groundwater withdrawal for industries is only partially known. TDRI (1990) estimates the total industrial water use in Bangkok Metropolitan Area in 1988 at 3.6 million m^3/d (1,314 million m^3/yr). The reported private deep well pumping is only 1.2 million m^3/d (438 million m^3/yr) and that pumped by MWA is 0.17 million m^3/d (62 million m^3/yr) (table 8). The unreported groundwater pumping which is mainly for industries is equal to the difference between the total industrial water use and the reported pumping from private groundwater deep wells. This is found to be 2.28 million m^3/d (832.2 million m^3/yr).

In Samut Prakarn, which is an important industrial province, the industrial water use in 1969 was only 2,800 m^3/d (1.02 million m^3/yr). Owing to the expansion of industry in the province, industrial water use increases every year. The main source of water supply is from groundwater. The amount of water use for industries in Samut Prakarn province in 1984 was 73,822 m^3/d (26.95 million m^3/yr). Of this amount, 10 per cent is used for cooling, 3 to 4 per cent for boilers, 14 per cent for in-factory domestic use and 72 per cent for industrial processes. The Group of Thai Consultants (1984) forecast that the amount of water use for industry in Samut Prakarn province in 1991 and 2004 would be 103,000 m^3/d (37.6 million m^3/yr) and 294,510 m^3/d (107.5 million m^3/yr), respectively.

At present, groundwater quality in the Bangkok Metropolitan Area decreases considerably and becomes lower than the standard requirement for industries at many locations. This is mainly due to salt water encroachment caused by overpumpage of groundwater. Land subsidence also occurs at an alarming rate of about 5 to 10 cm/yr affecting an area of 4,550 km^2. To solve the land subsidence problem, the supply of surface water to the critical land subsidence area has been increased with the aim to reduce groundwater pumping. However, it was found that the amount of private deep well pumping has not been reduced. The Government decided to prohibit further development of groundwater usage and to phase out the groundwater pumping in the future. Surface water will be supplemented by the MWA to meet the total demand of industrial water use.

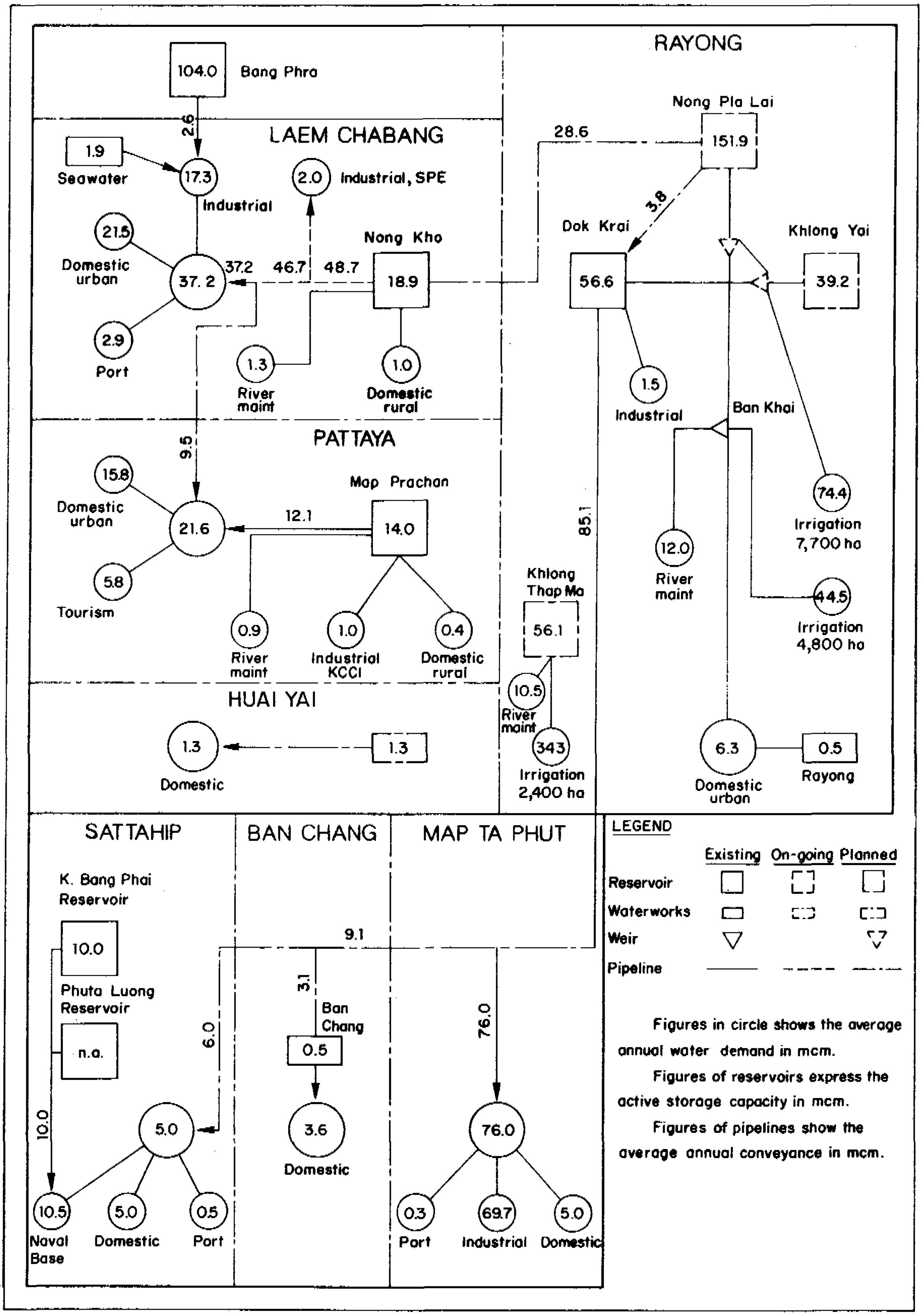


Figure 19. Multipurpose water resources development and supply plan for 2001, eastern part of Thailand

Source: Industrial Estate Authority of Thailand (1989).

Groundwater pumping has additional social costs not considered by the private sector notably, cost due to depletion of the aquifers, which is only partially renewable and environmental cost due to land subsidence such as partial costs of flood damages, structural damages and flood protection. Due to critical land subsidence and declining peizometric head of groundwater, the situation will become more critical unless strategies to conserve and reuse water for industry without contamination of groundwater resources are employed.

Currently, industrial water tariff is progressive through small increments up to 2,000 m^3/month and regressive thereafter. Proper pricing of groundwater would ensure that the scarce groundwater is put to its most effective and sustainable use at a minimal or no environmental cost.

3. *Industrial waste water treatment and BOD loadings to surface and groundwater*

In Thailand, industrial wastewater is mainly discharged into rivers or canals. Practically, there is no discharge of industrial waste to groundwater. The waste treatment plants are constructed in many industrial estates and factories. Table 6 shows the amount of BOD removal by waste treatment in the these areas of high BOD loadings in the northern region and in the Chao Phraya river basin of the central region. The efficiency of the waste treatment plants is about 80-90 per cent. Table 6 also shows the amounts of BOD loadings to the northern rivers and the Chao Phraya river during the period 1984-1985. These northern rivers are the Ping, Wang, Yom, Nan, Pasak and Mae Kok rivers. The amount of BOD loading due to industries is 18,087 kg/d

Table 21. Industrial water use

Location	*Type of industry*	*Average water use m^3/day*	*Water sources*
Samut Prakarn Province	Poultry processing	2,500	D.W*.
Bangkok District Bangkok	Integrated circuit component	350	D.W.
Klongtoey District Bangkok	Detergents, toiletries etc	230	D.W.+MWA**
Bangna District Bangkok	Poultry processing	1,600	D.W.
Bangpoo Samut Prakarn	Fish processing	370	D.W.
Samutsakorn Province	Squid processing	1,500	D.W.
Samrong District Samut Prakarn	Integrated circuit components	310	D.W. + MWA
Sampran District Nakorn Pathom	Fruit processing	940	D.W.
Bangkhen District Bangkok	Dairy products	329	D.W. + MWA

Sources: Nair, C. (1988)

* D.W. - Private Deep Wells

** MWA - Metropolitan Water Works Authority in the northern rivers, 11,005 kg/d in the Upper Chao Phraya river and 9,960 kg/d in the Lower Chao Phraya river. The total BOD loading from the industrial factories to the Chao Phraya river is 20,000 kg/d. In the Tha Chin river, the amount of BOD loading due to mainly food and textile industries is 10,520 kg/d in 1986.

In the Mae Klong river, the BOD loading is mainly from sugar mills which has an amount of 21,000 kg/d in 1986. In the Bang Pakong river, BOD loading is not significant except at some local spots. In the Andaman Sea, the tin mining in Phuket causes serious water turbidity problems in the southern part of the island. In the Gulf of Thailand, there is a certain amount of discharge of industrial waste into the sea.

4. Reuse of industrial wastewater

Industries in Thailand do not give much attention to water reuse. Water resources, especially groundwater in the Bangkok area and surrounding provinces, are being depleted drastically and contaminated at alarming rates due to overpumpage mainly for industrial uses. Control of groundwater withdrawal, well drilling and recharge of groundwater are being practiced to solve land subsidence problems. However, at present the situation has become so critical that conservation and reuse of water is urgently needed. Decisions concerning water reuse management and wastewater management have to be made in compliance with the existing laws and regulations.

Water reuse in Thailand is increasing, however, there are no figures on reuse ratios for major industries in Thailand. As practiced at present, in most factories cooling water and condensed steam are not reused for boiler feeding or new steam production. Process wastewater is seldom reused.

The utility of treated wastewater also depends on the capacity of the treatment plant on one hand and on the type of use of the treated wastewater on the other hand.

Due to insufficient information in the design of the water reuse systems as well as in analyzing their economic viability and feasibility, more data should be collected and studies should be carried out to set up strategies for water conservation and reuse in the industrial sector of Thailand.

D. Non-consumptive water use

1. Hydro power

Since 1960, the energy requirements of Thailand have increased tremendously. In 1979, the electricity consumption was 12,434 GWh. In 1988, the consumption increased to 28,253 GWh. The average annual water releases for hydro power generation of large and medium-scale plants (> 6MW) from 1985 to 1989 are shown in table 22. At present EGAT is mainly responsible for hydro power production throughout the country. The existing and planned hydro power projects of EGAT are shown in figure 20. The previous total energy and hydro power energy generations of Thailand from 1979 to 1988 are shown in figure 21. Hydro power projects require a costly investment of about 7,400 baht/kW compared to 3,500 baht/kW for thermal generation or 2,300 baht/kW for gas turbine or diesel generation. However, its operating cost is much lower e.g. 0.5 baht/kWh, while thermal power costs 1.1 baht/kWh. Another benefit is that hydro power is a renewable energy source. At present, implementation of large hydro power projects

Table 22. Water volume release for hydro power generation in Thailand

Region	*Hydro power Project*	*Data Period*	*Average Annual Release, (mcm/yr)+*
Northern	Bhumibol[2]	1985-1989	4,683.40
	Sirikit	1985-1989	4,461.99
	Mae Ngat[1]	1986-1989	184.69
North-eastern	Chulabom[1]	1985-1989	116.51
	Sirindhorn	1985-1989	1,106.07
	Ubol Ratana[2]	1985-1989	1,253.19
	Nam Pung	1985-1989	74.82
	Huai Kum[1]	1985-1989	46.60
Central	Srinagarind[1]	1985-1989	4,035.86
	Khao Laem	1985-1989	3,610.24
	Tha Thung Na[2]	1985-1989	3,818.68
	Kaeng Kra Chan	1985-1989	831.07
	Khiri Tham	1987-1989	79.16
Southern	Rajjaprabha	1987-1989	2,392.04
	Bang Lang	1985-1989	1,492.47

Source: Data from EGAT (1990)
+ mcm/yr = million m^3/yr
1 Its release is utilized by downstream project
2 Utilizes the release from the upstream project

development also depends on environmental factors. Many large project sites are occupied densely by people or are in national forest reserves. This causes difficulties in development of large hydro power projects.

On the other hand, the National Energy Administration (NEA) and the Provincial Electricity Authority (PEA) have been active in mini and micro-hydro power projects each having an installed capacity of less than 6 MW. These small hydro power projects are economical for small remote areas because the cost of this small hydro power project is less than the construction cost of transmission lines from the main power grid network. Hydro power projects provide enormous benefits to Thailand. They provide efficient peak power generation and help to stabilize the country's power system. The releases from large hydro power plants are regulated in connection to the requirement for downstream irrigation, flood control, salinity intrusion and navigation, etc.

Thailand has a total exploitable hydro power potential of about 7,007 MW which can produce an annual energy of 18,410 GWh. The hydro power potential in each region can be classified as shown as follows (EGAT 1990):

Project Types/ Regions	*No. of Projects*	*Capacity (MW)*	*Annual Energy (GWh)*
Medium and large scale projects($\geq$ 6 MW)			
Northern	25	2,968	7,813
Central	34	2,322	5,919
North-eastern	17	565	1,229
Southern	9	746	1,735
Subtotal	85	6,601	16,696
Small scale projects (< 6 MW)	235	406	1,714
Total	320	7,007	18,410

There is also a potential of 15 hydro power pumped storage schemes with a total capacity of 6,648 MW and an annual energy of 9,804 GWh.

At the end of 1988, EGAT had 21 hydro power plants with a total capacity of 2,250 MW and NEA had 10 mini and micro-hydro power plants with a total capacity of 29.6 MW. The combined installed capacities of EGAT and NEA was 2,279.6 MW or 32.5 per cent of the country's total installed capacity.

In 1988, the actual annual electrical energy generated from hydro power projects amounted to 3,779 GWh/year or 11.64 per cent of the total energy generation of Thailand of 32,464 GWh. Table 50 in the annex shows the installed capacity and electricity generation of the hydro power projects in comparison with those of various energy sources and their totals for the period 1979-1988.

2. *Inland navigation*

Transportation in Thailand consists of a road network, railways, air transport and waterways. In the past, inland waterway transport was the most important mode for bulk cargo transport from the north and the upper central plain. Compared with other modes, waterway transport is the most economical for large tonnage transport.

The inland water transport system in Thailand consists mainly of the following river systems, namely: Chao Phraya, Mae Klong, Tha Chin and Bang Pakong (figure 22). There are many interconnecting canals between these rivers. The Harbor Department of the Ministry of Communications mainly involved in inland waterways transport along these rivers. Apart from these rivers, the Mekong river, which serves as the border between Thailand and the Lao People's Democratic Republic, is another important river which has a moderate volume of waterway transport.

Excluding the Mekong river, there are 10 major rivers in Thailand, namely: Chao Phraya, Nan, Yom, Ping, Noi, Suphan, Lopburi, Pasak, Mae Klong and Bang Pakong. The total length of these 10 major rivers is 5,950 km. During dry seasons only 1,150 km are navigable and the maximum depth available is 1.7 m. In flood seasons 1,750 km are navigable with depths between 6 m to 7 m.

During dry seasons, when river discharges are low and large quantity of water is drawn for agricultural use, vessels have difficulty in navigation at some locations due to insufficient depths. In absence of a proper water regulation the navigation suffers in dry seasons, curtailing the navigable length.

With the aim of maintaining the volume of waterways transport of approximately 25 per cent of total transport volume at present and in the future, the Harbor Department has improved the navigation channels along the Chao Phraya and Nan rivers, by constructing a navigation channel of 1.7 m deep and 40 m wide at critical locations.

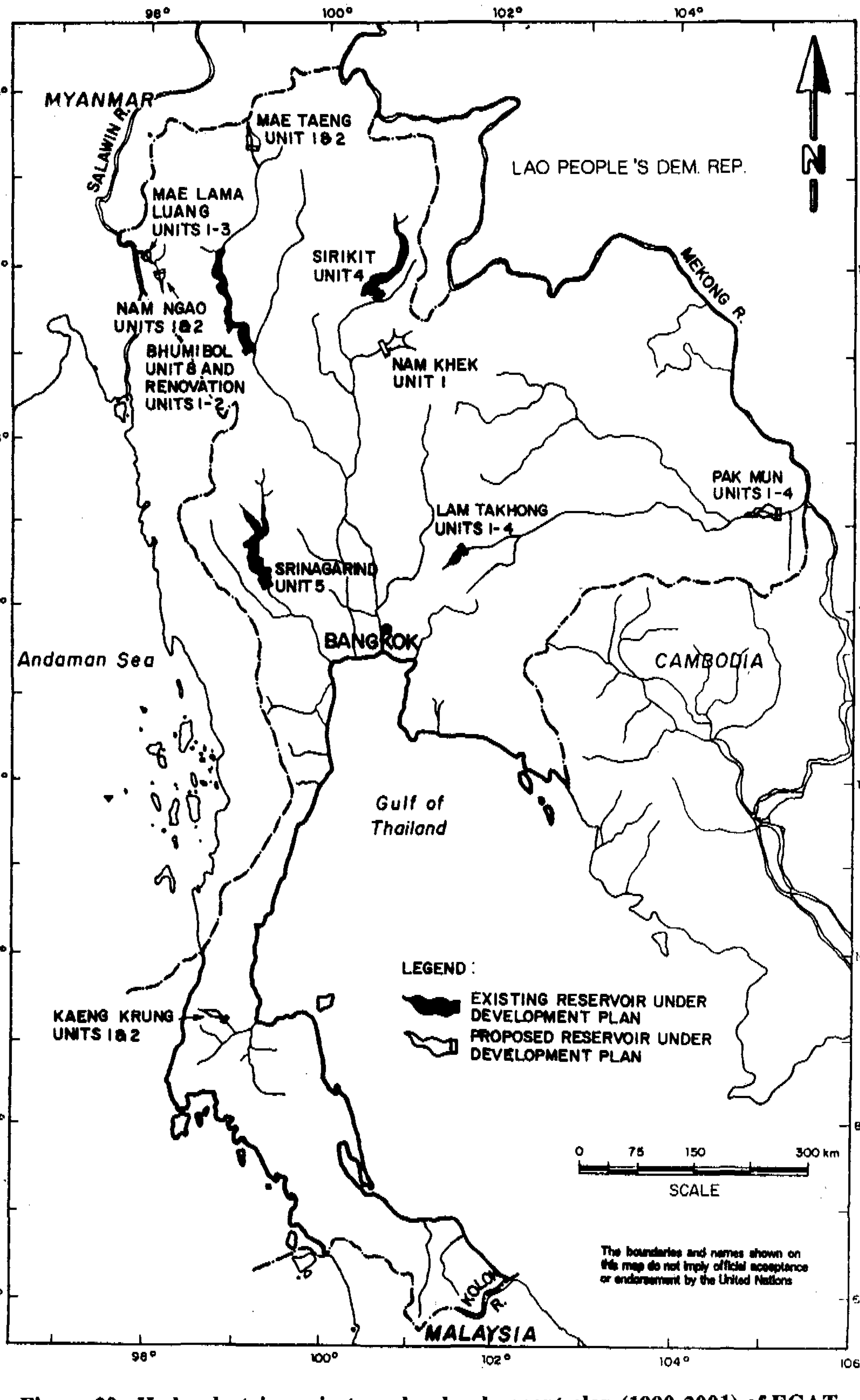


Figure 20. Hydroelectric projects under development plan (1990-2001) of EGAT

Source: EGAT, Hydroelectric Project (1990)

Thailand's inland waterways network consists mainly of rivers and canals in the Chao Phraya river basin. The Chao Phraya river slopes gently along a meandering bed with relatively low current velocities varying from 0.2 m/s in dry seasons to a maximum of 2 m/s during flood seasons. The water level in the Chao Phraya river is greatly influenced by the operation of three main dams built in the basin, namely:

- Bhumibol dam on the Ping river and Sirikit dam on the Nan river for the reaches downstream from the dams to Nakhon Sawan province.
- Chao Phraya dam on the Chao Phraya river for the reach from Chinat province to Ang Thong province.

The Upper Chao Phraya river has to obtain a water discharge from both dams of not less than 300 m^3/s in order to maintain a minimum depth of 1.70 m in a 40 m wide navigation channel (Phromprasert 1988). The Lower Chao Phraya river has to obtain a water discharge from Chao Phraya dam of not less than 80 m^3/s in order to maintain a minimum standard depth of 1.70 m for a channel width of 40 m. This 80 m^3/s discharge is the minimum release guaranteed by the Royal Irrigation Department at the Chao Phraya dam.

For the Lower Nan river downstream of the Phrom Piram (Phitsanulok) dam from Amphoe Taphan Hin to Nakhon Sawan, a minimum flow of 70 m^3/s is required to maintain a depth of 1.7 m in a 40 m wide navigation channel.

Unfortunately, at present, these minimum flows cannot be maintained due to the excessive use of water for dry season crops in the northern part in which the growing area increased from 9,600 ha in 1978 to about 72,000 ha in 1989. In 1988, the minimum flow downstream of the Chao Phraya river is lower than 80 m^3/s for 105 days. Due to insufficient flow, the flow depth in the navigation channel was less than 1.7 m. This caused the volume of waterways transport to decrease from 27 per cent of the total volume of transport in 1978 to only about 5 per cent at present. This matter remains unresolved.

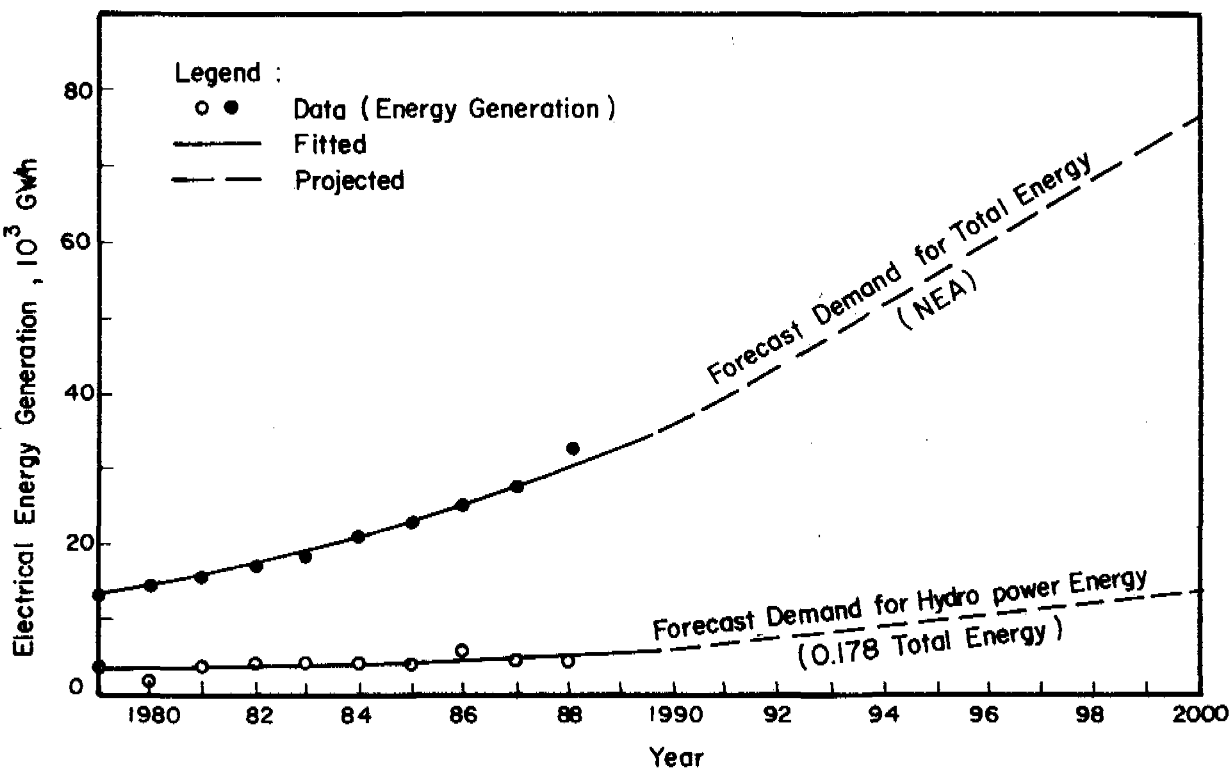


Figure 21. Total and hydro power generation and forecast demand

Source: NEA (1988)

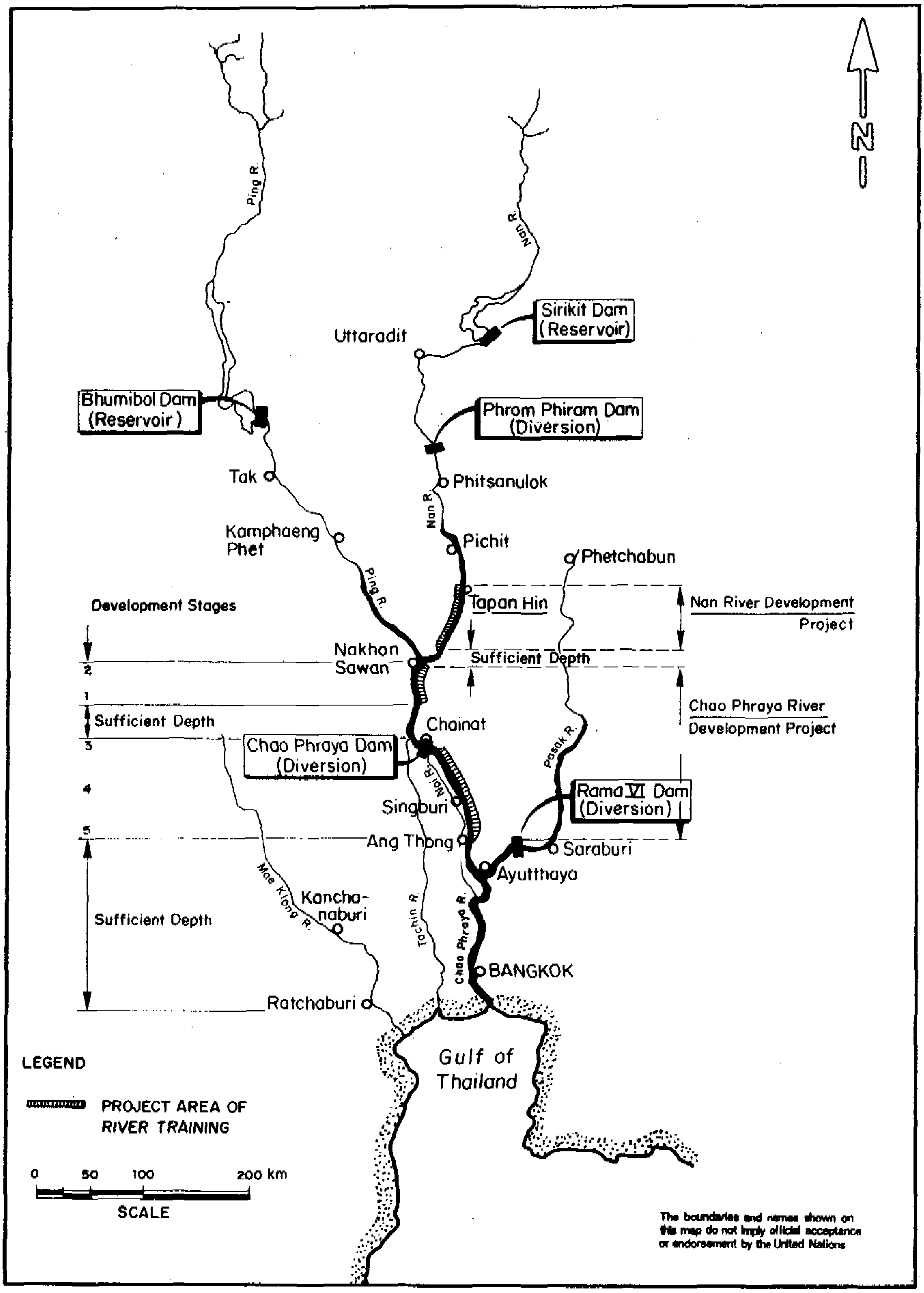


Figure 22. Locations of river training works required for inland navigation along the Chao Phraya, Ping and Nan rivers

Source: Phromprasert, K. (1988).

3. *Fisheries*

Out of the total area of 513,115 km^2 of Thailand, the inland water area is 3,750 km^2. Fisheries represent one of Thailand's important activities. Inland fisheries constitute about 10 per cent of the overall fisheries. The Inland Fisheries Division of the Department of Fisheries of Thailand is responsible for inland fishery in the country. The traditional light fish yields in the natural waters of central and coastal plains decreased over the past years because of habitat alternation in the form of dams as well as industrial, domestic and agricultural pollution. Thailand possesses a large number of natural and manmade reservoirs. The largest natural lake is the Songkhla lake in the south having a surface area of 1,400 km^2, an average depth of 1.5 m and a volume of 2,100 million m^3. The lake is connected to the sea and is therefore partly brackish. The other important inland natural lakes are Kwan Payao, Bung Boraphed and Nong Harn. Some of the important manmade reservoirs are Bhumibol, Sirikit, Sri Nagarind and Ubol Ratana.

The Fisheries Department undertook management of fisheries in the large manmade reservoirs such as the Ubolratana, Lam Pao, Lam Dom Noi as well as numerous irrigation tanks and the large natural lakes. The inland fishery in the Ubolratana Reservoir and its downstream irrigation area is a good example of integrating fishery in the multiple use of water. The main purpose of the Ubolratana reservoir project, which was completed in 1965, was for hydroelectric power and downstream irrigation. The reservoir has a maximum surface area of 401 km^2 with an average depth of 16 m and a maximum storage of 2,550 million m^3. Its minimum surface area is 160 km^2 with an average depth of 12 m. The water discharged through the power house enters the Nong Wai diversion to irrigate the land of 500 km^2. The reservoir has provided an ideal fishery resource to the local villagers who earn a better income from fishing than from farming. In 1978, there were more than 5,600 fishermen operating in this reservoir and the average annual catch was about 1,800 metric tons.

Fishery resources can be divided into three groups: freshwater fishery resources, brackishwater fishery resources and marine fishery resources. Freshwater fishery resources are found in streams, canals, rivers, marshes, swamps, lakes, manmade reservoirs and ponds. Brackishwater fishery resources include aquatic species existing in estuaries, mangrove areas and mud flats. These areas are subjected to tidal currents and fresh water run-off from land. Water salinity varies between 3 ppt and 28 ppt.

Aquaculture activities in Thailand can be divided into three categories: 1) freshwater culture 2) brackishwater culture and 3) mariculture.

Freshwater culture has long been practiced in Thailand and consists of four main types: pond culture, paddy field culture, ditch culture and cage culture. The yields from homestead fish culture of different species in Thailand is about 1,000 kg/ha/yr, while that from commercial fish farms of mainly Chinese carp is about 2,500 kg/ha/yr. Inland brackishwater culture is operated in exploited mangrove forest areas in many coastal provinces. Brackishwater culture concentrates on shrimp culture. The water is pumped into a pond. A pond is on average about 1.5 m deep. Sea bass culture is also carried out in Songkhla lake. Shrimp farmers usually flood their ponds with brackishwater. Brackishwater aquaculture is becoming increasingly popular especially in the coastal areas of the Gulf of Thailand such as Samut Sakhon, Samut Songkhram, Samut Prakarn, Chachoengsao, Chanthaburi, Songkhla, Surat Thani and Phangnga provinces. Freshwater and brackishwater aquaculture are increasing steadily, while marine culture production falling sharply.

The water demand for inland aquaculture is mainly for freshwater aquaculture and brackishwater aquaculture. Brackishwater aquaculture receives its water supply from the sea and therefore has no shortage problem. For freshwater aquaculture, the freshwater supply is from rivers or canals and also from rainfall and the groundwater. The central part of Thailand is the main area of freshwater aquaculture. In the northern, north-eastern and southern parts of the country, the extent of aquaculture is smaller compared with the central part. The water supply for freshwater aquaculture in the central part is mainly from rivers and canals, while that in the northern, north-eastern and southern parts the water supply is mainly from rainfall and the groundwater. Freshwater aquaculture is mainly in the form of pond culture and paddy field culture. The water losses from the pond culture and paddy field culture areas are due to evaporation, infiltration and others. The field data of fish pond culture area and paddy field culture area for the period 1978-1989 and their projections are shown in figure 23. By taking an average depth of 1.5 m for fish ponds and 0.5 m for paddy field culture and assuming that the water is changed annually, the water volumes required for fish pond and paddy field culture are calculated based on the area for the period 1990-2000 as shown in figure 24.

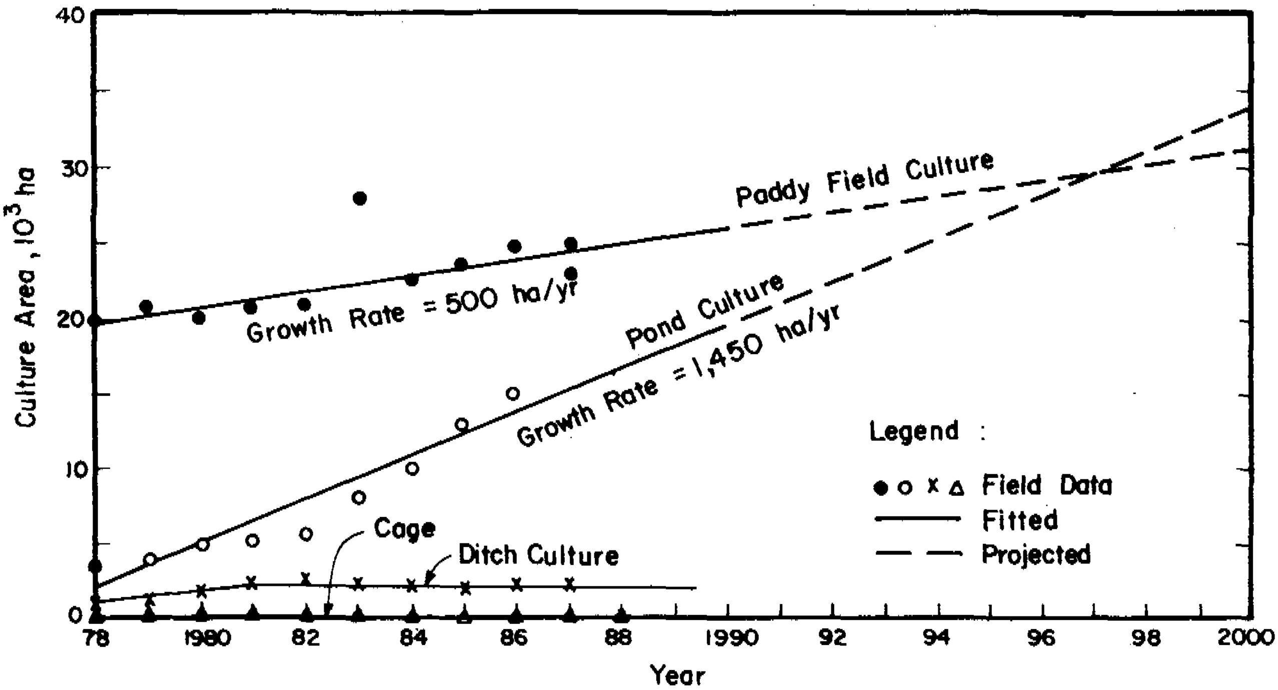


Figure 23. Freshwater aquaculture areas and their projections

Source: Ministry of Agriculture (1989).

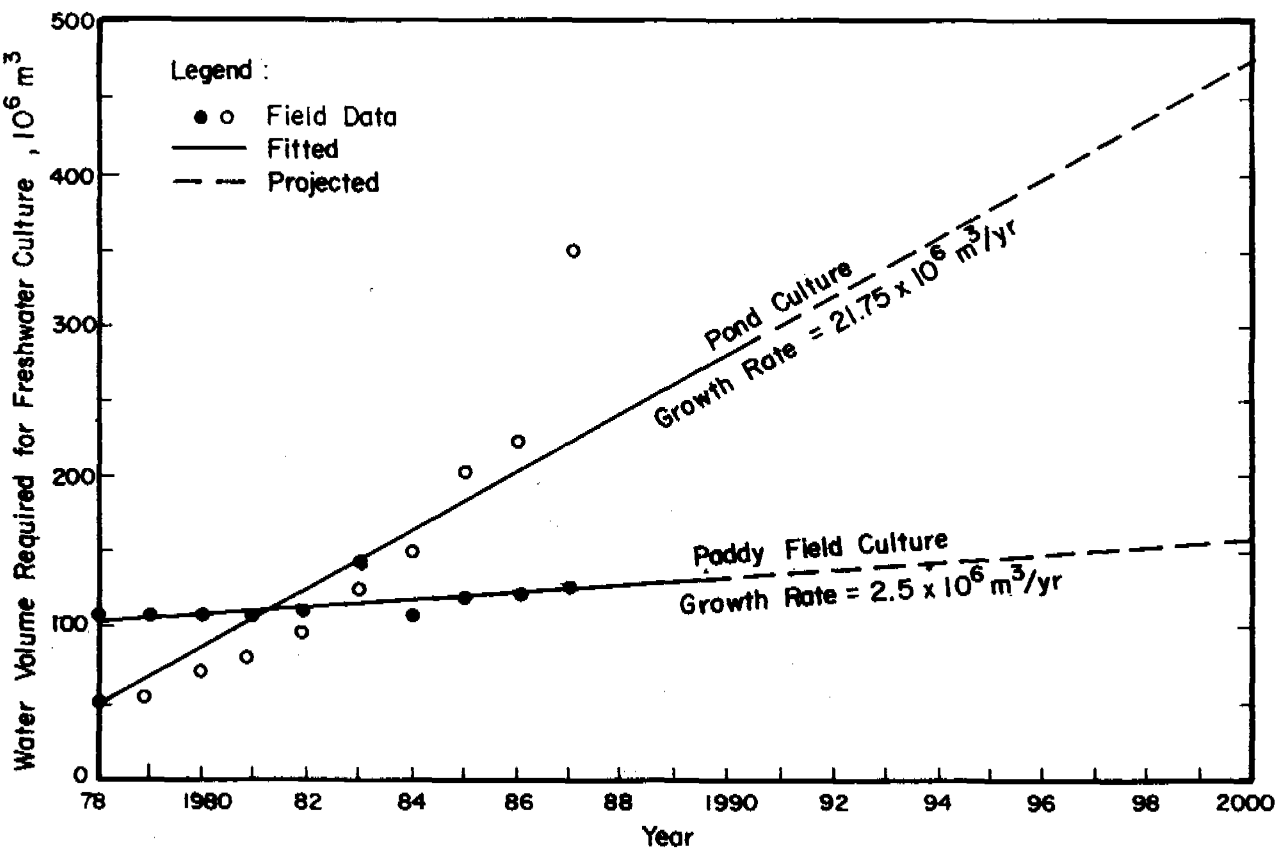


Figure 24. Water volume required for freshwater pond culture and paddy field culture and its projections

Source: Ministry of Agriculture (1989).

Deteriorating water quality in streams is mainly the result of domestic and industrial pollution. The use of agro-chemical fertilizers and pesticides is one of the major causes of river pollution. The degrading water quality affects the fish population and growth rate. Measures have to be taken to control river and estuarine pollution. In the fields, farmers might need to revive some of their traditional practices which could then be integrated with the proper use of pesticides. Industry should be encouraged to adopt new clean technologies to prevent water pollution. City dwellers need to learn how to minimize individual waste creation. With projected growth in both domestic and industrial wastes along the Chao Phraya, Tha Chin and Mae Klong rivers, the impact on aquaculture should be carefully monitored.

Fish and wildlife will benefit from rice and estuarine pollution control and maintaining substantial low flows. Control of water level and watershed management would be important for fishery. Increased activity in an watershed, especially agriculture, could have an adverse effect on fish production. Dam construction blocks migration of fish and could have a serious effect whereas siltation and agriculture or industrial chemicals may be more insidious.

4. Recreation

Most of the reservoirs in Thailand, such as Bhumibol and Sirikit in the north, Ubolratana in the north-east, Sri Nagarind in the west, Rajjaprapha and Bang Lang in the south, are attractive scenic spots for tourists. The water volume required in each of these reservoirs to maintain tourism is usually at their normal water levels. However, the water volume required for recreation is not the prime factor for reservoir operation. The reservoir level is mainly controlled based on maximizing power production and/or irrigation.

On the other hand, the reservoir release during the dry season mainly depends on the minimum requirements for irrigation, domestic and industrial water supply, navigation and salinity intrusion. These minimum releases are usually considered more important than the requirement for recreation.

Along river sections downstream of dams, weirs or gates are constructed to raise the water level to maintain the scenic view of the rivers. A rubber flexible head weir was built across the Wang river at Lampang province downstream of the Kiu Lom dam to raise the river water level from about 1.5 m during dry seasons to 3 m to 4 m depth for recreation purposes.

For natural inland lakes, such as Kwan Payao in Payao province in the north, Bung Boraphed in Nakhon Sawan province in the central part and Nong Harn in Sakon Nakhon province in the north-east, the water volume in the lake is controlled for multiple use such as fisheries, water supply and recreation. The required water volume for recreation is one of the controlling factors. Gates or weirs are constructed at the lake outlets to control the lake water level according to the inflow, the required water volume in the reservoir and the downstream demand.

In the Songkhla lake in Songkhla province the water volume fluctuates according to the sea level. There is no gate control in this lake, thus the requirement for recreation is not restricted.

III. OVERVIEW OF FUTURE WATER DEMAND

Rapid industrialization, tourist development, urbanization and income growth raise the demand for water. Water uses are increasingly diverted from crop irrigation to domestic and industrial users. Inefficient use of water by various sectors and deteriorating water quality due to excessive use of fertilizer and pesticides, urban sewage and industrial wastes create more serious problems to availability and adequacy of water resources. The knowledge of future water demand by various sectors is important for the effective planning and management of water resources.

In this chapter, the future water demands of various water use activities are predicted. The water use activities considered are as follows:

1. Water use for irrigation
2. Domestic water use
    a. rural water supply
    b. urban water supply
3. Industrial water use
4. Non-consumptive water use
    a. Hydropower
    b. Inland navigation
    c. Fisheries
    d. Recreation

A. Future water demand for irrigation

From the estimated annual volume of water use for irrigation and annual irrigated areas in the different regions of Thailand during the period 1980 to 1989 shown in figures 13 and 14, the annual volume of water use for irrigation and annual irrigated areas for the future period 1990 to 2000 are predicted by a linear interpolation. The predicted annual values are summarized in table 23 and are given in more detail in Chapter IV. In table 23, it can be seen that in the year 2000 the annual volume of water use for irrigation will be 38,500 million m^3/yr for the whole country. 68.5 per cent of this volume or 26,400 million m^3/yr will be used in the central region. In the same year, the annual irrigated area will be 3.4 million ha for the whole country and 2.25 million ha or 66.2 per cent for the central region. In the northern region, the annual volume of water use for irrigation and annual irrigated area will be only 4.5 million m^3/yr and 0.52 million ha, respectively, while in the north-east, they will be 4.3 million m^3/yr and 0.405 million ha, respectively.

The percentage increases in the annual volume of water use of the whole country for irrigation and the annual irrigated area from 1990 to 2000 will be 28.3 per cent and 14.1 per cent, respectively. It can be seen that the percentage increase in water use for irrigation will be twice that of the annual irrigated area. This means that the use of water for irrigation will be more restricted in the near future.

Table 23. Predicted annual volume of water use for irrigation and annual irrigated area

Region	*Annual Water Use for Irrigation (10^9 m^3/yr)*			*Annual Irrigated Area (10^6 ha)*		
	1990	*1995*	*2000*	*1990*	*1995*	*2000*
Northern	2.7	3.6	4.5	0.295	0.405	0.520
Central	22.25	24.25	26.40	2.16	2.20	2.25
North-eastern	3.0	3.6	4.3	0.310	0.380	0.405
Eastern	0.15	0.215	0.275	0.0101	0.0106	0.0112
Southern	2.0	2.5	3.0	0.128	0.156	0.183
Whole Country	30.00	34.25	38.50	2.92	3.16	3.40

B. Future water demand for domestic uses

1. *Future water demand for rural water supply*

Based on the previous data of rural water supply in Thailand in 1985, the Asian Development Bank (ADB) made a study in 1988 on Thailand Water Supply and Sanitation Sector Profile (table 24). By assuming the average growth rate of the rural population of 1 per cent per year for the period from 1990 to 1995, the results of the ADB study reveal that the demand for piped water supply in rural areas serviced by PWA is expected to increase from 61.21 million m^3/yr in 1990 and to 80.78 million m^3/yr in 1995.

Concerning the adequacy and sanitation of rural water supply, at the end of 1983, only about 5.2 million people or 15 per cent of rural population of Thailand were served by adequate water sources such as piped water supply, deep wells and sanitized shallow wells. The remaining about 85 per cent of the entire rural population had only access to adequate but not sanitized water resources. The predicted future demands of rural water supply in the different regions of Thailand are summarized in table 25. A more detailed description of the method of prediction is given in Chapter IV.

2. *Future water demand for urban water supply*

ADB (1988) predicted that at the end of 1991 MWA, PWA and DPW urban water supply systems will be able to serve about 11.4 million people in the country. During the period from 1980 to 1989, the demand for MWA water for domestic, commercial and industrial uses grew at an annual rate of 8 per cent from 286 million m^3/yr in 1980 to 628 million m^3/yr in 1989.

The demand projections, after analyzing MWA records of actual water production and sales, are shown in table 26. If the demand continues to grow at this rate over the next 10 years, the projected annual demand will be about 1,400 million m^3/yr in the year 2000. However, due to a higher growth rate of demand in 1989, TDRI (1990) predicts that the demand will grow at the rate of 10 per cent over the period from 1990 to 2000 reaching 1,792 million m^3/yr in the year 2000. MWA is planning to restrain this alarming growth rate with a water conservation programme, which imposes higher tariff on high water consumers, and a public information campaign on the water supply costs and the benefit of water conservation. MWA was successful in reducing the non-revenue water (NRW) from 63 per cent in 1971 to 34 per cent in 1988. It is expected that the share of non-revenue

Table 24. Previous, present and predicted water demand of rural water supply in the area serviced by PWA, Thailand

	1985			*1990*			*1995*		
	Village owned facilities	*Province owned facilities*	*Total*	*Village owned facilities*	*Province owned facilities*	*Total*	*Village owned facilities*	*Province owned facilities*	*Total*
Population in Service Area (million)	1.04	1.84	2.88	1.12	1.98	3.10	1.18	2.08	3.26
Percent Coverage	40	47	44	75	75	75	90	90	90
Population Connected (million)	0.41	0.86	1.27	0.84	1.49	2.33	1.06	1.87	2.93
Consumers per Connection	6.6	6.5	6.5	6.0	6.0	6.0	5.5	5.5	5.5
No. of Connections (1000)	62	132	194	140	248	388	192	340	532
Demand (lpcd)	28	80	63	40	90	72	50	90	75
Demand (million m^3/yr)	4.10	25.11	29.30	12.26	48.95	61.21	19.35	61.43	80.78

Source: ADB (1988)

water in the MWA system will be reduced to 25 per cent by the year 2000 after replacement of pipe and meters, disconnection of illegal tapping and leakage repair programme. By the end of 1991, MWA target was to achieve the reduction in groundwater abstraction to a level below the natural aquifer recharge rate, to reduce non-revenue water to about 30 per cent and to increase water production by 30 million m^3/yr. These would be achieved with the implementation of the on-going Third Bangkok Water Supply Project and the commencement of the Fourth Bangkok Water Supply Project in 1991.

The predicted future demands of urban water supply in the different regions of Thailand from 1990 to 2000 are summarized in table 25. A more detailed description of the method of prediction is given in Chapter IV.

C. Future water demand for industry

The demand for domestic, commercial and industrial water supply in Bangkok Metropolitan area is likely to grow faster than the economy as a whole. This is because of rapid industrialization, which would increase the industrial sector share in water use from 35 per cent today to 40 per cent by the year 2000. Based on this 40 per cent share of water, TDRI (1990) predicts that the water demand there for industrial use would be 716 million m^3/yr in the year 2000. Of this amount, 500 million m^3/yr will be withdrawn from surface water and the remaining of 216 million m^3/yr will be extracted from groundwater sources.

The predicted water demand for industries in the eastern region of Thailand (IEAT 1989) in 2001 is as follows:

Laem Chabang Industrial Estate	19.3 million m^3/yr
Map Ta Phut Industrial Estate	69.7 million m^3/yr
Rayong Industries	1.5 million m^3/yr
Total	90.5 million m^3/yr

More reservoirs will be constructed in the eastern part to satisfy this future demand (figure 18). The plan for water resources development and supply for this region in 2001 is shown in figure 19.

The predicted future demands of industrial water supply in the different regions of Thailand are summarized in table 27. A more detailed description of the method of prediction is given in Chapter IV.

D. Future water demand for non-consumptive uses

1. *Future water demand for hydro power generation*

To cope with fast growing demand for electricity, EGAT (1990) has explored and developed natural resources including water resources for electric power generation. EGAT's power development plan for 1988-2001 (figure 20 and table 51 in the annex) proposes 10 hydro power projects with an estimated total installed capacity of 1,311 MW and an estimated average annual

Table 25. Forecast annual urban and rural water supply by region, Thailand (1990-2000)

Region	*Forecast Annual Water Use for Urban and Rural Water Supply (million m^3 /yr)*					
	Urban Water Supply			*Rural Water Supply*		
	1990	*1995*	*2000*	*1990*	*1995*	*2000*
Northern	120	236	366	13.5	82.5	202.5
Central	1,031	1,322.5	1,638.5	10.5	65.5	161
North-eastern	129.5	254.5	394.5	26.5	161.5	396.5
Eastern	88	170	263	2	16	38
Southern	100	197	305	9.5	57.5	140
Total (Whole Country)	1,468.5	2,180	2,967	62	383	938

Source: ADB (1988), PWA (1990)

Table 26. Water demand projections of MWA

			1982	1985	1988[1]	1990	1995	2000
Billed Consumption per Capita (lpcd)								
Domestic			185	201	214	222	242	270
Industrial and Commercial			55	64	68	70	76	81
Institutional			15	14	12	11	10	10
Total Billed use	(1)		255	279	294	303	328	361
Non-Revenue Water (per cent of water supplied)								
Leakage			37	32	24	23	22	21
Underbilling			4	3	2	2	2	2
Unauthorized (illegal) Free Use			3	3	2	2	2	2
Authorized Free Use			2	2	2	2	1	0
Total (per cent)	(2)		46	40	30	27	27	25
NRW Equivalent (lpcd)	(3) =	$\frac{(1) \times (2)}{100 - (2)}$	217	186	126	124	121	120
Water Demand Equivalent per Capita (lpcd)	(4) =	(1) + (3)	472	465	420	427	449	481
Population Served - Central System (1000)	(5)		3,735	4,380	5,400	6,055	7,005	7,800
Water Demand (1000 m^3 /d)								
Billed Consumption		(1) x (5)	952	1,222	1,588	1,834	2,298	2,816
NRW		(3) x (5)	810	815	680	751	848	936
Total Average Demand	(6)		1,762	2,037	2,268	2,585	3,146	3,752
Total Maximum Day Demand[2]		(6) x 1.2	2,114	2,444	2,722	3,102	3,775	4,502
Supply Source Capacity (1000 m^3 /d)								
Bang Khen Treatment Plant			800	1,600	2,000	2,000	2,800	3,800
Sam Sen Treatment Plant			550	550	650	650	650	650
Thonburi Treatment Plant			170	170	170	170	170	170
Groundwater			447	200	-	-	-	-
Total			1,967	2,520	2,820	2,820	3,620	4,620

Source: ADB (1988)

[1] Upon completion of the Third Bangkok Water Supply Project.

[2] Analysis of daily flow variations has shown that maximum daily demand is about 1.2 times average daily demand.

Table 27. Forecast annual volume of water use for industry by region, Thailand (1990-2000)

Region	*Forecast Annual Water Use for Industry (million m^3 /yr)*								
	1990			*1995*			*2000*		
	Surface Water	*Ground Water*	*Total*	*Surface Water*	*Ground Water*	*Total*	*Surface Water*	*Ground Water*	*Total*
Northern	-	-	-	-	-	-	...	...	50
Central	66	1,431	1,497	83	1,716	1,799	99	2,000	2,099
North-eastern	-	-	-		-	-	...	...	50
Eastern	50	-	50	70	-	70	90	-	90
Southern	-	-	-		-	-	...	...	50
Total (Whole Country)	116	1,431	1,547	153	1,716	1,869	...	...	2,339

Source: TDRI (1990), MWA (1989), IEAT (1989)

energy output of 2,467 GWh. There are 4 projects under feasibility study and 5 projects under pending. The distribution of the existing and potential hydropower installed capacity in each region is given in table 52 in the annex.

The forecast of electrical energy demand in Thailand from 1990 to 1998 by National Energy Administration (NEA 1988) is shown in table 28. The share of hydropower generation in the total power generation during 1979-1988 was 17.8 per cent. Assuming the same percentage in the next period from 1990 to 1998, the forecast hydro power generation is shown in figure 21 and table 28.

In 1988, the annual water volume of 23,103.5 million m^3 was used to generate the annual hydro power energy of 3,779 GWh. The approximate ratio of water volume and the hydro power energy in 1988 was 6.11 million m^3/GWh. By using this ratio, the amount of water required to meet the forecast demand for hydro power generation is given in table 28.

2. *Future water demand for inland navigation*

Based on the existing 40 m wide navigation channels and the present design minimum flows for navigation as described in Section D.3 in Chapter II, the

Table 28. Forecast water demand for hydro power generation (1990-2000)

Year	*Forecast Demand (GWh)*		*Forecast Water Demand for Hydro Power (10^6 m^3/yr)*
	Total	*Hydro power**	
1990	34,741.5	6,194.4	37,847.8
1991	39,268.9	7,001.6	42,779.8
1992	43,622.1	7,777.8	47,522.3
1993	48,082.3	8,573.1	52,381.6
1994	52,324.9	9,329.5	57,003.2
1995	56,298.7	10,038.0	61,332.1
1996	60,370.1	10,763.9	65,767.4
1997	64,365.3	11,474.7	70,110.4
1998	68,554.8	12,223.3	74,684.4
1999	72,640.2+	12,930.0	79,132.4
2000	76,725.6+	13,657.2	83,580.5

Source: NEA (1988)

* Estimated to be 17.8% of forecast total demand.

\+ By linear extrapolation in this study.

Harbour Department (1990) envisages that the future water demand for inland navigation along the Chao Phraya river and the Lower Nan river will remain unchanged till the year 2000.

In view of the drastic decline of the share of inland waterway transport in the total cargo volume, i.e., from 27 per cent in 1978 to 5 per cent in 1989, the Harbour Department aims to increase this 5 per cent share to 25 per cent by the year 2000. Two barrages are planned to be constructed with navigation locks and hydropower plants. One barrage is proposed to be built across the Chao Phraya river at Ang Thong province downstream of the Chao Phraya dam and another at Phayuha Khiri upstream of the Chao Phraya dam. These two barrages will be designed to increase the existing water depth during low flows of less than 1.7 m to 3.5 m, storing water of 90 million m^3 for irrigation and generating hydroelectric energy.

According to the Harbour Department, it is envisaged that the existing navigation channel will be able to handle the volume of waterway transport up to the year 2000 despite a higher traffic density. With this navigation improvement, it is expected that the cargo volume of the waterway transport will increase from about 3,000,000 tons in 1989 to 3,949,000 tons in 1995 and 4,970,000 tons in 2000.

The Harbour Department has also carried out feasibility studies for inland navigation and recommended improvement for navigation along the following waterways:

(i) Pasak river from Amphoe Tharua, Ayutthaya province to Amphoe Kaeng Khoi, Saraburi province.

(ii) Klong Sunpasamit from its joining of the Tha Chin river at Samut Sakhon province and the Chao Phraya river at Samut Prakarn province.

(iii) Klong Tha Chin between Samut Songkram and Samut Sakhorn provinces.

(iv) Mae Klong river from Ratchaburi province to Kanchanaburi province.

The Harbour Department plans to start the improvement work in the Pasak river first by building a barrage to raise the flow depth to 4 m. For the Mae Klong river, the flow from the Vajiralongkorn Dam will be released to obtain a depth of 3.2 m for navigation. The discharge requirement and its equivalent annual flow volume in different reaches of the rivers in figure 22 are as follows: 70 m^3/s (2,270.5 million m^3/yr) for the Nan river from the Phrom Phiram Dam to Nakhon Sawan; 300 m^3/s (9,460 million m^3/yr) for the Chao Phraya river from Nakhon Sawan to the Chao Phraya dam and 80 m^3/s (2,522.8 million m^3/yr) for the Chao Phraya river from the Chao Phraya dam to Ang Thong.

3. Future water demand for inland aquaculture

As mentioned earlier in Chapter II, the water demand for inland aquaculture is mainly for fish pond culture and paddy field culture. RAPA/FAO (1990) reported that the indicator for development of overall aquaculture in Thailand over the period from 1979 to 1989 was about 9.3 per cent.

There are increasing trends in areas of pond culture and paddy field culture during 1978 to 1987 as shown in figure 23. The average increases in the areas of pond culture and paddy field culture are about 500 ha/yr and 1,450 ha/yr respectively. The production of freshwater aquaculture has increased to meet the demand of the increasing population of Thailand and also to substitute the reduction in the population of wild fish due to dam construction such as the Bhumibol and Sirikit dams in the northern part and the Chao Phraya dam in the central part. Before the existence of these dams, the flood plains along the river banks downstream of the damsites provided an ideal place for fish breeding and hence a significant increase in wild fish population. After the dam construction, flooding downstream of the dams was prevented and hence fish breeding cannot take place in the flood plain areas. This has caused the wild fish population to decrease significantly. On the other hand, overfishing has also affected the wild fish population seriously. Therefore, aquaculture has become increasingly more important.

Due to the very high cost of land at present, it is envisaged that fish pond farmers will not buy new land for aquaculture, but will utilize their existing unused land and increase the aquaculture productivity by using better technology.

A linear projection is made based on the data from 1978 to 1987. The predicted areas of pond culture and paddy field culture in the year 2000 are 33,500 ha and 31,000 ha, respectively (figure 23).

The average depths of 1.5 m for fish pond and 0.5 m for paddy field culture are used in calculating the water volumes required for these activities. Assuming that the water in the fish pond and paddy fields is changed once a year, in the absence of groundwater the projected water volumes required for these cultures are calculated based on these average depths and the projected areas. From figure 24, in the year 2000, the water volumes required for the pond culture and paddy field culture are estimated to be 470 and 155 million m^3/yr, respectively.

4. Future water demand for recreation

In Thailand, recreation normally takes place in large natural lakes and man-made reservoirs such as the Bhumibol and Sirikit reservoirs in the north, the Sri Nagarind reservoir in the west and the Ubol Ratana reservoir in the north-east. The water releases from these reservoirs are mainly controlled by a multi-purpose operation. The water volume required for recreation in these man-made reservoirs is normally sufficient. The construction of large man-made reservoirs in the future is difficult due to political, environmental and social concerns.

On the other hand, in the large natural lakes such as Kwan Payao in Payao province in the north, Bung Boraphed in Nakhon Sawan province in the central part and Nong Harn in Sakon Nakhon province in the north-east, the water releases from these lakes are mainly controlled by irrigation, domestic water supply, fishery and recreation. Normally, the water volumes stored in these natural lakes are sufficient for recreation. Therefore, the future water demand for recreation in these natural lakes will not be increased.

IV ANALYSIS OF WATER RESOURCES AVAILABILITY AND WATER USE

A. Method of computation of water resources availability and water use

The water resources availability and water use are calculated and analyzed for the past period 1980-1989 and for the future or forecast period 1990-2000. The analysis of water resources availability and water use is carried out on an annual basis for each region, namely: northern, central, north-eastern, eastern and southern, and also for the whole country. The annual rainfall volume in each region is calculated based on the data from the rainfall stations within the region. The results of the analysis of water resources availability and water use are shown in tables 29 to 34 for the period 1980-1989 and in tables 35 to 40 for the forecast period 1990-2000. The rainfall, evapotranspiration, streamflow imported and exported in each region are considered in the estimation of water resources availability.

For the computation in the past period, the rainfall and streamflow data are the measured field data. In the years in which the annual rainfall or streamflow data are not available, the long-term average values are used to represent the missing data.

In some river basins where the streamflow gaging stations are not located at the outlets, the basin outflow is calculated based on the area ratio method with respect to the streamflow at the nearest station.

The exported streamflow is that contributed by the run-off generated within the region plus that imported from the upstream region minus the consumptive water use.

In the central region, the imported streamflow is from the northern region through the Chao Phraya river at Nakhon Sawan and the Pasak river at about 50 km upstream of Saraburi.

In the northern and north-eastern regions, no imported streamflow is considered. The discharge of the Mekong river along the country's border line is not effectively utilized in these two regions, although the average annual flow of the Mekong river is, for example, 2,718 m^3/s at Chiang Saen in the north and 8,043 m^3/s at Mukdahan in the north-east. There is no imported streamflow in the other regions.

For the annual evapotranspiration, it is estimated to be 0.64 times annual rainfall according to Chindasaguan (1990).

The annual water resources availability is presented in terms of absolute annual volume and per capita annual volume.

In calculating the per capita water resources availability, the absolute annual water resources availability is divided by the annual population of the corresponding region in the corresponding year. The population data in each region are obtained from the study by the National Economic and Social Development Board (NESDB 1985).

For the forecast period 1990-2000, the same calculation procedure is used as for the past period 1980-1989. In each region, the long-term average values of annual rainfall and streamflows given by NWRE (1990) are used for every year. The annual population during the forecast period is also obtained from the population forecast study of NESDB (1985).

As shown in tables 29 to 34, the balance between rainfall, evapotranspiration, streamflows imported and exported is calculated as follows:

$$\text{Balance} = \text{Rainfall} - \text{Evapotranspiration} + \text{Streamflow Imported} - \text{Streamflow Exported}$$

The total water use is equal to the sum of water uses for irrigation, industry, urban and rural water supply. It is expressed in terms of annual absolute volume and per capita annual volume. In the computation of water use during 1980-1989, the estimation of each component of water use can be described as follows:

1. Water use for irrigation. RID is the main water user for irrigation. The data on water use for irrigation projects of RID in each region and in the whole country for the past period 1980-1989 are available from RID (1990). However, there are no data on water use for other irrigation projects. In order to obtain the total water use for all irrigation projects in the country, a factor of 1.3 which is equal to the ratio between the total irrigated area and the RID irrigated area is used to multiply to the RID irrigation water use.

2. Water use for industry. The industrial water use is mainly concentrated in the Bangkok Metropolitan Region of the central region and in the Eastern Industrial Estate of Thailand in the eastern region. In the eastern region of Thailand, the industrial water use is provided by the Industrial Estate Authority of Thailand (IEAT 1989). The industrial water use in the other regions is negligible.

3. Water use for urban water supply. The urban water supply of the whole country area is distributed to each region according to the ratio of the urban water supply areas of each region and of the whole country. The percentage distribution of the urban water supply area of each region is as follows: 2.8 per cent for the northern region, 16.8 per cent for the central region, 24.8 per cent for the north-eastern region, 16.6 per cent for the eastern region and 19.0 per cent for the southern region

4. Water use for rural water supply. The rural water supply is mainly obtained from shallow wells and deep wells. The Asian Development Bank (ADB 1988) provides the data for rural water supply in 1985. From 1980 to 1984, they are assumed to be the same as in 1985. The rural water supply data in 1985 and 1990 are interpolated to obtain the annual volumes for the years in between. The regional distribution of annual volume of the nationwide rural supply is calculated according to the ratio between the areas of the sanitary districts of each region and of the whole country. The percentage distribution of the rural water supply area of each region is as follows: 21.5 per cent for the northern region, 17 per cent for the central region, 42.5 per cent for the north-eastern region, 4 per cent for the eastern region and 15 per cent for the southern region

For the period 1990-2000, the forecast of the annual water use is done in the following way:

1. Water use for irrigation. The forecast of the annual water use for irrigation in each region as well as in the whole country is done by linearly extrapolating the 1980-1989 trend of the annual irrigation water use in the corresponding region. This is shown in figure 15.

2. Water use for industry. As mentioned previously, the industrial water use is mainly concentrated in the Bangkok Metropolitan Region and the Eastern Industrial Estate of Thailand. In the Bangkok Metropolitan Region, the industrial water supply comes from pumping of private deepwells and MWA water supply. The annual pumping from private deep wells during 1990-2000 is forecast based on the estimats for the years 1990 and 2000 by TDRI (1990). A linear interpolation is applied to estimate the annual pumping from the private deepwells in each year between 1990 and 2000. The MWA industrial water supply forecast is based on a 5 per cent growth rate from 1989 to 1990 and a 7 per cent annual growth rate from 1991 to 2000 (TDRI 1990).

For the Eastern Industrial Estate in the eastern part of Thailand, the forecast of annual volumes of industrial water use during 1990-2000 is done by interpolating the forecast data in 1990 and 2000 according to IEAT (1989) (figure 19).

In the other regions, namely : northern, north-eastern and southern, it is assumed that the industrial development lags 10 years behind the eastern region and as does the industrial water use in these regions. Therefore during 1990-1997, the industrial water use is negligible in these three regions. In 1998-2000, the annual industrial water use in each of these three regions is predicted to be equal to the average of 1988 and 1989 of the eastern region.

3. Water use for urban water supply. The forecast of urban water supply for the whole country is done by summing up the forecast urban water supply by MWA, PWA and DPW. The forecast of MWA annual urban water supply for the Bangkok Metropolitan Area is obtained by interpolating the forecast data in 1990, 1995 and 2000 provided by ADB (1988) (see table 26). The forecast of PWA annual water supply for the nationwide urban area excluding the Bangkok Metropolitan area during 1990-2000 was provided by PWA in 1990. The forecast of DPW annual urban water supply is calculated by multiplying a factor of 0.23 to the forecast data of PWA. The nationwide forecast urban water supply is distributed regionally in the same way as described for the period 1980-1989.

4. Water use for rural water supply. The forecast of nationwide annual rural water supply in 1990 was provided by ADB (1988). The forecast from 1991 to 2000 was provided by PWA in 1990. These forecast annual volumes are distributed regionally in the same way as previously described for the period 1980-1989.

Table 29. Water resources availability and water use in Thailand, 1980-1989

Year	*Water Resources Availability*							*Water Use*								
	Rainfall	*Evapo-transpira-tion*[1]	*Streamflow*		*Balance*[3]	*Popula-tion*	*Per Capita*[4]	*Irriga-tion*[5]	*Industry*[6]	*Urban Water Supply*			*Rural Water Supply*	*Total Water Use*	*% of Stream-Flow Exported*	*Per Capita*[8]
			Imported[2]	*Exported*						*MWA*	*PWA*	*DPW*[7]				
	$10^9 m^3/yr$					*Million*	*$10^3 m^3/yr$*	*$10^9 m^3/yr$*								*$10^3 m^3/yr$*
1980	798.7	511.7	-	199.0	88	46.72	4.259	18.8	0.936	0.575	0.157	0.036	0.029	20.533	10.32	0.439
1981	735.2	470.5	-	197.7	67	47.73	4.142	23.7	1.026	0.625	0.175	0.040	0.029	25.595	12.95	0.536
1982	667.3	427.0	-	184.3	56	48.74	3.781	26.3	1.123	0.630	0.194	0.045	0.029	28.321	15.37	0.581
1983	748.1	478.8	-	222.4	46.9	49.73	4.472	22.4	1.189	0.626	0.213	0.049	0.029	24.506	11.02	0.493
1984	680.1	435.2	-	172.0	72.9	50.71	3.392	27.6	1.275	0.731	0.231	0.053	0.029	29.890	17.38	0.589
1985	741.6	474.6	-	189.2	77.8	51.68	3.661	25.5	1.191	0.801	0.244	0.056	0.029	27.821	14.70	0.538
1986	681.7	436.3	-	202.5	42.9	52.65	3.846	26.8	1.236	0.821	0.256	0.059	0.035	29.121	14.38	0.553
1987	675.9	432.6	-	172.0	41.3	53.60	3.209	26.0	1.297	0.841	0.308	0.071	0.042	28.559	16.60	0.533
1988	804.4	514.8	-	206.9	82.7	54.54	3.793	25.4	1.421	0.860	0.360	0.083	0.048	28.172	13.62	0.516
1989	647.8	414.6	-	198.8*	34.4	55.45	3.585	30.2	1.436	0.934	0.412	0.095	0.055	33.150	16.67	0.598

Notes:
1 Evapotranspiration is taken to be 0.64 times rainfall (Chindasaguan 1990)
2 Not including flow of the Mekong River
3 Balance = Rainfall - Evapotranspiration + Streamflow Imported - Streamflow Exported
4 Streamflow exported/population
5 Irrigation water use of all projects is about 1.3 times irrigation water use of RID projects
6 During 1980-89, industrial water use is mainly in Bangkok Metropolitan Region and Eastern Seaboard
7 Urban water supply by DPW is about 0.23 of that supplied by PWA (ADB 1988)
8 Total water use/population
* Long-term average value

Table 30. Water resources availability and water use in the Northern Region of Thailand, 1980-1989

Year	*Water Resources Availability*							*Water Use*								
	Rainfall	*Evapo-transpira-tion*[1]	*Streamflow*		*Balance*[3]	*Popula-tion*	*Per Capita*[4]	*Irriga-tion*[5]	*Industry*[6]	*Urban Water Supply*			*Rural Water Supply*	*Total Water Use*	*% of Stream-Flow Exported*	*Per Capita*[8]
			Imported[2]	*Exported*						*MWA*	*PWA*	*DPW*[7]				
	$10^9 m^3/yr$					*Million*	$10^3 m^3/yr$	$10^9 m^3/yr$								$10^3 m^3/yr$
1980	198.2	126.8	-	47.4	24.0	9.427	5.028	0.770	-	-	0.036	0.008	0.006	0.820	1.73	0.087
1981	188.9	120.9	-	40.9	27.1	9.578	4.270	0.812	-	-	0.040	0.009	0.006	0.867	2.12	0.091
1982	162.4	103.9	-	37.5	21.0	9.730	3.854	1.631	-	-	0.045	0.010	0.006	1.692	4.34	0.174
1983	178.7	114.4	-	41.5	22.8	9.879	4.200	1.479	-	-	0.049	0.011	0.006	1.545	3.72	0.156
1984	174.6	111.7	-	36.3	26.6	10.029	3.619	1.830	-	-	0.053	0.012	0.006	1.901	5.23	0.189
1985	190.5	121.9	-	41.5	27.1	10.177	4.078	1.639	-	-	0.055	0.013	0.006	1.713	4.13	0.168
1986	158.4	101.4	-	36.2	20.8	10.335	3.503	2.203	-	-	0.058	0.014	0.007	2.282	6.30	0.220
1987	169.1	108.2	-	35.4	25.5	10.488	3.375	2.273	-	-	0.070	0.017	0.009	2.369	6.69	0.226
1988	191.9	122.8	-	35.5	33.6	10.634	3.338	2.292	-	-	0.082	0.019	0.010	2.403	6.76	0.226
1989	163.7	104.7	-	36.6*	20.9	10.774	3.397	2.638	-	-	0.094	0.022	0.012	2.766	7.26	0.257

Notes:

1 Evapotranspiration is taken to be 0.64 times rainfall (Chindasaguan 1990)

2 Not including flow of the Mekong River

3 Balance = Rainfall - Evapotranspiration + Streamflow Imported - Streamflow Exported

4 Streamflow exported/population

5 Irrigation water use of all projects is about 1.3 times irrigation water use of RID projects

6 During 1980-89, industrial water use is mainly in Bangkok Metropolitan Region and Eastern Seaboard

7 Urban water supply by DPW is about 0.23 of that supplied by PWA (ADB 1988)

8 Total water use/population

* Long-term average value

Table 31. Water resources availability and water use in the Central Region of Thailand, 1980-1989

Year	*Water Resources Availability*							*Water Use*								
	Rainfall	*Evapo-transpira-tion*[1]	*Streamflow*		*Balance*[3]	*Popula-tion*	*Per Capita*[4]	*Irriga-tion*[5]	*Industry*[6]	*Urban Water Supply*			*Rural Water Supply*	*Total Water Use*	*% of Stream-Flow Exported*	*Per Capita*[8]
			Imported[2]	*Exported*						*MWA*	*PWA*	*DPW*[7]				
	$10^9 m^3/yr$					*Million*	$10^3 m^3/yr$	$10^9 m^3/yr$								$10^3 m^3/yr$
1980	89.7	57.7	32.3	41.5	23.1	11.471	3.618	15.294	0.936	0.575	0.027	0.006	0.005	16.843	40.59	1.468
1981	95.7	61.2	27.9	58.0	4.4	11.775	4.925	19.618	1.026	0.625	0.029	0.007	0.005	21.310	36.74	1.809
1982	88.8	56.8	22.4	54.5	-0.1	12.071	4.515	21.050	1.123	0.630	0.032	0.008	0.005	22.848	41.92	1.893
1983	103.1	66.0	26.4	46.5	17.0	12.363	3.761	17.104	1.189	0.626	0.036	0.008	0.005	18.968	40.79	1.534
1984	76.5	48.9	21.2	31.8	17.0	12.649	2.430	22.054	1.275	0.731	0.039	0.009	0.005	24.113	75.82	1.906
1985	87.9	56.2	26.5	48.1	10.1	12.929	3.720	20.288	1.191	0.801	0.041	0.010	0.005	22.336	46.43	1.727
1986	86.9	55.6	20.9	48.7	3.5	13.202	3.689	20.246	1.236	0.821	0.043	0.010	0.006	22.362	45.92	1.694
1987	83.8	53.6	20.0	33.5	16.7	13.470	2.487	19.666	1.297	0.841	0.052	0.012	0.007	21.875	65.29	1.624
1988	107.8	69.0	20.2	39.0	19.4	13.733	2.840	18.026	1.371	0.860	0.061	0.014	0.008	20.340	52.15	1.481
1989	82.4	52.7	21.2*	43.0*	7.9	13.993	3.073	22.352	1.413	0.934	0.069	0.016	0.009	24.873	57.84	1.777

Notes:

1 Evapotranspiration is taken to be 0.64 times rainfall (Chindasaguan 1990)

2 From the northern Region

3 Balance = Rainfall - Evapotranspiration + Streamflow Imported - Streamflow Exported

4 Streamflow exported/population

5 Irrigation water use of all projects is about 1.3 times irrigation water use of RID projects

6 During 1980-89, industrial water use is mainly in Bangkok Metropolitan Region and Eastern Seaboard

7 Urban water supply by DPW is about 0.23 of that supplied by PWA (ADB 1988)

8 Total water use/population

* Long-term average value

Table 32. Water resources availability and water use in the North-eastern Region of Thailand, 1980-1989

Year	*Water Resources Availability*							*Water Use*								
	Rainfall	*Evapo-transpira-tion*[1]	*Streamflow*		*Balance*[3]	*Popula-tion*	*Per Capita*[4]	*Irriga-tion*[5]	*Industry*[6]	*Urban Water Supply*			*Rural Water Supply*	*Total Water Use*	*% of Stream-Flow Exported*	*Per Capita*[8]
			Imported[2]	*Exported*						*MWA*	*PWA*	*DPW*[7]				
	$10^9 m^3/yr$					*Million*	*$10^3 m^3/yr$*	*$10^9 m^3/yr$*								*$10^3 m^3/yr$*
1980	257.2	164.6	-	47.4	45.2	16.434	2.902	1.687	-	-	0.039	0.009	0.012	1.747	3.68	0.106
1981	214.3	137.1	-	31.8	45.4	16.765	1.897	2.207	-	-	0.043	0.010	0.012	2.272	7.14	0.135
1982	184.2	117.9	-	35.2	31.1	17.090	2.059	2.087	-	-	0.048	0.011	0.012	2.158	6.13	0.126
1983	202.8	129.8	-	43.3	29.7	17.408	2.487	2.311	-	-	0.052	0.012	0.012	2.387	5.51	0.137
1984	198.0	126.7	-	30.0	41.3	17.719	1.693	2.154	-	-	0.057	0.013	0.012	2.236	7.45	0.126
1985	216.1	138.3	-	43.5	34.3	18.024	2.413	2.109	-	-	0.060	0.014	0.012	2.195	5.04	0.122
1986	179.6	114.9	-	43.5	21.2	18.328	2.373	2.490	-	-	0.063	0.014	0.015	2.582	5.94	0.141
1987	191.8	122.7	-	30.8	38.3	18.622	1.654	2.276	-	-	0.075	0.018	0.018	2.387	7.75	0.128
1988	217.7	139.3	-	29.4	49.0	18.907	1.555	3.181	-	-	0.089	0.020	0.020	3.310	11.26	0.175
1989	185.7	118.8	-	43.5*	23.5	19.184	2.267	3.175	-	-	0.102	0.023	0.023	3.323	7.64	0.173

Notes:

1 Evapotranspiration is taken to be 0.64 times rainfall (Chindasaguan 1990)

2 Not including flow of the Mekong River

3 Balance = Rainfall - Evapotranspiration + Streamflow Imported - Streamflow Exported

4 Streamflow exported/population

5 Irrigation water use of all projects is about 1.3 times irrigation water use of RID projects

6 During 1980-89, industrial water use is mainly in Bangkok Metropolitan Region and Eastern Seaboard

7 Urban water supply by DPW is about 0.23 of that supplied by PWA (ADB 1988)

8 Total water use/population

* Long-term average value

Table 33. Water resources availability and water use in the Eastern Region of Thailand, 1980-1989

Year	*Water Resources Availability*							*Water Use*									
	Rainfall	*Evapo-transpira-tion*[1]	*Streamflow*		*Balance*[2]	*Popula-tion*	*Per Capita*[3]	*Irriga-tion*[4]	*Industry*[5]	*Urban Water Supply*			*Rural Water Supply*	*Total Water Use*	*% of Stream-Flow Exported*	*Per Capita*[7]
			Imported	*Exported*						*MWA*	*PWA*	*DPW*[6]				
	$10^9m^3/yr$					*Million*	*$10^3m^3/yr$*	*$10^9m^3/yr$*								*$10^3m^3/yr$*
1980	79.6	50.9	-	17.1	11.6	2.804	6.098	0.031	-	-	0.026	0.006	0.001	0.064	0.37	0.023
1981	73.3	46.9	-	20.4	6.0	2.874	7.098	0.075	-	-	0.028	0.007	0.001	0.111	0.54	0.039
1982	68.3	43.7	-	14.0	10.6	2.941	4.760	0.097	-	-	0.031	0.008	0.001	0.137	0.97	0.046
1983	87.4	55.9	-	36.1	-4.6	3.006	12.009	0.035	-	-	0.035	0.008	0.001	0.079	0.22	0.026
1984	62.4	39.9	-	17.8	4.7	3.068	5.802	0.072	-	-	0.038	0.009	0.001	0.120	0.67	0.039
1985	68.8	44.0	-	15.6	9.2	3.127	4.988	0.103	-	-	0.040	0.009	0.001	0.153	0.98	0.049
1986	67.2	43.0	-	24.6	-0.4	3.181	7.733	0.087	-	-	0.042	0.010	0.001	0.139	0.56	0.044
1987	64.9	41.5	-	16.6	6.8	3.232	5.136	0.065	-	-	0.051	0.012	0.002	0.129	0.78	0.040
1988	82.2	52.6	-	31.6	-2.0	3.284	9.622	0.173	0.05	-	0.059	0.014	0.002	0.298	0.94	0.091
1989	62.3	39.9	-	21.2*	1.2	3.335	6.357	0.060	0.05	-	0.068	0.016	0.002	0.196	0.92	0.059

Notes:

1 Evapotranspiration is taken to be 0.64 times rainfall (Chindasaguan 1990)

2 Balance = Rainfall - Evapotranspiration + Streamflow Imported - Streamflow Exported

3 Streamflow exported/population

4 Irrigation water use of all projects is about 1.3 times irrigation water use of RID projects

5 During 1980-89, industrial water use is mainly in Bangkok Metropolitan Region and Eastern Seaboard

6 Urban water supply by DPW is about 0.23 of that supplied by PWA (ADB 1988)

7 Total water use/population

* Long-term average value

Table 34. Water resources availability and water use in the Southern Region of Thailand, 1980-1989

Year	*Water Resources Availability*							*Water Use*								
	Rainfall	*Evapo-transpira-tion*[1]	*Streamflow*		*Balance*[2]	*Popula-tion*	*Per Capita*[3]	*Irriga-tion*[4]	*Industry*[5]	*Urban Water Supply*			*Rural Water Supply*	*Total Water Use*	*% of Stream-Flow Exported*	*Per Capita*[7]
			Imported	*Exported*						*MWA*	*PWA*	*DPW*[6]				
	$10^9 m^3/yr$					*Million*	*$10^3 m^3/yr$*	*$10^9 m^3/yr$*								*$10^3 m^3/yr$*
1980	174.0	111.4	-	77.9	-15.3	6.581	11.837	1.00	-	-	0.030	0.007	0.004	1.041	1.33	0.158
1981	163.0	104.3	-	74.5	-15.8	6.742	11.050	0.95	-	-	0.033	0.008	0.004	0.995	1.33	0.148
1982	163.6	104.7	-	65.5	-6.6	6.908	9.481	1.42	-	-	0.037	0.009	0.004	1.470	2.24	0.324
1983	176.1	112.7	-	81.4	-18.0	7.077	11.502	1.44	-	-	0.041	0.009	0.004	1.490	1.83	0.258
1984	168.6	107.9	-	77.3	-16.6	7.249	10.663	1.53	-	-	0.043	0.011	0.004	1.588	2.05	0.283
1985	178.3	114.1	-	67.0	-2.8	7.423	9.026	1.42	-	-	0.046	0.011	0.004	1.481	2.22	0.299
1986	189.6	121.3	-	70.4	-2.1	7.607	9.255	1.78	-	-	0.049	0.011	0.005	1.845	2.62	0.344
1987	166.3	106.4	-	75.7	-15.8	7.792	9.715	1.74	-	-	0.058	0.014	0.006	1.818	2.40	0.308
1988	204.4	130.8	-	91.0	-17.4	7.976	11.409	1.73	-	-	0.068	0.016	0.007	1.821	2.00	0.250
1989	153.7	98.4	-	75.7*	-20.4	8.161	9.276	2.00	-	-	0.079	0.018	0.008	2.105	2.78	0.258

Notes:
1 Evapotranspiration is taken to be 0.64 times rainfall (Chindasaguan 1990)
2 Balance = Rainfall - Evapotranspiration + Streamflow Imported - Streamflow Exported
3 Streamflow exported/population
4 Irrigation water use of all projects is about 1.3 times irrigation water use of RID projects
5 During 1980-89, industrial water use is mainly in Bangkok Metropolitan Region and Eastern Seaboard
6 Urban water supply by DPW is about 0.23 of that supplied by PWA (ADB 1988)
7 Total water use/population
* Long-term average value

Table 35. Forecast of water resources availability and water use in Thailand, 1990-2000

Year	*Water Resources Availability*							*Water Use*								
	Rainfall	*Evapo-transpira-tion*[1]	*Streamflow*		*Balance*[3]	*Popula-tion*	*Per Capita*[4]	*Irriga-tion*[5]	*Industry*[6]	*Urban Water Supply*			*Rural Water Supply*	*Total Water Use*	*% of Stream-Flow Exported*	*Per Capita*[8]
			Imported[2]	*Exported*						*MWA*	*PWA*	*DPW*[7]				
	$10^9 m^3/yr$					*Million*	*$10^3 m^3/yr$*	*$10^9 m^3/yr$*								*$10^3 m^3/yr$*
1990	761.7*	487.5	-	198.8*	75.4	56.340	3.553	30.05	1.547	0.943	0.427	0.098	0.062	33.127	16.66	0.588
1991	761.7*	487.5	-	198.8*	75.4	57.196	3.500	30.89	1.611	0.984	0.507	0.117	0.062	34.171	17.19	0.597
1992	761.7*	487.5	-	198.8*	75.4	58.040	3.449	31.74	1.676	1.025	0.580	0.133	0.131	35.285	17.75	0.608
1993	761.7*	487.5	-	198.8*	75.4	58.874	3.400	32.58	1.740	1.066	0.661	0.152	0.208	36.407	18.31	0.618
1994	761.7*	487.5	-	198.8*	75.4	59.695	3.354	33.42	1.803	1.107	0.752	0.173	0.292	37.547	18.89	0.629
1995	761.7*	487.5	-	198.8*	75.4	60.506	3.309	34.26	1.869	1.148	0.839	0.193	0.383	38.692	19.46	0.639
1996	761.7*	487.5	-	198.8*	75.4	61.312	3.265	35.10	1.932	1.192	0.923	0.212	0.478	39.837	20.04	0.649
1997	761.7*	487.5	-	198.8*	75.4	62.102	3.224	35.95	1.996	1.236	1.011	0.232	0.584	41.009	20.63	0.660
1998	761.7*	487.5	-	198.8*	75.4	62.878	3.184	36.79	2.210	1.281	1.098	0.252	0.693	42.324	21.29	0.673
1999	761.7*	487.5	-	188.8*	75.4	63.640	3.146	37.63	2.275	1.325	1.193	0.274	0.813	43.510	21.88	0.684
2000	761.7*	487.5	-	188.8*	75.4	64.390	3.109	38.48	2.339	1.369	1.299	0.299	0.938	44.724	22.50	0.695

Notes:

1 Evapotranspiration is taken to be 0.64 times rainfall (Chindasaguan 1990)
2 Not including flow of the Mekong River
3 Balance = Rainfall - Evapotranspiration + Streamflow Imported - Streamflow Exported
4 Streamflow exported/population
5 Irrigation water use of all projects is about 1.3 times irrigation water use of RID projects
6 See more details in Table 27
7 Urban water supply by DPW is about 0.23 of that supplied by PWA (ADB 1988)
8 Total water use/population
* Long-term average value

Table 36. Forecast of water resources availability and water use in the Northern Region of Thailand, 1990-2000

Year	*Water Resources Availability*							*Water Use*								
	Rainfall	*Evapo-transpira-tion*[1]	*Streamflow*		*Balance*[3]	*Popula-tion*	*Per Capita*[4]	*Irriga-tion*[5]	*Industry*[6]	*Urban Water Supply*			*Rural Water Supply*	*Total Water Use*	*% of Stream-Flow Exported*	*Per Capita*[8]
			Imported[2]	*Exported*						*MWA*	*PWA*	*DPW*[7]				
	$10^9 m^3/yr$					*Million*	$10^3 m^3/yr$	$10^9 m^3/yr$								$10^3 m^3/yr$
1990	186.1*	119.0	-	36.6*	30.5	10.908	3.493	2.70	-	-	0.097	0.023	0.013	2.833	7.74	0.260
1991	186.1*	119.0	-	36.6*	30.5	11.039	3.451	2.88	-	-	0.116	0.027	0.013	3.036	8.29	0.275
1992	186.1*	119.0	-	36.6*	30.5	11.162	3.413	3.06	-	-	0.132	0.031	0.028	3.251	8.88	0.291
1993	186.1*	119.0	-	36.6*	30.5	11.279	3.378	3.24	-	-	0.151	0.035	0.044	3.470	9.48	0.307
1994	186.1*	119.0	-	36.6*	30.5	11.387	3.346	3.42	-	-	0.171	0.040	0.063	3.694	10.09	0.324
1995	186.1*	119.0	-	36.6*	30.5	11.488	3.316	3.60	-	-	0.192	0.044	0.082	3.918	10.70	0.341
1996	186.1*	119.0	-	36.6*	30.5	11.573	3.292	3.78	-	-	0.211	0.049	0.103	3.909	10.68	0.338
1997	186.1*	119.0	-	36.6*	30.5	11.654	3.269	3.96	-	-	0.230	0.054	0.126	4.370	11.94	0.375
1998	186.1*	119.0	-	36.6*	30.5	11.733	3.247	4.14	0.05	-	0.250	0.058	0.149	4.647	12.70	0.396
1999	186.1*	119.0	-	36.6*	30.5	11.808	3.227	4.32	0.05	-	0.273	0.063	0.175	4.881	13.33	0.413
2000	186.1*	119.0	-	36.6*	30.5	11.880	3.207	4.50	0.05	-	0.298	0.068	0.202	5.118	13.98	0.431

Notes:
1 Evapotranspiration is taken to be 0.64 times rainfall (Chindasaguan 1990)
2 Not including flow of the Mekong River
3 Balance = Rainfall - Evapotranspiration + Streamflow Imported - Streamflow Exported
4 Streamflow exported/population
5 Irrigation water use of all projects is about 1.3 times irrigation water use of RID projects
6 See more details in Table 27
7 Urban water supply by DPW is about 0.23 of that supplied by PWA (ADB 1988)
8 Total water use/population
* Long-term average value

Table 37. Forecast of water resources availability and water use in the Central Region of Thailand, 1990-2000

Year	*Water Resources Availability*							*Water Use*								
	Rainfall	*Evapo-transpira-tion*[1]	*Streamflow*		*Balance*[3]	*Popula-tion*	*Per Capita*[4]	*Irriga-tion*[5]	*Industry*[6]	*Urban Water Supply*			*Rural Water Supply*	*Total Water Use*	*% of Stream-Flow Exported*	*Per Capita*[8]
			Imported[2]	*Exported*						*MWA*	*PWA*	*DPW*[7]				
	$10^9m^3/yr$					*Million*	*$10^3m^3/yr$*	*$10^9m^3/yr$*								*$10^3m^3/yr$*
1990	91.0*	58.3	21.23	43.03*	10.9	14.249	3.020	22.20	1.497	0.943	0.071	0.017	0.010	24.738	57.49	1.736
1991	91.0*	58.3	21.23	43.03*	10.9	14.491	2.969	22.62	1.557	0.984	0.085	0.020	0.010	25.276	58.74	1.744
1992	91.0*	58.3	21.23	43.03*	10.9	14.734	2.920	23.04	1.618	1.025	0.097	0.023	0.022	25.825	60.01	1.752
1993	91.0*	58.3	21.23	43.03*	10.9	14.978	2.872	23.46	1.678	1.066	0.110	0.026	0.035	26.375	61.29	1.761
1994	91.0*	58.3	21.23	43.03*	10.9	15.222	2.827	23.88	1.737	1.107	0.127	0.029	0.050	26.930	62.58	1.769
1995	91.0*	58.3	21.23	43.03*	10.9	15.469	2.782	24.30	1.799	1.148	0.141	0.033	0.065	27.486	63.87	1.777
1996	91.0*	58.3	21.23	43.03*	10.9	15.753	2.731	24.72	1.858	1.192	0.155	0.036	0.082	28.043	65.16	1.780
1997	91.0*	58.3	21.23	43.03*	10.9	16.020	2.686	25.14	1.918	1.236	0.170	0.039	0.100	28.603	66.47	1.785
1998	91.0*	58.3	21.23	43.03*	10.9	16.270	2.645	25.56	1.978	1.281	0.184	0.043	0.118	29.164	67.77	1.793
1999	91.0*	58.3	21.23	43.03*	10.9	16.503	2.607	25.98	2.039	1.325	0.200	0.047	0.139	29.730	69.09	1.801
2000	91.0*	58.3	21.23	43.03*	10.9	16.719	2.574	26.40	2.099	1.369	0.219	0.050	0.161	30.298	70.41	1.812

Notes:

1 Evapotranspiration is taken to be 0.64 times rainfall (Chindasaguan 1990)

2 Not including flow of the Mekong River

3 Balance = Rainfall - Evapotranspiration + Streamflow Imported - Streamflow Exported

4 Streamflow exported/population

5 Irrigation water use of all projects is about 1.3 times irrigation water use of RID projects

6 See more details in Table 27

7 Urban water supply by DPW is about 0.23 of that supplied by PWA (ADB 1988)

8 Total water use/population

* Long-term average value

Table 38. Forecast of water resources availability and water use in the North-eastern Region of Thailand, 1990-2000

Year	*Water Resources Availability*							*Water Use*								
	Rainfall	*Evapo-transpira-tion*[1]	*Streamflow*		*Balance*[3]	*Popula-tion*	*Per Capita*[4]	*Irriga-tion*[5]	*Industry*[6]	*Urban Water Supply*			*Rural Water Supply*	*Total Water Use*	*% of Stream-Flow Exported*	*Per Capita*[8]
			Imported[2]	*Exported*						*MWA*	*PWA*	*DPW*[7]				
	$10^9 m^3/yr$					*Million*	$10^3 m^3/yr$	$10^9 m^3/yr$								$10^3 m^3/yr$
1990	239.3*	153.1	-	43.5*	42.7	19.450	2.236	3.00	-	-	0.105	0.025	0.026	3.155	7.25	0.162
1991	239.3*	153.1	-	43.5*	42.7	19.689	2.209	3.13	-	-	0.125	0.029	0.026	3.310	7.61	0.168
1992	239.3*	153.1	-	43.5*	42.7	19.928	2.183	3.26	-	-	0.143	0.033	0.055	3.491	8.02	0.175
1993	239.3*	153.1	-	43.5*	42.7	20.167	2.157	3.39	-	-	0.163	0.037	0.088	3.678	8.45	0.182
1994	239.3*	153.1	-	43.5*	42.7	20.404	2.132	3.52	-	-	0.185	0.043	0.123	3.871	8.89	0.189
1995	239.3*	153.1	-	43.5*	42.7	20.643	2.107	3.65	-	-	0.206	0.048	0.161	4.065	9.34	0.197
1996	239.3*	153.1	-	43.5*	42.7	20.864	2.085	3.78	-	-	0.227	0.053	0.202	4.262	9.79	0.204
1997	239.3*	153.1	-	43.5*	42.7	21.093	2.062	3.91	-	-	0.249	0.057	0.247	4.463	10.26	0.211
1998	239.3*	153.1	-	43.5*	42.7	21.331	2.039	4.04	0.05	-	0.270	0.063	0.293	4.716	10.84	0.221
1999	239.3*	153.1	-	43.5*	42.7	21.577	2.016	4.17	0.05	-	0.294	0.068	0.343	4.925	11.32	0.228
2000	239.3*	153.1	-	43.5*	42.7	21.832	1.992	4.30	0.05	-	0.320	0.074	0.396	5.140	11.82	0.235

Notes:

1 Evapotranspiration is taken to be 0.64 times rainfall (Chindasaguan 1990)

2 Not including flow of the Mekong River

3 Balance = Rainfall - Evapotranspiration + Streamflow Imported - Streamflow Fxported

4 Streamflow exported/population

5 Irrigation water use of all projects is about 1.3 times irrigation water use of RID projects

6 See more details in Table 27

7 Urban water supply by DPW is about 0.23 of that supplied by PWA (ADB 1988)

8 Total water use/population

* Long term average value

Table 39. Forecast of water resources availability and water use in the Eastern Region of Thailand, 1990-2000

Year	*Water Resources Availability*							*Water Use*								
	Rainfall	*Evapo-transpira-tion*[1]	*Streamflow*		*Balance*[3]	*Popula-tion*	*Per Capita*[4]	*Irriga-tion*[5]	*Industry*[6]	*Urban Water Supply*			*Rural Water Supply*	*Total Water Use*	*% of Stream-Flow Exported*	*Per Capita*[8]
			Imported[2]	*Exported*						*MWA*	*PWA*	*DPW*[7]				
	$10^9 m^3/yr$					*Million*	*$10^3 m^3/yr$*	*$10^9 m^3/yr$*								*$10^3 m^3/yr$*
1990	74.6*	47.7	-	21.2*	5.7	3.386	6.261	0.151	0.050	-	0.071	0.017	0.002	0.291	1.37	0.086
1991	74.6*	47.7	-	21.2*	5.7	3.432	6.117	0.163	0.054	-	0.084	0.019	0.002	0.322	1.52	0.094
1992	74.6*	47.7	-	21.2*	5.7	3.479	6.094	0.176	0.058	-	0.095	0.022	0.005	0.356	1.68	0.102
1993	74.6*	47.7	-	21.2*	5.7	3.527	6.011	0.188	0.062	-	0.109	0.025	0.008	0.392	1.85	0.111
1994	74.6*	47.7	-	21.2*	5.7	3.577	5.927	0.200	0.066	-	0.124	0.029	0.012	0.431	2.03	0.120
1995	74.6*	47.7	-	21.2*	5.7	3.627	5.845	0.213	0.070	-	0.138	0.032	0.016	0.469	2.21	0.129
1996	74.6*	47.7	-	21.2*	5.7	3.686	5.751	0.225	0.074	-	0.152	0.035	0.020	0.506	2.39	0.137
1997	74.6*	47.7	-	21.2*	5.7	3.742	5.665	0.238	0.078	-	0.166	0.038	0.024	0.544	2.57	0.145
1998	74.6*	47.7	-	21.2*	5.7	3.795	5.586	0.250	0.082	-	0.180	0.042	0.028	0.582	2.74	0.153
1999	74.6*	47.7	-	21.2*	5.7	3.846	5.512	0.263	0.086	-	0.197	0.045	0.033	0.624	2.94	0.162
2000	74.6*	47.7	-	21.2*	5.7	3.895	5.443	0.275	0.090	-	0.214	0.049	0.038	0.666	3.14	0.171

Notes:

1 Evapotranspiration is taken to be 0.64 times rainfall (Chindasaguan 1990)

2 Not including flow of the Mekong River

3 Balance = Rainfall - Evapotranspiration + Streamflow Imported - Streamflow Exported

4 Streamflow exported/population

5 Irrigation water use of all projects is about 1.3 times irrigation water use of RID projects

6 See more details in Table 27

7 Urban water supply by DPW is about 0.23 of that supplied by PWA (ADB 1988)

8 Total water use/population

* Long term average value

Table 40. Forecast of water resources availability and water use in the Southern Region of Thailand, 1990-2000

Year	*Water Resources Availability*							*Water Use*								
	Rainfall	*Evapo-transpira-tion*[1]	*Streamflow*		*Balance*[2]	*Popula-tion*	*Per Capita*[3]	*Irriga-tion*[4]	*Industry*[5]	*Urban Water Supply*			*Rural Water Supply*	*Total Water Use*	*% of Stream-Flow Exported*	*Per Capita*[7]
			Imported	*Exported*						*MWA*	*PWA*	*DPW*[6]				
	$10^9 m^3/yr$					*Million*	$10^3 m^3/yr$	$10^9 m^3/yr$								$10^3 m^3/yr$
1990	179.0*	114.6	-	75.7*	-11.3	8.346	9.070	2.0	-	-	0.081	0.019	0.009	2.109	2.79	0.253
1991	179.0*	114.6	-	75.7*	-11.3	8.544	8.860	2.1	-	-	0.097	0.022	0.009	2.228	2.94	0.261
1992	179.0*	114.6	-	75.7*	-11.3	8.737	8.664	2.2	-	-	0.110	0.026	0.019	2.355	3.11	0.269
1993	179.0*	114.6	-	75.7*	-11.3	8.923	8.484	2.3	-	-	0.126	0.029	0.031	2.486	3.28	0.278
1994	179.0*	114.6	-	75.7*	-11.3	9.103	8.315	2.4	-	-	0.144	0.033	0.043	2.620	3.46	0.288
1995	179.0*	114.6	-	75.7*	-11.3	9.278	8.159	2.5	-	-	0.160	0.037	0.057	2.754	3.64	0.296
1996	179.0*	114.6	-	75.7*	-11.3	9.435	8.023	2.6	-	-	0.176	0.041	0.071	2.888	3.82	0.306
1997	179.0*	114.6	-	75.7*	-11.3	9.591	7.893	2.7	-	-	0.193	0.045	0.087	3.025	4.00	0.315
1998	179.0*	114.6	-	75.7*	-11.3	9.748	7.766	2.8	0.05	-	0.209	0.048	0.103	3.210	4.24	0.329
1999	179.0*	114.6	-	75.7*	-11.3	9.095	7.642	2.9	0.05	-	0.228	0.052	0.121	3.351	4.43	0.338
2000	179.0*	114.6	-	75.7*	-11.3	10.063	7.522	3.0	0.05	-	0.248	0.057	0.140	3.495	4.62	0.347

Notes:

1 Evapotranspiration is taken to be 0.64 times rainfall (Chindasaguan 1990)

2 Balance = Rainfall - Evapotranspiration + Streamflow Imported - Streamflow Exported

3 Streamflow exported/population

4 Irrigation water use of all projects is about 1.3 times irrigation water use of RID projects

5 See more details in Table 27

6 Urban water supply by DPW is about 0.23 of that supplied by PWA (ADB 1988)

7 Total water use/population

* Long-term average value

B. Analysis of water resources availability and water use, 1980-1989

The variations of annual water resources availability and annual water use in the different regions and in the whole country during 1980-1989 are shown in figures 25 and 26. In figure 25, the absolute annual volumes of water resources are shown and they are found to be approximately constant except in the northern and central regions where a decreasing trend can be observed. In figure 26, the per capita annual volumes of water resources availability in m^3/yr are shown and they are found to have a decreasing trend in the northern and central regions. The southern region is found to have the highest per capita water resources availability followed in descending order by the eastern, northern, central and north-eastern regions.

In general, the annual variations of water resources availability in the central, north-eastern and northern regions fluctuate less than those of the southern and eastern regions. This is due to less fluctuations of annual rainfall and streamflow in these regions. The annual rainfall in the north-east has nearly the same magnitude as in the central region, however due to high infiltration and evaporation in the north-eastern region, the rainfall-run-off ratio is the lowest in the country. The southern and eastern regions have large fluctuations of annual rainfall and streamflow and hence large fluctuations in the water resources amount.

The average annual absolute and per capita water resources availability and their increasing/decreasing rates for the past period 1980-1989 are given in tables 41 and 42, respectively. In table 42, it can be seen that the decreasing rates of the annual water resources availability in the northern and central regions are more significant than the other regions where there is practically no change.

In terms of the per capita water resources availability, the decreasing rate is significant in the southern, eastern, northern and central regions due to the increase in population and in the water use such as farming activities especially in the northern and central regions.

For the water use during 1980-1989, the absolute and per capita water use as shown in figures 25 and 26 increase almost linearly with time in all the regions. It can be seen from both figures that the central and northern regions have the highest and second highest increasing rates of absolute and per capita water use due to increases in farming activities and urban development. The average annual water use and its increasing rate during 1980-1989 in each region and in the whole country are shown in tables 41 and 42, respectively. The central region has the highest per capita water use followed by the southern, northern, north-eastern and eastern regions, respectively. From table 42, the average increasing rate of per capita annual use of the northern region is found to be the highest followed by the central, southern, eastern and north-eastern regions, respectively. It is important to remark that in the eastern region, the increasing rate of consumptive water use in 1988-1989 is much more than the average value during 1980-1989 due to the implementation of the eastern seaboard industrial projects. The central region which has the highest per capita water use is likely to face water shortage in the near future (figure 25). For example in 1989, the water use was nearly 2,000 m^3/capita/yr, while the water resources availability was only 3,000 m^3/capita/yr.

C. Forecast of water resources availability and water use, 1990-2000

The forecast of water resources availability and water use in the different regions of Thailand and the whole country during 1990-2000 is shown in figure 25 in terms of the annual volume and in figure 26 for the per capita annual volume, respectively. In the forecast of the total and per capita water resources availability, the long-term average values of rainfall and streamflow are used in the computation. As shown in figure 25, the forecast annual water resources availability in each region is constant with time. This is because the constant values of the long-term average annual rainfall and streamflow are used in the forecast. The forecasting of the per capita water resources availability and water use is based on the estimation of annual population obtained from the population forecast by the National Economic and Social Development Board (NESDB 1985).

It is found that the forecast per capita water resources availability decreases almost linearly with time. Tables 41 and 42 show the average values of the forecast absolute and per capita annual water resources availability in the different regions and the whole country area and their decreasing rates. From table 41, the southern region has the highest per capita water resources availability followed by the eastern, northern, central and north-eastern regions. Table 42 shows that the southern region has the highest decreasing rate of the per capita water resources availability due to a rapid increase in its population followed by the eastern, central, northern and north-eastern regions.

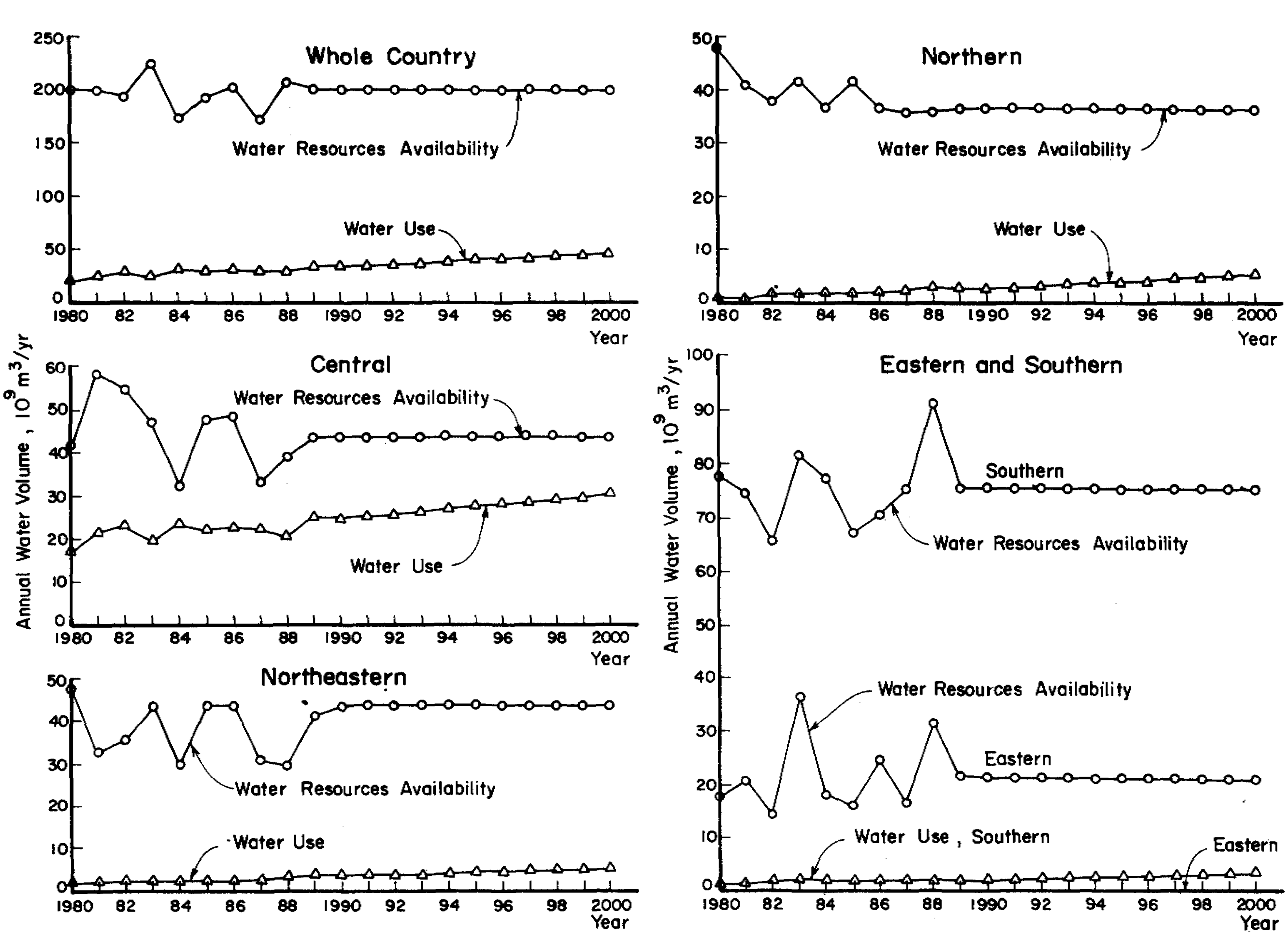


Figure 25. Annual water resources availability and water use in the different regions of Thailand: previous records 1980-1989 and forecast data 1990-2000

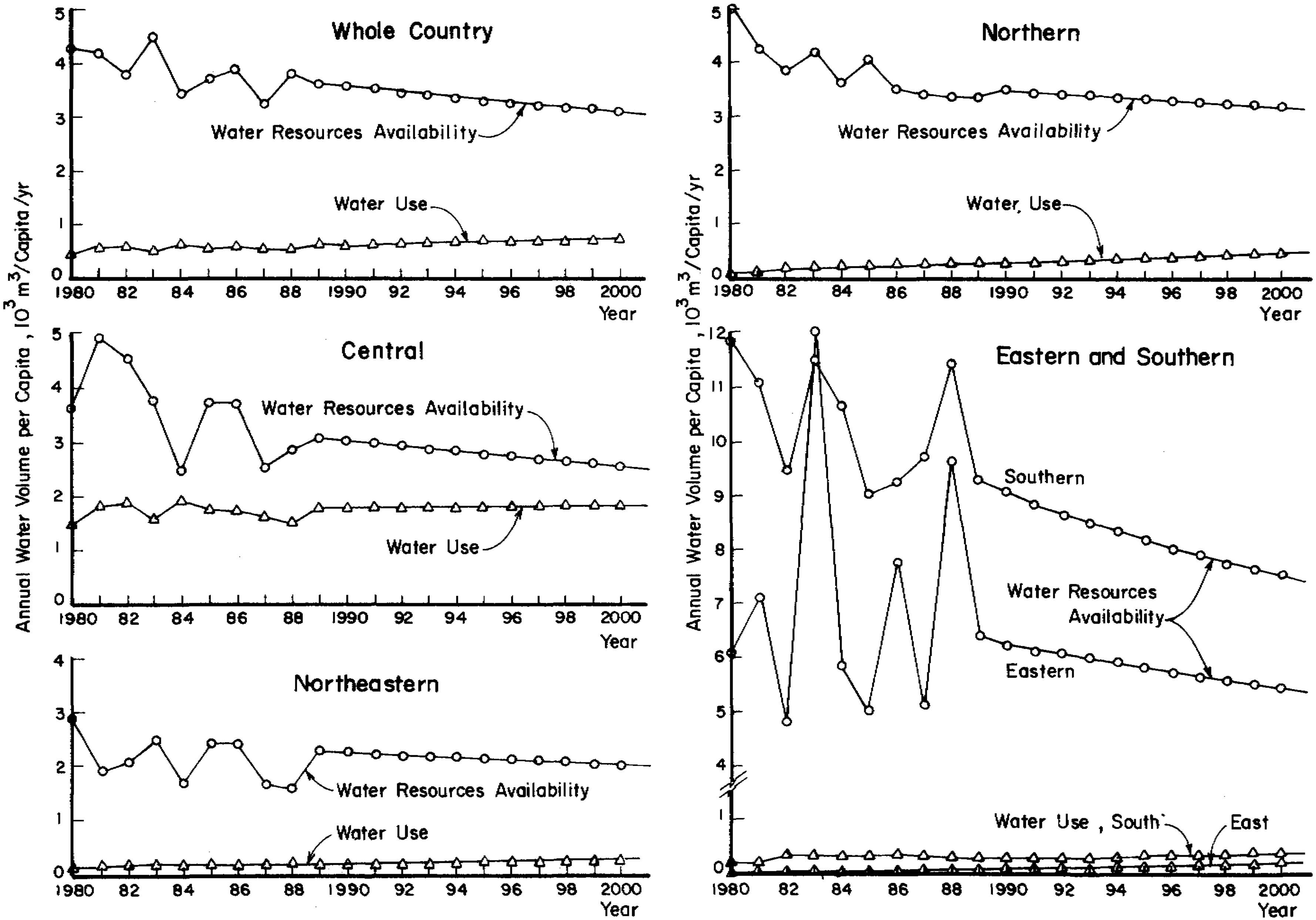


Figure 26. Per capita annual water resources availability and water use in the diferent regions of Thailand: previous records 1980-1989 and forecast data 1990-2000

Table 41. Average annual water resources availability and water use in Thailand by region during the period 1980-1989 and forecast period 1990-2000

Region	*Volume*				*Per Capita Volume*			
	Average Annual Water Resources		*Average Annual Water Use*		*Average Annual Water*		*Average Annual Water Use*	
	10^9 m^3/yr		*10^9 m^3/yr*		*10^3 m^3/yr*		*10^3 m^3/yr*	
	1980-1989	*1990-2000*	*1980-1989*	*1990-2000*	*1980-1989*	*1990-2000*	*1980-1989*	*1990-2000*
Northern	38.88	36.60	1.836	3.921	3.866	3.331	0.179	0.341
Central	44.46	43.03	21.587	27.497	3.512	2.785	1.691	1.774
North-eastern	37.84	43.50	2.460	4.098	2.130	2.111	0.137	0.197
Eastern	21.50	21.20	0.143	0.471	6.960	5.838	0.046	0.128
Southern	75.64	75.70	1.565	2.775	9.394	8.218	0.263	0.298
Whole Country	194.48	198.80	27.567	38.785	3.814	3.317	0.538	0.640

Table 42. Average annual changing rate of water resources availability and water use in Thailand by region during the period 1980-1989 and forecast period 1990-2000

Region	*Increasing/Decreasing Rate*				*Increasing/Decreasing Rate*			
	Annual Water Resources		*Annual Water Use*		*Annual Water Resources*		*Annual Water Use*	
	Absolute Volume				*Per Capita Volume*			
	10^9 m^3/yr		*10^9 m^3/yr*		*10^3 m^3/yr*		*10^3 m^3/yr*	
	1980-1989	*1990-2000*	*1980-1989*	*1990-2000*	*1980-1989*	*1990-2000*	*1980-1989*	*1990-2000*
Northern	-1.250	0	0.20	0.235	-0.030	-0.029	0.015	0.017
Central	-1.429	0	0.50	0.533	-0.030	-0.035	0.010	0.010
North-eastern	0	0	0.133	0.200	-0.011	-0.024	0.004	0.007
Eastern	0	0	0.020	0.125	-0.080	-0.084	0.006	0.008
Southern	0	0	0.100	0.125	-0.089	-0.160	0.007	0.009
Whole Country	-0.20	0	1.091	1.160	-0.025	-0.025	0.007	0.011

Tables 41 and 42 also show the forecast total and per capita annual water use and their increasing rates. It is found that the forecast water use and per capita use and their increasing rates are larger than those of the 1980-1989 values. The central region has the highest forecast per capita annual water use followed by the northern, southern, north-eastern and eastern regions. For the increasing rate of the forecast per capita water use, the northern region has the highest increasing rate followed in descending order by the central, southern, eastern and north-eastern regions.

Comparing the per capita values of water resources availability and water use in each region, it can be seen that by the year 2000 the amount of the per capita water use in the central region would reach 70 per cent of the per capita water resources availability. This would be critical and it is important that additional sources of water supply for the central region should be sought as soon as possible, while the efficiency of water use should be improved to obtain the maximum benefit. The Kok-Ing-Yom northern transbasin diversion project is under investigation by the Electricity Generating Authority of Thailand as one possibility to add more water supply from the Mekong river to the Chao Phraya river basin in the central region. This project would take a number of years to carry out before its operation can start.

In the eastern region, figures 25 and 26 show that the water resources availability is much larger than the water use. However, in the real situation, in the past few years the industrial development and the population are facing water shortage. This is because the existing storage capacity of reservoirs is not sufficient to store the available streamflow volume for use in dry seasons. RID is constructing more reservoirs in the eastern region to solve this problem.

V. CONCLUSIONS

A. General

For the purpose of assessment of annual water resources availability and water uses by various sectors, the country area of Thailand is divided into 5 hydrological regions, namely: northern, central, north-eastern, eastern and southern regions. The annual water resources availability is defined as annual volume of streamflow exported from each region. There are two main types of water use, namely : water use with withdrawal of water from its sources and non-consumptive or in-stream water use.

The period of the analysis is from 1980 to 1989 for the past period and from 1990 to 2000 for the forecast period. In the analysis of water resources availability, the annual rainfall, evapotranspiration, streamflow imported and exported are considered. In the computation of the past period 1980-1989, the annual rainfall and streamflows of each region are the measured field data. In the forecast period 1990-2000, the long-term average values of annual rainfall and streamflows are used. The data on the irrigation water uses in each region during 1980-1989 obtained from the Royal Irrigation Department have been extrapolated for the forecast period 1990-2000. For the industrial water use, the past data and forecast data of each region are available from the previous studies by the Metropolitan Water Works Authority (MWA), the Industrial Estate Authority of Thailand (IEAT) and the Thailand Development Research Institute (TDRI). The nationwide data on urban water supply during the past and forecast periods are available for certain years from the previous studies by the MWA, the Provincial Water Works Authority (PWA), and the Department of Public Works (DPW). These urban water supply data are interpolated and extrapolated to obtain annual values and they are distributed regionally according to the urban area of each region. For the rural water supply, the nationwide data are available for some years during the past and forecast periods from the study by ADB (1988). These data are interpolated and extrapolated to obtain annual data and they are distributed regionally according to the areas of sanitary districts in each region.

B. Water resources availability and water use

According to the results of this study, the water resources availability and water use in the different regions can be summarized as follows:

1) Northern Region : Rapid urbanization and increase in population and in farming activities significantly increase the water use and reduce the streamflow exported to the central region. In the northern region water use increased from 87 m^3/capita/yr in 1980 to 257 m^3/capita/yr in 1989.

2) Central Region : The central region has a significant decreasing trend in the water resources availability due to reduction in the streamflow from the north, e.g., of 3,618 m^3/capita/yr in 1980 to 3,073 m^3/capita/yr in 1989. The central region has only few small storage reservoirs the combined storage capacity of which is not very significant compared to the volume of streamflow imported into the region or the volume of water use there. The central region has the highest water use in the country, e.g. 1,777 m^3/capita/yr in 1989. It is forecast that in the year 2000, the water use will reach 1,812 m^3/capita/yr or 70 per cent of the water resources availability of 2,574 m^3/capita/yr. It is most likely that the central region will face water shortage in the near future. Some water transbasin diversion projects have been proposed in order to add more water supply to the Chao Phraya river basin in the central region.

3) Eastern Region : It is found that the water resources availability in the eastern region is much larger than the water use. However, due to lack of reservoirs, the streamflow cannot be stored and it is mainly discharged to the sea. Though the agricultural activities are not pronounced in this region, the industrial and urban development from 1988 to present is very significant and requires substantial amount of water supply. The average per capita water use in this region is the lowest in the country, e.g., in 1989 it was 59 m^3/yr. However, local shortage of water supply for industry and for domestic uses exists. RID is constructing more reservoirs to meet this shortage.

4) Southern Region : This region has the highest water resources availability due to heavy rainfall, e.g., of 7,570 million m^3/yr or 9,276 m^3/capita/yr in 1989. The annual fluctuation of the water resources availability is much larger than the central, northern or north-eastern regions due to large fluctuation of annual rainfall. A typical figure of annual water use in the southern region is rather low, but still higher than in the eastern and north-eastern regions, e.g., of 258 m^3/capita/yr in 1989. This is mainly due to the fact that only small amount of water is

required for irrigation in this region. The main agricultural land is mostly rainfed. Therefore, there is no water shortage in the south.

5) North-eastern Region : The amount of rainfall in the north-eastern region is nearly the same as in the central or northern region. However, the rainfall distribution is rather uneven in time and space in which a drought period of 5 to 7 weeks could occur frequently and cause severe crop damages. Due to high infiltration rate and lack of suitable reservoir storage sites and large population, the per capita water resources availability of the north-eastern region is the lowest in the country, e.g., 2,267 m^3/yr in 1989. The north-eastern region has the second lowest water use rate after eastern region, e.g., of 173 m^3/capita/yr in 1989. By comparing the water resources availability and water use, the north-eastern region has its water resources availability much far above its water use. However, in actual situation, there is local shortages of water supply for water use in some areas especially during the dry season. This is mainly due to lack of sufficient reservoir storages in the north-eastern region. RID has constructed many storage tanks (small ponds or small reservoirs) in this region to store water for use during the dry period. However, more storage tanks or small reservoirs are still needed for dry season irrigation and domestic water uses to cover up this shortage. The soil salinity, high infiltration rate and poor soil quality in the north-east are the main factors because of which more water is required to improve the soil condition and increase the agricultural production.

6) On the overall average, Thailand has sufficient water resources, for example, as much as 3,585 m^3/capita/yr in 1989 and 3,109 m^3/capita/yr in 2000. The per capita annual water use is estimated to be 598 m^3/yr in 1989 and 695 m^3/yr in 2000, this is comparatively much lower the water resources availability. However, in some regions, such as the north-east and east, localized water supply shortages occur frequently mainly due to lack of sufficient storages. The central region is most likely to face water shortage in the near future due to decreasing of streamflow from the northern region and the increase of the population in the central and northern regions.

C. Non-consumptive water use

The non-consumptive water use is for hydropower, inland navigation, aquaculture and recreation. The average annual volume of water use for hydro power generation in Thailand during 1985-1989 was 28,187 million m^3/yr (table 22). In 1990, the annual volume of water use was 37,850 million m^3. The availability of water for hydro power generation would mainly depend on the streamflow at the water use location, the project reservoir capacity, the annual inflow volume to the reservoir and the intervening flows. The National Energy Administration of Thailand predicts that the annual water demand for hydro power generation would increase to 61,330 million m^3 in 1995 and 83,580 million m^3 in 2000 (table 28).

For inland navigation in the Chao Phraya river and the Nan river, based on the existing width of navigation channel of 40 m, the minimum required depth for navigation is 1.7 m. The discharge requirement and its equivalent flow volume in the different reaches of the rivers (figure 22) are as follows : 70 m^3 (2,270.5 million m^3/yr) for the Nan river from the Phrom Phiram dam to Nakhon Sawan; 300 m^3/s (9,460 million m^3/yr) for the Chao Phraya river from Nakhon Sawan to the Chao Phraya dam and 80 m^3/s (2,522.8 million m^3/yr) for the Chao Phraya river from the Chao Phraya dam to Ang Thong.

At present, these minimum flows cannot be maintained due to large amount of diversion of water from the rivers for dry season irrigation in the northern and central regions. This greatly reduced the volume of inland waterway transport by about 5 times in the last 12 years (from 1978 to 1989). This matter is unresolved so far. The Harbour Department of Thailand has proposed a river bed dredging and a navigation channel improvement scheme along the above mentioned river reaches. The construction of barrages is also proposed to increase the flow depth along the Chao Phraya river from the Chao Phraya dam to Ang Thong to meet the minimum required depth of 1.7 m.

For the freshwater aquaculture, the water requirement is comparatively small compared to the other non-consumptive uses. The freshwater aquaculture is mainly practiced in the central region of Thailand in the form of pond culture and paddy field culture. The volume of water demand for freshwater aquaculture in 1989 was about 250 million m^3 for pond culture and 100 million m^3 for paddy field culture. It is forecast in this study that the water volume required for freshwater aquaculture in the year 2000 would be about 450 million m^3 for pond culture and 150 million m^3 for paddy field culture (figure 24).

As for recreation, the volume of water in the reservoirs is not controlled for recreational purpose but depends on the requirements for hydro power generation, downstream irrigation, water supply for domestic and industrial uses, navigation and salinity control. In the past there were no water shortage problems for the recreational purpose. The same situation is expected in the future.

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ANNEX

Table 43. Summary of groundwater resources, yields, groundwater quality and groundwater use in Thailand

Physiographic Region and Major Aquifers	*Location*	*Depth (m)*	*Thickness (m)*	*Yield (m^3/hr)*	*Drawdown (m)*	*Water Quality,*	*Groundwater Use*
1. Northern Highlands							
Alluvium Deposits	Chiang Mai, Lam Pang, Mae Chan, Phrae	Shallow 50		25 50	< 10	Good	Drinking Domestic Agriculture Industry
Old Terrace Deposits		200		150-200	30		
2. Upper Central Plain							
Alluvium Deposits	Flood Plains of Ping, Wang, Yom and Nan	60		10-70		Potable	Drinking Domestic Agriculture
Old Terrace Deposits	North and West of the above Flood Plains and Underneath		200-300	250		Good	
3. Lower Central Plains		(At DMR)					
- Bangkok		0-50					
- Phra Pradaeng		50-100				Good but Saline at Some Locations	Domestic Industry
- Nakhon Luang	Flood Plains of Chao Phraya, Tha Chin, Bang Pakong and their Tributaries (Area: 150 km x 200 km)	100-160					
- Nonthaburi		160-250	About 50-80 for each	300+ ~ 400	50		
- Sam Khok		250-300					
- Phya Thai		300-360				Good	Industry
- Thon Buri		360-450					
- Pak Nam		450-550					
4. Khorat Plateau							
- Upper Khorat Aquifer	Under flood plains (heavily populated areas)					Saline	Domestic Agriculture
	In Areas of Higher Elevations	60		5-50		with Sulphate Content	

Table 43. *(continued)*

Physiographic Region and Major Aquifers	*Location*	*Depth (m)*	*Thickness (m)*	*Yield (m^3/hr)*	*Drawdown (m)*	*Water Quality*	*Groundwater Use*
Lower Khorat Aquifer	Near Phu Phan Range		30-60	5-25		Good	
	West Side of Plateau			10-100		Good	Domestic Agriculture
	Northwest			20			
	Chi and Mun		50	25		Saline	
	Mekong River Bank						
5. Mae Klong Basin	Floodplains of Mae Klong River from Kanchanburi to River Mouth	Shallow (Jetted)	40				Agriculture
Shallow Unconfined Alluvium Aquifer							
6. South Peninsular							
Coastal Aquifers	Nakhon Srithammarat to Narathiwat (East Coast) 450 km x 22 km	Shallow		10-200			Drinking Domestic
7. Eastern Provinces							
Alluvium and Terrace Deposits	Cholburi, Rayong, Chanthaburi and Trat	Shallow		7-10		Potable	Drinking Domestic
Limestone Aquifer	Near Cambodian Border	Shallow		10-20		Potable	

Source: United Nations Publication, Natural Resources/Water Series No.15 (1986)

\+ Actual pumping rate is much more than safe yield

Table 44. Pump irrigation in various regions of Thailand under the National Energy Administration (NEA)

Region	*Expenditure (Million Baht) and Pumped Volume (mcm)*	*1983*		*1984*		*1985*		*1986*		*1987*		*1988*		*1989*	
		Dry	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*
Northern	Expenses	2.393	4.236	5.224	7.545	7.614	9.035	6.368	12.383	9.101	15.304	14.803	15.066	18.802	18.799
	Water Volume	18.59	32.91	40.71	58.62	59.16	70.20	49.62	96.22	70.71	118.91	115.02	117.06	146.10	146.06
North-eastern	Expenses	12.681	2.855	14.067	2.984	13.073	3.685	9.210	6.049	11.042	10.658	16.679	9.204	18.322	8.658
	Water Volume	98.53	22.18	109.30	23.18	101.58	28.63	71.56	47.00	85.79	83.12	129.60	71.51	142.36	67.27
Central and Eastern	Expenses	0.783	1.063	1.191	1.847	2.678	1.368	2.136	1.808	2.283	3.182	3.549	2.224	5.594	3.563
	Water Volume	6.08	8.26	9.25	14.35	20.80	10.63	16.60	14.05	17.74	24.72	27.57	17.28	43.46	27.68
Southern	Expenses	0	0.037	0.019	0.111	0.165	0.072	0.189	0.213	0.251	0.389	0.244	0.397	0.597	0.570
	Water Volume	0	0.29	0.15	0.86	1.28	0.56	1.47	1.65	1.95	3.02	1.89	3.08	4.64	4.43
Total	Expenses	15.857	8.191	20.500	12.487	23.530	14.160	17.921	20.453	22.677	29.573	35.275	26.891	43.315	31.590
	Water Volume	123.20	63.64	159.41	97.01	182.82	110.02	139.25	158.92	176.19	229.77	274.08	208.93	336.56	245.44

Source: Data from NEA (1990)

Table 45. Number of pump stations for irrigation under the National Energy Administration, Thailand

Region \ Year	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
1. North-eastern	13	1	13	14	13	32	97	27	35	33	20	15	9	17	33	40
2. Northern	0	0	0	0	0	5	26	37	24	22	10	16	4	30	30	37
3. Central and Eastern	0	0	0	0	0	0	7	13	13	14	0	12	2	13	12	16
4. Southern	0	0	0	0	0	0	0	3	10	9	3	7	1	26	4	15
Number of Pump Stations Installed Each Year	13	1	13	14	13	37	130	80	82	78	33	50	16	86	79	108
Total Number of Pump Stations	13	14	27	41	54	91	221	301	383	461	494	544	560	646	725	833

Source: Data from NEA (1990)

Table 46. Water supply facilities in rural areas of Thailand in terms of shallow wells, deep wells, piped water supply systems and surface water sources in 1983

Sources		Shallow Well		Deep Well		Piped Water Supply		Surface Water		Total	
		Total Number	Adequate Sources	Total Number	Adequate Sources	Total Number	Adequate Sources	Total Number	Adequate Sources	Total Number	Adequate Sources
Public	Sanitary	1,651	1,031	2,633	2,070	298	296	-	-	4,582	3,397
	Non-Sanitary	11,151	7,454	-	-	-	-	13,993	7,131	25,144	14,585
	Total	12,802	8,485	2,633	2,070	298	296	13,993	7,131	29,726	17,982
Non-Public	Sanitary	15,509	12,752	12,643	10,759	2,821	2,820	-	-	30,973	24,331
	Non-Sanitary	83,442	63,845	-	-	-	-	-	-	83,442	63,845
	Total	98,951	76,579	12,643	10,759	2,821	2,820	-	-	114,415	90,176
Total Sanitary		17,100	13,783	15,276	12,829	3,119	3,116	-	-	35,555	29,728
Total Non-Sanitary		94,593	71,299	-	-	-	-	13,993	7,131	108,586	78,430
Grand Total		111,753	85,082	15,276	12,829	3,119	3,116	13,993	7,131	144,141	108,158

Source: Asian Institute of Techno'ɔgy (1985)

Table 47. Water supply facilities in rural areas of Thailand in terms of shallow wells, deep wells and piped water supply systems and surface water sources in 1988

Sources		*Shallow Well*		*Deep Well*		*Piped Water Supply*		*Surface Water*		*Total*	
		Adequate	*Inadequate*	*Adequate*	*Inadequate*	*Adequate*	*Inadequate*	*Adequate*	*Inadequate*	*Adequate*	*Inadequate*
Public	Sanitary	11,023	-	20,541	-	1,168	-	-	-	32,732	-
	Non-Sanitary	78,183	-	37,135	-	2,045	-	74,556	-	191,919	-
	Total	89,206	43,467	57,676	15,091	3,213	804	74,556	70,915	224,651	130,277
Non-Public	Sanitary	123,705	-	27,826	-	7,934	-	-	-	159,465	-
	Non-Sanitary	598,970	-	52,793	-	14,679	-	-	-	666,442	-
	Total	722,675	218,529	80,619	14,056	22,613	5,653	-	-	825,907	238,238
Total Sanitary		134,728	-	48,376	-	9,102	-	-	-	192,197	-
Total Non-Sanitary		677,153	-	89,928	-	16,724	-	74,556	-	858,361	-
Grand Total		811,881	261,996	138,295	29,147	25,826	6,457	74,556	70,915	1,050,558	368,515

Source: ADB (1988)

Table 48. PWA regional offices, design capacities, in-used capacities and the population served (as of 1986)

Regional Office	Design Capacity (m^3/day)	Capacity In-Used (m^3/day)	Population Served
1. Chonburi	160,080	128,880	487,240
2. Saraburi	153,600	144,000	515,320
3. Bangkok	71,040	69,360	388,170
4. Surat Thani	64,800	61,680	268,640
5. Songkhla	106,080	92,400	507,830
6. Khon Kaen	85,920	83,280	588,890
7. Udon Thani	73,680	65,040	410,650
8. Ubol Ratchathani	88,200	84,840	510,170
9. Chiang Mai	157,920	148,080	651,520
10. Nakhon Sawan	76,080	68,400	408,830
Total	1,037,400	945,960	4,737,260

Source: ADB (1988)

Table 49. Partial list of concessional water works for urban areas (under supervision of DPW)

Waterworks Municipality	Capacity (m^3/d)	Population in Service Area	Number of Connections	Service Area,(km^2)
17 Muangs	168,080	946,559	112,439	214.98
16 Tambons	29,662	231,401	24,063	294.57
50 Sanitary Districts	39,312	364,087	24,611	351.79
Total	237,054+			

Source: ADB (1988)

\+ Equivalent to about 23% of PWA total design capacity

Table 50. Installed capacities and energy generation of hydro power and overall power systems in Thailand

Year	*Installed Capacity*		*Energy Generation*	
	Hydro MW	*Total MW*	*Hydro* GWh*	*Total GWh*
1979	910	2,963	3,263.3	13,443.0
1980	1,270	3,448	1,273.0	14,426.0
1981	1,361	4,008	2,974.3	15,377.3
1982	1,519	4,403	3,836.5	16,619.9
1983	1,501	5,032	3,689.8	18,856.6
1984	1,714	6,128	4,081.4	21,024.6
1985	2,004	6,705	3,692.2	23,074.4
1986	2,096	6,785	5,554.4	24,716.8
1987	2,256	6,985	4,075.3	28,652.2
1988	2,268	6,997	3,779.0	32,464.4

Source : NEA (1988)

* By comparing with the total energy generation, it is found that the average percentage of hydro power generation is about 17.8% of the total energy generation.

Table 51. Hydro power projects of EGAT under power development plan, feasibility study and pending.

PROJECT	LOCATION	INSTALLED CAPACITY (MW)	AVERAGE ANNUAL ENERGY (GWh)
TEN PROJECTS IN EGAT POWER DEVELOPMENT PLAN 1988-2001			
1. Srinagarind #5 (Reversible Pump Turbine)	Kanchanaburi	180	113
2. Bhumibol Hydro Power Plant Renovation (Unit 1 & 2)	Tak	11*	39
3. Pak Mun	Ubon Ratchathani	136	280
4. Kaeng Krung	Surat Thani	80	178
5. Mae Taeng	Chiang Mai	26	112
6. Lower Mae Ping	Tak	40	207
7. Bhumibol # 8	Tak	178**	259
8. Sirikit Stage 3 (#4)	Uttaradit	125 + 15	65
9. Nam Khek	Phitsanulok	120	313
10. Nam Chem	Phetchabun	400	901
	Sub Total	1,311	2,467
FOUR PROJECTS UNDER FEASIBILITY STUDY			
11. Loei - Upper Pasak			
- Nam Man	Loei	32	67
- Nam San	Loei	52	113
- Upper Pasak (Conventional)	Phetchabun	30	62
- Upper Pasak (Pumped Storage)		600	420
12. Kok - Yom Diversion			
- Mae Kok	Chiang Rai	48	194
- Kaeng Sua Ten***	Phrae	130	524
- Riang	Phayao	32	122
- Pong 2	Phayao	96	376
13. Sai Buri	Narathiwat	50	125
14. Nam Yuam			
- Lower Nam Yuam	Mae Hong Son	208	468
- Nam Ngao	Mae Hong Son	116	245
	Sub Total	1,394	2,716
FIVE PENDING PROJECTS			
15. Kud (Sop Kai)	Chiang Mai	67	240
16. Ing-Yom Diversion ***	Chiang Rai		
and Kaeng Sua Ten***		120	353
Nam Phae & Riang		102	283
17. La Ngu	Satun	30	58
18. Nam Pai	Mae Hong Son	225	547
19. Upper Quai Yai (Nam Chon)	Kanchanaburi	580	1,168
	Sub Total	1,124	2,649
	TOTAL	3,829	7,8322

Source: Hydroelectric Project in Power Development Plan, EGAT (1990)

* Increasing of 5.4 MW each from the former 70 MW and increasing average energy of 19.5 GWh each from the former 180 GWh

** Reversible Pump Turbine

*** Installed capacity and average energy will be 230 MW and 775 GWh respectively, if Kok-Yom and Ing-Yom Diversion Projects are developed.

Table 52. Existing and potential hydro power installed capacities of EGAT by region

Region	*Capacity*					
	Existing		*Potential*		*Total*	
	(MW)	*(%)*	*(MW)*	*(%)*	*(MW)*	*(%)*
Northern	930.0	41.2	2,060.9	43.0	2,990.9	42.3
Central and Eastern	909.2	40.3	1,592.7	33.1	2,501.9	35.5
Northeastern	107.2	4.7	499.3	10.4	606.5	8.6
Southern	312.0	13.8	645.6	43.0	957.6	13.6
Total	2,258.4	100.0	4,798.5	100.0	7,056.9	100.0

Source: Hydro power potential in Thailand, EGAT (1990)

* There is no hydro power plant in the east.

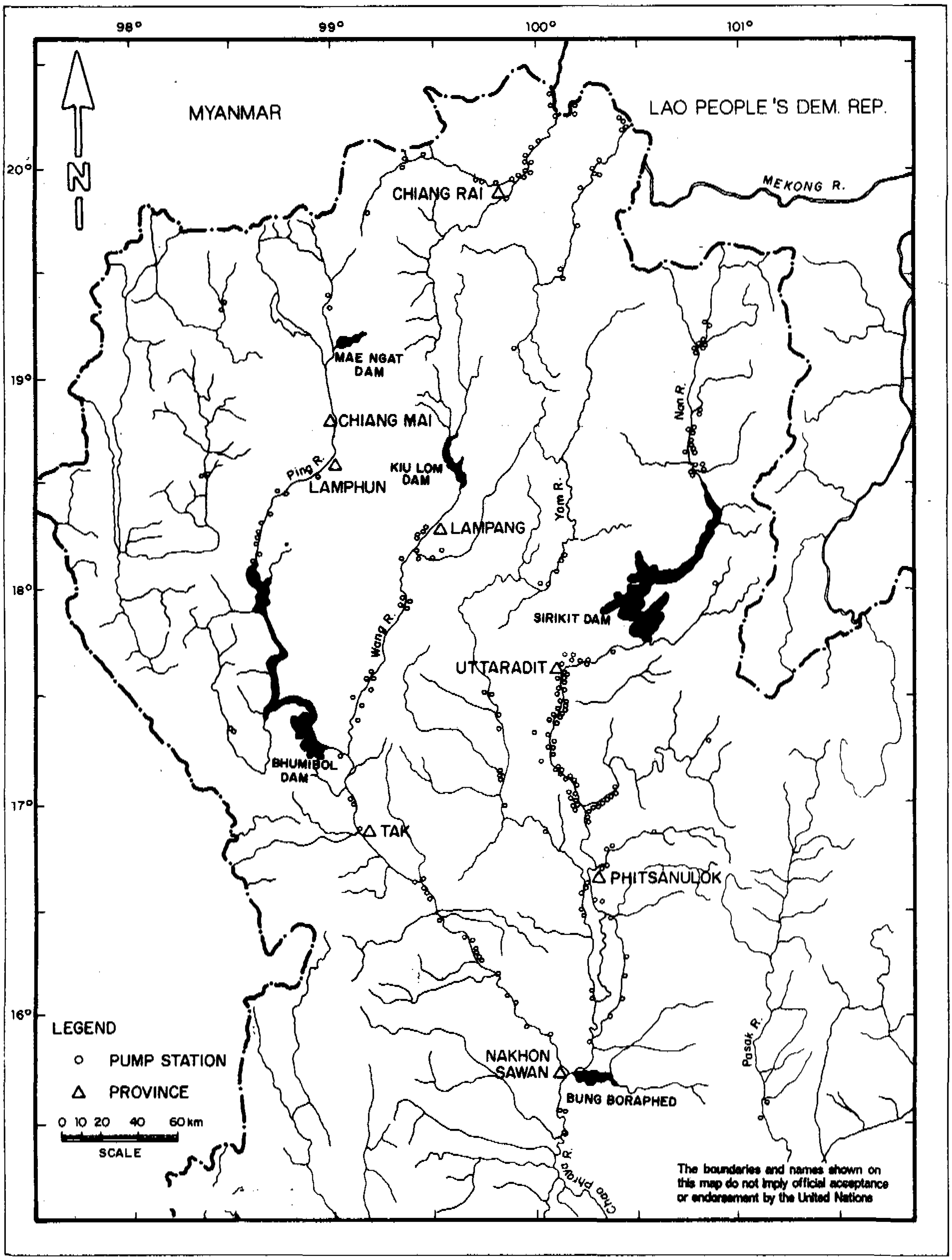

Figure 27. Locations of pump irrigation projects of the National Energy Administration, Northern Thailand

Source : Data from NEA(1990)

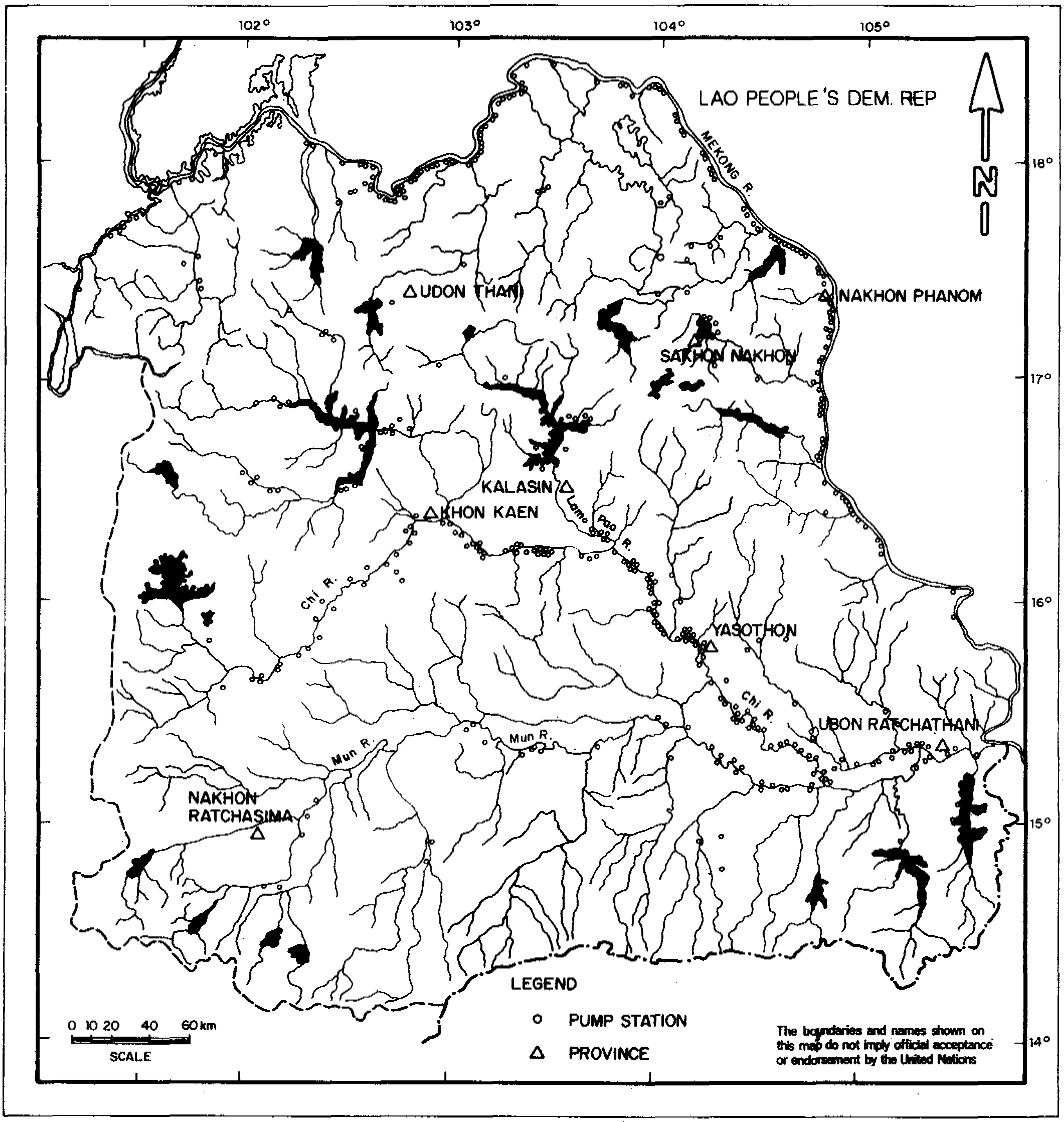

Figure 28. Locations of pump irrigation projects of the National Energy Administration, North-eastern Thailand

Source : Data from NEA (1990)

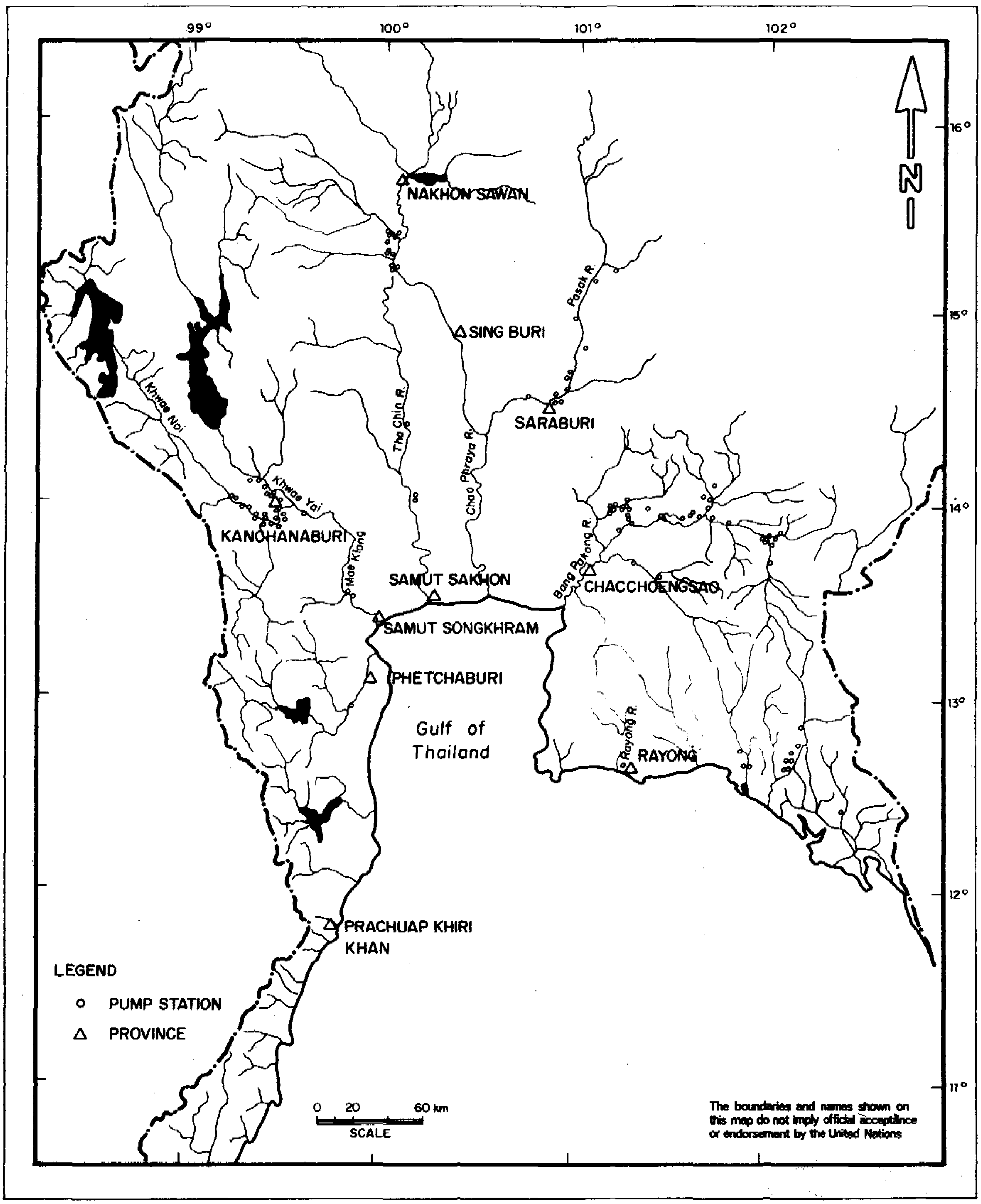

Figure 29. Locations of pump irrigation projects of the National Energy Administration, Central and Eastern Thailand

Source : Data from NEA (1990)

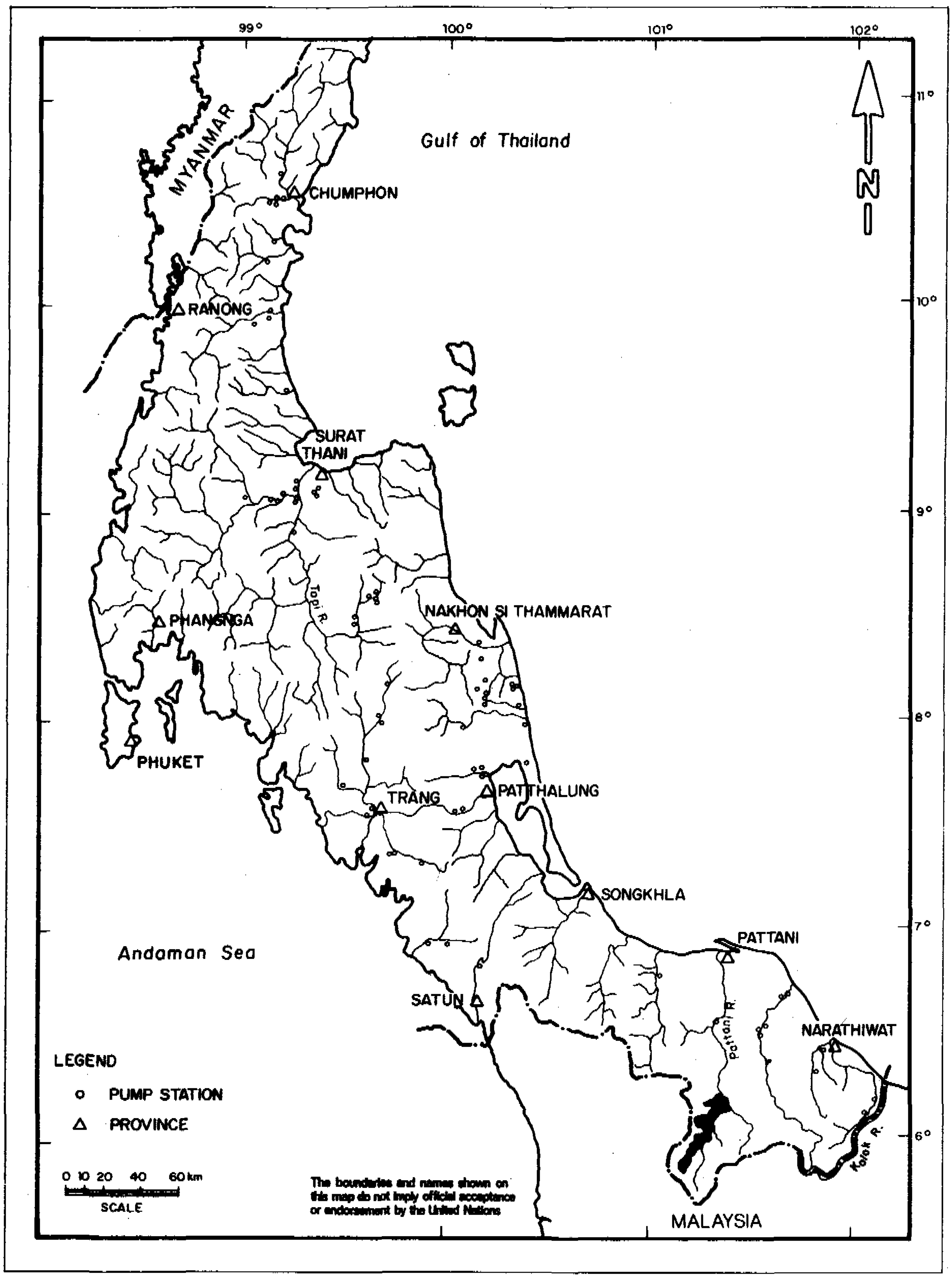

Figure 30. Locations of pump irrigation projects of the National Energy Administration, Southern Thailand

Source : Data from NEA (1990)