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No. 112

THE GOVERNMENT OF THE KINGDOM OF THAILAND

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

MAIN REPORT

FEBRUARY 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to a request from the Government of the Kingdom of Thailand, the Japanese Government decided to conduct a Feasibility Study on Purification of Klong Water in Bangkok and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Thailand a study team headed by Mr. Naohito Murata of Pacific Consultants International, comprising members from Tokyo Engineering Consultants from December 1987 to March 1988, from June 1988 to March 1989 and from July to August 1989.

The team held discussions with concerned officials of the Government of Thailand and conducted field surveys. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Kingdom of Thailand for their close cooperation extended to the team.

February, 1990

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

THE FEASIBILITY STUDY
ON
PURIFICATION OF KLONG WATER IN BANGKOK

Mr. Kensuke YANAGIYA
President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

Dear Sir,

We are pleased to submit herewith the final report entitled "THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK". This report has been prepared by the Study Team in accordance with the contract signed on 7 December 1987, 31 May 1988 and 18 May 1989 between the Japan International Cooperation Agency and the Joint Venture of Pacific Consultants International and Tokyo Engineering Consultants.

The report examines the existing condition of klongs in Bangkok and the pollution load generation, and presents the results of the feasibility study on an urgent klong water purification project consisting of dilution water introduction from the Chao Phraya River, dredging of klongs and aerated lagoon treatment.

The report consists of the Executive Summary, Main Report, and Supporting Study Reports. The Summary summarizes the results of all studies. The Main Report contains background conditions, urgent klong water purification project, recommendations and further studies. The Supporting Study Report includes data and technical details. In addition, a Data Book has been prepared and is submitted herewith.

All members of the Study Team wish to express grateful acknowledgement to the personnel of your Agency, Advisory Committee, Ministry of Foreign Affairs, Ministry of Construction, and Embassy of Japan in Thailand, and also to officials and individuals of the Government of Thailand for all assistance extended to the Study Team. The Study Team sincerely hopes that the results of the study will contribute to the enhancement of the aesthetics of the klong environment and the improvement of health and hygiene in Bangkok.

Yours faithfully

Murata

Naohito MURATA
Team Leader

SUMMARY

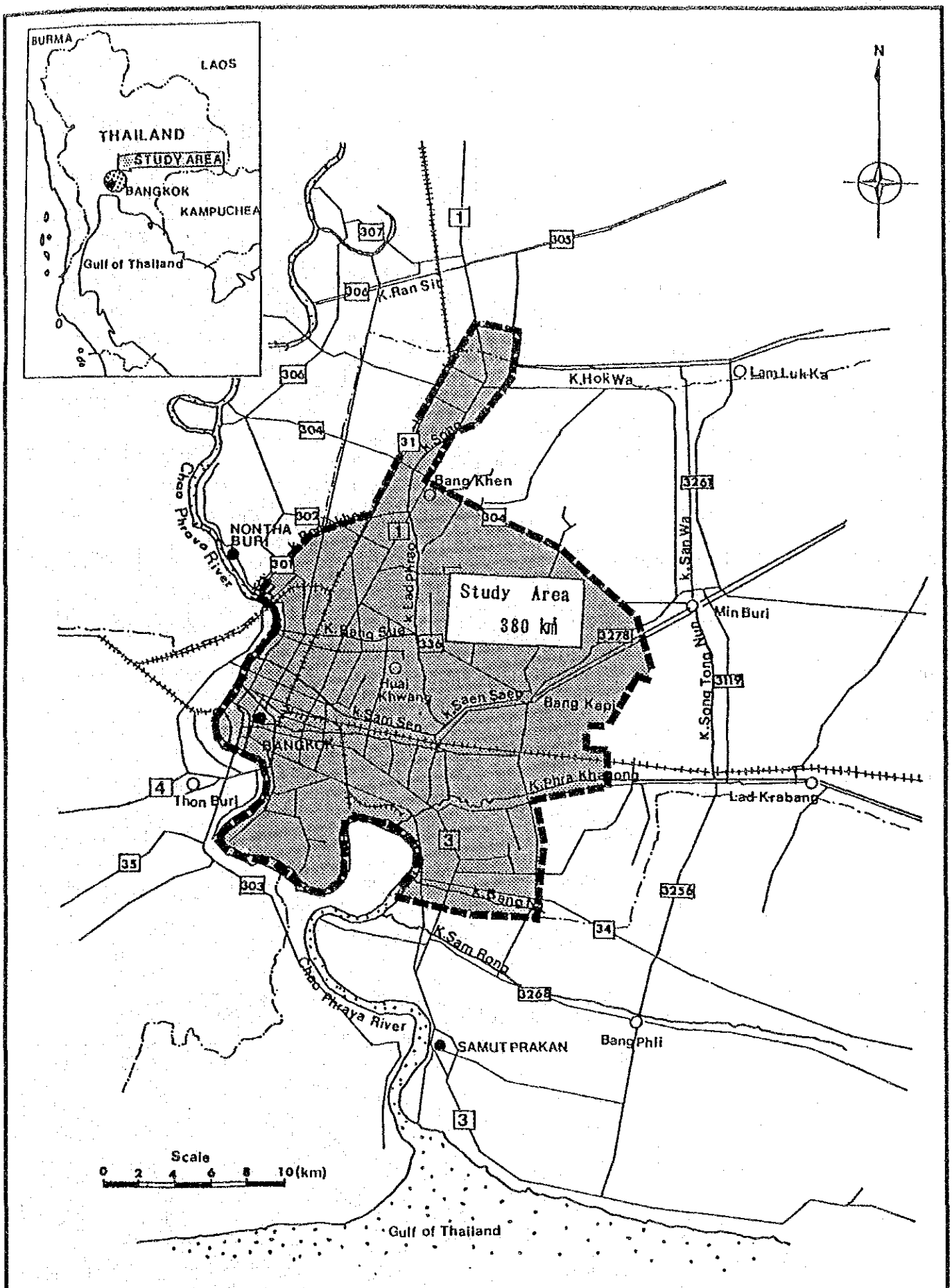
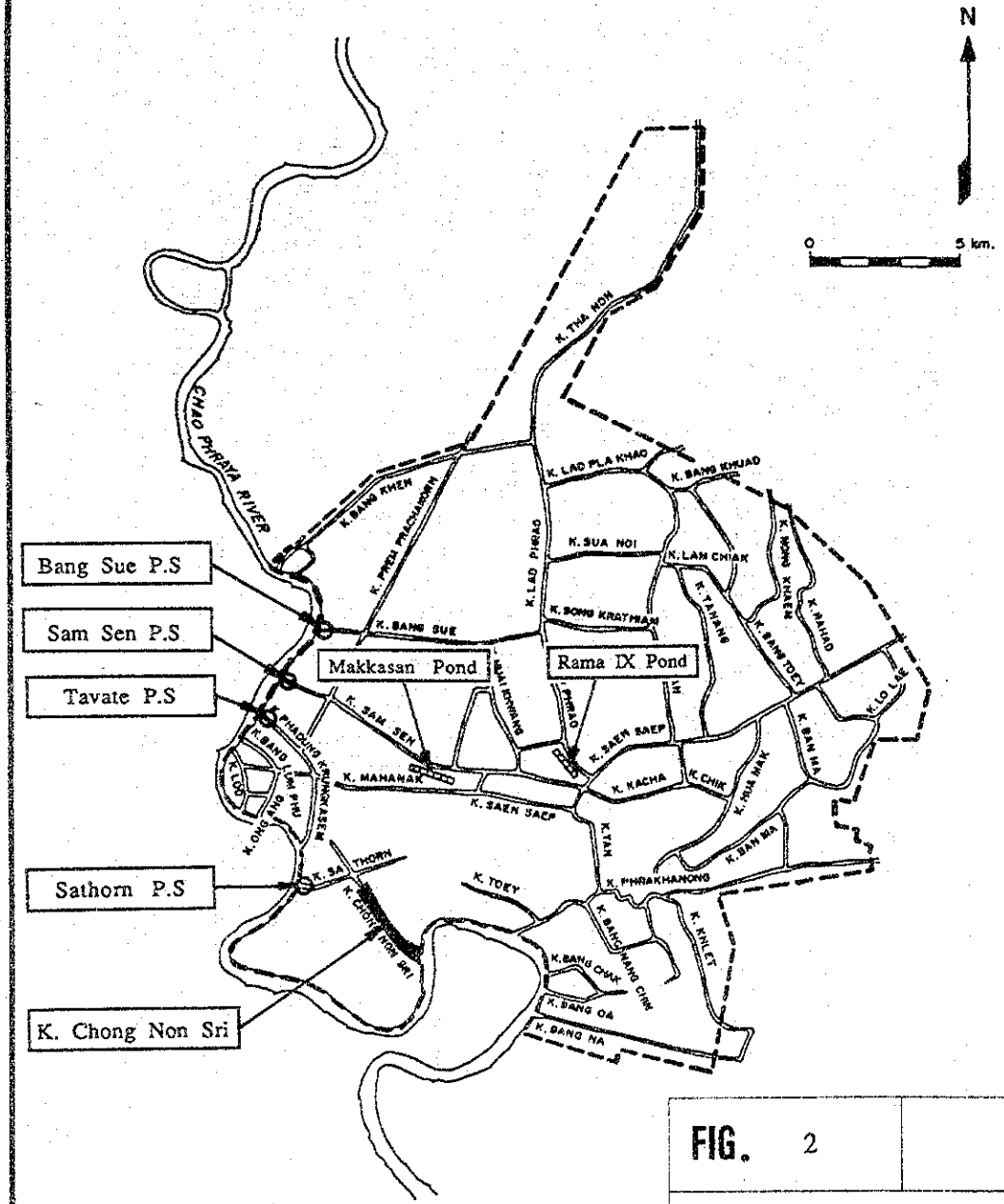


FIG. 1 LOCATION OF STUDY AREA

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.



Proposed Remodelled Pump Stations into Reversible Type

Name of P.S	Pump Capacity		
	Existing (Set) x (m^3/s)	Reversible (Set) x (m^3/s)	Additional (Set) x (m^3/s)
Bang Sue	17 x 3 = 51	4 x 3 = 12	-
Sam Sen	15 x 3 = 45	4 x 3 = 12	-
Tavate	5 x 1 = 5	-	2 x 3 = 6
Sathorn	2 x 3 = 6	-	2 x 3 = 6
Total	107	24	12

Proposed Klong Dredging

Name of Klong	Dredging Plan			
	Length(m)	Width(m)	Volume(m^3)	Bed EL (MSL.m)
Chong Non Sri	3,600	60.~10.0	77,000	-1.5~-2.0

Proposed Aerated Lagoon Treatment

Name of Pond	Pond Area	Pump Capacity	Aerator
Makkasan Pond	16 ha	60 m^3/min x 3 units	11 kw x 10 units
Rama IX Pond	20 ha	60 m^3/min x 3 units	11 kw x 10 units*

* Includes the three(3) existing aerators

FIG. 2 MAIN FEATURES OF THE PROPOSED FACILITIES

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.

SUMMARY

1. Introduction

The Bangkok Metropolitan area has been undergoing rapid urbanization and industrialization since 1960, which contributed to an impressive annual average economic growth rate of 8% in 1960-1980. However this has also caused serious environmental degradation. Water pollution of the klongs is one of such serious environmental issue confronting Bangkok Metropolis which is in need of urgent remedial measures.

This Study on Purification of Klong Water in Bangkok was carried out by the Study Team of the Japan International Cooperation Agency (JICA) in collaboration with the officials concerned of the Bangkok Metropolitan Administration (BMA) of the Government of Thailand from December 1987 to February 1990.

The Study proposed, as an urgent remedial measure of klong water quality improvement, the introduction of dilution water from Chao Phraya River along with aerated lagoon treatment in two (2) existing ponds, the Makkasan Pond and Rama IX Pond. Sewerage development is recommended to be necessary as a long term measure of klong water quality improvement.

2. Study Area

The Study Area, shown in Fig. 1, forms a portion of deltaic alluvial plain of the Chao Phraya River lying along its left bank. It covers the city core and eastern suburban areas of Bangkok with a total area of approximately 380 km^2, and is characterized by very low and flat land. The water stage of the Chao Phraya River exceeds the ground elevation during the period of high tide and floods.

Bangkok is affected by a severe land subsidence, which is estimated to be progressing at an average rate of about 5 cm/year.

Average annual rainfall is 1,477 mm. The wet season extends from May to October during which approximately 70% of the annual rainfall occurs. The heaviest rainfall occurs in September and October.

The population of Bangkok metropolitan area increased from 3.44 million in 1970 to 5.47 million in 1986. It is expected to increase further to 6.4 million in 1990 and 7.7 million in 2000. Consequently the urbanized area has expanded from 183 km^2 in 1971 to 350 km^2 in 1984, with a sprawl expansion along major roads and klongs.

3. Objectives of the Study

The objectives of the Study are:

1) to prepare an urgent water purification plan for the main klongs in central Bangkok.

2) to conduct technology transfer to the Thailand counterpart personnel.

4. Existing Conditions of Chao Phraya River and Klongs

4.1 Existing Conditions of River

The Chao Phraya River, flowing southerly through the central part of Thailand into the Gulf of Thai, has a total trunk length of 980 km and drains an area of 162,600 km^2, about one-third of the whole country.

The maximum, minimum and average seasonal river discharges in 14 years (1963-1976), recorded at Bang Sai located at about 50 km upstream of the Study Area, are as follows:

	Dry Season (Jan. - April)	Rainy Season (Aug. - Oct.)
Maximum	233 m^3/s	2,172 m^3/s
Minimum	120	264
Average	174	1,095

With due consideration to the river water demand for water supply, the maximum quantity of river water that could be withdrawn for klong water quality improvement by dilution is estimated at 70-80m^3/sec.

The water quality of the Chao Phraya River is affected by tide, river discharge and wastewater from Bangkok city.

The river water quality in rainy season varies very little along the whole river distance. However during dry season the water quality at downstream of 60 km of river distance deteriorates in comparison to upstream reaches. The overall variation of DO and BOD are as follows:

		River Distance	
		0 - 60 km	60 - 130 km
DO	Rainy Season	3 - 4 mg/l	3 - 4 mg/l
	Dry Season	1 - 2 mg/l	3 - 5 mg/l
BOD	Rainy Season	1 mg/l	1 mg/l
	Dry Season	2 - 3 mg/l	1 mg/l

Salinity intrusion is considered to be limited to a river distance of 40 km upstream of the river mouth.

4.2 Existing Conditions of Klongs

The klongs run in all directions through the whole Study Area with a high density of one (1) km/km^2 approximately. Out of all the existing klongs, 37 klongs were selected for the Study. The total length of the networks is 219.1 km. The width of the klongs ranges from a few meters to 50 m. Major klongs with a width of more than 20 m are K. Saen Saep, K. Lad Phrao, K. Phadung Krung Kasem and K. Phra Khanong.

The actual discharge capacity of the klongs varies depending on their downstream water level which is largely affected by the water stage of the Chao Phraya River. The maximum discharge capacity of the klongs are in the range of about 5 m^3/s to 50 m^3/s.

At present, the quantity of dilution water introduced from the Chao Phraya River to the klongs is about $16m^3/sec$.

The water quality of the klongs in the Study Area varies both locally and seasonally to a large extent. During dry season, klongs in the vicinity of the Chao Phraya River and those at eastern suburban areas show a moderate BOD level, less than 20 mg/l. However, high BOD levels of 20-50 mg/l are observed in the klongs of inner areas with high population density.

A qualitative evaluation of existing klong water quality was conducted, both during dry and rainy seasons, by the observation of color and odor in the klongs. There was a significant variation in klong water quality between dry season and rainy season, in the klongs along the Chao Phraya River. These klongs were greenish with no odor in dry season, but were blackish with strong odor in rainy season. However, the water quality of the klongs in inner areas are polluted with blackish color and strong odor throughout the year.

The relationship between klong appearance and klong water quality expressed as BOD are as follows.

1) Color

Green or brown	:	BOD<15mg/l
Black or black-gray	:	BOD>20mg/l

2) Odor

No odor or faint odor	:	BOD<15mg/l
Strong odor or offensive odor	:	BOD>20mg/l

4.3 Existing Drainage Systems

The river banks and polders in the Study Area are provided with gates and pumps at the inlets or outlets of the klongs to prevent flood waters entering from outside and to drain inner water.

In rainy season, all the gates are closed, in principle, and no river water enters into the Study Area. In dry season, the gates are kept open and dilution water from the Chao Phraya River is introduced into the klongs.

4.4 Pollution Load Generation

There are three (3) major sources of pollution load generation in the Study Area. These are of residential, commercial and industrial in origin.

The total pollution load generation in the Study Area under the existing conditions in the year 1986 is estimated at 119,000 kg.BOD/day.

The corresponding total future pollution load generation in the year 2000 is estimated at 230,000 kg.BOD/day.

5. Proposed Project

The proposed urgent project of klong water purification consists of the two (2) project components, introduction of dilution water to the klongs from the Chao Phraya River and aerated lagoon treatment of klong water in two (2) ponds, the Makkasan Pond and Rama IX Pond. The project facilities are illustrated in Fig. 2.

5.1 Dilution Water Introduction

The target klong water quality with respect to stream BOD is set at 15 mg/l. Based on the simulation analysis of klong water quality carried out assuming a dilution water introduction amounting 35m^3/sec from the Chao Phraya River, it is determined that the water quality of

almost all the klongs in the Study Area, during dry season, can be improved to the target stream BOD level not exceeding 15 mg/l which is sufficient to alleviate the existing color and odor problems. This will result in aesthetic enhancement of the klong environment.

This is a low cost option involving basically remodeling of some of the existing pump stations along the Chao Phraya River to reversible type in order to facilitate in dilution water introduction, even during low river tide. However, the benefit of this option is limited to only the dry season.

5.2 Aerated Lagoon Treatment

The introduction of dilution water to the klongs alone, though could improve the water quality of the klongs by dilution effect, would result in increase in pollution load discharge to the Chao Phraya River, and hence the water quality deterioration of the river. This is because of the reduction in self purification potential of the klongs anticipated by the increased stream flow velocity, and decreased pollutant concentration and sedimentation caused by the dilution water introduction.

In order to realize a net pollution load reduction of klong water, aerated lagoon treatment method was identified for detailed evaluation due to the availability of large ponds in the vicinity of major klongs, and simplicity of the system operation and maintenance and low cost.

Experimental studies were conducted utilizing the Rama IX Pond with wastewater influent from Klong Lad Phrao to evaluate the aerated lagoon treatment efficiency and other design requirements. It was found out that a 50% reduction in BOD along with significant color and odor removal could be achieved in aerated lagoon with a hydraulic detention time of one (1) day.

Finally, the following two (2) ponds were selected for aerated lagoon treatment:

1) Makkasan Pond to treat klong water from K. Sam Sen.
2) Rama IX Pond to treat klong water from K. Lad Phrao.

The above two aerated lagoons are estimated to contribute to a pollution load reduction of 4,470 kg.BOD/day, which is higher than the anticipated increase in pollution load discharge of 3,800 kg.BOD/day to the Chao Phraya River by dilution water introduction.

5.3 Project Cost

The total project cost, consisting of direct construction cost, engineering and administration costs, and physical contingency, amounts to 203.0 million Baht at October 1988 prices as given below (฿223.0 million including price escalation). The annual operation and maintenance cost is estimated at 56.3 million Baht.

	Cost Item	Amount (10^3 ฿)
A.	Direct Const. Cost	167,790
	(1) Reconst. of Ban Sue P.S.	9,280
	(2) Reconst. of Sam Sen P.S.	7,910
	(3) Reconst. of Tavate P.S.	10,370
	(4) Reconst. of Sathorn P.S.	10,420
	(5) Dredging of Klong	11,010
	(6) Const. of Makkasan Pond Aerated Lagoon	59,500
	(7) Const. of Rama IX Pond Aerated Lagoon	59,300
B.	Engineering & Administration Costs (10%)	16,779
C.	Physical Contingency (10%)	18,456
	Sub-Total	203,025
D.	Price Escalation (10%)	19,975
	Total	223,000
E.	Annual OM Cost	56,300

5.4 Project Evaluation

(1) Economic Evaluation

The expected major tangible benefits of the Project are as follows:

	Annual Benefit (10^3 ฿)
- Beneficial effects on klong transport and floating market	21,600
- Beneficial effects on health and hygiene	12,900
- Increased use of klong water for living	27,200
- Increased use of klong for recreation	100
Total	61,800

These benefits are expected to be fully realized since 1992 onwards, after the completion of this klong water purification project, and the total annual benefit is estimated at 61.8 million Baht.

The economic rate of return (EIRR) of the Project is determined to be 5.5%.

(2) Impact on the Chao Phraya River Water Quality

A slight beneficial effect as improvement in the Chao Phraya River water quality, with no adverse effects, by the Project is expected, because the reduction of pollution load in the two (2) aerated lagoons could more than offset the increase in pollution load discharge to the river by dilution water introduction.

(3) Necessity of Sewerage Development in Future

The klong water quality in the year 2000 is projected to deteriorate to 15-24 mg/l as stream BOD even with the continued functioning of the proposed project due to the rapidly increasing pollution load generation in Bangkok. Under such a future conditions, the stream BOD of the Chao Phraya River is forecasted to increase up to 6.5 mg/l from the present level of 3 mg/l.

Moreover, in rainy season, the klong water quality will be much deteriorated to a stream BOD level of 20-50 mg/l in the year 2000 due to lack of dilution water introduction from the Chao Phraya River.

To cope with this future water pollution problems, sewerage development is essentially required.

6. Recommendations and Further Studies

6.1 The Proposed Project

The proposed project will produce fruitful effects at a low investment cost with simple operation and maintenance requirement.

The dilution water introduction will improve the klong water quality in the Study Area to a stream BOD level of 15 mg/l resulting in a very significant improvement of color and odor. While the aerated lagoon treatment will marginally improve the water quality of the Chao Phraya River.

An early implementation of the Project is recommended.

As another means of klong water quality improvement, feasibility on direct aeration of the klong water itself to enhance the assimilative capacity of the klongs is recommended for further studies.

6.2 Reconstruction of Phra Khanong Pump Station

The dilution water introduced from the Chao Phraya River to the klongs is again discharged into the Chao Phraya River by the Phra Khanong and Krung Kasem pump stations.

In the year 2000, the ground elevation of the Study Area is expected to become lower than the low water level of the Chao Phraya River due to the progressing land subsidence activities affecting Bangkok.

By that time, a 24-hour pump drainage will be required by the Phra Khanong and Krung Kasem pump stations to discharge the introduced dilution water.

The Phra Khanong pump station, which is only a temporary type, shall be remodelled into a permanent type as early as possible to meet the requirement of long-time continuous operation.

6.3 Sewerage Development

The existing major pollution sources in central Bangkok are domestic wastes, wastes of toilet origin and commercial wastes. The domestic and commercial wastes are collected through the storm water drains consisting of road side ditches and main pipes and discharged into the klongs with no treatment. Toilet wastes are intended to be treated by septic tanks. However, overflow from septic tank is also discharged into the klongs through the storm water drains.

Since a full-scale conventional sewerage development in central Bangkok would require a high cost, a stage-wise implementation program shall be devised. A sewerage development focussing on abatement of water pollution of the klongs and the Chao Phraya River is recommended as the first step.

Construction of wastewater interceptors along the klongs is considered to be one of the cost-effective methods for abatement of the water pollution.

An early execution of the feasibility study on sewerage development is strongly recommended.

MAIN REPORT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

AIT	Asian Institute of Technology
฿	Baht (Thai Currency); US$=approximately ฿25.40
BMA	Bangkok Metropolitan Administration
BOD	Biochemical Oxygen Demand
Cl^-	chloride ion
cm	centimeters
COD	Chemical Oxygen Demand
DDS	Department of Drainage and Sewerage, BMA
Dept.	Department
Div.	Division
DO	Dissolved Oxygen
DOH	Department of Highways
EIRR	Economic Internal Rate of Return
Fig.	Figure
gcd	gram per capita per day
ha	hectares (10,000 m^2)
hrs	hours
HWL	High Water Level
JICA	Japan International Cooperation Agency
K.	Klong
kg/d	kilogram per day
klong	A term commonly used in Thailand for "canal"
km	kilometers
km^2	square kilometers
kw	kilowatt
kwh	kilowatt-hour
lcd	litter per capita per day
m	meters
m^2	square meters
m^3	cubic meters
m^3/s	cubic meters per second
m^3/d	cubic meters per day
mg/l	milligram per litter
mm	millimeters
MSL	Mean Sea Level

MWL	Mean Water Level
MWA (MWWA)	Metropolitan Waterworks Authority
NEB	National Environmental Board
NEDECO	Netherlands Engineering Consultants
NESDB	National Economic and Social Development Board
NH_4-N	Ammonia nitrogen
NSO	National Statistical Office
OECF	Overseas Economic Cooperation Fund (of Japan)
PAT	Port Authority of Thailand
PCI	Pacific Consultants International
Polder	A community surrounded by a dike to protect it from floods
ppm	part per million
P.St.	Pumping Station
PWD	Public Works Department
%	percent
R.C.	Reinforced Concrete
Rd	Road
RID	Royal Irrigation Department
SRT	State Railway of Thailand
SS	Suspended Solid
TDRI	Thailand Development Research Institute
TEC	Tokyo Engineering Consultants
TISTR	Thailand Institute of Scientific and Technical Research
T-P	Total Phosphorus
WHO	World Health Organization
¥	Yen(Japanese Currency); US$=approximately ¥145.0

Chapter 1.

INTRODUCTION

CHAPTER 1. INTRODUCTION

1.1 Background of the Study

The Bangkok Metropolitan Area has been undergoing rapid urban and industrial developments since 1960. The population has increased from 2.25 million in 1960 to 3.44 million in 1970, 5.07 million in 1980 and 5.47 million in 1986. Also the future population of Bangkok Metropolitan Area is projected to reach 6.4 million in 1990 and 7.7 million in 2000 (Refer to Study Report on Flood Protection and Drainage Project in Eastern Suburban-Bangkok, JICA, 1986). Consequently the urban area has expanded from 96 km^2 in 1958 to 183 km^2 in 1971 and about 350 km^2 in 1984, as shown in Fig. 1.2. This pressure due to increasing population has created a sprawl expansion of the urban area along the major roads and klongs.

Even though the rapid urbanization and industrialization has contributed to an impressive economic growth rate with an annual average of 8% (1960-1980), it has also caused serious environmental degradation. Water pollution of the klongs is one such serious environmental issue confronting Bangkok Metropolis. In the absence of suitable mitigatory measures, this problem would aggravate further in future due to increasing population pressure.

1.2 Study Area

Fig. 1.1 shows the location of Study Area, which forms a portion of deltaic alluvial plain of Chao Phraya River lying along its left bank, known as the Bangkok area. It covers the city core and eastern suburban areas of Bangkok with a total area of approximately 380 km^2, and is characterized by very low and flat land. The ground elevation ranges from 0.0 m M.S.L. to +2.5 m M.S.L. The water stage of the Chao Phraya River exceeds the ground surface during the period of high tide and floods.

The Study Area is being affected by a severe land subsidence due to excessive withdrawal of groundwater. The land subsidence is estimated to be progressing at a rate about 5 cm/year.

The climate is characterized by three (3) seasons; cool, hot and wet. The average annual temperature is 27.7°C, while the average monthly figures range from 25.5°C in December to 29.6°C in April.

Average annual rainfall is 1,477 mm. The wet season extends from May to October during which approximately 70% of the annual rainfall occurs. The heaviest rainfall occurs in September and October when the monsoon passes through the country on a wide front.

Monthly distribution of temperature and rainfall in the Study Area is shown in Fig. 1.2.

1.3 Objectives of the Study

The objectives of the Study are:

1) to prepare an urgent water purification plan for the main klongs in central Bangkok.

2) to conduct technology transfer to the Thailand counterpart personnel.

1.4 Implementation of the Study

The Department of Drainage and Sewerage (DDS) of the Bangkok Metropolitan Administration (BMA) was assigned as the counterpart executing agency of the Government of Thailand while the Japan International Cooperation Agency (JICA) was assigned as the official agency responsible for the implementation of the technical cooperation program of the Government of Japan.

The Study was carried out by the Japanese consultant team retained by JICA and counterpart staff of DDS.

The Study was conducted from December, 1987 to January, 1990. The members involved in the Study are listed below.

(1) JICA Study Team

Mr. Naohito Murata	(PCI) :	Team Leader
Mr. Masami Kondo	(PCI) :	Deputy Team Leader, Water Pollution Control Planning
Mr. Daijiro Sezaki	(TEC) :	Treatment System Planning
Mr. Masaharu Takasugi	(TEC) :	Facility Planning/Design
Mr. Masahiro Kawachi	(TEC) :	Pollution Load Analysis
Mr. Toshiyuki Sato	(PCI) :	Hydrologic Analysis
Mr. Yoshikazu Katagiri	(PCI) :	Water Quality Analysis
Mr. Osamu Nogoshi	(PCI) :	Klong Survey
Mr. Naomichi Ishibashi	(PCI) :	Economic/Financial Analysis
Dr. Kinichi Ohno	(PCI) :	Institutional Planning

(2) JICA Advisory Committee

Chairman

Mr. Taigo Matsui
Ministry of Construction

Dr. Ken Murakami (Former)
Ministry of Construction

Members

Mr. Haruki Takahashi Japan Sewage Works Agency	Sewerage/Drainage Planning
Mr. Kouichi Uzuka Ministry of Construction	Hydrology/Hydraulic Analysis
Mr. Ryohei Umemoto Ministry of Construction	Water Purification Planning
Mr. Junzo Sago Ministry of Construction	Hydrology/Hydraulic Analysis (Former)

(3) Government of Thailand

Dr. Wicha Jiwalai	:	Deputy Governor of BMA
Mr. Prasert Samalapa	:	Deputy Permanent Secretary of BMA
Mr. Sante Thrachoo	:	Director General of DDS
Mr. Mana Noppan	:	Deputy Director General of DDS
Mr. Pirun Charoenkul	:	Director of Drainage Control Division of DDS
Mr. Pitool Koolchai	:	Director of Wastewater Control Division of DDS
Mr. Sanan Prasartsil	:	Director of Canal Maintenance Division of DDS
Mr. Somchitt Kattiyawara	:	Director of Technical Division of DDS

(4) DDS Counterparts

Mr. Chanchai Vitoonpanyakij	:	Counterpart Leader
Miss Apinan Jaruchaiyakul	:	Pollution Control Planning Treatment System Planning Facility Planning/Design
Mrs. Injira Poontaweewat	:	Facility Planning / Design Pollution Load Analysis Water Quality Analysis
Mr. Anuchit Titikawin	:	Hydrologic Analysis
Mr. Sacha Wattanasanvetchakul	:	Klong Survey
Mr. Yodying Manoi	:	Klong Survey

1.5 Composition of Report

This report consists of four (4) volumes: Summary Report, Main Report, Supporting Report, and Data Book.

The Main Report presents the summarized results of all the studies. In Chapter 2 through 5, the basic information for the Study are described. Chapter 6 deals with the aerated lagoon treatment plan. In

Chapter 7, the feasibility study on purification of klong water by introducing the dilution water from the Chao Phraya River is described. From Chapter 8 to Chapter 10, construction plan and cost estimate, operation and maintenance of facilities for klong water purification project consisting of dilution water introduction, dredging of klongs and aerated lagoon treatment and project evaluation are described. A supplementary study on klongs in Thonburi area is described in Chapter 11. Chapter 12 deals with recommendations and further studies.

1.6 Acknowledgement

In undertaking the Study, the Study Team has attached great importance to the incorporation of the views of departments and agencies of the Government of Thailand relating to the various aspects covered by the Study. The contributions to the Study by the officials of the Department of Sewerage and Drainage of the Bangkok Metropolitan Administration, and other individuals who have provided information and data, participated in discussions, given valuable advices, and provided other forms of assistance to the Study are gratefully acknowledged.

A heartfelt gratitude is also extended to the officials of the Embassy of Japan in Thailand, the Ministry of Foreign Affairs and Ministry of Construction of the Government of Japan who gave advice and provided various supports during the execution of the Study. In reality, the Study can be regarded as a joint effort by the Thai and Japanese officials and individuals concerned and the Japanese Study Team. The Study Team sincerely hopes that this effort will contribute to the water quality improvement of the klongs and thereby contributing towards the enhancement of public health and the quality of life of the residents in Bangkok.

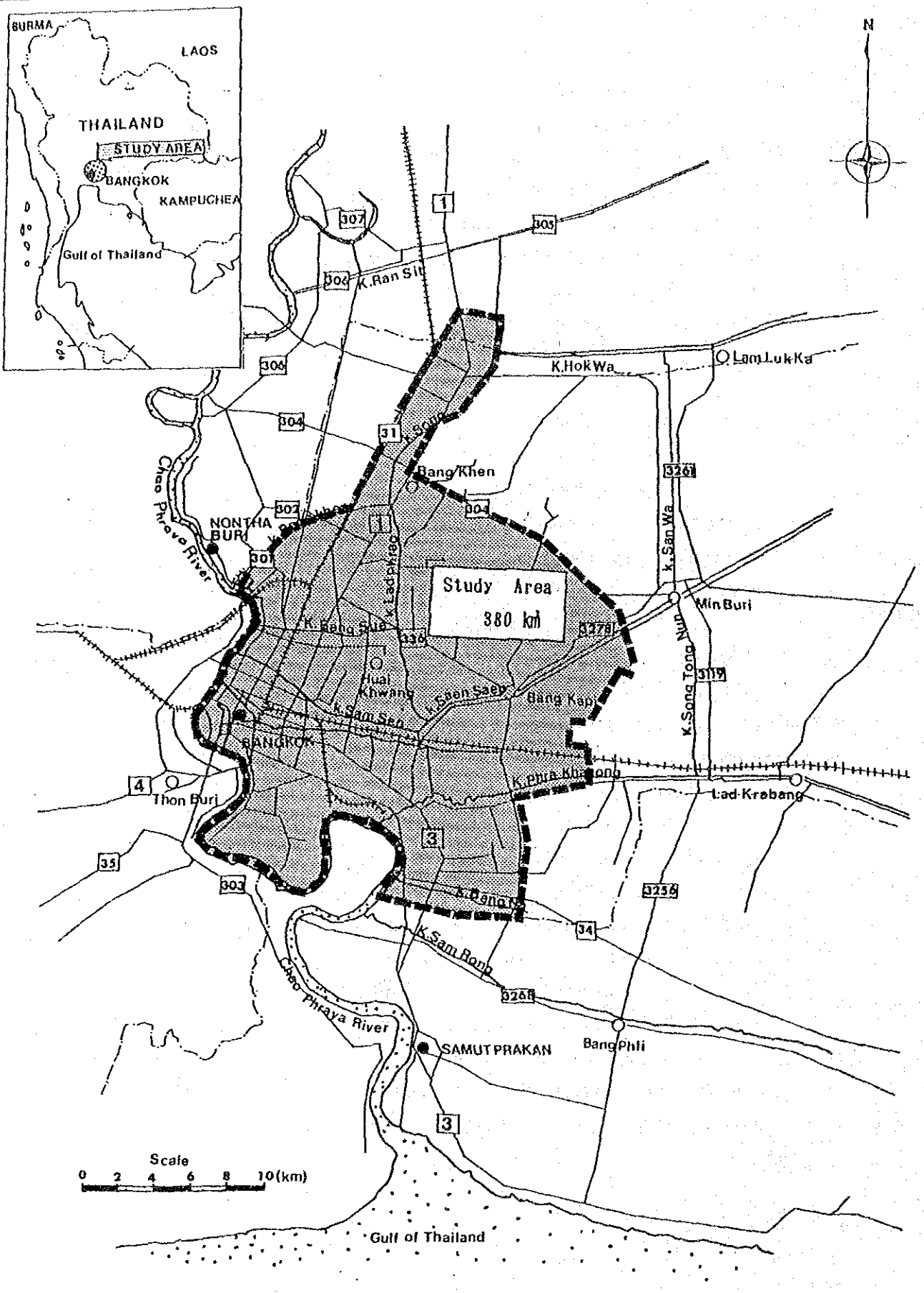
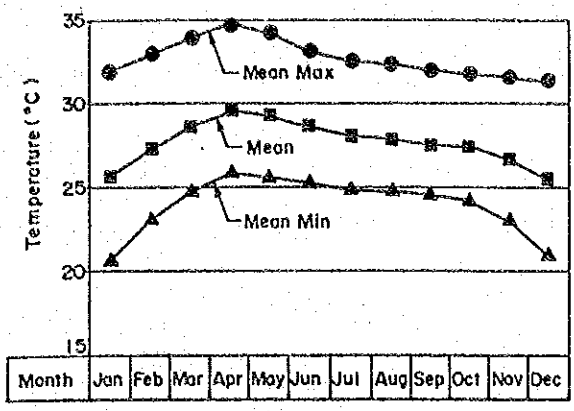


FIG. 1.1 LOCATION OF STUDY AREA

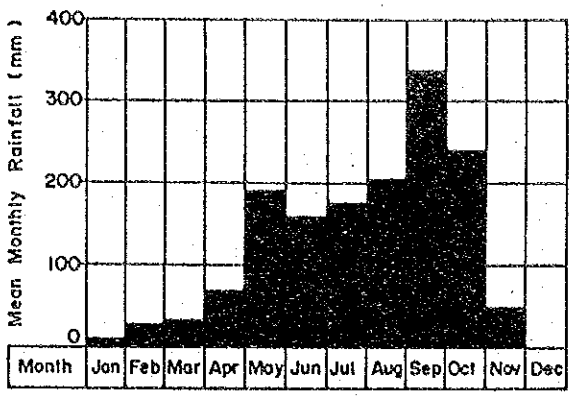
THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.

Climate Condition

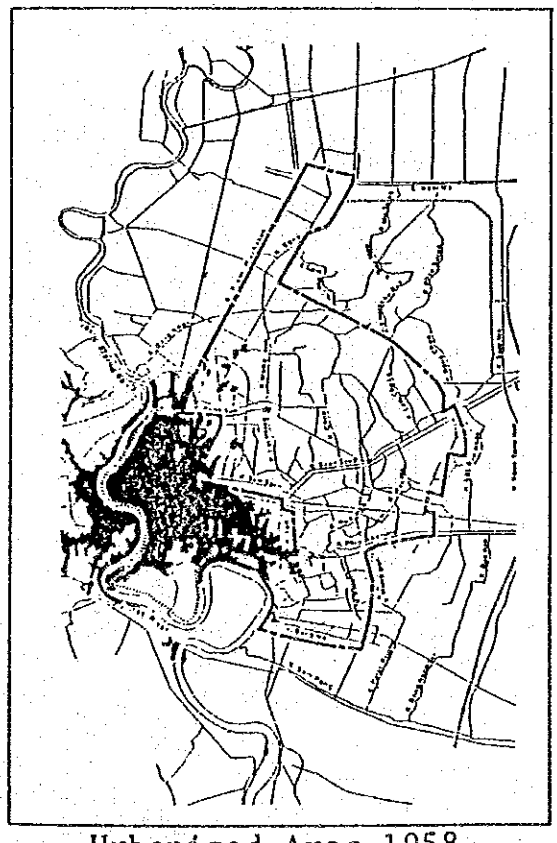


Temperature



Monthly Rainfall

Progress of Urbanization



Urbanized Area 1958

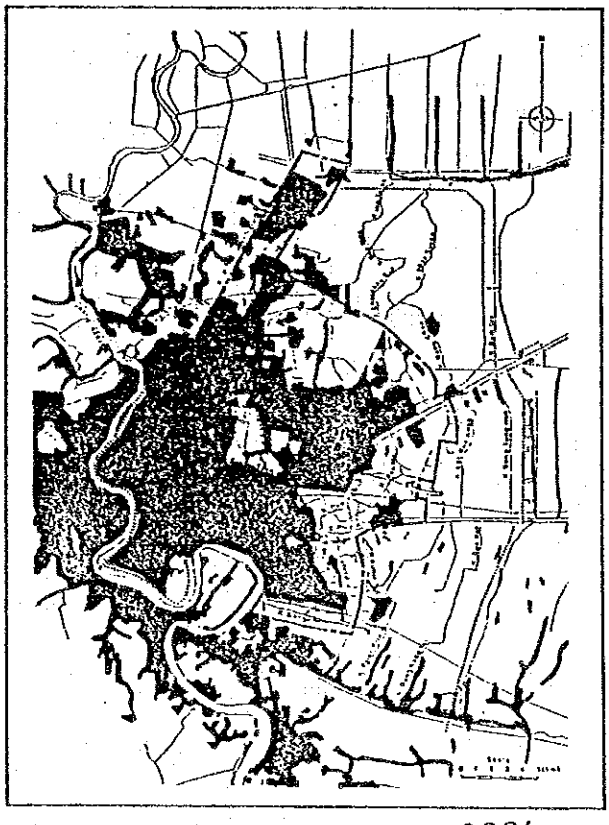


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FIG. 1.2 CLIMATE AND PROGRESS OF URBANIZATION IN BANGKOK

Chapter 2.

CHAO PHRAYA RIVER CONDITON

CHAPTER 2. CHAO PHRAYA RIVER CONDITION

2.1 General

The Chao Phraya River, flowing southerly through the central part of Thailand into the Gulf of Thai, has a total trunk length of 980 km and drains an area of 162,600 km^2, about one-third of the whole country.

The River irrigates a vast agricultural land extending over the downstream of Nakhon Sawan. Also, it is highly used for hydropower generation, navigation and domestic and industrial water supply. While, in the rainy season, it floods a wide area of the downstream delta, including Bangkok city.

2.2 River Flow

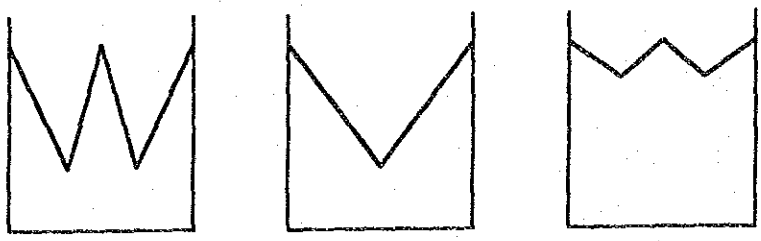
River flow data in the lower reaches of the Chao Phraya River is available at Bang Sai, located approximately at 50 km upstream of the Study Area.

The recorded maximum, minimum and average seasonal discharges in 14 years (1963-1976), both during dry season and rainy season are as follows:

	Dry Season (Jan. - April)	Rainy Season (Aug. - Oct.)
Maximum	233 m^3/s	2,172 m^3/s
Minimum	120	264
Average	174	1,095

2.3 River Water Stage

The river stage data obtained during the 5 year period from 1983 to 1987 at the Memorial Bridge were adopted to analyze the river stage characteristics in the Study. The river stage at the station varies hourly and is strongly influenced by tidal action. The river stage profile was classified into three (3) patterns as shown below.



I II III

The frequency of occurrence of pattern II, which is a diurnal tide, is the highest of about 80% both during the dry and rainy seasons, followed by that of pattern I. The frequency of occurrence of pattern III, which occurs during high discharge period in rainy season, is negligible.

Also the amplitude of pattern II was high, approximately of 1.4 m, whereas that of pattern I was low, of 1 m.

Accordingly, the river stage profile of pattern II was adopted for the Study and the design tidal levels are:

Dry season:

High tide level	:	+1.00 m M.S.L.
Low tide level	:	-0.45 m M.S.L.

Rainy season:

High tide level	:	+1.10 m M.S.L.
Low tide level	:	-0.40 m M.S.L.

2.4 River Water Quality

(1) Water Quality

The water quality of the Chao Phraya River is affected by tide, river discharge and wastewater form Bangkok city.

The water quality in rainy season varies very little along the whole river distance. While in dry season, there is a marked difference in the water quality between the downstream and upstream stretches of the 60 km river distance. In the downstream stretches, the water quality become worse in dry season than in rainy season. On the other hand, the water quality in the upstream stretches remains nearly unchanged throughout the year. Seasonal and regional variation of DO and BOD are summarized below.

		River Distance	
		0 - 60 km	60 - 130 km
DO	Rainy Season	3 - 4 mg/l	3 - 4 mg/l
	Dry Season	1 - 2 mg/l	3 - 5 mg/l
BOD	Rainy Season	1 mg/l	1 mg/l
	Dry Season	2 - 3 mg/l	1 mg/l

The river water is polluted by the discharge of wastewater from the Bangkok city. The water quality at the mouth of Klong Phra Khanong (28 km distance) and Wat Chalermprakeit (62 km distance) are compared as follows.

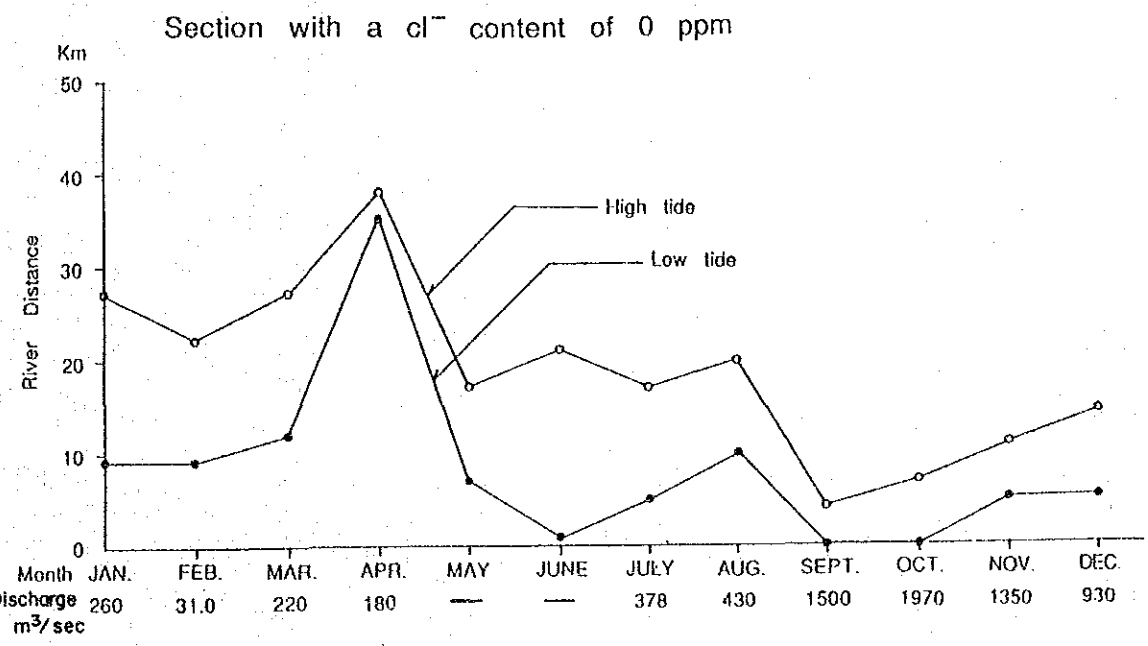
	Yearly Average Water Quality (mg/l)				
	DO	BOD	COD	NH4-N	T-P
Mouth of Klong Phra Khanong	1.0	2.5	20	2.5	0.8
Wat Chalermprakeit	3.0	1.5	18	0.5	0.5

(2) Salinity Intrusion

Data on the salinity intrusion of the Chao Phraya River are available at the Port Authority of Thailand. The data of 1976 are the latest available ones.

Monthly variation of the distance of salinity intrusion in 1976 is shown in Fig. 2.1. This figure shows the distance of salinity intrusion for the river sections with a measured Cl^- content of 0 ppm and 1,000 ppm respectively. The furthest distance of salinity intrusion was registered in April when the river flow was the minimum (180 m^3/s). The saline water sections with Cl^- contents of 0 ppm and 1,000 ppm reached 40 km and 30 km respectively at high tide. The observation made by the Study Team on salinity intrusion on August 8 and November 1, 1988 also confirmed the above phenomenon.

Based on the above studies, salinity intrusion of the Chao Phraya River could be considered to be limited to about 40 km of river distance upstream from the River Mouth.



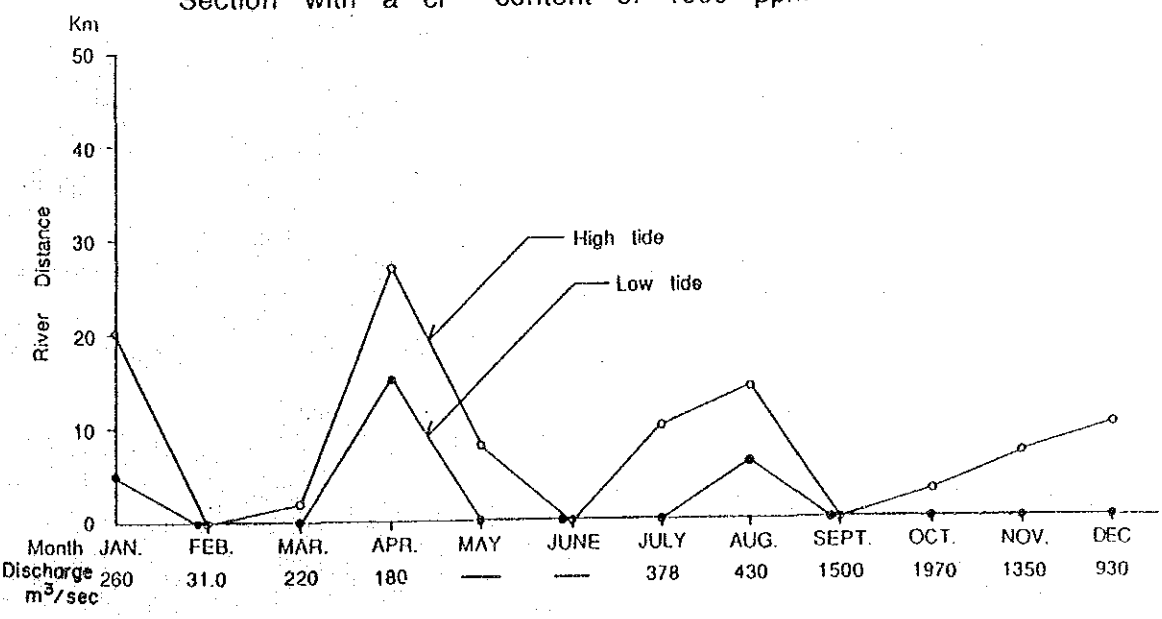


FIG. 2.1 MONTHLY VARIATION OF SALINITY INTRUSION IN THE CHAO PHRAYA RIVER

Chapter 3.

KLONG CONDITION

CHAPTER 3. KLONG CONDITION

3.1 Klong Network

The klongs run in all directions through the whole Study Area with a high density of one (1) km/km^2 approximately. Out of all the existing klongs, 37 klongs were selected for the Study. The selected klong networks are shown in Fig. 3.1.

The total length of the networks is 219.1 km. The width of the klongs ranges from a few meters to 50 m. Major klongs with a width of more than 20 m are K. Saen Saep, K. Lad Phrao, K. Phadung Krung Kasem and K. Phra Khanong.

3.2 Drainage System and Facilities

The Study Area (380 km^2) is surrounded by the Chao Phraya River banks on the west and south sides, and by the polders on the north, east and south sides. The river banks and polders are provided with gates and pumps at the inlets or outlets of the klongs to prevent flood waters coming from outside and to drain inner water. Fourteen (14) pumps with gates and five (5) gates are provided on the Chao Phraya River banks. 16 gates are installed on the polders.

In rainy season, all the above mentioned gates are closed, in principle, and no river water enters into the Study Area. In dry season, the gates are kept open. The Study Area receives surplus irrigation water of the outer areas from the north and east sides, and dilution water of the klongs from the Chao Phraya River.

The Ramkamhaeng area (9 km^2) is surrounded by a secondary polder. Inner water of the area is discharged into the K. Saen Saep by three (3) pumps with gates and three (3) gates.

Moreover, the klongs are provided with 24 gates and one (1) pump in the middle of their courses to control water flow of the klong networks.

Locations of the river banks, polders, gates and pumps are shown in Fig. 3.2.

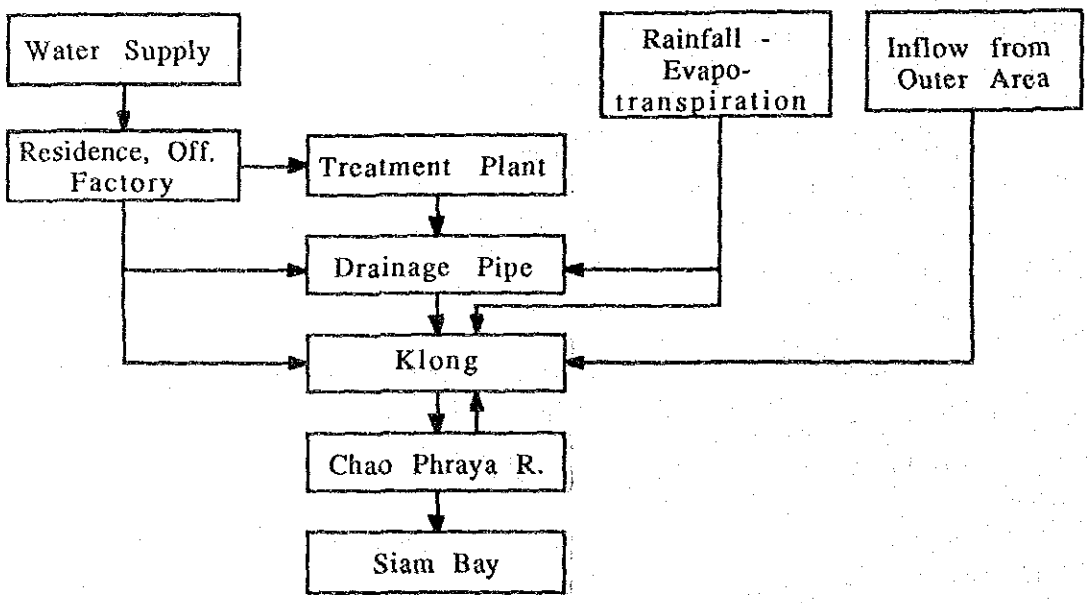
The existing gates and pumps along the Chao Phraya River banks are shown in Fig. 3.3.

3.3 Water Balance of the Study Area

The waters governing the water balance of the Study Area are:

- Water supply to the Study Area
- Rainfall in the Study Area
- Evapo-transpiration from the Study Area
- Inflow water from the outer areas of the polders
- Inflow water from the Chao Phraya River
- Outflow water to the Chao Phraya River

The water run-off routes of the Study Area are conceptualized as follows.



Typical monthly water balance of the Study Area in dry and rainy seasons, that was determined based on the daily water balances observed during the Study, are given below.

Typical Monthly Water Balance

(Unit: million m^3)

Season	Dry Season			Rainy Season		
	Income	Outgo	Remarks	Income	Outgo	Remarks
Water Supply	29			29		
Rainfall	12		31.5 mm/month	82		215 mm/month
Evapo-transpiration		21	55 mm/month		40	105 mm/month
Inflow from Outer Area	26		10 m^3/s	91		35 m^3/s
Inflow from Chao Phraya River	58			7		
Outflow to Chao Phraya River		104			169	
Total	125	125		209	209	

3.4 Bank Condition

In the city core area, the banks of the klongs are all protected by concrete retaining wall. While, in the eastern suburban areas, the concrete retaining wall is limited to some areas and most of the klongs are still under natural condition.

Length of the existing concrete retaining wall totals 112.5 km, covering 26% of the total klong stretches of 219.1 km (total bank length: 438.2 km).

Location of the existing concrete klong retaining walls is shown in Fig. 3.4.

3.5 Discharge Capacity

The water level and gradient of the klongs are largely affected by the water stage of the Chao Phraya River. The actual discharge capacity of the klong sections varies depending on their downstream water level. The expected maximum discharge capacity is calculated by the uniform flow formula on the assumption that the hydraulic gradient is equal to the existing bed slope.

The calculated maximum discharge capacities of all the klongs are shown in Fig. 3.5.

3.6 Water Flow

3.6.1 Observation of Water Flow

The Study Team made a consecutive 24 hour observation of the klong water flow at every one (1) hour interval to establish the existing conditions of the klong water flow variation, both during dry season and rainy season. In dry season, the observation was made for four (4) times at 31 selected locations of main klongs, along with water quality observation. In rainy season, the observation was made for two (2) times with the addition of five (5) more locations.

The results of observation are illustrated in details in Appendix-B.

3.6.2 Basic Flow Route

(1) Dry Season

The observed maximum dry season discharges of the major klongs along their typical flow directions, on Jan. 28 and Feb. 3-4 (two (2) times) are shown in Fig. 3.6. Those flow directions are defined as the normal flow direction (positive direction) for this project study. The normal flow direction of the major klongs are shown in Fig. 3.7.

The major routes of dilution water in dry season under the existing conditions are:

1) Bang Khen → Lad Phrao → Tan → Phra Khanong
2) Phadung Krung Kasem
3) Bang Lum Phu, Ong Ang, Phadung Krung Kasem → Mahanak → Saen Saep → Tan → Phra Khanong

Introduction of dilution water into the inner parts of K. Bang Sue and K. Sam Sen is limited due to the bottlenecks existing along their courses.

(2) Rainy Season

In rainy season, in principle, the gates on the Chao Phraya River are kept closed. No dilution water is introduced from the Chao Phraya River, instead inner water is drained into the Chao Phraya River by the drainage pumps. The major sources of the inner water are storm rainfall and surplus irrigation water from the eastern outer areas.

The typical direction of klong water flow in rainy season is quite different from the normal flow direction. The maximum discharge of the klongs in the typical flow direction of rainy season, observed during one observation of July 16-17 is shown in Fig. 3.8. The basic routes of the klong water flow in rainy season under the existing conditions of the klongs, gate and pump operation are as follows.

1) Eastern Outer Areas → Lad Phrao → Tan → Phra Khanong
2) Eastern Outer Areas → Saen Saep → Tan → Phra Khanong
3) Eastern Outer Areas → Phra Khanong

3.6.3 Characteristics of Water Flow

Characteristics of the klong water flow in typical dry and rainy seasons are summarized as follows.

(1) The klongs in the Chao Phraya River side areas are affected by the tide of the Chao Phraya River in dry season. However, they are not affected in rainy season because the gates along the Chao Phraya River bank are usually closed. The largely affected klongs are K. Bang Sue, K. Prem Prachakorn and K. Sam Sen.

(2) The Chao Phraya River side klongs in the Ratanakosin area

In dry season, Upper Phadung Krung Kasem, Bang Lum Phu, Lod, Ong Ang are maintained only to introduce the dilution water from the Chao Phraya River by a proper gate operation. On the other hand, the lower Phadung Krung Kasem is kept only to drain the introduced dilution water and wastewater by gate and pump operation. The rate of introduction of dilution water varies hourly, while the pump discharge remains constant and limited in capacity. As a result:

- When the introduced water is large, it is drained by the Krung Kasem P.S., K. Mahanak and K. Saen Saep.
- When the water introduction is small, the Krung Kasem P.S. drains not only the introduced water but also the water of K. Mahanak and K. Saen Saep.
- The water of K. Mahanak flows both in the normal and opposite directions.

During rainy season, the gates along the Chao Phraya River bank are closed and inner water is drained by pumping from the Krung Kasem P.S. Hence the water of the klongs flows towards the Krung Kasem P.S.

(3) Flow of K. Lad Phrao is nearly constant at 6 m^3/s, both in dry and rainy seasons. Its flow direction is always from north to south, the normal one throughout the year.

(4) Drainage discharge of the Phra Khanong P.S. varies to a great extent. The maximum discharge in dry season is estimated to be approximately 30 m^3/s. It is drained by opening the gates at the time of low tide. At the time of high tide, the pumps are operated to discharge the water at 9 m^3/s to 24 m^3/s. While in the rainy season, a large number of pumps are operated to discharge the water at 60 to 80 m^3/s.

(5) Dilution water from the Chao Phraya River is introduced during high tide. However, part of the introduced water is discharged again into the Chao Phraya River during low tide.

Based on the survey results dealt with in the previous section, it is concluded that

- Introduction of dilution water from the Chao Phraya River during typical dry season is approximately one (1) million m^3 per day. (about 12 m^3/s)
- Introduction of dilution water from the Chao Phraya River during typical rainy season is negligible.

3.7 Water Quality

3.7.1 Water Quality under Steady State

3.7.1.1 Yearly and Seasonal Variation

No significant yearly variation in water quality is recognized based on the available data in the recent six (6) years (1981-1986).

Clear seasonal changes of the water quality have been observed in some part of the Study Area in recent years. Average water quality (BOD) in dry (Nov.-Apr.) and rainy (May-Oct.) seasons during the period between 1984 and 1986 is shown in Fig. 3.9.

(1) In the Chao Phraya River side and the Ratanakosin areas, the klong water shows a lower BOD concentration in dry season than in rainy season. This may be due to the effects of the gate and pump operation that was improved after the 1983 floods.

(2) The water in K. Tan and the lower reaches of K. Phra Khanong is less contaminated in rainy season than in dry season. This may be due to the fact that the klongs collect the rainfall water of a wide area in rainy season thereby diluting the pollution loads.

(3) However, the klongs in the other inner parts of the Study Area show no clear difference between dry and rainy seasons. It seems that the inner areas are little benefited either by the dilution water from the Chao Phraya River or by the dilution effects of rainfall.

3.7.1.2 Regional Distribution

Based on the recent water quality data of six (6) years (1981-1986), the klong water quality of the Study Area varies to a great extent depending on the locality.

(a) DO

The regional distribution of DO is shown in Fig. 3.10. A comparatively high DO value (1-2 mg/l) is observed in the Chao Phraya River side and Eastern Suburban areas. While in the inner part areas, DO is nearly zero, indicating anaerobic conditions.

(b) BOD

The regional distribution of BOD is shown in Fig. 3.11. Moderate BOD contents less than 20 mg/l is observed in the Chao Phraya River side and Eastern Suburban areas. High BOD values with 20 - 50 mg/l are observed in the inner areas.

This regional variation in water quality is attributed to the following factors:

- The klong water in the Chao Phraya River side areas is improved by dilution / flushing water from the Chao Phraya River in dry season.
- The Eastern Suburban area is sparsely populated.
- The klongs in the core and inner areas receive high pollution load from the drainage areas.

The variation of other water quality parameters, COD, SS and NH_4N are as follows (for details refer to Appendix-B):

COD	10 ~ 130 mg/l
S S	9 ~ 76 mg/l
NH_4N	0.1 ~ 9.8 mg/l

These variations are in conformity with the variation of DO and BOD.

3.7.1.3 Color and Odor of Klong Water

Color and odor tests were conducted during the middle of March (dry season) and the beginning of August, 1988 (rainy season) for the whole Study Area. The test results are shown respectively in Fig. 3.12 and Fig. 3.13. Additional tests were also conducted for the City Core Area in July, 1988.

Based on these observations the following overall phenomenon could be recognized, qualitatively, concerning the klong water.

(1) There was a significant variation in klong water quality between dry season and rainy season, in the klongs along the Chao Phraya River. These klongs were greenish with no odor in dry season, but were blackish with strong odor in rainy season. This is attributed to introduction and non-introduction (opening and closing of gates) of dilution water in these seasons.

(2) No significant benefit to the klongs in inner areas are realized by the introduction of dilution water. The water quality of these klongs are rather polluted with blackish color and strong odor, and the condition deteriorated further during rainy season.

3.7.1.4 Bed Material

Investigation of bed material properties and mud layer were conducted in the main klongs in the Study Area during mid-March and mid-August, 1988. Mud layers thicker than 1.0 m, as shown in Fig. 3.14, were found in the K. Bang Khen, K. Bang Sue, K. Sam Sen, K. Mahanak, K. Saen Saep, and K. Huai Khwang, which are severely polluted. Other klongs had mud layers varying from 0.5 to 1.0 m thick. The bed material is organic in nature and emitted strong odor.

3.7.2 Water Quality under Unsteady State

3.7.2.1 Consecutive Water Quality Observation

Consecutive water quality observations, together with the discharge and flow direction, were made by the Study Team at thirty-two (32) locations during the dry season and at thirty-five (35) locations during the rainy season at selected main klongs, in order to examine the klong water quality variation. The results of observation are illustrated in Appendix-B.

3.7.2.2 Characteristics of Klong Water Quality

From the above-mentioned consecutive observation results, the characteristics of the klong water in the Study Area are summarized as follows:

(1) Lower BOD values are observed in the klongs with a large discharge. While, high BOD values are observed in the klongs having a small discharge.