MANAGEMENT OF WATER QUALITY IN MIDDLE AND LOWER THA CHIN RIVER USING MATHEMATICAL MODEL (MIKE 11) IN COORPERATION WITH GEOGRAPHIC INFORMATION SYSTEM (GIS)

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MANAGEMENT OF WATER QUALITY IN MIDDLE AND LOWER THA CHIN RIVER USING MATHEMATICAL MODEL (MIKE 11) IN COORPERATION WITH GEOGRAPHIC INFORMATION SYSTEM (GIS)

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ABSTRACT

This study aimed to predict water quality in the middle and lower Tha Chin River by using Mathematical Modeling (MIKE11) incorporated with the Geographic Information System (GIS). Calibration of MIKE 11 model: Hydrodynamic Module, Advection-Dispersion Module and Water quality Module were made during low flow period, i.e. February – May, in the year 2005. Verification of the model was further conducted during the low flow period in the year 2006. The study areas covered the middle and lower parts of Tha Chin River, which was about 202 km long, starting from Phopraya Regulators in Suphanburi through the estuary at Samut Sakorn. Selected water quality parameters i.e. dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia, salinity and temperature were made.

BOD loading in the year 2005 was calculated based on information about communities, industries, fishery farms, and piggery sources in the areas of Suphanburi, Nakhon Pathom, and Samut Sakorn provinces. Simulation water quality in Tha Chin river year 2005 was calculated by taking into account the population, pig farm, fishery farm numbers and recorded data of factories in the study area.

The study results and prediction indicated that water quality of middle and lower Tha Chin River in the year 2005 was higher than those of the required surface water quality standard level 4. However, the average values of water quality actually met the required standards if proper controlled pollution discharge under 3 scenarios (50% reduction of all pollution discharge by an equal loading, 75% reduction of only the fishery farm discharge and 20-75% reduction of pollution discharge at the critical point) were established. Therefore, development of a proper pollution management strategy to ensure good water quality in the river should be seriously considered.

KEY WORDS: WATER QUALITY MODEL / MIKE11 / GEOGRAPHICAL INFORMATION SYSTEMS / THA CHIN RIVER / HYDRODYNAMIC MODEL

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การจัดการคุณภาพน้ำในแม่น้ำท่าจีนตอนกลางและตอนล่างโดยใช้แบบจำลองทางคณิตศาสตร์ (MIKE 11) ร่วมกับระบบสารสนเทศทางภูมิศาสตร์ (GIS) (MANAGEMENT OF WATER QUALITY IN MIDDLE AND LOWER THA CHIN RIVER USING MATHEMATICAL MODEL (MIKE 11) IN COORPERATION WITH GEOGRAPHIC INFORMATION SYSTEM (GIS)).

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บทคัดย่อ

ในการศึกษาครั้งนี้เป็นการใช้แบบจำลองทางคณิตศาสตร์ (MIKE11) ร่วมกับระบบสารสนเทศทางภูมิศาสตร์ (GIS) เพื่อการพยากรณ์คุณภาพน้ำในแม่น้ำเจ้าท่าจีนตอนกลางและตอนล่าง การปรับเทียบแบบจำลองได้ดำเนินการในช่วงฤดูร้อน (กุมภาพันธ์ – พฤษภาคม) ปี พ.ศ. 2548 จากนั้นทำการตรวจสอบความถูกต้องของแบบจำลองในช่วงฤดูร้อน ปี พ.ศ.2549 พื้นที่ศึกษาครอบคลุมบริเวณแม่น้ำท่าจีนตอนกลางและตอนล่างโดยขอบเขตต้นน้ำอยู่ที่ประตูระบายน้ำโพธิ์พระยา จังหวัดสุพรรณบุรี ขอบเขตปลายน้ำอยู่บริเวณปากแม่น้ำเจ้าท่าจีน จังหวัดสมุทรสาคร รวมระยะทางประมาณ 202 กิโลเมตร พารามิเตอร์ทางคุณภาพน้ำที่ใช้ในการศึกษาครั้งนี้ คือ ปริมาณออกซิเจนละลายน้ำ ค่าความต้องการออกซิเจนทางชีวเคมี แอมโมเนีย ความเค็ม และ อุณหภูมิ

สำหรับข้อมูลปริมาณความสกปรกที่ไหลลงสู่ลำน้ำท่าจีนตอนกลางและตอนล่างในปี พ.ศ.2548 คำนวณจากจำนวนประชากร จำนวนสุกร ฟาร์มเลี้ยงปลาและกุ้ง ในพื้นที่ที่ทำการศึกษา ในส่วนของโรงงานอุตสาหกรรมได้คำนวณจากข้อมูลบันทึกปริมาณน้ำทิ้ง และค่าความสกปรกของน้ำโดยกรมโรงงาน พื้นที่ศึกษาครอบคลุม 3 จังหวัด คือ สุพรรณบุรี นครปฐมและสมุทรสาคร

ผลจากการศึกษาและคาดการณ์พบว่าคุณภาพน้ำในแม่น้ำท่าจีนปี พ.ศ. 2548 มีค่าเกินที่กำหนดไว้ในมาตรฐานแหล่งน้ำผิวดินประเภทที่ 4 อย่างไรก็ตามผลจากการควบคุมปริมาณมลพิษที่ปล่อยลงสู่แม่น้ำภายใต้การจำลองเหตุการณ์ใน 3 กรณี โดยการลดมลพิษจากทุกแหล่งกำเนิด 50%, การลดมลพิษเฉพาะจากการเพาะเลี้ยงสัตว์น้ำ 75% และการลดมลพิษเฉพาะจุดที่เกิดมลพิษสูง 20-75% ทำให้คุณภาพน้ำโดยเฉลี่ยเป็นไปตามเกณฑ์มาตรฐานแหล่งน้ำประเภทที่ 4 และควรต้องมีการพัฒนาแผนยุทธศาสตร์ที่เหมาะสมในการจัดการลดมลพิษทางน้ำอย่างจริงจัง เพื่อให้คุณภาพน้ำเป็นไปตามมาตรฐานที่กำหนดไว้

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CHAPTER I
INTRODUCTION

1.1 Rationales and Justifications

Tha Chin River basin is located in the Central River Basin of Thailand, covering 14,000 km^2. The main channel of the Tha Chin River is 325 km in length and flows through four provinces: Chainat, Suphanburi, Nakhonpathom and Samutsakorn, and discharging directly to the Gulf of Thailand. This river has been subdivided into three sections: lower, middle, and upper based on the national surface water quality standard and its classification. The middle Tha Chin starts from Phopraya Regulators in Suphanburi province and ends at Nakorn Chaisri in Nakhonpathom province the lower Tha Chin starts from Nakorn Chaisri in Nakhonpathom province and ends at Muaeng in Samutsakorn province.

Over a decade, population growth, land use changing, urbanization, intense agriculture, farming and industrialization have produced substantial changes in the Tha Chin River basin. The problems include water quality degradation, toxic dumping, and saltwater intrusion, leading to conflicts and confrontations among various water user sectors. In 2000-2002 State of Environment Report, the Tha Chin River has the dubious distinction of having the worst water quality in Thailand. The Tha Chin River, in the lower part from Nakorn Chaisri District of Nakorn Pratom Province to estuary in Samut Sakorn Province, was heavily polluted and the water quality was very much below the standard level set for surface water quality, especially dissolved oxygen. The main sources of pollution are point sources originating from domestic, swine farm and industrial effluent, and non-point pollution generated by human activities, such as paddy fields, orchards, and urban runoff. Despite repeated efforts at rehabilitation and management, the lower portion of the Tha Chin River and its surrounding area have remained extremely polluted for decades.

In recent years, water quality model has become an important part of most water quality management and planning process. Thailand has applied water quality model as a tool for water quality management for many years. Among the most widely used river water quality models, MIKE 11 is the model for simulating flow, water quality and sediment transport in estuaries, rivers, irrigation canals and other surface water bodies in many regions. MIKE 11 is a general river modeling system developed by DHI (Danish Hydraulic Institute). It is the most advanced and comprehensive model of its type today, and it is presently used by more than 1500 users around the world (USEPA, 2006). MIKE 11 has used in many countries, including Australia, New Zealand, and Bangladesh and in many European countries. It contains modules for run-off simulations, hydrodynamics, flood forecasting, transport and dilution of dissolved substances, sediment transport, and river morphology as well as various water quality processes. MIKE 11 has an interface to GIS allowing for preparation of model input and presentation of model output in a GIS environment. The water quality module in MIKE 11 was developed by the VKI (Water Quality Institute, Denmark). It describes the basic processes of river water quality in areas influenced by human activities, e.g. oxygen depletion and ammonia levels as a result of organic matter loads. The water quality module solves the system of coupled differential equations describing the physical, chemical and biological interactions in the river.

In this study, it aims to use MIKE 11 model as a tool to study water quality under different wastewater discharge scenarios. It generates scenarios aiming for an overall reduction of source-specific loads discharging to the river.

1.2 Research Objectives

1.2.1 General Objective

The general objective of this study is to predict the water quality of the middle and lower Tha Chin River by an application of MIKE 11 incorporation with GIS.

1.2.2 Specific Objectives

Specific objectives of this study are as follows:

1.2.2.1 To calibrate and verify the hydrodynamic, dispersion, and water quality in the Tha Chin River in the year 2005 and 2006.

1.2.2.2 To simulate water quality in year 2005 to meet the water quality standard classification by controlling pollution discharge.

1.2.2.3 To recommend appropriate water quality managements and strategies for the Tha Chin River.

1.3 Scope of Study

The scope of the study covers on the followings:

1.3.1 The study area is at the middle and lower reach of the Tha Chin River, starting from Phopraya Regulators, Suphanburi Province (RKM 202) to the estuary at Samut Sakorn Province. The total length of the stretch is about 202 Km. (Figure 1.1)

1.3.2 Water quality data was acquired from Water Quality Management Division, Pollution Control Department.

1.3.3 Cross-section of Tha Chin River was acquired from the Royal Irrigation Department.

1.3.4 Hourly water level, daily water level, and discharge were acquired from Port Authority of Thailand and the Royal Irrigation Department.

1.3.5 GIS datasets of the district and province boundary and stream of Suphanburi, Nakhon Pathom and Samut Sakhon provinces were provided by Mahidol University.

1.3.6 Population distribution data, Pig farm distribution data, and Industrial distribution data were derived from National Statistical office, Department of Livestock Development and Department of Industrial Work, respectively.

1.3.7 Calibration of MIKE 11: Hydrodynamic module, Advection-Dispersion Module and Water quality module took place during low flow period (February – May) of 2005.

1.3.8 Verification of MIKE 11 model took place during low flow period (February – May) of 2006.

1.3.9 Simulation of MIKE 11 model tool place in year 2005 to meet the water quality standard classification by controlling pollution discharge.

1.4 Definition of Keywords

1.4.1 Water quality model - The tool of evaluation of the water quality impacts. It can be categorized into 4 types, basing on the number of spatial dimension used, e.g. one-dimension, two-dimension, three-dimension and multilayered models. In this work, the model used is the one-dimension model.

1.4.2 Mathematical model - A quantitative formulation of chemical, physical, and biological processes that simulate the system.

1.4.3 State variable –The dependent variable that bring modeled.

1.4.4 Model Parameter – coefficients in the model that used to formulate the mass balance equation. (e.g. rate constant, equilibrium, constant).

1.4.5 Model input – forcing function or constants required to run the model. (e.g. flow rate, hydraulic data, cross-section).

1.4.6 Calibration - a statistically acceptable comparison between model result and filed measurements; adjustment or tuning the model parameter is allowed with in the range of experimentally determined value reported in the literature review.

1.4.7 Verification - a statistically acceptable comparison between model result and second (independent) set of filed data of another year or the alternate site; model parameters are fixed and no further adjustment is allowed after the calibration step.

1.4.8 Simulation – use of the model with any input data set (even hypothetical input) and not requiring calibration of verification with filed data.

1.4.9 Geographic Information System (GIS) -A configuration of computer hardware and software that captures, stores, analyzes, and displays geographic information.

1.4.10 Database – A collection of interrelated information managed, storage as a unit, usually or some form of mass-storage system, such as magnetic tape or disk. A GIS database includes data about the spatial location, shape and attributes of geographic features.

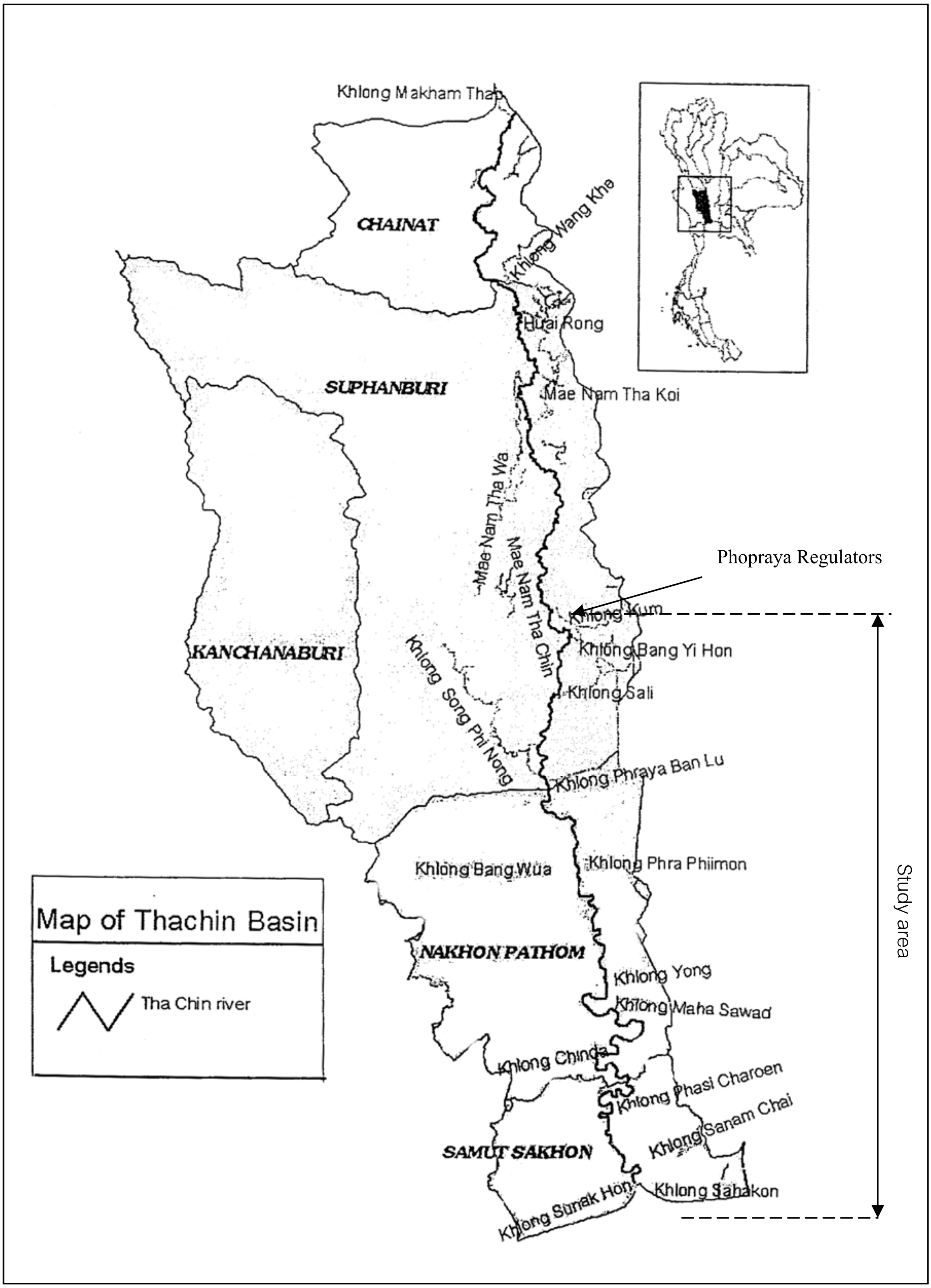


Figure 1.1 Study area

1.5 Conceptual Framework of Study

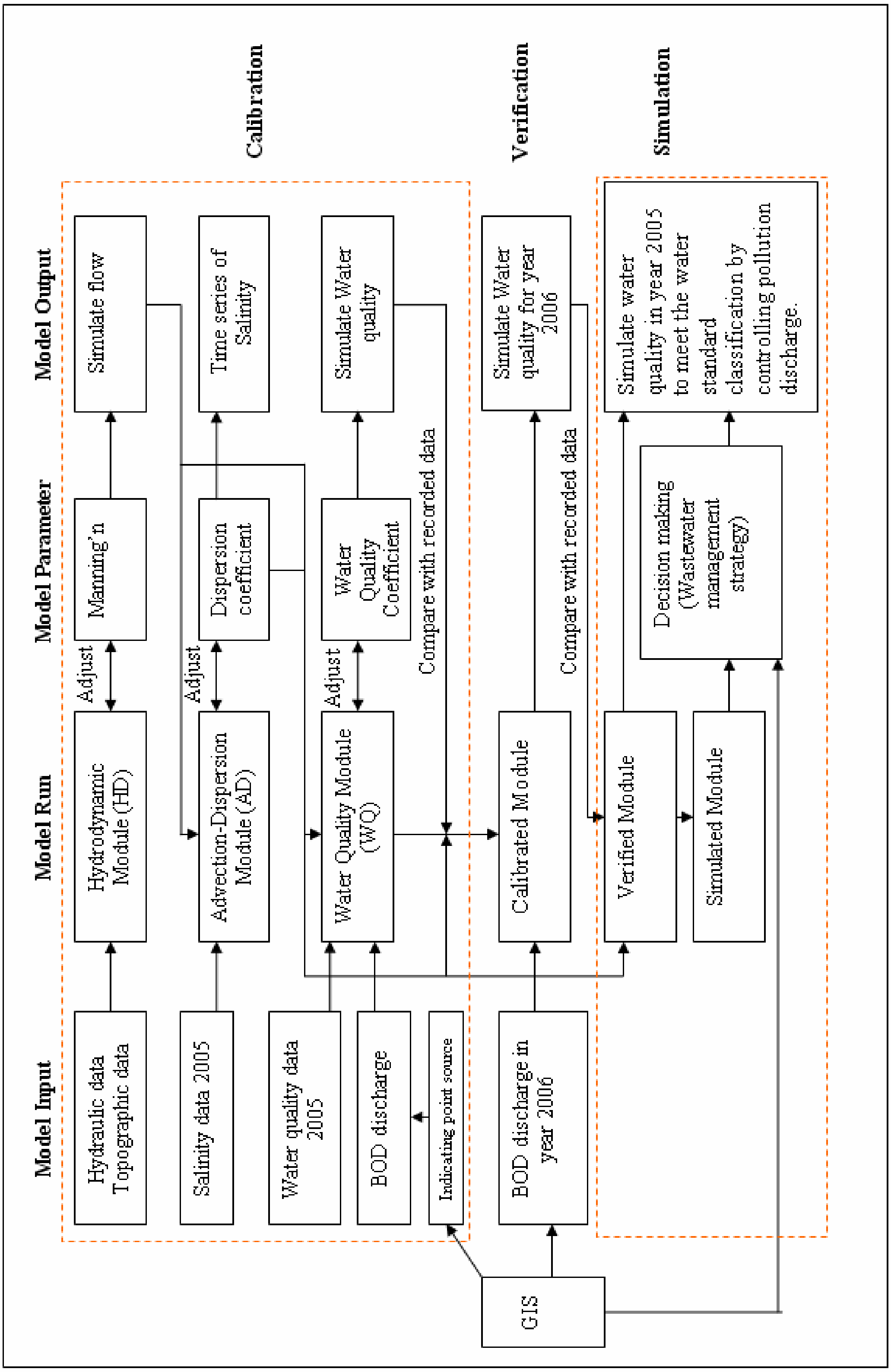


Figure 1.2 Conceptual framework of study

1.6 General Information of Study Area

1.6.1 Natural Conditions

The Tha Chin River is located in the central part of Thailand. Its watershed is connected to The Chao Phraya River Basin to the east, and the Mae Klong River Basin and the Khwae Yai River Basin to the west. To the north is the Sa Krae Krang River Basin. The Tha Chin River is a major branch of the Chao Phraya River, and is subject to frequent flooding. The drainage basin of the Tha Chin River covers 13,559 km^2, with a maximum elevation of 1,475 m above mean sea level (MSL). The watershed is located in the Northeast of the Chainat and Uthai Thani Provinces and the Southwest of the Kanchanaburi Province.

Soil in the basin is mainly well-drained sand to clay. In the lowland, dark clays and the sand-loam soils are often found (Simachaya, 1999). In the middle area, to northern side of basin, there are primarily brown color soils, which are typical for the tropical region, and the soil support abundant vegetation. In the northeastern to western sides of the basin, there are red color soils that are enriched in hydrated iron oxides. Soils along the riverbanks consist mainly of clay.

The climate of The Tha Chin Drainage Basin is influenced by monsoon with clear divisions of hot, rainy and winter seasons. The hot season extends from February to the middle of May and is influenced by the southeast monsoons from South China Sea. The rainy season is from middle May to October, due to the southwest monsoons from the Indian Ocean. The winter season occurs from November to January influenced by the northeast monsoons from China.

The average annual temperatures recorded from 1973 to 2003 are between 27.7 and 28.1 ^oC, with the highest average temperature being in April at 36.3-37.2 ^oC and the lowest one at 18.1-18.4 ^oC in January. The annual relative humidity is approximately 70% (DEQP,2003). The total annual mean rainfall is between 1012 and 1035 mm. The highest average monthly rainfall is between 224 and 226 mm in September (DEQP,2003).

The Tha chin Basin has only one major river with many tributaries. The depth and width of the major riverbeds are 3 to 12 m and 50 to 600 m, respectively. The maximum flow rate in the river occurs between September and November (rainy season). The major use of water in the middle and upper reaches of the river is for agricultural activities. In the lower reach, the water is mainly for industrial and transportation purposes. However, flow of the Tha Chin needs to be administered in order to:

- Mitigate the effects of flooding in the rainy season,
- Provides sufficient water supply to the lower-reach users,
- Provide water for irrigation purpose,
- Protect the river from saline intrusion.

1.6.2 Socio-Economic Conditions

1.6.2.1 Population and Land Use

The entire basin has a population of 2.44 million. The majority of the region's population are concentrated in the rural areas (Provincial Administration, 2005). Projection of population from 2000 to 2015 are based on the National Development Policy Framework. The data was provided by PCD in 1997 for water quality management planning in the Central River Basins. The province with the largest population is the Nakhon Pathom Province. The majority of industries, cities and farms are clustered along the Tha Chin River in the provinces of Suphan-buri, Nakhon Pathom, and Samut Sakhon. The cultural, financial, commercial, and administrative centers are normally located in the downtown areas of these provinces.

The changing of the land use has direct and indirect effects on water quality in the Tha Chin River, such as increased water consumption and water pollution. As such, information about land use is important for water quality management. The basin is predominatly agriculture (comprising 77.83 percent or 10,553.26 km^2 of the total area) (PCD, 2005). The agricultural lands are mainly for paddy farms (5,519.39 km^2) and vegetable/fishery/livestock farm (5,033.87 km^2). The land use picture is shown in Figure 1.3.

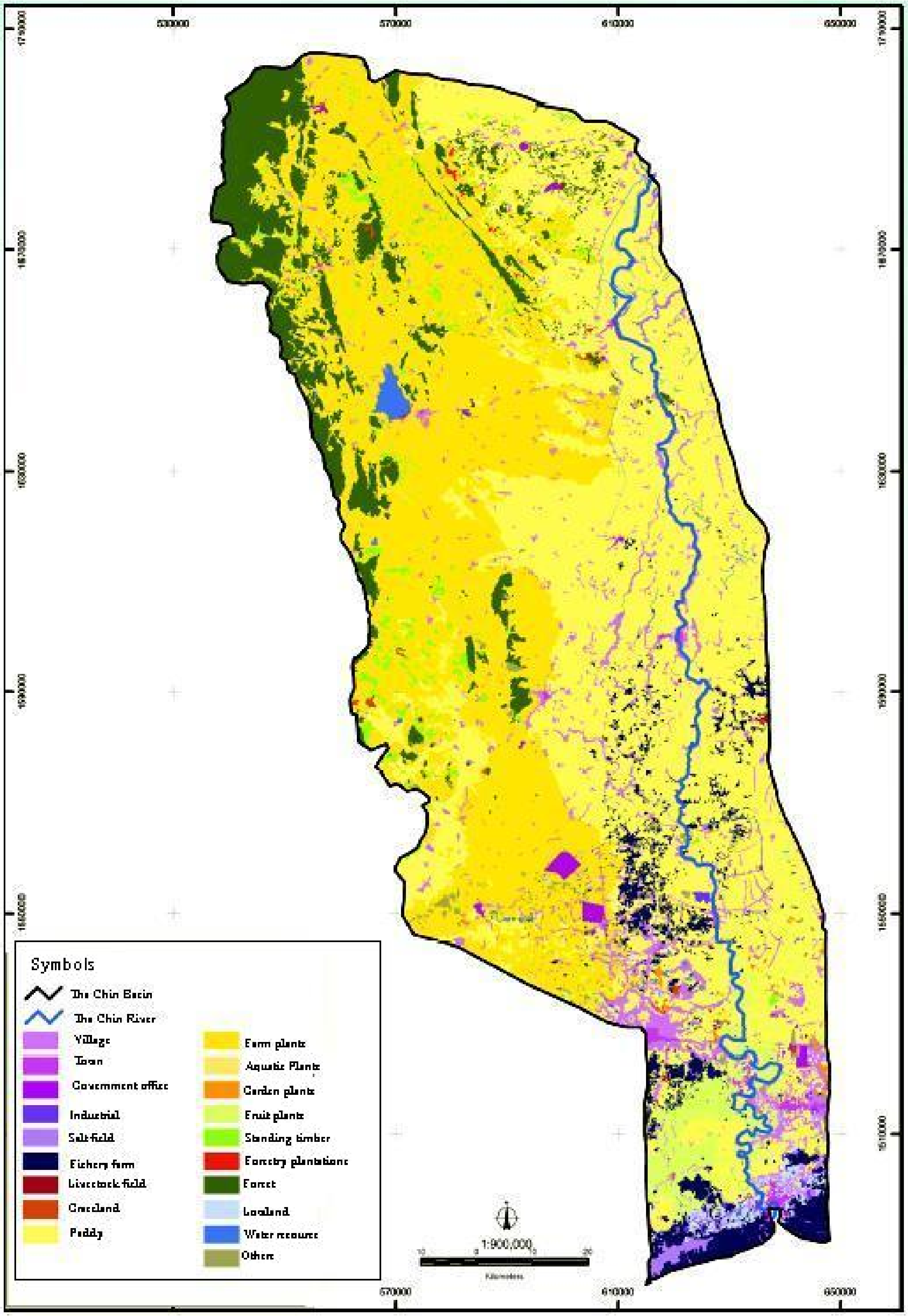


Figure 1.3 Land use (Land Development Department, 2003)

1.6.2.2 Water use

Three major activities (agricultural, industrial and domestic) dominate the water usage in the basin.

- **Agricultural use**

Water use for agriculture takes 5,047.97 million cubic meters per year approximately 88 percent of total water supply in the basin (Department of Water Resources, 2006). Agricultural activities are also the major sources of income for people living in the basin.

- **Industrial use**

Water use for industrial activities varies with respect to the type of industry. Most of industries in the basin use groundwater for their production processes.

- **Residential use**

The quantity of domestic water usage is dependent on the population. Water demands for rural areas are generally lower than those of the urban ones.

1.6.3 Environmental Problems

In the Tha Chin River Basin, the main environmental problems originated from the rapid population increase and economic development. Four major environmental problems can be identified in the Tha Chin River Basin:

1.6.3.1 The river water quality is changing from submesotrophic to mesotrophic in the Suphanburi Province. The increased nutrient discharges, especially nitrides and phosphates from agricultural and domestic activities, are the major causes of the pollution problem.

1.6.3.2 Decline of water level in the Tha Chin River caused by increasing drought and water dim has led to deteriorated water quality, increased salinity concentration, and increased soil erosion (PCD, 1997).

1.6.3.3 The development of population, agriculture and industry raised the demand for water, resulting in declined water level and deteriorated river ecosystem.

1.6.3.4 The low efficiency in wastewater treatment caused problems of river water pollution and injuries on aquatic species (Simachaya, 1999).

1.6.4 Pollution Sources

1.6.4.1 Point Pollution Sources

- **Industrial sources**

Industrial water pollution in the Tha Chin River Basin is generated from industries and industrial settlements. Water use in industrial system is dependent upon the type of industry such that the wastewater from industrial discharges varies in type and amount. Hence, size of industry can affect the waste quality and quantity. In the study system, the types of industry can be divided into nine principal groups. They are food-processing, textile/leather, wood fiber, chemical, metal, non-metal, motor, liquid material, and special material industries.

There are 8,870 industries in Suphanburi, Nakhonpathom and Samutsakorn province (Department of Industrial Works, 2007). However, some small industries and household factories are not registered, and controlled by any legislations. The followings are details of the industrial sources (Table 1.1).

- **Residential Wastewater**

Residential wastewater is another main source of water pollution in the basin. The wastewater, polluted by domestic use, is generates from living activities. The residential originated from private residences, slaughterhouses and governmental building. Most of residential wastewater was generated near densely populated areas, especially along the river (PCD, 1995).

The residential wastewater constitutes 60 to 80 percent of the water used from the residential water supply. There were approximately 99,850 kg/d of

BOD, 16,000 kg/d of total-N and 3,980 kg/d of total-P generated from residential activities (PCD, 1997). The followings are the number of population. (Table1.2).

Table 1.1 Details of the industrial source year 2007 (DIW, 2007).

Detail	**Province**		
	Suphanburi	Nakhon Pathom	Samut Sakhon
- Number of factories	1,134	2,985	4,751
- Number of factories releasing effluent to Tha chin basin	7	150	179
- Maximum wastewater summary (m^3/d)	16,290	661,875	1,560,226
- Exist wastewater summary (m^3/d)	12,574	533,586	697,038
- Discharge summary (m^3/d)	1,328	477,512	666,167

- **Commercial and institutional wastewaters**

Commercial activities are mostly located in urban and domestic area. Commercial wastewater is mainly from commercial buildings, hotels, restaurants and food makers. The total BOD loading from commercial activities is approximately 625 kg/d. The BOD loading from institutional buildings and hospitals were 160 and 300 kg/d, respectively.

Table 1.2 Details of the population in the year 2002. (Provincial Administration Office, 2005).

Province	**District**	**Number of population**		
		Urban	**Rural**	**Total**
Suphanburi	Bang Pla Ma	7,099	75,759	82,858
	Dan Chang	5,876	57,951	63,827
	Don Chedi	5,900	39,436	45,336
	Doem Bang Nang Buat	13,492	61,127	74,619
	Muang	50,591	111,952	162,543
	Nong Ya Sai	2,651	45,863	48,514
	Samchuk	14,224	41,753	55,977
	Sri Prachan	6,429	56,960	63,389
	Song Phinong	15,801	110,206	126,007
	Utohng	11,756	107,787	119,543
Nakhon Pathom	Bang Len	14,059	75,174	89,233
	Don Tum	13,139	32,247	45,386
	Kamphang San	6,718	111,334	118,052
	Muang	108,311	156,461	264,772
	Nakhon Chaisri	10,378	92,889	103,267
	Samphran	35,637	124,339	159,976
	Phutthamonthon	9,773	18,502	28,275
Samut Sakhon	Ban Phaeo	46,037	44,526	90,563
	Krathumbaen	62,313	72,659	134,972
	Muang	60,774	156,378	217,152
Total		500,958	1,593,303	2,094,261

1.6.4.2 Non-point Sources

Non-point pollution sources in the Tha Chin River Basin were mainly from agricultural activity, which is the third major contributor to the river pollution problems. Soil loss from agricultural farmlands and other human activities are other problems related to water quality in the river. In 879 farms, there were livestock husbandry activities; mainly pig and poultry farms. At present there are roughly two million pigs, and more than 70 percent of pig farms are located in the Nakhon Pathom Province (Simachaya,1999). Livestock waste in the basin is discharged directly into the river and streams without any treatment. Wastewater from livestock activities was roughly 41 tons/d (PCD, 1997).

In general, the non-point pollution sources in the Tha Chin River Basin can be divided into 4 categories:

(1) Agricultural runoff

Agricultural runoff is a non-point source of water pollution, which has been recognized as being of great importance. The impact of agricultural runoff is mainly from the increase inorganic pollution in the storm water draining into rivers and streams. The following factors are found to be attributable to this problem:

- Nutrients and pesticides runoff due to excessive uses of fertilizers and pesticides;

- Soil and nutrients losses due to rainfall or rainstorm in agricultural farmland;

- Soil and nutrients over flow from paddy and vegetable farms.

(2) Livestock husbandry and fishery activities

Livestock husbandry and fishery activities contribute the most to the non-point source pollution problem in the Tha Chin River Basin. Wastewater from these sources are enrich in BOD and nutrients. When the wastewater is discharged into the rivers and streams, it will cause direct impacts on the water quality. Most of farmers in the basin lack the ability to treat wastewater from these activities. The followings are more details of the residential sources (Table 1.3 and 1.4):

Table 1.3 Details of livestock husbandry source in year 1997 (PCD, 1997).

Province	District	Pig farm (head)	Duck farm (head)	BOD loading (Kg/day)
Suphanburi	Bang Pla Ma	14,960	390,100	515
	Dan Chang	4,930	2,980	120
	Don Chedi	4,987	7,899	123
	Doembang Nang Buat	1,590	61,184	63
	Muang	31,550	76,000	788
	Nong Ya Sai	5,000	3,000	121
	Samchuk	5,400	5,750	132
	Sri Prachan	24,098	17,250	585
	Song Phinong	25,900	228,200	713
	Utohng	44,650	34,230	1,085
Nakhon Pathom	Bang Len	31,250	1,500,320	1,350
	Don Tum	22,411	64,265	564
	Kamphang San	100,550	20,472	2,421
	Muang	112,4765	520,200	27,202
	Nakhon Chaisri	73,000	200,000	1,832
	Samphran	193,264	11,181	4,643
Samut Sakhon	Ban Phaeo	1,120	3,780	28
	Krathumbaen	7,95	10,550	23
	Muang	1,400	232,500	127
Total		1,710,825	3,389,861	42,435

Table 1.4 Details of fishery farm source in year 1997 (PCD, 1997).

Province	District	Fish farm (farm)	Shrimp farm (farm)	BOD loading (Kg/day)
Suphanburi	Bang Pla Ma	471	-	618
	Dan Chang	300	-	393
	Don Chedi	257	-	337
	Doembang Nang Buat	300	-	393
	Muang	642	-	842
	Nong Ya Sai	300	-	393
	Samchuk	257	-	337
	Sri Prachan	342	-	449
	Song Phinong	642	-	842
	Utohng	685	-	899
Nakhon Pathom	Bang Len	369	-	484
	Don Tum	142	-	186
	Kamphang San	510	-	670
	Muang	765	-	1,005
	Nakhon Chaisri	425	-	558
	Samphran	510	-	670
Samut Sakhon	Ban Phaeo	1,245	863	1,823
	Krathumbaen	1,681	1,941	2,630
	Muang	3,299	3,810	5,163
	Total	13,142	6,614	18,692

(3) Soil erosions

The eroded soils in the river come from natural and human-made sources. The natural sources come mainly from mountain ranges in the Northeast and Southwest of the basin. The human-made sources are from agricultural activities such as paddy and vegetable farms. The following factors are found to be responsible to the soil erosion problem:

- Destruction of forest and grass land;
- Excessive reclamation on hilly areas and grasslands;
- Reclamation of waste lands and excessive use of steep slopes;
- Landslide.

(4) Village wastewater

Wastewater from villages is discharged directly or indirectly into rivers and streams. The following factors are related to this pollution problem:

- Increased pollution loading due to discharge of sewage from villages;
- Garbage and soil waste generation and accumulation beside river and streams.

From Pollution Control Department 2000, the lower section of Tha Chin river is the most polluted river section in the country. In this section, major contributors of waste and wastewater are from industries (41%), pig farms (25%), resident (22%), fishery ponds (11%) and duck farms (1%). The Table 1.5 and Figure 1.4-1.6 show the percentage of pollution loads in the Tha Chin River.

Table 1.5 Percentage of pollution loads in the Tha Chin River.

Pollution sources	Upper Tha Chin River (%)	Middle Tha Chin River (%)	Lower Tha Chin River (%)
Industries	12	4	41
Pig farms	19	16	25
Resident	41	56	22
Fishery ponds	21	18	11
Duck farms	7	6	1
Total	100	100	100

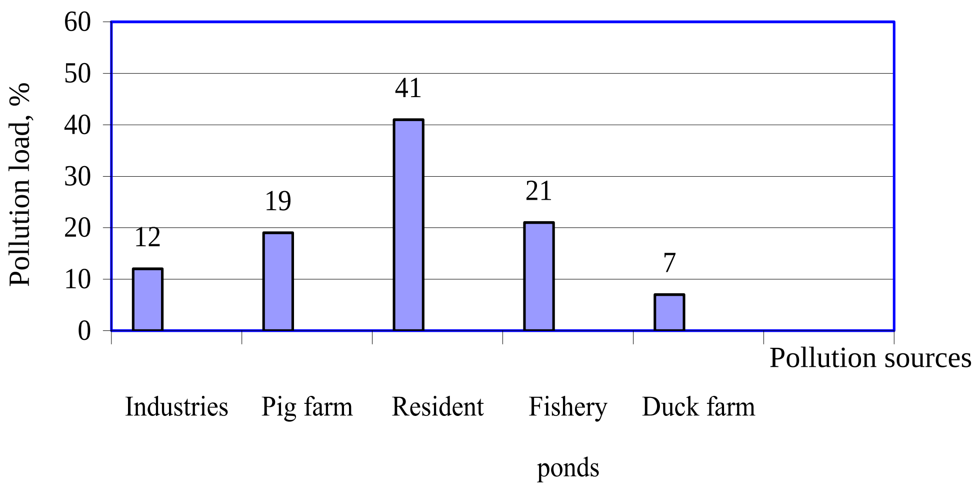


Figure 1.4 Percentage of pollution loads in the upper Tha Chin River

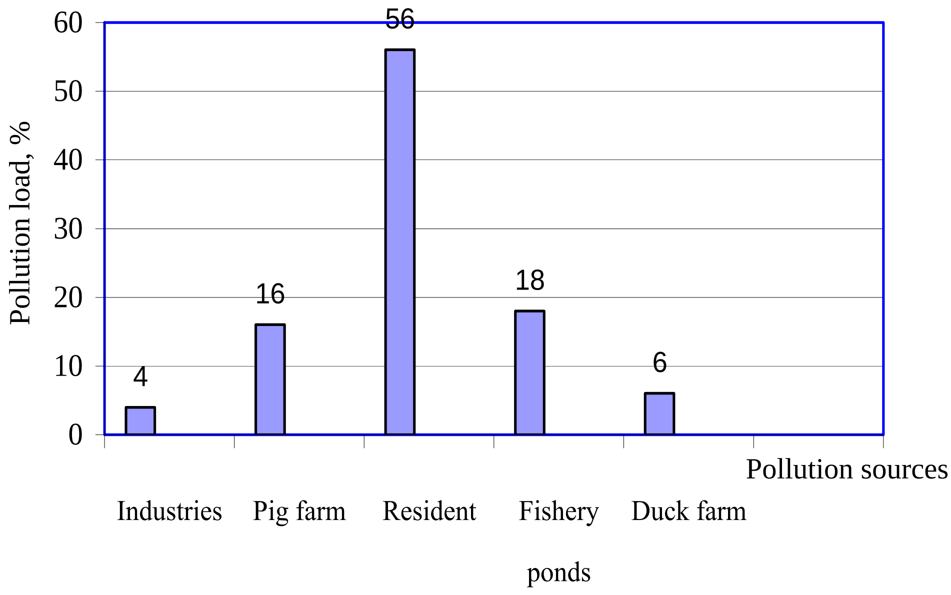


Figure 1.5 Percentage of pollution loads in the middle Tha Chin River

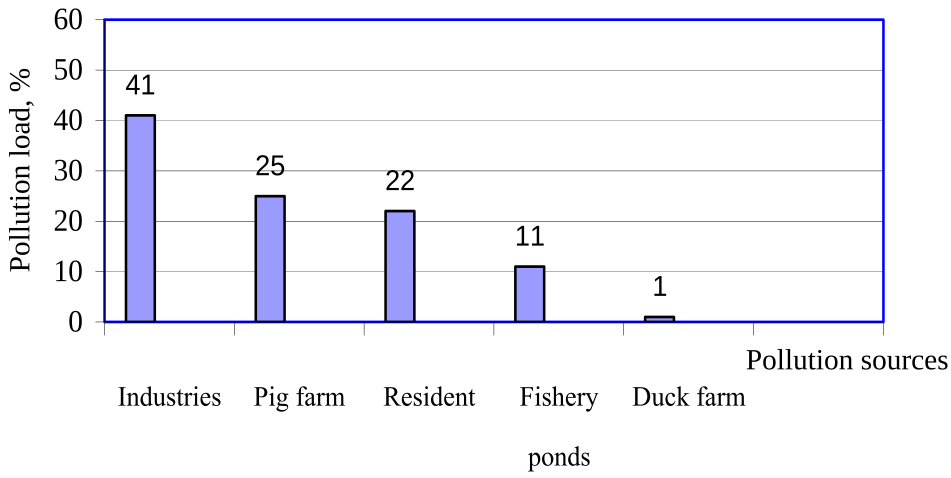


Figure 1.6 Percentage of pollution loads in the lower Tha Chin River

1.6.5 Water Quality of Tha Chin River

The Tha Chin river has been subdivided into three sections: lower, middle, and upper based on the national surface water quality standard and its classification. The surface water quality standards are classified into 5 classes as followed:

Class 1: Extra clean for conservation purposes

Class 2:Very clean used for (1) consumption which requires ordinary water treatment processes (2) aquatic organism conservation (3) fisheries, and (4) recreation [DO > 6 mg/L, BOD < 1.5 mg/L, Ammonia <0.5 mg/L)

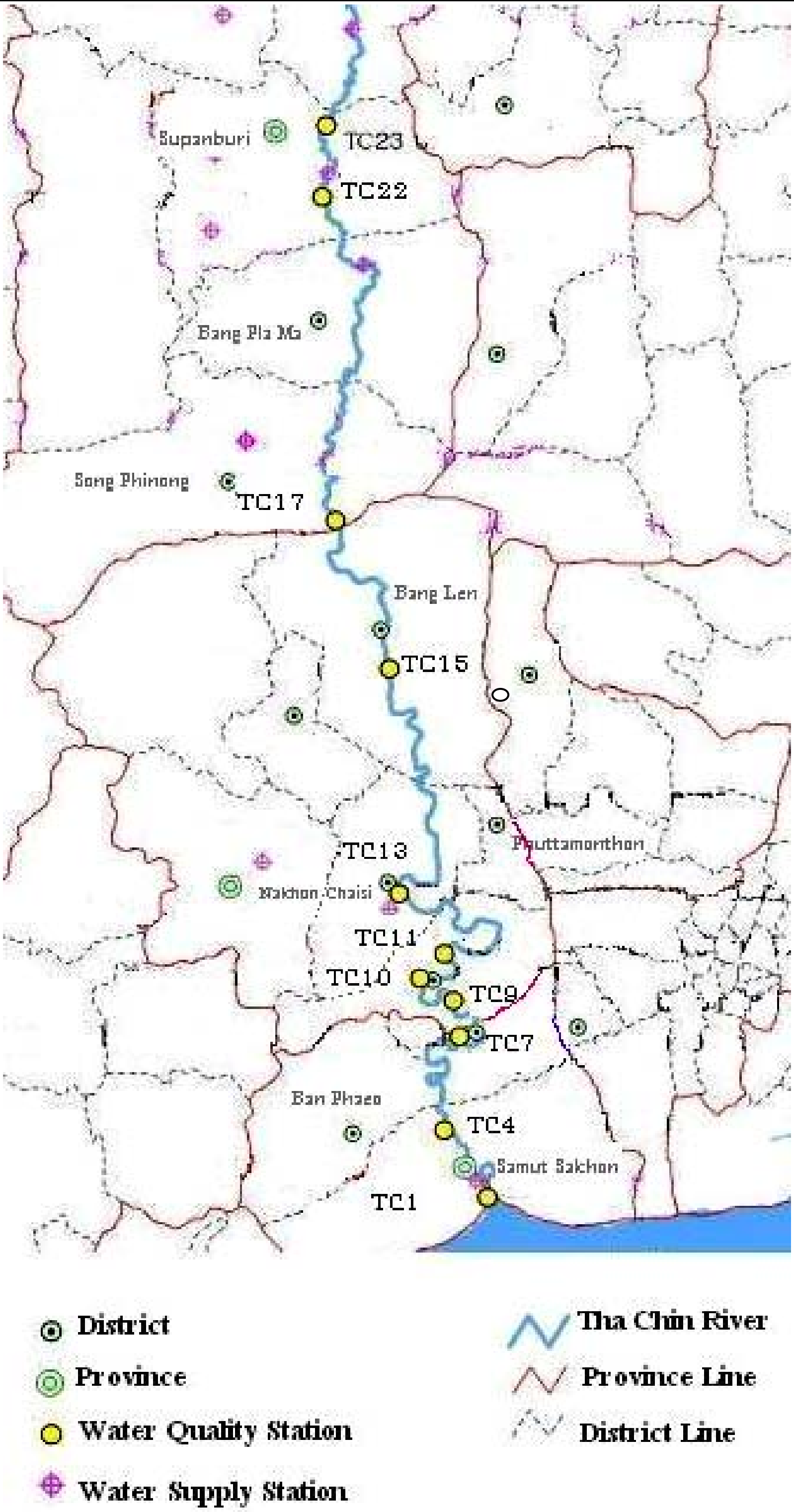
Class 3:Medium clean used for (1) consumption but passing through an ordinary treatment process and (2) agriculture [DO > 4 mg/L, BOD < 2 mg/L, Ammonia <0.5 mg/L)

Class 4:Fairly clean used for (1) consumption, but requires special treatment process and (2) industry [DO > 2 mg/L, BOD < 4 mg/L, Ammonia <0.5 mg/L)

Class 5: Waters are not classification in class 1-4 and used for navigation

The Tha Chin River was separated into 3 sections as followed: the upper reaches of the river, from the Phopraya Regulator to the Polthep Regulator, Chainat with total length of 123 km as class 2; the middle reaches, from the Nakhon Chaisi District to the Phopraya Regulators, Suphanburi Province as class 3; and the lower reaches from the river delta up to the Nakhon Chaisi District in the Nakhon Pathom Province with total length of 82 km as class 4.

There are 28 environmental monitoring stations covering the 3 sections of the Tha Chin River. At present, 14 stations are routinely monitored for observing the river water quality. Figure 1.7 shows 11 water quality monitoring stations in the middle and lower Tha Chin River.



TC23 - Phopraya Regulators

TC22 -Bamg Pla Ma Bridge

TC17 -Chokechai Pattana Rice mill, Song Phinong District

TC15 -Bang Len Bridge

TC13 -Nakhon Chaisri District office

TC11 -Pho Kaew Bridge

TC10 -Bang Chang Neu Temple

TC9 -Tein Dud Temple

TC7 -Ban Pong Leum School

TC4 -Sirimongkol Temple

TC1 -Estuary

Figure 1.7 The water quality monitoring stations in the middle and lower Tha Chin River

In the upper reaches of the river, starting from the Phopraya Regulator to the Polthep Regulator, Chainat Province (RKM 320), the river was less polluted. The DO levels in almost all of the monitoring stations were between 1.4 and 6.9 mg/L, which was the regulated DO standard. Concentrations of NH_3-N and total-P in this section were ND to 0.19 and ND to 0.16 mg/L, respectively. The water turbidity was 28 to 188 NTU and the average BOD was 1.5 mg/L in the upper part.

In the middle reaches, starting from the Nakhon Chaisi District to the Phopraya Regulators, Suphanburi Province (RKM 202), the river was moderately polluted. The DO levels in almost all of the monitoring stations were slightly lower than the regulated value (the observed DO values ranges from 0.8 to 3.4 mg/L). Concentrations of NH_3-N and total-P in this section were ND to 0.55 and 0.01 to 0.11 mg/L, respectively. The water turbidity was 12 to 122 NTU and the average BOD was 2.5 mg/L. The major contributors of pollution in this sector were domestic and agricultural activities.

In the lower reaches, starting from the river delta (RKM 0) up to the Nakhon Chaisi District in the Nakhon Pathom Province (RKM 82), the river was seriously contaminated. Dissolved oxygen (DO) levels in almost every monitoring station were lower than the regulated value in the surface water quality standard (the observed DO values ranged from 0.1 to 2.3 mg/L). Concentrations of NH_3-N and total-P in this section were 0.02 to 1.08 and ND to 0.8 mg/L, respectively. The water turbidity was 4 to 100 NTU and the average biological oxygen demand (BOD) was about 5.0 mg/L. The major contributors to pollution in this sector were generated mainly from industrial activities, domestic sewage, and pig farming.

In general, the water quality of the Tha Chin River is “clean” in the upper reach and “seriously polluted” in the lower ones. DO and BOD are main indicators of the river's water quality. Low DO level is the most alarming water-quality problem in the river. The regulated DO standards for the upper, middle and lower reaches were 6.0, 4.0 and 2.0 mg/L, respectively; but the average observed DO levels were 3.6, 2.8 and 0.7 mg/L, respectively (PCD, 1995).

CHAPTER II
LITERATURE REVIEW

2.1 Water Quality Modeling

Several ways of estimating riverine load of substances, terrestrial leakage, and retention in the aquatic system have been developed during the last decades. In environmental surveys it is important to separate the contributions from various sources and to distinguish between natural variability and anthropogenic impact, as this enables efficient environmental control and the introduction of the best management practices. It would be difficult and expensive to construct a satisfactory picture of e.g., soil leakage and water transport based only on measurements; consequently some kind of model must be applied. Modelling also enables predictions for the future by scenario simulations. A model is here defined as a numerical method to estimate water quality and transport of substances, which is based on various theoretical assumptions and generalisations.

Water quality models may first be categorised into steady-state and dynamic models. Steady-state models have no time component but describe average temporal conditions for the period studied, while dynamic models have a time dimension with specific rates for different processes, creating time-series for temporal variability. Steady-state models may be categorised according to their spatial starts for the calculations as: 1) Imission models, where estimated transport or concentration at the catchment outlet is related to upstream characteristics (e.g., Bauder et al., 1993; Grimvall and Stålnacke, 1996; Mattikalli, 1996), and 2) emission models, which summarise leakage coefficients and/or empirical emission data for different contribution classes in a catchment to reveal the outlet conditions (e.g., Haith and Shoemaker, 1987; Wendland, 1994; Johnes, 1996). Steady-state models may or may not be based on results from a hydrological model.

Dynamic N-transport models, on the other hand, are often based on a hydrological model, as water flow is the transport medium and most of the variability in substance transport is an effect of hydrological variability. As a consequence, the most frequently used hydrological models may also have a water quality routine linked to them (see, e.g., Singh, 1995). Dynamic models may be categorised according to their distribution in time and space and their degree of process description (see, e.g., Thorsen et al., 1996). Temporally, the calculations are often repeated with an hourly or daily time step. Event-based models, for example, AGNPS (Young et al., 1989), simulate transport development only during a single storm, while continuous models may simulate seasons, years, or decades. Spatially, the model may simulate the transport in one dimension, for example, a soil profile as in SOIL-N (Johnsson et al., 1987) and DAISY (Hansen et al., 1991), or it may include a full spatial distribution of transport in three dimensions, as in NELUP (Lunn et al., 1996) or NTT-Watershed (Heng and Nikolaidis, 1998). Dynamic models are often process-based and thus attempt to imitate nature by describing the physical and biogeochemical processes governing the water quality.

2.1.1 Water-quality models for river channels

Several models are available for water-quality simulations within rivers (Table2.1). This study has chosen MIKE11 because it is the most advanced and comprehensive of its type today, and it is presently used by more than 1500 users around the world (USEPA, 2006). Below follows a short description of each model in Table 2.1.

Table 2.1 Water-quality models for river channels with applications in Europe.

Model name	Origin	European applications (Nation)	Purpose / Substances modelled	Process description
AQUASIM	EAWAG; 1994	BE, DK, DE, FI, FR, GR, UK, IRL, IT, NL, NO, AUT, POL, PRT, ROM, SE, CH, SLO, ESP, CZ, TUR, HU	substance transport and transformation in open channels	mechanistic

Table 2.1 Water-quality models for river channels with applications in Europe (Continued).

Model name	Origin	European applications (Nation)	Purpose / Substances modelled	Process description
CE-QUAL	USACE; 1982	POR, DE, ESP, BE, CZ, UK, TUR	substance transport and dispersion	mechanistic
MIKE11	DHI; 1999	distributed to all European countries, but unclear if used for water quality modelling	water quality and sediment transport	mechanistic
PC-QUASAR	Centre for Ecol. & Hydr.; UK; 1997	10 users in e.g., UK, DE, CH, NL	river flow, ammonia, PH, nitrate, temperature, E.coli, biochemical oxygen demand, dissolved oxygen, and conservative pollutant or tracer	conceptual / mechanistic
QUAL2E	US EPA; 1987	widely used in e.g. UK, GR, BE, ESP, SLO	nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration, dissolved oxygen balance. 15 water quality concentrations.	Conceptual / mechanistic

Table 2.1 Water-quality models for river channels with applications in Europe (Continued).

Model name	Origin	European applications (Nation)	Purpose / Substances modelled	Process description
TELEMAC	Centre for Ecol. & Hydr.; UK; 1991	FR, UK, DE, IT, ESP.	environmental impact of reclamations and dredging schemes, strategic water quality planning, outfall design and pollutant dispersion, dredged material disposal, coastal defence design, port and harbour design, navigation and design of shipping channels, and wave activity including harbour resonance	conceptual / mechanistic

References: Berit Arheimer and Jonas Olsson. (2004)

2.1.1.1 AQUASIM Model

- Developer: Swiss Federal Institute of Technology (EAWAG); 1994 Model web

- Purpose/substances: General framework for modelling of aquatic systems

- Abstract: AQUASIM defines the spatial configuration of the system to be investigated as a set of compartments, which can be connected to each other by links. Currently, the available compartment types include mixed reactors, biofilm reactors (consisting of a biofilm and a bulk fluid phase), advective-diffusive reactors (e.g. plug flow with or without dispersion) and river sections (describing water flow and substance transport and transformation in open channels). Compartments can be connected by two types of links. Advective links represent water flow and advective substance transport between compartments, including bifurcations and junctions. Diffusive links represent boundary layers or membranes, which can be penetrated selectively by certain substances. For the model as defined by the user, the program is able to perform simulations, sensitivity analyses and parameter estimations using measured data.

- Applications: AQUASIM is widely applied at Swiss Federal Institute of Technology and all over Europe. According to the model manager there, at present (February, 2002) 121 AQUASIM licenses have been issued in BE, DK, DE, FI, FR, GR, UK, IRL, IT, NL, NO, AUT, POL, PRT, ROM, SE, CH, SLO, ESP, CZ, TUR, and HU. Besides for rivers, the system has also been applied for quality modelling in e.g. porous media and lakes.

2.1.1.2 CE-QUAL Model

- Developer: United States Army Corps of Engineers (USACE); 1982

-Purpose/substances: Water quality in reservoirs and rivers

- Abstract: The CE-QUAL family comprises three models. CE-QUAL-R1 is a spatially one- dimensional and horizontally averaged model for reservoirs; temperature and concentration gradients are computed only in the vertical direction. The reservoir is conceptualised as a vertical sequence of horizontal layers where thermal energy and materials are uniformly distributed in each layer. CE-QUAL-W2 is a two-dimensional, longitudinal/vertical, hydrodynamic and water quality model. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow waterbodies exhibiting longitudinal and vertical water quality gradients. CE-QUAL-RIV1 is a one-dimensional (cross-sectionally averaged) hydrodynamic and water quality model, meaning that the model resolves longitudinal variations in hydraulic and quality characteristics and is applicable where lateral and vertical variations are small. It can be used to predict one-dimensional hydraulic and water quality variations in streams and rivers with highly unsteady flows, although it can also be used for prediction under steady flow conditions.

- Applications: No information has yet been provided concerning the overall application of CEQUAL-R1 and CE-QUAL-RIV1 in Europe. According to the model manager of CE-QUALW2, it is widely used in Europe, including in POR, DE, ESP, BE, CZ, UK, and TUR.

2.1.1.3 MIKE 11 Model

- Developer: Danish Hydraulic Institute; 2000

- Purpose/substances: Water flow and quality in rivers

- Abstract: MIKE 11 is a engineering software package for the simulation of flows, water quality and sediment transport in estuaries, rivers, irrigation systems, channels and other water bodies. It is a dynamic one-dimensional modelling tool for the detailed design, management and operation of both simple and complex river and channel systems. The rainfall-runoff module contains three different models that can be used to estimate catchment runoff. The hydrodynamic module contains an implicit, finite difference computation of unsteady flows in rivers and estuaries. The advection-dispersion module is based on the one-dimensional equation of conservation of mass of a dissolved or suspended material. The water quality module is coupled to the advection-dispersion module and simulates the reaction processes of multi-compound systems including the degradation of organic matter, the photosynthesis and respiration of plants, nitrification and the exchange of oxygen with the atmosphere. A non-cohesive sediment transport module can be used to study the sediment transport and morphological conditions in rivers.

-Applications: According to model managers, the total number of European users amount to some 500 distributed over virtually all European countries. It is, however, unclear how much of this application that concerns water quality.

2.1.1.4 PC-QUASAR (UK) Model

- Developer: Centre for Ecology & Hydrology, Wallingford, UK; 1997

- Purpose/substances: Water flow and quality in rivers

- Abstract: PC-QUASAR is a water quality and flow model for river networks. It is designed to be used by river regulatory authorities and water/sewerage utility companies to help manage river water quality. PC-QUASAR can provide distributions of flow and quality at key sites, allowing river regulators to set effluent consent levels designed to meet river quality objectives. PC-QUASAR can also provide river flow and water quality estimates at each reach boundary over a period of time, allowing proposed changes in the river's use, flow or quality to be assessed. The following determinants can be modelled: river flow, ammonia, PH, nitrate, temperature, E.coli, biochemical oxygen demand, dissolved oxygen, and conservative pollutant or tracer.

- Applications: According to model managers, the total number of European organisational users is around 10 in e.g. UK, DE, CH, and NL.

2.1.1.5 QUAL2E (Enhanced Stream Water Quality Model)

- Developer: United States Environmental Protection Agency (US EPA); 1987

- Purpose/substances: Water flow and quality in rivers

- Abstract: QUAL2E is applicable to well mixed, dendritic streams. It simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration and their effects on the dissolved oxygen balance. It can predict up to 15 water quality constituent concentrations. It is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality characteristics of nonpoint sources. By operating the model dynamically, the user can study diurnal dissolved oxygen variations and algal growth. However, the effects of dynamic forcing functions, such as headwater flows or point source loads, cannot be modelled with QUAL2E.

QUAL2EU is an enhancement allowing users to perform three types of uncertainty analyses: sensitivity analysis, first order error analysis, and Monte Carlo simulation.

- Applications: No information has yet been provided concerning the overall application of QUAL2E in Europe, but from the literature and the web the model has been rather widely used in e.g. UK, GR, BE, ESP, and SLO.

2.1.1.6 TELEMAC Model

- Developer: Laboratoire National d'Hydraulique, FR, and Centre for Ecology & Hydrology, Wallingford, UK; 1991

- Purpose/substances: Water flow and quality in rivers

- Abstract: TELEMAC is a finite element based modelling system for simulation of physical processes associated with rivers, estuaries and coastal waters. TELEMAC uses an unstructured triangular grid allowing realistic representations of complicated coastlines and bathymetries. TELEMAC comprises modules for hydrodynamics (TELEMAC2D/TELEMAC-3D), water quality (WQ 2D/3D), sediment transport (SUBIEF, SEDPLUME 3D), dispersion of pollutants (PLUME-RW, SISYPHE), wave dynamics (ARTEMIS, BOUSSINESQ, COWADIS), and pre- and post-processing (MATISSE, RUBENS). Applications include environmental impact of reclamations and dredging schemes, strategic water quality planning, outfall design and pollutant dispersion, dredged material disposal, coastal defence design, port and harbour design, navigation and design of shipping channels, and wave activity including harbour resonance.

- Applications: "Current Users" on the model web site include institutions in FR, UK, DE, IT, and ESP.

2.2 The MIKE 11 System

MIKE11 is developed by DHI Water and Environment. It is a software package for simulating flows, water quality and sediment transport in estuaries, rivers, irrigation systems, channels and other water bodies. It is a dynamic, user-friendly one-dimensional modeling tool for the detailed design, management and operation of both simple and complex river and channel systems. Due to its exceptional flexibility and speed MIKE 11 provides a complete and effective design environment for engineering, water resources, water quality management and planning applications

The model includes three modules, hydrodynamic (HD) module, advection-dispersion (AD) module and water quality (WQ) module. The HD model computes water level and discharge in the pollution canal while AD module is couple with WQ module describing how pollutant travels and disperses along the canal with time. The outputs of HD and pollution load are inputs of AD model to calculate DO and BOD at each node at each time step. In models, a finite difference implicit scheme is used to solve following equations.

2.2.1 The Hydrodynamics Module (HD)

The Hydrodynamic module (HD) uses an implicit, finite difference scheme for computation of unsteady flow in rivers and estuaries. The module can describe sub critical as well as super critical flow conditions through a numerical scheme, which adapts according to the local flow condition. (in time and space)

2.2.1.1 Saint Venant equation

MIKE 11 applied with the fully dynamic descriptions solves the vertically integrated equations of conservation of mass and momentum (the ‘Saint Venant’ equations), which are derived on the basis of the following assumptions:

1. The water is incompressible and homogeneous, i.e. without significant variation in density;
2. The bottom – slope is small;
3. The wave – lengths are large compared to the water - depth. This ensures that the flow everywhere can be regarded as having a direction parallel to the bottom, i.e. vertical acceleration can be neglected and a hydrostatic pressure variation along the vertical can be assumed.
4. The flow is sub – critical.

For a rectangular cross section with a horizontal bottom and a constant width, the conservation of mass and momentum can be expressed as follows (in the first instance neglecting friction and lateral inflows):

Conservation of mass:

$$\frac{\partial(\rho Hb)}{\partial t} = -\partial\frac{(\rho Hb\overline{u})}{\partial x} \qquad (2.1)$$

Conservation of momentum:

$$\frac{\partial(\rho Hb\overline{u^2})}{\partial t} = -\frac{\partial(\alpha' \rho Hb\overline{u}^2 + \frac{1}{2}\rho gbH^2)}{\partial x} \qquad (2.2)$$

Where:

ρ is the density (m/s^2)

H is the depth (m)

b is the width (m)

u is the average velocity along the vertical (m^2/s)

α' is the vertical velocity distribution coefficient (m^2/s)

g is gravitational acceleration (m/s^2)

Introducing the bottom slope, I_b, and allowing for the channel width to vary will give rise to two more terms in the momentum equation. These terms describe the projections in the flow direction of the reaction of the bottom and side-walls to the hydrostatic pressure.

The momentum equation now becomes:

$$\frac{\partial(\rho Hb\overline{u^2})}{\partial t} = -\frac{\partial(\alpha' \rho Hb\overline{u}^2)}{\partial x} + \frac{\partial b}{\partial x}\frac{\rho gH^2}{2} - \rho gHbI_b$$

$$= -\frac{\partial(\alpha' \rho Hb\overline{u}^2)}{\partial x} - b\frac{\partial(\frac{1}{2}\rho gH^2)}{\partial x} - \rho gHbI_b \qquad (2.3)$$

When the water level, h, is introduced into the relationship instead of water depth:

$$\frac{\partial h}{\partial x} = I_b + \frac{\partial H}{\partial x} \qquad (2.4)$$

And the equations are divided by ρ, the conservation laws of mass and momentum become:

$$\frac{\partial(Hb)}{\partial t} = -\frac{\partial(Hb\overline{u})}{\partial x} \quad (2.5)$$

$$\frac{\partial(Hb\overline{u})}{\partial t} = -\frac{\partial(\alpha Hb\overline{u^2})}{\partial x} - Hbg\frac{\partial h}{\partial x} \quad (2.6)$$

These equations can be integrated to describe the flow through cross-sections of any shape when divided up into a series of rectangular cross sections as shown in Figure 2.1.

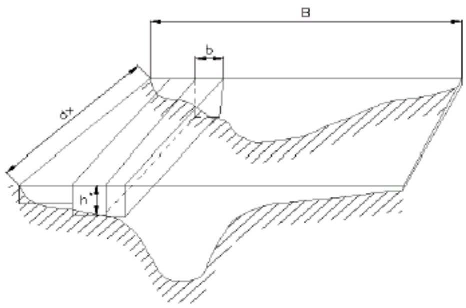


Figure 2.1 Cross section divided into a series of rectangular channels (Danish Hydraulic Institute,1995)**.**

According to the previous assumptions, ρh/ ρx is constant across the channel and no exchange of momentum occurs between the sub channels. If the integrated cross sectional area is called A and the integrated discharge Q, and B is the width of the channel, then

$$A = \int_0^B H db \quad (2.7)$$

$$Q = \int_0^B H\overline{u} db = \overline{uA} \quad (2.8)$$

Integrating the mass and momentum conservation equations and introducing Equations 2.7 and 2.8 yields:

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=0 \quad (2.9)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial(\frac{\alpha Q^2}{A})}{\partial x}+gA\frac{\partial h}{\partial x}=0 \quad (2.10)$$

Including the hydraulic resistance, e.g. using the Chezy description and the lateral inflow; q into these equations leads to the basic equations used in MIKE 11:

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q \quad (2.11)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial(\alpha\frac{Q^2}{A})}{\partial x}+gA\frac{\partial h}{\partial x}+g\frac{Q|Q|}{C^2AR}=0 \quad (2.12)$$

Where:

A is the flow area (m^2)
M is the reciprocal Manning number ($m^{1/3}$ s^{-1})
g is the acceleration of gravity (m s^{-2})
h is level above the horizontal reference level (m)
Q is discharge (m^3 s^{-1})
t is the time (s)
x is the distance (m),
R is the hydraulic radius (m)
a is a momentum distribution coefficient
q is lateral inflow (m^3 s^{-1})

2.2.1.2 Solution Scheme

The solution to combined system of equations at each time step is performed according to the procedure outlined below.

The transformation of Equations 2.11 and 2.12 in Saint Venant Equation, to a set of finite differences equations is performed on a computational grid consisting of alternating Q- and h- points, i.e. points where the discharge, Q and water level h, respectively, are computed at each time step, see Fig 2.2. The computational grid is generated automatically by the model on the basic of the user requirements. Q-point are always placed midway between neighboring h-points, while the distance between h-point may differ. The discharge will, as a rule, be defined as positive in the positive x-direction (increasing chainage).

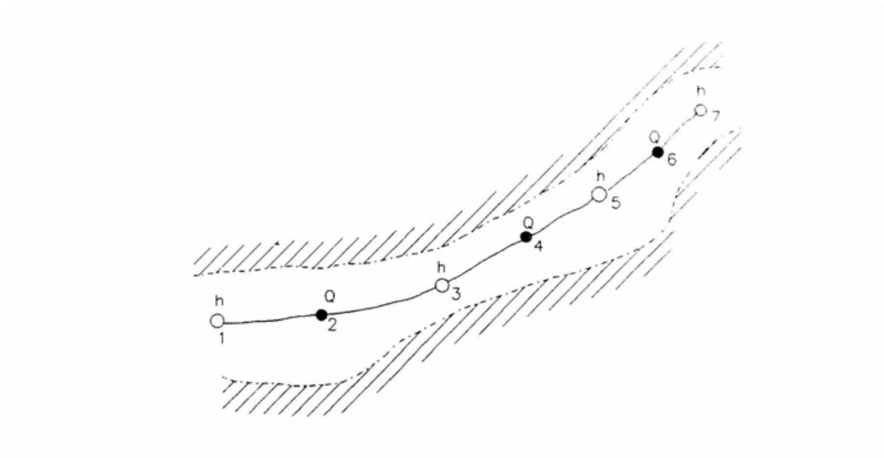


Figure 2.2 Channel section with computational grid (Danish Hydraulic Institute, 1995).

The adopted numerical scheme is a 6- point Abbott-scheme as shown in Figure 2.3

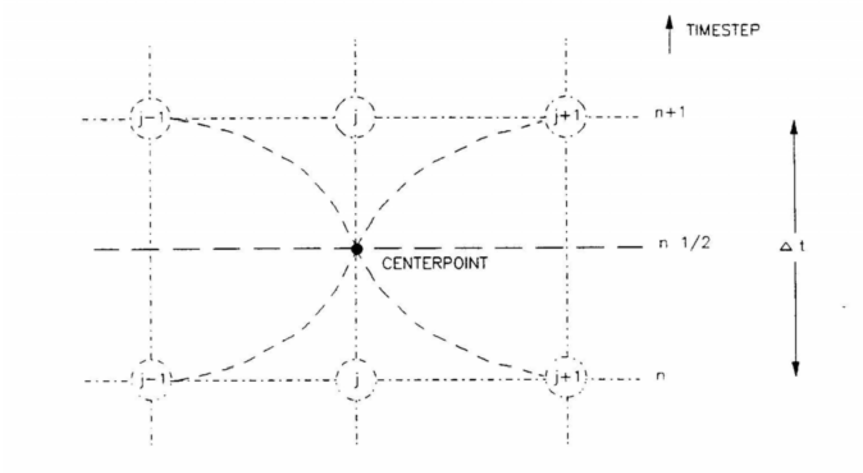


Figure 2.3 Centered 6 –point Abbott scheme (Danish Hydraulic Institute,1995).

- Continuity equation

In the continuity equation the storage width, b_s is introduced as:

$$\frac{\partial A}{\partial t} = b_s \frac{\partial h}{\partial t} \tag{2.13}$$

Giving:

$$\frac{\partial A}{\partial t} + b_s \frac{\partial h}{\partial t} = q \tag{2.14}$$

As only Q has a derivative with respect to x, the equation can easily be centered at h-point, see Figure 2.4

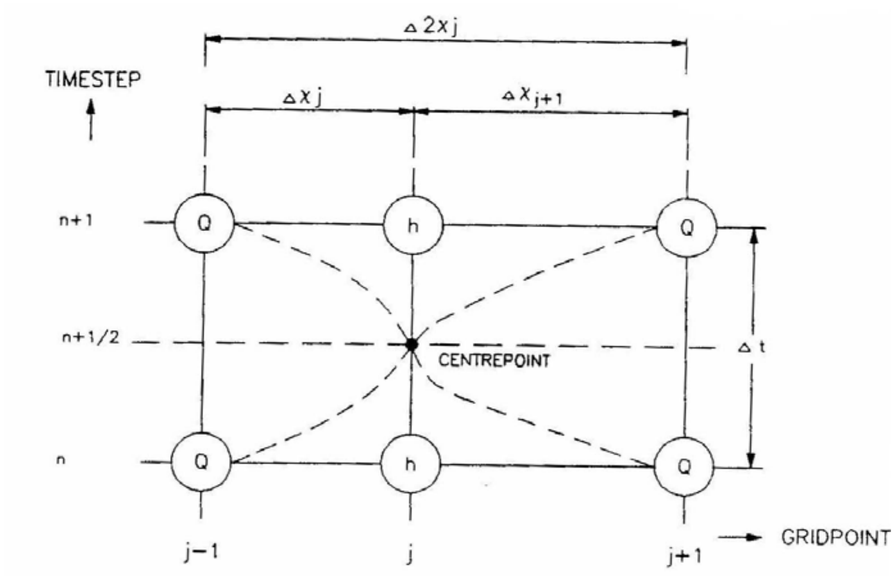


Figure 2.4 Centering of continuity equation in 6 –point Abbott scheme (Danish Hydraulic Institute,1995)**.**

The derivatives in Equation 2.14 are expressed at the time level, n + ½, as follow:

$$\frac{\partial Q}{\partial x} = \frac{\dfrac{\left(Q_{j+1}^{n+1} + Q_{j+1}^{n}\right)}{2} - \dfrac{\left(Q_{j-1}^{n+1} + Q_{j-1}^{n}\right)}{2}}{\Delta 2x_j} \tag{2.15}$$

$$\frac{\partial h}{\partial t} = \frac{(h_j^{n+1} - h_j^n)}{\Delta t} \tag{2.16}$$

b_s in Equation 2 .14 is approximated by :

$$b_s = \frac{(A_{0,j} - A_{0,j+1})}{\Delta 2x_j} \tag{2.17}$$

Where $A_{o,j}$ is the surface area between grid point j-1 and j, $A_{o,j+1}$ is the surface area between grid point j and j+1, $\Delta 2x_j$ is distance between point j-1 and j+1

Substituting for the derivatives in Equation 2.14 gives a formulation form:

$$\alpha_j Q_{j-1}^{n+1} + \beta_j h_j^{n+1} + \gamma_j Q_{j+1}^{n+1} = \sigma_j \tag{2.18}$$

Where : α, β and γ are function of b and, moreover, depend on Q and h at time level n and Q on time level n + ½.

- Momentum equation

The momentum equation is centered at Q-point as illustrated in Figure 2.5

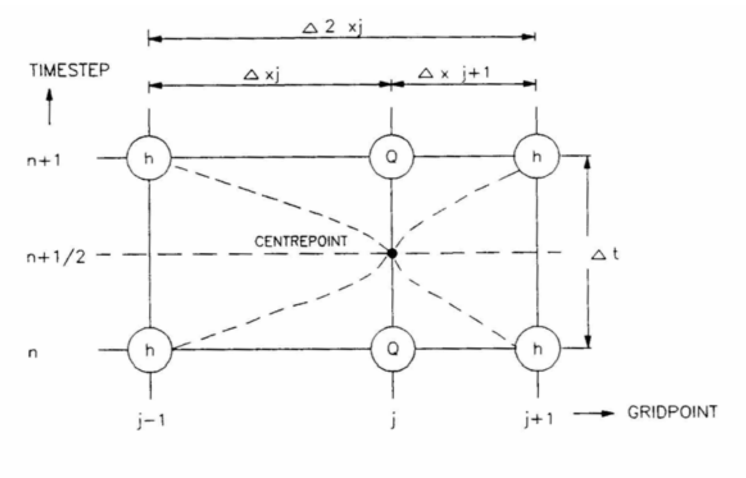


Figure 2.5 Centering of momentum equation in 6 –point Abbott scheme (Danish Hydraulic Institute,1995).

The derivatives of Equation 2.12, are expressed in the following

$$\frac{\partial Q}{\partial t} \approx \frac{(Q_j^{n+1} - Q_j^n)}{\Delta t} \tag{2.19}$$

$$\frac{\partial\left(\alpha \frac{Q^2}{A}\right)}{\partial x} \approx \frac{\left(\left[\alpha \frac{Q^2}{A}\right]_{j+1}^{n+\frac{1}{2}} - \left[\alpha \frac{Q^2}{A}\right]_{j-1}^{n+\frac{1}{2}}\right)}{\Delta 2x_j} \tag{2.20}$$

$$\frac{\partial h}{\partial x} \approx \frac{\frac{\left(h_{j+1}^{n+1} + h_{j+1}^n\right)}{2} - \frac{\left(h_{j-1}^{n+1} + h_{j-1}^n\right)}{2}}{\Delta 2x_j} \tag{2.21}$$

For the quadratic term in 2.20, a special formulation is used to ensure the correct sigh for this term when the flow direction is changing during a time step:

$$Q^2 \approx fQ_j^{n+1}Q_j^n - (f-1)Q_j^n Q_j^n \tag{2.22}$$

With all the derivatives substituted, the momentum equation can be written in the following form:

$$\alpha_j h_{j-1}^{n+1} + \beta_j Q_j^{n+1} + \gamma_j h_{j+1}^{n+1} = \delta_j \tag{2.23}$$

Where:

$$\alpha_j = f(A)$$
$$\beta_j = f(Q_j^n, \Delta t, \Delta x, C, A, R)$$
$$\gamma_j = f(A)$$
$$\delta_j = f(A, \Delta x, \Delta t, \alpha, q, v, \phi, h_{j-1}^n, Q_{j-1}^{n+1/2}, Q_j^n, h_{j+1}^n, Q_{j+1}^{n+1/2}$$

2.2.1.3 Boundary Condition

External boundary conditions are required at all model boundaries, i.e. all upstream and downstream ends of model braches which are not connected at a junction. The relationships applied at these limits can consist of

(i) Constant value of h or Q

(ii) Time varying value of h or Q

(iii) A relationship between h and Q (e.g. a rating curve)(Should only be used at downstream boundaries)

2.2.1.4 Calibration of hydrodynamic module

Calibrate hydrodynamic module operated by adjusting bed resistance until the simulated flows are fitted to the recorded flow and water level data.

2.2.1.5 Bed Resistance

MIKE 11 allows for two difference types of bed resistance descriptions:

(i) Chezy, and

(ii) Manning

For the Chezy description, the bed resistance term in the momentum equation is description as:

$$\frac{g \cdot Q \cdot |Q|}{C^2 \cdot A \cdot R} \qquad (2.24)$$

Where Q is discharge, A is flow area and R is resistance or hydraulic radius.

For the Manning description, in term is:

$$\frac{g \cdot Q \cdot |Q|}{M^2 \cdot A \cdot R^{\frac{4}{3}}} \qquad (2.25)$$

The Manning number, M is equivalent to the Strickler coefficient. Its inverse is the more conventional Manning's n. The value of n is typically in the range 0.01(smooth channel) to 0.10 (thickly vegetated channel). The corresponding values for M are from 100 to 10.

The Chezy coefficient is related to Manning's n by

$$C = \frac{R^{\frac{1}{6}}}{n} = MR^{\frac{1}{6}} \qquad (2.26)$$

Values for the resistance numbers, C, M or n, should be determined though model calibration where possible, or based on other calibrated models with similar topographic characteristics. A rough guide to values of Manning's n can be found in most publications dealing with open channel hydraulics.

R is calculate using either a resistance radius, R_*, or a hydraulic radius, R_h. The formulation for R_* and R_h are discussed follow.

- **Resistance Radius, R_***

The resistance radius is calculate as

$$\sqrt{R_*} = \frac{1}{A}\int_0^B y^{\frac{3}{2}}\,db \qquad (2.27)$$

Where, y is the local water depth and B is the water width at the same elevation.

This formulation ensures that the manning number is almost independent of the water depth in the case of composite cross section.

The effect of the relative resistance, r_r is included in the above formulation by adjusting the physical area to give the effective flow area, A_e as:

$$A_e = \sum_{i=1}^{N_s}\left(\frac{A_i}{r_{r_i}}\right) \qquad (2.28)$$

Where, N_s= Number of sub-sections which equals the number of x-z values in law data less one.

Equation 2.27 now as:

$$\sqrt{R_*} = \frac{1}{A_e}\int_0^B \frac{y}{r_r}^{\frac{3}{2}}\,db \qquad (2.29)$$

- **Hydraulic Radius, R h**

The hydraulic Radius formulation is based on the parallel channel analysis where the total conveyances, K, of the section at a given elevation is equal to the sum of conveyances of the parallel channel of a cross- section are defined as those parts of the cross-section where the relative resistance, r_r , remains constant.

Where, N is the number of parallel channels we have,

$$K = \sum_{i=1}^{N} K_i \tag{2.30}$$

Which may be expressed using Manning's n as:

$$R_h = \left[\frac{\sum_{i=1}^{N} \left(\frac{A_i^{5/3}}{r_{r_i} P^{2/3}} \right)}{A} \right]^{\frac{2}{3}} \quad \text{Where } R_h = \frac{A_i}{P_i} \tag{2.31}$$

Where Pi is the wetted perimeter of the parallel channel, P_i is not include the interface between adjoining parallel channel i.e. a zero shear interface has been adopted.

Where the relative resistance is constant across the whole cross – section the above formulation reduces to the well – known form:

$$R_h = \frac{A}{P} \tag{2.32}$$

In this study used Manning's n as bed resistance. Values for Manning's n should be determined though model calibration where possible, or based on other calibrated models with similar topographic characteristics. A rough guide to values of Manning's n can be found in most publications dealing with open channel hydraulics. Literature summaries of Manning's n for open channels are reported in Table 2.2.

Table 2. 2 A rough guide to values of Manning's n

Open Channels	Manning's n		
	Minimum	Regular	Maximum
1) Natural stream channels			
- Clean, strange	0.025	0.030	0.033
- Clean, winding	0.033	0.040	0.045
- Weeds and pools	0.035	0.045	0.050
- Heavy brush, timber	0.035	0.035	0.100
2) Artificially lined channels			
- Concrete		0.012	
- Alphas		0.016	
- Glass		0.010	
- Gravel bottom with side:			
Concrete		0.020	
Mortared stone		0.023	
Riprap		0.033	
3) The Tha Chin River Channel, (PCD,2006)		0.033	

2.2.2 The Advection-Dispersion Module (AD)

The transport of dissolve matter in water principally depends on two phenomena: advection and dispersion. Advection refers to movement of dissolved or varies fine particulate material at the current velocity in any of three directions (longitudinal, lateral or transverse, and vertical). Dispersion refers to the process by which these substances are mixed within the water column. Dispersion can also occur in three directions (longitudinal, lateral or transverse, and vertical).

In this study the AD-module is based on the one-dimensional (only longitudinal)

2.2.2.1 Advection-Dispersion Equation

The basic equation describing advection and dispersion of dissolve matter is based on the principle of conservation of mass and Fick's Law. For a conservative substance, the principle of conservation of mass can be stated: (3)

$$\frac{\partial C}{\partial t} = -\frac{v\partial C}{\partial x} + D_x \frac{\partial^2 C}{\partial x^2} \qquad (2.33)$$

Where *C* is the concentration (g m^{-3}), *D* is the longitudinal dispersion coefficient (m^2 s^1), *u* is velocity. (m/s)

For a non - conservative substance, it also has degradation process.

$$\frac{\partial C}{\partial t} = -KC \qquad (2.34)$$

Where K is linear decay coefficient

So the one-dimensional (vertically and laterally integrated) advection -dispersion equation reads:

$$\frac{\partial AC}{\partial t} + \frac{\partial QC}{\partial x} - \frac{\partial}{\partial x}(AD\frac{\partial C}{\partial x}) = -AKC + qC_s \qquad (2.35)$$

Where *C* is the concentration (g m^{-3}), *D* is the dispersion coefficient (m^2 s^{-1}), *A* is the cross-sectional area (m^2), *K* is a linear decay coefficient (s^{-1}), *q* is the lateral discharge (m^3 s^{-1}), C_s is the source/sink concentration (g m^{-3}), *x* is the space coordination (m), *t* is the time coordination (s) and *Q* is the discharged (m^3 s^{-1}).

In this study used salinity (conservative substance) to determine the transport characteristics of a natural water body.

2.2.2.2 Solution Scheme, AD

The advection-dispersion equation is solved with a fully time and space centered implicit finite difference scheme in order to minimize any artificial (numerical) dispersion. Moreover, it I has been ensured that the discrimination is mass conservative. The finite difference scheme is derived by considering the mass flux into a box situated around the grid point j. The boundaries of this box are the river bed, the water surface and the two cross-sections situated at j-1/2 and j + ½, respectively, see Figure 2.6.

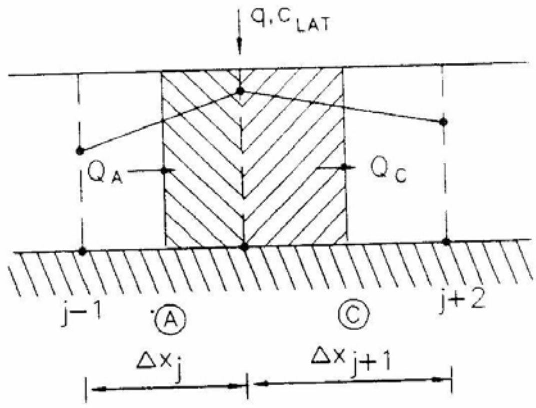


Figure 2.6 Definition sketch for the box-model (Danish Hydraulic Institute,1995)**.**

The two equations are considered the continuity equation and the advection – dispersive transport equation.

Continuity equation:

$$\frac{V_j^{n+1/2} C_j^{n+1}}{\Delta t} - \frac{V_j^{n} C_j^{n+1/2}}{\Delta t} + T_{j-1/2}^{n+1/2} - T_{j-1/2}^{n+1/2} = q^{n+1/2} C_q^{n+1/2} - V_j^{n+1/2} K \qquad (2.36)$$

Where C is concentration, V is box (storage) volume, T is transport though box walls, q is lateral inflow, t is time step, Cq is concentration of lateral inflow source, Advective-dispersive transport equation:

$$T_{j+1/2}^{n+1/2} = Q_{j+1/2}^{n+1/2} C_{j+1/2}^{*} - A_{j+1/2}^{n+1/2} D \frac{C_{j+1}^{n+1/2} - C_{j}^{n+1/2}}{\Delta x} \quad (2.37)$$

Where $Q_{j+1/2}^{n+1/2}$ is discharge at the right wall of the box, $A_{j+1/2}^{n+1/2}$ is the cross sectional area of the right wall, D is the dispersion coefficient, $C_{j+1/2}^{*}$ is an upstream interpolated concentration given by:

$$C_{j+1/2}^{*} = \frac{1}{4}(C_{j+1}^{n+1} + C_{j}^{n+1} + C_{j-1}^{n} \quad (2.38)$$

$$-\min\left\{\frac{1}{6}\left(1+\frac{\sigma^2}{2}\right), \frac{1}{4\sigma}\right\} \cdot (C_{j+1}^{n} - 2C_{j}^{n} + C_{j-1}^{n})$$

In which σ is the Courant number. The last term of Equation 2.38 is an explicit third order corrective term.

Substitution and rearrangement of the above equations give a general implicit finite difference equation which relates the concentration in three neighboring gridpoints to each other at any time level as:

$$\alpha_j C_{j-1}^{n+1} + \beta_j C_{j}^{n+1} + \gamma_j C_{j+1}^{n+1} = \delta_j \quad (2.39)$$

2.2.2.3 Boundary Conditions

At external boundaries, a series of conditions can be applied:

- Open boundary outflow
- Open boundary inflow – User defined values of the concentration (time varying or constant)
- Closed boundary

2.2.2.4 Calibration of Advection- Dispersion module

Calibration of advection-dispersion module operated by adjusting dispersion coefficient until dissolve matter concentration is fitted to recorded data (In this study used salinity).

2.2.2.5 Dispersion Coefficient

Longitudinal dispersion is caused by the combined action of a non-uniform velocity distribution and diffusion. The longitudinal spreading under the influence of non-uniform velocity distribution is much greater than would be achieved by molecular and turbulent diffusion alone. The dispersive transport follows Fick's diffusion law.

The dispersion coefficient is determined as a function of the mean flow velocity:

$$D_j^{n+1} = a \cdot \left| \frac{Q^{n+1/2}}{A^{n+1/2}} \right|_j^b \tag{2.40}$$

Where, a and b are constants to be specified by user. D is dispersion coefficient (m^2/s)

From Equation 2.40, it possible to specify the dispersion coefficient as a function of the velocity calculates by the following expression:

$$D = fV^{ex} \tag{2.41}$$

Where D is dispersion coefficient (m^2/s), f is dispersion factor, V is the flow velocity and ex is a dimensionless exponent.

The unit of the dispersion factor (f) depends on the selection of the exponent (ex). If the exponent is selected to be zero, (dispersion coefficient is independent of the flow velocity), and then the unit of dispersion factor will be m^2/s. If the exponent is one, (dispersion coefficient is a linear function of the flow velocity), and then the unit of the dispersion factor will be meter.

2.2.3 The Water Quality Module (WQ)

The water quality module deals with the basic aspects of river water quality in areas influenced by human activity: e.g. oxygen depletion and ammonia levels as a result of organic matter loadings. The WQ-module is coupled to the AD module, which means that the WQ module deals with the transforming processes of compounds in the river and the AD module is used to simulate the simultaneous transport process. The WQ module solves the system of coupled differential equations describing the physical, chemical and biological interaction in the river.

The river water quality can be dealed with different levels of detail by the model:

1. BOD-DO relationships
2. BOD- DO relationships including exchange with organic matter from the river bed
3. BOD-DO relationships including nitrification
4. BOD-DO relationships including the exchange with the river bed and nitrification and denitrification
5. BOD-DO relationships including immediate and delayed oxygen demand and exchange with the river bed
6. BOD-DO relationships including all the above mentioned processes

The details of each model levels can describe as the table 2.3 and 2.4.

Table 2.3 State variables at the different model levels

Model level	1	2	3	4	5	6
State variables						
Temperature	✓	✓	✓	✓	✓	✓
Oxygen	✓	✓	✓	✓	✓	✓
Ammonia	-	-	✓	✓	-	✓
Nitrate	-	-	✓	✓	-	✓
BOD	✓	✓	✓	✓	-	✓
Dissolved BOD	-	-	-	-	✓	-
Suspended BOD	-	-	-	-	✓	✓
BOD at the bed	-	-	-	-	✓	✓
Dissolved P	✓	✓	✓	✓	✓	✓
Particulate P	✓	✓	✓	✓	✓	✓
Feacal Coliforms	✓	✓	✓	✓	✓	✓
Total Coliforms	✓	✓	✓	✓	✓	✓

Table 2.4 Process types included at the different model levels

Model level	1	2	3	4	5	6
Process Type						
Re-aeration	/	/	/	/	/	/
Degradation of organic matter						
- Immediate oxygen demand	/	/	/	/	-	-
- Immediate and delayed oxygen demand	-	-	-	-	/	/
Exchange with bottom/ sediment	-	/	-	/	/	/
Nitrification	-	-	/	/	-	/
Denitrification	-	-	-	/	-	/
Phosphorus process in water	/	/	/	/	/	/
Phosphorus exchange with bottom/ sediment	/	/	/	/	/	/
Die-off, Coliforms	/	/	/	/	/	/

In this study, investigates BOD, DO and Temperature were investigated, therefore WQ module level 1 is applied.

2.2.3.1 State variables

- **Dissolved oxygen, DO**

The main reason for modeling the dissolved oxygen concentration is to ensure that it is above acceptable levels for biota in the area under consideration.

Oxygen in the aquatic environment is produced by photosynthesis of algae and plants and consumed by respiration of plants, animal and bacteria, BOD degradation, sediment oxygen demand and oxidation of nitrogen compounds. Additionally dissolved oxygen is re-aerated through interchange with the atmosphere.

Figure 2.7 shows the dissolved oxygen sag curve that is changed due to the sewage discharge into the river or stream. In initial state, the stream is unpolluted; the dissolved oxygen levels nearly reach the saturation. After stream flow through the wastewater discharged point, the dissolved and solid organic matter will increase. The right side of the cycle in Figure 2.8 becomes dominant. Large populations of decomposer organisms break down the organic matter in the water and in the process deplete the dissolve oxygen. In addition, decomposition of organic matter takes place in sludge bed and sediment oxygen demand supplement the decay in the water.

Therefore, the dissolved oxygen is changed, which is caused by the process as belowed:

- Reaeration from atmosphere
- Photosynthetic oxygen production
- DO in incoming tributaries or effluent
- Oxidation of carbonaceous waste material
- Oxidation of nitrogenous waste material
- Oxygen demand of sediment of water body
- Use of oxygen for respiration by aquatic plants

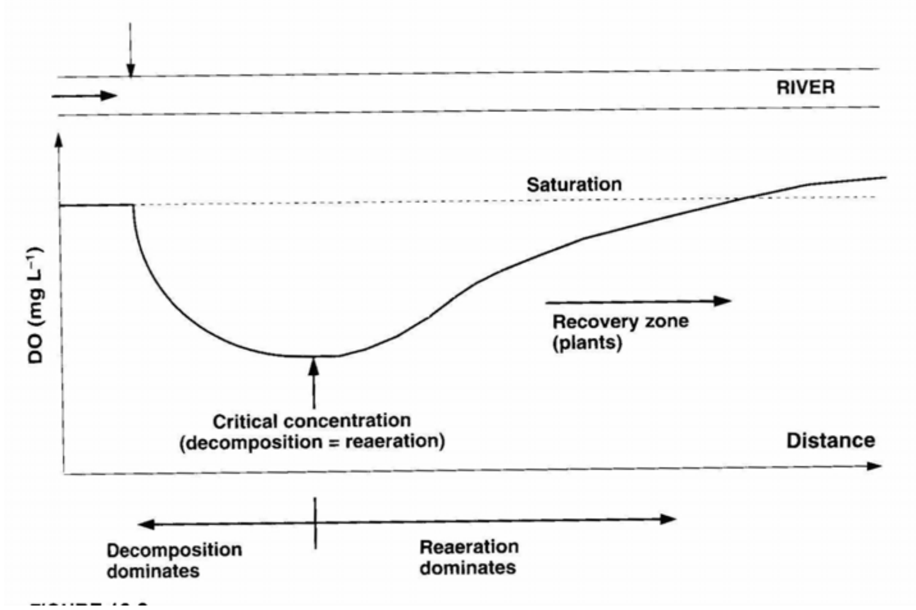


Figure 2.7 The dissolve oxygen sag that occurs below sewage discharge in to stream (Danish Hydraulic Institute,1995).

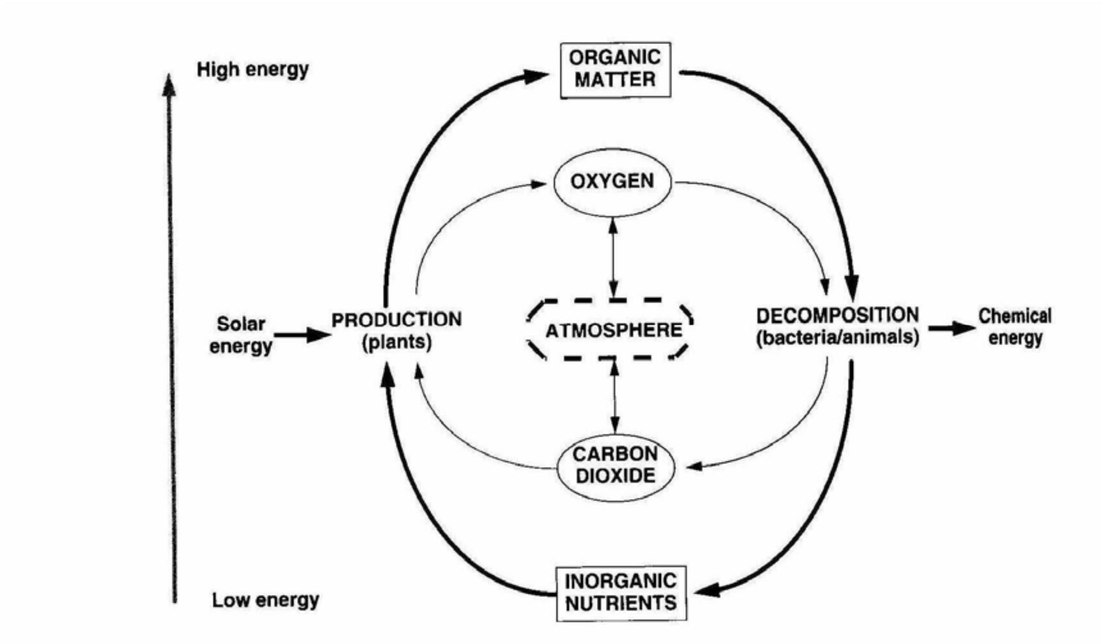


Figure 2.8 The natural cycle of organic production and decomposition (Danish Hydraulic Institute,1995).

- **Biological Oxygen Demand, BOD**

The carbonaceous biological oxygen demand is an expression for the organic matter content of the water. That is to say the biodegradable part of the organic matter, giving rise to oxygen consumption. The organic matter content is measured by registering the oxygen consumed during the degradation for a period of 5 days. The unit of BOD is, therefore, at a gO_2/m^3.

The oxidation of carbonaceous biological oxygen demand is generally written as a first order reaction.

$$\frac{dBOD}{dt} = K'_d BOD \qquad (2.42)$$

Where BOD is ultimate BOD concentration (gO_2/m^3) and K'_d is the first order decay oxygenation rate.

Arrhenius developed the equation for the dependence of rate constants on absolute temperature in 1889. If activation energy is constant over a small temperature range (not always the case), the Arrhenius equation can be simplified

$$K = A_e^{-E_a / RT} \qquad (2.43)$$

Where E_a is the activation energy, R is the universal gas constant, T is absolute temperature, and A is the pre-exponential constant. Equation 2.42 is often simplified still further to a logarithmic relationship for changing temperature with respect to reference value. For deoxygenation rate constants:

$$K'_d (T \circ C) = K_d (20 \circ C) \theta^{(T-20)} \qquad (2.44)$$

Where $K'_d (T \circ C)$ is deoxygenation rate constant at temperature T, K_d is rate constant for deoxygenation at a reference temperature 20 °C, θ is number raised to the power (T-20) and T is any temperature with in the range, usually 0-30 °C.

So, the oxidation of carbonaceous biological oxygen demand is generally written as belowed:

$$\frac{dBOD}{dt} = K_d BOD\theta^{(T-20)} \qquad (2.45)$$

- **Temperature**

A large number of reactions in the environment are temperature dependent. Reactions involving biological elements are directly affected due to the increased biological activity at higher temperatures. Other reactions can also be increased with increasing temperature partly owing to the higher molecular activity.

The temperature function (Arrhenius expression) is centered around 20 °C, having unity value there, and then changing in the same direction as the temperature:

$$f(T) = \phi^{(T-20)} \qquad (2.46)$$

Where T is the temperature and ϕ is the temperature coefficient

2.2.3.2 Solution Scheme

The mass balance for the parameters involved is calculated for all gridpoints at all time steps using a rational extrapolation method in an integrated four-step procedure with the AD-module.

1. Calculation of Advection/Dispersion at time n+1 returned as: $C_{n+1,AD}$
2. Calculation of Advection/Dispersion gradient : $\delta C_{n+1,AD} = (C_{n+1,AD} - C_{n,AD}) / \delta t$
3. Calculation of Water Quality at time n+1 returned as: $C_{n+1,WQ}$
4. Integration of $\delta C_{n+1,WQ} = \delta C_{n+1,WQ} - \delta C_{n+1,AD}$

The final result C_{n+1}, returned from the Integration Routine, is thereby calculated as a numerical integration of time step gradients from both the Advection / Dispersion and from the water quality differential equation.

The results give a resolution in space and time depending on the details of the chosen grid and the time step used. A fine grid should always used in stretches where rapid changes are expected, e.g. around outlets from larger sewer system with a high pollution load.

2.2.3.3 Boundary Condition

The initial conditions for the water quality module are the same identified in AD module.

2.2.3.4 Oxygen Process

The WQ module is integrated with the AD module and simulates the reaction processes in multicompound system. The WQ module solves the system of differential equations describing the physical, chemical, and biological interactions involved in the survival of bacteria, resulting oxygen conditions and excess levels of nutrients in the aquatic environment. The solution is based on a numerical integration routine.

As a basis for the description of the water quality conditions the AD calculates the conservative transport of the modeled components. The WQ processes in combination with the AD transport give the final result.

Due to this study investigates BOD, DO and temperature. Only oxygen processes affect the state variables.

The factors affecting the oxygen concentration are photosynthetic production and respiration, re-aeration (exchange with the atmosphere), BOD decay, and nitrification

Re-aeration:

$$\frac{dDO}{dt} = K_a(C_s - DO) \qquad (2.47)$$

Cs = saturation concentration of DO

= 14.652+ T (-0.41022+T (0.007991-0.000077774T)

Where T is water temperature (°C) and K_a is re-aeration constant at 20 °C(day^{-1})

The five different expressions for K_a are based upon empirical connection between the re-aeration constant and flow velocity, water depth and river slope in the stream. The four first expressions are standard expressions, whereas the last may be specified by the user.

1. The Thyssen expression is recommended for application to small streams.

$$K_a = 27185 \cdot u^{0.931} \cdot h^{-0.692} \cdot I^{1.09}$$

2. O'Connor-Dubbins expression to ordinary rivers.

$$K_a = 3.9 \cdot u^{0.5} \cdot h^{-1.5}$$

3. Churchill-expression to rivers with high flow velocities.

$$K_a = 5233 \cdot u \cdot h^{-1.67}$$

4. Owens expression to river with low flow velocities.

$$K_a = 6.92 \cdot u^{0.73} \cdot h^{-1.75}$$

5. Specified by the user

$$K_a = a \cdot v^b \cdot h^c I^d$$

Where K_a is re-aeration constant at 20 °C (day^{-1}), u is flow velocity(m/s), h is water depth (m), I is river slope (m/m) and where a is coefficient in the re-aeration expression, b is exponent for flow velocity, c is exponent for water depth, d is exponent for river slope.

Photosynthesis:

$$P = \begin{cases} P_{max} \cdot \cos 2\pi (\tau/\alpha), \text{ if } \tau \in (t_{up}, t_{down}) \\ 0 \quad , \text{ if } \tau \notin (t_{up}, t_{down}) \end{cases} \quad (2.48)$$

Where P is actural production (g O_2/m^2/day), P_{max} is maximum production at noon (g O_2/m^2/day), τ is actural time of the day related to noon, α is actural relate day length and $t_{up,down}$ is time of sunrise and sunset.

Respiration:

$$R = R_{20} \cdot \theta_2^{(T-20)} \quad (2.49)$$

Where R is actural respiration rate of plants, bacteria, and animal (g O_2/m^2/day), R20 is respiration rate at 20 °C (g O_2/m^2/day) and θ_2 is Arrhenius temperature coeffient.

Nitrification:

$$\frac{dNH_3}{dt} = K_4 \cdot NH_3 \cdot \theta_4^{(T-20)} \tag{2.50}$$

$$\frac{dNH_3}{dt} = K_4 \cdot (NH_3)^{1/2} \cdot \theta_4^{(T-20)}$$

Where NH_3 is concentration of ammonia (mg/l), K_4 is nitrification rate at 20 °C (day $^{-1}$) and θ_4 is Arrhenius temperature coefficient.

BOD Decay:

- Oxygen consumption from degradation of dissolved organic matter

$$\frac{dBOD_d}{dt} = K_{d3} \cdot BODd \cdot \theta_{d3}^{(T-20)} \tag{2.51}$$

Where BOD_d is actural concentration of dissolved organic matter(mgO_2/l), K_{d3} is degradation constant for dissolved organic matter at 20 °C (day $^{-1}$) and θ_{d3} is Arrhenius temperature coefficient.

- Oxygen consumption from degradation of suspended organic matter

$$\frac{dBODs}{dt} = K_{s3} \cdot BODs \cdot \theta_{s3}^{(T-20)} \tag{2.52}$$

Where BOD_s is actural concentration of suspended organic matter(mgO_2/l), K_{s3} is degradation constant for suspended organic matter at 20 °C (day $^{-1}$) and θ_{s3} is Arrhenius temperature coefficient.

- Oxygen consumption from degradation of deposited organic matter

$$\frac{dBODb}{dt} = K_{b3} \cdot BODb \cdot \theta_{b3}^{(T-20)} \tag{2.53}$$

Where BOD_b is actural concentration of suspended organic matter (mgO_2/l), K_{b3} is degradation constant for deposited organic matter (day^{-1}) and θ_{b3} is Arrhenius temperature coefficient.

2.3 Review Summary of Water Quality Models

Mahasandana (1994) used the MIKE 11 model for the investigation of water quality in the Chao Phraya River from Bangsai District, Ayuttaya to mouth of river at Samut Prakarn province, 112 Km. distances. The study showed that during the low effect from irrigation (dry season) maximum BOD concentration was 6.2 mg/l which was below the required standards for surface water quality.

Pengthemkeerati (1998) applied the MIKE 11 model for prediction of water quality in Lower Maeklong River. This study was based on the calibration of three modules: Hydrodynamic module, Advection-Dispersion module, and Water Quality module. The part of wastewater loading, including wastewater quality and BOD loading, were taken only from the major checkpoint of wastewater resources from communities, industrial zones and livestock farms along the riverside of the sub district areas in Ratchaburi and Samutsongkram provinces. Wastewater loading were determined the drain quality from sewage drains and canals. The values were obtained by a calculation from several researches and the designs of the collection system and sewage treatment plant. The result of the study indicated that water quality of lower Maeklong River was under the required standards for surface water quality.

Manusthiparom (2000) developed a model for forecasting hourly water levels and discharges in the Chao Phraya River at Bangkok Memorial Bridge, which was 48 km. far from the river mouth. This was done by using Neural Network Model known as Back- Propagation algorithm (BP). The model considered the river reach form the river mouth at Fort Chula to Bangsai, a reach length of 112 km. The model was calibrated and verified, based on the observed data and computed results of the MIKE11 Hydrodynamic model.

Pradyanothai (2002) predicted the water quality in the lower Tha Chin River using MIKE 11 model. The study showed that the future river water quality in year 2007 and 2017, without the planned control gates and without additional wastewater treatment, was predicted and found to have similar patterns of distribution along the river as those in the year 1996, but more deteriorated, and was classified as Class 5 standard level. However with wastewater treatment considered the most practical (i.e. 75 percent removal efficiency for domestic and industrial wastes, and 40 percent removal for agricultural waste), the overall river water quality was improved. With the exception of the concentrations of D.O. (1.61 mg/L) and coliform bacteria (greater than 20,000 MPN/100 mL), making the river water quality to be in Class 4 standards, which could be used for industrial and navigation purpose only, and mighy be used for agricultural purpose as well.

Blois, C.J. (2003) illustrated the analysis of the impact of long term policy measures on the water quality in a Rhine Basin using RHIMO (THIne Model). The RHIMO pollutant transport model was defined for the Rhine from its origin to Lobith, where the river enters the Netherlands. Downstream of Lobith, the river is more and more influenced by tides, which makes modeling pollutant transport very complex matter.

From the analysis of the field data it was found that during a period of strong precipitation the pollutant discharges to the river increase. This effect resulted from the increase of surface runoff and leaching, resuspension of river sediment, atmospheric deposition, and sewerage overflow.

Wongbilsaji (2003) illustrated the water quality in the lower reach of Chao Phraya River by using mathematical modeling (MIKE 11) in corporation with the Geographic Information System (GIS). The study was based on calibration of three modules: MIKE 11 Hydrodynamic module, Advection-Dispersion module, and Water Quality module. Selected water quality parameters for calibration and verification were as dissolved oxygen (DO), biochemical oxygen demand (BOD), salinity and temperature. The study results indicated that water quality in the lower Chao Phraya River in the year 1995 and 2001 were lower than those of the required surface water quality standard. However it is expected that the average valued of water quality would meet the required standard up to the year 2007 if seven wastewater treatment projects could be fully implemented according to the Bangkok Metropolitan Region wastewater management plan. After 2007, the water quality is expected to be lower than the required standard again due to the high population growth rate.

2.4 Geographic Information System (GIS)

Geographic Information System (GIS) has a longer history than the most can realize. Depending of what lineage one trances, one can find hints of what was come in GIS, perhaps some 25 or more year ago, though computer-assisted cartography and in civil engineering. GIS was widely used to analyze spatially related problems, concerning scientific investigation, resource management, development planning and an application within environmental topic. GIS as applied to environmental topic has been a long – standing concern. As in any filed, topics mature with continued effort and focus. The theme of the 2002 international workshop, organized by Department of Sanitary Engineering, Mahidol University and TUCED-DUCED I&UA, was made on environmental issues.

Although there has been a marvelous growth in knowledge related to GIS, there is still considerable room for improvements. These improvements will focus on several fronts, including issues related to institutional arrangements, data, software and hardware. Many other improvements make GIS even more efficient and effective in the future.

Another major part of those improvements, dealing with the study of environment, will involve the linking of GIS and environmental process models. Although analytical models have a part of GIS, the cross- fertilization between environmental process model and GIS is only getting started.

In the strictest sense, the GIS is a computer system capable of assembling storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations, Practitioners also regard the total GIS as an inclusion of operating personnel, and the data that go into the system.

2.4.1 The application of Geographic Information System

In 1960, the Land Use and Natural Resources Inventory of U.S. and The Canadian Geographic Information System, made use of an applied GIS. These departments were the first, which have since become widely known as LUNRI and CGIS. About thirty years later, the same influences are still among the most frequently heard on a justification for the use of GIS, particularly in the amount of environmental modeling and policy development. GIS is aimed as a general-purpose technology for handing data in digital form and specific needs, among others:

- The ability to preprocess data from suitable for analysis as reformatting, change of projection, resampling, and generalization.
- Direct support for analysis and modeling as forms of analysis, calibration of models, forecasting and prediction is all handled though instruction to the GIS.
- Post processing of results as tabulation, report generation and mapping.

GIS applications now span a wide range from sophisticated analysis and modeling of spatial data to simple inventory and management.

Currently, the improvements of computer systems made GIS even more efficient and effective. GIS are widely applied in many fields; for example Businesses are using GIS to market products and even to develop mailing lists, based on selected spatial criteria. Fire departments have a need for GIS to enhance their routing capabilities to ensure rapid response in emergencies. Local governments employ GIS to develop plans and develop growth. The military could use GIS to organize troop movement. The potential users of GIS are nearly unlimited. In this work, there will be focused on the environmental field applications.

2.4.2 Environmental Geographical Information System

The application of Geographic Information System (GIS) as a tool of landfill selection was an example for application of GIS on the environmental field. This study, aimed to select potential site for landfill construction center of Tumbon, municipal in Ubonrachathani, Thailand. GIS was established, containing data on natural conditions of study area; elevation, soil depth, the yearly rainfall recorded, land use, and water quality classification. Overlay technique as the factors utilized by GIS, was used.

Using GIS for sustainable energy planning in Denmark was the example for an application of GIS on local, regional, and nation levels. This work included 3 cases: Local district heating planning on the Island of Samsϕ; Regional wind energy planning; and National planning of energy systems in particular power transmission networks and distributed energy systems. For the first case, Local district heating planning on the Island of Samsϕ, GIS and energy systems models were used to assess the feasibility of new district heating systems. In the GIS, the spatial aspects of the planning process were analyzed and the energy systems model allowed for the complex analysis of the system operation and the proposed scenario so. In the second case, GIS was applied for wind energy planning using kriging and overlay techniques. The last case included an application of spatial analysis for sustainable energy planning.

In case of an application of GIS to the air pollution, one study illustrated methods and steps of determining the area affected by an emission source through the applications of air dispersion model (ISCT) and GIS. The Bangpakong Power Plant was used as the case study. The study area covered two provinces Choensao and Chonburi. The model predicted the SO_2 concentration at various times receptor points. This prediction was imported to the GIS for determining the affected area.

2.4.3 GIS and Environmental Modeling

Most environmental problems do have an obvious spatial dimension within the domain of environmental modeling. This is addressed by spatially distributed models that describe the environmental phenomena in one dimension (river models), two dimensions (atmospheric models), or three dimensions (air models). Conversely, geographic information systems serve as tools to capture, manipulate, process, and display spatial or geo-referenced data. They contain both geometry data (coordinates and topological information) and attribute data, that is, information describing the properties of geometrical spatial: points; lines; and polygons.

In GIS, the basic concept is one of location, of spatial distribution and relationship, and basic elements are spatial objects. In environmental modeling, by contrast, the concept is one of state, expressed in terms of numbers, mass, or energy, of interaction and dynamics. Populations and species, environmental media such as air, water, and soil, and environmental chemicals are basic units. Since all the basic units in environmental modeling do have a spatial distribution, and this distribution does affect the processes and dynamics of their interactions considerably. GIS a lot of explicit dynamics, can make it a more attractive tool as well.

The overlap and relationship is apparent, and thus the integration of these two fields of research, technologies, or sets of methods, that is, their paradigms are obvious and promising results.

GIS can be integrated with environmental models in many forms. In this work, a connection of MIKE 11 model and GIS.

The function of science is to understand, predict, and control. GIS-based environmental models become accepted, they will become part of decision support systems for environmental managers and decision-makers, and environmental model will be used to predict, and perhaps ultimately control, both the consequences for the environment of human actions and the impact on humans environment.

CHAPTER III
MATERIALS AND METHODS

3.1 Software Programs

3.3.1 MIKE 11 version 4.03 and MIKE VIEW version 4.03 for modeling
3.3.2 ArcView version 3.2a and ArcInfo version 3.5 for GIS application

3.2 Data Collection

3.2.1 Physical Data

3.2.1.1 GIS datasets of the district and province boundary and stream of Suphanburi, Nakhon Pathom and Samut Sakhon provinces were provided by Sanitary Engineering Department, Faculty of Public Health, Mahidol University.

3.2.1.2 Cross-section of Tha Chin River was acquired from the Royal Irrigation Department.

3.2.2 Hydraulic Data

3.2.2.1 Hourly water level, daily water level and discharge flow rate were acquired from Port Authority of Thailand and the Royal Irrigation Department.

3.2.2.2 Water quality data was acquired from Water Quality Management Division the Pollution Control Department.

3.3 Methods

The methods in this study can be categorized into two parts as follows:

3.3.1 Investigation of water quality in the middle and lower Tha Chin River in the year 2005 and 2006

3.3.2 Simulation water quality in year 2005 to meet the water standard classification by controlling pollution discharge as follows.

3.3.2.1 Reduce every pollution discharge by equality loading reduction.

3.3.2.2 Reduce only important pollution discharge such as fishery, industrial and pig farm loading.

3.3.2.3 Reduce pollution discharge at pollution peak.

Figures 3.1 and 3.2 display the conceptual flow diagram of this study, showing the followed steps.

3.3.1 Investigation of water quality for the year 2005

MIKE 11 model is used to simulate flow, sediment transport, and water quality in the study areas.

3.3.1.1 Model set up and calibration

Calibration of MIKE 11 Model for this study can be summarized into three modules as hydrodynamic, advection-dispersion, and water quality. The calibration was performed to the typical hot (dry) season data as the worst case for river water quality. Dry season is defined as the period from the beginning of February to the end of May inclusively.

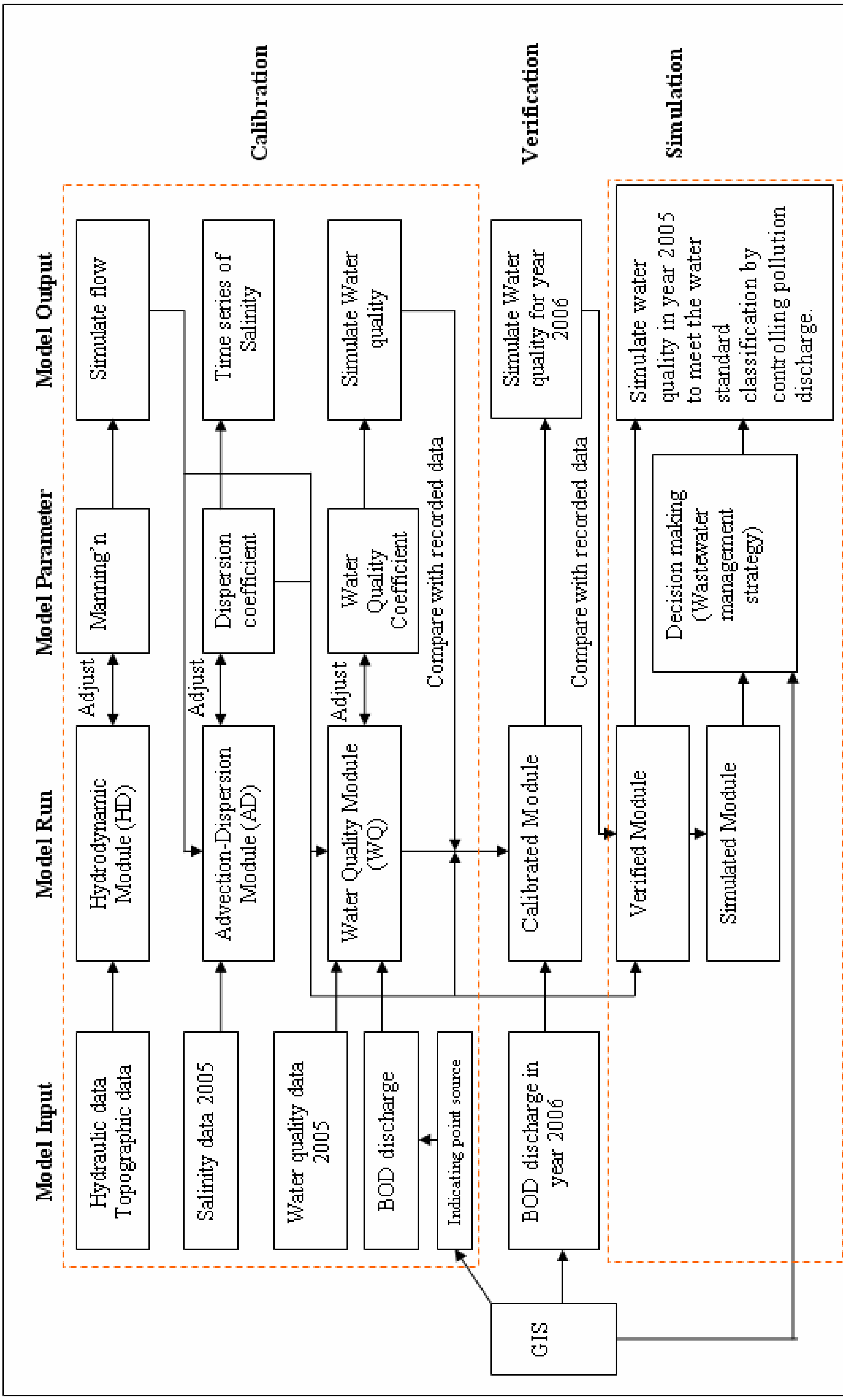


Figure 3.1 Conceptual flow diagram

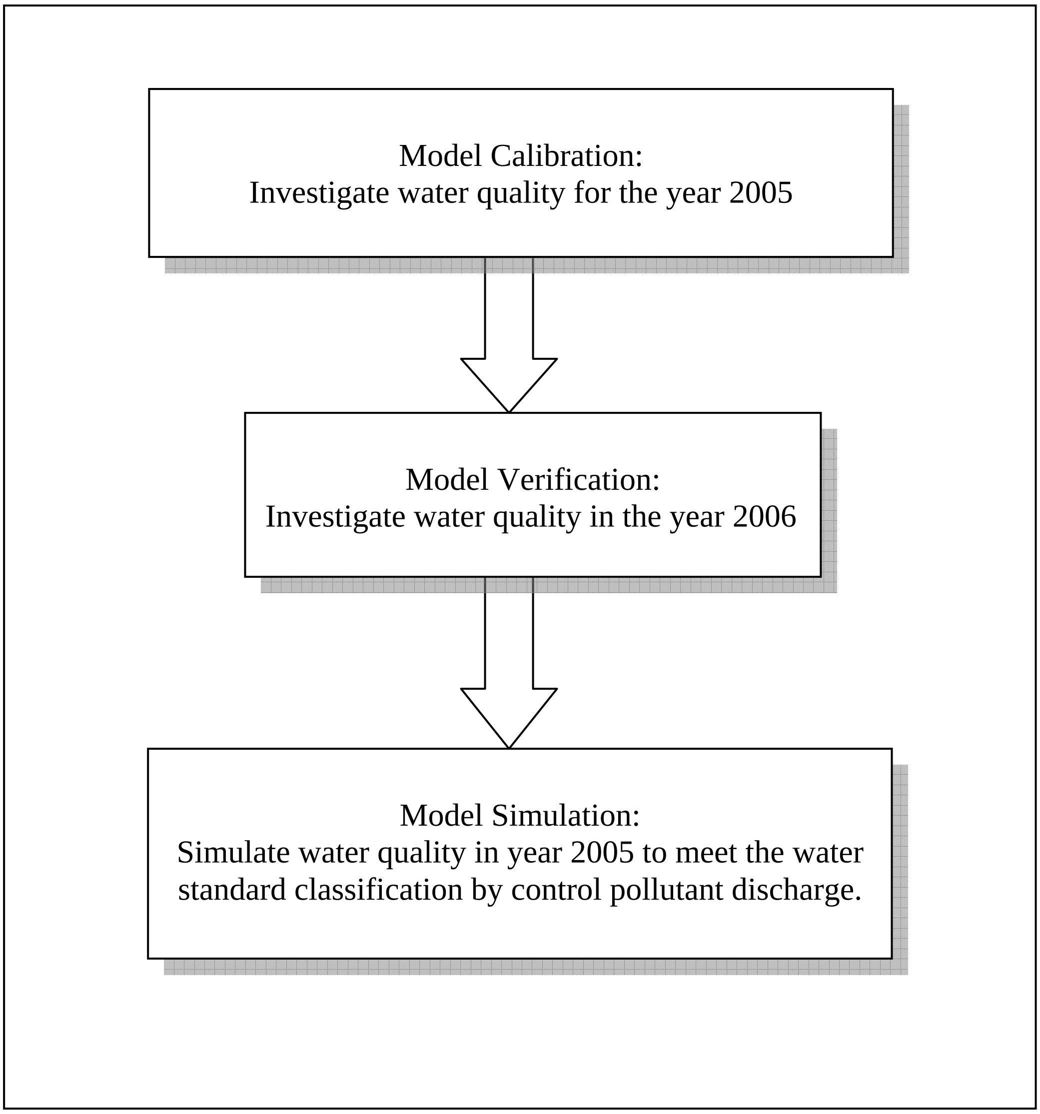


Figure 3.2 Flow of Methods

- **Hydrodynamic Module (HD)**

The hydrodynamic module is based on the equations of conservation of mass and momentum. Inputs for the hydrodynamic module are topographic data, hydrodynamic data, and Manning's resistance number of lower Tha Chin. The details of the input data are shown in Table 3.1. For a simulation of flows in the river, the hydrodynamic module of MIKE 11 is set-up, by entering cross section at given chainage of the river with an interval 3-4 km (Figure 3.3). Lateral inflows and outflows are taken into account. The upstream flow at Phopraya regulators, Mueang, Suphanburi Province. The module is calibrated by adjusting the Manning number until the simulating flows and water levels are fitted with the observed flows and water levels.

Table 3.1 Input for hydrodynamic module

Input Data	Details	Sources
1. Topographic data		
1.1 shape of river channel	-Tha Chin River from Suphanburi to Samutsakorn province	Mahidol University (year 2005)
1.2 cross section	- 56 cross sections for study area	Royal Irrigation Department (1989)
1.3 description of the river and channel network	- Coordinates	Royal Irrigation Department (1989)
2. Hydraulic data		
2.1 daily flow	9 regulator stations (1February 2005 to 31 May 2006)	Royal Irrigation Department (2006)
2.2 daily water level	9 regulator stations (1February 2005 to 31 May 2006)	Royal Irrigation Department (2006)

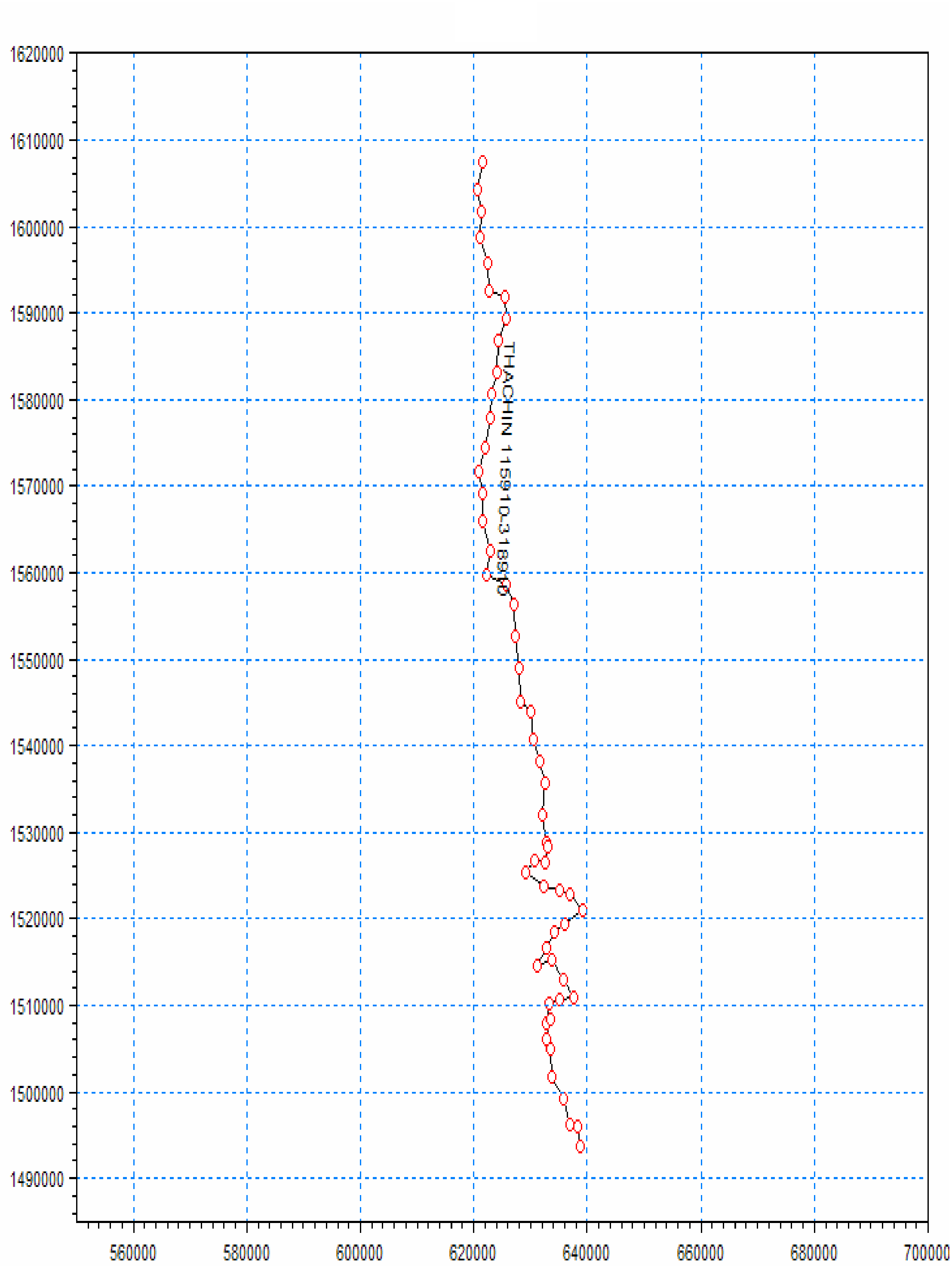


Figure 3.3 Display the river network at given chainage of Tha Chin River, illustrating the information of cross-section, flow, water level and water quality.

- **Advection – Dispersion Module (AD)**

Advection – Dispersion Module require inputs from HD in terms of discharges and water levels in time and space, salinity, and dispersion coefficient. The AD is calibrated by adjusting the dispersion coefficient until the simulating salinity is fitted with the recorded salinity.

Salinity data during the dry season (Feb-May) of the year 2005 was provided by Water Quality Management Division, Pollution Control Department.

- **Water Quality Module (WQ)**

The WQ module consists of six different levels, however, in this study, model level 3 where DO, BOD, Ammonia and temperature are taken into account is applied for water quality simulation. Nakhon Chaisri District office, located at Nakhonpathom province, is assigned as downstream boundary. This module requires input from HD in terms of discharges and water levels in time and space, dispersion coefficient, and time series of water quality components (pollution discharge), water quality datasets as well as model parameters that are re-aeration constant at 20 °C (K_a), first order decay constant (K_d), maximum photosynthesis (P_{max}) respiration rates(R). The details of input data are shown in Table 3.2.

This module is calibrated by comparing simulating water quality with recorded water quality. The model parameters are adjusted until the simulating and the recorded data are fit. The details of the input data are shown in Table 3.2.

3.3.1.2 Model Integration with GIS database

The river carries waste discharge from pollution sources including point sources (industrial and domestic discharges) and non-point sources (agricultural activity discharges). Since the model was set up during dry seasons when the stream flow is low and the effect of wastewater discharges from urban area becomes more significant. BOD loading from point source can be analyzed by using GIS database to indicate the location of sources within study area. After that, the results is overlaid with population, factories and pig farms database to examine the amount of the BOD

Table 3.2 Input data for water quality module

Input Data	Details	Sources
1.Water quality datasets		
1.1.DO 1.2.BOD 1.3.Temperature 1.4 Ammonia	- Recorded data during the dry season (1 February 2006 to 31 May 2006)	Water Quality Management Division, Pollution Control Department (year2005 to 2006)
2. Pollution discharges (BOD, Ammonia loading)	- Indicate point sources by using GIS	-GIS datasets were provided by Sanitary Engineering Department, Mahidol University
2.1 From communities	- Estimate loading from communities by using equivalence and population distribution data.	-Population distribution data in year 2005 was derived from the National Statistical office.
2.2 From livestock	- Estimate loading from pig farms	-Pig farm distribution data in year 2005 was derived from department of livestock development.
	- Estimate loading from fishery farms	-Fishery farm distribution data in year 2005 was derived from department of fisheries.
2.3 From Industries	- Estimate loading from Industries by using Industrial data.	- Industrial data in the year 2005 was derived from department of Industrial Work.

discharged from the sources with in the study area into the river. In addition, Geospatial Hydrologic Modeling Extension in Arcview is used to indicate the amount of water that flow from canal to the river. In this study BOD loading from point sources is estimated by using criteria as shown as the following.

(1) Residential Loads

The details of the load criteria for residential areas per capita of population are shown in Table 3.3.

(2) Agricultural Loads

Chicken waste is collected and sold as a valuable fertilizer product. It is therefore unlikely that pollution from chickens has any significant impact on drains and waterways.

Cattle waste is also likely to be insignificant, party because the waste accumulates on the soil and little runoff occurs; but also because there are comparatively few cattle in this region.

Both duck and pig farm prevail in the study area. Pig farm were well organized and pig farm generate a large amount of waste. Current practice appears to consist of collection of the waste followed by ponding in some cases. Supernatant from the pond is discharged to the nearest drain or canal while sludge is periodically removed. It can be safety assumed that such practice is generally carried out but there will almost certainly be areas where no treatment of discharge occurs. A similar situation is thought to apply to ducks.

Fish, shrimp and prawn farms exist throughout the region. These farms consist of ponds which are aerated but generally have little flow through them, except towards harvest time when the flow and pollutant loads become very high.

Table 3.3 Load criteria for residential areas per capita of population.

Criteria			References
Residential wastewater			
1.Water Consumption	250 L /person/day		PCD, 2000
- Increasing	1.2 % per year		
2. Wastewater	80 % of water consumption		PCD, 2000
3. Pollution Equivalence			PCD, 2000
- Suphanburi			
BOD	25	g / capita / day	
Nitrate	0.23	g / capita / day	
Ammonia	10	g / capita / day	
- Nakhon Pathom			
BOD	30	g / capita / day	
Nitrate	0.23	g / capita / day	
Ammonia	10	g / capita / day	
- Samut Sakorn			
BOD	30	g / capita / day	
Nitrate	0.23	g / capita / day	
Ammonia	10	g / capita / day	
4. Population growth rate			
Density (person/km^2)	growth rate (% per year)		PCD, 1993
More than 25,000	-3.20		
20,000-25,000	-2.25		
15,000-20,000	-1.10		
10,000-15,000	2.15		
Less than 10,000	3.90		

In table 3.4 (PCD, 1995) the pollutant loads for shrimp, prawns and fish are based on the area of the farm in rai. The average year production of salt/brackish water shrimp is estimated to be 245 kg per rai. This production rate relates to extensive shrimp farm management as practiced in Samut Sakhon province. For freshwater prawns the average year production is also estimated at 245 kg per rai. This production estimate is the same as the average freshwater prawn production in Thailand for 1987. The last, an average fish production is 1,470 kg per rai.

Table 3.4 Estimate of Exist, Average Loads Discharged to the Tha Chin from Various Animals

Parameter	Units	Animals				
		Pigs (No)	Duck (No)	Fish (Rai)	Shrimps (Rai)	Prawns (Rai)
Average flow	L/d per unit	40	1	480,000[1]	160,000[1]	160,000[1]
BOD	g/d per unit	24	0.4	210	35	84
COD	g/d per unit	68	3	420	70	160
SS	g/d per unit	23	0.5	100	17	40
Ammonia	g/d per unit	13	1	19	3.2	7.7
TKN	g/d per unit	26	2	74	12	30
Total P	g/d per unit	5	2	4.2	0.7	1.7
Faecal Coliform	MPN/d per unit	$5x10^7$	$2x10^6$	-	-	-

Remark: 1 This flow is essentially a recirculated flow-there is no net discharge to the river

Pollution loading year 2005 from municipal, livestock and fishery farm are calculated under load criteria in Table 3.3-3.4. Pollution loading from factory is calculated using recorded data from the Department of Industrial Work. The detail of pollution loading is shown in Figure 3.4 and Table 3.5- 3.6.

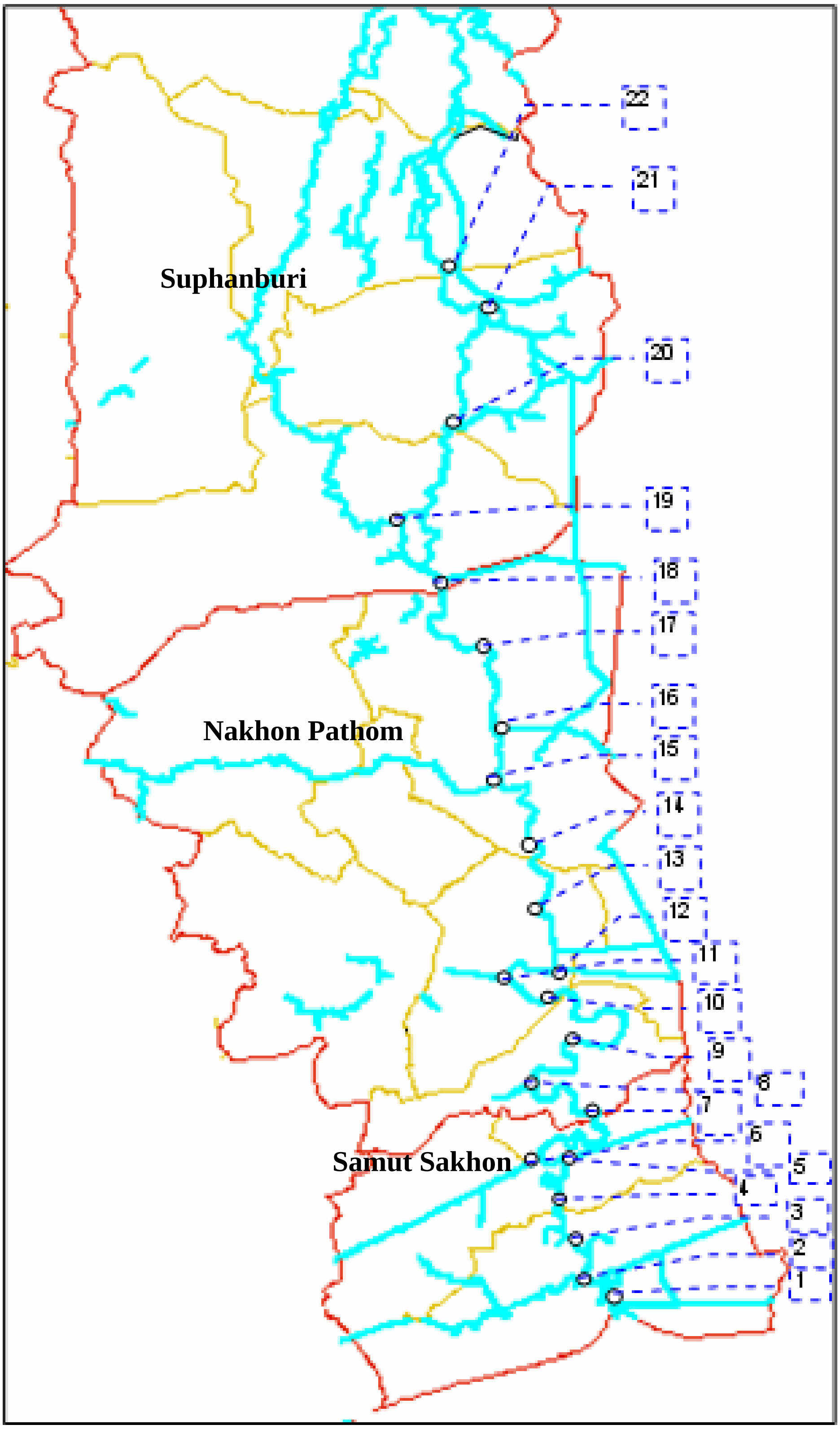


Figure 3.4 Display pollution discharge points

Table 3.5 BOD loading discharge to Tha Chin river year 2005

Discharge points	BOD Loading (kg/d)				
	Population	Pig Farm	Fishery	Factory	Total
1	1,986	-	48	1,715	3,749
2	825	49	1,235	2,049	4,158
3	150	-	436	14,168	14,754
4	42	-	5,422	860	6,324
5	2,245	12	453	2,980	5,690
6	750	2	5,834	-	6,586
7	183	61	-	255	499
8	1,464	14,554	8,639	1,195	25,852
9	83	95	1,763	1,413	3,354
10	453	1,361	3,926	58	5,798
11	453	421	1,504	157	2,535
12	342	80	647	36	1,105
Total (Lower Tha Chin)	8,976	16,635	29,907	24,886	80,404
13	71	36	625	-	732
14	11	1,098	10,056	-	11,165
15	900	1,268	6,834	285	9,287
16	145	60	932	-	1,137
17	78	14	401	4	497
18	124	274	1,732	-	2,129
19	1,153	576	66	-	1,795
20	119	0	790	-	909
21	129	0	70	-	200
22	1,047	100	2,085	-	3,233
Total (Middle Tha Chin)	3,777	3,426	23,591	289	31,083
Total	12,753	20,061	53,498	25,175	111,487

Table 3.6 Ammonia loading discharge to Tha Chin river year 2005

Discharge points	Ammonia Loading (kg/d)				
	Population	Pig Farm	Fishery	Factory	Total
1	624	-	2	1,173	1,799
2	259	13	25	1,173	1,470
3	47	-	10	7	64
4	13	-	88	753	854
5	705	4	11	1,967	2,687
6	235	1	143	7	386
7	57	16	-	600	673
8	1,307	4,002	214	1,633	7,156
9	83	26	43	1,348	1,500
10	142	374	98	36	650
11	233	116	37	672	1,058
12	107	22	16	96	241
Total (Lower Tha Chin)	3,812	4,574	687	9,45	18,538
13	22	9	15	-	46
14	1	301	224	-	526
15	282	348	73	-	703
16	45	16	13	-	74
17	24	3	-	-	27
18	38	75	39	-	152
19	362	158	1	-	521
20	37	-	19	-	56
21	40	-	2	-	42
22	329	27	49	-	405
Total (Middle Tha Chin)	1,180	937	435	-	2,552
Total	4,992	5,511	1,122	9,465	21,090

3.3.2 Investigation of water quality in the year 2006

3.3.2.1 Model verification

MIKE 11 model verification, during the low flow period (February-May) 2006, is carried out after the model calibration to reassure that the calibrated model represents flow situation and water quality of any flow conditions while the model parameters determined from the calibration are fixed. As the fitted curve between the calculated and the observed water quality parameters are obtained, the model is finally verified.

The hydrodynamic module is carried out under hydrodynamic conditions of the year 2006 the same as these of the advection-dispersion module and water quality module. Pollution discharge data for the year 2006 are the result of 2005 situation adjustment.

3.3.3.2 Simulation water quality in year 2005 to meet the water standard classification by controlling pollution discharge as following.

1) Reduction of all pollution loading discharge by an equal loading.
2) Reduction of only the major sources of pollution discharge (such as fishery, industry and pig farm loading).
3) Reduction of pollution discharge at the critical point (peak load).

CHAPTER IV
RESULTS

MIKE 11 model was used to simulate flow, sediment transport, and water quality in the study areas. All input data are the existing one under the dry season of the year due to its worst-case duration of the year. In this study can be categorized into three parts as: model calibration; model verification; and model simulation.

4.1 Model Calibration

The model calibration part is intended to investigate the water quality in the middle and lower Tha Chin River in the year 2005.

4.1.1 Hydrodynamic Module (HD)

The data are used for HD model calibration are water level at the regulators in February to May 2005. The result are obtained by comparing the simulated data and observed one of water level by changing Manning coefficient from 0.030 to 0.040. The results are shown from Figure 4.1 to Figure 4.4.

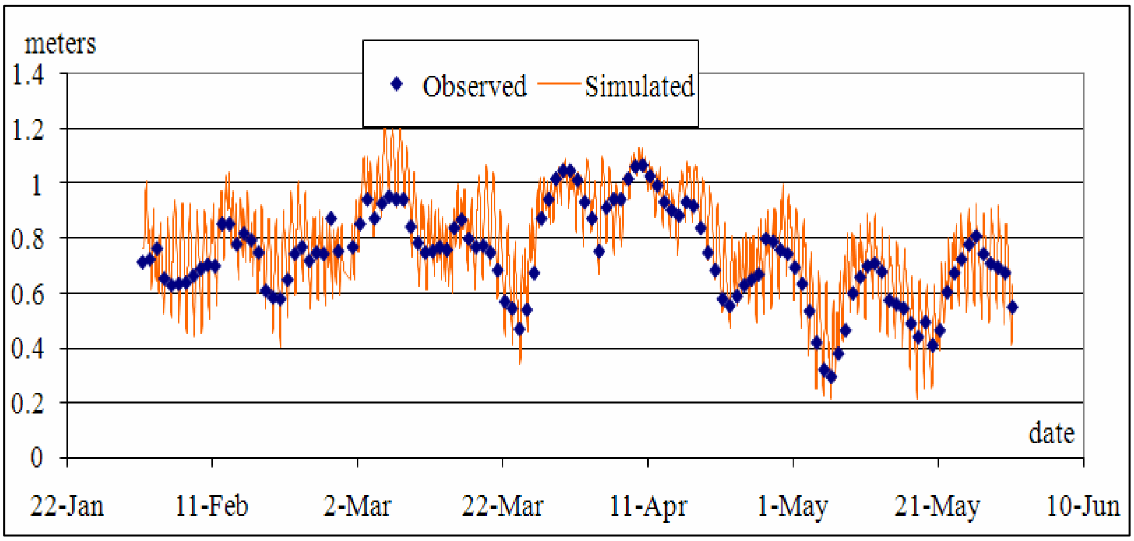


Figure 4.1 Comparison between observed and simulated water level in February to May 2005 at Songpeenong Regulator (R^2 = 0.8430, n=118)

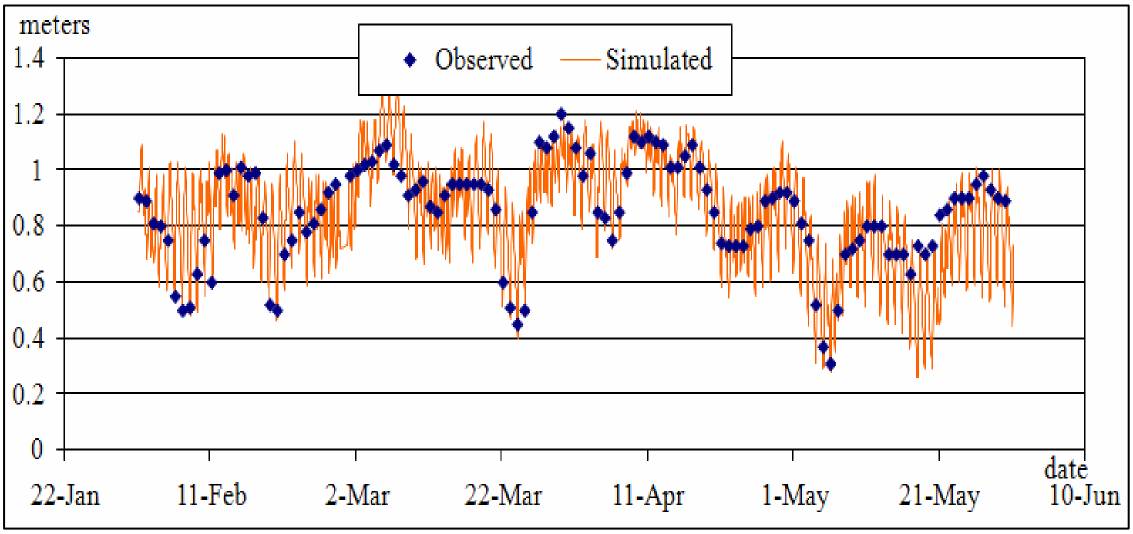


Figure 4.2 Comparison between observed and simulated water level in February to May 2005 at Prayabanlae Regulator (R^2 = 0.8221, n=118)

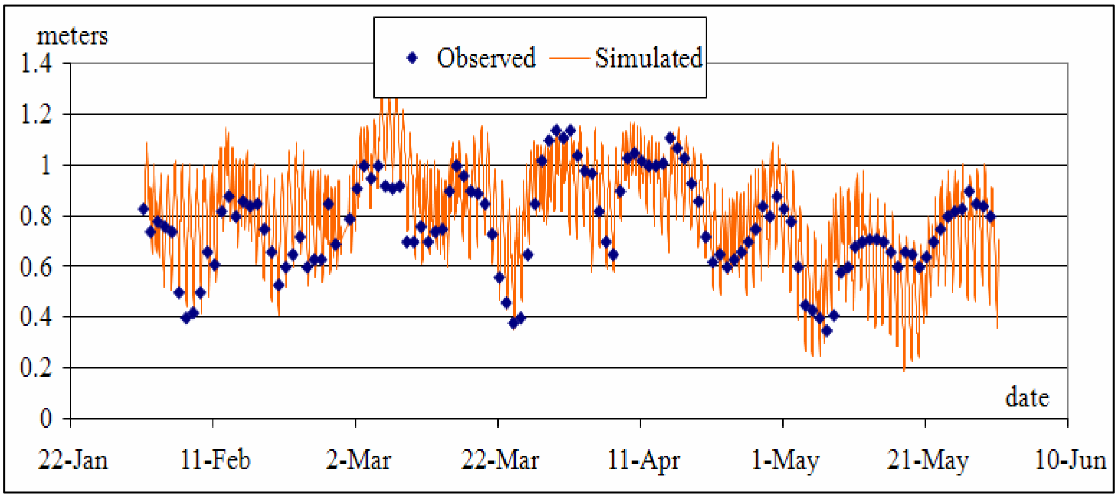


Figure 4.3 Comparison between observed and simulated water level in February to May 2005 at Prapimol Regulator (R^2 = 0.8207, n=118)

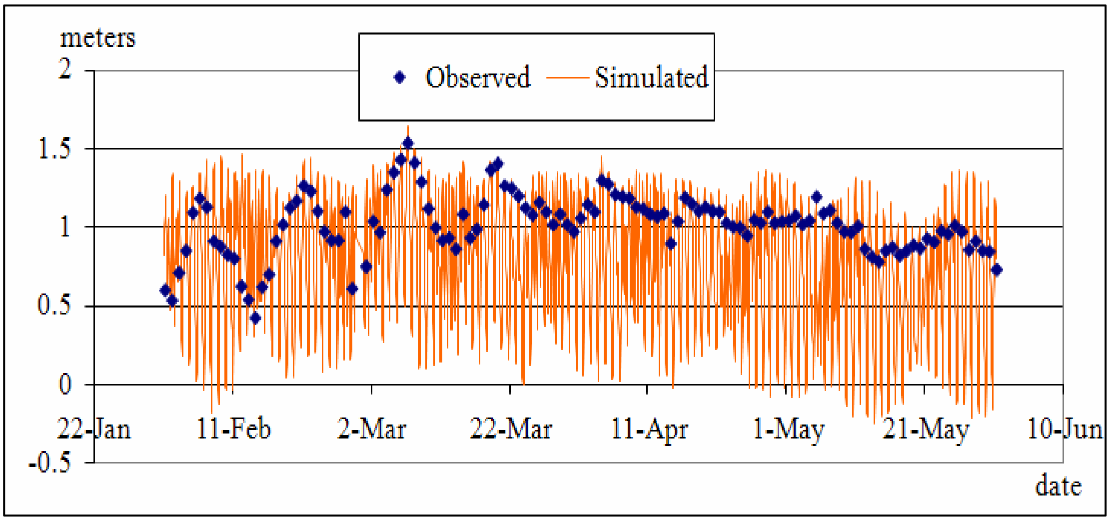


Figure 4.4 Comparison between observed and simulated water level in February to May 2005 at Bangyang Regulator (R^2 = 0.8368, n=118)

According to the above Figures (Figure 4.1-4.4), they showed that simulated water levels are closely related to the recorded water levels. It is recommended that the simulated water levels from MIKE 11 model represent the existent water levels.

4.1.2 Advection-Dispersion Module (AD)

The Advection-Dispersion Module is calibrated by adjusting the dispersion coefficient until the results of salinity from simulation and the observation are fitted at all eleven water quality monitoring stations. After a consecutive trial, the dispersion factor is adjusted to 300, exponent is 0.5 and dispersion coefficient is in the range of 100-3000 m^2/s. The results are shown in Figure 4.5.

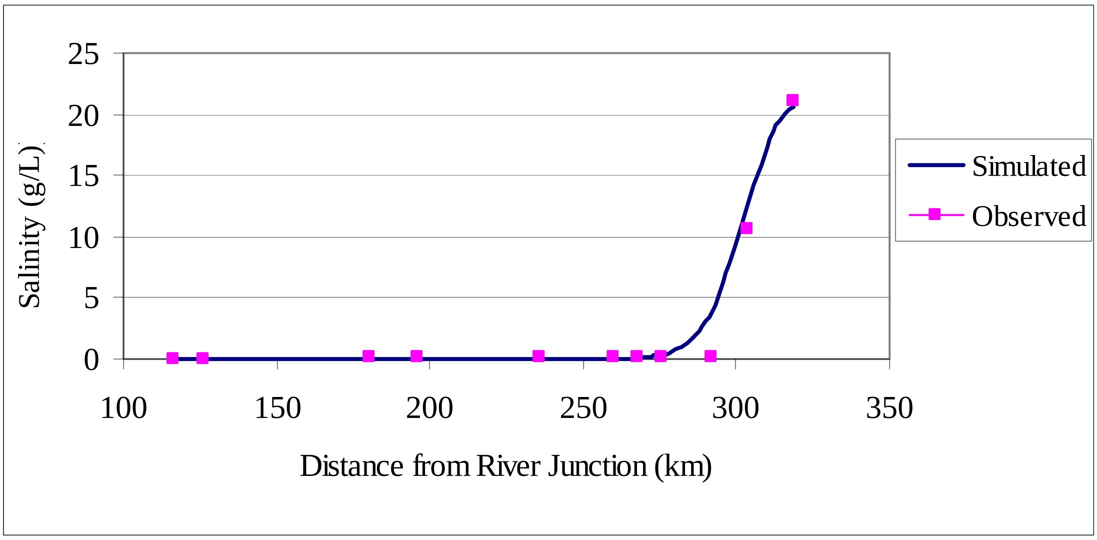


Figure 4.5 Comparison between simulated and observed Salinity in February, 2005 (R^2=0.9677, n=11)

4.1.3 Water Quality Module (WQ)

Water Quality Module is calibrated by adjusting model parameters, which consist of re-aeration constant (K_a), first order decay constant (K_d), maximum photosynthesis (P_{max}) and respiration rates (R). The process of calibration is the same as those previous ones by fitting the simulated results with the observed ones (BOD, DO and temperature) at eleven water quality stations (TC01, TC04, TC07, TC09, TC10, TC11, TC13, TC15, TC17, TC22 and TC23). As a result, the adjusted model parameters are shown in Table 4.1. Comparisons of simulated and observed water quality are shown in Figure 4.6-4.9.

Table 4.1 Values for model parameters

Model Parameter	Values
Max. Absorbed Solar Radiation ($kJ/m^2/hr$)	5000
Solar Radiation Displacement (hr)	1.00
Emitted Heat Radiation ($kJ/m^2/hr$)	1000
No. of reaeration expression	2
Reaeration Temperature Coefficient	1.05
Respiration of Plants and Animals ($g/m^2/day$)	0.01
Respiration Temperature Coefficient	1.05
Max. O_2 production by photosynthesis ($g/m^2/day$)	0.01
Displacement of O_2 production maximum (hr)	1.00
1^{st} order BOD (per day)	0.25
Temperature Coefficient	1.024
Half Saturation O_2 Concentration (mg/L)	2.00
Sediment Oxygen Demand ($gO_2/m^2/day$)	0.20
SOD Temperature Coefficient	1.00
Resuspension of Organic Matter ($gO_2/m^2/day$)	0.50

Table 4.1 Values for model parameters (continued)

Model Parameter	Values
Sedimentation of Organic Matter (m/day)	0.80
Critical Velocity of Organic Matter (m/s)	1.00
Ammonia Released on BOD decay (gNH_3-N/gBOD)	0.02
Uptake of Ammonia in Plants (gNH_3-N/gO_2)	0.01
Uptake of Ammonia in Bacteria (gNH_3-N/gO_2)	0.01
Nitrification Reaction Order	1.00
Ammonium Decay Rate (per day)	0.25
Temp Coefficient for Ammonium Decay	1.08

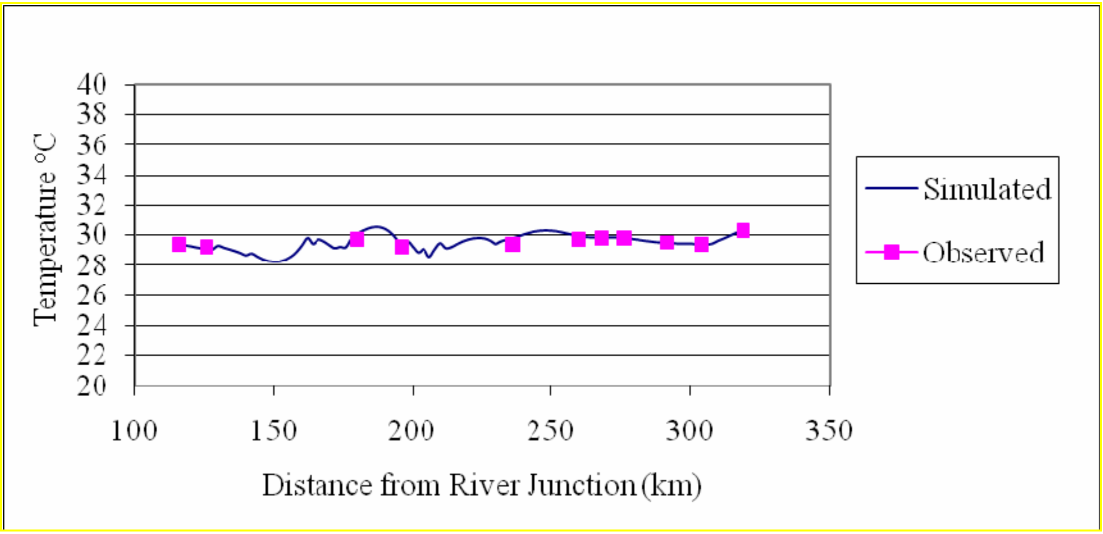


Figure 4.6 Comparison between simulated and observed Temperature in February, 2005 (R^2=0.8015, n=11)

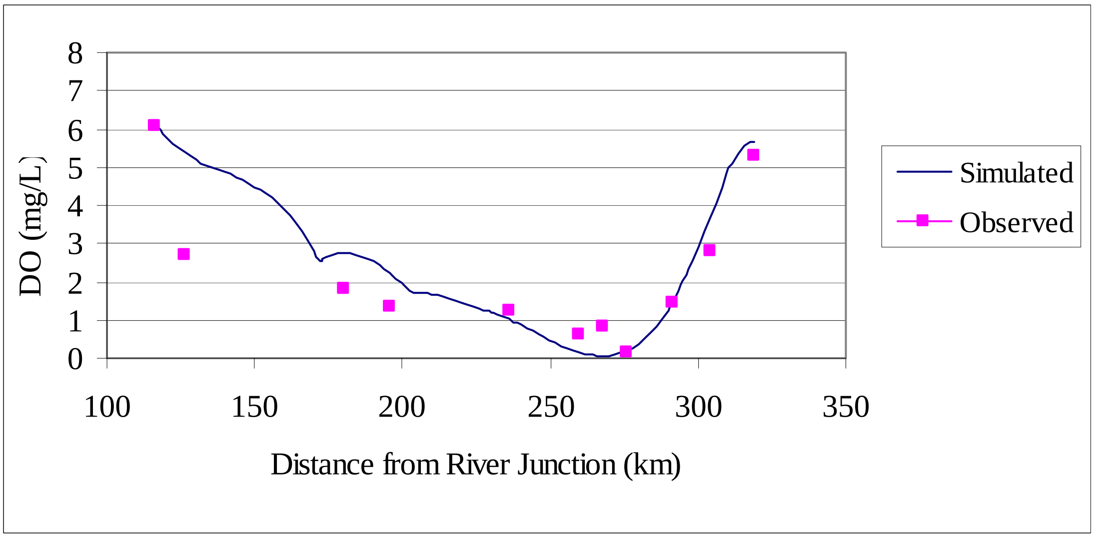


Figure 4.7 Comparison between simulated and observed DO in February,2005 (R^2=0.8432, n=11)

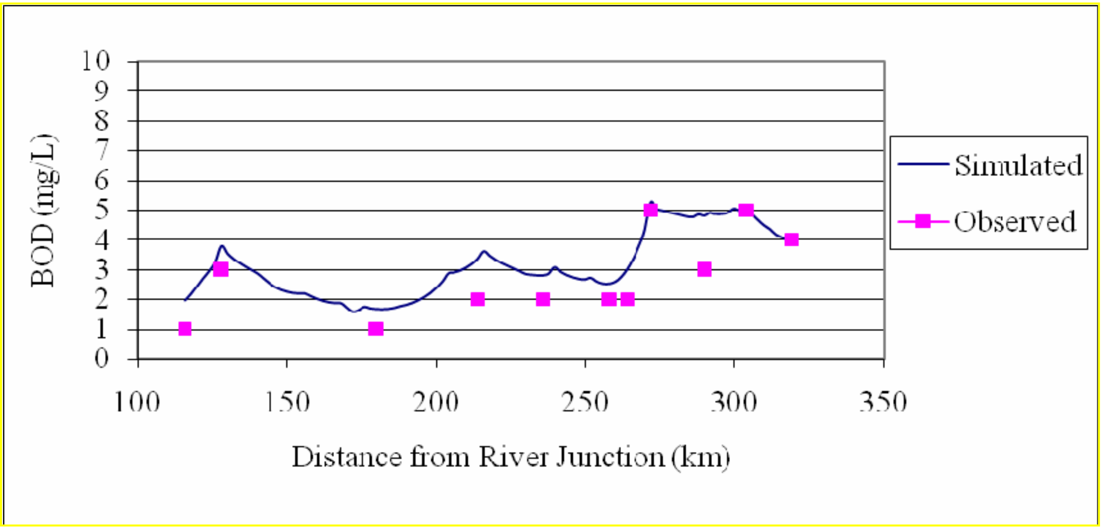


Figure 4.8 Comparison between simulated and observed BOD in February, 2005 (R^2=0.8474, n=11)

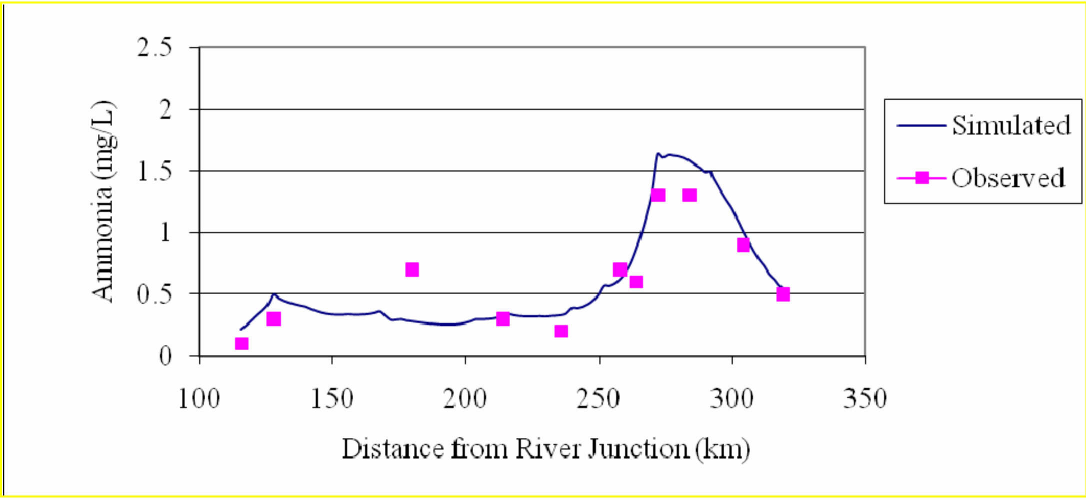


Figure 4.9 Comparison between simulated and observed Ammonia in February, 2005 (R^2=0.8384, n=11)

The result showed that simulated dissolved oxygen (DO) is closely related to the recorded DO with R^2 = 0.8744, n=11. In addition simulated biological oxygen demand (BOD) and Ammonia are closely related to recorded data with R^2 =0.8474, n=11 and R^2 =0.8384, n=11 respectively.

4.2 Model verification

The model verification part is intended to compare between model result and data of year 2006. After verification HD and water quality in the year 2006, it was found that R^2 value was low. Because the flow of middle and lower Tha Chin River was controlled by 10 regulators then it was not the natural flow. However, the difference of water level value in the year 2005 and 2006 did not exceed 0.5 meters. The details of model verification were shown in Appendix A.

4.3 Simulation of water quality

BOD loading in the year 2005 was calculated based on information about communities, industries, fishery farms, and piggery sources in the areas of

Suphanburi, Nakhon Pathom, and Samut Sakorn provinces. Simulation water quality in Tha Chin river year 2005 was calculated by taking into account the population, pig farm, fishery farm numbers and recorded data of factory effluent (treated wastewater) and community wastewater plant effluent in the study area. The details of pollution discharge were shown in Table 3.5 to 3.6.

After calibration of the MIKE 11 model, model can be used to simulate water quality in Tha Chin river year 2005 to meet the water quality standard classification by controlling pollution discharge as following

4.3.1 Reduction of all pollution discharge by an equal loading.

4.3.1.1 Reduce BOD loading discharge at 25%, 50%, and 75%. The results were shown in Figure 4.10-4.13.

4.3.1.2 Reduce Ammonia loading discharge at 50%. The results were shown in Figure 4.14

The results showed that BOD in the year 2005 after reducing all pollution discharge of about 50% could raise water quality to meet the required water quality standard Class 3 and Class 4, BOD levels were varied in the range of 0.86 mg/L to 2.69 mg/L. When reducing all pollution discharge of about 75% could upgrade water quality standard classification in both middle and lower Tha Chin River from Class 3 and Class 4 to Class 2, BOD levels were varied in the range of 0.44-1.29 mg/L.

DO in the year 2005 after reducing all pollution discharge of about 50% could raise water quality to meet the required water quality standard Class 3 and Class 4, DO levels were varied in the range of 3.18 mg/L to 6.38 mg/L.

Ammonia in the year 2005 after reducing all pollution discharge of about 50% could raise water quality to meet the water quality standard Class 3 and Class 4, Ammonia levels were varied in the range of 0.001 mg/L to 0.450 mg/L.

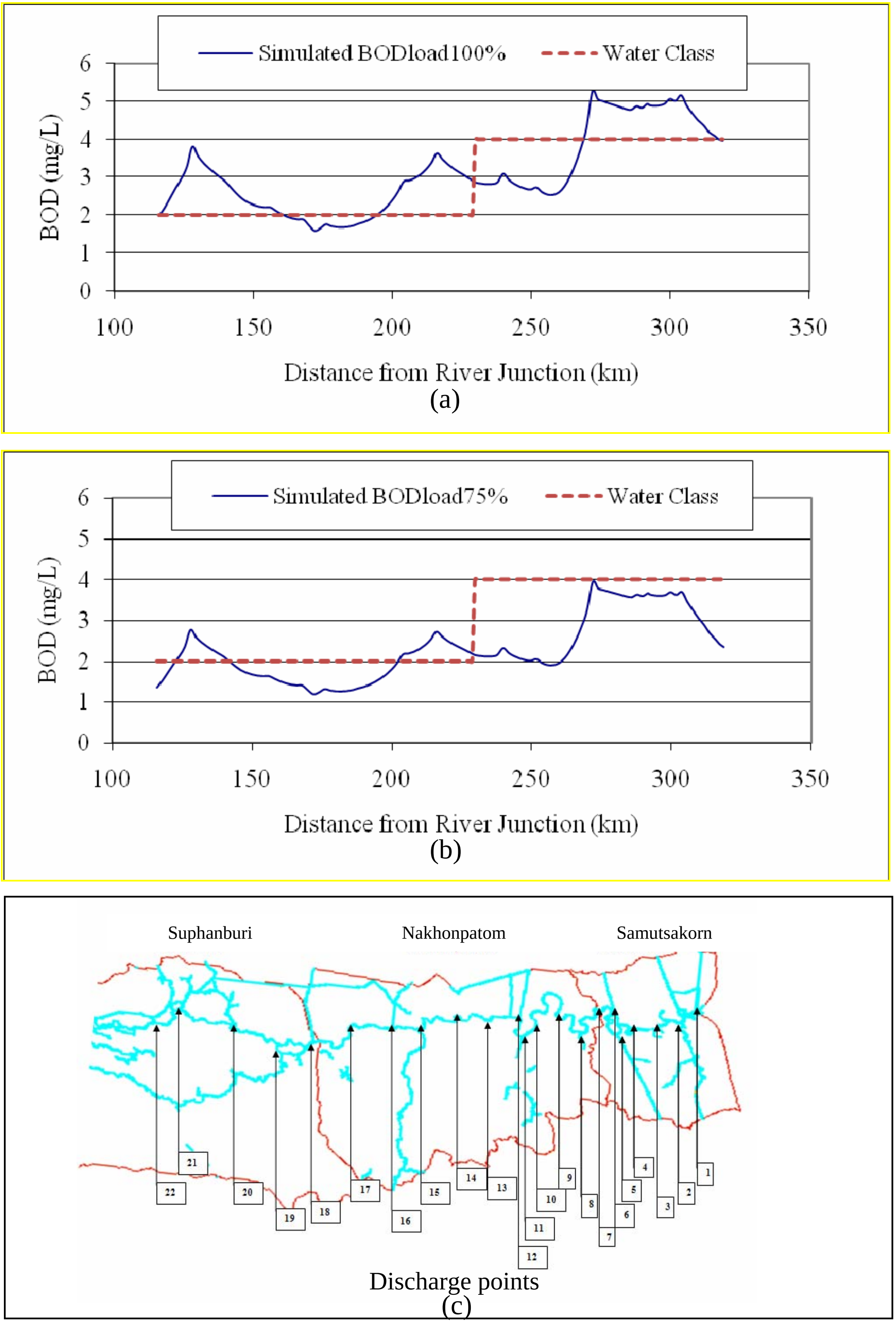


Figure 4.10 Result of simulated BOD in the year 2005 after reducing all pollution discharge (a) at 0%, (b) at 25% and (c) discharge points

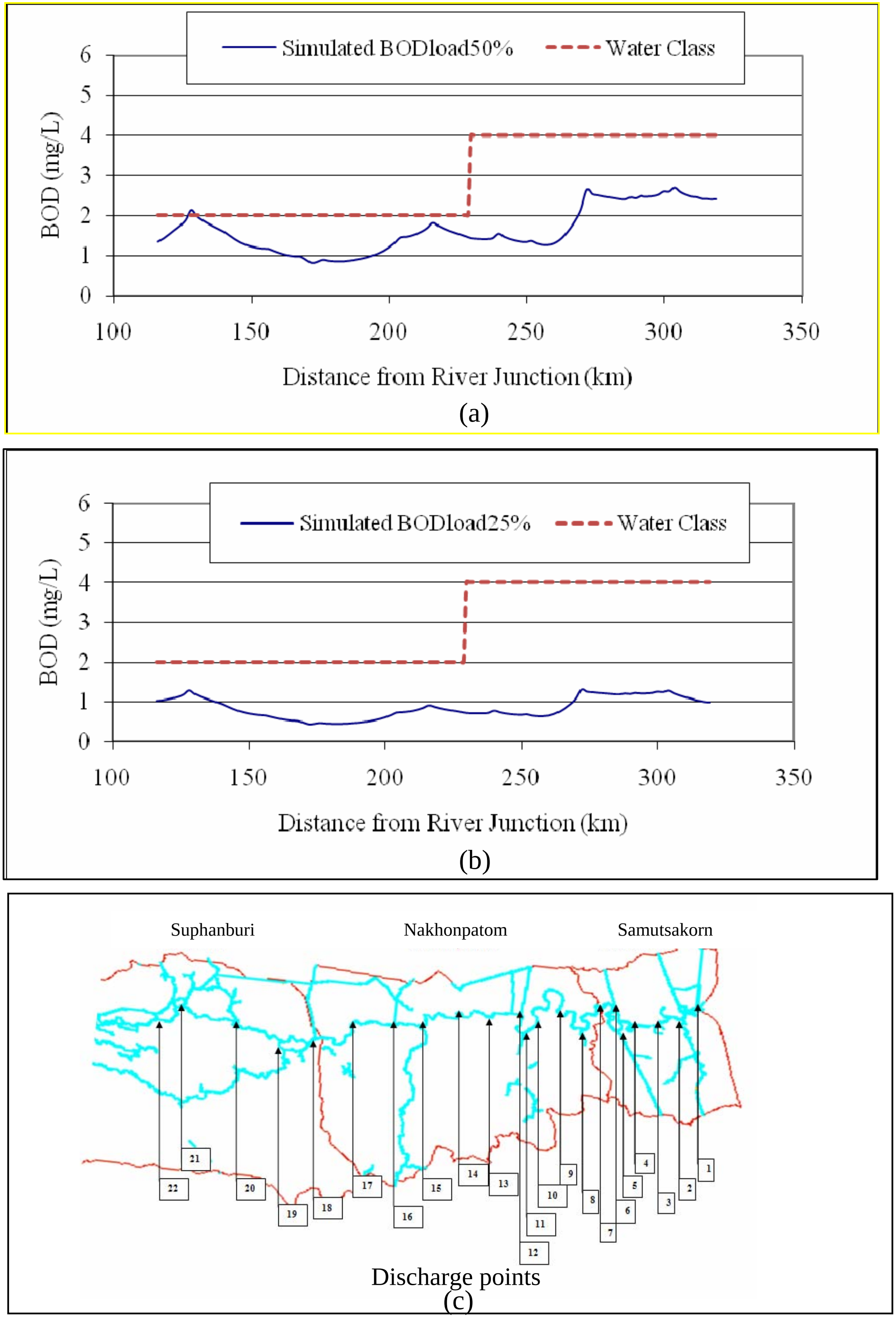


Figure 4.11 Result of simulated BOD in the year 2005 after reducing all pollution discharge (a) at 50%, (b) at 75% and (c) discharge point.

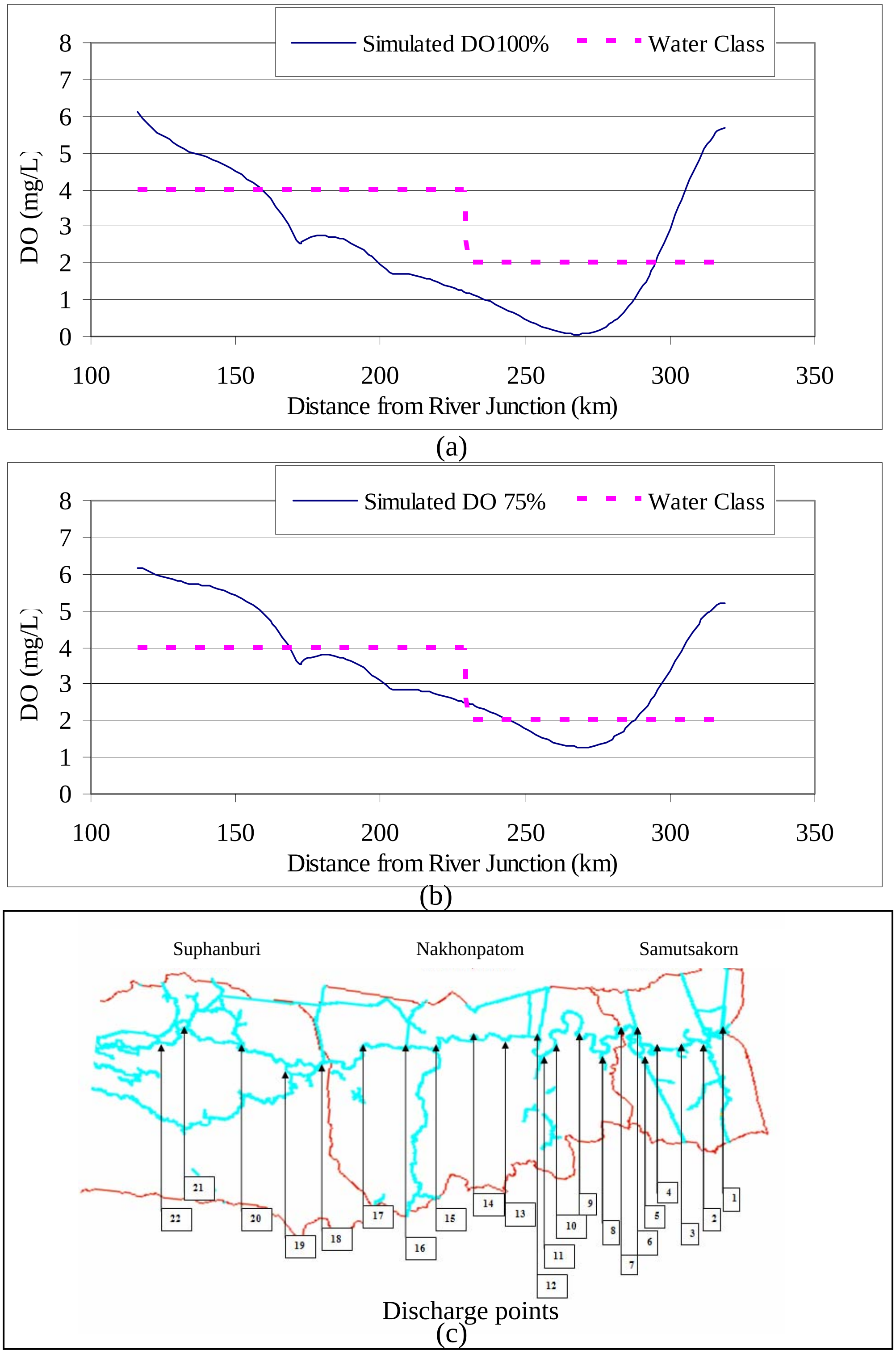


Figure 4.12 Result of simulated DO in the year 2005 after reducing all pollution discharge (a) at 0%, (b) at 25% and (c) discharge point.

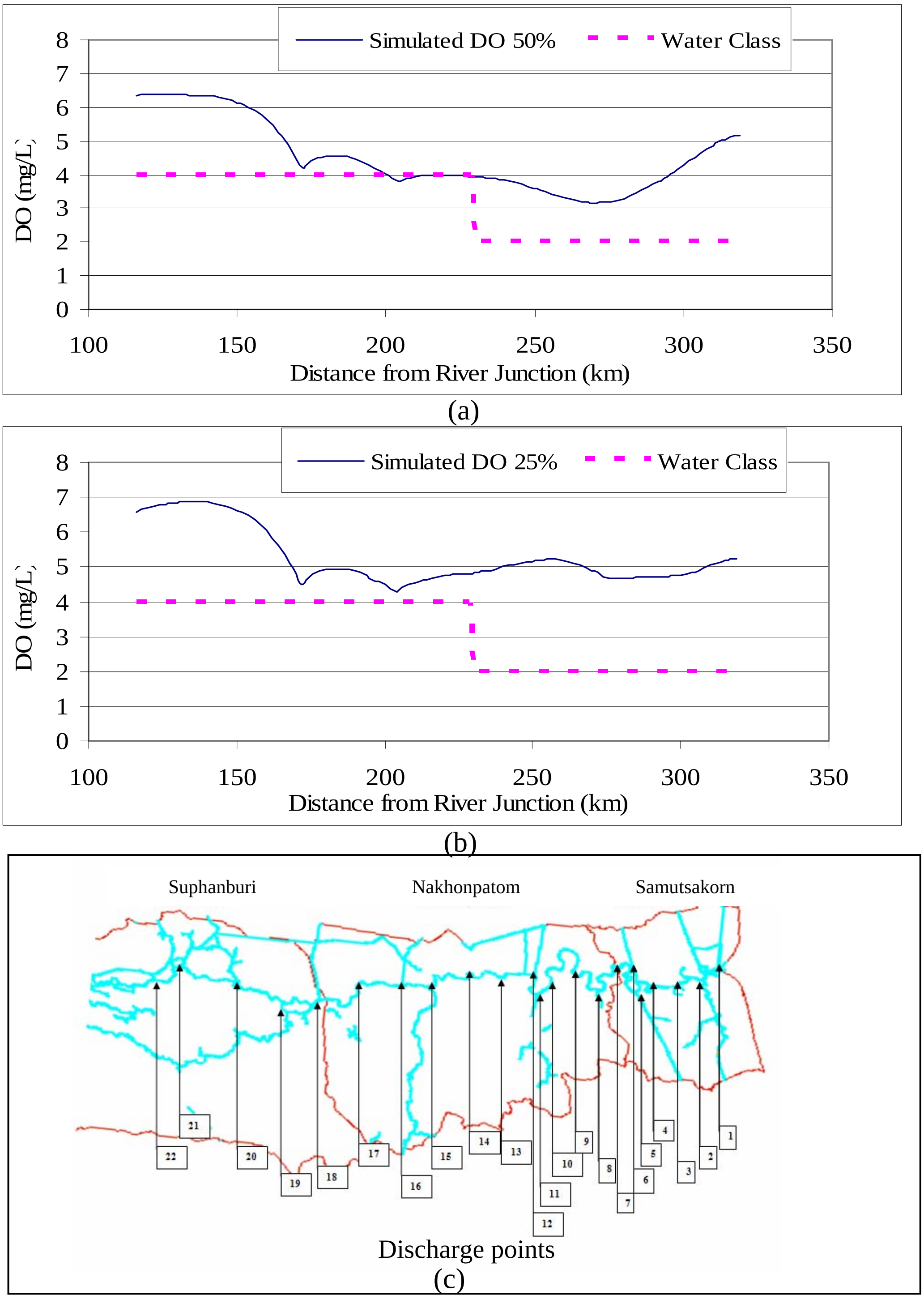


Figure 4.13 Result of simulated DO in the year 2005 after reducing all pollution discharge (a) at 50%, (b) at 75% and (c) discharge point.

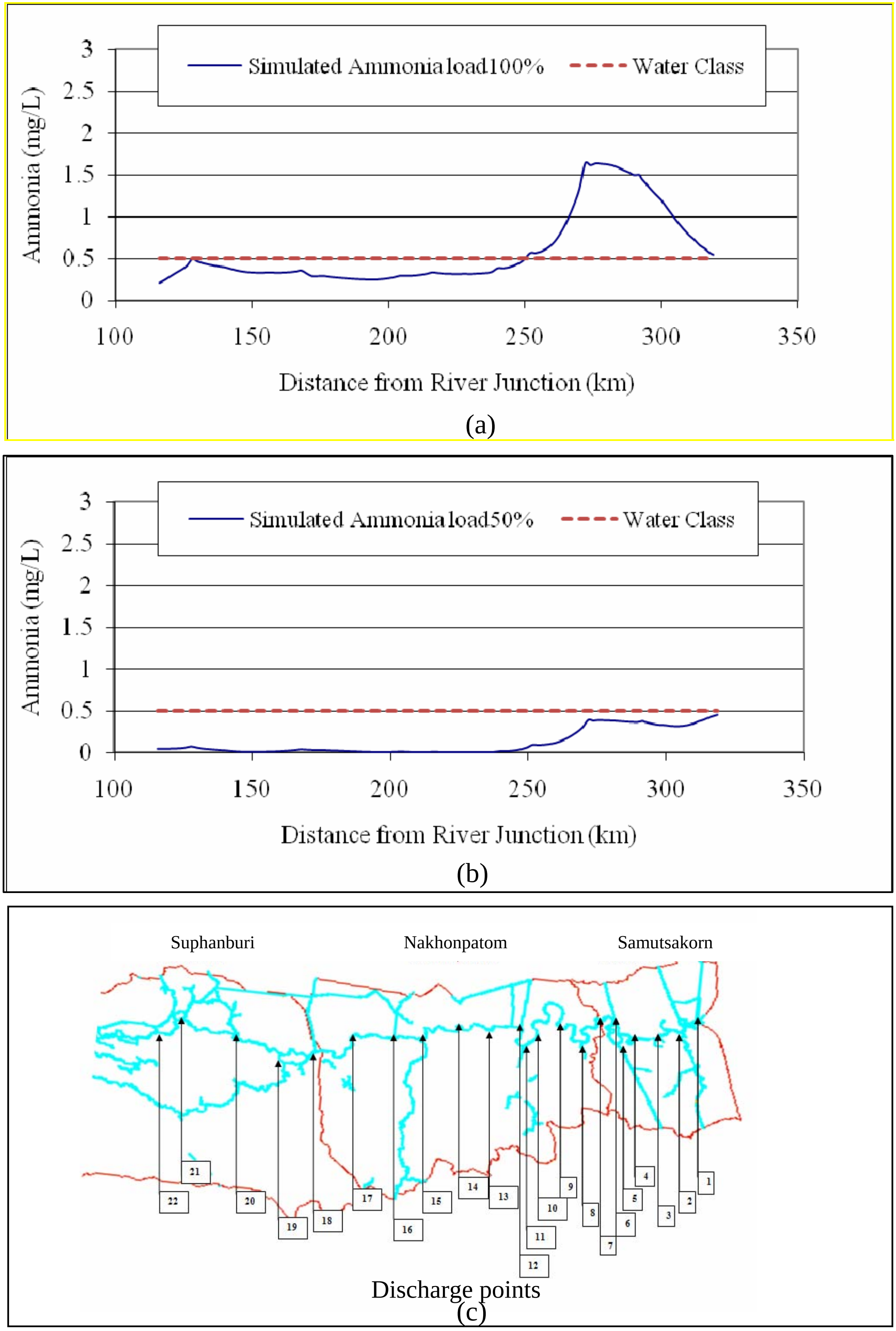


Figure 4.14 Result of simulated Ammonia in the year 2005 after reducing all pollution discharge (a) at 0%, (b) at 50% and (c) discharge point.

4.3.2 Reduction of only the major sources of pollution discharge (such as fishery, industry and pig farm loading).

4.3.2.1 Reduce BOD loading discharge from fishery at 50% and 75%. The results were shown in Figure 4.15-4.16.

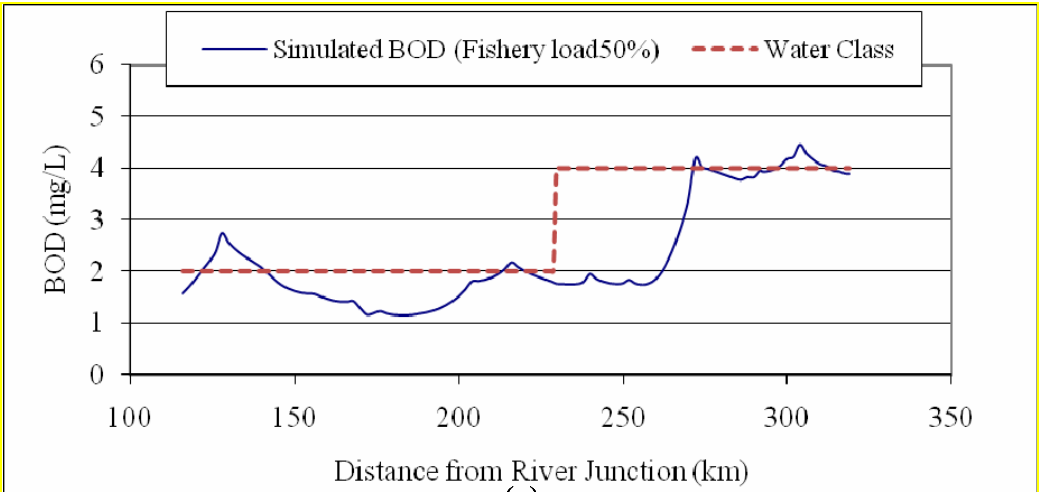
4.3.2.2 Reduce BOD loading discharge from fishery at 75% factory 75% and pig farm 50%. The results were shown in Figure 4.17.

4.3.2.3 Reduce Ammonia loading discharge from factory at 75% and pig farm 75%. The results were shown in Figure 4.18.

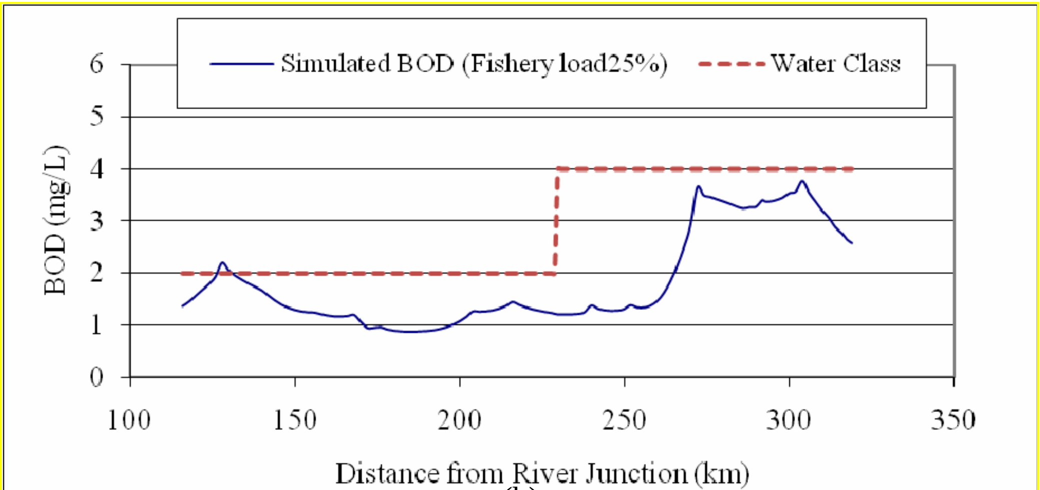
The results showed that BOD in the year 2005 after reducing BOD loading discharge from fishery at 75% could raise water quality to meet the required water quality standard Class 3 and Class 4, BOD levels were varied in the range of 0.91 mg/L to 3.77 mg/L. When reducing BOD loading discharge from fishery at 75% factory 75% and pig farm 50% could upgrade required water quality standard classification in lower Tha Chin River from Class 4 to Class 3, BOD levels were varied in the range of 0.79 mg/L to 2.15 mg/L.

DO in the year 2005 after reducing pollution loading discharge from fishery at 75% could raise water quality to meet the required water quality standard Class 3 and Class 4, DO levels were varied in the range of 2.14 mg/L to 6.33 mg/L.

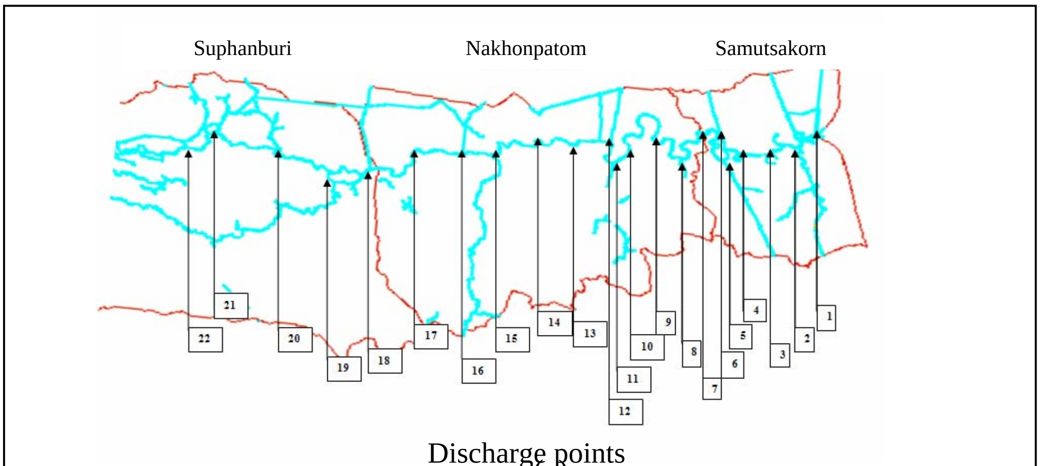
Ammonia in the year 2005 after reducing Ammonia loading discharge from factory at 75% and pig farm 75% could raise water quality to meet the water quality standard Class 3 and Class 4, Ammonia levels were varied in the range of 0.07 mg/L to 0.49 mg/L.



(a)

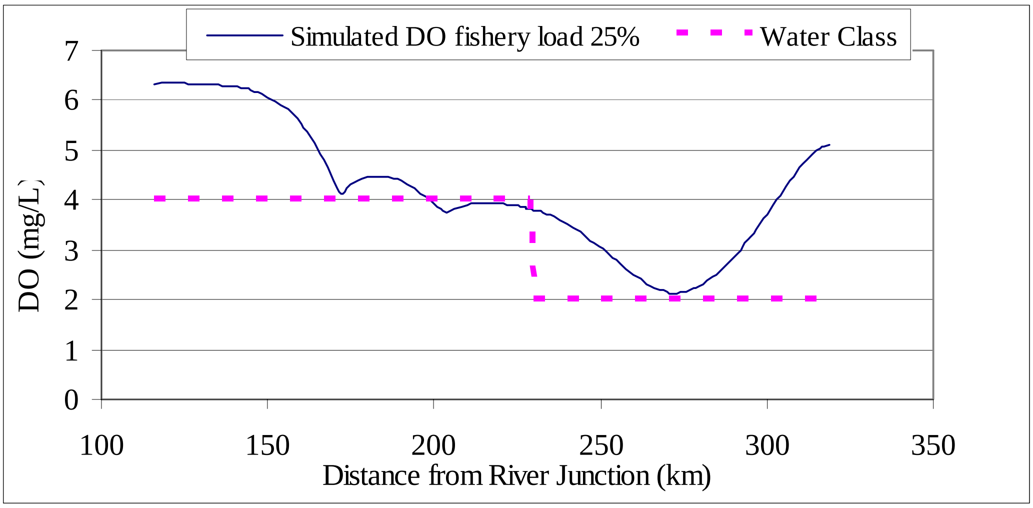


(b)

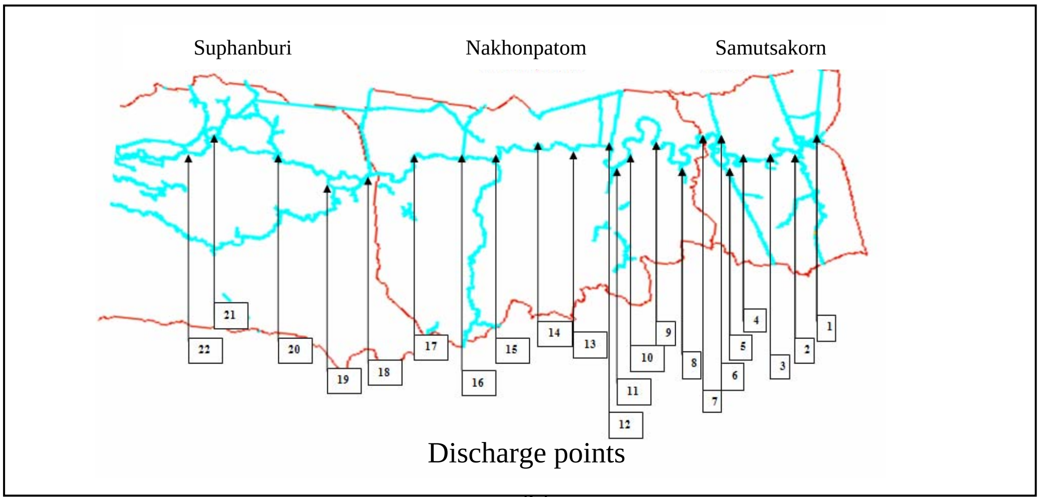


(c)

Figure 4.15 Result of simulated BOD in the year 2005 after reducing pollution discharge from fishery (a) at 50%, (b) at 75% and (c) discharge point.

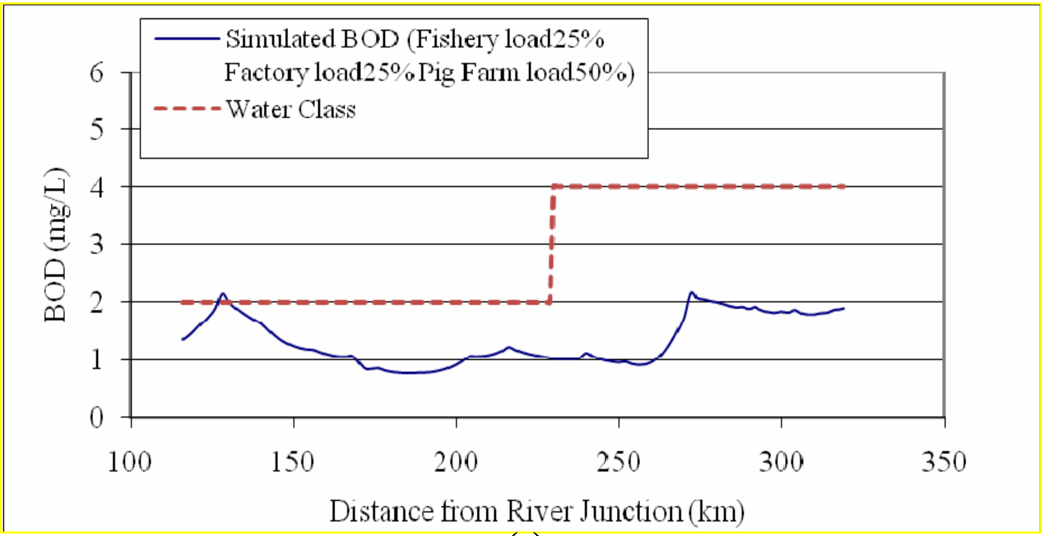


(a)

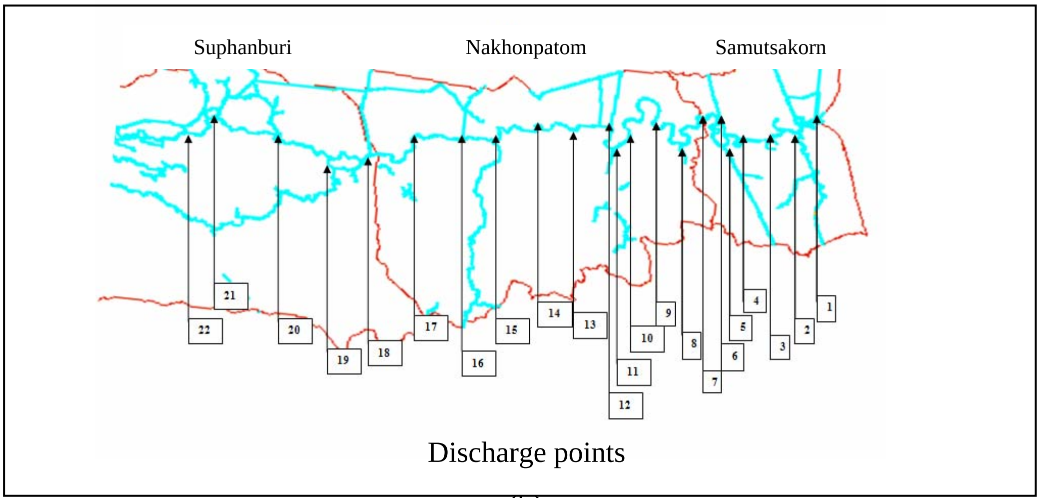


(b)

Figure 4.16 Result of simulated DO in the year 2005 after reducing pollution discharge from fishery (a) at 75%, (b) discharge point.

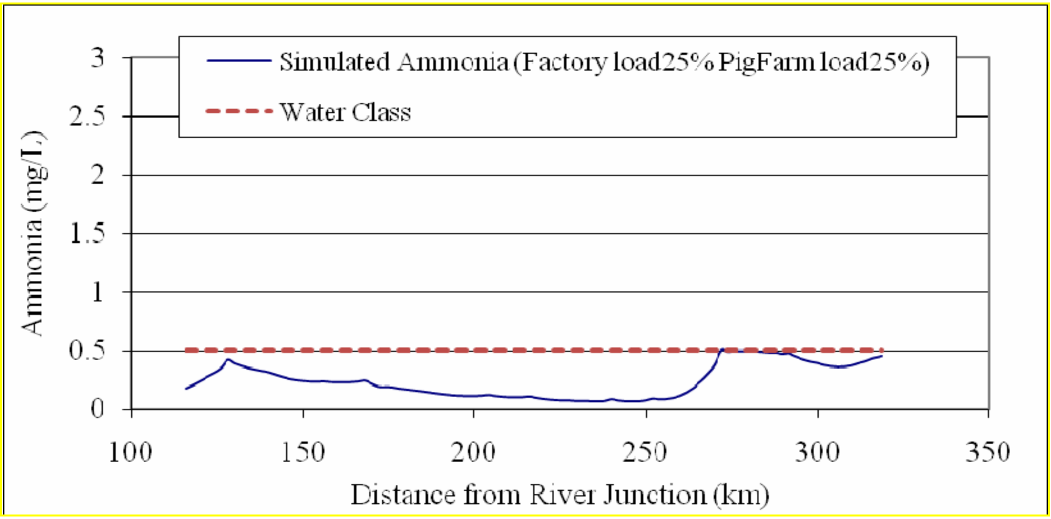


(a)

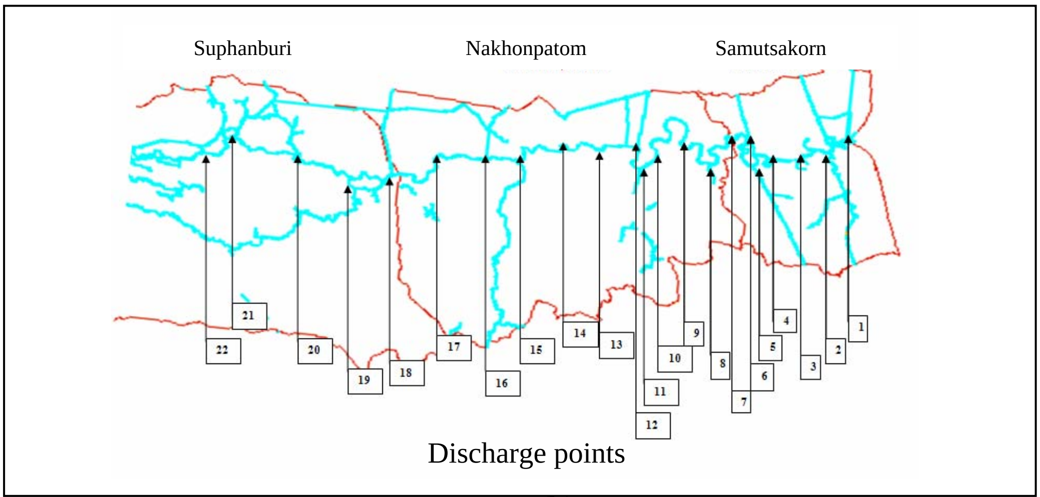


(b)

Figure 4.17 Result of simulated BOD in the year 2005 after reducing pollution discharge (a) from fishery at 25%, factory25% and pig farm75%, (b) discharge point.



(a)

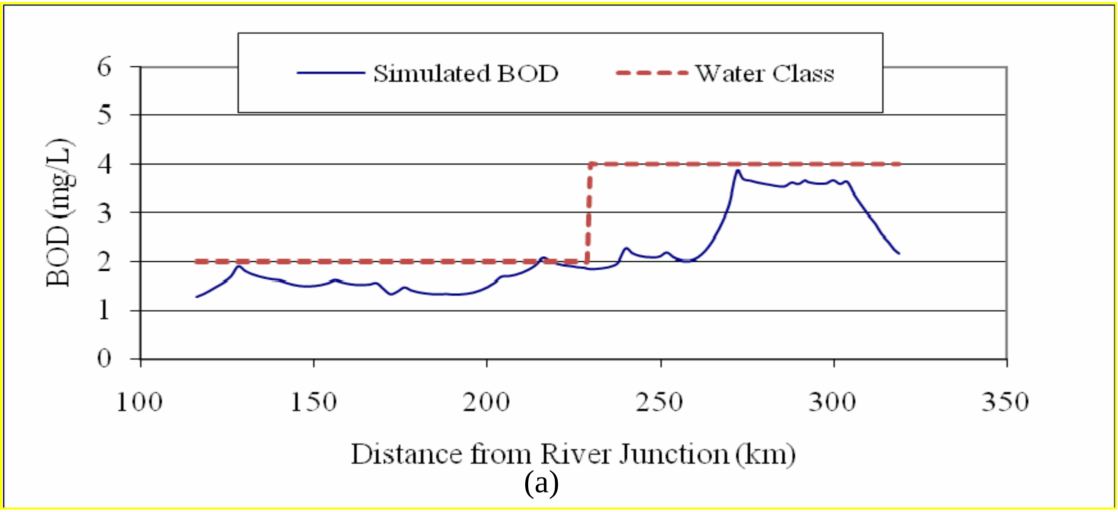


(b)

Figure 4.18 Result of simulated Ammonia in the year 2005 after reducing pollution discharge (a) from factory at 75% and pig farm75%, (b) discharge point.

4.3.3 Reduction of pollution discharge at the critical point (peak load)

4.3.2.1 Reduce pollution loading discharge at BOD peak loading by reducing at discharge points no.3=30%, no.4=25%, no.5=20%, no.6=20%, no.8=30%, no.14=50%, no.15=50%, no.16=50% and no.22=60%. The results were shown in Figure 4.19.



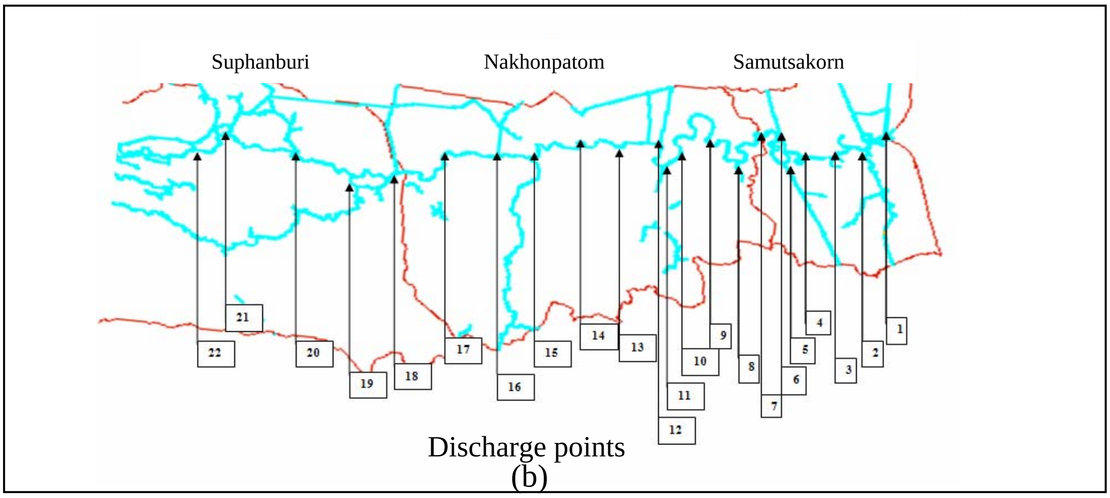
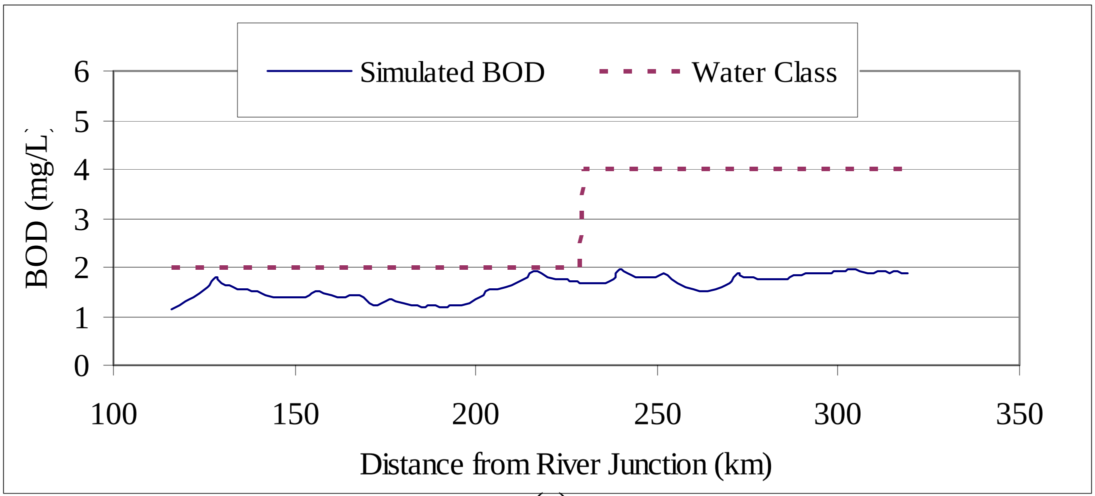


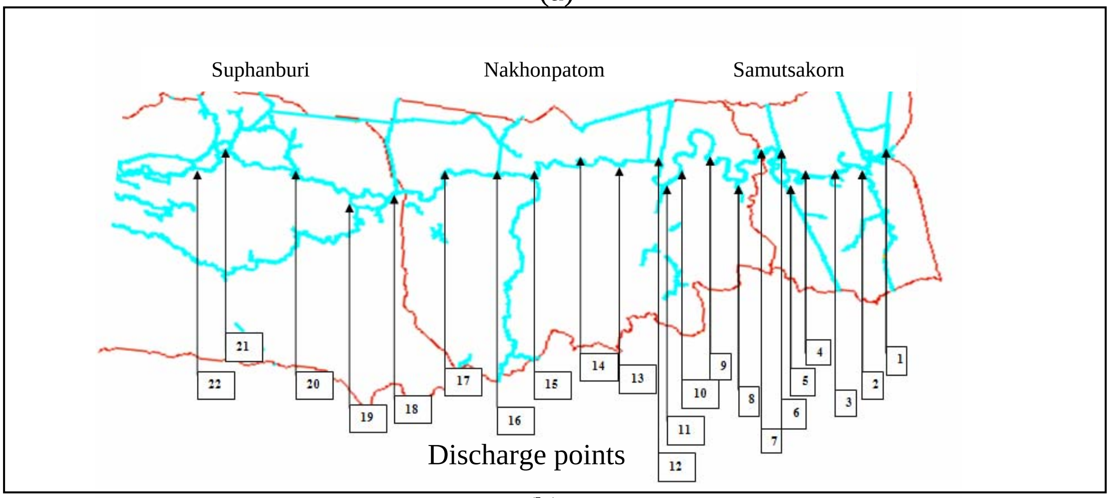
Figure 4.19 Result of simulated BOD in the year 2005 (a) after reducing pollution discharge at BOD peak load, (b) discharge point.

The result showed that BOD levels were varied in the range of 1.26 mg/L to 3.70 mg/L which met the required water quality standard Class 3 and Class 4.

4.3.2.2 Reduce pollution loading discharge at BOD peak loading by reducing at discharge points no.3=75%, no.4=60%, no.5=50%, no.6=50%, no.8=75%, no.10=20% no.14=50%, no.15=50%, no.16=50% and no.22=60%. The results were shown in Figure 4.20.



(a)



(b)

Figure 4.20 Result of simulated BOD in the year 2005 (a) after reducing pollution discharge at BOD peak load, (b) discharge point.

The result showed that BOD levels were varied in the range of 1.15 mg/L to 1.97 mg/L which upgrade water quality standard classification in the lower Tha Chin River from Class 4 to Class 3.

4.3.2.3 Reduce pollution loading discharge at DO peak by reducing pollution loading at discharge points no.8=25%, no.10=50%, no.14=75%, no.15=75%, no.16=75%, no.18=75%, no.19=50% and no.22=50%. The results were shown in Figure 4.21.

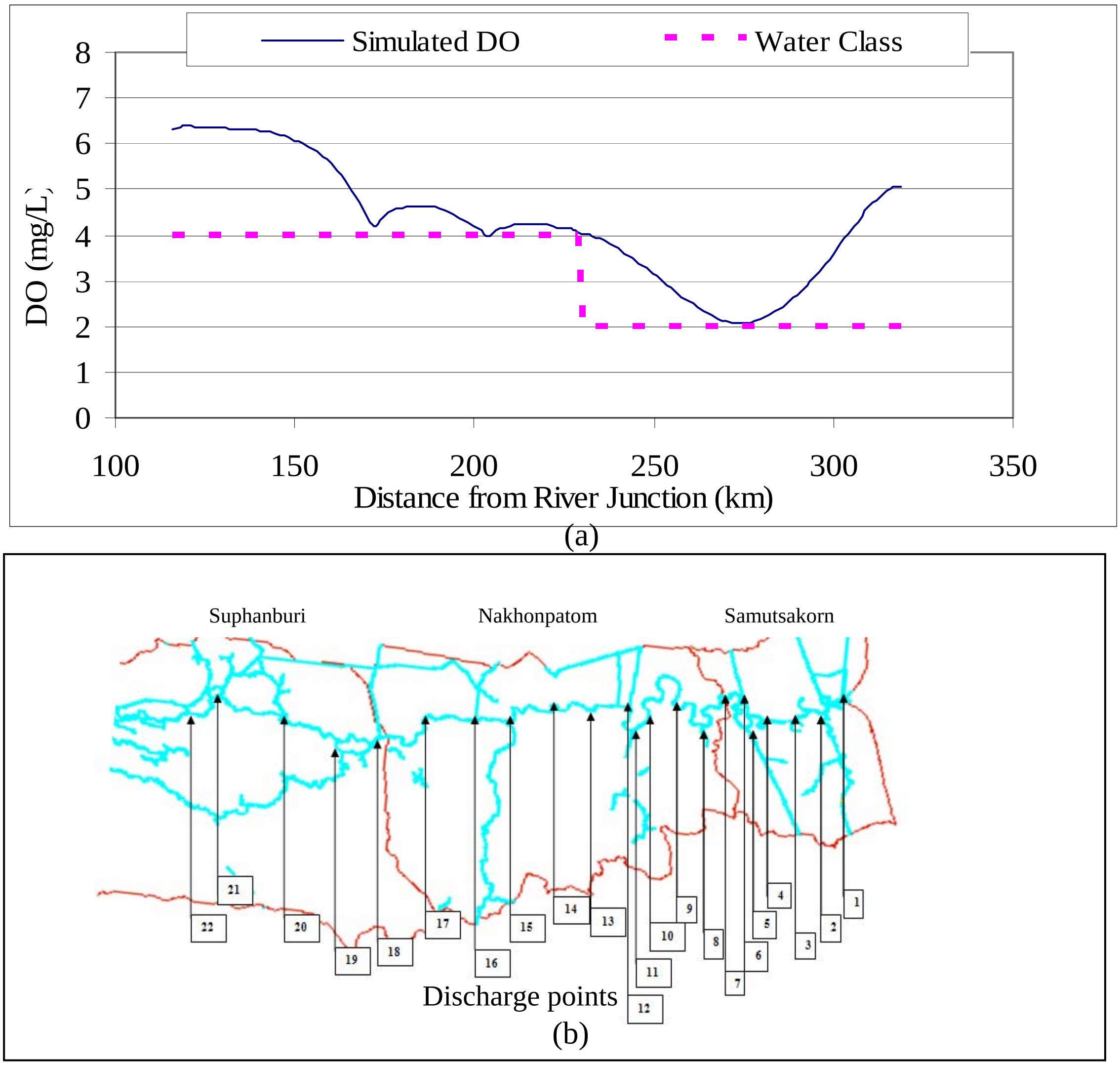


Figure 4.21 Result of simulated DO in the year 2005 (a) after reducing pollution discharge at DO peak load, (b) discharge point.

The result showed that DO levels were varied in the range of 2.12 mg/L to 6.34 mg/L which met to the required water quality standard Class 3 and Class 4.

4.3.2.4 Reduce pollution loading discharge at DO peak by reducing pollution loading at discharge points no.8=75%, no.10=75%, no.11=50%, no.14=75%, no.15=75%, no.16=75%, no.18=75%, no.19=50% and no.22=50%. The results were shown in Figure 4.22.

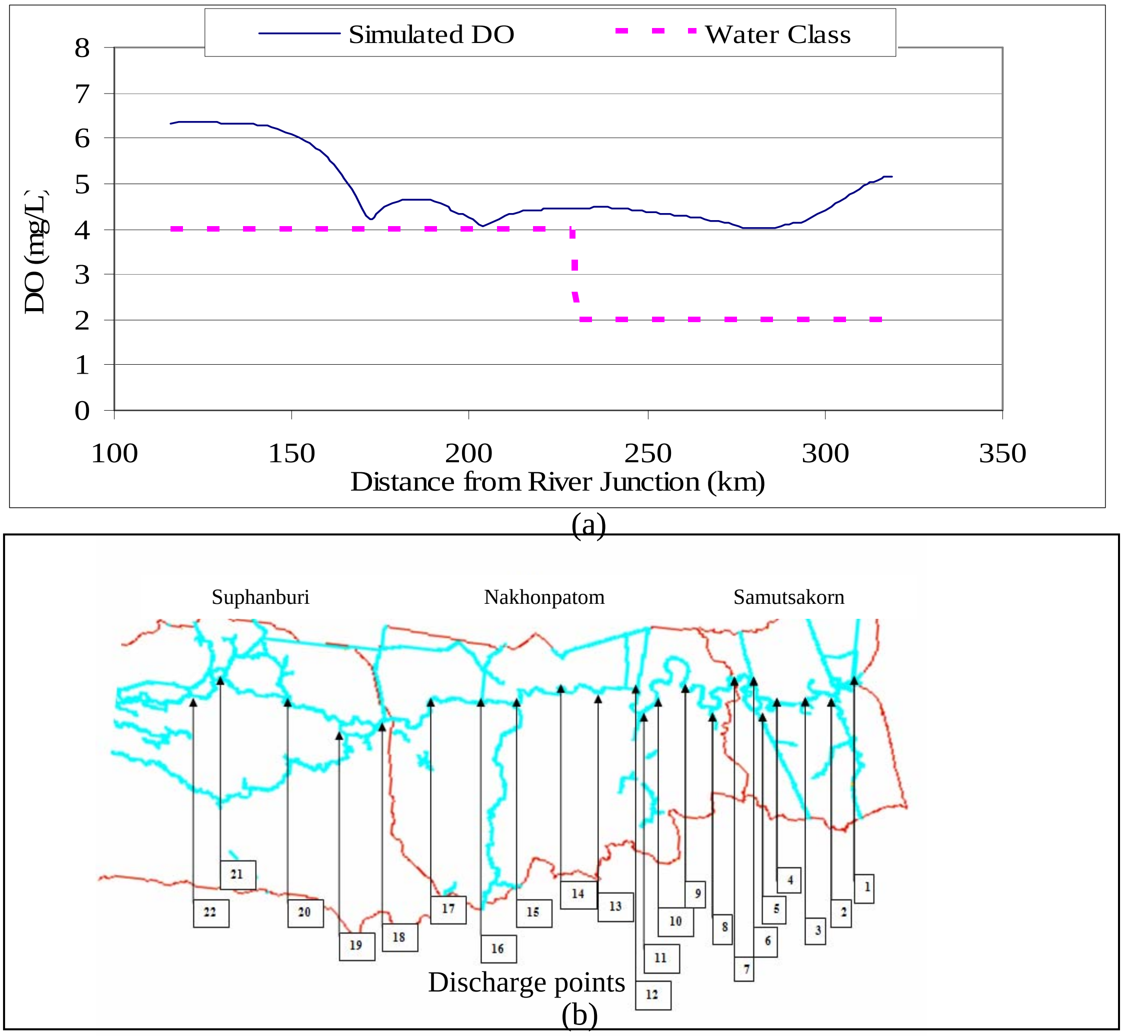


Figure 4.22 Result of simulated DO in the year 2005 (a) after reducing pollution discharge at DO peak load, (b) discharge point.

The result showed that DO levels vary in the range of 4.12 mg/L to 6.34 mg/L which upgrade water quality standard classification in the lower Tha Chin River from Class 4 to Class 3.

4.3.2.5 Reduce Ammonia loading discharge at Ammonia peak load by reducing at discharge points no.1=40%, no.2=40%, no.5=60%, no.8=75% and no.9=40%. The results were shown in Figure 4.23

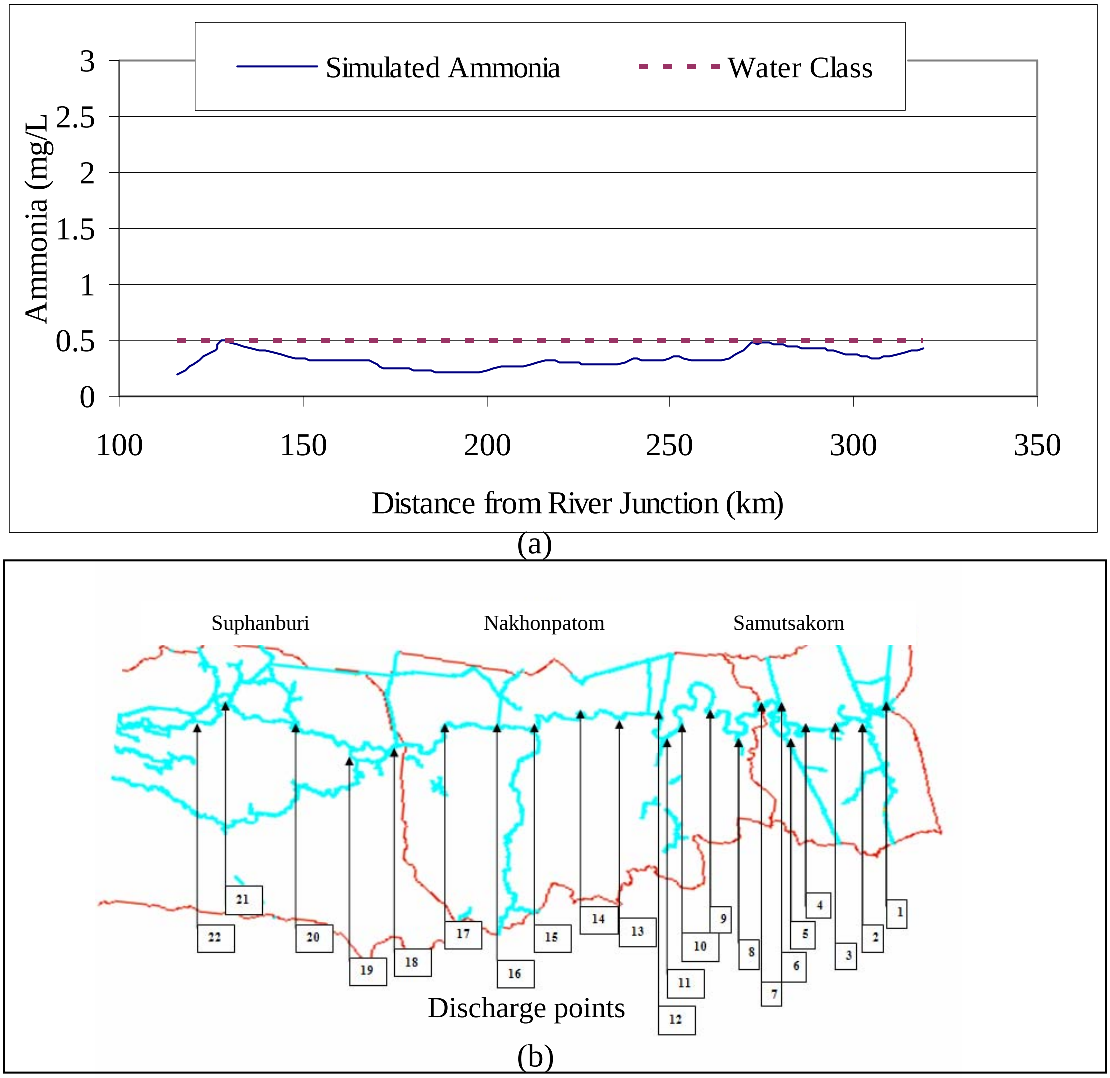


Figure 4.23 Result of simulated Ammonia in the year 2005 (a) after reducing pollution discharge at Ammonia peak, (b) discharge point.

The result showed that Ammonia levels were varied in the range of 0.18 mg/L to 0.50 mg/L which met the required water quality standard Class 3 and Class 4.

CHAPTER V
DISCUSSIONS

Although the Geographic Information System (GIS) has been simply used in many research areas, it has also been applied as a tool for the water quality modeling by a few researchers. This work aims to be an initial work for the future research in an application of GIS to other environmental models. The general objectives of this study are to simulate the water quality of middle and lower Tha Chin River by an application of MIKE 11 and GIS, and also to illustrate the methods and steps of integrating MIKE11 and GIS for a prediction of water quality.

5.1 Calibration of HD, AD and Water Quality in The Year 2005

5.1.1 Hydrodynamic Module (HD)

The results of Manning coefficient (n) in the study area starting from Phopaya Regulator along the Tha Chin River varies linearly; it ranges from 0.030 to 0.040. Previous study of the Tha Chin River indicated that Manning coefficient (n) was in the range of 0.030 - 0.040. For example PCD (2005) used MIKE 11 for an investigation of water quality in the Tha Chin River. The results showed that Manning coefficient (n) was 0.033. Thus Manning coefficient (n) in the study was consistent with that of the previous study.

5.1.2 Advection – Dispersion Module (AD)

PCD (1994) developed an action plan to improve water quality in Tha Chin basin, Thailand. The outcome from MIKE 11 model showed that dispersion coefficient for the Tha Chin River was in the range of 100-5000 m^2/s. Moreover, in this study, dispersion coefficient was in the range of 100 – 3000 m^2/s. Hence, dispersion coefficient in this study was in agreement with that of the previous study.

5.1.3 Water Quality Module (WQ)

PCD (1994) used MIKE 11 model for an investigation of water quality in the Tha Chin River. The result was shown in Table 5.1.

Table 5.1 Calibrated water quality modeling coefficients in MIKE 11

Model Parameter	PCD	This study
Max. Absorbed Solar Radiation ($kJ/m^2/hr$)	5000	5000
Solar Radiation Displacement (hr)	1.00	1.00
Emitted Heat Radiation ($kJ/m^2/hr$)	4000	1000
No. of reaeration expression	2	2
Reaeration Temperature Coefficient	1.024	1.050
Respiration of Plants and Animals ($g/m^2/day$)	0.05	0.01
Respiration Temperature Coefficient	1.047	1.050
Max. O_2 production by photosynthesis ($g/m^2/day$)	0.01	0.01
Displacement of O_2 production maximum (hr)	1.00	1.00
1^{st} order BOD (per day)	0.20	0.25
Temperature Coefficient	1.024	1.024
Half Saturation O_2 Concentration (mg/L)	2.00	2.00
Sediment Oxygen Demand ($gO_2/m^2/day$)	0.50	0.20
SOD Temperature Coefficient	1.00	1.00
Resuspension of Organic Matter ($gO_2/m^2/day$)	0.50	0.50
Sedimentation of Organic Matter (m/day)	0.80	0.80
Critical Velocity of Organic Matter (m/s)	1.00	1.00
Ammonia Released on BOD decay (gNH_3-N/gBOD)	0.29	0.02
Uptake of Ammonia in Plants (gNH_3-N/gO_2)	0.066	0.01
Uptake of Ammonia in Bacteria (gNH_3-N/gO_2)	0.109	0.01
Nitrification Reaction Order	1.00	1.00

Table 5.1 Calibrated water quality modeling coefficients in MIKE 11 (continued)

Model Parameter	PCD	This study
Ammonium Decay Rate (per day)	0.30	0.25
Temp Coefficient for Ammonium Decay	1.088	1.08
O_2 demand by Nitrification (gO_2/gNH_3-N)	4.47	4.33

By checking an accuracy of simulated results from the MIKE11 model with observed data, it was found that simulated water quality values were closely related to those observed data (Temperature R^2=0.8015, DO R^2=0.8744, BOD R^2=0.8474 and Ammonia R^2=0.8384). It is recommended that the simulated water quality from the MIKE 11 model represent the existent water quality.

5.2 Verification of HD and Water Quality in The Year 2006

After verification HD and water quality in the year 2006, it was found that R^2 value was very low. Because the flow of middle and lower Tha Chin River was controlled by 10 regulators then it was not the natural flow. However, the difference of water level value in the year 2005 and 2006 did not exceed 0.5 meters.

5.3 Simulation of Water Quality in The Year 2005

5.3.1 Reduction of all pollution discharge by an equal loading.

The results showed that BOD in the year 2005 after reducing all pollution discharge of about 50% could raise water quality to meet the required water quality standard Class 3 and Class 4. When reducing all pollution discharge of about 75% can upgrade water quality standard classification in both middle and lower Tha Chin River from Class 3 and Class 4 to Class 2.

DO in the year 2005 after reducing all pollution discharge of about 50% could raise water quality to meet the required water quality standard Class 3 and Class 4.

Ammonia in the year 2005 after reducing all pollution discharge of about 50% could raise water quality to meet the water quality standard Class 3 and Class 4.

However reducing all pollution loading discharge by an equal loading is not the good choice for management in the Tha Chin basin in term of fairness since it does not consider the critical pollution source and some certain areas released very small amount of pollution loads while others released a great deal of pollution load.

5.3.2 Reduction of only the major sources of pollution discharge (such as fishery, industry and pig farm loading).

The major BOD loading in the middle Tha Chin River was the discharge from fishery farm and municipal, while in the lower Tha Chin River, it discharge was from factory and pig farm. Reduction of BOD (value) in the river should reduce the major pollution source. After reducing BOD loading discharge from fishery at 75%, it raises water quality to meet the required water quality standard Class 3 and Class 4. But in the middle Tha Chin River, the BOD value still slightly exceed those required standards because the wastewater treatment plant in Suphanburi province has stopped operating for a few months. As soon as it started running again, the BOD value would be down. For DO value, after reducing pollution loading discharge from fishery at 75%, it can raise water quality to meet the required water quality standard Class 3 and Class 4. For Ammonia values, reduction of Ammonia loading discharged from factory at 75% and pig farm at 75%, can raise water quality to meet the required water quality standard Class 3 and Class 4.

Considering the BOD loading, it was found that fishery farm especially those keeping fish in the floating basket was the major source in both the middle and the lower parts of Tha Chin River. There are no wastewater treatment systems available for the floating basket. For the other fishery farm, it should force the farmer to build the wastewater treatment system. The study of Prathak Tabthipwon (2006), it was found that the wastewater treatment system for fishery farm should be Aerated lagoon + Wetland + Sludge lagoon. The system illustrated the removal efficiency to reduce BOD loading of about 87.5% (BOD influent≤20 mg/L), as shown in Table 5.2.

Table 5.2 Efficiency of water treatment system for reducing waste loading from aquaculture activity

Treatment system	parameter	Aerated lagoon (%)	Wet land (%)	Wetland and fish culture (%)	Sludge lagoon (%)	Over all efficiency (%)
Design 1:	BOD	75	50	-	40	87.5
	TSS	0	> 80	-	90	80.0
Aerated lagoon + Wetland + Sludge lagoon	Ammonia nitrogen	65	25	-	60	73.7
	Total nitrogen	30	45	-	80	61.5
	Total phosphorus	7	30	-	20	34.9

Regarding the BOD loading from factory, it was found that 44% of the factories released the effluent loading exceeding the required industrial effluent standards. Some factories released the BOD effluent more than 1,000 mg/L. Industries must control effluent quality to meet the industry standards. Furthermore, they should specify the Ammonia value in the industrial effluent standards because Ammonia loading from factories is the critical one.

For the pig farm, the study of PCD (2005) found that the pig farm in Tha Chin basin did not have the wastewater treatment system. BOD effluent levels were varied in the range of 1,500 mg/L to 7,000 mg/L. The effluent from pig farms should be treated to meet the pig farm effluent standards (BOD), which was not more than 100 mg/L for 6-600 Livestock Unit (LU.) and BOD was not more than 60 mg/L for more than 600 Livestock Unit (1 LU. = Weight of pig = 500 kg).

The pollution loading from municipal was not the problem since there were wastewater treatment plants in Suphanburi and Nakhonpathom provinces and, in the future, there will be wastewater treatment plants in Samutsakorn province. The wastewater treatment plants in Suphanburi province has stopped operating for a few months, thus the BOD value in Suphanburi was high. The wastewater treatment plant in Nakhonpathom has been operated, its effluent such as BOD value was 22 mg/L and TKN value was at 3 mg/L.

Considering the DO loading, it was found that DO value was inversely related to BOD value. When BOD loading was high, DO value would be down.

5.3.3 Reduction of pollution discharge at the critical point (peak load).

In the middle Tha Chin River, there is the pollution peak load at area 23, Amphur Muang, Suphanburi province. The major pollution sources are municipality and fishery farm. There should be reduction of the pollution loading of about 60%. The next pollution peaks are area 14, 15 and 16. The major pollution sources are pig farm and fishery farm. They should be reduction of the pollution loading at 50%. The other pollution peak was at area 8, Amphur Nakhon Chaisri, Muang and Samphran, Nakhon Pathom province. The major pollution sources are the pig farm and the fishery farm. They should be a decrease of pollution loading at 30%. The last pollution peaks were the area 3, 4, 5 and 6. The major pollution sources are fishery farms and factories. They should be decreased the pollution loading at 30%, 25%, 20% and 20% respectively. After decreasing pollution at the peak areas, it made the water quality to meet those required water quality standard Class 3 and Class 4.

For DO peak, by reducing pollution loading at discharge points no.8=25%, no.10=50%, no.14=75%, no.15=75%, no.16=75%, no.18=75%, no.19=50% and no.22=50%, it can raise water quality to meet those required water quality standard Class 3 and Class 4. A case of pollution loading reduction in areas 4 and 5 can be summarized and illustrated as followed.

In area 4, BOD loading was discharged from several sources as population of about 42 kg/d, fishery farm 5,422 kg/d and factory 860 kg/d with the total BOD loading of about 6,324 kg/d. The target of decreasing BOD loading was 1,581 kg/d (25%).

Considering the BOD loading from fishery, it was found that the fishery farm releasing the effluent (BOD) of about 20 mg/L. If all farm in area 4 had the water treatment system which having the efficiency to reduce BOD loading of about 87.5%. It could make the effluent (BOD) equal to 2.5 mg/L, the BOD loading from fishery farm will counted up to 677 kg/d. It can decrease BOD loading from the total BOD loading equal to 4,745 kg/d (75%) which more than the target (25%).

In area 5, BOD loading was discharged from several sources as population of about 2,245 kg/d, pig farm 12 kg/d, fishery farm 453 kg/d and factory

2,980 kg/d with the total BOD loading of about 5,690 kg/d. The target of decreasing BOD loading was about 1,138 kg/d (20%).

Considering the BOD loading from factory, it was found that 32 factories from all factories in area 5 (78 factories), releasing the effluent (BOD) exceeding 20 mg/L. If all factories in area 5 released the effluent (BOD) equal to 20 mg/L, the BOD loading from factories will be counted up to 1,212 kg/d. It can decrease BOD loading from the total BOD loading equal to 1,768 kg/d (31%) which more than the target (20%).

5.4 Tha Chin Partnership Agreement

On July 29, 2002, the Director General of Pollution Control Department, and the Governors from four provinces: Chainat, Suphanburi, Nakhon Pathom, and Samut Sakhon all agreed to cooperate to restore the basin by signing The Partnership Agreement of the Tha Chin River Basin, 2002. The Parthnership agrees to take action for restoration of the Tha Chin River Basin as followed:

- Cooperating to dramatically reduce pollutant loads in the receiving waters of the Basin with a goal of fully achieving water quality standards.
- Monitoring ambient water quality and effluent discharges from critical pollution sources, measuring progress and distributing the information to relevant agencies and the public.
- Establishing an Information Centre for the Basin in each province and the Centre of the Basin Information in the Pollution Control Department.
- Promoting and supporting public participation in water quality management and decision making.
- Supporting implementation of the Tha Chin Rehabilitation Plans.
- Meeting of the Partnership at least once a year to evaluate and review the progress of the implementation plan and to establish new goals as appropriate. The Pollution Control Department will serve as a coordinator and the secretariat of the Partnership Agreement.

This is the first agreement in Thailand among the federal government and governors in the basin to cooperate in a mutually beneficial manner to restore the Tha Chin River Basin as a whole.

CHAPTER VI
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The research aims to study the water quality in the middle and lower Tha Chin River by using the MIKE 11 model and Geographic Information system (GIS). As a result, it proves that MIKE11 can be used for predicting the water quality in the middle and lower Tha Chin River. Accordingly, MIKE11 can be applied for an evaluation of existing water quality condition in the river and simulation under various loading scenarios and management action alternatives. Conclusions of this research can be summarized as follows:

6.1.1 Water quality of the study area in 2005 is severely degraded. The trend of BOD level is steadily increased from Nakhon Pathom to Samut Sakhon. The lowest DO level (DO=0.71 mg/l) is in the Tein Dud Temple, Samphran, Nakhon Pathom, it is critical value for aquatic animals. The highest BOD level (BOD=5.0 mg/l) is in the Tein Dud Temple, Samphran, Nakhon Pathom and Sirimongkol Temple, Muang, Samut Sakhon. After that it is decreased until reaching the regulated value issued in the surface water quality standard (BOD=4.0 mg/L) at the river mouth of Samut Sakhon.

6.1.2 In this study, the way for controlling water quality in Tha Chin River by the year 2005 to meet the required water standard classification is to control the pollution discharge. It can be summarized as followed;

6.1.2.1 When reducing BOD loading from all pollution discharge at 50%, it can raise water quality to meet the required water quality standard Class 3 and Class 4. The reducing Ammonia loading from all pollution discharge at 50%, it can raise water quality to meet the required water quality standard Class 3 and Class 4. DO in the year 2005 after reducing all pollution discharge at 50%, it can raise water quality to meet the required water quality standard Class 3 and Class 4.

6.1.2.2 When reducing pollution loading discharge from fishery at 75%, it can raise BOD value to meet the required water quality standard Class 3 and Class 4. And when reducing pollution loading discharge from fishery at 75%, it can raise DO value to meet the required water quality standard Class 3 and Class 4. The reducing ammonia loading discharge from factory at 75% and pig farm 75% can raise water quality to meet the required water quality standard Class 3 and Class 4.

6.1.2.3 When reducing BOD loading discharge at BOD peak by reducing at discharge points no.3=30%, no.4=25%, no.5=20%, no.6=20%, no.8=30%, no.14=50%, no.15=50%, no.16=50% and no.22=60%, it can raise water quality to meet the required water quality standard Class 3 and Class 4. For DO value, when reducing pollution loading at discharge points no.8=25%, no.10=50%, no.14=75%, no.15=75%, no.16=75%, no.18=75%, no.19=50% and no.22=50%, it can raise water quality to meet the required water quality standard Class 3 and Class 4. And when reducing ammonia loading discharge at ammonia peak by reducing at discharge points no.1=40%, no.2=40%, no.5=60%, no.8=75% and no.9=40%, it can raise water quality to meet the required water quality standard Class 3 and Class 4.

In conclusion, comparing all the scenarios mentioned above, the most feasible choice for management in the Tha Chin basin with the **long term** objective is the reduction of pollution discharge from fishery at 75%. Furthermore, government must seriously control the effluent from the other major sources discharge (such as industry and pig farm) so as to meet the required effluent standard. In the **short term**, the reduction of pollution discharge at the critical area by considering the areas those released the great amount of pollution loads is recommended.

6 .2 Recommendations

The following recommendations are drawn from the study for further considerations:

6.2.1 Frequency of the water quality monitoring should be improved for a better and the accurate input data for modeling.

6.2.2 3-dimension model of MIKE (MIKE 21) should be further applied.

6.2.3 An enhanced application of spatial analysis (sub-model of ArcView) to calculate the discharge area of the Tha Chin River should be further investigated.

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APPENDIX A
MODEL VERIFICATION

Model Verification

The model verification part is intended to compare between model result and data of year 2006.

1. Hydrodynamic Module (HD)

The data are used for HD model verification are water level at the regulators in February to May 2006. The result are obtained by comparing the simulated data and observed one of water level. The results are shown from Figure A-1 to Figure A-4.

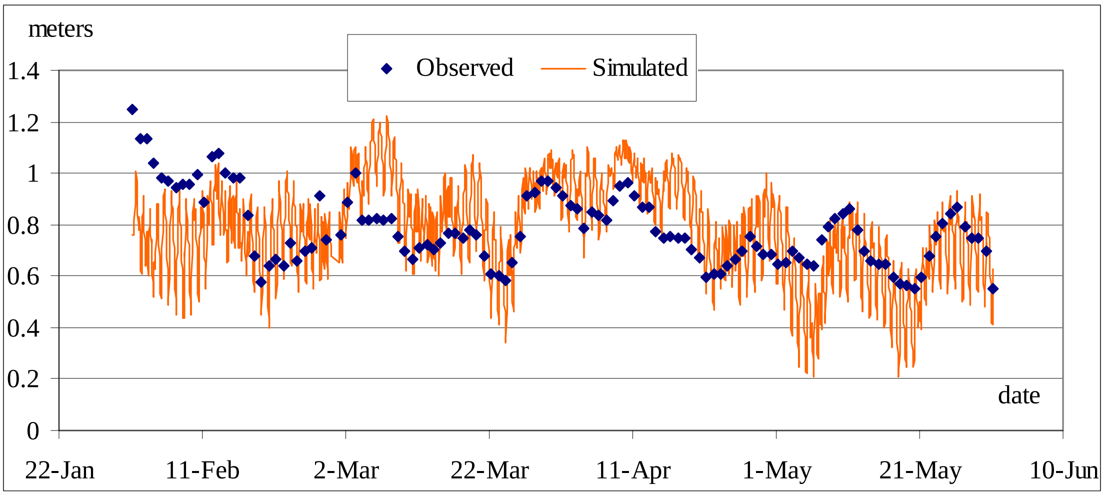

Figure A-1 Comparison between observed and simulated water level in February to May 2006 at Songpeenong Regulator (R= 0.5126, R^2 = 0.2628, n=118)

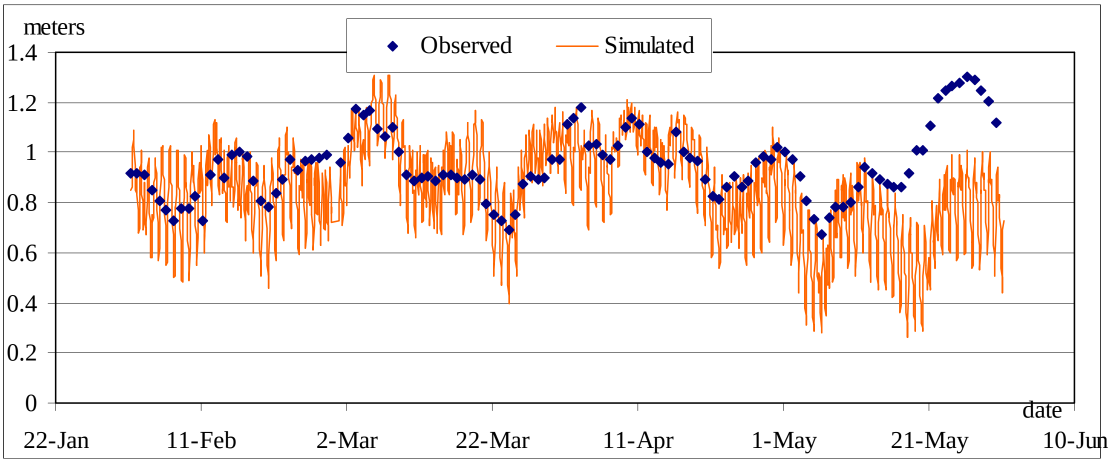

Figure A-2 Comparison between observed and simulated water level in February to May 2006 at Prayabanlae Regulator (R= 0.6247, R^2 = 0.3903, n=118)

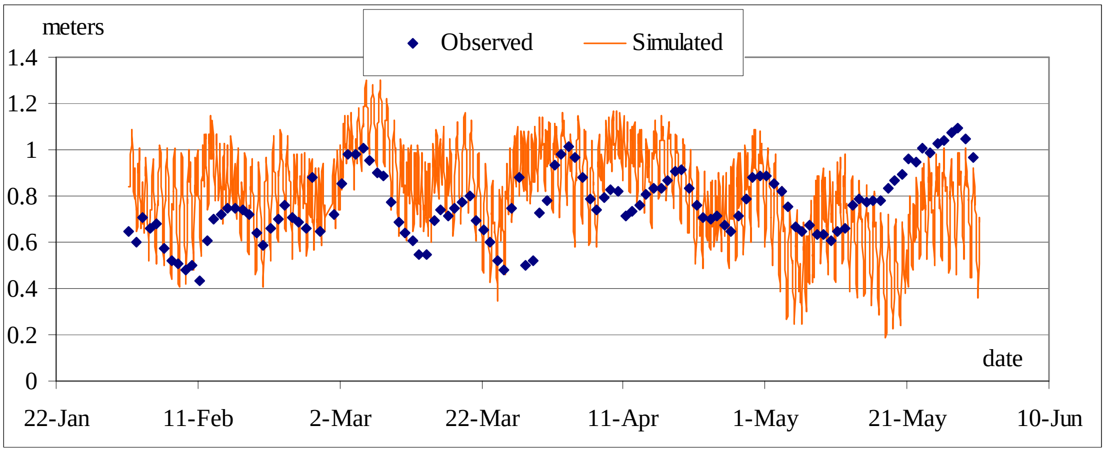

Figure A-3 Comparison between observed and simulated water level in February to May 2006 at Prapimol Regulator (R= 0.5543, R^2 = 0.3073, n=118)

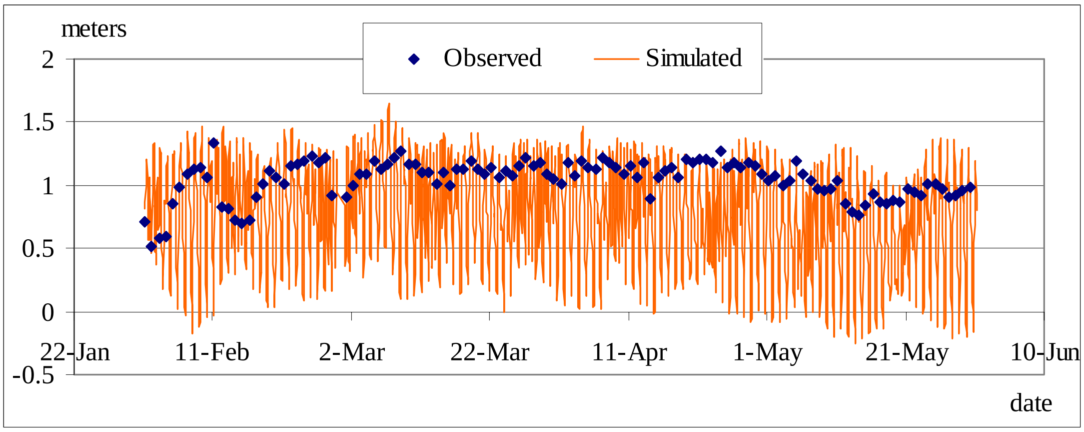

Figure A-4 Comparison between observed and simulated water level in February to May 2006 at Bangyang Regulator (R= 0.7399, R^2 = 0.5475, n=118)

2. Water Quality Module (WQ)

The data, used for WQ model verification, are those water qualities at eleven water quality stations (TC01, TC04, TC07, TC09, TC10, TC11, TC13, TC15, TC17, TC22 and TC23) between February and May 2006. The result are obtained by comparing the simulated data and observed one of water level. The results are shown from Figure A.5 to Figure A.8.

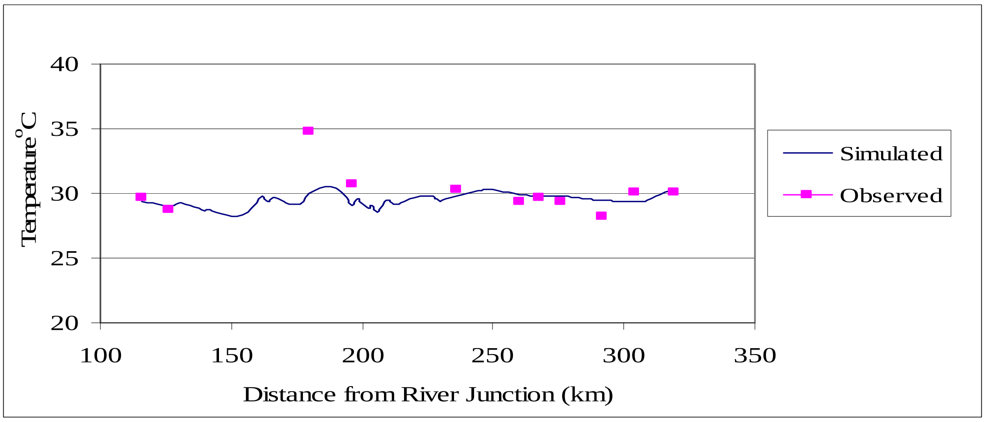

Figure A-5 Comparison between simulated and observed Temperature in February,2006 (R^2=0.5270, n=11)

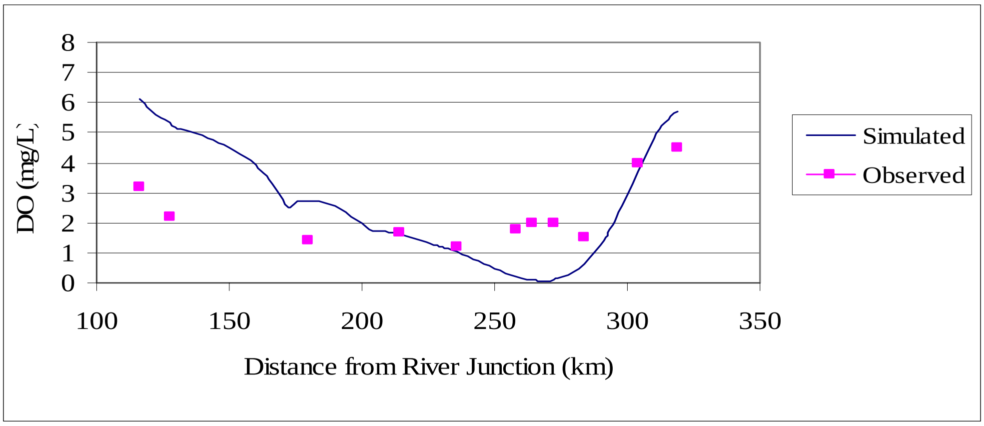

Figure A-6 Comparison between simulated and observed DO in February,2006 (R^2=0.4499, n=11)

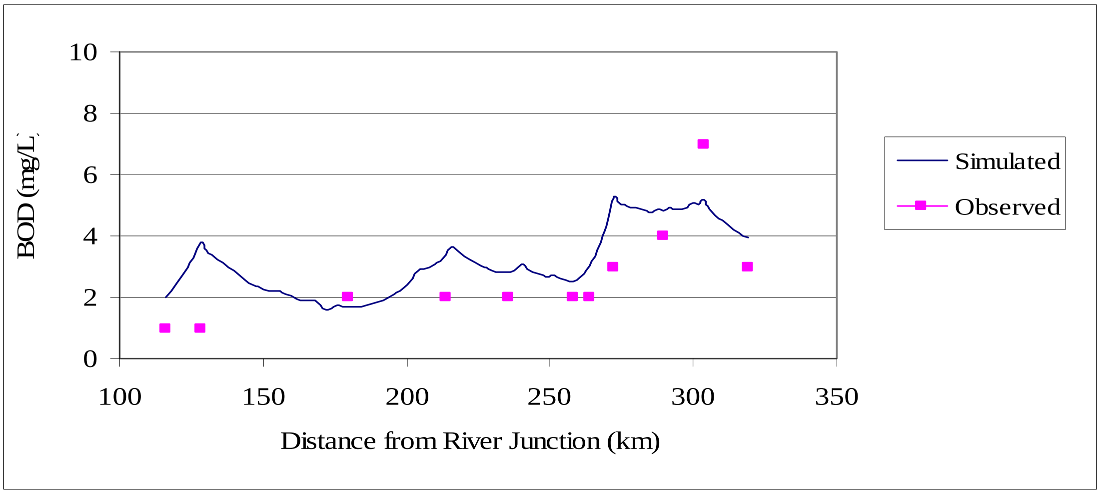

Figure A-7 Comparison between simulated and observed BOD in February,2006 (R^2=0.5021, n=11)

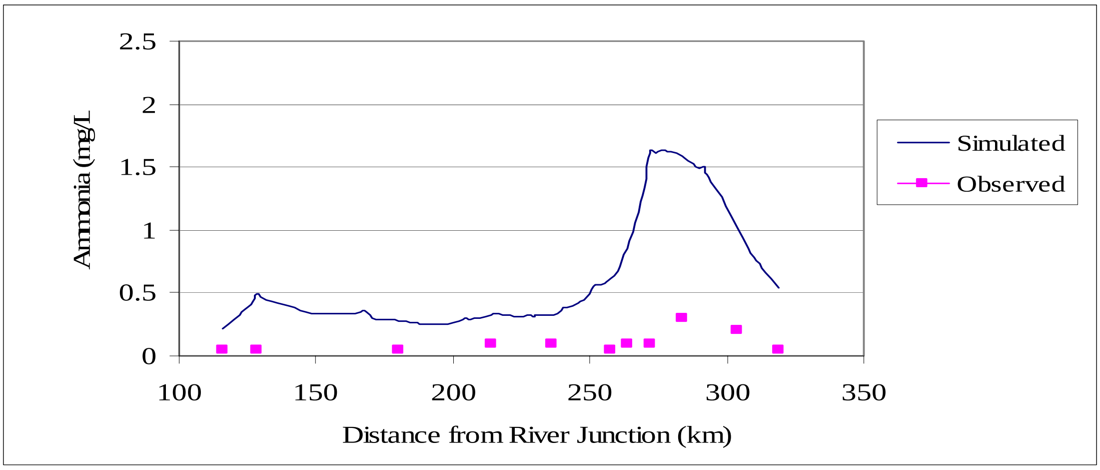

Figure A-8 Comparison between simulated and observed BOD in February,2006 (R^2=0.4856, n=11)

APPENDIX B
THE EXAMPLE OF THE MIKE 11 MODEL OUTPUT

The example of MIKE 11 model output (BOD values)

Date Time	MIKE 11 Chainage					
	THACHIN 115910.0	THACHIN 117910.0	THACHIN 119910.0	THACHIN 121910.0	THACHIN 123910.0	THACHIN 125910.0
22/2/2005 0:00	2.0440	2.2581	2.5052	2.7532	2.9839	3.2741
22/2/2005 1:00	2.0359	2.2506	2.4974	2.7443	2.9749	3.2676
22/2/2005 2:00	2.0272	2.2427	2.4899	2.7366	2.9671	3.2609
22/2/2005 3:00	2.0178	2.2341	2.4818	2.7291	2.9603	3.2562
22/2/2005 4:00	2.0079	2.2253	2.4744	2.7226	2.9544	3.2518
22/2/2005 5:00	1.9980	2.2165	2.4668	2.7161	2.9487	3.2481
22/2/2005 6:00	1.9875	2.2073	2.4594	2.7102	2.9439	3.2455
22/2/2005 7:00	1.9770	2.1985	2.4525	2.7047	2.9395	3.2429
22/2/2005 8:00	1.9662	2.1892	2.4452	2.6993	2.9354	3.2412
22/2/2005 9:00	1.9550	2.1799	2.4386	2.6945	2.9319	3.2398
22/2/2005 10:00	1.9439	2.1707	2.4318	2.6898	2.9287	3.2392
22/2/2005 11:00	1.9326	2.1615	2.4256	2.6862	2.9269	3.2404
22/2/2005 12:00	1.9228	2.1538	2.4213	2.6846	2.9279	3.2460
22/2/2005 13:00	1.9178	2.1505	2.4226	2.6901	2.9384	3.2661
22/2/2005 14:00	1.9268	2.1598	2.4385	2.7124	2.9696	3.3127
22/2/2005 15:00	1.9539	2.1829	2.4646	2.7440	3.0078	3.3504
22/2/2005 16:00	1.9793	2.2013	2.4763	2.7558	3.0163	3.3341
22/2/2005 17:00	1.9929	2.2128	2.4820	2.7568	3.0111	3.3239
22/2/2005 18:00	2.0109	2.2307	2.5000	2.7708	3.0234	3.3401
22/2/2005 19:00	2.0335	2.2485	2.5126	2.7804	3.0307	3.3381
22/2/2005 20:00	2.0477	2.2588	2.5156	2.7787	3.0237	3.3209
22/2/2005 21:00	2.0573	2.2673	2.5200	2.7773	3.0173	3.3114
22/2/2005 22:00	2.0644	2.2723	2.5201	2.7719	3.0069	3.2949
22/2/2005 23:00	2.0631	2.2698	2.5121	2.7589	2.9892	3.2719
23/2/2005 0:00	2.0562	2.2640	2.5042	2.7469	2.9737	3.2572
23/2/2005 1:00	2.0483	2.2570	2.4968	2.7377	2.9635	3.2500
23/2/2005 2:00	2.0399	2.2493	2.4894	2.7302	2.9568	3.2460
23/2/2005 3:00	2.0317	2.2418	2.4827	2.7240	2.9509	3.2410
23/2/2005 4:00	2.0228	2.2335	2.4749	2.7170	2.9445	3.2361
23/2/2005 5:00	2.0134	2.2252	2.4680	2.7110	2.9393	3.2328
23/2/2005 6:00	2.0043	2.2171	2.4613	2.7054	2.9346	3.2297
23/2/2005 7:00	1.9946	2.2086	2.4541	2.6995	2.9298	3.2266
23/2/2005 8:00	1.9847	2.2001	2.4475	2.6943	2.9254	3.2240
23/2/2005 9:00	1.9745	2.1914	2.4406	2.6889	2.9212	3.2218
23/2/2005 10:00	1.9638	2.1825	2.4338	2.6839	2.9174	3.2202
23/2/2005 11:00	1.9531	2.1736	2.4272	2.6792	2.9140	3.2191
23/2/2005 12:00	1.9422	2.1645	2.4208	2.6750	2.9114	3.2193
23/2/2005 13:00	1.9322	2.1565	2.4159	2.6727	2.9115	3.2236
23/2/2005 14:00	1.9263	2.1523	2.4158	2.6764	2.9195	3.2398
23/2/2005 15:00	1.9324	2.1589	2.4285	2.6950	2.9463	3.2808
23/2/2005 16:00	1.9561	2.1794	2.4531	2.7254	2.9841	3.3226

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