KINGDOM OF THAILAND

MINISTRY OF AGRICULTURE AND COOPERATIVES

ROYAL IRRIGATION DEPARTMENT

THE EAST COAST WATER RESOURCES DEVELOPMENT PROJECT (PHASE II)

VOLUME 5-2

SECTORAL REPORT

V ENVIRONMENTAL ASPECTS

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VIII GEOLOGY

IX GROUNDWATER RESOURCES

AUGUST 1983

JAPAN INTERNATIONAL COOPERATION AGENCY

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LIST OF VOLUMES

ABBREVIATIONS AND LOCAL TERMS

A. ABBREVIATION OF MEASURES

(1) Length
- mm = millimetre
- cm = centimetre
- m = metre
- km = kilometre

(2) Area
- m^2 = square metre
- ha = hectare = $10^4 m^2$
- km^2 = square kilometre = $10^6 m^2$
- rai = 0.16 ha

(3) Volume
- lit, l = litre = 1,000 cm^3
- kl = kilolitre = 1 m^3
- m^3 = cubic metres
- MCM = million cubic metres = 1,000,000 m^3

(4) Weight
- mg = milligramme
- g = gramme
- kg = kilogramme
- t = ton = 1,000 kg
- qwt = quintal = 100 kg

(5) Time
- s = second
- min = minute
- h = hour
- d = day
- yr = year

(6) Money
- ฿ = Baht (unit of Thai currency US$ 1 = ฿ 23.0)
- $ = US dollar
- ¥ = Japanese Yen

(7) Electric Measures
- kV = kilovolt
- kW = kilowatt
- MW = megawatt = 1,000 kW
- kWh = kilowatt hour
- kVA = kilovolt Ampere

(8) Other Measures
- mmho = micromho = conductance
- ppm = parts per million
- ppb = parts per billion
- % = per cent
- LCD = litre per capita per day
- PS = 0.736 kW
- pH = scale for acidity
- ° = degree
- ' = minute
- " = second
- °C = degree centigrade
- 10^3 = thousand
- 10^6 = million
- 10^9 = billion (milliard)

(9) Derived Measures Based on the Same Symbols
- m^3/s = cubic metre per second
- ton/ha = ton per hectare
- $10^6 m^3/yr$, MCM/yr = million cubic meter per year

B. OTHER ABBREVIATIONS

- GDP = gross domestic product
- GRP = gross regional product
- El. = elevation
- HWS = high water surface
- SD = sanitary district
- DA = development area
- ESS = Eastern Seaboard Study
- FOB = free on board
- CIF = cost, insurance and freight
- WHO = World Health Organization

C. ABBREVIATION OF ORGANIZATIONS

MOAC	Ministry of Agriculture and Cooperatives
RID	Royal Irrigation Department
DOF	Department of Fisheries
LDD	Land Development Department
NESDB	National Economic and Social Development Board
NEB	National Environment Board
NSO	National Statistical Office
MOI	Ministry of Industry
DMR	Department of Mineral Resources
DIW	Department of Industrial Works
MOC	Ministry of Communications
HD	Harbor Deparment
DHW	Department of Highways
DOH	Department of Health
RTN	Royal Thai Navy
PWWA	Public Water Works Authority
MD	Meteorology Department
DOLA	Department of Local Administration
TAT	Tourism Authority of Thailand

D. LOCAL TERMS

Changwat	:	Province
Amphoe	:	District (Township)
Tambon	:	Township (Town)
Muban	:	Village
Muang	:	Administrative Center of Province
King Amphoe	:	Sub-district
Mae Nam	:	River
Khwae	:	Main tributary of a river
Huai	:	Stream, creek or small tributary
Khlong	:	Canal
Khao	:	Mountain

SECTORAL REPORT V
ENVIRONMENTAL ASPECTS

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1. INTRODUCTION

This sectoral report presents the result of preliminary evaluation of impacts of water resources development on the environmental aspects of the Study Area.

Chapter 2 presents the result of the assessment of surface water quality of rivers based on the available data with the view of followings.

(1) To introduce the water quality standard/criteria being adopted in Thailand.

(2) To evaluate the water quality of surface water in the Khlong Luang and Rayong rivers, in which the water resources development facilities are being planned.

(3) To reveal water pollutant sources presently existent.

(4) To assess preliminarily the quantity of polluted effluent to rivers.

Chapter 3 contains study items such as physical resources, ecological resources, human use values and quality of life values. These items are set up on the basis of "The Manual of NEB Guidelines for Preparation of Environmental Impact Evaluation".

2. WATER QUALITY

2.1 Water Quality Standard

In Thailand, there are three kinds of water quality standard established by National Environment Board (NEB), Department of Health (DOH), and Department of Industrial Works (DIW).

(1) NEB Standard

This standard is applied to fresh surface water, mainly river, from the viewpoint of maintenance of natural environment.

Rivers are classified into five classes based on the purpose of water use. For such uses as domestic, fishery and agriculture, certain level is required to be preserved for several items and water quality is managed to satisfy the required standard. Until now classification has been completed only along the Chao Phraya river. Details of NEB standard are shown in Tables 1 and 2.

(2) DOH Standard

The DOH is now preparing water quality standard for water supply, which is expected to be issued in 1983. For the time being, The standards recommended by WHO, comprising the standard for potable water and that for water source, are applied. Tables 3 and 4 present the DOH standards.

(3) DIW Standard

This standard is applied to wastewater from industrial factories and is presented in Table 5.

The NEB standard is deemed most suitable for the study, since it mainly concerns with water quality of fresh surface water of rivers.

2.2 Water Quality at Present

2.2.1 Rayong River

A series of water quality surveys has been carried out at the Rayong river by DOH. Data is available for five consecutive years from 1978 to 1982 at four sampling points along the Rayong river. The sampling points

are located at 3 km, 8 km, 10 km and 13 km upstream of the river month respectively.

Tables 6 to 9 show the survey results and Table 10 presents the comparison of the survey results and the NEB Standard. They are summarized in the table below for the year 1982.

Grade of Water Quality by NEB Standard

Items	Sampling Points			
	1	2	3	4
Dissolved Oxygen	3	3	3	3
Biochemical Oxygen Demand (BOD)	3	2	3	1
Total Coliform	4	1	1	1
Nitrogen (NO_3)	1-3	1-3	1-3	1-3
Copper (Cu)	1-3	1-3	1-3	-

Source : DOH

The results show that most of the items are classified into the grade between the first and the third. Water of these grades can be used for agriculture, fishery and domestic use. For domestic use general treatment is needed.

At present water of the Rayong river is used for irrigation water in Ban Khai area as well as for domestic use in Ban Khai and Rayong. There are two water works along the river; Ban Khai rural water works and Rayong large scale water works. Water quality of the Rayong river at present satisfies the required standard for domestic purpose.

2.2.2 Khlong Luang River

Two kinds of data are available concerning the water quality of the Khlong Luang river as shown in Tables 11 and 12. Table 11 indicates the results of the survey conducted in 1970. The survey was carried out aiming at evaluating the suitability of water for irrigation use and the

quality was judged to be acceptable for that purpose.

Result of the survey conducted jointly by RID and the study team in 1982 is summarized in the table below and presented in Table 12.

Survey Result of Khlong Luang River

Items	Unit	Result	Corresponding Grade by NEB Standard
Nitrogen (NH_3)	ppm	nil	1-3
Nitrogen (NO_3)	ppm	0.58	1-3
Manganese (Mn)	ppm	0.15	1-3
BOD	ppm	5.0	5

Comparison with NEB Standard is presented in Table 10.

The result shows that most items are classified into the grade between the first and the third except BOD. Although BOD is classified into the grade 5 based on the NEB standard, it is within the permissible level according to the DOH standard for water source which sets the maximum level at 6 ppm.

At present, water of Khlong Luang river is used out of harm's way for agricultural use and for domestic use for which water is taken at Tha Bun Mi water works. The water supply for Tha Bun Mi is treated in general way.

Despite the general conclusion reached above, it is expected that the more broad and detailed data are collected by establishing the monitoring system in the Khlong Luang river.

2.3 Existing Water Pollutant Sources

An attempt was made to find out the major pollutant sources in such sectors as industrial, domestic, and livestock in the Study Area and then to roughly estimate quantity of polluted effluent to rivers. BOD is used as a indicator of water quality, because it is useful to indicate a level of organic pollution and is easy to be estimated.

BOD load is estimated by the following general formula.

$$L = A \times \sum_{i} Bi \times Ni$$

where, L : BOD load

A : run-off ratio, defined as a rate of waste which reaches major rivers to the total waste discharged from pollution sources

Bi: basic unit of BOD load in the activity i.

Ni: number of pollution sources in the activity i.

(1) Pollution from industrial sector

In the present study, tapioca starch mills and white sugar mills are taken into account for estimation of BOD loads from industrial waste for the two reasons.

(a) Firstly, as shown in Sectoral Report I, Socio-Economy, the industrial activities in the Study Area are, at present, mainly based on agro-industry, particularly tapioca and sugar industries.

(b) Secondly, BOD load from tapioca starch mill and white sugar mill is remarkably high compared with other industrial activities as shown in Table 14.

The total BOD load is estimated based on the following basic assumptions.

(a) On the average, BOD loads are 6,000, 1,100 and 4,500 kg/day/factory for tapioca starch mill of first grade type, that of second grade type and white sugar mill respectively. Tapioca starch mill of the first grade type is featured by the machine-

oriented process, including centrifugal process, as shown in Fig. 1, the second grade type is simpler and has the labour intensive process with a little mechanization, as shown in Fig. 2.

(b) 30% of BOD is being removed by treatment system owned by factories.

(c) The run-off ratio is broadly taken at 60% based on empirical data in Japan.

(d) The number of tapioca starch mills is 61 and that of white sugar mills is 8 in the Study Area as shown in Table 13.

(e) 15% of the total tapioca mills is of the first grade type, while 85% of that is of the second grade type.

The total BOD load from the industry is estimated at about 62 tons per day for the whole Study Area as shown in Table 15.

(2) Pollution from domestic sewage

The total BOD load is estimated based on the following basic assumptions.

(a) In the Study Area, most of domestic sewage is discharged by permeation-type, which removes Suspended Solids but hardly decreases BOD load. Hence, the basic unit of BOD load which is assumed to be 40 g/day/person is considered to discharge totally into rivers.

(b) The run-off ratio is 60% for urban area and 10% for rural area.

(c) Population in 1981 is 358 x 10^3 in urban area and 570 x 10^3 in rural area.

The estimated total BOD load is 11 tons per day for the whole Study Area as presented in Table 16.

(3) Pollution from livestock

The following basic assumptions are introduced in estimating BOD load.

(a) The Basic units of BOD load are 640 g/day/head for buffalo and cattle and 200 g/day/head for swine respectively.

(b) The run-off ratio is 5%.

(c) Number of livestock is as shown in Table 17.

Consequently, BOD load is estimated to be 3 tons/day at present as shown in Table 17.

(4) Total BOD load

The total BOD load in the Study Area is estimated to be 76 tons/day at present as shown in Table 18. The most influencial pollutant source is the industrial source, especially tapioca starch mills and white sugar mills, whose BOD load accounts for 82% of the total BOD load. The domestic sewage source weighs down 14% and the livestock source 4%.

2.4 Water Quality in Future

(1) Probable pollutant source in industry

The prospect of industrial activity in future comprises two elements. One is the prospect of existing industry, particularly tapioca starch and white sugar industries, and the other is that of heavy industries newly planned by the Eastern Seaboard development.

For tapioca factories and sugar mills, no considerable growth in number is expected for the following reasons. Firstly, there is little room left in the Study Area for expansion of such upland crops as sugarcane and cassava. Secondarily, the policy of the diversification from cassava to other crops will be promoted to lower the production of cassava to meet the demand level based on the Fifth National Plan. Thirdly, neighbourhood of the Study Area including

the southern part of Northeastern region has no major productive area of sugarcane. For these reasons, it is justified to conclude that there is hardly possibility that the number of the factories which are the pollutant source of river water will increase in the future.

With regard to the Eastern Seaboard development, the significant increase in industrial activities is expected mostly along the seashore. Wastewater from the new industrial centers will be discharged directly to the sea and is considered to have little effect on the river water.

For these reasons, it is concluded that no industrial pollutant source is expected to increase in the Study Area in future, so far as river water is concerned.

(2) Prospect of domestic pollutant sources

The pollutant from domestic sewage will increase because of population growth and improvement in living standard.

Basic figures for domestic sewage is assumed for the year 2001 as follows:

(a) The basic unit of BOD load will increase from 40 g/day/person to 45 g/day/person in 2001.

(b) The run-off ratio will be kept at the present level of 60%.

(c) Population in 2001 is projected as follows:

Urban : 705×10^3

Rural : 645×10^3

The BOD load from domestic sewage is estimated to be 22 tons/day in 2001 as shown in Table 16.

(3) Livestock pollutant source

The pollutant from livestock is assumed to be negligibly small even though increase takes place in future in view of its small share in the total BOD load.

(4) Water quality in future

As discussed already, pollutant source which is considered to increase in future is domestic sewage water. Increase of BOD load in domestic sewage is projected to increase by 100% from 11 ton/day in 1981 to 22 ton/day in 2001. Total BOD load in the Study Area will increase by 13% from 76 ton/day to 87 ton/day in 2001 as presented in Table 18. Consequently, share of three pollutant sources in the total BOD load will be 71%, 25% and 4% for industrial, domestic and livestock respectively.

3. ENVIRONMENTAL IMPACT EVALUATION

3.1 NEB Guideline

The National Environmental Board (NEB) is the responsible agency for preservation of the nation's environment and making recommendations to the Government on environmental impacts of projects. NEB prepared "The Manual of NEB Guidelines for Preparation of Environmental Impact Evaluation" in 1979, which contains study items and descriptions for evaluation of various kinds of projects. The Chapter "Dam and Reservoir" includes the following four items:

(1) Physical resources

This item deals with physical aspects of environmental impacts of a project.

(2) Ecological resources

This item deals with ecological aspects of environmental impacts of a project.

(3) Human use values

This item comprises impacts evaluation on human life originating directly from construction of dams and other facilities.

(4) Quality of life values

This item comprises evaluation of beneficial and adverse effects on human life originating indirectly from construction of dams and other facilities.

Based on this guideline, the environmental impact evaluation of the project are presented.

3.2 River Maintenance Flow

In the water resources development of the Study Area, the concept of river maintenance flow is introduced in order to minimize the possible adverse effects on the environment.

The river maintenance flow is the minimum discharge which is able to maintain water depth, flow velocity, water quality, channel stability, aquatic ecosystem and scenery to the extent necessary for navigation, fish catch, operation and maintenance of intakes, maintenance of river facilities, sea water repulsion, prevention of estuary clogging, conservation of groundwater, preservation of riparian land and people's amenity.

3.3 Physical Resources

(1) Soils

The soils of the Khlong Luang, Ban Khai Extension, Thap Ma, and Ban Khai Irrigation Scheme areas mainly belong to the soils of recent alluvium, which are mainly clayey, but locally loamy or even sandy in the minor brook valleys. These soils are moderately suitable for rice and upland crop cultivation.

In agricultural development plan, groundnuts and mungbeans are proposed as second crops after rice in a rotation cropping system taking into account their function of soil improvement, in order to minimize the reduction of fertility of soil which might be caused by continuous irrigation and drainage.

3.4 Ecological Resources

(1) Fisheries

As for inland fishery, the main activity is fish pond culture. The fish catch in the two provinces is only 2×10^3 tons in 1980 or 1.5% of the whole Thailand and commercial fishery of large scale is not found.

Although slight change in ecological system might take place, the construction of dams will not bring about serious effect on the fishery at downstream of the rivers, since river maintenance flow is guaranteed. By the development of new reservoir, chances will be increased for fishry and fish catch and it will contribute to the improvement of the living standard of local people to a great extent.

(2) Fauna and flora

It is difficult to assess the impacts on fauna and flora because few data and information are available at present.

River water system and flood-chain might be changed because of the construction of dams. But its impact on the area is considered to be small because the impounded area of dams is small compared with the total catchment area and no rare species to be protected have been reported in the Study Area according to the data collected from the Royal Forest Department.

(3) Forests

Forests to be conserved are established by the Royal Decree in Thailand. In the two provinces, 15 forest reserves are established and cover an area of about 2,794 km^2.

Forest of Pa Tha Bun Mi and Bo Thong was established in 1964 as a forest to be conserved. The impounded area of the Khlong Luang dam includes 1.28 km^2 of this forest, which is 0.5% of its total area of 273 km^2. The impact of submergence on the conservation of forest is considered to be negligible small in view of its small share in the total forest area.

(4) Fertilizer and agro-chemical use

Major crops cultivated in the Study Area are rice, cassava and sugarcane. At present, as for rice, most of formers apply no fertilizer or agro-chemicals.

In accordance with the agricultural development in the project areas, more fertilizer and pesticide will be applied to the production of crops.

However, its impact on water quality and other environmental aspects is considered to be little. Amount of fertilizer being planned to be introduced is 30-100 kg/ha of nitrogen and 20-50 kg/ha of phosphate for rice of which amount is not especially big compared with the practice of other countries. Besides, most fertilizer and pesticide at present do not contain such harmful substance as being toxic to fish etc. Introduction of new agricultural imports, however, should be carefully promoted with due attention to the maintenance of environment.

3.5 Human Use Values

(1) Water supply

Newly developed water will be supplied stably for domestic and industrial use and for irrigation as follows:

Water Supply (MCM/year)	Dam Scheme		
	Khlong Luang	Khlong Yai	Khlong Thap Ma
Domestic and industrial water supply	12.4	31.3	0
Irrigation water supply	60.1	65.8	30.6

In the Study Area, present service factor, which is the ratio of population served with pipe-water supply to the total population in the area is estimated to be 53%, 53% and 3% in the Development, non-development and rural areas, respectively. In 2001, service factor is expected to increase to 100%, 70% and 30% in these areas, respectively in accordance with water resources development.

The irrigation area, which covers approximately 27,140 ha at present will be expanded to 39,440 ha by the year 2001 along with the irrigation development.

Prevailing of pipe water supply will contribute to the decrease of water-borne diseases, such as malaria, dengue fever and liver flukes. Use of clean water will improve the sanitary conditions of the local people.

(2) Flood control

The rivers in the Study Area are narrow and meandering remarkably. The flooding pose a severe hazard to the population and exert a negative effect on economic growth of the area.

The construction of dams will reduce the magnitude and frequency of flooding remarkably and contribute to the social and economic development of the area greatly.

3.6 Quality of Life Values

(1) Socio-economy

The water resources development project in the Study Area aims chiefly at supplying domestic, industrial and irrigation water. Domestic and industrial water supply is one of the most essential requisites for the Eastern Seaboard Development, which is one of the key projects in the Fifth National Plan. Agricultural development in accordance with irrigation water supply in the rural backward area is also essential to promote the balanced development of the regional economy.

Thus, water resources development in the Study Area is one of the basic requisites for the economic development of the area, and in this respect, induces great effect on the living of the local inhabitants and economic activities in the area.

(2) Recreation

The rapid increase of population in the Study Area will cause a significant increase in the use of reservoir for recreational activities, such as fishing, camping, day picknicking and boating.

Rapid urbanization in the Study Area will exalt the importance of natural resources including reservoir for their recreational use.

3.7 Preliminary Evaluation

Environmental impacts of the Khlong Luang, Khlong Yai and Khlong Thap Ma Dam Schemes are evaluated in numerical values according to the NEB standard and presented in 20.

4. RECOMMENDATIONS

Environmental impacts of the Schemes are evaluated preliminarily in the present study. It is proposed that detailed study will be conducted according to the NEB standard at the implementation stage of the Schemes.

Following actions are recommended to be taken by the executive agency before the implementation of the Schemes.

(1) Detailed survey on the environmental conditions in the Scheme areas

(2) Establishment of specific counter measures against possible adverse effect

(3) Establishment of regular monitoring system on water quality, fauna and flora, etc.

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TABLES

Table 1 NEB STANDARD FOR FRESH SURFACE WATER

Item	Unit	Class				
		1	2	3	4	5
Temperature	°C	n	n'	n'	n'	-
Dissolved oxygen (DO)	ppm	n	6	4	2	-
Biochemical oxygen demand (BOD)	ppm	-	1.5	2.0	4.0	-
pH	-	6-8	6-8	6-8	6-8	6-8
Coliform bacteria	MPN/100ml					
- Total coliform		-	5,000	20,000	-	-
- Faecal coliform		-	1,000	4,000	-	-
Nitrate (NO_3) as N	ppm	5.0				
Ammonia (NH_3) as N	ppm	0.5				
Phenols	ppm	0.05				
Copper (Cu)	ppm	0.1				
Nickel (Ni)	ppm	0.1				
Manganese (Mn)	ppm	1.0				
Zinc (Zn)	ppm	1.0				
Radioactivity	curie	none				
Toxic substances						-
Total Mercury (Hg)	ppm	0.002				
Cadmium (Cd)	ppm	0.005/1, 0.05/2				
Chromium (Cr)	ppm	0.05				
Lead (Pb)	ppm	0.05				
Arsenic (As)	ppm	0.01				
Cyanide (CN)	ppm	0.005				
Pesticides	ppm	0.05				

Note ; n natural state
n' natural state but changing not more than 3°C

/1 : Water hardness expressed as $CaCO_3$ less than 100 ppm
/2 : Water hardness expressed as $CaCO_3$ more than 100 ppm

Source : NEB

Table 2 WATER QUALITY CRITERIA OF FRESH SURFACE WATER
(CLASSIFICATION STANDARDS)

Class	Standard (Water Use)
1	Very good quality water sources used for - consumption and supply without passing any treatment except normal sterilizing - conservation of water sources ecosystem to enhance the natural growth of basic life
2	Good quality water source used for - consumption and supply after general treatment - conservation of aquatic life with regard to fishery - fishery - entertainment
3	Medium quality water sources used for - consumption and supply after general treatment - agriculture
4	Fair quality water sources used for - consumption and supply after special treatment - industrial purposes - other purposes
5	Water sources which are not in class 1-4 used for - transportation

Source : NEB

Table 3 DOH STANDARD FOR POTABLE WATER

Item	Unit	Highest desirable level	Maximum permissible level
pH	-	7.0-8.5	6.5-9.2
Colour, Pt-Co scale	Units	5	50
Turbidity, Silica scale	Units	5	25
Total solids	mg/l	500	1,500
Hardness (as $CaCO_3$)	mg/l	100	500
Calcium (as Ca)	mg/l	75	200
Magnesium (as Mg)	mg/l	30/1	150
Iron (Total as Fe)	mg/l	0.1	1.0
Manganese (as Mn)	mg/l	0.05	0.5
Copper (as Cu)	mg/l	0.05	1.5
Zinc (as Zn)	mg/l	5	15
Lead (as Pb)	mg/l	-	0.1
Chromium (Total as Cr)	mg/l	-	0.05
Cadmium (as Cd)	mg/l	-	0.01
Sulfate (as SO_4)	mg/l	200	400
Chloride (as Cl)	mg/l	200	600
Fluoride (as F)	mg/l	0.6-0.8/2	-
Nitrate (as N)	mg/l	-	10
Coliform bacteria 37 °C 48 hrs.	(MPN/100 ml)	less than 2	-

/1 : Not more than 30 mg/l if there are 250 mg/l of sulfate; if there is less sulfate, magnesium up to 150 mg/l may be allowed.

/2 : Annual average of maximum daily air temperature 26.3-32.6 °C

Source : DOH

Table 4 DOH STANDARD FOR WATER SOURCE

Item		Standard
Colour, Pt-Co scale	Units	300
Dissolved solids	mg/l	1,500
Iron (as Fe)	mg/l	50
Manganese (as Mn)	mg/l	5
Copper (as Cu)	mg/l	1.5
Zinc (as Zn)	mg/l	1.5
Lead (as Pb)	mg/l	0.05
Chromium, hexavalent (as Cr)	mg/l	0.05
Fluoride (as F)	mg/l	1.5
Ammonia (as NH_3)	mg/l	0.5
Total Nitrogen (as N)	mg/l	1
Nitrate (as N)	mg/l	10
Biochemical Oxygen Demand	mg/l	6
Chemical Oxygen Demand	mg/l	10

Bacteriological Standards

Classification	Coliform bacteria /1 (MPN/100 ml)
I. Bacterial quality applicable to disinfection treatment only	0-50
II. Bacterial quality requiring conventional methods of treatment (coagulation, filtration, disinfection)	50-5000
III. Heavy pollution requiring extensive types of treatment	5000-50000
IV. Very heavy pollution, unacceptable unless special treatments designed for such water are used : source to be used only when unavoidable	greater than 50000

/1 : When more than 40% of the number of coliform bacteria represented by the MPN Index are found to be of the faecal coliform group, the water source should be considered to fall into the next higher category with respect to the treatment required.

Source : DOH

Table 5 DIW STANDARD FOR INDUSTRIAL WASTE WATER

Item	Unit	Maximum permissible level
pH	-	5-9
Permanganate value	ppm	60
Dissolved solids	ppm	2000
Sulfite (SO_2) as H_2S	ppm	1
Cyanide (CN) as HCN	ppm	0.2
Copper (Cu)	ppm	1.0
Nickel (Ni)	ppm	0.2
Manganese (Mn)	ppm	5.0
Zinc (Zn)	ppm	5.0
Mercury (Hg)	ppm	0.005
Cadmium (Cd)	ppm	0.03
Chromium (Cr)	ppm	0.5
Lead (Pb)	ppm	0.2
Arsenic (As)	ppm	0.25
Barium (Ba)	ppm	1.0
Selenium (Se)	ppm	0.02
Tar	-	nil
Oil and grease	ppm	5
Formaldehyde	ppm	1
Phenols & Cresols	ppm	1
Free Chlorine	ppm	1
Insecticide & Radioactive substance	-	nil
BOD (at 5 day, 20 °C)	ppm	20-60
Temperature	°C	40

Source : NEB

Table 6 WATER QUALITY ANALYSIS OF RAYONG RIVER AT 3 KM POINT

(Unit : ppm)

Items	1978	1979	1980	1981	1982
pH	6.6	7.0	8.2	6.1	6.8
Conductivity /1	550	7,000	50,000	1,000	900
Dissolved Oxygen	3.7	3.8	14.0	4.7	5.0
Color (Pt-Co Scale)	>500	35	30	45	75
Turbidity (JTU.)	480	95	15	270	40
Suspended solids	78	91	17	220	35
Dissolved solids	564	3,917	27,117	750	487
Alkalinity (Total $CaCo_3$)	26	-	-	-	-
Calcium (Ca)	14	-	-	-	-
Magnesium (Mg)	12	-	-	-	-
Chloride (Cl)	188	1,819	12,796	270	54
Nitrogen (Total)	2.35	1.06	0.28	1.74	1.12
Nitrogen (NH_3)	-	-	-	1.74	-
Nitrogen (NO_3)	0.50	0.70	0.65	0.50	0.10
Phosphorus (PO_4)	0.20	0.14	0.02	0.10	0.82
BOD_5	<1	1.9	5.3	2.0	2.3
Arsenic (As)	-	-	-	-	nil
Cadmium (Cd)	-	-	-	-	nil
Chromium (Cr)	-	-	-	-	nil
Copper (Cu)	-	-	-	0.09	0.002
Iron (Fe)	-	-	-	4.7	1.50
Lead (Pb)	-	-	-	0.06	nil
Manganese (Mn)	-	-	-	0.27	0.08
Mercury (Hg) /2	-	-	-	0.08	0.43
Zinc (Zn)	-	-	-	0.13	0.13
Coliform bacteria (MPN/100 ml)	-	4,600	2,400	>24,000	24,000
Faecal bacteria (MPV/100 ml)	-	<20	80	16,000	7,800
Date of sampling	May 18	May 17	Apr. 13	May 20	Jun. 3

/1 : Indicated in micromhos/cm.

/2 : Indicated in ppb

Note ; Sampling addres : Sapan Chalermchai, A.M. Rayong, 3 km upstream from the river mouth

Source : DOH

Table 7 WATER QUALITY ANALYSIS OF RAYONG RIVER AT 8 KM POINT

(Unit : ppm)

	1978	1979	1980	1981	1982
pH	6.7	6.9	8.2	5.8	-
Conductivity/1	450	1,500	30,000	5,000	-
Dissolved Oxygen	2.6	5.1	11.2	3.7	-
Color (Pt-Co scale)	500	45	40	45	-
Turbidity (JTU.)	420	75	30	65	-
Spspendid solids	65	60	38	35	-
Dissolved solids	542	850	16,948	2,965	-
Alkalinity (Total, $CaCO_3$)	26	-	-	-	-
Calcium (Ca)	10	-	-	-	-
Magnesium (Mg)	9	-	-	-	-
Chloride (Cl)	131	326	8,297	1,330	-
Nitrogen (Total)	1.96	1.40	0.62	2.02	-
Nitrogen (NH_3)	-	-	-	2.02	-
Nitrogen (NO_3)	0.40	0.60	0.25	0.16	-
Phosphorus (PO_4)	0.39	0.20	0.02	0.16	-
BOD_5	2.4	1.6	4.4	1.2	-
Arsenic (As)	-	-	-	-	-
Cadmium (Cd)	-	-	-	-	-
Chromium (Total)	-	-	-	-	-
Copper (Cu)	-	-	-	0.02	-
Iron (Fe)	-	-	-	1.7	-
Lead (Pb)	-	-	-	0.03	-
Manganese (Mn)	-	-	-	0.15	-
Mercury (Hg)/2	-	-	-	0.33	-
Zinc (Zn)	-	-	-	0.12	-
Coliform bacteria	-	48,000	1,300	1,700	-
Faecal coliform bacteria	-	35,000	50	700	-
Date of Sampling	May 18	May 17	Apr. 13	May 20	-

/1 : micromhos/cm

/2 : Indicated in ppb

Note ; Sampling address : Ban Noen Phra, A.M. Rayong, 8 km upstream of the river mouth

Source : DOH

Table 8 WATER QUALITY ANALYSIS OF RAYONG RIVER AT 10 KM POINT

(Unit : ppm)

	1978	1979	1980	1981	1982
pH	6.5	6.9	7.0	-	7.6
Conductivity/1	80	120	900	-	100
Dissolved Oxygen	3.8	3.9	5.2	-	5.6
Color (Pt-Co Scale)	>500	45	40	-	90
Turbidity (JTU.)	480	90	40	-	40
Suspended solids	387/2	79	29	-	63
Dissolved solids		239	395	-	149
Alkalinity (Total, $CaCO_3$)	34	-	-	-	-
Calcium (Ca)	7.2	-	-	-	-
Magnesium (Mg)	0.9	-	-	-	-
Chloride (Cl)	6	12	161	-	2
Nitrogen (Total)	1.46	1.40	1.46	-	0.84
Nitrogen (NH_3)	-	-	-	-	-
Nitrogen (NO_3)	0.50	0.70	0.10	-	0.27
Phosphorus (PO_4)	0.32	0.09	0.04	-	nil
BOD_5	<1	3.4	2.8	-	2.1
Arsenic (As)	-	-	-	-	nil
Cadmium (Cd)	-	-	-	-	nil
Chromium (Total)	-	-	-	-	nil
Copper (Cu)	-	-	-	-	0.004
Iron (Fe)	-	-	-	-	2.69
Lead (Pb)	-	-	-	-	nil
Manganese (Mn)	-	-	-	-	0.13
Mercury (Hg) /3	-	-	-	-	nil
Zinc (Zn)	-	-	-	-	0.15
Coliform bacteria	-	6,200	3,500	-	4,600
Faecal coliform bacteria	-	4,900	780	-	1,300
Data of Sampling	May 18	May 17	Apr. 13	-	Jun. 3

/1 : micromhos/cm

/2 : total solids

/3 : Indicated in ppb

Note ; Sampling addres : Sapan Ramphonsa, A.M. Rayong, 10 km upstream from the river mouth

South : DOH

Table 9 WATER QUALITY ANALYSIS OF RAYONG RIVER AT 13 KM POINT

(Unit : ppm)

	1978	1979	1980	1981	1982
pH	6.5	6.5	7.3	-	-
Conductivity /1	100	110	150	-	-
Dissolved Oxygen	4.8	5.0	5.3	-	-
Color (Pt-Co scale)	>500	45	35	-	-
Turbidity (JTU.)	480	95	40	-	-
Suspendid solids	87	91	18	-	-
Dissolved solids	261	210	145	-	-
Alkalinity (Total, $CaCo_3$)	34	-	-	-	-
Calcium (Ca)	7.2	-	-	-	-
Magnesium (Mg)	0.9	-	-	-	-
Chloride (Cl)	5	10	19	-	-
Nitrogen (Total)	2.30	0.95	1.12	-	-
Nitrogen (NH_3)	-	-	-	-	-
Nitrogen (NO_3)	0.50	0.70	0.10	-	-
Phosphorus (PO_4)	0.08	0.48	0.02	-	-
BOD_5	<1	1.4	1.2	-	-
Arsenic (As)	-	-	-	-	-
Cadmium (Cd)	-	-	-	-	-
Chromium (Total)	-	-	-	-	-
Copper (Cu)	-	-	-	-	-
Iron (Fe)	-	-	-	-	-
Lead (Pb)	-	-	-	-	-
Magnanese (Mn)	-	-	-	-	-
Mercury (Hg)	-	-	-	-	-
Zinc (Zn)	-	-	-	-	-
Coliform bacteria	-	700	2,400	-	-
Faecal coliform bacteria	-	460	270	-	-
Date of sampling	May 18	May 17	Apr. 13	-	-

/1 : micromhos/cm

Note ; Sampling address : Sapan Ban Don, A.M. Rayong, 13 km upstream of the river mouth

Source : DOH

Table 10 WATER QUALITY OF RAYONG AND KHLONG LUANG RIVER IN COMPARISON WITH NEB STANDARD

Item	Unit	Class of NEB Standard 1	2	3	4	5	Rayong River 1	2/3	3	4/4	Khlong Luang River
Dissolved Oxygen (DO)	ppm	n	6	4	2	-	5.0	3.7	5.6	5.3	-
Biochemical Oxygen Demand (BOD)	ppm	-	1.5	2.0	4.0	-	2.3	1.2	2.1	1.2	5.0
p^H	-	6-8	6-8	6-8	6-8	6-8	6.8	5.8	7.6	7.3	-
Coliform Bacteria (Total)	MPN/100 ml	-	5,000	20,000	-	-	24,000	1,700	4,600	2,400	-
Coliform Bacteria (Faecal)	MPN/100 ml	-	1,000	4,000	-	-	7,800	700	1,300	270	-
Nitrogen (NO_3)	ppm	5.0					0.10	0.16	0.27	0.10	0.58
Nitrogen (NH_3)	ppm	0.5					1.74/3	2.02	-	-	nil
Manganese (Mn)	ppm	1.0					0.08	0.15	0.13	-	0.15
Copper (Cu)	ppm	0.1					0.002	0.02	0.004	-	-
Zinc (Zn)	ppm	1.0			-		0.13	0.12	0.15	-	-
Mercury (Hg)	ppm	0.002					0.00043	0.00033	nil	-	-
Cadmium (Cd)	ppm	0.005/1 0.05/2					nil	-	nil	-	-
Chromium (Cr)	ppm	0.05					nil	-	nil	-	-
Lead (Pb)	ppm	0.05					nil	0.03	nil	-	-
Arsenic (As)	ppm	0.01					nil	-	nil	-	-

/1 : Water hardness expressed as $CaCo_3$ less than 100 ppm

/2 : Water hardness expressed as $CaCo_3$ more than 100 ppm

/3 : Figure of 1981

/4 : Figure of 1980

Table 11 WATER QUALITY ANALYSIS OF KHLONG LUANG RIVER AT KGT 19

Items	Unit	Results
P^H		7.4
Conductivity	micromhos/cm	210
Total Solid	ppm	268
Sodium adsorption ratio	-	1.2
Soluble Sodium percentage	%	46
Residual Sodium Carbonate	meq/e	0.0
Calcium (Ca)	meq/e	0.65
Magnesium (Mg)	"	0.31
Sodium (Na)	"	0.81
Kalium (K)	"	0.33
Chloride (Cl)	"	0.78
Bicarbonate (HCO_3)	"	0.88
Sulfate (SO_4)	"	0.22

Sampling Point : KGT 19
Sampling Date : March 25, 1970
Data Source : RID

Table 12 WATER QUALITY ANALYSIS OF KHLONG LUANG RIVER AT PHANAT NIKHOM

Items	Unit	1982
p^H	-	7.1
Conductivity	micromhos/cm	180
Color (Pt-Co Scale)	unit	136
Turbidity	ppm	135
Suspendid Solids	ppm	166
Dissolved Solids	ppm	124
Alkalinity (Total, $CaCo_3$)	ppm	63
Calcium (Ca)	ppm	13
Magnesium (Mg)	ppm	6.9
Chloride (Cl)	ppm	13
Nitrogen (NO_3)	ppm	0.58
Nitrogen (NH_3)	ppm	nil
Phosphorus (PO_4)	ppm	0.16
BOD_5	ppm	5
Iron (Total)	ppm	1.0
Iron (Dissolved)	ppm	0.45
Manganese (Mn)	ppm	0.15

Remarks ; Sampling address : Ban Si Wichai, A.Phanat Nikhom
Date of sampling : 28 October 1982

Table 13 TAPIOCA STARCH MILL AND SUGAR MILL IN STUDY AREA

(Unit : number)

	Tapioca Starch Mill		Sugar Mill	
	Factory	Employee	Factory	Employee
Chon Buri Province				
Chon Buri district	21	104	0	0
Phanat Nikhom district	0	0	1	202
Ban Bung district	4	235	3	1,202
Si Racha district	4	129	1	171
Bang Lamung district	18	212	0	0
Nong Yai sub-district	0	0	1	490
Sub-total	47	770	6	2,065
Rayong province				
Rayong district	12	210	0	0
Ban Khai district	1	19	1	250
Pluak Daeng district	1	6	1	241
Sub-total	14	235	2	491
Total	61	1,005	8	2,556

Source: DIW

Table 14 BASIC UNIT OF INDUSTRIAL WASTE

	Waste water/1 (m^3/day/factory)	BOD/2 (ppm)	BOD load/3 (kg/day/factory)
Tapioca starch mill			
First grade type	1,500	4,000	6,000
Second grade type	190	5,600	1,100
Sugar mill	5,600	800	4,500
Canned food	50	3,000	150
Animal food	50	500	25
Vegetable oil	50	2,000	100
Fish source	15	1,300	20

/1 : Waste water discharged

/2 : BOD concentration of waste water discharged

/3 : BOD load produced

Source: NEB

Table 15 CALCULATION OF BOD LOAD FROM INDUSTRY

	1981	2001
Basic Unit of BOD load (kg/day/factory)		
Tapioca factory (first grade type)	6,000	6,000
Tapioca factory (second grade type)	1,100	1,100
White sugar mill	4,500	4,500
Removing rate by treatment systems (%)	30	30
Arrival rate of waste to rivers (%)	60	60
Number of factories		
Tapioca factory (first grade type)	9	9
Tapioca factory (second grade type)	52	52
White sugar mill	8	8
Total BOD load (tons/day)	62	62

Table 16 CALCULATION OF BOD LOAD FROM DOMESTIC SEWAGE

	1981	2001
Basic unit of BOD load (g/day/person)	40	45
Arrival rate of waste to rivers (%)		
Urban area	60	60
Rural area	10	10
Population (10^3 persons)		
Urban area	350	705
Rural area	570	645
Total BOD load (tons/day)	11	22

Table 17 CALCULATION OF BOD LOAD FROM LIVESTOCK

	1981	2001
Basic unit of BOD load (g/day/head)		
Buffalo	640	640
Cattle	640	640
Swine	200	200
Arrival rate of waste to rivers (%)	5	5
Number of livestock (head) /1		
Buffalo	65,000	65,000
Cattle	19,000	19,000
Swine	50,000	50,000
Total BOD load (tons/day)	3	3

/1 : The figures are of both Chon Buri and Rayong provinces, which includes the Study Area (Source : MOAC)

Table 18 ESTIMATED BOD LOAD IN 1981 AND 2001

Pollutant Source	BOD Load (tons/day)		Share (%)	
	1981	2001	1981	2001
Industry	62	62	81.6	71.3
Domestic Sewage	11	22	14.5	25.3
Livestock	3	3	3.9	3.4
Total	76	87	100.0	100.0

Table 19 ESTIMATED BOD LOAD FROM DOMESTIC SEWAGE BY AREA

	Population /1 (10^3)		BOD Load (ton/day)			Share of Increment (%)
	1981	2001	1981	2001	Increment	
Development Area						
Chon Buri	134	211	3.2	5.7	2.5	22
Laem Chabang	48	166	1.2	4.5	3.3	30
Pattaya	37	103	0.9	2.8	1.9	17
Sattahip	19	26	0.5	0.7	0.2	2
Rayong	45	119	1.1	3.2	2.1	19
Sub-total	283	625	6.9	16.9	10.0	90
Other Urban Area	67	80	1.6	2.2	0.6	5
Rural Area	570	645	2.3	2.9	0.6	5
Total	920	1,350	10.7	22.0	11.2	100

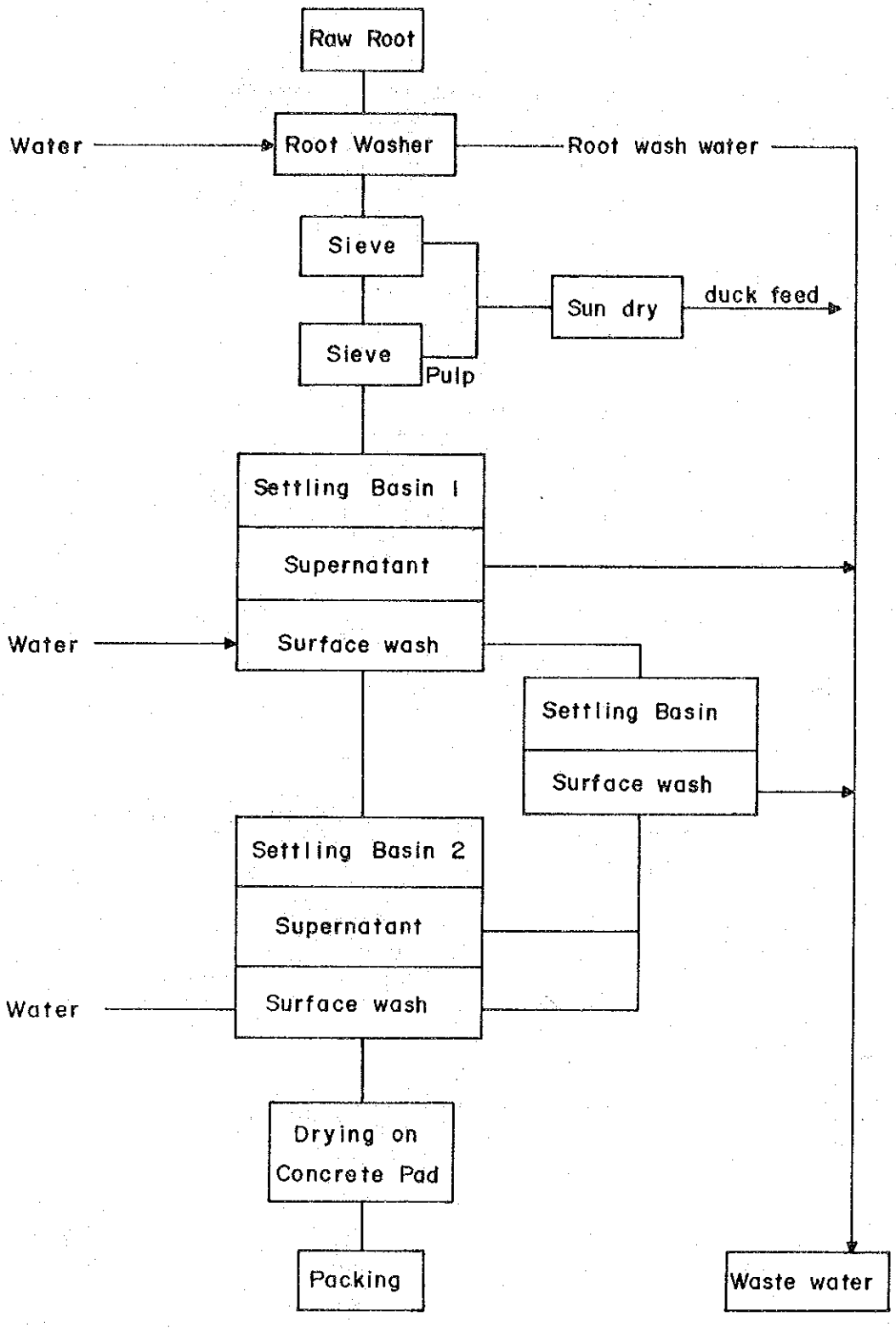
/1 : Sectoral Report IV, Domestic and Industrial Water Demand

Table 20 ENVIRONMENTAL IMPACT EVALUATION

Environmental Resources	Item	Grade	
		Dam and Reservoir	Irrigation System
Physical Resources	Water Quality	2 and (1)	(1)
	Soils	-	(2)
Ecological Resources	Fisheries	2 and (1)	1
	Fauna & Flora	(1)	2
	Forests	(1)	-
	Fertilizer & Agro Chemical	-	(1)
Human Use Value	Water Supply	3	3
	Flood Control	3	-
Quality of Life Values	Socio-economy	3	3
	Public Health	2	1
	Recreation	3	1

Note: 1, 2, 3; Beneficial impact of major, intermediate and minor.
(1), (2), (3); Adverse effect of minor, intermediate and major.

FIGURES



Source : NEB

Fig. 1 Flow Diagram of First Grade Tapioca Starch Processing

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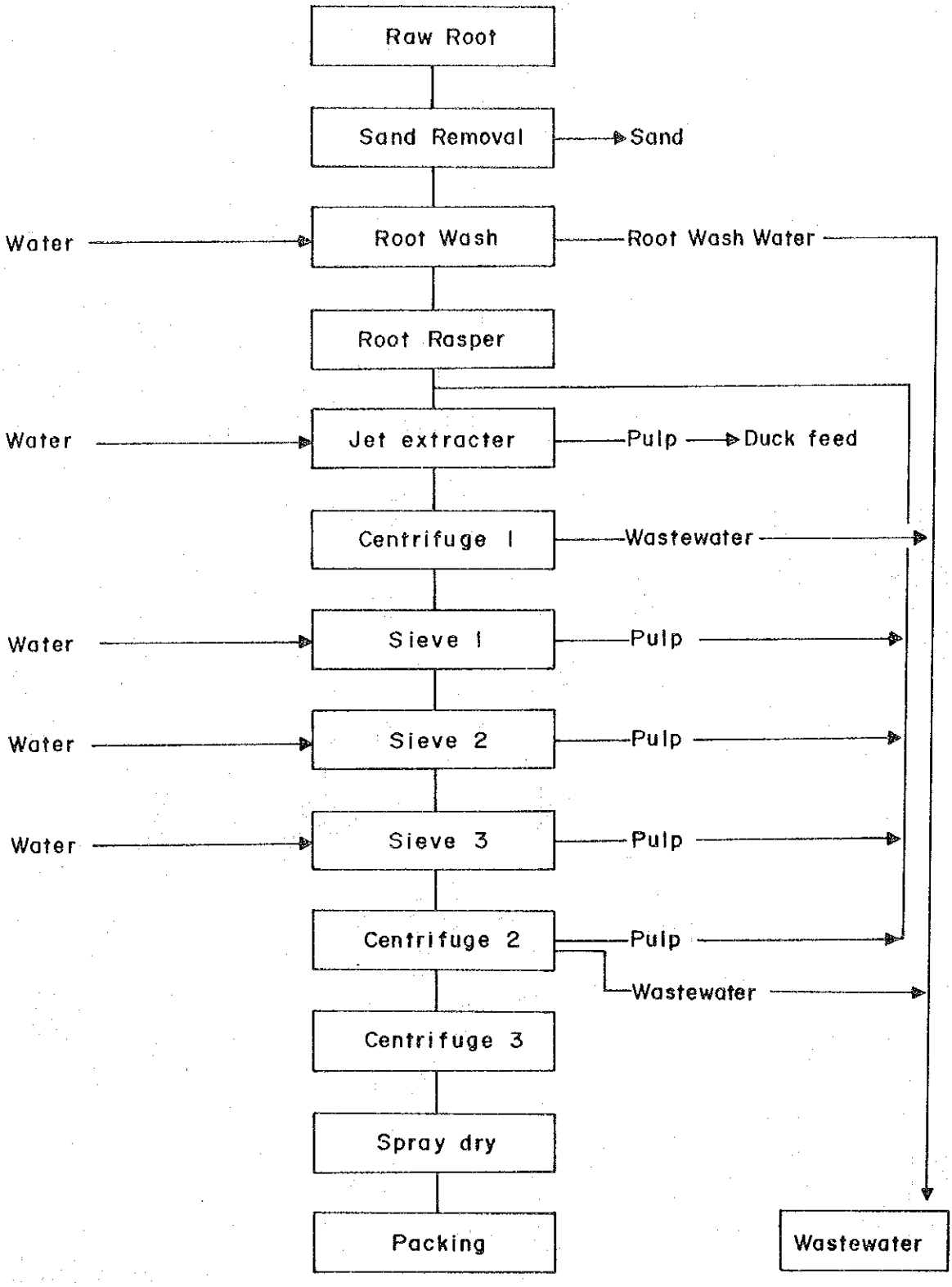
JAPAN INTERNATIONAL COOPERATION AGENCY



Source : NEB

Fig. 2 Flow Diagram of Second Grade Tapioca Starch Processing

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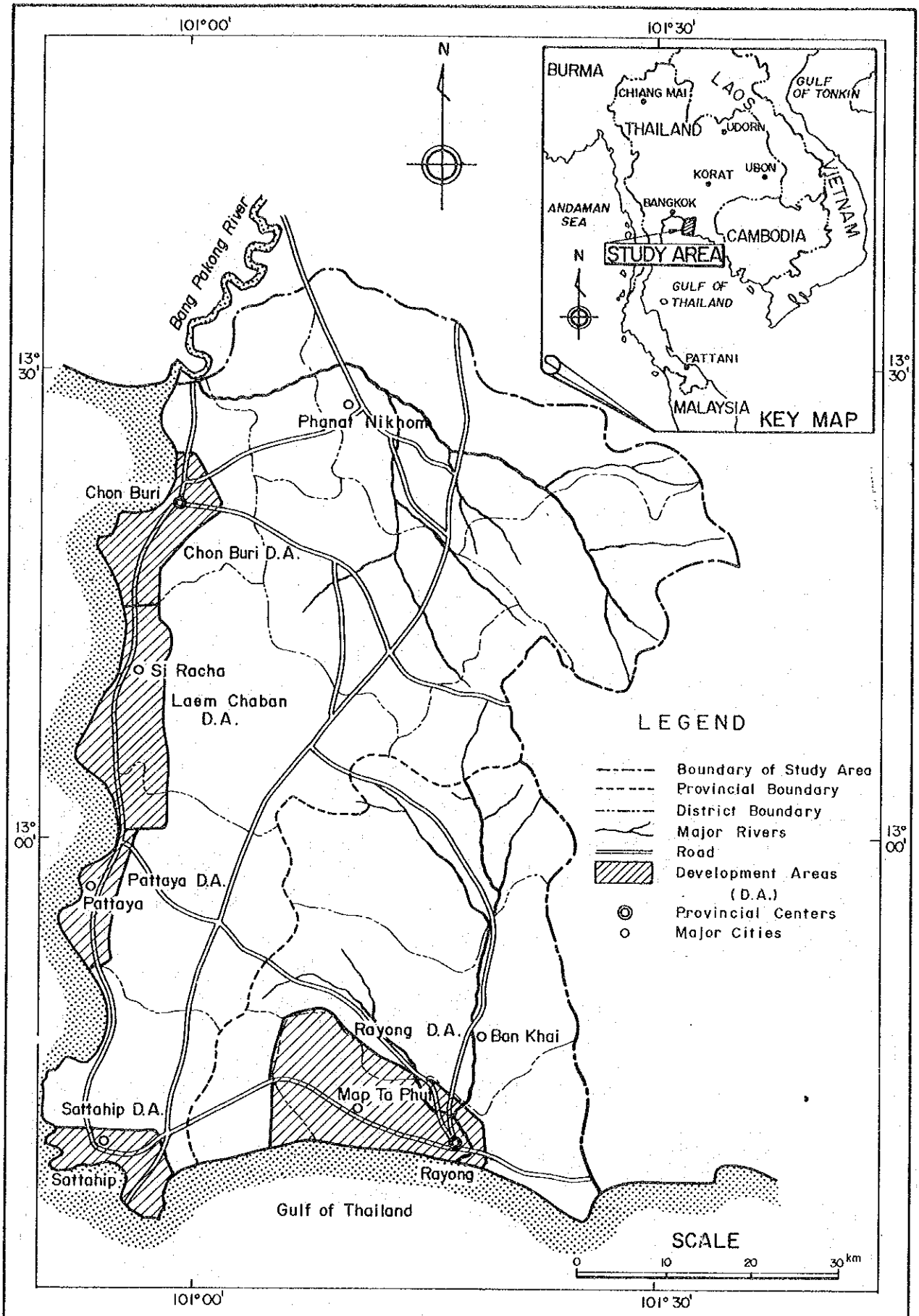

Fig. 3 Location of Major Rivers and Development Areas

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SECTORAL REPORT VI
TOPOGRAPHIC SURVEY

TABLE OF CONTENTS

1. INTRODUCTION

The topographic survey was carried out during the period from August 26 to November 19, 1982. Major activities were directed to collect the existing survey data and to execute the supplemental topographic survey to the proposed reservoir area, damsites and irrigation service areas. The supplemental survey were accomplished in collaboration with the Topographic Survey Division of RID.

Compensation survey was conducted by RID during the period from October 25 to November 20, 1982 in accordance with the minutes between RID and JICA Advisory Team in the date of August 30th, 1982. The survey was aimed to clarify the size of compensation cost of reservoir areas of the Khlong Luang, Khlong Yai and Khlong Thap Ma Dams.

2. AVAILABLE SURVEY DATA

The under-listed survey data are made available from the RID.

(1) Topographic Map

Reservoir	Scale	Contour Intervals (m)	Nos. of Sheet
(a) Reservoir and Irrigation Service Area			
Khlong Luang	1/20,000	1.0	3
Khlong Yai	1/10,000	1.0	3
Khlong Thap Ma	1/10,000	1.0	1
Ban Khai	1/10,000	1.0	4
	1/20,000	1.0	5
(b) Proposed Damsites			
Khlong Luang	1/4,000	1.0	3
Khlong Yai	1/4,000	1.0	2
Thap Ma	1/1,000	1.0	3
(c) Longitudinal Profile, Canals and Roads			
Khlong Luang, Right main canal	H: 1/2,000 V: 1/100		6
Khlong Luang, Left main canal	H: 1/4,000 V: 1/100		3
Khlong Luang, Access road	H: 1/2,000 V: 1/100		2

3. SUPPLEMENTAL SURVEY

3.1 Topographic Mapping

(1) Reservoir Area

(1.1) Khlong Luang

The existing map covers up to El. 40.0 m, which the dam crest elevation is planned at around El. 43.0 m. The supplemental topo-mapping was made up to El. 45.0 m. The mapping area is 64 km^2.

(1.2) Khlong Yai

The supplemental topo-mapping extended up to El. 49.0 m, since the existing map covers an area below El. 42.0 m. The mapping area is 17 km^2.

(1.3) Khlong Thap Ma

The existing map covers up to El. 27.0 m, whereas the dam crest elevation is proposed to be around El. 31.0 m. The supplemental survey expanded the existing map up to El. 35.0 m. The mapping area is 13 km^2.

(2) Irrigation Service Area

The additional topo-mapping was carried out for the proposed Thap Ma irrigation area in a scale of 1/10,000 with one meter contour intervals. The map was subsequently connected with the existing topographic map of Ban Khai irrigation service area.

(3) Damsite

Topographic mapping of the Khlong Luang damsite was conducted for the whole area, since topographic relief of the damsite has been changed largely by earth borrowing work. The map is prepared in a scale of 1/1,000 with 0.5 m contour intervals.

(4) Diversion Weir Sites

For the purpose of irrigation development in the Ban Khai Extension area, diversion weir will be constructed in the Rayong river. Two prospective sites have been choosen. The topographic map is prepared for both sites in a scale of 1/2,000 with 0.5 m contour intervals.

3.2 River Profile and Cross-Sectional Survey

For the preliminary planning of the river improvement works, the river profile and cross-sectional survey was carried out along the Khlong Luang, Khlong Yai and Khlong Thap Ma rivers. The cross-section was taken at average intervals of one km with a width of 50 m from bank.

Rivers	Surveyed Length (km)	Cross-Section (nos)
Khlong Luang	46	31
Khlong Yai	11	12
Khlong Thap Ma	11	12

4. FURTHER SURVEY

The following survey works need to be accomplished for the performance of the detailed design of dams, raw water conveyance system and irrigation and drainage system.

(1) Dams

(1.1) Topographic mapping, intake and spillway

Scale: 1/1,000, contour intervals: 0.5 m

Khlong Luang	:	320,000 m^2
Khlong Yai	:	100,000 m^2
Khlong Thap Ma	:	600,000 m^2

(2) Raw Water Conveyance System

(2.1) Route alignment survey

Topo-map; scale: 1/1,000, contour intervals: 0.5 m, wide: 80 m
Longitudinal profile; H: 1/1,000, V: 1/200, intervals: 50 m
Cross-section ; H: 1/200, V: 1/200, intervals: 500 m
Min. wide: 50 m

Khlong Luang	:	56 km
Nong Pla Lai	:	53 km
Ban Khai	:	16 km

(2.2) Topographic mapping, structural sites

Scale: 1/200, contour intervals: 0.5 m

Khlong Luang,	4 sites:	72,000 m^2
Nong Pla Lai,	4 sites:	48,000 m^2
Ban Khai,	2 sites:	29,000 m^2

(3) Irrigation and Drainage System

(3.1) Aerial-photo mapping of the service area

Scale: 1/5,000, contour intervals: 0.5 m

Khlong Luang	:	100 km^2
Ban Khai plus Ban Khai Extension	:	180 km^2
Khlong Thap Ma	:	50 km^2

(3.2) Topographic mapping

Scale: 1/200, contour intervals: 0.25 m

Nong Pla Lai headwork	:	1.8 km^2
Khlong Yai headwork	:	1.5 km2

(3.3) Route alignment survey

Topo Map; Scale: 1/1,000, controur intervals: 0.5 m
Longitudinal Profile; H: 1/1,000, V: 1/200, intervals: 50 m
Cross-section ; H: 1/1,000, V: 1/200, intervals: 50 m
min. wide 200 m for diversion and main canal and 100 m for lateral canal and drains.

Diversion canal	:	1.8 km
Khlong Luang, main	:	53 km
lateral	:	34 km
drain	:	37 km
Ban Khai Extension, main	:	45 km
lateral	:	123 km
drain	:	124 km
Ban Khai, main	:	22 km
lateral	:	48 km
drain	:	52 km
Khlong Thap Ma, main	:	17 km
lateral	:	38 km
drain	:	39 km

5. COMPENSATION SURVEY

Compensation survey was conducted to clarify the quantity and unit price of the land and properties located within the areas which are expected to be submerged by the reservoirs. Properties surveyed include house, crops, trees, public buildings, and factories. The Survey was carried out mainly by staffs of Law and Land Division and Region IX office of RID.

Survey results are summarized in the table below.

Item	Unit	Quantity	Unit Price (฿10^3)	Amount (฿10^3)
I. Khlong Luang Dam				
1. Land Acquisition Cost	ha	3,232	50.0	161,600
2. Compensation Cost	-	-	-	63,890
2.1 Houses	No.	450	20.0	9,000
2.2 Crops	-	-	-	36,100
(1) Cassava	ha	1,120	7.5	8,400
(2) Sugar Cane	ha	1,280	15.0	19,200
(3) Rice	ha	160	21.9	3,500
(4) Others	clump	50,000	100.0	5,000
2.4 Trees	-	-	-	17,900
(1) Coconut	No.	14,000	0.4	5,600
(2) Jackfruit	No.	14,000	0.45	6,300
(3) Others	No.	30,000	0.2	6,000
2.5 Public Building	-	-	-	890
(1) School	No.	1	250.0	250
(2) Residence of Teachers	No.	2	70.0	140
(3) Monastery	No.	1	500.0	500
Total	-	-	-	225,490
II. Khlong Yai Dam				
1. Land Acquisition Cost	ha	560	46.9	26,250
2. Compensation Cost	-	-	-	29,390
2.1 House	No.	384	20.0	7,680
2.2 Crops	-	-	-	13,950
(1) Cassava	ha	560	7.5	4,200
(2) Sugarcane	ha	560	15.0	8,400
(3) Rice	ha	16	21.9	350
(4) Others	clump	10,000	0.1	1,000

Item		Unit	Quantity	Unit Price (฿10^3)	Amount (฿10^3)
2.3	Tree	-	-	-	4,700
(1)	Coconut	No.	2,000	0.4	800
(2)	Jackfruit	No.	2,000	0.45	900
(3)	Others	No.	15,000	0.2	3,000
2.4	Public Building	-	-	-	3,060
(1)	School	No.	4	500	2,000
(2)	Residence of Teacher	No.	8	70	560
(3)	Monastery	No.	1	500	500
	Total	-	-	-	55,640
Khlong Thap Ma					
1.	Land Acquisition Cost	ha	1,152	112.5	129,600
2.	Compensation Cost	-	-	-	13,130
2.1	House	No.	276	30.0	8,280
2.2	Crops	-	-	-	5,150
(1)	Cassava	ha	120	7.5	900
(2)	Rice	ha	80	21.9	1,750
(3)	Others	clump	25,000	0.1	2,500
2.3	Trees	-	-	-	109,500
(1)	Coconut	No.	100,000	0.4	40,000
(2)	Rubber	No.	35,000	0.4	14,000
(3)	Rambutan	No.	35,000	0.3	10,500
(4)	Durian	No.	35,000	1.0	35,000
(5)	Others	No.	50,000	0.2	10,000
2.4	Factory	-	-	-	1,900
(1)	Rice Mill	No.	1	500	500
(2)	Cassava Drying Field	m^2	7,000	0.2	1,400
2.5	Public Building	-	-	-	6,480
(1)	School	unit	2	250	500
(2)	Residence of Teacher	unit	4	70	280
(3)	Temple	unit	1	5,200	5,200
(4)	Monastery	unit	1	500	500
	Total	-	-	-	260,910
	Grand Total	-	-	-	542,040

SECTORAL REPORT VII
METEOROLOGY AND HYDROLOGY

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1. INTRODUCTION

The study on meteorology and hydrology covers (1) meteorology of the Study Area, (2) run-off analysis, (3) flood analysis, and (4) sediment transport.

The meteorological study outlines the meteorological features of the Study Area such as temperature, relative humidity, evaporation, wind, cloud cover, and rainfall. These are the indispensable information to water resources development planning.

The run-off analysis provides statistical surface flow data for water utilization planning such as irrigation and domestic and industrial water uses.

The flood analysis aims at determining the flood discharges for the design of river channel and spillway of dam. For the estimation of flood run-off from rainfall, a run-off simulation model by dimensionless unit graph method is applied.

Sediment transport are studied so as to design the dead water storage of the proposed reservoir.

2. METEOROLOGY

2.1 General

The Study Area has tropical climatic characteristics. There are two distinct seasons in a year. Dry season with the northeast monsoon lasts from November to April and is generally sub-divided into two periods, namely, cool winter period from November to January and hot summer period from February to April. The cool winter period is the most favourable period throughout the year and minimum air temperature occurs in the period. The hot summer period is hot and humid and air temperature is the highest throughout the year. Wet season with the southwest monsoon starts from May and ceases in October. During the wet season, approximately 80 % of annual rainfall occurs. Table 1 summarizes the climatic features of the Study Area.

The solar radiation and air temperature is sufficient to grow the various sub-tropical and tropical crops. However, irrigation is unavoidable due to uneven distribution of rainfall throughout the year.

The MD collects the majority of the synoptic climatological data. The RID also conducts the climatological observation at some particular sites. At present, the MD operates two synoptic stations. Sattahip station has abandoned its activity in later 1970s. The RID operates 5 semi-synoptic stations within the Study Area. They are located at Rayong, Ban Nong Mapring, Ban Pak Phraek, Bang Phra and Ban Mai, respectively. There are 8 rain-gauge stations in the Study Area, all of which are administrated by the MD. Fig. 1 shows the locations of the semi-synoptic, synoptic and rain gauge-stations and Fig. 2 shows the availability of the climatological data.

2.2 Air Temperature

The air temperature records observed at the Chon Buri, Sattahip and Ban Nong Mapring are shown in Fig. 3 as representative. The air temperature in the inland area is a little lower than that in

the coastal area. For instance, the mean annual temperature is 26.9°C at the Ban Nong Mapring station, and 27.9 C at the Sattahip station. The seasonal variation is shown below for the selected three stations.

Stations	Highest Mean Monthly		Lowest Mean Monthly		Variation
	Temp. (°C)	Month	Temp. (°C)	Month	(°C)
Chon Buri	29.9	May	25.8	December	4.1
Sattahip	29.7	April	26.1	December	3.6
Ban Nong Mapring	28.1	April	24.7	January	3.4

At the Sattahip Station, the extreme maximum rises as high as 40.5°C in April and the extreme minimum declines as low as 12.3°C. The average diurnal variation is approximately 8.3°C, varying between 11.1°C in January and 6.3°C in July.

2.3 Relative Humidity

The relative humidity of the Study Area is represented by that observed at the Chon Buri, Sattahip and Ban Nong Mapring stations. The daily maximum and minimum values are not recorded at the Ban Nong Mapring station. Fig. 4 shows the relative humidity collected at the said three stations.

The mean relative humidity in the inland area is generally higher than that in the coastal area and remains almost constant throughout the year. The mean annual relative humidity is approximately 93% in the inland area, while that in the coastal area is approximately 75%. The seasonal variation of the mean monthly relative humidity is approximately 15% in the coastal area and approximately 8% in the inland area. The mean monthly relative humidity is high in September and low in December.

2.4 Evaporation

The MD's synoptic stations are equipped with piche, while the RID's semi-synoptic stations are provided with US Class-A pan. In general, the evaporation measured by the Class-A pan is commonly applied for water resources engineering and irrigation engineering. The evaporation record is therefore referred to the Ban Nong Mapring, Bang Phra and Ban Mai Stations, which are equipped with the Class-A pan.

The average annual evaporation over the Study Area is approximately 1,200 mm. Fig. 5 shows the average monthly evaporation of the three selected stations.

2.5 Wind

The wind direction is characterized by monsoon. At the Chon Buri station, the northeast wind is dominant during the dry season and the south wind during the wet season.

The wind velocity at the Bang Phra and Ban Mai stations are measured at one meter above the ground surface for the convenience of calculating the evapotranspiration. At the Chon Buri and Sattahip, it is observed at 12 m above the ground surface.

The mean annual wind velocity is 13.9 km/hr at the Sattahip station and 11.7 km/hr at the Chon Buri station. The monthly wind velocity is illustrated in Fig. 6. According to "Climatological Data of Thailand, 25 Year Period (1951-1975)", the Sattahip station recorded 73 knots i.e. 135 km/hr of the maximum wind velocity.

2.6 Cloud Cover

The cloud cover records are available at the Chon Buri and Sattahip stations and are indicated in terms of oktas. It was applied for calculation of the evapotranspirations. Fig. 7 shows the average monthly cloud cover at the two stations.

2.7 Rainfall

The Study Area is blessed with relatively abundant rainfall, approximately 1,300 mm per annum as shown in Fig. 8.

The rainfall distribution is uneven throughout the year. Approximately 80% of the annual rainfall occurs during the wet season. Fig. 9 indicates the seasonal variation of the rainfall.

The rainfall amount varies considerably from place to place and from year to year. As shown in the isohyetal map in Fig. 8, annual rainfall tends to decrease toward the west. According to the rainfall records at the Sattahip rain gauge station, the annual rainfalls varied from 757.5 mm in 1955 to 2,089.4 mm in 1970. Fig. 10 indicates the historical variation of the annual rainfall during a 30-year period from 1952 to 1981. Tables 2 to 9 show the monthly rainfalls at the selected stations.

3. RUN-OFF ANALYSIS

3.1 General

The Study Area extends over approximately 5,480 km^2 and can broadly be divided into 3 areas as shown below.

Khlong Luang river basin	:	2,118 km^2 /1
Rayong river basin	:	1,776 km^2
Coastal area	:	1,585 km^2

The Khlong Luang river originates in the Mt. Khao Ang Kraden (El. 338 m) and flows down northerly. At around Ban Wang Bong it turns its flow course toward the northwest and reaches the Amphoe Phanat Nikhom. Then the river flows meandering in flood plain with direction toward the west and joins with the Bang Pakong river at approximately 13 km north of Chon Buri. The total river length is approximately 150 km and average gradient is approximately 1/5,000.

The Rayong river basin is bounded on the north with the Khlong Luang river basin. The Rayong river takes its origin in the Mt. Khao Chomphu (El. 725 m) and runs toward the south until the confluence of the Huai Yai river, where it turns its flow direction toward the southeast. At approximately 11 km north of the Amphoe Ban Khai, it joins with the Khlong Dok Krai and changes its flow direction toward the south. At about one km downstream from the confluence, the Rayong river joins with another tributary, the Khlong Yai river, and flows down with southern direction until Rayong. In the proximity of Rayong, it forms a large meandering and then runs into the Gulf of Thailand. The river length is approximately 90 km in a total and river gradient is approximately 1/4,000.

There are a large number of small rivers in the coastal area. Most of the rivers have the catchment area lesser than 150 km^2 and generally originates in low hills, which form the watershed with the Rayong river basin on the east and with the Khlong Luang river basin on the north.

/1 Including approximately 193 km^2 of the Bang Pakong river basin.

The RID has been carrying out the systematic stream-gauge observation in the Study Area. At present, there are 6 stream gauge stations in the Rayong river basin and one stream gauge station in the Khlong Luang river basin. There is no stream gauge in the coastal area. Out of 6 stream gauges in the Rayong river basin, 3 stream gauges are located at inlets of diversion channels in estuary but stream flow measurement has never been conducted there. A few stream gauges have been abandoned but the records before the abolishment are available. Fig. 1 shows the location of the stream gauge stations and Fig. 11 the availability of the stream gauging records.

The run-off analysis was made for 5 stream gauge stations; the Ban Mai station in the Khlong Luang river basin and the Ban Mae Nam Khu, Ban Nong Mapring, Ban Pak Phraek and Ban Khai stations in the Rayong river basin. In order to obtain the run-off data in rivers in the coastal area, the Huai Sukhrip, where the reservoir operation records are available from the Bang Phra reservoir, was selected as the representative and an attempt was made to calculate back the inflows into the reservoir by means of water balance equation. The resulted figures indicate abnormally high run-off coefficient in comparison with rainfall, probably due to inaccurate recording in reservoir water level and amount of water abstruction. Therefore, they are not adopted in the present study. The run-offs at the damsites and balance points were estimated from those recorded at the above five stations.

For the purpose of the water balance study over the Study Area, a hydrological year 1979 was chosen as a standard year which was the most draught year during a 14-year period from 1968 to 1981. The 10-day discharges at the stream gauge stations and balance points are calculated to facilitate the water balance study.

3.2 Stream Gauging Records

3.2.1 Ban Mai Stream Gauge Station

The Ban Mai stream gauge station is located in the main stream of the Khlong Luang river, approximately 500 m downstream from the proposed Khlong Luang damsite . The catchment area at the station is presented to be 535 km² in hydrological documents issued by RID. After careful field investigation,

it was found that the above figure may include the catchment area of a small stream on the left bank of the Khlong Luang river. The said small stream joins far downstream from the gauge station and has 50 km² of the catchment area. For this reason, the catchment area was corrected to 484 km².

The stream flow measurement has been conducted periodically during the period from 1967 to 1974 and has been suspended since 1975. Stage-discharge curves established by RID were carefully examined and they were adjusted by applying the least-square method. New stage-discharge curves are shown in Fig. 12. The stage-discharge curve in 1974 was verified to be employed in calculating discharges after 1975, presuming that there have never been drastic changes in hydraulic condition in the gauge site.

3.2.2 Ban Mae Nam Khu Stream Gauge Station

The Ban Mae Nam Khu stream gauge station has abandoned its operation in March 1973, owing to the construction of the Dok Krai dam. It was established in May 1967 at the existing dam site in the Khlong Dok Krai. The catchment area of the Khlong Dok Krai river is 291 km^2 at the damsite. The water stage and stream flow measurement records are available during the period from May 1967 to March 1973 and during the period from 1967 to 1972, respectively.

The stage-discharge curves established by RID were carefully reviewed in viewpoint of the distribution and accuracy of the stream flow measurement results and were modified by means of the least-square method as shown in Fig. 13.

3.2.3 Ban Nong Mapring Stream Gauge Station

The Ban Nong Mapring gauge station is located in the Khlong Nong Pla Lai river at approximately 2 km downstream from the proposed Nong Pla Lai damsite. The station was established in May 1967 and is equipped with the ordinary staff gauge. The catchment area of the Khlong Nong Pla Lai river is 416 km^2 at the gauge station.

The water level has been observed continuously since 1967 at intervals of 5 times a day during the normal flow period and at one hour intervals during the flood period. The stream flow measurement results are available

for a 8-year period from 1967 to 1974. No stream flow measurements have been conducted since 1975.

The stream flow measurement results were carefully examined from the viewpoint of distribution and tolerance and were finally assorted into three groups. The measurement results obtained during the period from 1967 to 1971 were judged to be distributed within a certain confidential limit. The measurement results in 1972 indicates a little difference from those recorded in the previous period. The measurement results obtained during 1973 and 1974 are also distinguishable from those in 1972. Therefore three rating curves were constructed as presented in Fig. 14. The rating curve No. 3 is applicable to calculate the discharges in and after 1974.

3.2.4 Ban Pak Phraek Stream Gauge Station

The Ban Pak Phraek stream gauge station is situated in the Khlong Yai river at approximately 2 km downstream from the proposed Khlong Yai dam-site and at approximately 500 m upstream from the confluence of the Khlong Yai river and Khlong Ma Mui rivers. The hydrological documents of RID define the catchment area at 244 km². The figure most probably includes the catchment area of the Khlong Ma Mui river, 83 km². Therefore the catchment area of the Khlong Yai river at the Ban Pak Phraek was corrected to be 161 km².

The station was established in May 1977, and since then the gauge height records have been accumulated by RID. The stream flow measurements have been periodically carried out by RID since establishment of the gauge station. The stage-discharge curves were prepared for every hydrologic year as presented in Fig. 15.

3.2.5 Ban Khai Weir Site

The Ban Khai weir is located in the main stream of the Rayong river at approximately 4.5 km upstream from Ban Khai and commands 1,143 km^2 of catchment area. The gauge height observation and amount of water abstraction from the Rayong river have been monitored by RID since June 1967. The stream flow measurement has never been conducted there.

3.3 10-Day and Monthly Mean Discharges at Stream Gauge Stations

3.3.1 Ban Mai Stream Gauge Station

Tables 10 and 11 present the 10-day discharges in 1979 and the monthly mean discharge during the period from April 1968 to March 1982, respectively.

The annual mean discharges range between 0.96 m^3/s in 1979 and 5.55 m^3/s in 1978. The average annual discharge is 3.66 m^3/s or 115.4 x 10^6 m^3.

3.3.2 Ban Mae Nam Khu Stream Gauge Station

The Ban Mae Nam Khu station is lacking in gauge height records after April 1973, because it was abolished by completion of the Dok Krai dam. Two different methods were adopted to supplement the lacking discharge data.

Discharge data during the period from April 1973 to March 1975 were converted from the Ban Nong Mapring station in proportion of catchment areas. As shown in Fig. 16, specific discharge at the Ban Mae Nam Khu station is proportional to that at the Ban Nong Mapring station.

Discharge data during the period from April 1975 to March 1982 were principally calculated by the following water balance equation. The resulted figures were compared to the observed discharge at the Ban Nong Mapring station to confirm their accuracy and were refined if any discrepancies were found out.

$$\Delta S = Qi - Qo - (E + R) \quad \ldots\ldots\ldots \quad (3.1)$$

$$E = 0.7 \cdot Ep \cdot A \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

where,

- ΔS : change in reservoir storage
- Qi : inflow into reservoir
- Qo : outflow from reservoir
- E : evaporation loss from reservoir surface
- R : rainfall fallen directly on reservoir
- Ep : Pan evaporation, observed by Class "A" pan
- A : reservoir surface area.

The 10-day discharges in 1979 and monthly mean discharges during the period from April 1968 to March 1982 are shown in Table 10 and 12, respectively. The annual mean discharges vary from 1.12 m^3/s in 1979 to 4.55 m^3/s in 1972. The average annual discharge is 3.22 m^3/s, or 101.5×10^6 m^3.

3.3.3 Ban Nong Mapring Stream Gauge Station

The Ban Nong Mapring gauge station has the longest discharge records among the stream gauge stations in the Rayong river basin. The 10-day discharges in 1979 is shown in Table 10. The monthly mean discharges are presented in Table 13 for the period from April 1968 to March 1982.

The hydrological year 1979 marked the driest year with annual discharge 1.51 m^3/s and that 1974 recorded the maximum annual discharge 5.38 m^3/s. The average annual discharge is 4.08 m^3/s, or 128.7×10^6 m^3.

3.3.4 Ban Pak Phraek Stream Gauge Station

The daily discharges were calculated for the period from May 1977 to March 1982 based on the observed daily gauge heights and the rating curves. For the period from April 1968 to May 1977, discharge data were extrapolated from those recorded at the Ban Nong Mapring station by means of the run-off correlation. The run-off correlation between the two stations are shown in Fig. 17 and is indicated by the following equation.

$$Qy = 0.952 \cdot Qn^{1.58} \quad \ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

where,

Qy : specific discharge at Ban Pak Phraek station, $m^3/s/100\ km^2$

Qn : specific discharge at Ban Nong Mapring station, $m^3/s/100\ km^2$.

Table 10 shows the 10-day discharges in 1979 and Table 14 the monthly mean discharges for the period from April 1968 to March 1982. The average annual discharge is estimated at 2.05 m^3/s, or 64.6×10^6 m^3.

3.3.5 Ban Khai Weir Site

The discharges at the weir site are theoritically obtainable by the following equations.

$$Qr = Qo + Qa \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.4)$$

$$Q = Qr + (Qdi - Qdo) \quad \ldots\ldots\ldots\ldots\ldots \quad (3.5)$$

where,

Q : natural flow at the weir site, m^3/s

Qo : weir overflow discharge , m^3/s

Qa : intake discharge , m^3/s

Qr : discharge at the weir site after April, 1975, m^3/s

Qdi : inflow into Dok Krai reservoir, m^3/s

Qdo : outflow from Dok Krai reservoir, m^3/s

The equation (3.4) is applicable for the period from April 1968 to March 1975, prior to the construction of the Dok Krai dam. The equation (3.5) is adopted for the period after April 1975, since the stream flow regime at the weir site has been completely altered by the Dok Krai reservoir. The intake discharge and weir overflow discharge have been monitored precisely, from day to day by RID.

The resultant figures should fulfill the following conditions.

$$Q > Qy + Qn + Qd \quad \ldots\ldots\ldots\ldots\ldots \quad (3.6)$$

where,

Q : discharge at the weir site, m^3/s

Qy : discharge at Ban Pak Phraek station, m^3/s

Qn : discharge at Ban Nong Mapring station, m^3/s

Qd : discharge at Ban Mae Nam Khu station, m^3/s

In case that the computed figure was inconsistent with the condition, it was modified accordingly. The estimated figures were compared with the recorded discharges at the Ban Nong Mapring station as presented in Fig. 18, in order to verify their accuracy. It could be said that the estimated figures are fairly accurate as far as seen in Fig. 18.

Tables 10 and 15 shows the 10-day discharges in 1979 and the monthly mean discharges during the period from April 1968 to March 1982, respectively.

3.4 Rainfall-Run-off Correlation

The Study Area is poorly provided with the rain gauge stations, only 15 rain gauge stations for 5,500 km^2. There is only one or two rain gauge station in the catchment area of the five stream gauge stations. It is hardly capable of analyzing the real rainfall-run-off correlation. The rainfall-run-off correlation contained herein is to indicated a general tendency for reference purpose.

Table 16 shows the annual run-off, annual rainfall and run-off coefficient at the five stream gauge stations. The summary is given hereunder.

Gauge Station	Catchment area	Average annual rainfall	Average annual run-off	Run-off coefficient
	(km^2)	(mm)	($10^6 m^3$)	
Ban Mai	484	1,269	115.4	0.19
Ban Mae Nam Khu	291	1,425	101.5	0.25
Ban Nong Mapring	484	1,425	128.7	0.22
Ban Pak Phraek	161	1,425	64.6	0.28
Ban Khai	1,143	1,425	494.8	0.30

3.5 10-Day Run-offs at Balance Points

For the purpose of the study of the long-term water demand and supply balance plan, the Study Area was divided into 10 zones as shown in Fig. 19. Each zone excepting zone 7 has a representative river, in which balance points are selected as discribed below.

Zone No.	Representative river	Balance Point	
		Location	Catchment area (km^2)
1	Khlong Luang	Khlong Luang damsite	526
1-1	Huai Ban Bung /1	Ban Bung dam	51.2
2	Khlong Yai Cheng	Estuary	30.1

(to be continued)

/1 : Sub-zone.

Zone No.	Representative river	Balance Point	
		Location	Catchment area (km^2)
3	Huai Sukhrip	Bang Phra dam	123
4	Khlong Bang Lamung	Estuary	301
5	Huai Nong Pru	Map Prachan dam	37.9
6	Huai Yai	Estuary	119
7	-	-	-
8	Khlong Phayun	Estuary	31.8
9	Khlong Huai Yai	Estuary	120
10	Rayong	Ban Khai	1,143
10-1	Khlong Thap Ma/1	Khlong Thap Ma damsite	158

The 10-day run-offs in 1979 were estimated for the above 11 balance points, as presented in Tables 17 and 18.

The 10-day run-off at Zone 1 balance point was converted from the Ban Mai gauge in proportion of the catchment areas. The 10-day run-off at balance points in Zones 2 to 9 and 10-1 was extrapolated from those at the Ban Mae Nam Khu gauge station in proportion to the catchment areas, while the run-off at balance point in Zone 10 is referred to the recorded discharge at Ban Khai.

3.6 Monthly Mean Run-offs at Damsites

As described in Sectoral Report XI "Water Resources Engineering", 9 potential damsites have been identified by RID, out of which 3 damsites, Khlong Luang, Khlong Yai and Khlong Thap Ma damsites, are contemplated to be studied at feasibility level. The potential damsites are listed up hereunder.

/1 : Sub-zone.

Potential Damsites	Zone No.	Rivers	Catchment area
			(km^2)
Khlong Luang	1	Khlong Luang	526
Pa Daeng	1	Huai Pa Daeng	53.8
Huai Bung	4	Huai Bung	68.5
Huai Takhian Tia	4	Huai Takhian Tia	33.0
Khlong Na Klua	5	Khlong Na Klua	22.3
Huai Chak Nok	6	Huai Chak Nok	18.1
Huai Yai	6	Huai Yai	65.9
Khlong Yai	10	Khlong Yai	218
Khlong Thap Ma	10	Khlong Thap Ma	158

In addition, in the Study Area there are 4 dams in operation, one dam under construction and 2 dams under planning as tabulated hereunder.

Dams	Zone No.	Rivers	Catchment area
			(km^2)
1. Dam in Operation			
Ban Bung	1	Huai Ban Bung	51.2
Bang Phra	3	Huai Sukhrip	123.0
Map Prachan	5	Huai Nong Pru	37.9
Dok Krai	10	Khlong Dok Krai	291.0
2. Dam under Construction			
Nong Kho	4	Huai Nong Kho	48.3
3. Dam under Planning			
Ban Bung/1	1	Huai Ban Bung	51.2
Nong Pla Lai	10	Khlong Nong Pla Lai	408.0

The 10-day and monthly mean run-offs at all the above-listed damsites and dams were estimated for the period from April 1968 to March 1982 for the purpose of the study of the long-term water demand and supply plan. The estimate was made simply in proportion of catchment areas between the dam/damsite and the selected gauge stations. Tables 19 thru 21 present the estimated 10-day mean run-offs, and Tables 22 through 35 present the

/1 Replacing the existing Ban Bung dam

monthly mean run-offs.

3.7 Maintenance Flow at Balance Points

To determine the maintenance flow at each balance point, monthly run-offs were estimated. The monthly run-offs at balance points were estimated by the same procedure as described in Section 3.5. These are shown in Tables 36 to 44 and 46.

The maintenance flow at the balance point of Zone 10 is deemed to be indicated by the discharge immediately downstream from Ban Khai weir. The weir overflow discharge is shown in Table 45.

For Sub-zone 1-1, the river maintenance flow was assessed based on the historic water supply records of the Ban Bung reservoir.

The maintenance flow which are assumed to be equal to 90 % dependable monthly discharge. Estimated values are summarized as shown below. It should be noted that the amount of the river maintenance flow is nil, if the balance point is located at estuary.

Zone No.	Balance Point	Maintenance Flow (m^3/s)	Maintenance Flow (MCM/yr)
1	Khlong Luang damsite	0.06	1.9
1-1	Ban Bung dam	0.01	0.4
2	Estuary of the Khlong Yai Cheng river	-	-
3	Bang Phra dam	0.26	8.0
4	Estuary of the Khlong Bang Lamung river	-	-
5	Map Prachan dam	0.08	2.5
6	Estuary of the Huai Yai river	-	-
8	Estuary of the Khlong Phayun river	-	-
9	Estuary of the Khlong Huai Yai river	-	-
10	Ban Khai weir	0.38	12.0
10-1	Khlong Thap Ma damsite	0.33	10.5

4. FLOOD ANALYSIS

4.1 General

Flood analysis of the Khlong Luang and Rayong river basins are conducted aiming at determination of the probable flood runoffs for the design of river channels and spillway of dams. The probable flood run-offs are estimated from design rainfall by the simulation model.

The analysis mainly consists of rainfall analysis to set the design rainfall and runoff analysis to calculate the probable flood runoff by the simulation model.

The rainfall analysis includes the studies on probability, basin rainfall, and rainfall pattern. For the runoff analysis, dimensionless unit graph method is adopted in consideration of the availability of rainfall and runoff data in the basins.

4.2 Rainfall Analysis

4.2.1 Available Data

The daily rainfall data are available in 4 stations in the Khlong Luang river and 7 stations in the Rayong river basin. Among these, 5 stations have recording rain gauges, but the recording charts are not processed yet and not ready for use.

On the other hand, the rainfall intensity data are available at A.M. Chon Buri located near the both basins. These data are applicable to the present study.

The annual maximum daily rainfall data are available at the stations listed below.

Station	Available Data on Annual Maximum Rainfall	Sample Nos.
Ban Mai	1965 - 1981	17
Phanat Nikhom	1954 - 1969, 1972 - 1981	26
Ban Bung	1952 - 1981	30
Phan Thong	1952 - 1955, 1958 - 1981	28
Ban Khai	1957 - 1981	25
Rayong	1952 - 1981	30

4.2.2 Probable Point Rainfall

The annual maximum rainfall data for different durations of 1, 2, 3 and 4 days are compiled in Table 47 . The probabilities of them are calculated by the Gumbel method. The calculation results are presented in Table 48 and Fig. 20. The probable rainfalls at Ban Mai and Ban Khai stations are summarized below.

Station	Duration	Return Period (year)				
		10	30	50	100	500
Ban Mai	1-day	104.0	125.8	135.8	149.2	180.3
	2-day	143.1	176.2	191.4	211.8	258.9
	3-day	168.8	208.1	226.1	250.2	306.1
Ban Khai	1-day	138.0	165.0	177.3	193.9	232.3
	2-day	176.5	211.1	226.8	248.1	297.3
	3-day	214.7	255.6	274.2	299.4	357.5

4.2.3 Basin Rainfall

The relation between the basin mean rainfall and the point rainfall is studied for the Khlong Luang, Nong Pla Lai and Rayong river basins, using the daily rainfall records of the selected major storm in the

past. The basin rainfall is calculated as an arithmetical mean of the daily rainfalls observed at the rain gauge stations in and around the respective basins.

The result of study is shown in Table 49. According to the results, depth-area relation curve is prepared as shown in Fig. 21. Applying this curve, the ratios of point and basin mean rainfalls are estimated as follows for the basins upstream of the proposed Khlong Luang, Khlong Yai and Khlong Thap Ma damsites:

Damsite	Drainage Area (km^2)	Point-Basin Rainfall Ratio
Khlong Luang damsite	526	0.64
Khlong Yai damsite	218	0.70
Khlong Thap Ma damsite	158	0.73

4.2.4 Design Probable Rainfall

Hourly rainfall data compiled by the MD are available at Chon Buri station for the period from Jan. 1964 to Sep. 1974. Among these selected are the 1964-May, 1966-May, 1966-September, 1969-September, 1971-August and 1973-September storms of which 24-hr rainfall heights are more than 80 mm.

Relationship between rainfall and duration of these selected storms are shown in Table 50 and Fig. 22. This relationship indicates that about 50 % of 24 hr rainfall concentrates, on average, during 1 hour and 85 % during 6 hours.

On the other hand, the difference between probable 3 and 4-day rainfall is so small that the 3-day probable rainfall is adopted for the flood analysis.

4.2.5 Probable Maximum Precipitation

The probable maximum precipitation (PMP) is estimated for the drainage areas of the proposed Khlong Luang, Khlong Yai and Khlong Thap Ma dams, in order to estimate the maximum possible flood to be used for check of safety of dam.

The maximum daily rainfalls recorded at stations around the Study Area listed below.

Station	Province	Date	Max. Rainfall (mm/day)
Aranyaphathet	Prachin Buri	23 Apr. 1968	129.7
Prachin Buri	Prachin Buri	25 Jun. 1964	168.0
Chon Buri	Chon Buri	13 Oct. 1952	145.4
Sattahip	Chon Buri	30 Nov. 1970	319.6
Chanthaburi	Chanthaburi	21 Oct. 1952	336.8
Khlong Yai	Trat	16 Aug. 1970	553.7

The rainfalls at Chanthaburi and Khlong Yai exhibit strong orographic effect of the Chanthaburi and Banathat mountains, so that the storms cannot be transposed into the Study Area. The daily rainfall recorded at Sattahip station on November 1970 is therefore adopted to estimate the maximum probable precipitation. The calculation of the PMP is shown in Table 51. The results are summarized as follows.

Damsite	Basin Rainfall (mm)		
	1-day	2-day	3-day
Khlong Luang	200.1	245.6	286.5
Khlong Yai	257.7	327.8	368.8
Khlong Thap Ma	283.0	360.0	405.0

The return periods of these PMP are assessed around 20,000 to 200,000 years for the basin of Khlong Luang dam according to the rainfall frequency curve at Ban Mai, and 30,000 to 150,000 years for the basins of Khlong Yai and Khlong Thap Ma dams according to the curve at Ban Khai.

4.2.6 Effective Rainfall

The effective rainfall is expressed as a ratio between total rainfall over basin and total run-off from the basin during a storm. The ratios are estimated for several storms as shown in Table 52. The average effective rainfall ratio is figured out to be 0.55 for the Khlong Luang river basin and 0.65 for the Rayong river basin.

4.3 Flood Run-off Analysis

4.3.1 Methodology

Run-off simulation model is established for the flood run-off analysis. The simulation model consists of mainly three elements of analysis, i.e., (1) run-off calculation of sub-basin, (2) channel flow calculation, and (3) flood regulation by dam.

For the analysis, a river basin is divided into sub-basins as shown in Figs. 23 and 24. The river is divided into adequate number of reaches and a run-off system model is prepared as shown in Figs. 25 and 26. The run-off system model is a network of the sub-divided channels linked to the sub-basins and dams if any.

(1) Runoff Calculation of Sub-basin

The unit graph method is applied to the run-off calculation of sub-basins.

Unit Hydrograph

Unit graph is derived from dimensionless hydrograph and lag time.

Dimensionless hydrograph is constructed from the recorded hydrographs not significantly affected by flood retardation and is shown in Fig. 27.

Lag Time in Sub-basin (Lg)

Since no hourly rainfall record concurrent to the discharge hydrograph are available, lag time of the sub-basin is calculated by the following two empirical formulae.

a. Formula by U.S. Bureau of Reclamation:

$$Lg = 0.165 \ (L \times Lca/(s)^{0.5})^{0.382} \quad \ldots\ldots\ (4.1)$$

where

L : Length of the longest watercourse from the objective point to watershed divide (km)

Lca: Length of the watercourse from the objective point to intersection of perpendicular from centroid of basin to stream alignment (km)

s : Overall slope of the longest watercourse from the object point to watershed divide

b. Formula by Kraven:

$$Lg = L/W \quad \ldots\ldots\ (4.2)$$

Propagation Velocity (W) is assumed as presented below.

River Slope	Propagation Velocity (m/sec)
more than 1/100	3.5
1/100 - 1/200	3.0
less than 1/200	2.1

Factors involved in the above formula is presented in Tables 53 and 54.

Base Flow

Base flow of sub-basin is assumed nil, since its magnitude is excessively small compared with peak discharge.

(2) Channel Flow Calculation

The run-off from each sub-basin is subject to retard due to storage in each channel and lag time up to the object point.

Flood Retardation by Channel Storage

The flood retardation by channel storage is calculated by the storage function method. The storage function method is described in the run-off storage relationship expressed as;

$$S = KQP \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (4.3)$$

$$\frac{ds}{dt} = I - Q \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (4.4)$$

where

S : Channel storage (m^3)

Q : Outflow from the channel stretch (m^3/sec)

K, P: Storage functions

dt : Unit time (sec)

ds : Incremental channel storage during the time dt (m^3)

I : Inflow to the channel stretch (m^3/sec)

In the above equation, the storage functions are estimated using the non-uniform or uniform flow calculation.

Lag Time of Channel

The Kraven formula which has been presented in the section of "lag time of sub-basin" is adopted in the present study.

Table 55 slows the lag times of each channel reach.

(3) Flood Regulation by Dam

Flood regulation by the existing and proposed dams are calculated by the following equations:

Equation of continuity

$$\frac{ds}{dt} = I - Q \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (4.5)$$

Reservoir storage curve

$$s = f\ (H) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (4.6)$$

Outflow from reservoir

$$Q = CB\ (H - Z)^{3/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.7)$$

where

dt: Unit time (sec)

ds: Incremental reservoir storage during the time dt (m^3)

I : Inflow to the reservoir (m^3/sec)

Q : Outflow from the reservoir (m^3/sec)

s : Reservoir storage (m^3) which is a function of water level (h) in the reservoir

C : Discharge coefficient assumed at 2.0

B : Spillway width (m)

H : Water level in the reservoir (El. m)

Z : Crest elevation of spillway (El. m)

4.3.2 Probable Flood Run-off

Probable floods are calculated based on probable rainfalls and run-off simulation model as shown in Tables 56 and 57. Probable maximum flood is calculated only for the proposed damsite to ascertain the safety of dam.

Flood hydrographs of 50 -, 100 - and 500-year and probable maximum floods are presented in Figs. 28 to 39.

5. SEDIMENT TRANSPORT

5.1 Available Data

The record of reservoir sedimentation is available only at the Ban Bung reservoir in the Khlong Luang river basin. According to the record the sedimentation of reservoir amounted to 170,000 m^3 during 23 years from 1958 to 1981. The annual sediment yield rate at Ban Bung damsite is estimated considering the trap efficiency of the reservoir as presented in Table 58. The result are summarized as follows:

Description	Values
a. Sediment trapped	144 $m^3/yr/km^2$
b. Trap ratio	85 %
c. Annual yield	169 $m^3/yr/km^2$

No sediment measurement record is available in the Khlong Luang and Rayong river basins. In the Bang Pakong river basin which is an northern adjacent basin of the Khlong Luang river, sediment records are available at four gauging stations at Kabin Buri, Ban Wan Khian, Ban Kaeng and Ban Thung Faek. However these data may not be applicable to the study area because of difference of locations and basin sizes.

5.2 Sediment Transport Rate

The available data are too short to estimate the sediment yield at each damsite. Further sediment studies based on the additional survey and measurements will be necessary before the final decision of design sediment inflow.

The sediment yield rate of 300 $m^3/yr/km^2$ has been adopted to the Ban Bung dam scheme in the Khlong Luang river basin and Nong Pla Lai dam scheme in the Rayong river basin.

Therefore, the design sediment yield rate of 300 $m^3/yr/km^2$ is applied to the design of proposed dam scheme in the present study.

Reservoir sedimentation for each potential reservoir is calculated as shown in Table 59. In calculating the reservoir sedimentation volume, the following conditions are adopted:

a. Design sediment inflow of 300 $m^3/yr/km^2$ is applied to all the potential reservoirs.

b. Sedimentation for 100 years is estimated.

c. Trap efficiency of the reservoir is assumed to be 100 %.

6. RECOMMENDATION

The hydrological data play a basic role among the flood control and water resources development projects.

After collection and arrangement of the hydrological data in the Study Area, the Study Team would like to present some recommendation on the observation and processing the hydrological data as follows.

a. Installation of additional raingauge station: As a whole, the number of raingauge stations is not sufficient enough to estimate the basin rainfall. At least two additional raingauge stations are necessary for each of the Khlong Luang and Rayong river basins. The villages named Ban Thap Rang in Phanat Nikhom district (N13°12',E101°28') and Wat Ban Chaloem Lap in Ban Bung district (N13°05',E101°16') are suitable site for installation of raingauge station in due consideration of observation purpose and its maintenance and management.

b. Processing of recording raingauge data: There are one recording raingauge station in the Khlong Luang river basin and 3 stations in the Rayong river basin. The processing of recording sheets of these stations is delayed and hourly rainfall records are not ready for use. It is desirable that the recording sheets are processed within one month after the recording.

c. Observation at Ban Khai station: At present, stream gauging at Ban Khai weir is carried out twice a day. Since Ban Khai gauging station plays an important role in water resources study of the Rayong river basin, times of observation should be increased or the automatic stream gauge should be installed.

d. Operation record of reservoir: Further detailed and frequent recording of reservoir operation, which include the gate operations and stream gauging, is recommended to each dam.

e. Measurement of sediment discharge: No sediment discharge record is available in the Study Area. Sediment discharge records are necessary for the studies on sediment problems of the river and maintenance of irrigation facilities. The measurement of sediment discharge should be executed periodically both in the Khlong Luang and Rayong rivers and their tributaries.

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