SURVEY AND RESEARCH ON CHARACTERISTICS OF BANGKOK LOWLAND

Winai Liengcharernsit Guest Professor, Institute of Lowland Technology, Saga University
Hiroyuki Araki Associate Professor, Institute of Lowland Technology, Saga University

1. INTRODUCTION

Bangkok, the capital of Thailand, is one of typical lowlands and rapidly developing city in southeast Asia. There are various kinds of problems which are similar to other lowlands, such as land subsidence, soft clay, flood, water pollution, salt water intrusion, and etc. In general, however, background and countermeasures of these problems may be different from place to place. It is, therefore, useful for the lowland research to investigate and collect information of various lowlands in the world.

This survey research is projected to collect data of Bangkok lowland and finally try to reveal its characteristics. In this report, only the main topics are summarized due to the page limitation. Details will be published from ILT on another opportunity.

2. CHARACTERISTICS OF THE AREA

2.1 Physical Features

Bangkok is located on alluvial soils of the deltaic plain near the mouth of the Chao Phraya River. It covers a total area of 1,572km² (Figure 1). The average ground surface elevation is in the range of 1.0–1.2m above the mean sea level. Bangkok is the center for residential, commercial and industrial development of the country. The Chao Phraya River is the major river which flows through Bangkok from the north to the south to drain into the Gulf of Thailand. This river plays an important role in Bangkok life. Besides the Chao Phraya River, there exist several canals excavated during 80–100 years ago for irrigation and transportation purposes. Nowadays, these canals are mainly used for storm water and wastewater drainage.
2.2 Climate

Bangkok has warm and humid climate influenced by the southwest and the northeast monsoons. Based on temperature and amount of rainfall, three seasons can be classified, namely summer, rainy season, and winter. Summer begins in March and lasts until mid May. The rainy season begins in mid May and lasts until October, during which the southwest monsoon prevails and carries moisture from the Indian Ocean. Winter starts from November and lasts until February. During this period the northeast monsoon prevails and carries cold air from China.

The temperature in Bangkok is rather high all year round with the maximum mean temperatures in December and April of approximately 31 and 35°C, respectively. The minimum mean temperatures in January and April are 21 and 26°C, respectively. The relative humidity is rather high with an annual average of 77%, ranging from 71% in January to 82% in September. The average annual evaporation is about 1,800mm with a monthly value ranging from 126mm in November to 190mm in April. The mean monthly rainfall varies from 9mm in January to 344mm in September (Figure 2). The average
annual rainfall is about 1,500mm.

2.3 Geotechnical Features

Most soil strata in Bangkok area are sandy clays and fine sands occurred from deposition of eroded material transported along the Chao Phraya River in the ancient time. These soil strata are covered by a thick layer of homogeneous grey clay with some interleaved organic matter. Borehole logs drilled to a depth of more than 300m indicate no rock strata.

Soil strata of the upper 30-m depth in Bangkok can be classified into four categories, i.e.

Top Soil—This soil layer is a dark grey clay with 0.5-3.0m in thickness. In some areas, the top soil is brown or brown-grey in color.

Compressible Clay—This layer is composed of soft and very soft clay of dark grey color with 3-8m in thickness overlying moderately stiff clay of grey color with 2-8m in thickness. An unconfined compressive strength of this layer is usually less than 10 tons/m².

Stiff and Very Stiff Clay—This layer is underlying the compressible clay layer. Clay in this layer is grey. Its depth varies from 8 to 14m. The standard penetration test shows remarkably higher values than that of the compressible clay layer. This layer has an unconfined compressive strength in the range of 10 — 40 tons/m². Pile foundations of most small buildings are designed to rest on this stratum.

Hard Clay and Underlying Granular Deposit—This hard clay layer has a yellow or brown color with thickness in the range of 2-6m. The unconfined compressive strength is usually greater than 40 tons/m² with standard penetration resistance

![Groundwater Aquifer in Bangkok](image)

Figure 3 Groundwater Aquifer in Bangkok
greater than 30 per foot. The granular deposit lies under the hard clay layer with the interface at the depth of 21-24m from ground surface. Pile foundations of most medium and some large buildings are designed to rest on this stratum.

2.4 Hydrogeology

Groundwater resource in Bangkok area originates in the southern area of the central plain. Water flows horizontally through clay and rock layers and is stored in the underlying granular deposits before flowing into the Gulf of Thailand. Groundwater aquifers in Bangkok area can be classified into 8 layers based on hydraulic and some specific hydrogeologic properties (see Figure 3).

Most aquifers are composed of granular deposits with some interleaved clay layers and are separated by aquitards of very dense clay layers. The aquifers mostly used are Nakhon Luang, Phra Padaeng and Nonthaburi aquifers due to their good water quality and high yield. At present, deeper aquifers are not used due to higher cost in well drilling. Most aquifers have transmissivity in the range of 15-150m$^3$/m/hr with storage coefficient in the range of 0.0005-0.001.

2.5 Land Use

A land use study in 1986 had classified land utilization in Bangkok into 14 types as shown in Table 1.

Rapid expansion of domestic economy in the past five years created significant impact on land use pattern and land prices in Bangkok. It is apparent that locations of dwelling and commercial units in city core of Bangkok are being replaced by high-rise buildings. Consequently, real estate development has extended to the areas along major roads from adjacent provinces. Due to great demand of dwelling units in conjunction with increasing land prices in the city core of Bangkok, it is anticipated that new housing projects will be developed in suburban areas of Bangkok and nearby cities.

2.6 Population

During the past few decades, the number of population in Bangkok has increased at

Table 1 Land Use in Bangkok

<table>
<thead>
<tr>
<th>Land Utilization</th>
<th>Area km²</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacant Lands</td>
<td>623.87</td>
<td>39.77</td>
</tr>
<tr>
<td>Agricultural Lands</td>
<td>543.13</td>
<td>34.62</td>
</tr>
<tr>
<td>Residential Area</td>
<td>181.0</td>
<td>11.54</td>
</tr>
<tr>
<td>Commercial Area</td>
<td>17.84</td>
<td>1.14</td>
</tr>
<tr>
<td>Industrial Area</td>
<td>22.25</td>
<td>1.42</td>
</tr>
<tr>
<td>Warehouse Area</td>
<td>6.86</td>
<td>0.44</td>
</tr>
<tr>
<td>Government Offices</td>
<td>41.73</td>
<td>2.6</td>
</tr>
<tr>
<td>Educational Institution</td>
<td>13.10</td>
<td>0.84</td>
</tr>
<tr>
<td>Religious Places</td>
<td>7.08</td>
<td>0.45</td>
</tr>
<tr>
<td>Parks</td>
<td>4.29</td>
<td>0.27</td>
</tr>
<tr>
<td>Public Areas</td>
<td>4.00</td>
<td>0.25</td>
</tr>
<tr>
<td>Roads</td>
<td>38.45</td>
<td>2.45</td>
</tr>
<tr>
<td>Rivers and Canals</td>
<td>54.37</td>
<td>3.47</td>
</tr>
<tr>
<td>Others</td>
<td>10.80</td>
<td>0.69</td>
</tr>
</tbody>
</table>

Table 2 GDP Composition

<table>
<thead>
<tr>
<th>Industry</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture, Forestry and Fisheries</td>
<td>16.0</td>
</tr>
<tr>
<td>Manufacturing industry</td>
<td>26.1</td>
</tr>
<tr>
<td>Construction, Public works</td>
<td>9.5</td>
</tr>
<tr>
<td>Transportation, Communication</td>
<td>6.8</td>
</tr>
<tr>
<td>Wholesale, Retail</td>
<td>15.2</td>
</tr>
<tr>
<td>Finance, Real estate</td>
<td>9.2</td>
</tr>
<tr>
<td>Administration, others</td>
<td>17.2</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>
remarkably high rates, i.e. from 3.1 million in 1970 to 4.7 million in 1980 and 5.6 million in 1990. Many of them migrated from other provinces because there was higher opportunity to find good jobs in Bangkok.

2.7 Socio-economic Status

Economic status has taken a favorable turn since 1986 due to decrease of oil price, investment from foreign countries, political effort for economic growth, and etc. Especially industries have developed remarkably. Table 2 shows the composition of GDP based on the industrial activity.

The rapid economic growth was attained with its rate of more than 10% per year during 1987 to 1990. However, significant difference is found in economic status in the country and the development of agro-industry is still thought to be important for the economical base.

3. WATER RESOURCES

3.1 The Chao Phraya River

The Chao Phraya River is the most important and largest river in Thailand. It originates in the mountain ranges in the north and covers nearly all the areas in the Northern and Central regions. The river basin has a drainage area of 178,000km². The average annual runoff at the river mount is 30,300Mm³. The majority of agricultural products are produced in this basin. The Chao Phraya River flows through Bangkok from the north to the south to drain into the Gulf of Thailand. It is the main water resource of the area.

At present, there exist many medium-scale and large-scale water resources development facilities in the Chao Phraya River Basin. These facilities have been constructed to provide irrigation water to agricultural lands in the basin and to generate electricity.

3.2 Water Quality

Since 1985, the Office of the National Environment Board (ONEB) has continuously monitored water quality in the Chao Phraya River at 34 monitoring stations distributed from the river mouth (Km 0) to Nakhon Sawan (Km 379). The results obtained from the monitoring showed that water quality in the Chao Phraya River was influenced by tidal fluctuation as well as the amount of fresh water released from the Chao Phraya Dam located approximately 200km north of Bangkok. At low flow period (river flow less than 100m³/sec), sea water could intrude up to Ang Thong Province which is about 175km from the river mouth, while at high flow rate (river flow more than 4,000m³/sec), sea water intrusion could be monitored only at Pathum Thani Province (Km 75).

The results of dissolved oxygen (DO) measurement from 1985 to present showed that there was a declining trend of DO content in the Chao Phraya River. The DO content in the lower part of the Chao Phraya River was usually less than 2.0mg/l. During the dry season, the DO levels in some parts of the lower Chao Phraya River
decreased to 1.0mg/l or lower. In the middle and upper portions of the river, the DO levels were in the range of 4.0-6.0mg/l and also had a tendency to decrease.

The results of biochemical oxygen demand (BOD₅) measurement showed that the BOD₅ levels in some monitoring stations had an increasing trend. The monitored values were in the range of 1.5-5.0mg/l.

In regard to total coliform bacteria, it was found that the total coliform bacteria in the lower parts of the Chao Phraya River in 1990 were in the range of 1.07-3.55×10⁶ MPN/100 ml which increased from the previous figures in 1985 which were in the range of 0.78-1.24×10⁵ MPN/100 ml. In the upper portion of the river, the total coliform bacteria were in the range of 8,000-51,800 MPN/100ml in 1990 which increased from the figures in 1985 which were in the range of 7,000-24,000 MPN/100ml.

Regarding heavy metal contamination, the results obtained from the monitoring in April 1984 showed that copper fluctuated between 4.8×10⁻³ and 66.9×10⁻³mg/l in water and between 10.4×10⁻³ and 41.7×10⁻³mg/kg in sediment. Nickel in water ranged from 2.7×10⁻³ to 0.14mg/l, cadmium ranged from not detectable to 4.3×10⁻³ mg/l, and lead ranged from not detectable to 4.1×10⁻³ mg/l. The average concentrations of cadmium and lead in the sediment were 0.4 and 22.6mg/kg, respectively. Sediment contamination seems to be most pronounced in the lower stretches of the river (Onodera, 1985).

Organochlorine pesticides such as Aldrin, BHC, DDD, DDE, DDT, Dieldrin, Heptachlor and Lindane were all found in the Chao Phraya River. The concentrations of Aldrin, BHC and Dieldrin in water in April 1984 were 0.126, 0.002×10⁻³ and 0.08×10⁻³mg/l, respectively. Concentrations of these pesticides in sediments were found to be 10 to 100 times greater than in water (Onodera, 1985).

Many investigations on planktons in the Chao Phraya River conducted during 1978-1990 concluded that the most common phytoplanktons were in Phylum Cyanophyta, Chlorophyta and Crysophyta. It was found that in the lower portion of the river, phytoplanktons were more abundant in the dry season due to high concentration of nutrients and high temperature. However, at some upper parts of the river, more phytoplanktons were observed in the rainy season. This might be due to heavy load of nutrients discharged from nearby agricultural lands.

The monitoring results during 1976-1991 revealed that there was a remarkable change in benthic organism in terms of species, abundance and diversity index. At Phra Pradaeng District, Samut Prakarn Province (Km 18), the density of benthic organism in 1976 was 27,575 individuals/m² with a diversity index of 0.27. These values decreased to zero in 1991. At Bangkok Bridge (Km 41.5), the density of benthic organism decreased from 21,300 to 1,000 individuals/m² while the number of species decreased from 4 to 1 species and the diversity index changed from 0.11 to zero during the same period.

The number of fish species in the Chao Phraya River has decreased remarkably during the past few decades, especially in the lower portion. The numbers found in
1955, 1964, 1981, 1989 and 1991 were 127, 90, 66, 22 and 18 species, respectively. These monitoring results implied continuous deterioration in water quality in the river.

3.3 Water Use

Water uses in Bangkok are for 2 main purposes, i.e., 1) domestic consumption and commercial activities; and 2) industrial use. The main source of water is from water supply system of the Metropolitan Water Works Authority (MWA) which utilizes the Chao Phraya River and some groundwater wells as raw water sources.

Groundwater is also an important water source in Bangkok area. The records in 1991 from the Groundwater Division, Department of Mineral Resources, showed that the total groundwater pumping rate in Bangkok was as high as 0.64Mm³/day. About 0.49Mm³/day was pumped by private sectors and another 0.15Mm³/day was pumped by the MWA and some other agencies. Furthermore, unlicensed pumping of groundwater was estimated about 50% of the legal licensed pumping rate (TDRI, 1987). That is the overall groundwater pumping rate could be as high as 0.96 Mm³/day.

4. EXISTING WATER ENVIRONMENTAL PROBLEMS

With a total population of more than 6 million, the daily demand of water supply and the amount of wastewater generated in Bangkok are quite high. As previously mentioned, the rate of groundwater pumping in this region might be as high as 0.96Mm³/day which far exceeds the safe yield. The over-pumping of groundwater has resulted in falling of piezometric heads in the underlying groundwater aquifers, which subsequently resulted in land subsidence. Investigation on land subsidence caused by groundwater pumping was conducted by AIT during 1978–1980 and it was concluded that excessive groundwater extraction caused the decline of groundwater level at the rate of 2.5 to 3.0m/year and the drop in groundwater level was the main cause of widespread land subsidence. During 1978–1979, the rate of land subsidence was about 5.0cm/year in the central part of Bangkok and as high as 10cm/year in the southeastern part of the city (AIT, 1980).

The falling in piezometric heads of groundwater also resulted in intrusion of saline water from the sea, especially in those wells located in the southern part of Bangkok which is close to the Gulf of Thailand. Many wells could supply fresh water for some period of time, but later when more wells were developed and pumping continued, the withdrawn water became more and more brackish. Several wells have been abandoned and new wells have to be drilled to the deeper aquifers.

Besides seepage of saline water into groundwater aquifers, farther intrusion of sea water to upstream portions of the Chao Phraya River has occurred especially during the dry period. In some drought years, lot of damage occurred to fruit trees and other crops grown in the areas located near the river and connecting canals.

In spite of shortage of water in the dry season, Bangkok has been subject to frequent flooding in the rainy season. Flooding in Bangkok is caused by combination of several factors, including surface runoff from floodplain on the northern part,
heavy rainfall within Bangkok area, spill water from the Chao Phraya River during peak discharge and high tide, land subsidence due to over-pumping of groundwater, as well as inadequate drainage systems in the area. The big flood in 1982 caused damage valued at 6,200 million baht (about US $ 253 million) (TDRI, 1987).

Nowadays, water quality in the Chao Phraya River and various canals in Bangkok is very polluted. In most canals in Bangkok, water has become anaerobic. The recorded dissolved oxygen concentrations in the Chao Phraya River have shown depressed sag curves. However, as a result of dilution with sea water during the high tide which helps flush the polluted river water out into the sea during the low tide, the DO levels in the river water can still maintain the aerobic condition even during the dry period.

The main cause of water pollution problems in Bangkok is that there exist very limited central wastewater collection and treatment systems. It was estimated that only 2% of Bangkok's population were connected to the existing sewers. Most households will install an individual on-site treatment unit which is composed of a septic tank followed by a seepage pit. Since sub-surface soils in Bangkok area are clayey with very low permeability, wastewater cannot percolate into the ground but will drain into the nearby storm sewers which is finally discharged into a canal and results in deteriorated water quality.

It was estimated that the volume of wastewater discharged from the residential areas and commercial establishments in Bangkok in 1990 was as high as 1.23Mm³/day with the total BOD₅ loading of about 200,000kg/day (Pollution Control Department, 1993). Besides domestic and commercial wastewater, industries are also the main source of pollutant loading in Bangkok. Though all the polluting factories must install suitable wastewater treatment facilities in order to obtain their annual operating permits from the Industrial Works Department (DIW), many of these facilities have not been operated to their full capacities due to the lack of qualified personnel and awareness of the owners or managers. It was estimated that the average efficiency of all industrial wastewater treatment facilities would not be more than 70%. With this estimated efficiency and available data on factory inventory collected from the DIW, it was estimated that the BOD₅ loading discharged from the factories located in Bangkok was approximately 40,000kg/day (Pollution Control Department, 1993).

Over the years, several plans for Bangkok's sewerage system were proposed, e.g., Litchfield, et al (1960), Husband & Co. (1962), Tholin (1962), CDM (1968), JICA (1981), etc. However, none of these plans have been fully implemented due to the lack of budget and political will. In the past few decades, the Bangkok Metropolitan Administration (BMA) and the government considered flood control as the top-ranking priority because the flooding problems were much more obvious. At present, the government is more aware of the water pollution issue and willing to invest in the central sewerage and treatment systems. Some new facilities are being constructed
and detailed designs are being prepared in several zones.

5. TECHNICAL APPROACHES IN SOLVING THE PROBLEMS

5.1 Flood Protection and Drainage

As previously mentioned, flooding in Bangkok is caused by several factors. Therefore, a combination of polders, dikes, canal networks, barrages and pumping stations are used in flood protection and drainage.

In general, the protected area is divided into a number of polders, each of which is bounded by existing roads, temporary or permanent dikes. In each polder there exists a canal network system with barrages and pumping stations constructed at the ends of the main canals. Flood water in each polder is drained out by this canal network system into the river or to some main canals in the adjacent polder.

Surface runoff from the floodplain in the northern part of Bangkok is prevented from entering the central area by constructing dikes and diversion canals. Some existing roads are embanked to a higher elevation and used as a dike. Dikes are also constructed along the banks of the Chao Phraya River and some canals where overflow of water normally occurs during the high tide or high flow period.

The canal network systems in Bangkok play a very important role in drainage. Most of these canals were constructed during 80–100 years ago. The original main purposes were for navigation and water supply. Nowadays, their main functions are for wastewater collection and drainage.

5.2 Control of Groundwater Usage

In order to control the usage of groundwater, the Groundwater Act was issued in 1977. Under the provisions of the Act, one must obtain an official permit to utilize groundwater from designated groundwater areas. At present, the Act is being implemented in some areas where over-exploitation and groundwater quality have been critical problems.

The Minister has issued directives on the technical principles of groundwater management (Piancharoen, 1982) as follows: (1) Bangkok and the five adjacent provinces have been designed as the Bangkok Groundwater Area. Groundwater occurring at depths exceeding 15m below the ground surface in this area is subject to control under the Act; (2) specifications for drilling and the construction of wells are provided under the Act. Standard forms for daily drilling reports, well records and other information are prescribed; (3) methods of groundwater extraction and conservation are outlined; (4) technical measures to protect groundwater from pollution are described and drinking water standards are issued; and (5) technical principles are given for the disposal or injection of water or liquids into an aquifer through a well. Emphasis is placed on the monitoring of water quality in the affected aquifer and neighboring aquifers through a network of observation wells (TDRI, 1987).

5.3 Solving Water Shortage Problem

In order to solve the problems on water shortage in the Lower Chao Phraya
Basin, especially the domestic, commercial and industrial water supply of which the demand has been sharply increased, some measures have been implemented. A committee consisting of representatives from EGAT, RID and MWA was set up to determine the amount of water to be released from the Bhumibol and Sirikit Reservoirs in each period of the year. This committee will have a meeting periodically to evaluate requirements of various water users and available water in the reservoirs, and then decide for the water volume to be released from the reservoirs. The decision of this committee will be the guidelines for EGAT’s personnel who are responsible in reservoir operation.

Transbasin water resources development projects are considered in solving water shortage in the Chao Phraya Basin. The MWA is constructing a diversion canal to divert water from the Mae Klong River at the rate of 60m³/sec to the new water treatment plant which is constructed on the west bank of the Chao Phraya River. This treatment plant will supply water to the western part of MWA’s service area.

5.4 Solving Water Pollution Problem
To solve the problem of water pollution in the Chao Phraya River as well as various canals in Bangkok, it is necessary to reduce the waste load which have been discharged into these water bodies. At present, the government is willing to invest in the municipal wastewater collection and treatment systems. The construction of central treatment plants has been carried out in some inner zones. Detailed design and feasibility studies are being conducted in some other zones of Bangkok.

6. EXISTING AND PLANNED WATER MANAGEMENT PROJECTS

6.1 Flood Protection and Drainage Projects
Flood protection and drainage systems in Bangkok are divided into several zones as follow:
- The inner Bangkok
- The eastern suburban area of Bangkok
- The western Bangkok

1) The Inner Bangkok on East Bank of the Chao Phraya River. The east bank flood protection system in the inner Bangkok consists of polders, dikes or embankments, and canals equipped with gates and pumping stations. The protected area is divided into 5 zones. The system functions by opening the gates to drain water into the Chao Phraya River when water level in the river is low or closing the gates and using pumps to drain water out when water level in the river is high.

2) The Eastern Suburban Area of Bangkok. This is the suburban area on the east of the inner Bangkok to His Majesty’s initiatory dike. The system consists of polders, dikes, drainage canals equipped with gates and pumps. The canal system in this area is connected to canals in the inner Bangkok and flood water in this area is drained through the inner Bangkok to the Chao Phraya River.

3) The Western Bangkok. The flood protection system in the western Bangkok
consists of a number of polders where existing roads, temporary and permanent dikes, as well as concrete walls are used as polder boundaries to prevent flood water from entering the protected areas. Inside each polder, there are some drainage canals with gates and pumping stations. Flood water from the polders is drained out into the Chao Phraya River.

6.2 Wastewater Collection and Treatment Projects

Since Bangkok is a large city covering the total area of approximately 1,572km², it is necessary to divide the area into several zones to minimize the cost of wastewater collection system. At present, BMA has started with 6 projects in the central Bangkok. The details of each project are summarized as follow:

A) Ratanakosin Project. This project will serve an area of 4.0km² in Phra Nakhon District. Intercepting sewers will be constructed along the canals in the service area. Wastewater will be collected and transported to the activated sludge plant located at Ban Phan Thom. The capacity of the treatment plant is 40,000m³/day. At present, the construction work is being conducted.

B) Si Phraya Project. This project will serve an area of 2.7km² in Pomprab-satru-pai and Sampanthawong Districts. Domestic wastewater will be collected by intercepting sewers and transported to an activated sludge plant with a capacity of 30,000m³/day. Construction of the treatment plant was completed in 1992. Construction of the wastewater collection system is being conducted.

C) Yannawa Project. The service area covers about 28.5km² in Bang Rak, Yannawa, Sathorn and Bang Korlaem Districts. Wastewater will be collected and transported to the activated sludge plant with a capacity of 390,000m³/day. The detailed design has been finished. The construction work will begin soon.

D) Turn-key Project–Phase 1. The service area of this turn-key project is divided into 2 parts as follow:

(a) Part 1: Lumpini Park Treatment Plant. The service area of this part covers 17.65km². Wastewater will be transported to a treatment plant located at Lumpini Park. It has been estimated that the wastewater volume is about 179,300m³/day and the BOD₅ loading is 35,860kg/day.

(b) Part 2: BMA–2 Treatment Plant. This part will serve a total area of 17.85km². The wastewater treatment plant is located at the nursery plant in the second campus of the Bangkok Metropolitan Administration (BMA–2). It has been estimated that the wastewater volume is 167,000m³/day and the BOD₅ loading is 33,400kg/day.

This turn-key project is now under the bidding process.

E) Nong Kham–Pasicharoen Project. This service area covers about 40km² in Nong Kham and Pasicharoen Districts. Wastewater will be collected and transported to the activated sludge plant with a capacity of 176,000m³/day. The detailed design has been finished. The construction work will begin soon.

F) Rachaburana Project. This project will serve an area of 35km² in Rachaburana District. The estimated wastewater volume is 65,000m³/day. The activated sludge
process is also used as the treatment system. The detailed design has been finished and the construction work will begin soon.

7. CONCLUSION AND RECOMMENDATION

Due to the fact that water resources are vital assets to development and there exist several water-related problems in Bangkok, more attention is required from the government. From the existing situations described above, the following conclusions can be made and some recommendations are provided:

1) River Basin Management Plans. Water-related problems in Bangkok are caused by several factors. Therefore, a combination of mitigation measures are required in solving the problems. In fact, it is necessary to have properly planned water resources management systems for the whole river basin in which various components of water resources, water uses, and all the related problems are taken into consideration.

2) Solutions for the Problems on Shortage of Water Supply. Due to the rapid increase in water demand in the Lower Central Plain of Thailand especially in Bangkok City, it is likely that the problems on shortage of water supply will be more severe in the near future. Some development and management plans are required to avoid or minimize the problems. These include implementation of transbasin water resources development projects, encouragement on efficient use of water, improvement in existing water supply and irrigation systems, development of a plan for conjunctive use of surface and groundwater resources, etc.

3) Solutions for Flood Protection and Drainage Problems. During the past few decades, the flood protection and drainage problems in Bangkok have received high attention from the government and responsible agencies. However, due to the fact that Chao Phraya Basin covers very area and enormous amount of surface runoff will flow through Bangkok before discharging into the Gulf of Thailand, severe flooding still occurs periodically. More investment and improvement in flood protection and drainage facilities are necessary. More effective use of the existing canal network systems in the area in conjunction with other facilities such as pumping stations, dikes, retarding basins, etc., can help reduce the severity of the problem.

4) Solutions for Water Pollution Problems. It is evident that degradation in water quality in the main river and various canals in Bangkok is very severe at present, the government should provide more attention in solving this problem. Investment on sewerage systems and central wastewater treatment facilities is urgently required. In order that the installed facilities can function properly, proper design and construction are of utmost importance.

5) Laws and Enforcement. Several laws related to water pollution control are still not up-to-date. Penalties for those who violate the laws are not adequate. Another important issue is law enforcement which is still lacking. It is necessary that these water-related laws be amended to suit the current situations and emphasis should also be placed upon law enforcement.
6) Implementation Problems. There exist several problems in implementing water resources management and water pollution control projects in Thailand, these include limitation of available budget, inadequate qualified personnel, lack of investment and management policies, organization overlapping, lack of cooperation among various concerned agencies, etc. These problems must be solved in order that more effective water management can be performed in the future.

REFERENCES

Pollution Control Department, Bangkok Metropolitan Region Wastewater Management Master Plan, prepared by MACRO Consultants Co., Ltd. et al., March 1993.