ผลกระทบของการใช้ที่ดินต่อคุณภาพน้ำในพื้นที่ลุ่มน้ำลำตะคอง จังหวัดนครราชสีมา

นางสาวกลิ่นสุคนธ์ สุวรรณรัตน์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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THE EFFECT OF LAND USE ON WATER QUALITY IN LAM TAKONG BASIN, NAKHON RATCHASIMA PROVINCE

Glinsukol Suwannarat

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Environmental Biology

Suranaree University of Technology

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THE EFFECT OF LAND USE ON WATER QUALITY IN LAM TAKONG BASIN, NAKHON RATCHASIMA PROVINCE

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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กลิ่นสุคนธ์ สุวรรณรัตน์ : ผลกระทบของการใช้ที่ดินต่อคุณภาพน้ำในพื้นที่ลุ่มน้ำลำตะคอง จังหวัดนครราชสีมา (THE EFFECT OF LAND USE ON WATER QUALITY IN LAM TAKONG BASIN, NAKHON RATCHASIMA PROVINCE) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.พงศ์เทพ สุวรรณวารี, 170 หน้า.

จากการวิเคราะห์ข้อมูลคุณภาพน้ำย้อนหลัง 13 ปี (พ.ศ. 2539-2551) จากจุดเก็บน้ำ 7 สถานีในแม่น้ำลำตะคองของกรมควบคุมมลพิษ พบว่าน้ำในลำตะคองมีคุณภาพปานกลาง ยกเว้นช่วงที่ไหลผ่านตัวเทศบาลนครนครราชสีมา ที่มีสารอาหารอยู่ในช่วงปานกลางถึงสูง เนื่องจากพบค่าออกซิเจนละลายในน้ำเฉลี่ยต่อปีต่ำสุด 1.7 มก./ล. แต่แอมโมเนียมีค่าเฉลี่ยต่อปีสูงสุด 2.51 มก./ล. ที่ชุมชนวัดสามัคคี ขณะที่ค่าบีโอดีและไนเตรท มีค่าเฉลี่ยต่อปีสูงสุด 5.5 มก./ล. และ 0.6 มก./ล. ที่บ้านยองแยง ส่วนฟอสฟอรัสทั้งหมด มีค่าเฉลี่ยต่อปีสูงสุด 3.5 มก./ล. ที่บ้านบุกระเฉด

ส่วนคุณภาพน้ำในลำตะคองสายหลักและลำน้ำสาขา ในปี พ.ศ. 2551-2552 จากการเก็บตัวอย่างน้ำจาก 20 สถานี จำนวน 6 ครั้ง ในเดือนตุลาคมและธันวาคม พ.ศ. 2551 กุมภาพันธ์ เมษายน มิถุนายน และสิงหาคม พ.ศ. 2552 พบว่า ดัชนีชี้วัดคุณภาพน้ำต่างๆ อยู่ในเกณฑ์มาตรฐานน้ำผิวดินประเภทที่ 3 ยกเว้นค่าแอมโมเนียไนโตรเจน ฟอสเฟต และบีโอดี โดยค่าแอมโมเนียไนโตรเจนมีค่าสูงสุด 12.6 มก./ล. ณ จุดเก็บสะพานกรมพลาธิการ ฟอสฟอรัสมีค่าสูงสุด 2.7 มก./ล. ณ เก็บจุดสูบน้ำประปาเทศบาลนครนครราชสีมา ในอ่างเก็บน้ำลำตะคอง และบีโอดีมีค่าสูงสุด 8.7 มก./ล. ณ จุดเก็บบ้านท่ากระสังข์ ที่ทำให้บริเวณดังกล่าวมีคุณภาพน้ำผิวดินประเภทที่ 4 เมื่อประเมินระดับสารอาหาร พบว่าลำตะคองจัดเป็นแหล่งน้ำที่มีสารอาหารปานกลาง ยกเว้นช่วงที่ไหลผ่านตัวเทศบาลนครนครราชสีมา ที่น้ำมีสารอาหารปานกลางค่อนข้างสูง ที่บ้านท่ากระสังข์ และเขื่อนทดน้ำกันผมซึ่งเป็นจุดที่ลำตะคอง บรรจบกับลำบริบูรณ์ ก่อนไหลลงสู่แม่น้ำมูล

นอกจากนี้ฤดูกาลก็มีผลต่อคุณภาพน้ำ โดยค่าความเป็นกรด–เบส ออกซิเจนละลาย บีโอดี และแอมโมเนียมีค่าสูงในฤดูแล้งมากกว่าในฤดูฝน มีนัยสำคัญทางสถิติที่ระดับ 0.01 แต่อุณหภูมิ ความเค็ม และของแข็งแขวนลอยทั้งหมดมีค่าต่ำกว่า มีนัยสำคัญทางสถิติที่ระดับ 0.01 อย่างไรก็ตาม ค่าความขุ่น ปริมาณสารอินทรีย์ทั้งหมด ไนเตรท ไนไตรท์ และคลอโรฟิลล์-เอ ในฤดูฝนมีค่าสูงกว่าฤดูแล้งแต่ไม่แตกต่างกันอย่างมีนัยสำคัญทางสถิติ

เมื่อศึกษาความสัมพันธ์ของการใช้ประโยชน์ที่ดิน 9 ประเภท ต่อคุณภาพน้ำโดยวิธีสหสัมพันธ์ของเพียร์สัน พบว่า ความเป็นเมือง มีความสัมพันธ์ต่อค่าบีโอดี ออกซิเจนละลาย แอมโมเนีย ฟอสเฟต และคลอโรฟิลล์-เอ โดยมีค่าสัมประสิทธิ์ 0.425 0.380 -0.259 0.445 และ 0.339 ตามลำดับ รองลงมาคือ อุตสาหกรรม ป่าเสื่อมโทรม และแหล่งน้ำ แต่ไนเตรทพบมี

ความสัมพันธ์กับแหล่งน้ำ ความสัมพันธ์ของปัจจัยที่ได้สามารถนำมาสร้างสมการทางคณิตศาสตร์ เพื่ออธิบายผลของการใช้ที่ดินต่อคุณภาพน้ำในพื้นที่ศึกษา

ส่วนการพยากรณ์คุณภาพน้ำในอนาคต โดยใช้ WASP จากสถานการณ์จำลอง 3 สถานการณ์ ได้แก่ คุณภาพน้ำในปัจจุบัน คุณภาพน้ำในอนาคตสิบปีข้างหน้า และคุณภาพน้ำในอนาคตเมื่อมีน้ำเสียลดลงร้อยละ 25 พบว่าคุณภาพน้ำยังมีแนวโน้มลดลงเมื่อไหลผ่านเขตชุมชน โดยเฉพาะเมื่อไหลผ่านเทศบาลนครนครราชสีมา โดยอีกสิบปีข้างหน้าปริมาณออกซิเจนละลายจะมีค่าต่ำสุด 1 มก./ล. แต่ถ้าลดปริมาณน้ำเสียลงร้อยละ 25 จากการสร้างระบบบำบัดน้ำเสียรวมและเพิ่มบ่อดักไขมัน ปริมาณออกซิเจนละลายจะเพิ่มสูงขึ้น โดยมีค่าต่ำสุดเพียง 2.75 มก./ล.

สาขาวิชาชีววิทยา
ปีการศึกษา 2554

ลายมือชื่อนักศึกษา ____________
ลายมือชื่ออาจารย์ที่ปรึกษา ____________

GLINSUKOL SUWANNARAT : THE EFFECT OF LAND USE ON WATER QUALITY IN LAM TAKONG BASIN, NAKHON RATCHASIMA PROVINCE. THESIS ADVISOR : ASST. PROF. PONGTHEP SUWANWAREE, Ph.D. 170 PP.

LAM TAKONG BASIN/WATER QUALITY/TROPHIC LEVEL/LAND USE CHANGE/EUTROPHICATION

The 13 years of the analysis of the water quality from 7 test stations in along the Lam Takong River by The Pollution Control Department showed that the Lam Takong water quality was mostly mesotrophic. Nowever, it became meso-eutrophic in the area of the passing through Nakhon Ratchasima Municipality. The minimum DO (1.7 mg/L) and the maximum NH_3 (2.51 mg/L) were found at Wat Samakkee, whereas the maximum BOD (5.5 mg/L) and NO_3 (0.6 mg/L) were found at Ban Yong Yang. The maximum Total Phosphorous (3.5 mg/L) was found at Ban Bu Krachet.

In addition, the water quality assessment in the Lam Takong River and tributaries, from 20 stations, (6 times (October and December, 2008; February, April, June and August, 2009)), revealed that the overall water quality ranked at Class 3 of Thailand Surface Water Standard, except NH_3-N, P and BOD. The maximum of NH_3-N (12.6 mg/L), Phosphate 2.7 mg/L and BOD (8.7 mg/L) were found at the location of the Quartermaster Department Royal Thai Army Bridge, Nakhon Ratchasima Municipality pump in Lam Takong reservoir and Ban Ta Krasang, respectively, leading to a class 4 surface water standard classification in these areas. Moreover, trophic level of Lam Ta Khong River was mesotrophic; except they were meso-

eutrophic after passing through Nakhon Ratchasima Municipality, Ban Ta Krasung, and Kan Pom dam before reaching the Mool River.

The season also affected on water quality. The value of pH, DO, BOD and NH_3-N were significantly higher in dry season ($p<0.01$), while temperature, salinity and TSS were significantly lower in dry season ($p<0.01$). However, turbidity, TOC, NO_3, NO_2 and Chlorophyll-a were in rainy season higher than in the dry season but not statistically different.

Pearson's Correlation of 9 land use types on water quality showed that water from urban area was correlated with BOD, DO, NH_3-N, PO_4 and Chlorophyll-a (0.425, 0.380, -0.259, 0.445, and 0.339, respectively) higher than the industrial area, scrub forest and water body. However, nitrate was mostly correlated with water body. Later, statistical models were developed from these results.

WAPS was used to predict water quality in Lam Takong River. Three scenarios (present, 10 years, and 10 years with 25% BOD reduction) were simulated. The model predicts that water quality still decreases when the water flows through Nakhon Ratchasima Municipality. The minimum DO would reach 1 mg/L in ten years. However, if 25% BOD reduction is ached by future wastewater treatment plant and septic tank construction, the minimum DO would be 2.75 mg/L.

School of Biology — Student's Signature Glinsukol Suwanmanat

Academic Year 2011 — Advisor's Signature P. Suwan

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LIST OF ABBREVIATIONS

BOD	=	Biochemical Oxygen Demand
°C	=	Degree of Celsius
Chlo-a	=	Chlorophyll-a
DO	=	Dissolved Oxygen
d	=	day
ha	=	hectare
hr	=	hour
km	=	kilometer
m	=	meter
mg/L	=	milligram per liter
mm	=	millimeter
mS/cm	=	milliSiemen per centimeter
NTU	=	Nephelometric Turbidity Unit
sp./ spp.	=	species (singular)/ (plural)
TDS	=	Total Dissolved Solid
TP	=	Total Phosphorus
TSS	=	Total Suspended Solid
$\mu E/m^2.s$	=	microEinsteins per square meter per second
µg/L	=	microgram per liter

CHAPTER I

INTRODUCTION

1.1 Background and problems

The Lam Takong River is an important river of Northeastern Thailand, flowing through six districts of Nakhon Ratchasima Province, as a main bloodline. The Lam Takong basin is the major subbasin of the Mool River providing people with food, water supply, transportation and recreation. An Increasing population needs more agricultural, industrial, and residential areas. The impacts of land use change on water quality are related to the expansion of cultivation, irrigation, urbanization and industrialization while water qualities such as total suspended solid, dissolved organic carbon, total phosphorus, total nitrogen, are generally related to land use and land cover in catchment area. Land use change and wastewater from human activities along the river may cause water pollution of the Lam Takong river. The Pollution Control Department, Regional Environmental Office 11 and the Municipality of Nakhon Ratchasima are concerned about this problem and they have been monitoring the water quality in Lam Takong River for decades. From the data, water status of Lam Takong River is highly deteriorated especially in the lower part. Biochemical Oxygen Demand (BOD) and ammonia-N (NH_3-N) are major problems (Pollution Control Department, 2007). Srituranon and Polsan (2004) studied the microbiological water quality in Lam Takong and assessed the factors that influence bacterial contamination in water. The analysis showed that water in Lam Takong River may not be used directly. It should reduce the consumption of bacteria by boiling. There were 22 genus of bacteria in riverine water Bacillus, Flavobacterium, Stephylococcus, Pseudomonas and Acinetobacter were mostly found. The analysis showed that the rainy season is a major factor effecting on water quality, especially at the beginning of the rainy season. The amount of bacteria usually increased when it started raining. The water runoff and soil organic matter, nutrients and microorganisms in the soil run into the water, especially in agriculture and urban areas. Cheenawut (2000) studied the residues of organochlorine insecticides in water, sediment, and fishes in the Lam Takong Reservoir and found heptachlor, aldrin and dieldrin contaminations in water. In the sediment, alpha-BHC, delta-BHC, heptachlor, heptachlor epoxide, lindane, aldrin, dieldrin, endrin, DDD, DDE, DDT and o,p'-DDT deteted. Fish contained, on the other how, heptachlor, dieldrin, DDE and DDT. However concentration of insecticide were not higher than the standard level of surface water. Therefore, the water quality in the Lam Takong reservoir is still suitable for the aquatic life.

The water quality of Lam Takong was assessed by using QUAL2K model (Ramakomut, 2010). The water quality of upstream Samples in the Lam Takong River could be classified as class 3. When the river had passed Nakhon Ratchasima Municipality, the water quality was classified as class 4 of the surface water quality ranking. The mathematic model showed that at the critical condition in 2013 and 2018, DO concentrations had a values between 3.72-4.00 mg/L and 3.68-4.00 mg/L, respectively. BOD concentrations were 2.50-2.72 mg/L and 2.48-2.80 mg/L, respectively. The water quality was classified as class 4 of the surface water quality standard. Mathematic Model and Aquatic Ecology Center of Pollution Control Department (2010) was also concerned about the water Quality of Lam Takong in lower reach. They used Water quality Analysis Simulation Program (WASP) to assess BOD variations. The results showed that the concentration of BOD in lower part was more than 4 mg/L is excess the surface water quality standard as class 4. If BOD Loading was reduce 50%, BOD concentration would be decreased. The water quality standard would be as class 4 or better. For studying algae in Lam Takong, Panuvanitchakorn (2001) found nine species of toxic cyanobacteria, e.g. *Microcystis auruginosa* kützing, *M. weesenbergii* komárek, *Cylindrospermopsis raciborskii* (Wolosz) Seenayy & Sbba, *Aphanizomenon* sp., *Anabaena catenula* (kg.) Born et Flah., *An. aphanizomenoides* Forti, *An. spiroides* Kelbahn, *Anabaena* sp., and *Lyngbya* sp. in Lam Takong reservoir during April 2000-March 2001. The water quality in the reservoir of Lam Takong Dam was classified as mesotrophic status and in the categories 2-3, according to water quality standard of Thailand.

Although water qualities in Lam Takong River have been assessed, they were monitored only in the main river. Tributaries of Lam Takong river were not studied. In this research, the water quality of the main river and the tributaries can be addressed. In addition, eutrophication will be also investigated because it usually occurs in Lam Takong River with effects on aquatic animal and human health along the stream. Knowledge of the effect of land use on water quality, we can establish a proper water resource management plan for the whole basin, and thus on important issue of research

1.2 Research objectives

1) To analyze the water quality in the Lam Takong river over a period of 13 years from 1996-2008 and predict the water quality in the Lam Takong main river and its tributaries in 2008-2009.

2) To compare water qualities between dry and rainy seasons.

3) To investigate the effects of land use on the water quality in Lam Takong river and its tributaries.

4) To predict the future water quality in Lam Takong River.

1.3 Research hypotheses

1) Urban and industry are the cause of varying water quality in Lam Takong Basin.

2) The effected on water quality and trophic level status in Lam Takong Basin due to land use changes.

1.4 Scope and limitations of the study

1) Sampling periods

Water samplings were collected in October and December 2008 and in February, April, June, and August 2009.

2) Sampling stations

Water samples were collected from 20 stations in the Lam Takong Basin, along the main river channel and its tributaries.

3) Water parameters

In this research, 15 water quality parameters were determined pH, temperature, dissolved oxygen (DO), biological oxygen demand (BOD), turbidity, salinity, conductivity, total suspended solid (TSS), total dissolved solid (TDS), total organic carbon (TOC), chlorophyll a (Chl-a), nitrate (NO_3-N), nitrite (NO_2-N), ammonia (NH_3-N), and phosphate (PO_4).

4) Land use type

Land use with respect to the classification by Department of Land Development in 2001 and 2008 were compared for the location of the study.

CHAPTER II

LITERATURE REVIEW

2.1 Concept of land use and land cover

The knowledge of land use and land cover is important for planning and management concerned with the surface of the earth (Bin, 1994). The geographers describe the term of land cover related to the type of features that appear on the surface of the earth. Urban area, trees, paddy, bare soil are all examples of land cover type. In addition, the land use pattern of an area is a physical expression of various human activities associated with a specific piece of land. Thus, the same parcel of land has a land cover consisting of roofs, pavements, yards and trees are classified as residential areas. Land use has a major impact on natural resources including water, soil, nutrients, plants and animals. A number of studies have shown that the density of population and housing can affect the concentration of chloride, nitrate, and a variety of pesticides in streams that drain urban and suburban setting.

2.2 Effect of land use on water quality in other countries

Stream, river, and lake are important parts of the landscape, as they provide water supply, recreation, and transportation for human, and places to live for a variety of plant and animal. In some areas, contamination from natural and human sources has affected the quality of surface water. For example, natural minerals within bedrock can impair the taste of groundwater and in some cases limit its use.

Moreover, the spilling and leaking of chemicals at land surface can contaminate nearby streams and lakes.

The type and severity of water contamination are often directly related to human activities, which can be quantified in terms of the intensity and type of land use. The pattern analysis of land use and population provides tools in the investigation of sites with known contamination, and in the prediction and prevention of future contamination of downstream water.

Natural vegetation, as forest with higher infiltration decreasing in runoff, is usually the least harmful land use for water quality. High vegetated land cover and low population density are often found in this area. In Upper Hua River Basin, Li *et al*. (2008) indicated that water temperature, potassium permanganate index, and nitrogen were significantly related to vegetated coverage and subwatershed. In higher vegetation cover, they found less turbidity, suspended particulate matter, potassium permanganate index, nutrients and total dissolved solids. Additionally, Ngoye and Machiwa (2004) found that water samples taken from stations with forested catchments showed high level of dissolved oxygen but low level of turbidity, suspended particulate matter, total dissolved solids, potassium permanganate index, ammonia-N and nitrate-N in Ruvu River, Tanzania.

In contrast, urbanized area has large impermeable surface (by pipes and sewer networks) and the natural channels are decreased. The impervious surface reduces infiltration, lessens the recharge of groundwater and contribute to poor water runoff quality. Both Sliva and Williams (2001) and Ngoye and Machiwa (2004) studied nitrate concentrations in stream water of urbanized areas. They showed that nitrate concentration was varied. In general, nitrate was low in vegetated coverage area, perhaps by the reduction of nitrogen loss from soil. The concentration of nitrate increased during rainy season. Water quality in urban catchments as in the major main rivers of Scotland, England and Wales were also highly value in ammonium-N, orthophosphate-p and suspended solids (Ferrier *et al.*, 2000). Finally, There was a clear trend of increased wastewater with increasing urban land use intensity within a watershed (Sliva and Williams, 2001).

Agriculture is a major practice of land use, including row crop, rangeland, livestock, aquaculture, and agribusiness. Cropping involves soil and water manipulation through tillage and irrigation, thereby affecting runoff and groundwater resources. If improperly used, fertilizers and plant protection chemicals can affect water resources and ecosystems. The percent of agriculture at basin scale is a primary predictor for nitrogen, phosphorus and total suspended solids (Ahearn *et al*., 2005; Ferrier *et al*., 2000; Li *et al*., 2008). The consequences of a decline in soil nitrogen following ploughing of permanent pasture were demonstrated in nitrate export at the Slapton Wood catchment scale, England. (Worrall and Burt, 1999). Ahern *et al*. (2005) indicated that logging in upper watershed was an important source of dissolved organic carbon and nitrate, while agriculture area in lower watershed contributed the majority of sediment, Total nitrogen and total phosphorus in Western Sierra Nevada, California.

2.3 Effect of land use on water quality in Thailand

Many researchers have studied the effects of land use and land cover changes on water quality in many part of Thailand. In the North, at the Royal Watershed Development, Maetang and Doi Pui in Chiengmai Province, bacteriological quality of water was more affected in human settlement than agriculture and reforestation area (Naenna, 1982 ; Nuntapotidech, 1990).

In the central, the physical parameters, including pH, total solids, turbidity and electrical conductivity in forest-agricultural watershed were less than in upland and lower agricultural watershed in Bang Pakong River Basin and Maetaeng Choen and Klong Yan Watershed (Lohkam, 1999; Mee-ong, 1986). Ngamsiri (1995) found that total coliform bacteria and fecal streptococci from agricultural and residential area were low in the upper watershed of Lin Tin subbasin, Maklong watershed, Kanchanaburi Province. In Klong Tha Lat Basin, Chachoengsao Province, BOD values were higher when the stream flow pass communal areas and livestock farms, with the maximum concentrations detected at downstream. Domestic waste increased phosphate concentration while filed crop cultivation increased nitrate concentration (Polpraprut, 1993).

Kungkakat and Krutnoi (1990) showed that in the Northeast region, at Nong Han, Sakon – Nakon Province human activities led to the spread of aquatic weeds, such as water hyacinth and macro algae, over water body and increased water shallowness. Due to wastewater from urban and agricultural area, the accumulation of nutrient in surface water was increased. At the headwater of Lam Takong, Khao Yai National Park, Finally, Niphonkit (2004) found that the agricultural land with less than 70% forest cover had the higher value of pH, turbidity, colour, electrical conductivity, total dissolved solids, acidity, alkalinity, and hardness water than in forest area.

2.4 Lam Takong Basin

2.4.1 Location and boundary

The Lam Takong Basin is a part of the Mool watershed, in the Northeastern region of Thailand. The basin has total area of 3,518 km^2 covering nine districts of three provinces including Prachantakham district in Pracheenburi Province, Pak plee district in Nakon Nayok Province, Pak Chong, Si Khio, Sung Noen, Kham Thale So, Dan Kuntod, Mueang Nakhon Ratchasima and Chaloem Phra Kiat districts in Nakhon Ratchasima Province as shown in Figure 2.1. The Lam Takong Basin consists of six subbasins (Water Resource Regional Office 5, 2006) as shown in Table 2.1. There are many tributaries flowing into Lam Takong river before emptying to Lam Takong reservoir. From the Lam Takong Dam to Nakhon Ratchasima district, the water from subbasin drains to Lam Takong river directly at the right bank. Although the area on the left bank from Lam Takong Dam to Si Khio District has many subbasin, There are only the headwater in valley around the hill at the downstream of Lam Takong reservoir. Mostly of agricultural area relatively found at the lower part of Lam Takong which has a large flat area before met the Mool river. (Royal Irrigation Department, 2005)

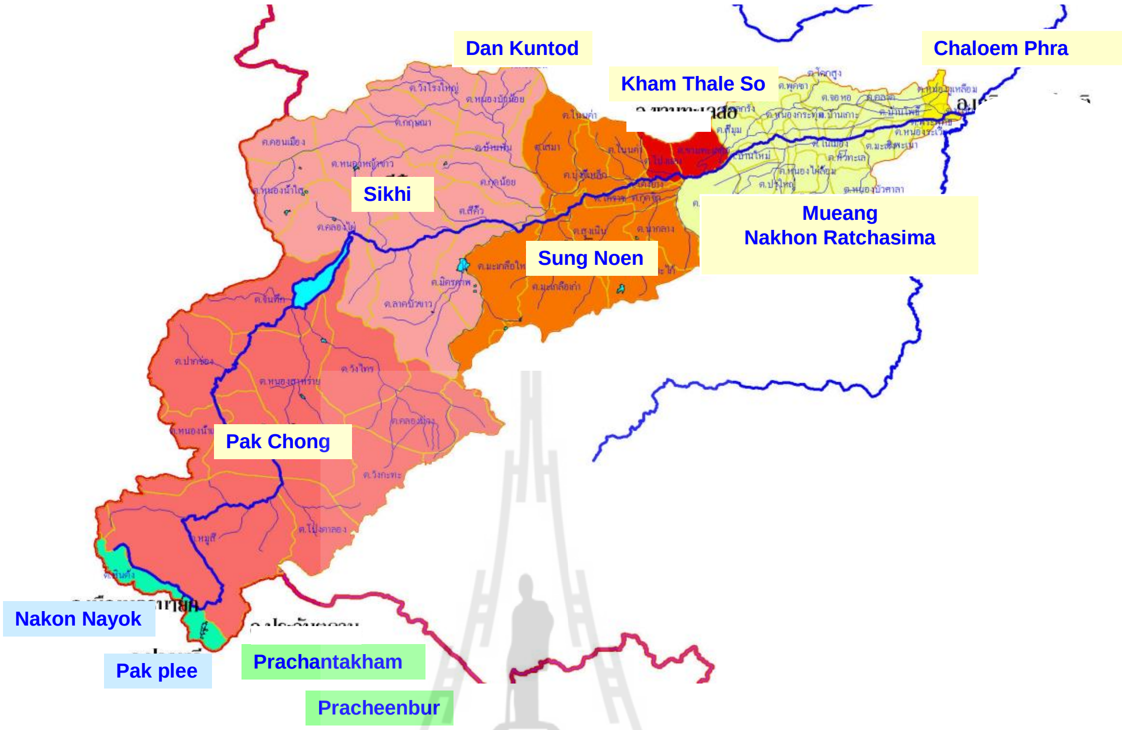


Figure 2.1 Boundary of Lam Takong Basin (Water Resource Regional Office 5, 2006).

Table 2.1 Subbasins of Lam Takong Basin.

Name of subbasin	Code of basin	Area (km^2)
Lamtakong part 1	50501	888
Subpradoo	50502	160
Huai banyang	50503	29
Lamtakong part 2	50504	1,382
Lamtakong part 3	50505	517
Than Asoke	50506	542
Total		**3,518**

Source: Water Resource Regional Office 5 (2006)

2.4.2 Topography

Lam Takong River is originated from Dong Phaya Yen mountain range, near San Kampang mountain range, in Khao Yai National Park. The basin has a slope down from the southwest toward the east. The headwater area has a steep valley (Pak Chong district), narrow plain and rather high bank. When river flows through Si Khio to Chaloem Phra Kiat district, an area has wide plain along the stream as shown in Figure 2.2 and 2.3. Lam Takong basin has many creeks, such as Houy Sai, Houy Yang and Subpradoo.

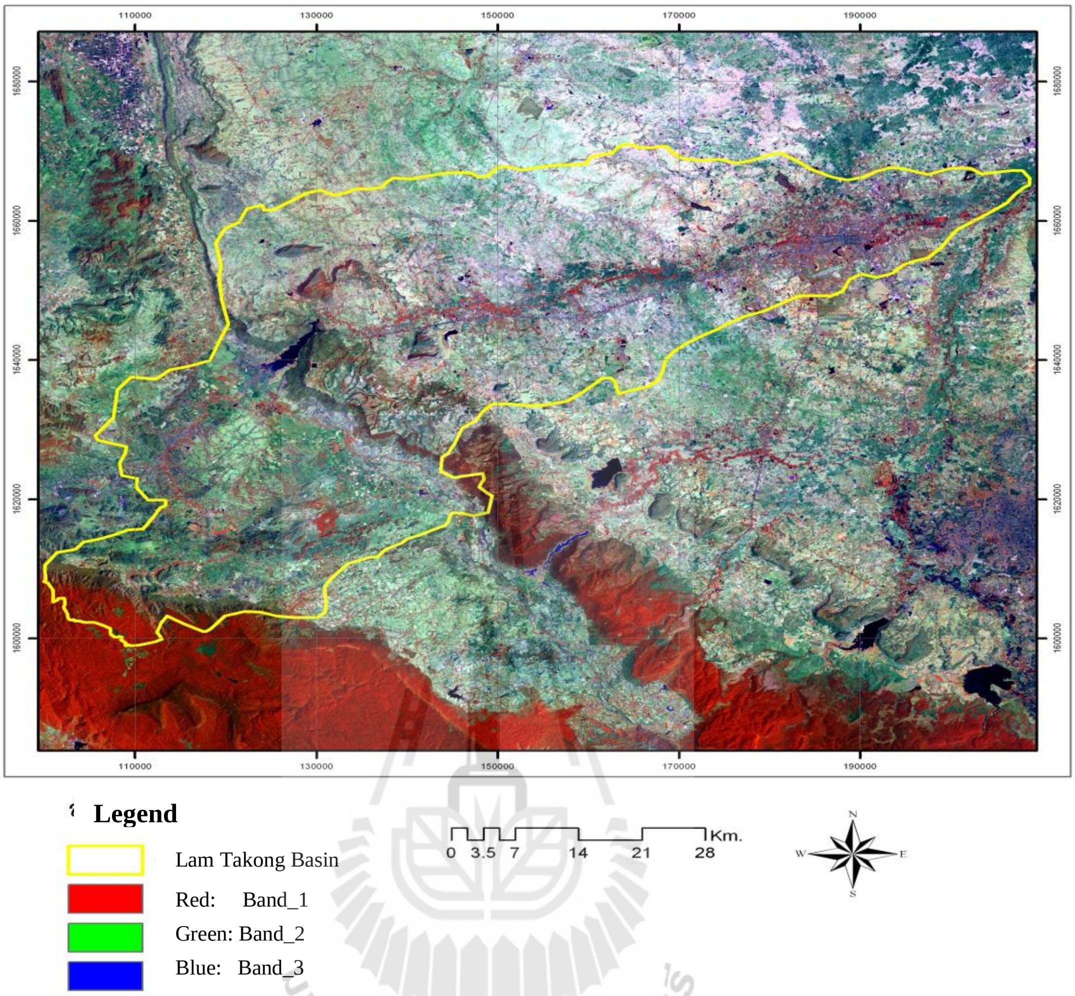


Figure 2.2 Satellite image of the Lam Takong Basin (GISTDA, 2006).

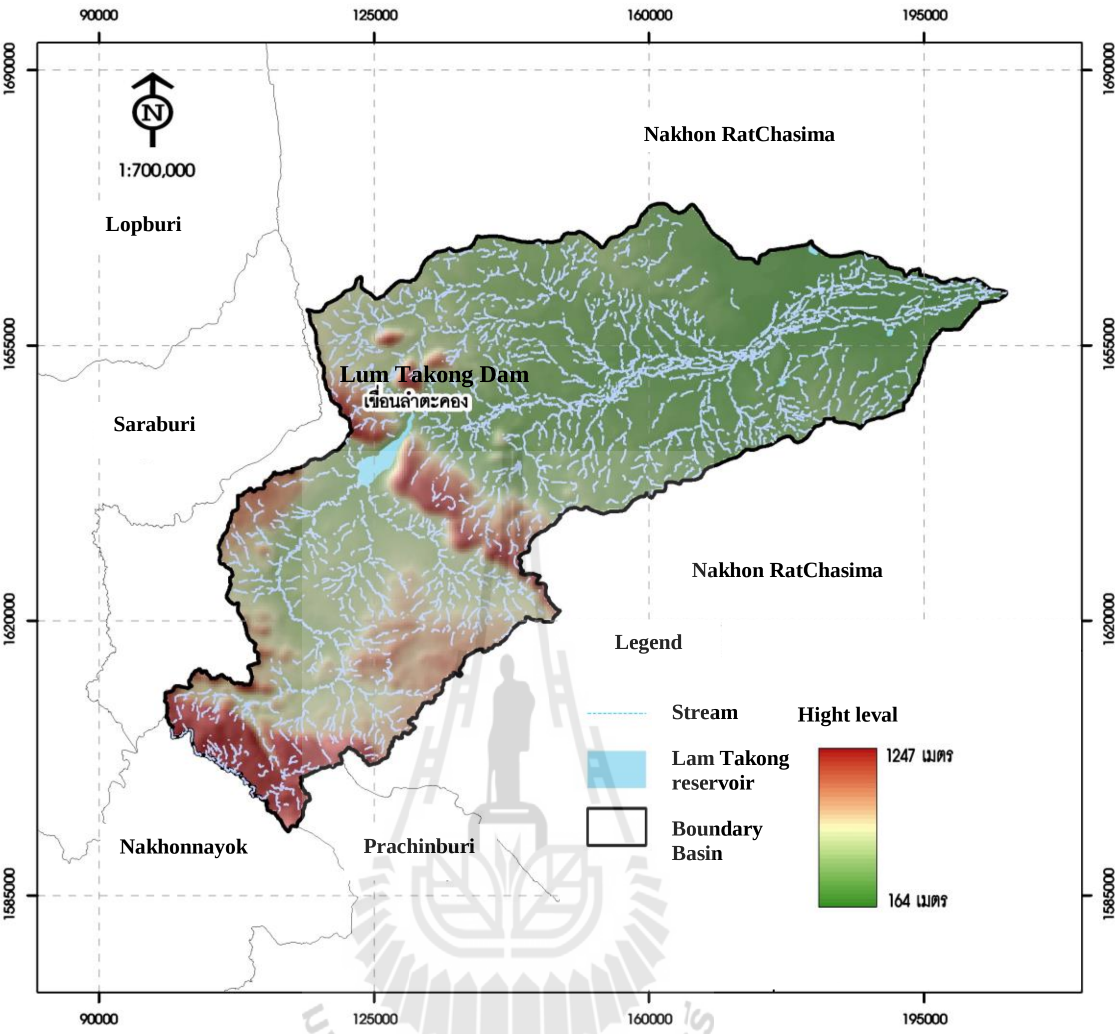


Figure 2.3 Lam Takong topography.

2.4.3 Climate

The Lam Takong basin is located in the tropical, having both high temperature and humidity, and dominated by monsoon. From May to October, the south-west monsoon brings moisture from the Indian Ocean that falls as rain, peaking in August and September. The average amount of rainfall for 10 years (1997-2007) was 800-1,100 mm/year, while heavy rain was in September. Upper part of Lam Takong Basin had the most amount of rainfall (more than 1,100 mm/year). The amount of rainfall in middle part was 900-1,100 mm/year while the lower part was 800-900 (Figure 2.3). From October to February the wind direction is reversed and a cooler, drier north-east monsoon wind blows off the Asian landmass, bringing a cold season. Temperature falls slightly with short transitional period between the monsoons during March and April. This is the hottest period of the year. Lam Takong Basin has 27.52 °C temperature, 4.66 mm/month evaporation, 1.90 km/ hr wind speed and 71.30% relative humidity (Thai Meteorological Department, 2009).

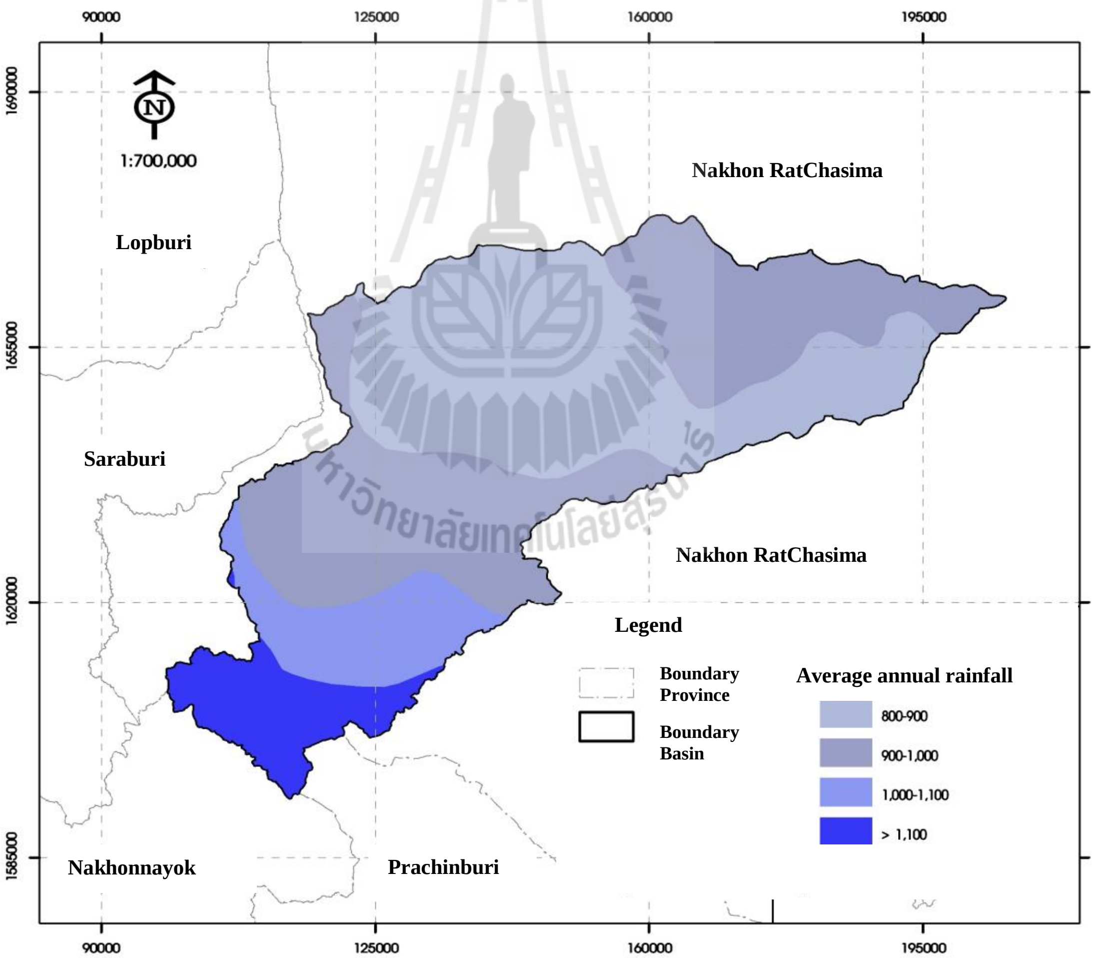


Figure 2.4 The amount of rainfall in Lam Takong basin.

2.4.4 Runoff

1) The annual runoff and the rate of water use

The annual volume of runoff during 41 years from 1963-2003 was varied from 80.5-497.8 million km^3 and the average of runoff was 254.3 million km^3/year. Rate of basin yield is up to 24.8 L/sec/km^2 at headwater and slightly decreases down to 5.3 L/sec/km^2 at the downstream where the intersection of Lam Takong and Mool river. Beside the basin yield of Lam Takong basin yield was not different from Mool river which giving the basin yield was 1.6-25.8 L/sec/km^2. Although Lam Takong basin has basin yield more than other nearly basins, the basin yield was lower than Lam Dome Yai and Lam Dome Noi at the end of Mool basin (Regional Environment Office 11, 2007 a; Royal Irrigation Department, 2005).

2) The amount of monthly runoff

The amount of monthly runoff which flowed through Lam Takong reservoir was estimated data from Klong Pai water station measurement. The amount of monthly runoff flowing into basin was about 254.3 million km^3/year (87.9%) in May and November. The highest monthly runoff occurred in October and the lowest occurred in February (Regional Environment Office 11, 2007 a; Royal Irrigation Department, 2005).

3) The great flood

The maximum amount of flood since the Lam Takong Dam established in 41 years period (1963-2003) was 362.5 km^3/sec which occurred on September 19, 1972. After Lam Takong reservoir was used, the highest flow rate was 132 km^3/sec in October 1, 1996. It means that reservoir could be controlled the great flood, especially at the end of reservoir. When analyzing the relationship between the maximum envelope flood with basin area in Northeast region found the maximum envelope flood for the same size of Lam Takong basin around dam area (1,430 km^2) was 2,700 m^3/sec (Regional Environment Office 11, 2007a; Royal Irrigation Department, 2005).

4) The amount of sediment

The survey of sediment in reservoir was overwhelmed by the Royal Irrigation Department in 2003 indicated that since 1978-2003, the amount of sediment was 11.25 million km^3 (50%) of design capacity for sedimentation at level +261.00 m (mean sea level). From determine of Royal irrigation Department, showed sedimentation in Lam Takong reservoir not a problem to water management (Regional Environment Office 11, 2007a; Royal Irrigation Department, 2005).

2.4.5 Irrigation system

Lam Takong characteristically different from other rivers in Thailand. The Royal Irrigation Department used Lam Takong as an Irrigation system to drain water for agricultural area in Nakhon Ratchasima province.

1) Irrigation Project in the Lam Takong Basin

The Irrigation Project was established since 1939 divided by the total duration in 4 phases. Phase 1 was constructed Autsadang floodgate for Nakhon Ratchasima water supply in 1929, Phase 2 was constructed 9 of Barrages (5 barrages in Lam Bariboon and 4 barrages in Lam Takong) for drained water to farmland in 1939-1957, Phase 3 was constructed Lam Takong Dam for storage water and flooding prevention in 1964-1969, Phase 4 was was constructed 2 barragrs in Lam Takong River for irrigated water to agricultural area in 1980-1985, The total of 11 barrages was shown in Figure 2.5.

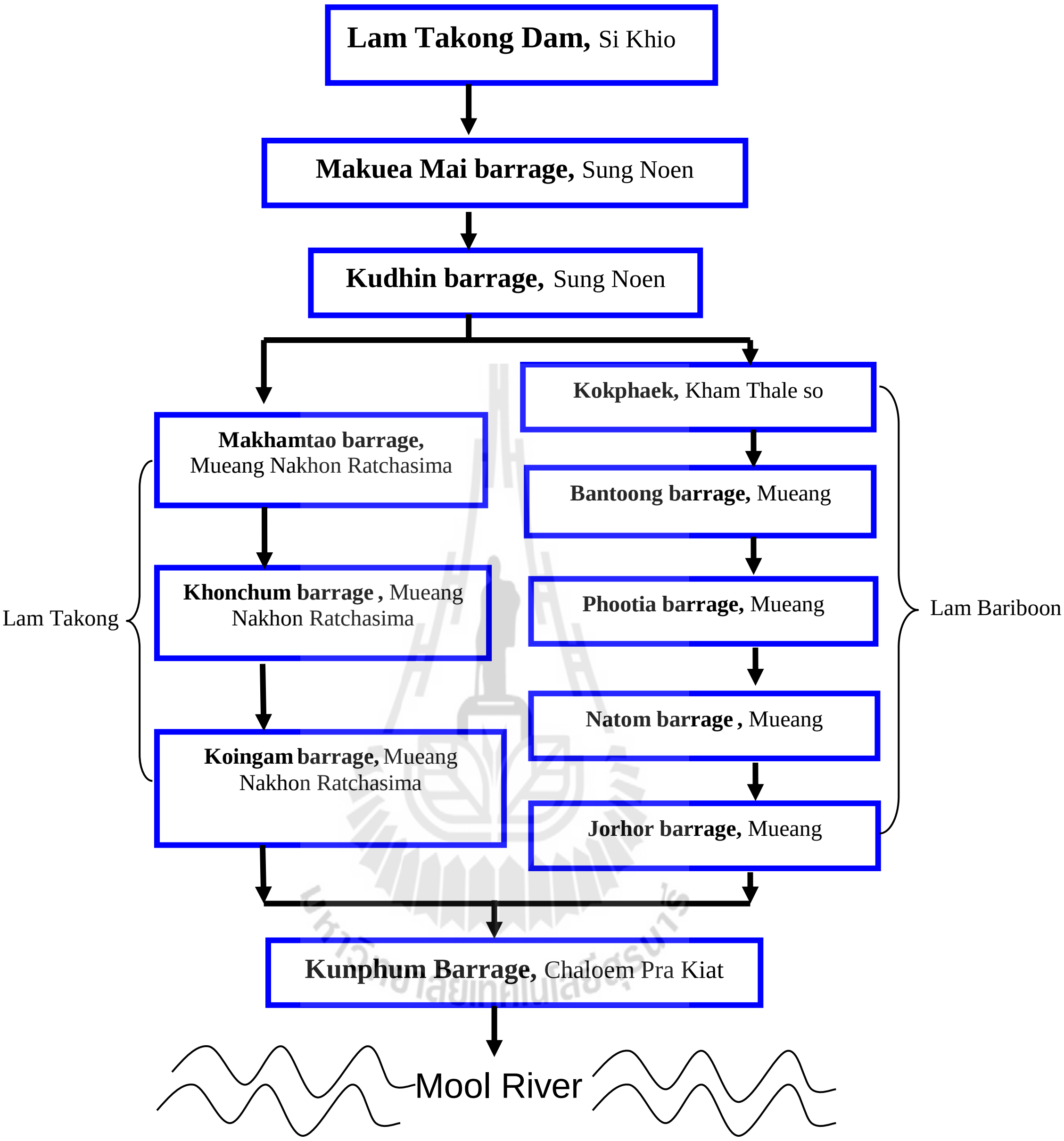


Figure 2.5 Position of dam and barrages in Lam Takong Basin.

2) Lam Takong dam and reservoir

Lam Takong dam is located on the edge of Mittraphap Highway, approximately 70 km from Nakhon Ratchasima downtown (Figure 2.6). The reservoir has storage capacity of 314.49 m^3, capable of supplying 238,000 rai of agricultural area. Lam Takong, Hydro-electric Power Plant**,** situated near in Lam Takong Dam area, can produce 500 MW electricity (Electricity Generating Authority of Thailand, 2008).

The most area of Lam Takong reservoir are in Pak Chong district. The reservoir has 10 km length and 4.70 km maximum width. The highest of water level is 44.7 m (Irrigation Office 8, 2009).

Figure 2.6 Lam Takong Dam and Reservoir (Google Earth, 2009).

3) Cultivation condition and economic condition when developed irrigation project

Most people in area of irrigation project was growing rice in rainy season and growing crops, vegetables and farming in dry season. At least 17% of agricultural land of all farmers in basin could be received water from irrigation project. Average of rice can produce up to 70% of the average rice yield of Nakhon Ratchasima. The benefit from developed irrigation project can be classified including provided water to residential, industrial and agricultural area, reduced flooding in Mool Basin, water supply tap water for Nakhon Ratchasima Municipality and 5 districts, and also used for recreation (Royal Irrigation Department, 2005).

2.4.6 Land use

Land use type in Lam Takong Basin can be divided into four parts which are shown in Table 2.2

Table 2.2 Land use types in Lam Takong Basin.

Landuse	Area	
	km^2	%
1. Agricultural area	1,876.25	48.4
2. Forest and mountain	1,433.50	37.0
3. Water body	391.25	10.1
4. Urban, rural and industrial area	173.00	4.5
Total	3,874.00	100

Source: Environmental Care Center and Suranaree University of Technology, (1996).

2.4.7 Population

The total population of Nakorn Ratchasima province in six districts in 2007 is 921,121 people. The most populated district is Mueang Nakhon Ratchasima, followed by Pak Chong, Si Khio, Sung Noen, Chaloem Phra Kiat, and Kham Thale So, respectively. For the most population density showed in Mueang Nakhon Ratchasima district (Table 2.3).

Table 2.3 Number and density of population in six districts in Lam Takong Basin in 2007.

District	Population	Population Density (people/ km^2)
1. Mueang Nakhon Ratchasima	429,853	124.57
2. Pak Chong	182,588	100.17
3. Si Khio	120,817	97.88
4. Sung Noen	78,503	100.41
5. Chaloem Phra Kiat	65,723	138.07
6. Kham Thale So	34,637	135.29
Total	912,121	Average 116.07

Source: National Statistical Office of Thailand and Department of Provincial Administration, 2008.

2.4.8 Pollution loading

Because of population, economic and industrial expansion led to a deteriorated water quality in this basin. Even though the river can purify itself, high pollution loading, beyond the carrying capacity, can make it irreversible. The Pollution loading usually come from an activities along the river such as industry, agriculture, farming.

Regional Environment Office 11 (2008) calculated loading in Lam Takong basin and found BOD loading of urban was 30,661 kgBOD/day, Actually the real loading was 11,063 kgBOD/day while loading of agriculture was 28,540 kgBOD/day, livestock (only swine farm) was 6,907 kgBOD/day, industry was 690 kgBOD/day. Ramkomut *et al*. (2009) were used QUAL2K model for predict in crisis status in 2013 and 2018 found loading capacity along the river in 2013 was 102,724.04 kgBOD/day and in 2018 was 99,098.13 kgBOD/day due to increasing population and more increasing wastewater made less loading capacity.

2.5 Eutrophication

2.5.1 Definition of eutrophication

Eutrophication refers to a high concentration of nutrients and inorganic matters in water that advances the excessive growth of algae and aquatic plants. It affects water quality and aquatic organisms (Harper, 1992; Mason, 1991; OSPAR, 1999). The excessive nutrients added to bodies of water and causes long-term changes in aquatic organisms is identified as hypertrophication or nutrient pollution. However, hypernutrification or nutrient contamination is a condition where bodies of water containing high nutrients, but cause insignificant effects (Elliott and de Jonge, 2002).

Eutrophication phenomenon in water bodies spotted by the amount of phytoplankton can be identified by Chlorophyll a or the amount of primary production. Eutrophication phenomenon supposedly occurs in water bodies where there are over 10 μ g/L of Chlorophyll a (Nedwell *et al*., 2002) or over 300 gC/m^2/yr of primary production (Black, 2001). Macroalgae can be found in shallow water (1-1.5 m depth), in deep water (more than 2 m depth) microalgae is found (Department of System Research and Management of Coastal Fisheries, 2004).

2.5.2 Causes of eutrophication

Generally, essential nutrients that lead to the cause of eutrophication are nitrogen and phosphorus as they are major elements needed for the growth of primary productions in water. The immediate spread of single-cell algae and other aquatic plants can occur in waters where there are excessive nutrients. These can cause a change in water colour and a reduction of the oxygen gas that is dissolved in water that affects aquatic animals during the nights. Furthermore, certain single-cell algae are dangerous to both humans and animals for they may release toxins that cause allergies or irritations. These dead aquatic plants and algae pollute the water (Harper, 1992).

Two major sources of nitrogen and phosphorus are from nature and human activities. The natural source is from rock or mineral deposits and the atmosphere caused by nitrogen and phosphorus cycles. Various human activities like household, agriculture and industrial activities can also cause water contaminations toward both nutrients (Harper, 1992).

Sometimes, silicon, potassium, calcium, iron or manganese can also lead to eutrophication. It is not easy to identify the exact cause of eutrophication, therefore it is wiser to use reference conditions in describing the nutrients in water. The level of nutrient concentration can be explained in three different ways; the term "oligotrophic" is used to illustrate as having a deficient nutrients; "mesotrophic" as having a moderate nutrients; and "eutrophic" as having excess nutrients (Harper, 1992).

2.5.3 Toxin caused by the growth of algae

The algae that cause trouble in many global waters is among one of the oldest livings; cyanobacteria or blue-green algae. Cyanobacteria is found in any water or place like in fresh water, sea, hot spring, or snow and it grows along side with other creatures both plants and animals (Peerapornpisal, 1999). Thus, cyanobacteria can produce various kinds of toxins. Carmichael *et al*. (1988) divided them according to chemical structures into 3 groups; cyclic peptide, alkaloids and lipopolysaccharides (LPS) or into 6 groups if categorized according to functions; hepatotoxic cyclic peptides, neurotoxic alkaloids, cytotoxic alkaloids, dermatotoxic alkaloids, irritant toxins and others.

Most cyanobacteria toxins found in fresh and brackish water are hepatotoxic cyclic peptides, two of the commonly found toxins are microcystins and nodularin. Microcystins was first recovered in *Microcystis aeruginosa* (Carmichael *et al.*, 1988), but can also be found in *Anabaena*, *Nostoc, Oscillatoria* and *Anabaenopsis*

(Codd, 1998) with common structures and amino acids (Table 2.4). The structure of nodularin is pentapeptides (Sivonen and Jones, 1999) categorized in 6 groups can be found in *Nodularia spumigena* (Codd, 2001; Metcalf *et al.*, 2000).

Table 2.4 Types of microcystins.

Name	X-position Amino Acid	Y-position Amino Acid	Molecular Weight
Microcystin LA	Leucine (L)	Alanine (A)	910.06
Microcystin YR	Tyrosine (Y)	Arginine (R)	1045.19
Microcystin RR	Arginine (R)	Arginine (R)	1038.20
Microcystin LR	Leucine (L)	Arginine (R)	995.17

Source: Codd (1998); Sivonen and Jones (1999).

2.5.4 The accumulation of cyanobacterial toxins in organisms

Organisms receive toxins from cyanobacteria by directly eating cells of the toxic algae or drinking the toxic contaminated waters and indirectly by eating toxic water animals in food chain. Basically, the amount of toxins acquired from waters is little, and less in cyanobacteria's cells since the toxins are dissolved in water or absorbed by aquatic creatures or decomposed by light or bacteria. (Harada, 1996) Phytoplankton and protozoa suffer more from low levels of toxins than other creatures in higher food chain (Christoffersen, 1996; Ibelings *et al.*, 2001). stated that microcystis toxin can be detected in waters where there is a rapid growth of microcystis and in zooplankton, shells, fish's livers and aquatic birds. Furthermore, Lawrence (2001) revealed that toxin nodularin and microcystis are excessively found in shells when there was a fast growth of toxic algae in the Baltic Sea.

2.5.5 Toxin standards

There are many toxins that cause a variety of blue-green algae or cyanobacteria, but the proposed standards for toxins have yet to cover all types of toxins. The World Health Organization (WHO) has determined the tolerable daily intake (TDI) of microcystin in value of 0.067 µg/kg/d. and the TDI value of 0.04 µg/kg/d for microcystin–LR (Dow and Swoboda, 2000; Kuiper-Goodman *et al*., 1999). However, there are still certain drawbacks on the proposed standards for toxins due to lack of studies on the humans.

However, there are drawbacks in the process of proposing toxin standards due to the insufficiency of studies on the toxic effects in human. The studies are needed since the sensitivity toward toxins for animals and humans is different and toxicity depends on how animals and humans get it, for example many toxins will be more serious when directly inject through blood vassal, but will be less serious through eating (Dow and Swoboda, 2000).

Australia, a country affected by the toxins, stipulated the standards of microcystin to be in value of 1.3 µg/L (Burch, 2001). In addition, WHO has given terms on proposed toxic microcystin standard for raw water used in water supply not to exceed 1 µg/L. Such standard is widely and globally applied (Carmichael, 1995; Codd, 2001).

2.5.6 Cyanobacteria's growth factors

The rapid growth of cyanobacteria often comes from the increasing amounts of nutrients in the water as well as suitable temperature and sunlight (Park and Watanabe, 1996). Sunlight is principally considered one of many fundamental and essential factors for balancing the ecosystem in freshwater as it basically serves as an energy source for activating and controlling metabolism of water creatures (Wetzel, 1983). Each algae needs different amount of sunlight (Lee, 1999; Oliver and Ganf, 2000). Even though cyanobacteria or blue-green algae can grow in low intensity of sunlight, they grow much faster in high intensity of sunlight (Mur *et al*., 1999; Park and Watanabe, 1996). Additionally, sunlight plays a very important role in producing toxins as revealed in the experiment of Utikilen and Gjølme (2001) that *M. aeruginosa* growing a continuous culture style produced more toxins where the intensity of sunlight was 40 $\mu E/m^2.s$. However, they produced less toxins in higher sunlight intensity and in lower sunlight intensity, they ceased producing toxins, but increased producing biomass. Therefore, microcystis toxins are not varied according to the growth of algae.

Another important environmental factor is temperature. Watanabe (1996) discovered that *Microcystis aeruginosa*, species M228 are the most toxicant in the temperature of 18 °C. Van Der Westhuizen and Eloff (1985) and Codd and Poon (1988) found out that *M. aeruginosa* produce more toxins in the temperature of 15, 28 and 38 °C.

Microcystis can be found in any natural conditions all year round, especially in rather warm or tropical areas. (Park and Watanabe, 1996) For example, *M. aeruginosa* can be seen at Hartbeespoort Dam in South America almost all through the year and they are spotted as scum during the winter when the water temperature drops to 11-12 °C (Zohary and Robarts, 1989).

The pH is one of many physical growth factors of cyanobacteria. The study at Steilacoom Lake revealed that the increased pH help speed up the growth of cyanobacteria. (Jacoby *et al*., 2000) The result from the experiment proved that while the toxins of cyanobacteria are the lowest at the pH 9.0, the growth rate is the highest too (Eloff and Van der Westhuizen, 1981).

Another chemical factor is nutrients as they are necessary for phytoplankton, especially cyanobacteria. (Park and Watanabe, 1996) Cyanobacteria grows well in high nutrients water therefore may assume that they need high intensity of nitrogen and phosphorus. However, they can also grow where there are low intensity of water dissolved phosphorus. It is possible that cyanobacteria can compete with other planktons where nitrogen and phosphorus are limited conditions. (Mur *et al*., 1999) Steilacoom Lake in Washinton, Jacoby *et al*. (2000) discovered that *Microcystis* sp. grew better in low N:P and low nitrate and nitrogen, but there was unstable toxin production in the Summer of year 1994 and 1995. They also found that the intensity of microcystis was related to the increased amounts of soluble reactive phosphorus. This suggested that the ability in producing toxins was limited by the amount of phosphorus. Kotak *et al*. (2000) chose high nutrients waters in Alberta as their study areas and learned that *M. aeruginosa* and MC-LR were positively related to the amount of phosphorus, but negatively related to the ratios of N:P and organic nitrogen.

Besides the nutrients, Zn and Fe also affect the produced amounts of cyanobacterial toxins (Watanabe, 1996) by Utkilen and Gjølme (2001) found out that toxic *M. aeruginosa* develop and grow better in the water rich in Zn, but non-toxic *M. aeruginosa* cannot grow or grow very slowly in a limited Zn condition.

Apart from all factors mentioned, the rapid growth of cyanobacteria is highly related to the growth rate. Reynold (1984) stated that normally, the growth rate of cyanobacteria is lower than other algae's. The algae with low growth rate usually grow well in high retention times water. That is to say, it is rare to find cyanobacteria in low retention times water. Moreover, Watanabe *et al*. (1989) revealed that microcystis toxins are growing more exuberantly during the exponential phase than the stationary phase or death phase.

Durations and seasons are also influential to the algae growth. The colonies of *Microcystis* sp. float during the day and the float is doubled up during the night. *Microcystis* sp. grow well during summers and rainy seasons. They multiply better in higher temperature and with vacuole gas, they can compete with other types of algae since larger colonies will be able to float or sink much quicker than other unicellular algae (Goldman and Horne, 1983). *Microcystis* sp. will be found at the bottom of the lakes during the winter, and they can live for 2-3 years without sunlight or oxygen, they will float again in summer when the sunlight gets to them (Reynold *et al*., 1981).

2.5.7 The studies of eutrophication in Thailand

There are extensive studies of eutrophication phenomena primarily in important bodies of water in the country such as Songkla Sea, Noi Sea, etc.

Specifically in Songkla Sea, The Institute of Coastal Fisheries, Songkla Province has studied the amount of necessary nutrients like Nitrogen and Phosphorus in the lake during 1992-2003 and found out that there was a dramatically rapid spread of large aquatic plants which almost all of them were *Najas* sp. Consequently, Cladophora was found growing over *Najas* sp. covering large areas (La-ongsiriwong *et al*. (2004)).

Additionally, in certain parts in the central of the lake, phytoplankton called *Spirogyra* was found having an unusually rapid increase in numbers covering large areas. Such phytoplankton was clearly visible and noticeable (Department of System Research and Management of Coastal Fisheries, 2004).

Chaichana (2003) studied the amount and the spread of plant nutrients that led to the eutrophication in Bang Phra Reservoir, Chonburi Province and found phytoplankton called *Aulacoseira* which is in Division Chromophyta and found most in June and November, 2001 and January, 2002, it could be said that during such months there were phenomena of phytoplankton booming.

Thitisutti *et al*. (2005) studied the diversity, the spread and the profound research on the ecosystem of plankton population in Doi Tao Reservoir, Chiang Mai Province from October 2003-September 2004. All phytoplankton found during the study are in 7 divisions, 66 genus, 185 species. *Anabaena* sp., *Aulacoseira granulate* (Ehrenberg) Ralfs and *Microcystis auruginosa* Kutzing are outstanding phytoplankton.

Keawsi *et al*. (2009) revealed the study on the effects of area usage and human activities toward certain water quality. This also covered the study of the variety of phytoplankton in Payao Lake, Payao Province during May-September, 2008. All phytoplankton found are in 3 divisions, 30 families, 65 genus by which they are in

Division Cyanophyta 4 families, 9 genus; Division Chlorophyta 10 families, 29 genus; Division Chromophyta 16 families, 27 genus and the planktons recovered in the study area are *Microcystis* sp. and *Anabaena* sp.

Manokum (2008) studied the eutrophication in community waters and recovered that the amount of rain was one of many factors that led to the eutrophication. Surface soil erosion and surface flow caused by rainfall that flows from communal and agricultural areas into water resource made sediment and suspension accumulated in water during rainy season, consequently intensified P-PO_4^{3-} and led to eutrophication.

Blue-green algae that spreads fast and causes the most trouble in Thailand is *Microcystis.* The reported types of this algae found were *M. aeruginosa*, *M. viridis*, *M. ichthyoblabe* and *M. wesenbergii* (Yongmanitchai *et al*., 1991).

Peerapornpisal and Peggao (2005) took a study on the variety of cyanobacteria that toxicated 70 water bodies in Thailand from October 2002 to December 2004 and found toxicant cyanobacteria in 8 families 16 types. The most commonly found are *Cylindrospermopsis raciborskii* (Wolosz) Seenayya & Subba and *Microcystis auruginosa* Kutzing. In addition, the levels of nutrients in water were ranged from deficient, moderate to excessive consequently. Khomsan et al is currently studying how to control and terminate *Microcystis auruginosa* Kutzing, one of many toxic cyanobacteria using biological methods (La-ongsiriwong *et al*., 2004).

Due to several occurrences of eutrophication phenomena in Lam Taklong Reservoir in 1998, Panuvanitchakorn (2003) studied the spread of toxic microcystis as well as the water quality in Lam Taklong Reservoir, Nakhon Ratchasima Province during 2000-2001. She discovered nine other toxic bacteria namely *M. auruginosa* Kutzing, *M. weesenbergii* komarek, *Cylindrospermopsis raciborskii* (Wolosz) Seenayya & Subba, *Aphanizomenon* sp., *Anabaena catenula* (kg.) Born et Flah., *Anabaena aphanizomenoides* Forti, *Anabaena spiroides* Kelbahn, *Anabaena* sp. and *Lyngbya* sp. The least found was *M. auruginos*a and the number of this bacterium rose up in March, 2001 while *C. raciborskii*, most commonly found during the studies, was gauged to have spread approximately 673 cell/mL. Moreover, the water quality in Lam Taklong Reservoir was evaluated to be mesotrophic and in the 2-3 category (Good-Fair) when compared to the standard of surface water quality.

After 1998, there have been reportedly more frequent eutrophocation phenomena in Lam Taklong Reservoir. One of the phenomena in the mentioned reservoir was in 2007 (Figure 2.7).

Figure 2.7 Eutrophication phenomenon in Lam Taklong Reservoir in September, 2007.

CHAPTER III

MATERIALS AND METHODS

3.1 Water quality assessment

3.1.1 Water quality in Lam Takong River in 13 years (1996-2008)

The water quality analysis in 13 years from 7 stations in Lam Takong main river collected by the second data from the Pollution Control Department. The water sample was sampling at the middle of river. The water sampling stations were shown in Table 3.1 and Figure 3.2.

The data of water quality of Lam Takong Basin during 13 years period from 1996 to 2008 obtained from the Pollution Control Department were assessed. Dissolved oxygen, Biochemical Oxygen Demand, Ammonia, Nitrate, Total Phosphorus, and Conductivity were used for water quality index of Lam Takong.

Table 3.1 Water sampling site of the Pollution Control Department.

Station No.	Area	Geographic position
LT1	Ban Bukachad	14°6397 'N, 101°4205'E
LT2	Ban Nong Salai	14°7277 'N, 101°4373'E
LT3	Quartermaster Department Royal Thai Army Bridge	14°4759'N, 101°4581'E
LT4	Klong Pai	14°8571'N, 101°5591'E
LT5	Ban Kutchanuan	14°8421'N, 101°6142'E
LT6	Wat-Samukkee	14°9814'N, 101°1083'E
LT7	Ban Yongyang	14°0085'N, 102°2050'E

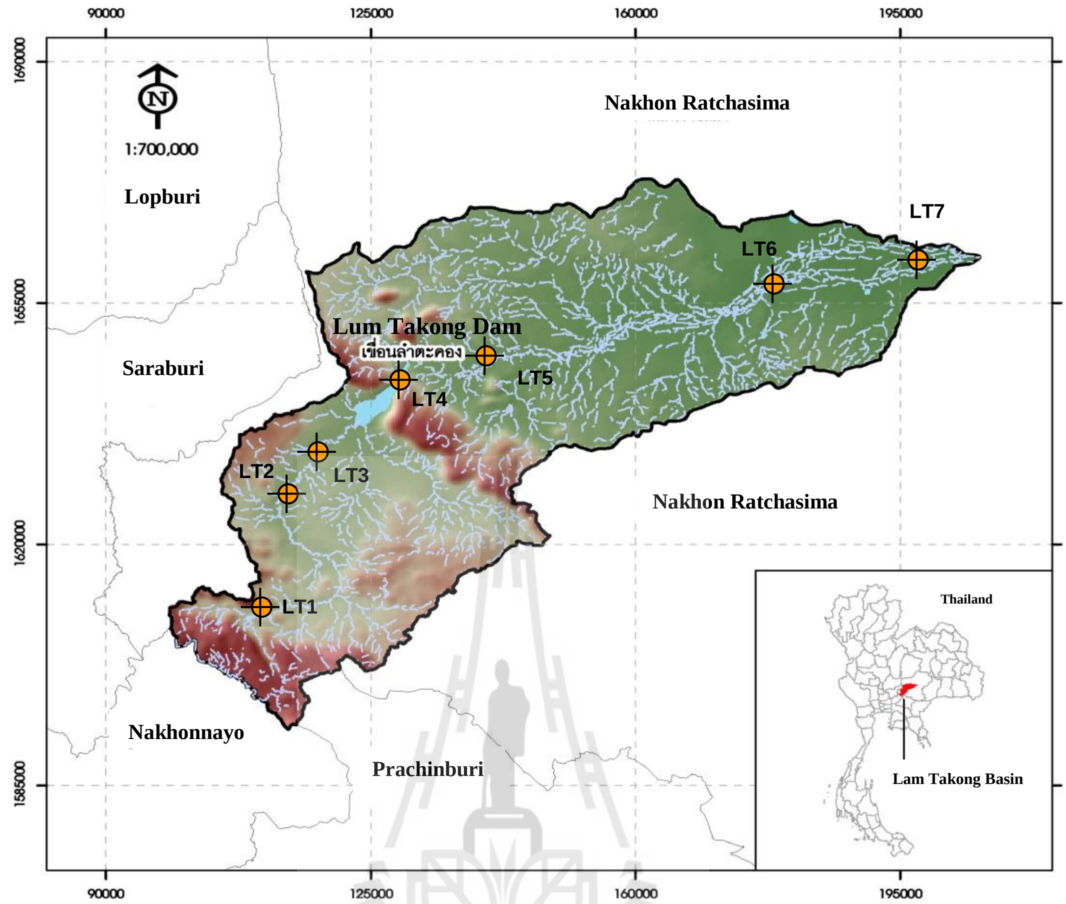


Figure 3.1 Water sampling stations of the Pollution Control Department.

3.1.2 Water quality in Lam Takong basin and tributaries in 2008-2009

A total 20 sites were studies in the riverine network along Lam Takong Basin (Table 3.2 and Figure 3.2). Water samples were collected at light intensity level depth three times in October and December 2008 to February, April, June, and August 2009.

Table 3.2 Sampling stations in Lam Takong Basin.

Station No.	Area	Geographic position
1	Lam Takong headwater ,Khao Yai National Park	14°26.137 'N, 101°22.848'E
2	Bukachad Bridge	14°63.976 'N, 101°42.059'E
3	Ban Thamanao Bridge	14°72.773'N, 101°43.742'E
4	Quartermaster Department Royal Thai Army Bridge	14°75.982'N, 101°45.818'E
5	Klong Yang	14°73.546'N, 101°50.951'E
6	Huai Hinlub	14°75.989'N, 101°51.764'E
7	Lam Takong Dam	14°85.715'N, 101°55.952'E
8	Huai Numsub	14°87.207'N, 101°56.123'E
9	Huai Subwa	14°84.193'N, 101°61.438'E
10	Ban Kutchanuan Bridge	14°87.742'N, 101°69.224'E
11	Ban Bunglamyai Bridge	14°88.043'N, 101°74.285'E
12	Kut Hin barrage	14°91.566'N, 101°82.784'E
13	Huai Subtakhor	14°91.398'N, 101°93.517'E
14	Kham Thale So Bridge	14°93.847'N, 101°95.100'E
15	KonChum barrage	14°98.472'N, 102°05.257'E
16	Lam Bariboon Bridge	15°02.446'N, 102°13.655'E
17	Wat-Samukkee Bridge	14°98.116'N, 102°10.870'E
18	Ban Tha Krasang	14°98.739'N, 102°14.569'E
19	Yongyang Bridge	15°00.849'N, 102°20.506'E
20	Kunphum barrage	15°01.408 'N, 102°23.366'E

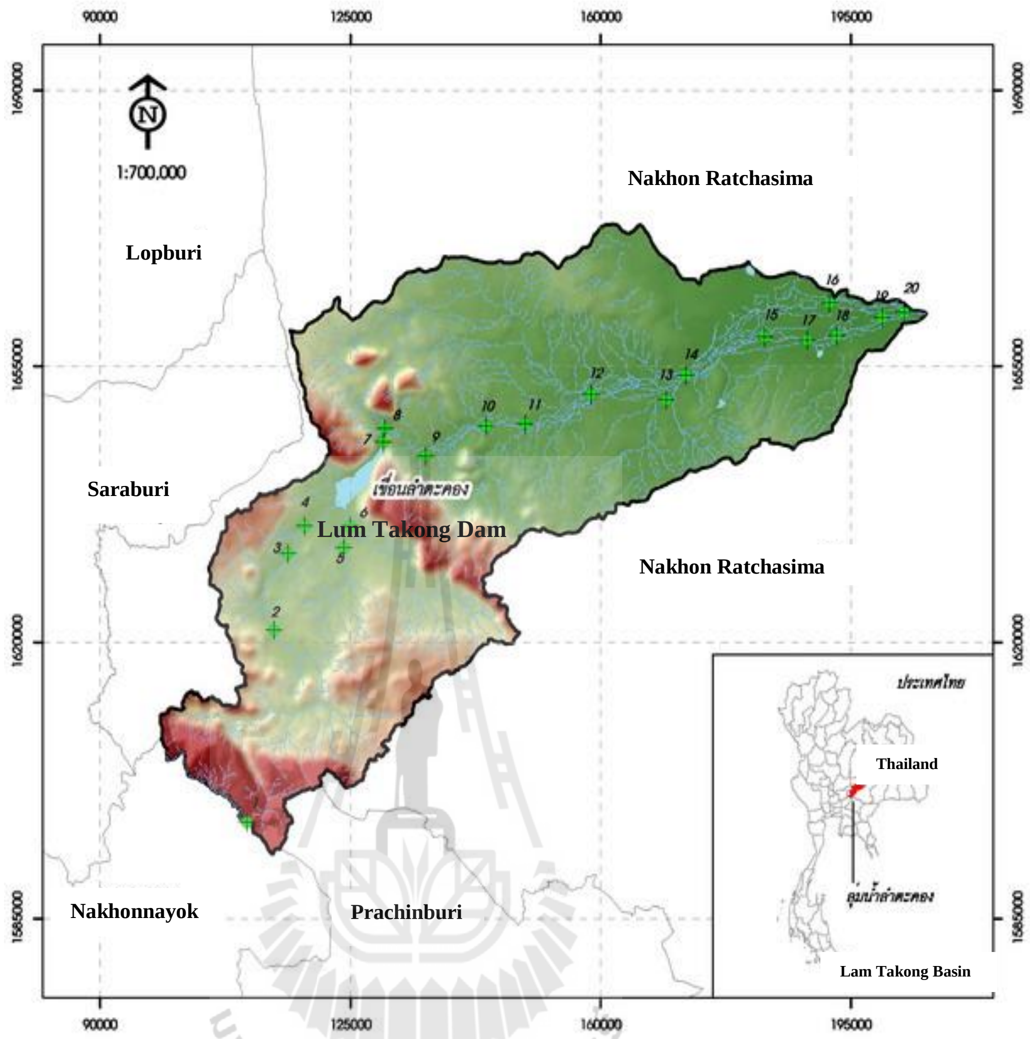


Figure 3.2 Water sampling stations of Lam Takong Basin in 2008-2009.

The water samples were stored in PE bottles which using previously acid-washed and refrigerated at 4 °C for later laboratory analysis. Water samples were analyzed by the methods described in the *Standard Method for Examination of Water and Wastewater*, (APHA, AWWA and WPCF, 1999) as shown in Table 3.3

Table 3.3 Methods and instruments for water analyses.

Parameter	Method/Instrument
pH*	pH meter
Temperature*	Thermometer
Conductivity*	Conduct meter
Turbidity*	Turbidimeter
Salinity*	Salinity probe
Total Suspended Solid (TSS)	Filter and dry at 105 °C
Dissolved Oxygen (DO)*	DO meter
Biological Oxygen Demand (BOD)	BOD 5 day
Ammonia (NH_3-N)	Distillation technique
Nitrite (NO_2-N)	Ion chromatography
Nitrate (NO_3-N)	Ion chromatography
Phosphate (PO_4)	Ion chromatography
Total Organic Carbon (TOC)	TOC Analyzer
Chlorophyll a (Chl-a)	Filter and Spectrophotometry
Phytoplankton	Microscope

Remark: * Measured on-site

3.2 Trophic level assessment

3.2.1 Trophic level status in Lam Takong River in 13 years (1996-2008)

The physical and chemical properties of water in Lam Takong River from 1996-2008 of the Pollution Control Department i.e. colour and odor of water, pH, DO, BOD, EC, Chlorophyll a contents, amount of nitrate nitrogen, ammonium nitrogen and soluble reactive phosphorous were used in combination to evaluate the trophic level (Applied Algal Research Laboratory, 2006) This water quality assessment is called "AARL- PC Score" which applied by Lorraine and Vollenweider (1981) and Peerapornpisal *et al*. (2004) as shown in Appendix A. For this study, six parameters of water including DO, BOD, EC, amount of nitrate- Nitrogen, ammonium-Nitrogen and soluble reactive phosphorous were assessed. The water quality was categorized into 6 statuses using 1-10 score. Each status was divided by the data from the water analyses. The standard score of water quality base on trophic level status were used to classify the trophic status as show in Table 3.4.

Table 3.4 Water quality scores followed trophic level and general water quality (Applied Algal Research Laboratory, 2006).

Score	Water quality by trophic level	General water quality
1.0-2.0	Oligotrophic status	Clean
2.1-3.5	Oligo-mesotrophic status	Clean- moderate
3.6-5.5	Mesotrophic status	Moderate
5.6-7.5	Meso-eutrophic status	Moderate- polluted
7.6-9.0	Eutrophic status	Polluted
9.1-10.0	Hypereutrophic status	Very polluted

3.2.2 Trophic status of Lam Takong river and tributaries in 2008-2009

For study the water quality by trophic level, 20 stations of water samples were collected from Lam Takong main river and tributaries that flows through six districts of Nakhon Ratchasima province for 6 months. Six parameters of water including DO, BOD, EC, amount of nitrate- Nitrogen, ammonium-Nitrogen and soluble reactive phosphorous were assessed (AARL- PP Score) as in 3.2.1.

3.3 The seasonal effect on Lam Takong water quality

Data of rain fall from Thai Meteorological Department in 2009 and water quality of Lam Takong Basin in 2008-2009 were used for compare correlation water qualities between dry (October, December 2008 and February 2009) and rainy season. (April, June and August 2009). The seasonal effect on water parameters were tested using *t*-test with statistical significance when $p < 0.05$. All the statistical analyses were performed by using SPSS 13.0 for windows.

3.4 Land use type classification

3.4.1 Land use type in Lam Takong Basin

Land use data file of Nakhon Ratchasima province in 2008 (Department of Land Development) and Topographic map (Scale 1: 50,000; Royal Thai Survey Department) were classified land use type in Lam Takong Basin by using Arc view 9. Land use type in each subbasins of Lam Takong Basin was also classified. There are 9 land use types were classified including Agricutural area, Forest, Mixed orchard, Urban, Scrub forest, Flat area, Industrial area, Water body, Grassland.

3.4.2 Land use change (change detection)

For study land use change, Nine land use types were classified including Agricutural area, Forest, Mixed orchard, Urban, Scrub forest, Flat area, Industrial area, Water body, Grassland by using land use data file of Nakhon Ratchasima province in 2001 and 2008 from Department of Land Development. In each land use type were compared by year using Arc view 9.

3.5 Loading assessment

The carrying capacity of water resource (BOD Loading) can be determined by assess pollutant from point source in basin and calculated by the amount of wastewater from point source multiply by BOD value of water (Regional Environment Office 11, 2009).

BOD loading = Q x BOD / 1000

When Q = flow rate (m^2/day)

BOD = BOD value (mg/L)

Due to the pollution source is both point source and non- point source, point source such as urban wastewater can be estimated from the volume of wastewater from 80% of water demand. In the other hand, non-point source such as agricultural land, BOD loading can be calculated by assess data of water runoff and rain fall (Thai Meteorological Department, 2009). The surface water runoff (mm) multiplied by drainage area (km^2) and BOD of runoff from each land use type as shown in Table 3.5. For this study, Sources of pollution in the area of Lam Takong Basin can be divided into 5 major sources including urban, industry, agriculture, livestock and aquaculture area.

Table 3.5 BOD value of runoff (Intarapirat, 2009).

Land use type	BOD value of runoff (mg/L)
Agriculture area	3.83
Forest	2.05
Shrub	2.37
Community forest	4.40

3.6 Effect of land use on Lam Takong water quality

Studying the effect of land use on Lam Takong water quality, Data of land use type from Department of Land Development were used. Land use type and area were classified. Subbasins of Lam Takong Basin can be divided into 36 subbasins. In each subbasins has the same land use type but different area. Biochemical Oxygen Demand, Dissolved Oxygen, Ammonia, Nitrate, Phosphate, Chlorophyll-a were representative of water parameters. Land use types in each subbasin that flowed into each sampling station and water quality was analyzed by using Pearson Correlation method ($p<0.01$) in SPSS program version 16.

3.7 Prediction of water quality in Lam Takong basin

Three types of land use that has mostly correlation with each water quality (result from 3.6) were determined water quality prediction. Multiple regression analysis is the tool of SPSS program version 16 was used. The model which has highly R^2 value is suit for prediction water quality of Lam Takong River. Although the R^2 value is nearly by other models, the model which has a few variables is better.

3.8 Water quality modeling in Lam Takong basin

The result of water quality analysis in Lam Takong River and tributaries (2008-2009) were used to predict the water quality in the middle and lower part of Lam Takong due to these areas are crowded with population, agriculture areas, and factories. WASP Model was used for prediction (Jame,1993). Complexity Level 2^c or Modified Streeter–Phelps with NBOD (Nitrogenous Biochemical Oxygen Demand) method was selected that can be considered the relationship between BOD-DO with SOD (Sediment Oxygen Demand) and NBOD (Nitrogenous Biochemical Oxygen Demand). Mostly of variables and other constants were followed default of model and literature review were shown in Tables 3.6-3.7 (United States Environmental Protection Agency, 2010).

Table 3.6 Variables and Kinetic Processes.

KINETIC PROCESSES	
1. Ammonia(NH_3)	**2. Dissolved Oxygen (DO)**
Mineralization of Organic Nitrogen	Reaeration
Phytoplankton Death	Phytoplankton Growth
Algal Uptake (Growth)	Nitrification
Ntrification	CBOD Oxidation
	Sediment Oxygen Demand

Table 3.6 Variables and Kinetic Processes. (Continued).

KINETIC PROCESSES
3. Carbonaceous Biochemical Oxygen Demand (CBOD)
Phytoplankton Death
Oxidation
CBOD Denitrification
Setting

Table 3.7 Constant value in WASP model.

Variable	Constant	Sources
Ammonia		
Nitrification Rate Constant @ 20 °C (per day)	0.1	Typical Default
Nitrification Temperature Coefficient	1.08	Typical Default
Nitrate		
Denitrification Rate Constant @ 20 °C (per day)	0.5	Typical Default
Denitrification Temperature Coefficient	1.05	Typical Default
Oganic N		
Dissolved Organic Nitrogen Mineralization Rate Constant @ 20 °C (per day)	0.001	Typical Default
Dissolved Organic Nitrogen Mineralization Temperature Coefficient	1.05	Typical Default
Faction of Phytoplankton Death Recycled to Organic Nitrogen	0.5	Typical Default
Organic P		
Mineralization Rate Constant for Dissolved Organic P @ 20 °C (per day)	0.22	Typical Default
Factor of Phytoplankton Death Recycled to Organic Phosphorus	1	Typical Default
CBOD		
BOD (1) Decay Rate Constant @ 20 °C (per day)	0.5	Typical Default
BOD (1) Decay Rate Temperature Correction Coefficient	1.05	Typical Default

Table 3.7 Constant value in WASP model (Continued).

Variable	Constant	Sources
BOD (1) Half Saturation Oxygen Limit (mg/L)	0.5	Typical Default
Phytoplankton		
Phytoplankton Light Formulation Switch (1=DiTOro, 2=Smith)	1	Typical Default
Phytoplankton Carbon to Chlophyll Ratio	30	Typical Default
Phytoplankton Optimal Light Saturation	300	Typical Default
Phytoplankton Phosphorus to Carbon Ratio	0.025	Typical Default
Phytoplankton Phosphorus to Carbon Ratio	0.25	Typical Default
Dissolved Oxygen		
Oxygen : Carbon Stoichiometric Ratio	2.66	Typical Default
Reaeration Rate Constant @ 20 °C (per day)	0.22	Typical Default
Transformation		
CBOD : BOD_5	1.09	Simachaya, 1999
SOD g/(m^2/d)	0.36-0.69	Simachaya, 1999
Dispersion Coefficient (m^2/s)	1	Simachaya, 1999

3.8.1 Model calibration and validation

WASP (Water Quality Analysis Simulation Program) was started with calibration each parameter after that validation for prediction the value of pollutant at that time. In addition, only DO value of ten water sampling stations in main river after Lam Takong Dam were used. The data in February 2009 were selected for model calibration until the simulated DO value is close to observed DO value in April 2009. After model calibration, DO value was used for model validation by compare with DO value in August 2009.

3.8.2 Scenario setting

An interesting scenarios are consisted of basic case and reduce pollutant loading case. In this study has 3 scenario including :

Scenario 1 Present situation (Lam Takong water quality in 2008).

Scenario 2 Future situation (Lam Takong water quality in 2018).

Scenario 3 Future situation (Lam Takong water quality in 2018 when reducing pollutant loading 25% off.).

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Water qualities in Lam Takong River from 1996-2008

The Pollution Control Department monitored water quality of Lam Takong Basin during 13 years period from 1996 to 2008 from total of seven sampling stations (Figure 3.2). The water qualities were shown in Appendix B. Particularly, these study was also interested. The annual average value of each parameter has been presented in Figures 4.1-4.7

4.1.1 Dissolved oxygen

Dissolved Oxygen were found to be in the range of 0-9.5 mg/L (Figure 4.1). During the 13 years period, the samples were collected at the station LT6 (Wat-Samukkee) has the minimum amount of Dissolved Oxygen especially, in 1998 because these stations were point of Lam Takong river flow through the municipality of Nakhon Ratchasima. The second lowest is station LT7 (Ban Yongyan) that located at downstream of Lam Takong River.

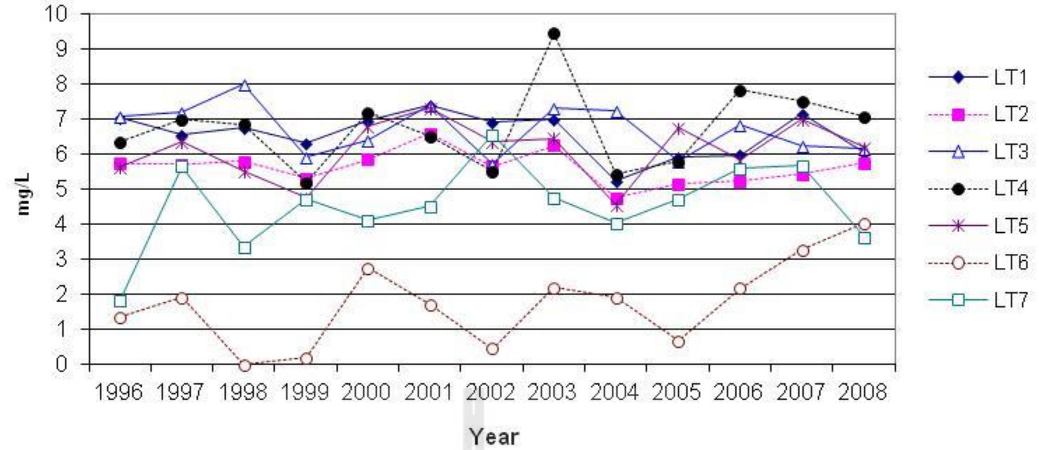


Figure 4.1 The annual average of Dissolved Oxygen in Lam Takong River From 1996-2008.

4.1.2 Biochemical oxygen demand

BOD values from 1996-2008 were in the range of 0.6-10.2 mg/L (Figure 4.2). From the graph, the average BOD were collected at LT6 (Wat-Samukkee) and LT7 (Ban Yongyan) has high value in 1998. The trend of BOD will be slightly up from headwater to the end.

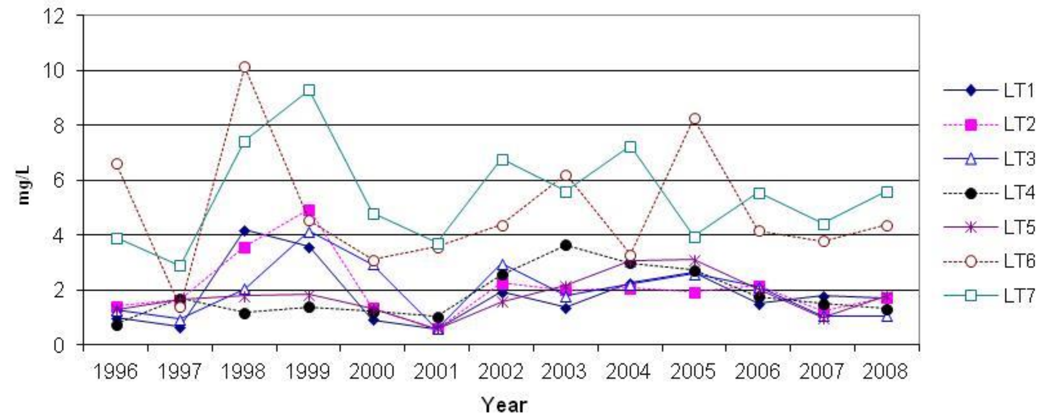


Figure 4.2 The annual average of BOD in Lam Takong River from1996-2008.

4.1.3 Ammonia

Ammonia found to be in the range of in the range of 0.00-15.87 mg/L (Figure 4.3). The annual average of ammonia was highest at station LT6 (Wat-Samukkee) where Lam Takong flow through Nakhon Ratchasima Municipality, especially in 1998 and 2008.

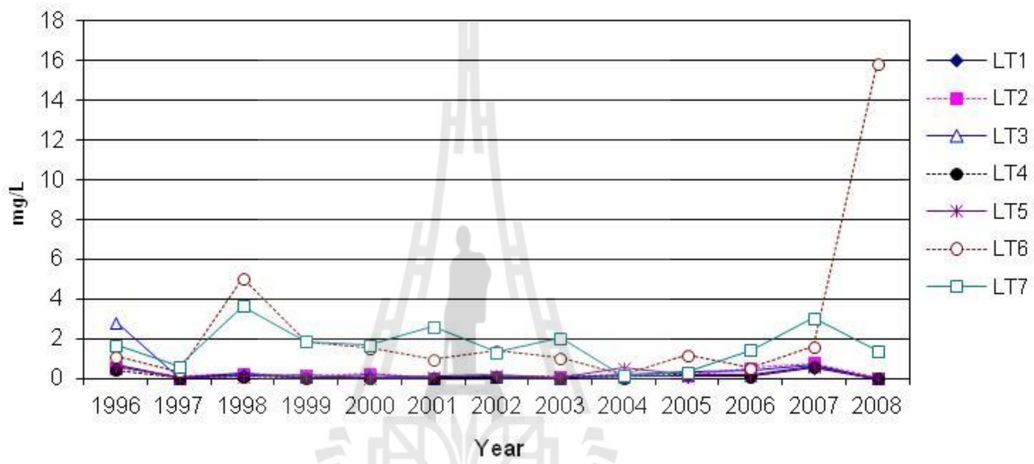


Figure 4.3 The annual average of ammonia in Lam Takong River from 1996-2008.

4.1.4 Nitrate

Nitrate of each station in Lam Takong River from 1996-2008 were in the range of 0.02-4.77 mg/L (Figure 4.4). In 2000, the annual average of nitrate was highest at LT3 (Quartermaster Department Royal Thai Army Bridge) and LT2 stations (Ban Nong Salai), respectively. Agricultural and farming activities which crowded in this area are the major cause of nitrate contamination.

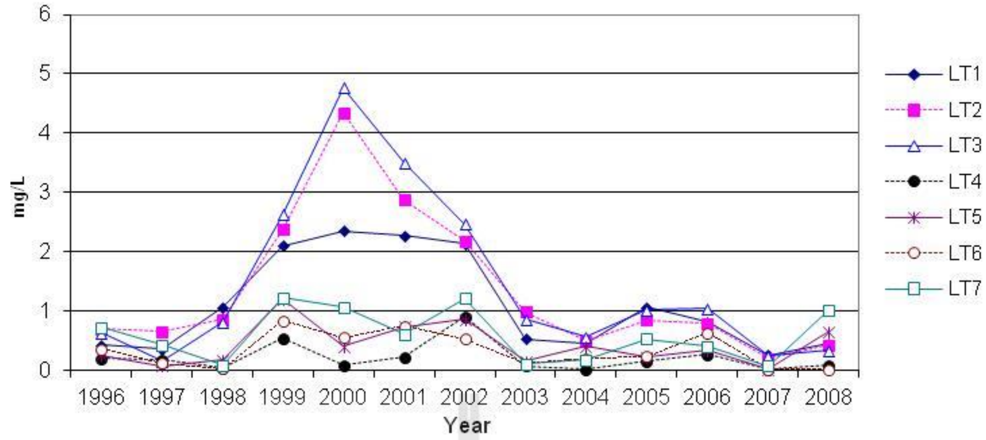


Figure 4.4 The annual average of nitrate in Lam Takong River from 1996-2008.

4.1.5 Total phosphorus

Total Phosphorus were found to be in range 0-1,150.1 mg/L (Figure 4.5) which is very unusual in March at station LT1(Ban Bukachad), LT2 ((Ban Nong Salai), and LT3 (Quartermaster Department Royal Thai Army Bridge) was 40, 1,150.1, 200.2 mg/L, respectively. The annual average Total Phosphorus of each station by cutting unusual values was found that the high value were at station LT6 (Wat-Samukkee) and LT7 (Ban Yongyan) in 1998, 2001, 2004, 2005.

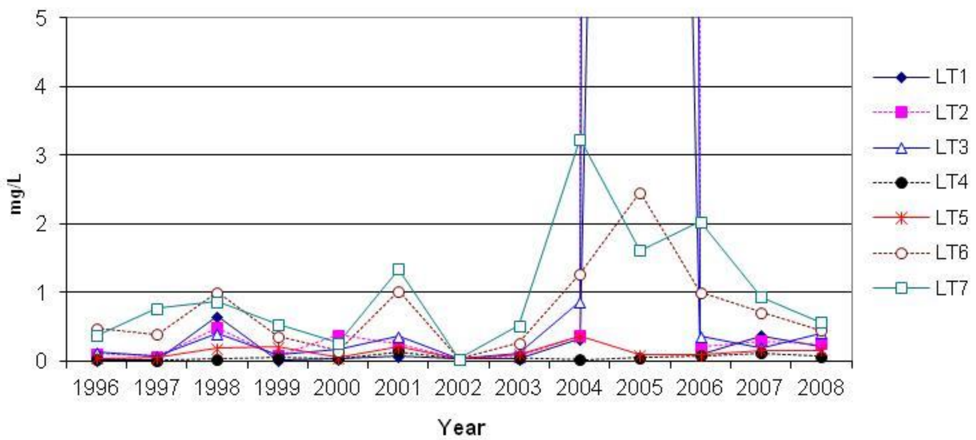


Figure 4.5 The annual average of Total Phosphorus in Lam Takong River from 1996-2008.

4.1.6 Conductivity

Conductivity from 1996 to 2008 were in the rang 252-1,270 mS/cm (Figure 4.6), The average of conductivity of each year showed that the maximum value at LT6 (Wat-Samukkee) and LT7 (Ban Yongyan), especially in year 2005, 2001, 2000, respectively.

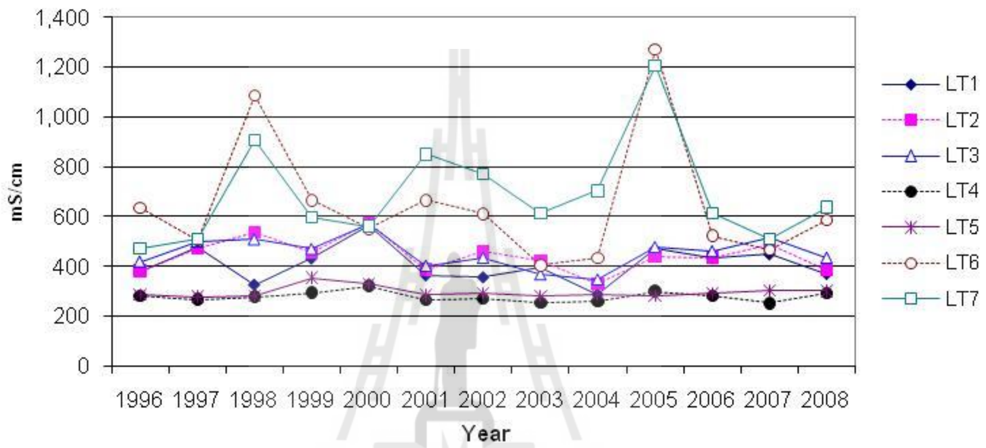


Figure 4.6 The annual average of conductivity in Lam Takong River from 1996-2008.

4.2 The water quality in the Lam Takong River and tributaries in 2008-2009

A total of 20 sampling sites were selected in the main river and tributaries of Lam Takong River of Thailand. The study was conducted 6 times during October 2008 to August 2009.

4.2.1 pH

The pH of Lam Takong River and tributaries in 6 months were in the range of 4.85-8.50 (Figure 4.7 and 4.8) , still in the range of water quality standard of surface water (pH 5-9). The station 5 (Klong Yang) had a minimum value while the maximum value was Station 7 (Lam Takong Dam) in August 2009. There was a lot of rain in August 2009, therefore the different pH value between water sampling stations were higher than any other months.

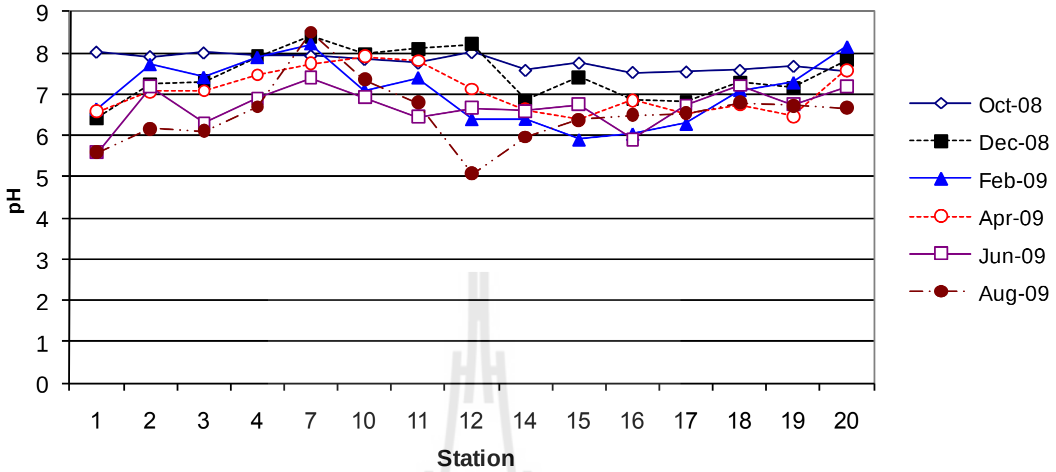


Figure 4.7 pH values of Lam Takong main river.

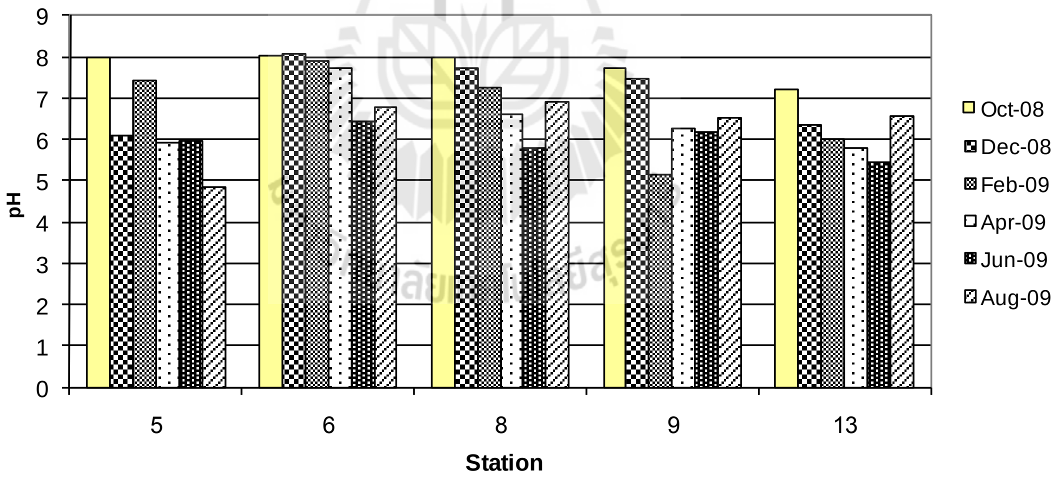


Figure 4.8 pH values of Lam Takong tributaries.

4.2.2 Temperature

The comparison of temperature at each station in the same month was different because it due to the different of day time and terrain to collecting water samples. The minimum temperature found at station 1 (Lam Takong Headwater) was

18.0-31.4 °C (Figures 4.9 and 4.10). The Lowest temperature found in December 2008 because it was cold season.

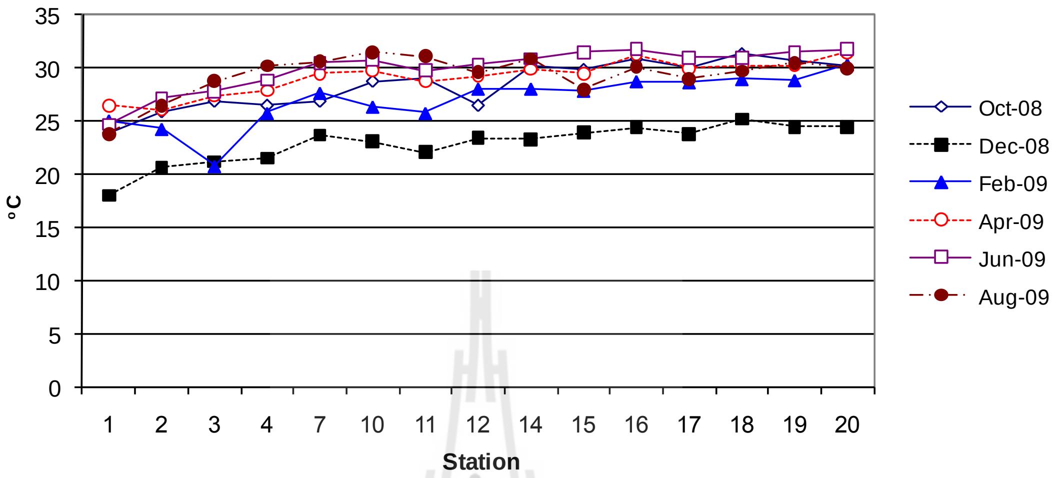


Figure 4.9 Temperature value of Lam Takong main river.

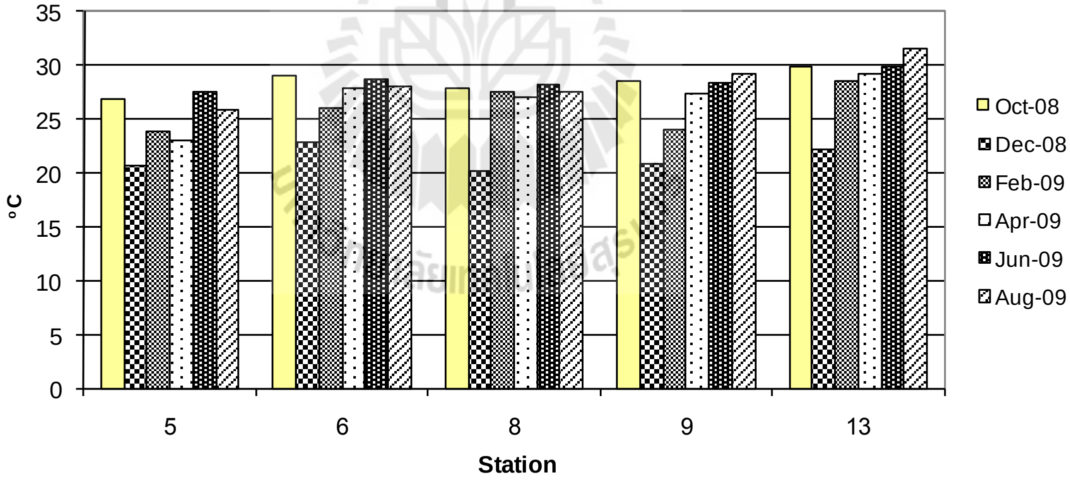


Figure 4.10 Temperature value of Lam Takong tributaries.

4.2.3 Conductivity

The value of Conductivities in each stations were found in the rage of 38-957 mS/cm (Figures 4.11 and 4.12). The minimum value was found at station 1 (Lam Takong Headwater) in June 2009 while the maximum value was found at station 3 (Ban Thamanao Bridge) in October 2008 during rainy season. The conductivity values were changed in each month. This might be attributed to type and concentration of ion and temperature when measured.

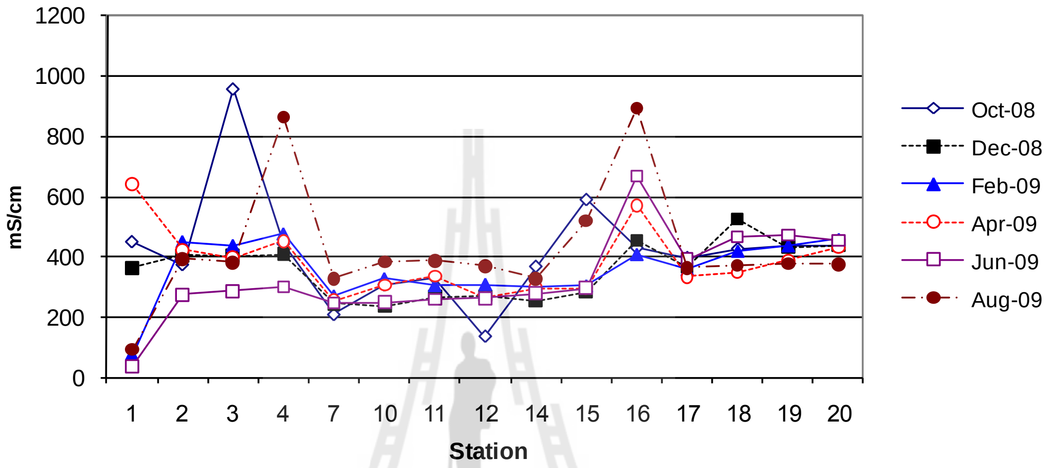


Figure 4.11 Conductivity values of Lam Takong main river.

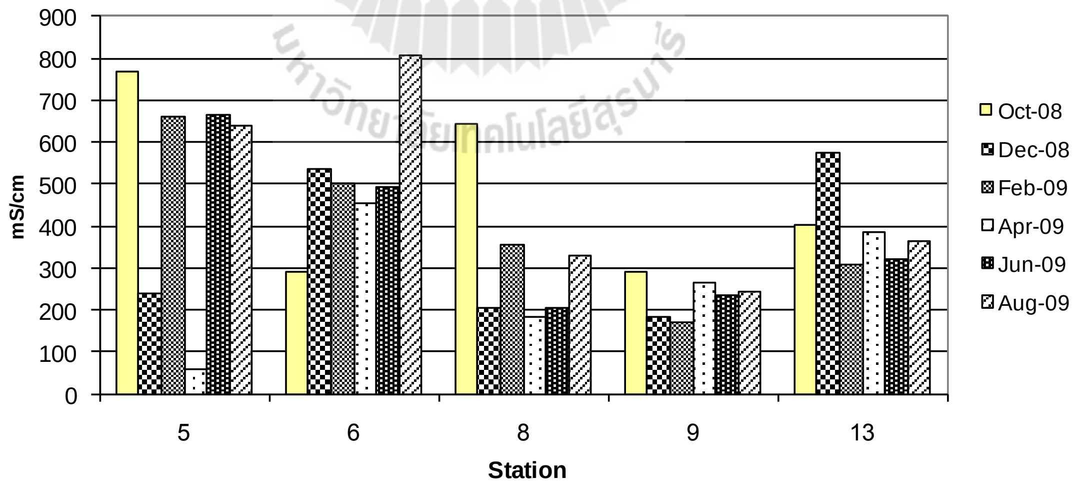


Figure 4.12 Conductivity values of Lam Takong tributaries.

4.2.4 Turbidity

Turbidities in Lam Takong Basin showed that its in the range of 1.47-164 NTU (Figures 4.13 and 4.14). The station which has high turbidity was station 4 (Quartermaster Department Royal Thai Army Bridge). In this station, Lam Takong has high velocity especially in August 2009. The low value of turbidity found at station 2 (Bukachad Bridge). Most of turbidity found to be higher during periods of high rainfall, April onwards.

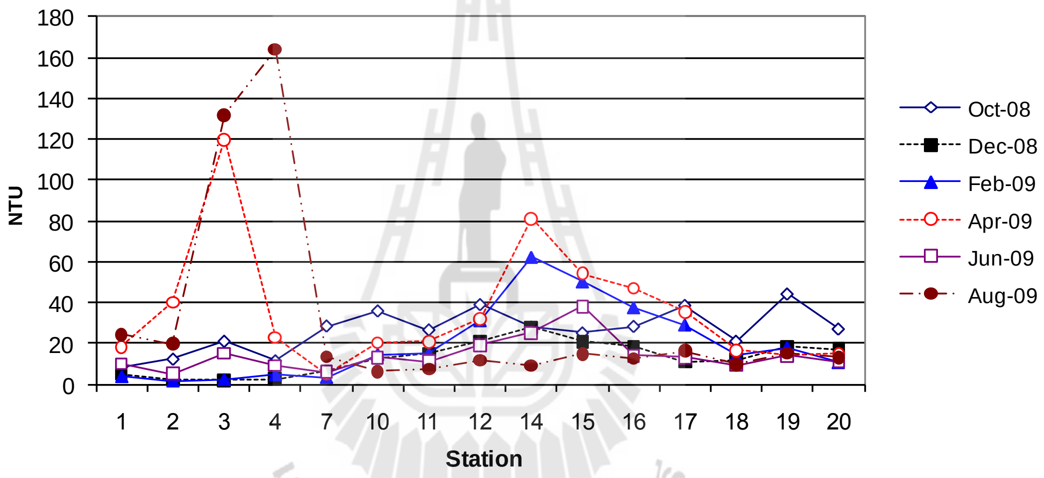


Figure 4.13 Turbidity values of Lam Takong main river.

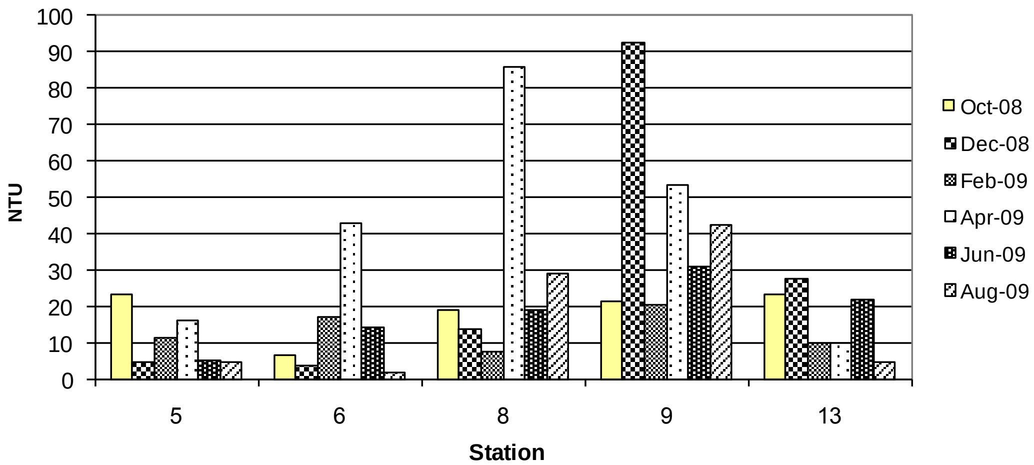


Figure 4.14 Turbidity values of Lam Takong tributaries.

4.2.5 Salinity

The salinity values of water were in the range of 0.0-0.4 ppt (Figures 4.15 and 4.16). The highest salinity was found at station 4 (Quartermaster Department Royal Thai Army Bridge), station 6 (Huai Hinlub), and station 16 (Lambariboon Bridge) during rainy season in August 2009. At Korat plateau, It has salt rock in underground. The surface runoff which flow through the limestone layer coursing the saline water in Lam Takong main river and tributaries.

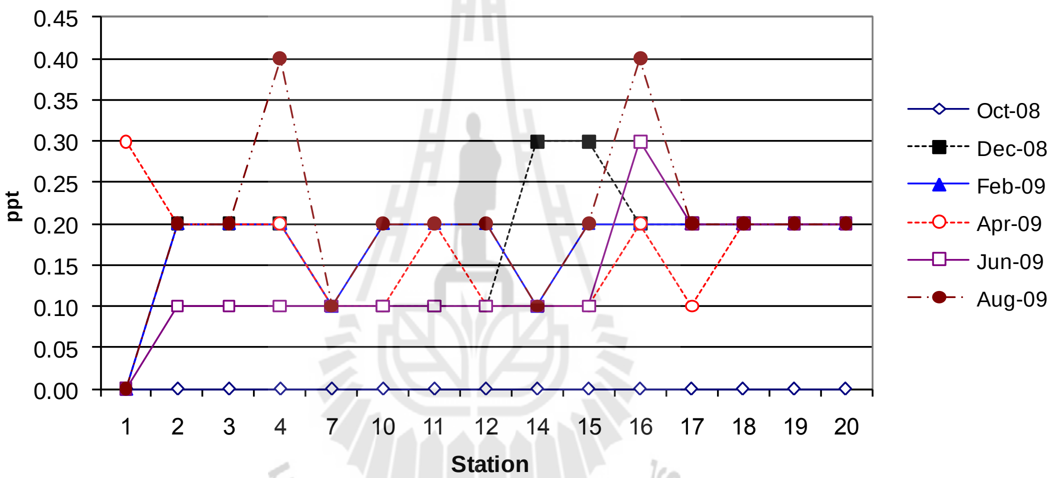


Figure 4.15 Salinity values of Lam Takong main river.

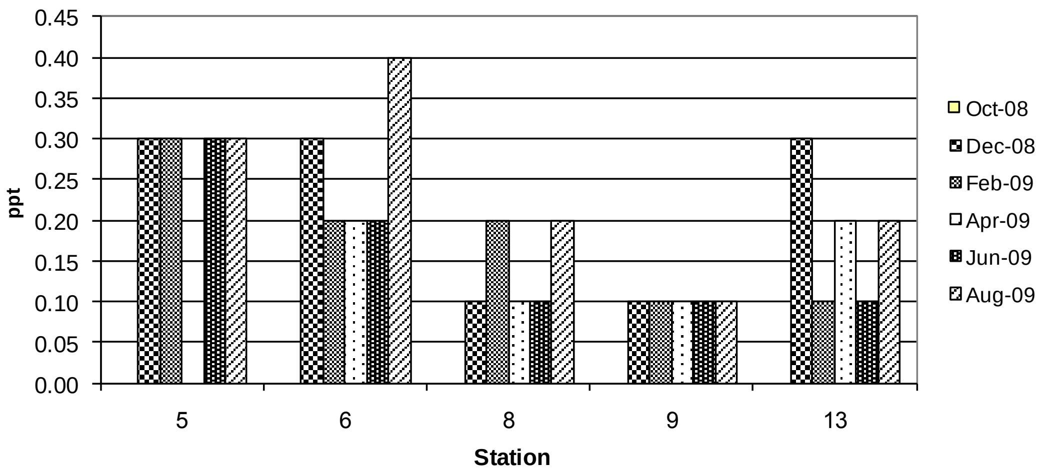


Figure 4.16 Salinity values of Lam Takong tributaries.

4.2.6 Total suspended solid

Total Suspended Solid found in the range of 1-1,325 mg/L (Figures 4.17 and 4.18) was higher in August 2009 at station 4 (Quartermaster Department Royal Thai Army Bridge). In June-August 2009, the value of Total Suspended Solid has a lot of changed because there was a lot of rainfall in basin during these months. The Lowest value was found in October 2008.

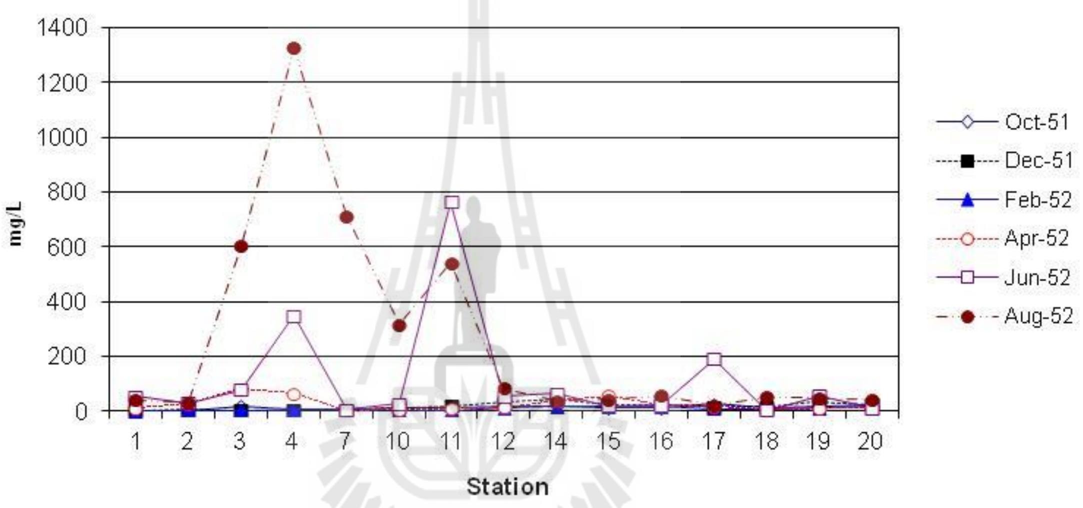


Figure 4.17 Total Suspended Solid values of Lam Takong main river.

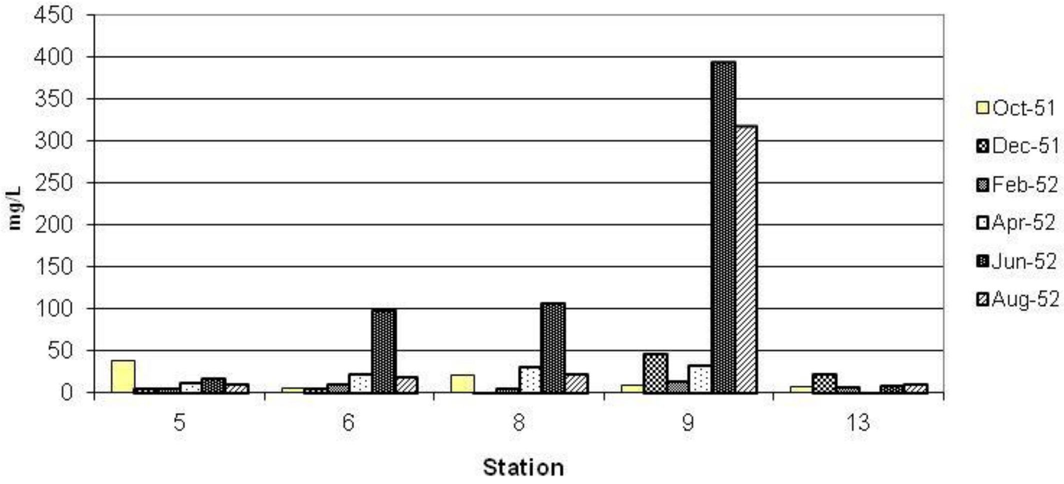


Figure 4.18 Total Suspended Solid values of Lam Takong tributaries.

4.2.7 Total dissolved solid

The values of Total Dissolved Solid found in the range of 19.3-490.0 mg/L (Figures 4.19 and 4.20). At station 11 (Ban Bunglamyai Bridge) had a highest value in October 2008 while the lowest value was found at station 1 (Lam Takong headwater) in June 2009.

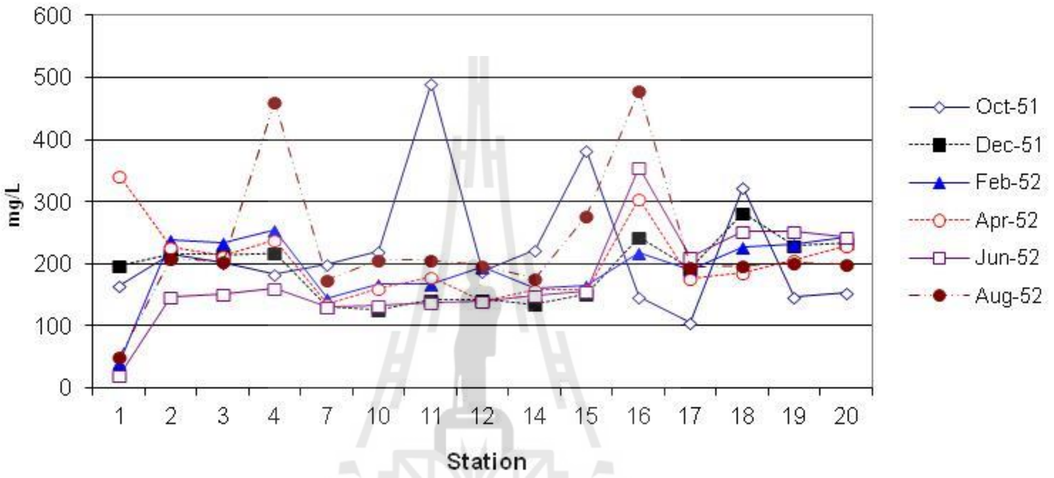


Figure 4.19 Total Dissolved Solid values of Lam Takong main river.

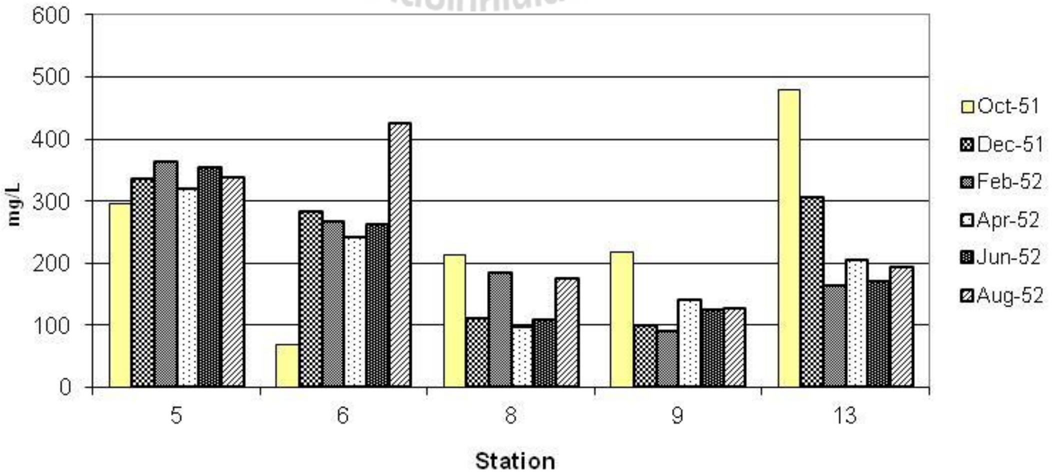


Figure 4.20 Total Dissolved Solid values of Lam Takong tributaries.

4.2.8 Dissolved oxygen

The values of Dissolved Oxygen were found in the range of 2.05-9.30 mg/L (Figures 4.21 and 4.22). The average amount of Dissolved Oxygen was reduced in station 9 (Huai Subwa) which was Lam Takong tributariy, station 4 (Quartermaster Department Royal Thai Army Bridge), station 17 (Wat-Samukkee Bridge), station 18 (Ban Tha Krasang). When the river flow passed Nakhon Ratchasima Municipality, the dissolved Oxygen value was in class 3 of surface water quality standard (Pollution Control Department, 2005). The trend of Dissolved Oxygen will be decreased from upstream to downstream. The average of Dissolved Oxygen is low in summer because oxygen has less dissolved in high temperature water.

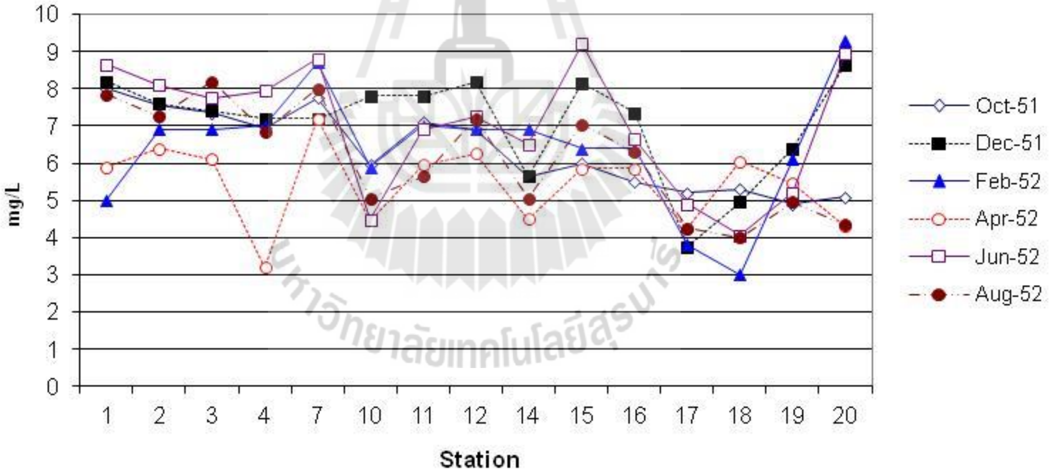


Figure 4.21 Dissolved Oxygen values of Lam Takong main river.

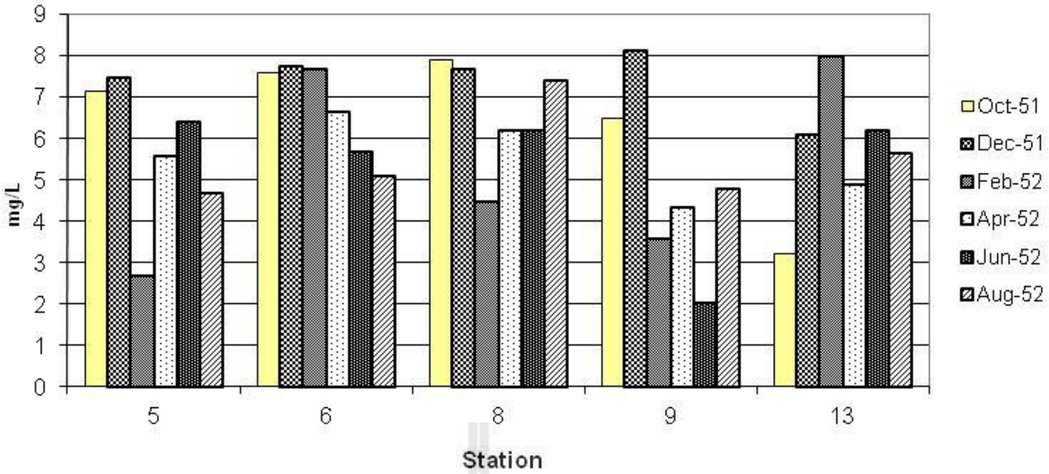


Figure 4.22 Dissolved Oxygen values of Lam Takong tributaries.

4.2.9 Biochemical oxygen demand

Biochemical Oxygen Demand values showed in the range of 0.1-8.7 mg/L (Figures 4.23 and 4.24). Based on the average value of all study found that the BOD value was exceed the surface water quality standard which was more than 4 mg/L (Pollution Control Department, 2005). At station 5 (Klong Yang), station 18 (Ban Tha Krasang), and Station 19 (Yongyang Bridge) where Lam Takong flow pass the Nakhon Ratchasima Municipality had high value of BOD in October 2008. The trend of BOD value will be increased at the downstream due to the combination of waste water from residential area.

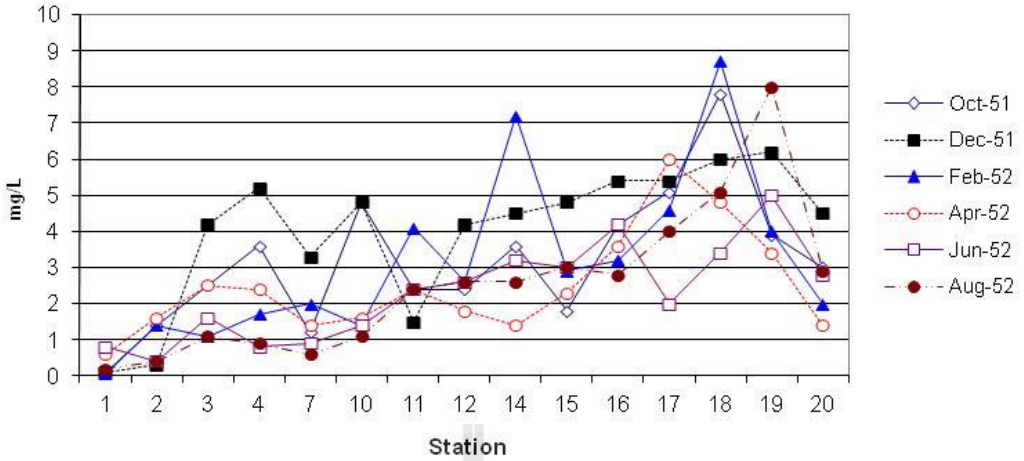


Figure 4.23 Biochemical Oxygen Demand values of Lam Takong main river.

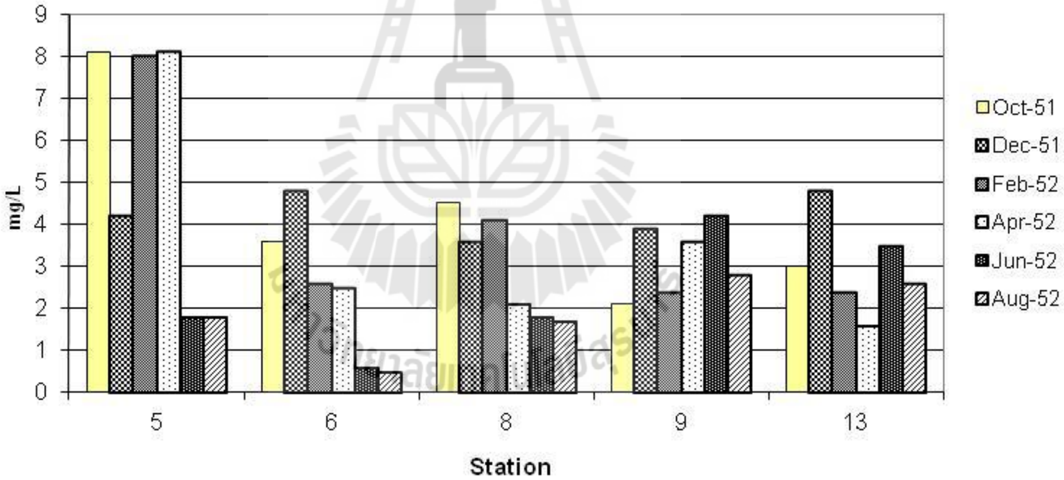


Figure 4.24 Biochemical Oxygen Demand values of Lam Takong tributaries.

4.2.10 Ammonia

The values of ammonia found that in the range of 0.0-12.6 mg/L (Figures 4.25 and 4.26). The highest ammonia showed in station 4 (Quartermaster Department Royal Thai Army Bridge) in rainy season (October 2008) which was exceed the surface water quality standard (more than 0.5 mg/L) coursing by the high density of agriculture and livestock area (Livestock Department Nahkon Ratchasima, 2009). When consider the average of ammonia in 6 moths showed that the station 18 (Ban Tha Krasang) and station 19 (Yongyang Bridge), respectively where the river after flow passed Nakhon Ratchasima Municipality had the highest vale.

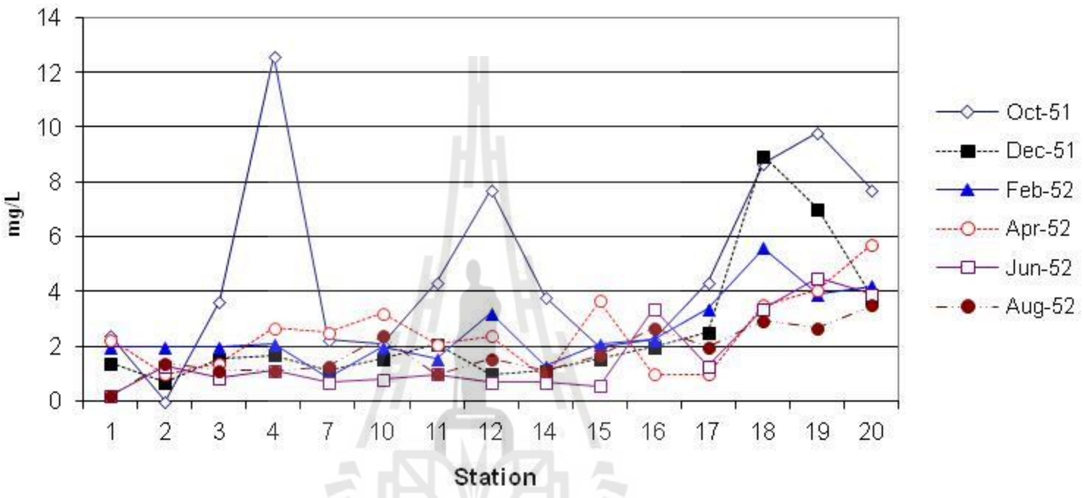


Figure 4.25 Ammonia values of Lam Takong main river.

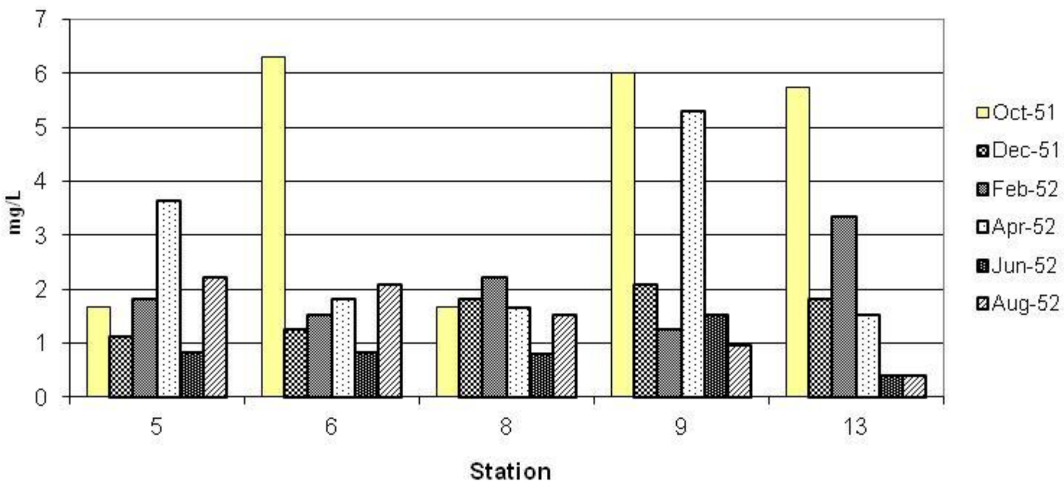


Figure 4.26 Ammonia values of Lam Takong tributaries.

4.2.11 Nitrite

The nitrite values in Lam Takong basin found in range of 0.00-0.70 mg/L (Figures 4.27 and 4.28). The highest value was showed at station 20 (Kunchum barrage) where the Lam Takong river before flow into the Mool river, and station 4 (Quartermaster Department Royal Thai Army Bridge) found in dry season, April 2009. The average of nitrate from 6 months indicated that station 20 (Kunchum barrage) had the highest value following by station 18 (Ban Tha Krasang) and station 19 (Yongyang Bridge), respectively where the end of river after flow passed Nakhon Ratchasima Municipality.

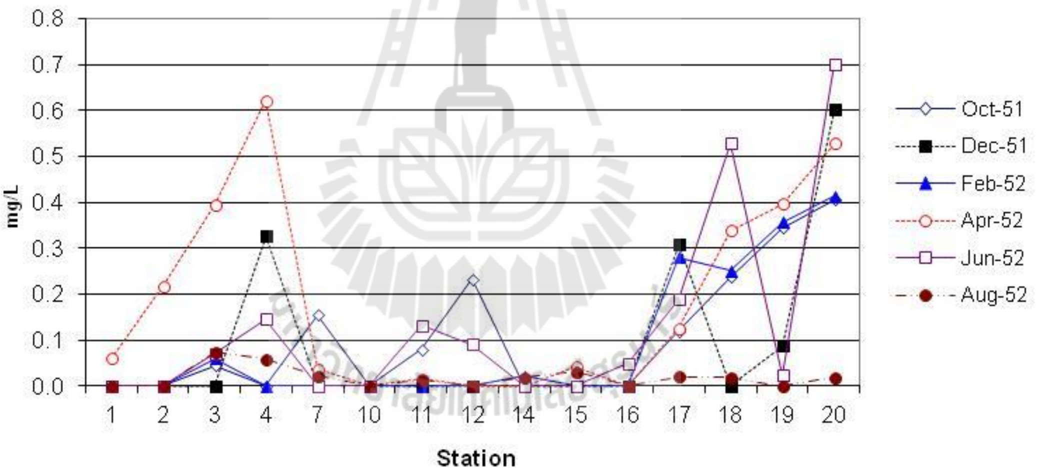


Figure 4.27 Nitrite values of Lam Takong main river.

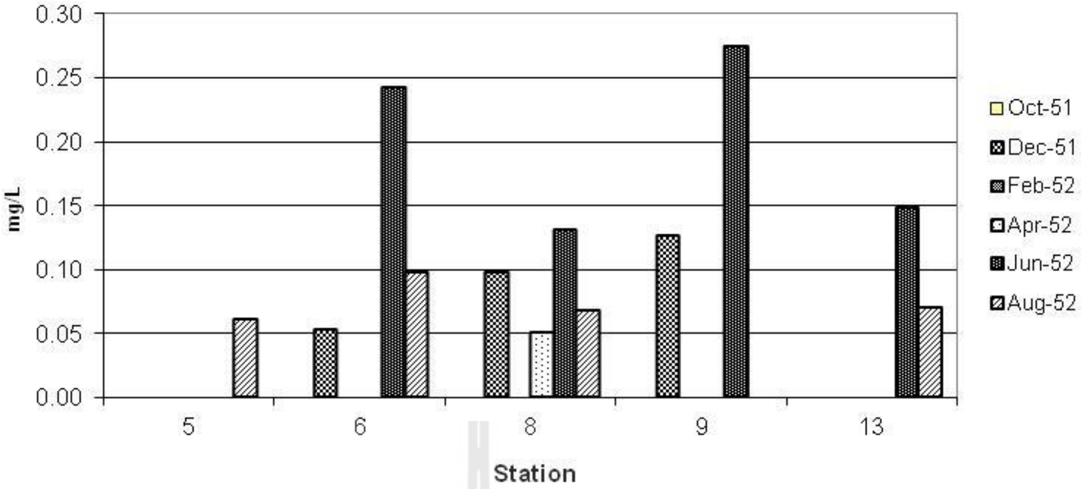


Figure 4.28 Nitrite values of Lam Takong tributaries.

4.2.12 Nitrate

The nitrate value found in the rage of 0.00-34.30 mg/L (Figures 4.29 and 4.30). The values was exceed the surface water quality standard (> 5 mg/l). The highest value found at station 6 (Huai Hinlub), the largest tributary of Lam Takong river, following by Station 8 (Huai Numsub) that it is also Lam Takong tributary. For the Lam Takong main river, the maximum of nitrate found at station 4 (Quartermaster Department Royal Thai Army Bridge). Because of high density of farming and agriculture area due to nitrate contaminated into water. In addition, the value of nitrate was higher in dry season.

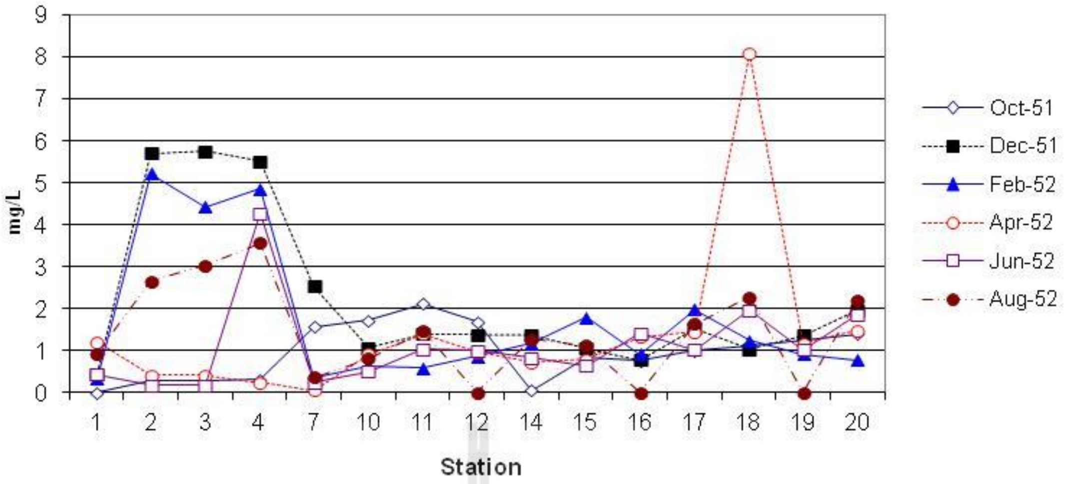


Figure 4.29 Nitrate values of Lam Takong main river.

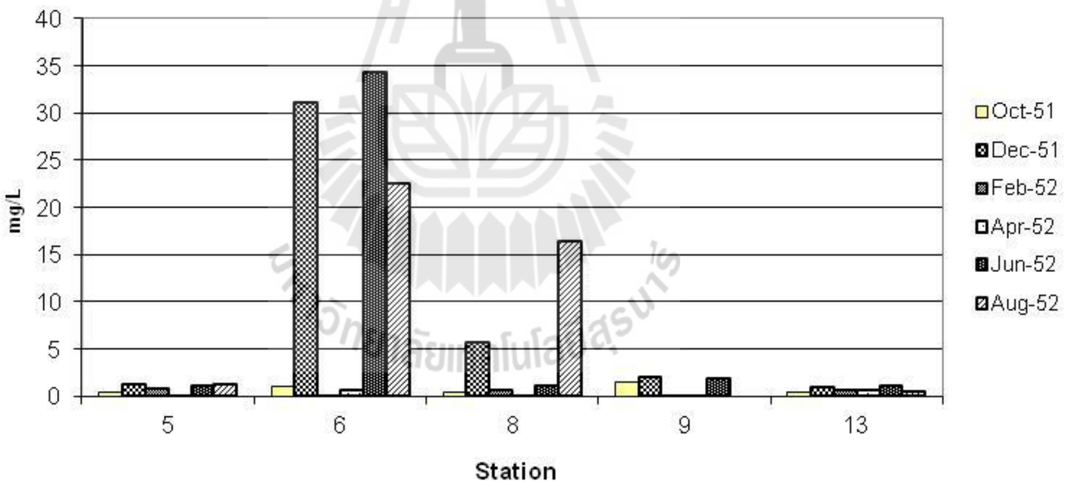


Figure 4.30 Nitrate values of Lam Takong tributaries.

4.2.13 Phosphate

Phosphate found in Lam Takong water in the range 0.00-0.70 mg/L (Figures 4.31 and 4.32) were high during the dry season. the highest value was found at station 7 (Lam Takong Dam) where Nakhon Ratchasima water supply pump in

April 2009. Based on the average of Phosphate in 6 months, the result showed that there was highest phosphate at station 20 (Kunchum Barrage), station 19 (Yongyang Bridge), and station 18 (Ban Tha Krasang), respectively.

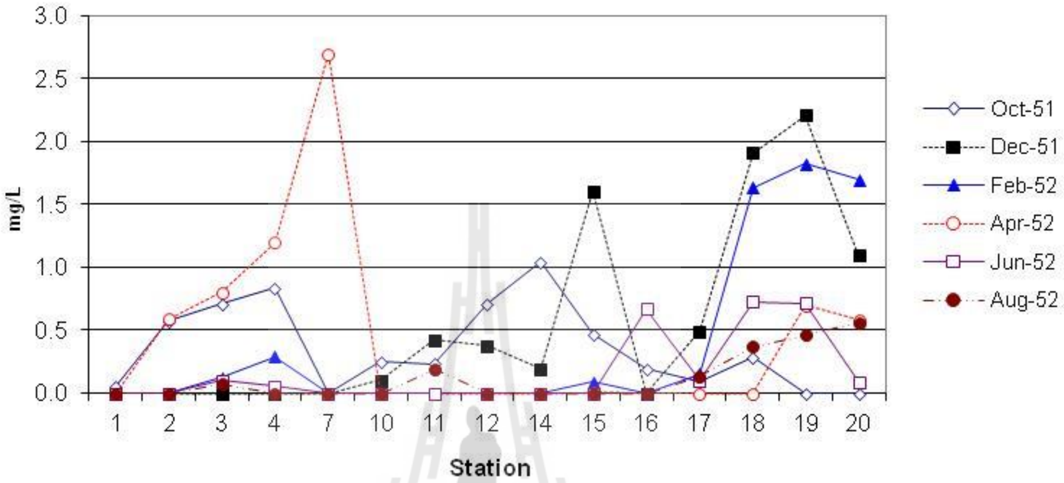


Figure 4.31 Phosphate values of Lam Takong main river.

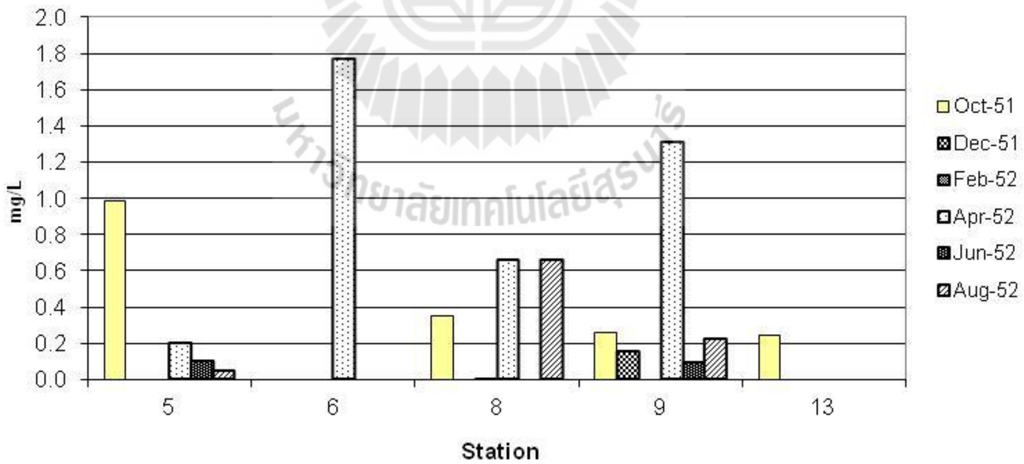


Figure 4.32 Phosphate values of Lam Takong tributaries.

4.2.14 Total organic carbon

The total organic carbon found in the range 0.00-32.77 mg/L (Figures 4.33 and 4.34). The maximum value were found during dry season at station 15

(KonChum Barrage) in April 2009. If consider the average value of total organic carbon in 6 months, the result showed that the highest value were found at station 15 (KonChum Barrage), station 2 (Bukachad Bridge), and station 13 (Huai Subtakhor), respectively.

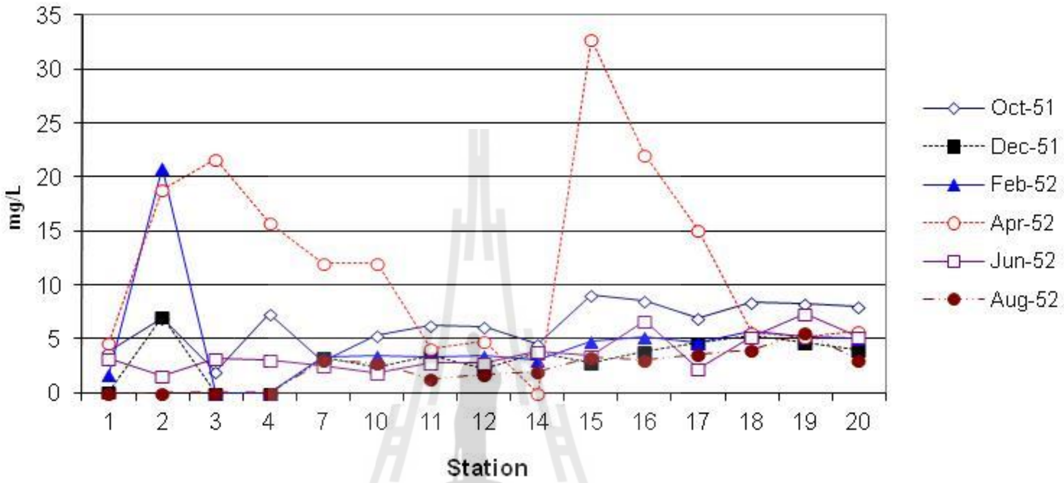


Figure 4.33 Total Organic Carbon values of Lam Takong main river.

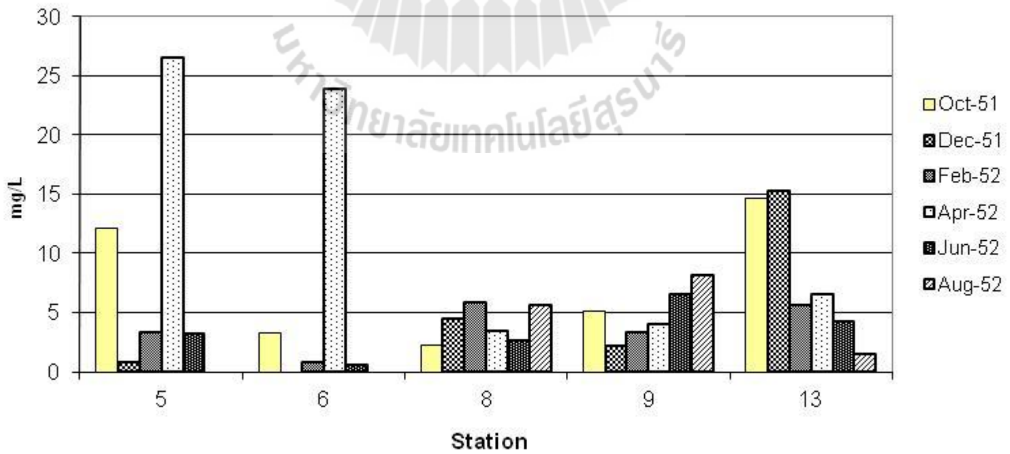


Figure 4.34 Total Organic Carbon values of Lam Takong tributaries.

4.2.15 Chlorophyll-a

The values of chlorophyll-a found in the Lam Takong basin were 0.00-38.62 µg/L (Figures 4.35 and 4.36). The highest value was found at station 20 (Kunchum Barrage) in February 2009. The average value of chlorophyll-a in 6 months were considered, the result showed that at station 20 (Kunchum Barrage), station12 (Kut Hin Barrage), and station 7 (Lam Takong Dam), respectively. The value of chlorophyll-a might be come from algae bloom phenomenon in Lam Takong reservoir during rainy season in June and August when the dam kept water in reservoir for water supply in dry season. While the water released from dam, algae will be flowed out and accumulated in front of check dam which was along the river. In addition, the chlorophyll-a was high value at the nutrient enrich such as station 18 (Ban Tha Krasang) etc.

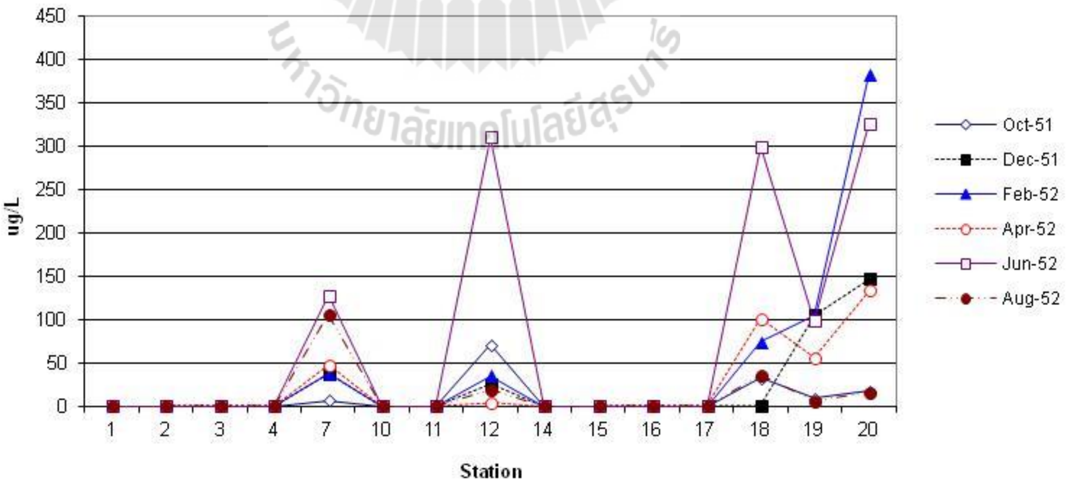


Figure 4.35 Chlorophyll-a values of Lam Takong main river.

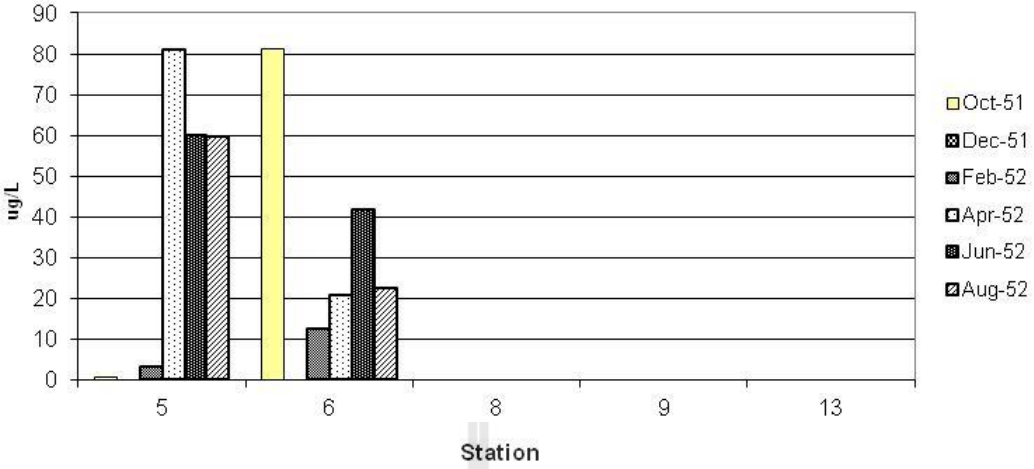
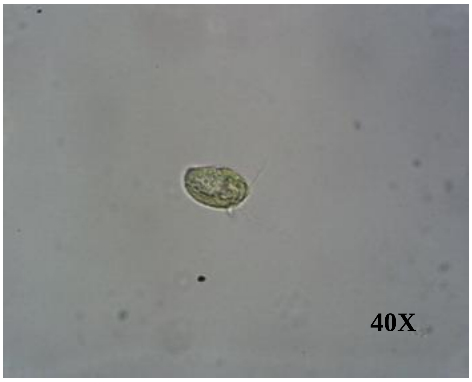


Figure 4.36 Chlorophyll-a values of Lam Takong tributaries.

4.2.16 Algae in Lam Takong Basin

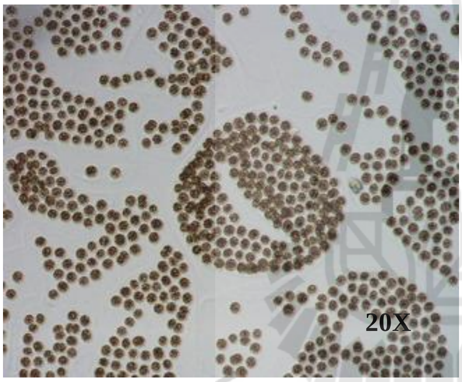
For classification of phytoplankton in Lam Takong basin, the total water samples from 20 stations were collected. Twenty liters of water samples were filled through 10 micron of plankton net. Keep water left in the bottle at the tail of plankton net and then preserved with lugol's solution and keep samples cool. Microscope was used for classification. The result found that there are 89 species in 5 divisions and the number of phytoplankton in Lam Takong Basin as shown in Table 4.1

The sample of phytoplankton are shown in Figures 4.37-4.41 while abundance of phytoplankton are shown in Table 4.2. Division Cyanophyta (blue green algae) is an important algae that usually bloom rapidly when eutrophication was occurring in Lam Takong reservoir. *Microcystis* sp. which has toxic substance, microsistin, was mostly found (Panuvanitchakorn, 2001).

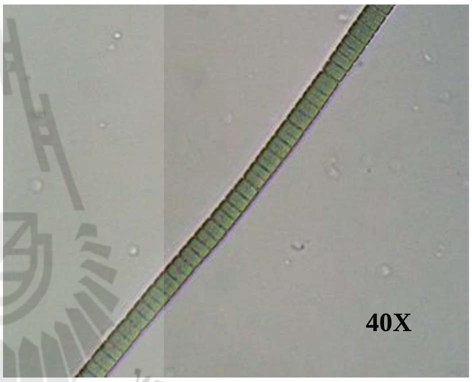


Chilomonas sp.

Figure 4.37 Phytoplankton in division Cryptophyta.

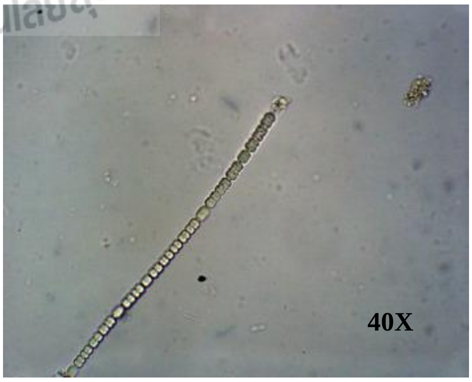


Microcystis sp.



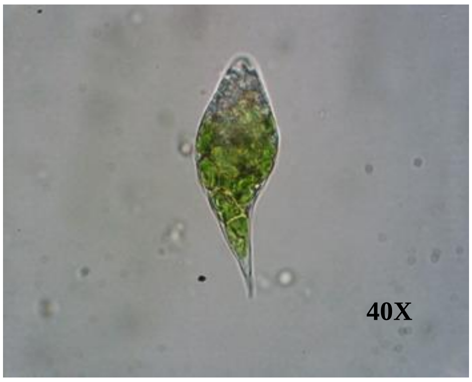
Oscillatoria rubescens DC ex Gomont

Spirulina cf. *platensis* (Noedst)



Anabaena sp.

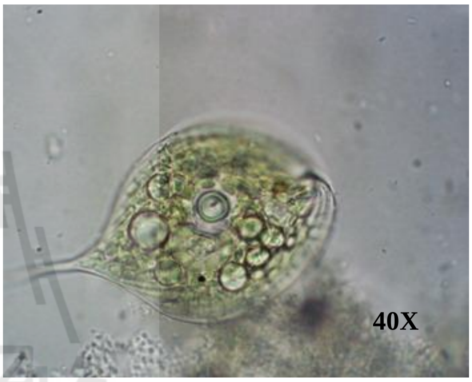
Figure 4.38 Phytoplankton in division Cyanophyta.



Euglena caudata

Trachelomonas horrid

Euglena spiroides

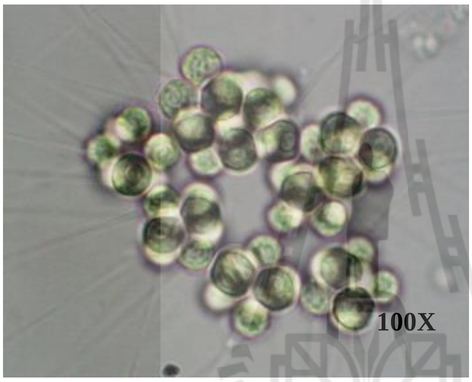


Phacus torta

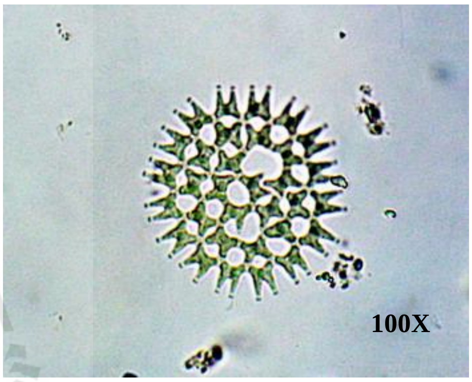
Figure 4.39 Phytoplankton in division Euglenophyta.

Scenedesmus acuminatus (Lagerh.)

Scenedesmus decorus Hortob.



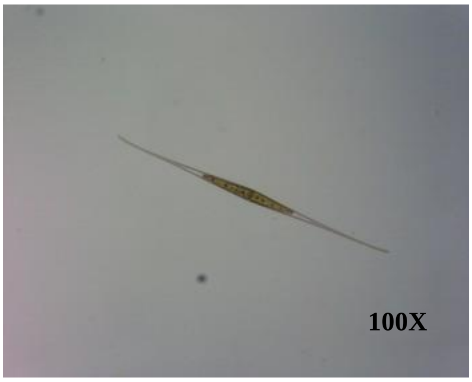
Micractinium quadrisetum



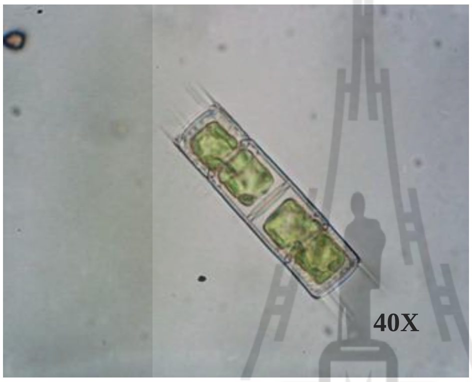
Pediastrum duplex var. *asperum* (A.Br.)

Figure 4.40 Phytoplankton in division Chlorophyta.

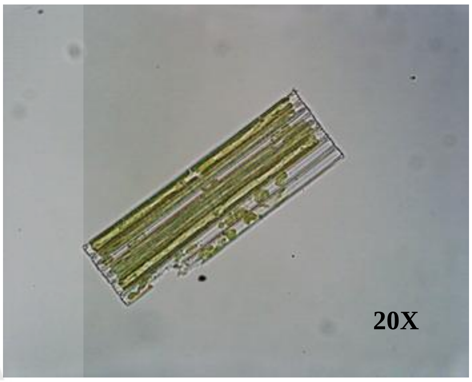
Gymnodinium sp**.**



Closterium kuetzingii BREB



Aulacoseira granulate (Ehrenberg) Simonsen



Synedra ulna (Nitzsch) Ehrenberg

Figure 4.41 Phytoplankton in division Chromophyta.

Table 4.1 Phytoplankton in Lam Takong River.

	Division Cyanophyta : Cyanophyceae
1	*Anabaena affnis* Lemm.
2	*Anabaena* sp.
3	*Anabaenopsis elekinii* Miller.
4	*Anabaenopsis raciborski* Wol.
5	*Anabaenopsis* sp.
6	*Chroococcus turgidus* Nag.
7	*Merismoprdia elegans* A. Braun.
8	*Merismoprdia punctata* Meyen.
9	*Microcystis aeruginosa* Kiitzing.
10	*Microcystis* sp.
11	*Oscillatoria limnetica* Lemm.
12	*Oscillatoria prolifica* Gom.
13	*Oscillatoria rubscens* DC ex Gomat.
14	*Oscillatoria* sp.
15	*Spirulina* cf. *platensis* (Noedst) Geitler Gomont Nach
16	*Spirulina subsalsa* Oersted.
17	*Spirulina laxissima* G. S. West.

	Division Euglenophyta : Euglenophyceae
1	*Euglena acus* Ehr.
2	*Euglena proxima* Dang.
3	*Euglena mainxi* Def.
4	*Euglena splendens* Dang.
5	*Euglena caudata*.
6	*Euglena spiroides*.
7	*Phacus pyrum* Ehr.
8	*Phacus longicaulatus* Duj.
9	*Phacus hamatus* Poch.

	Division Chlorophyta : Chlophyceae
10	*Phacus ranula* Poch.
11	*Phacus torta*
12	*Strombomonas australica* Def.
13	*Trachelomonas crebea* Kell.
14	*Trachelomonas superb* Swir.
15	*Trachelomonas horrid*.
11	*Phacus torta*
12	*Strombomonas australica* Def.

	Division Chlorophyta : Chlophyceae
1	*Botryococcus braunii* kibitzing
2	*Chlamydomonas* sp.
3	*Closterium gracile* Breb.
4	*Closterium parvulum* Nageli.
5	*Closterium acerosum* Ehr.
6	*Coelastrum microporum* Nag.
7	*Closterum kuetzingii* BREB.
8	*Coelastrum polychordum* (korsv) Hind.
9	*Cosmarium monomazum* Lundell
10	*Cosmarium* sp.
11	*Crucigenia trucata* G. M. Smith.
12	*Eudorina elegans* Ehr.
13	*Monoraphidium contolum* Kom.
14	*Micractinium quadrisetum*
15	*Pandorina morum* Bory.
16	*Pediastrum simplex*
17	*Pdiastrum simplex* var. *echinulatum* Wittr.
18	*Pediastrum duplex*
19	*Pediastrum duplex* var. asperum (A.Br.)
20	*Pediastrum* sp.
21	*Scenedesmus acuminatus* Chod.
22	*Scenedesmus arcuatus* Lemm.
23	*Scenedesmus armatus* Kiitzing.
24	*Scenedesmus brasiliensis* Bohlin.
25	*Scenedesmus dimorplus* Kiitzing.
26	Senedesmus decorus Hortob.
27	*Staurastrum bullardil* G.M. Smith
28	*Tetraedron gracile* Hans.

	Division Chlorophyta : Chlophyceae
29	*Tetraedron minimum* Hans.
30	*Tetraedron incus* Smith
31	*Tetraedron* sp.
32	*Tetrahedron trigonum* Hans.
33	Tetrahedron tumidulum Hans.
34	*Volvox* sp.,with daughter colony
30	*Tetraedron incus* Smith
31	*Tetraedron* sp.

Table 4.1 Phytoplankton in Lam Takong River (Continued).

	Division Chromophyta : Bacillariophyceae
1	*Aulacoseira granulate* (Ehrenberg) Simonsen
2	*Fragilaria* sp.
3	*Cyclotella stelligera* Cleve & Grunow.
4	*Gyrosigma attenuatum* Rab.
5	*Gyrosigma balticum* Ehr.
6	*Gyrosigma spencerii* (Smith) Cleve
7	*Navicular exigua* Miller.
8	*Navicular* sp.
9	*Nitzschia accicularis* W. Smith.
10	*Rhizosolenia styliformis* Brig.
11	*Surirella angusta* kützing
12	*Surirella linearis* W. Smith.
13	*Surirella elegans* Ehr.
14	*Surirella robusta* Ehr.
15	*Synedra ulna* (Nitzsch) Ehrenberg
16	*Synedra* sp.
17	*Treubaria triappendiculata* Bernard
18	*Ceratium hirundinella, dorsa*l

Table 4.2 Phytoplankton found in each sampling station.

Species	Station																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Division Cyanophyta : Cyanophyceae																				
Anabaena affnis Lemm.				X	X		X		X	X	X	X		X			X	X	X	X
Anabaena sp.							X	X	X	X	X	X	X	X	X	X	X	X	X	
Anabaenopsis elekinii Miller.				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Anabaenopsis raciborski Wol.				X											X	X	X	X	X	
Anabaenopsis sp.					X															
Chroococcus turgidus Nag.		X	X		X			X		X		X		X		X		X	X	
Merismoprdia elegans A. Braun.				X					X				X							
Merismoprdia punctata Meyen.						X		X		X					X					
Microcystis aeruginosa Kiitzing.							X					X					X	X	X	X
Microcystis sp.							X					X					X	X	X	X
Oscillatoria limnetica Lemm.		X	X				X		X		X	X	X	X	X	X	X	X	X	X
Oscillatoria prolifica Gom.				X	X	X				X	X		X	X		X				
Oscillatoria rubscens DC ex Gomat.				X	X	X	X	X	X		X	X	X		X	X	X		X	X
Oscillatoria sp.						X		X	X			X		X		X	X		X	X
Spirulina cf. *platensis* (Noedst)				X			X			X	X	X	X	X	X	X	X	X	X	X
Spirulina subsalsa Oersted.		X					X	X	X	X	X	X	X	X	X	X	X			
Spirulina laxissima G. S. West.							X					X			X		X	X	X	X
Division Chlorophyta : Chlophyceae																				
Botryococcus braunii kibitzing																				
Chlamydomonas sp.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Closterium gracile Breb.				X			X	X	X	X	X	X	X		X	X	X	X	X	X
Closterium parvulum Nageli.				X			X								X			X	X	
Closterium acerosum Ehr.																				
Coelastrum microporum Nag.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 4.2 Phytoplankton found in each sampling station. (Continued).

Species	Station																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Closterum kuetzingii BREB.				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Coelastrum polychordum (korsv) Hind.			X		X			X	X				X	X						
Cosmarium monomazum Lundell	X		X	X	X	X	X	X	X	X	X	X	X	X						
Cosmarium sp.	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X			
Crucigenia trucata G. M. Smith.								X							X					
Eudorina elegans Ehr.			X		X	X			X	X	X	X	X				X	X	X	
Monoraphidium contolum Kom.											X	X					X	X		X
Micractinium quadrisetum									X		X		X	X	X		X			
Pandorina morum Bory.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pediastrum simplex				X			X	X	X	X		X			X	X	X	X	X	X
Pdiastrum simplex var. *echinulatum* Wittr.				X			X	X	X	X		X			X	X	X	X	X	X
Pediastrum duplex					X				X			X					X	X	X	X
Pediastrum duplex var. asperum (A.Br.)							X					X						X	X	
Pediastrum sp.							X											X	X	
Scenedesmus acuminatus Chod.					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Scenedesmus arcuatus Lemm.											X					X				
Scenedesmus armatus Kiitzing.							X	X	X			X	X	X			X	X	X	X
Scenedesmus brasiliensis Bohlin.							X	X	X	X	X	X	X	X	X		X	X	X	
Scenedesmus dimorplus Kiitzing.		X			X				X			X					X	X		
Senedesmus decorus Hortob.																				
Staurastrum bullardil G.M. Smith																				
Tetraedron gracile Hans.	X				X					X	X					X				
Tetraedron minimum Hans.			X					X	X				X						X	
Tetraedron incus Smith																				
Tetraedron sp.									X					X						

Table 4.2 Phytoplankton found in each sampling station. (Continued).

Species	Station																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Tetrahedron tumidulum Hans.		X		X		X				X	X			X						
Volvox sp.,with daughter colony									X	X										
Division Euglenophyta : Euglenophyceae																				
Euglena acus Ehr.							X	X	X			X	X	X		X	X	X	X	X
Euglena proxima Dang.					X	X	X	X	X	X	X	X	X	X	X	X	X		X	
Euglena mainxi Def.				X						X										
Euglena splendens Dang.														X			X	X	X	
Euglena caudata.																	X	X	X	X
Euglena spiroides.					X	X				X							X			
Phacus pyrum Ehr.			X	X				X			X	X	X	X		X	X	X	X	
Phacus longicaulatus Duj.																				
Phacus hamatus Poch.				X	X		X		X			X	X	X	X		X	X	X	X
Phacus ranula Poch.					X								X	X	X	X				
Phacus torta				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Strombomonas australica Def.																				
Trachelomonas crebea Kell.				X	X		X		X			X	X	X	X		X	X	X	X
Trachelomonas superb Swir.											X		X		X			X		
Trachelomonas horrid.		X		X					X			X					X	X	X	
Division Chromophyta : Bacillariophyceae																				
Aulacoseira granulate (Ehrenberg) Simonsen																				
Fragilaria sp.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cyclotella stelligera Cleve & Grunow.										X				X						
Gyrosigma attenuatum Rab.	X															X				

Table 4.2 Phytoplankton found in each sampling station. (Continued).

Species	Station																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Gyrosigma balticum Ehr.	X										X									
Gyrosigma spencerii (Smith) Cleve	X																			
Navicular exigua Miller.	X																			
Nitzschia accicularis W. Smith.	X		X	X		X	X		X			X								
Rhizosolenia styliformis Brig.					X		X		X		X			X	X	X		X		
Surirella angusta kützing		X					X		X	X	X	X	X	X	X					
Surirella linearis W. Smith.		X	X	X		X	X	X	X	X	X	X	X	X	X					
Surirella elegans Ehr.			X	X	X	X	X	X	X	X	X	X			X					
Surirella robusta Ehr.		X	X	X		X	X	X	X	X	X	X	X	X	X					
Synedra ulna (Nitzsch) Ehrenberg		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Synedra sp.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Treubaria triappendiculata Bernard									X											
*Ceratium hirundinella, dorsa*l			X				X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ceratium kofoidii Jor.							X			X	X	X	X	X	X	X	X	X		
Ceratium sp.	X						X		X	X	X	X	X	X	X	X	X			X
Gymnodinium sp.	X			X			X	X	X	X	X	X			X					
Peridinium aciculiferum							X			X	X		X			X				
Peridinium sp.							X			X	X		X			X				
Peridinium inconspiuum Lemm.							X			X	X		X			X				
Division Cryptophyte																				
Chilomonas sp.									X			X	X				X	X	X	X
Gyrosigma balticum Ehr.	X										X									
Gyrosigma spencerii (Smith) Cleve	X																			

Remark: * founded

4.3 The seasonal effect on Lam Takong water quality

Water samples were collected in two seasons: dry season (October, December 2008 and February 2009) and rainy season (April, June and August 2009). By comparison of monthly average water parameters between dry and rainy season, we found that pH, DO, BOD and NH_3-N were significantly higher in dry season ($p<0.01$) while temperature, Salinity and TSS were significantly lower in dry season ($p<0.01$) as shown in Table 4.3. However, Turbidity, TOC, NO_3, NO_2 and Chl-a in rainy season were higher than dry season but not statistically different.

Table 4.3 Monthly and seasonal average water quality variables in Lam Takong River and tributaries.

Parameter	**Dry season**	**Rainy season**	***t*-test (*p* value)**
pH	7.4 ± 0.1	6.6 ± 0.1	<0.01
Water temperature (°C)	25.9 ± 0.4	29.1± 0.4	<0.01
Conductivity (mS/cm)	385.1 ± 23.0	379.2 ± 27.0	0.81
Salinity (ppt)	0.12 ± 0.01	0.17± 0.01	<0.01
Turbidity (NTU)	19.7 ± 2.5	26.7 ± 4.6	0.21
TDS (mg/L)	209.0 ± 12.2	206.7 ± 15.6	0.87
TSS (mg/L)	13 ± 1.6	119.2 ± 34.9	0.01*
TOC (mg/L)	4.9 ± 0.9	6.1 ± 12.0	0.18
DO (mg/L)	6.6 ± 0.2	6.0 ± 0.26	<0.01
BOD (mg/L)	3.6 ± 0.3	2.5 ± 0.3	<0.01
NH_3-N (mg/L)	3.2 ± 0.4	1.9 ± 0.2	<0.01
NO_3 (mg/L)	2.0 ± 0.5	2.4 ± 0.9	0.53
NO_2 (mg/L)	0.08 ± 0.02	0.1 ± 0.02	0.17
PO_4 (mg/L)	0.4 ± 0.08	0.3 ± 0.05	0.30
Chlo-a (mg/L)	19.7 ± 9.6	32.8 ± 11.8	0.11

Remark: ± SEM , * significantly different at p<0.05

The highest mean pH was 8.2 (station 7) in dry season, while the lowest was 5.6 (Station5) in rainy season (Figure 3). Water temperature showed the highest mean value occurred during rainy season was 31.1 °C in station 20 and the lowest was 22.3 °C (station 1) in both seasons. DO showed the highest mean value during rainy season as 8.0 mg/L (station 7) and the lowest mean value in dry season was 4.25 mg/L (station 9) while BOD had the highest value of 7.5 mg/L (station18) and the lowest value was found at the headwater (0.08 mg/L) in dry season. Since Lam Takong dam released water during dry season for agricultural area but reserved water in reservoir during rainy season.

Higher NH_3-N was found in dry season than rainy season. The highest mean NH_3-N was 7.7 mg/L (station 18) in dry season, while the lowest was 0.8 mg/L (station 13) in rainy season. TSS had the highest mean 578.8 mg/L (station 4) during rainy season, while the lowest was 1.2 mg/L (station 1) in dry season. Because soil erosion was occurred in rainy season and released high sediment into the river.

Eutrophication normally occurres in still, high nutrient water. The concentration of Chlol-a, an index of algae bloom, was not different in both seasons. The highest mean value was 182.1 ug/L (station 20) in dry season and the lowest mean value was 0.001 mg/L (in most station except 5, 6, 7, 12, and 20) in both seasons.

4.4 Trophic level assesment

The physical and chemical properties of water i.e. colour and oder of water, pH, DO, BOD, EC, chlorophyll a contents, amount of nitrate nitrogen, ammonium nitrogen and soluble reactive phosphorous were used in combination to evaluate the water quality (Lorraine and Vollenweider, 1981; Peerapornpisal *et al.*, 2004) This water quality assessment is called "AARL- PP Score". The standard score of water quality base on trophic level status. The water quality was categorized into 6 status using 1-10 scores. The score was shown in Appendix A

4.4.1 Trophic level status of Lam Takong river in 13 years (1998 -2008)

For study the water quality by trophic level in 13 year, 7 stations of water sampling of Pollution Control Department were used to analyze by using the AARL-PP Score. The result from total of 224 samples (Appendix C) showed that the eutrophic status was found twice (6%) in November 1998 and March 2005 at station 6 (Wat-Samukkee) and found once (3%) in August 2008 at station 7 (Ban Yongyang). For mesotrophic-eutrophic status found 37 times. Twenty times found at station 6 (Wat-Samukkee) while seventeen times found at station 7 (Ban Yongyang), and once found at station 2 (Ban Nong Salai). Base on the result can be concluded that the water quality of Lam Takon river from 1996-2008 were moderate. In addition, the water quality was Moderate- polluted when it flow pass Nakhon Ratchasima Municipality (Figure 4.42 and Table 4.4).

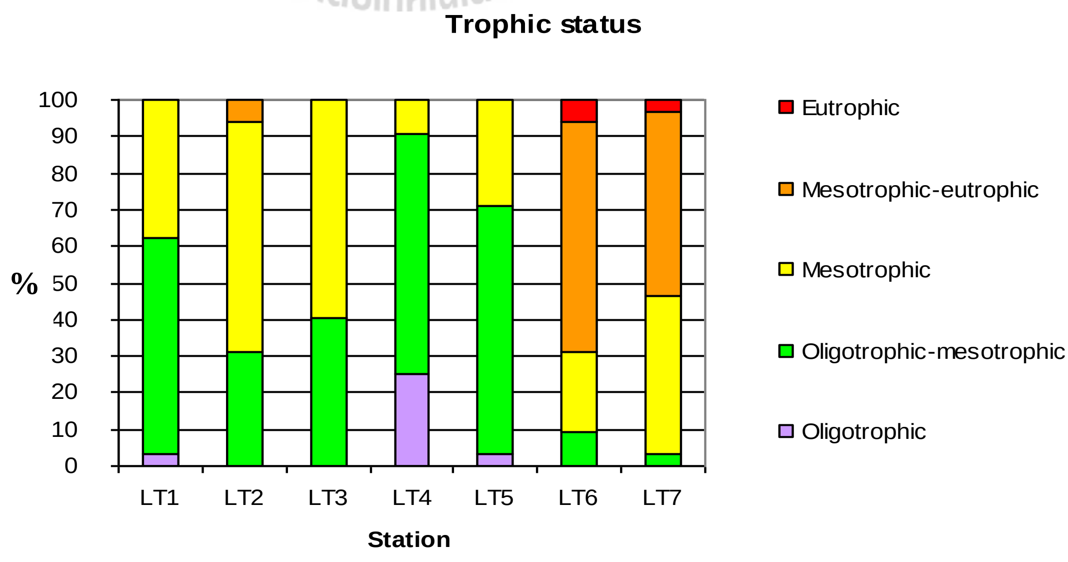


Figure 4.42 Trophic status in Lam Takong River in 13 years (1996-2008).

Table 4.4 Water quality by trophic level and general water quality in Lam Takong River in 13 years (1996-2008).

Station	Water quality by trophic level	General water quality
1	Oligotrophic-mesotrophic	Clean- moderate
2	Mesotrophic	Moderate
3	Mesotrophic	Moderate
4	Oligotrophic-mesotrophic	Clean- moderate
5	Oligotrophic-mesotrophic	Clean- moderate
6	Mesotrophic-eutrophic	Moderate-polluted
7	Mesotrophic	Moderate

4.4.2 Trophic status of Lam Takong River and tributaries in 2008-2009

For study the water quality by trophic level, 20 stations of water samples were collected from Lam Takong main river and tributaries. The physical and chemical parameter of water were assessed. The water quality was categorized into 6 status (Table 3.4). Each status was divided by the data from the water analyses. The standard score of water quality base on trophic level status were used for classified the trophic status. The result showed that the Mesotrophic-eutrophic level was found in 6 times (Appendix C). Four times (December, 2008 February, June, August 2009), representing 67% were found at station 18 (Ban Tha Krasang) and this level found once (December 2008), representing 17% at station 17 (Wat Samukkee Bridge) and station 19 (Yongyang Bridge).

The water quality by trophic level can be summarized as nutrient levels and general water quality of each water station as shown in Figure 4.43 and Table 4.5. It was found that water quality of main river rater modurate (Oligotrophic-mesotrophic status) only at the upper part of Lam Takong River. But, the overall of Lam Takong main river and tributaries were moderate (Mesotrophic status). The water quality is quite poor (Mesotrophic-eutrophic status) at Station 18 when the river flow pass the Municipality of mueang Nakhon Ratchasima.

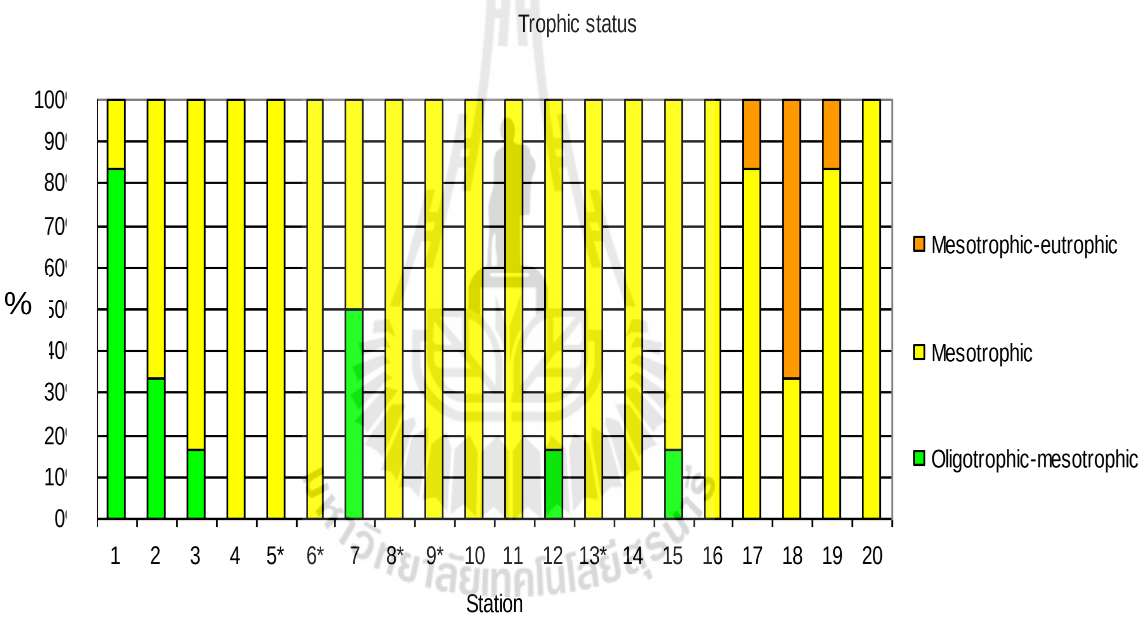


Figure 4.43 Trophic status in Lam Takong River and tributaries in 2008-2009.

Table 4.5 Water quality by trophic level and General water quality in Lam Takong River and tributaries in 2008-2009.

Station	Water quality by trophic level	General water quality
1	Oligotrophic-mesotrophic	Clean- moderate
2	Mesotrophic	Moderate
3	Mesotrophic	Moderate
4	Mesotrophic	Moderate
5	Mesotrophic	Moderate
6	Mesotrophic	Moderate
7	Mesotrophic	Moderate
8	Mesotrophic	Moderate
9	Mesotrophic	Moderate
10	Mesotrophic	Moderate
11	Mesotrophic	Moderate
12	Mesotrophic	Moderate
13	Mesotrophic	Moderate
14	Mesotrophic	Moderate
15	Mesotrophic	Moderate
16	Mesotrophic	Moderate
17	Mesotrophic	Moderate
18	Mesotrophic-eutrophic	Moderate- polluted
19	Mesotrophic	Moderate
20	Mesotrophic	Moderate

4.5 Land use type classification

4.5.1 Land use type classification in Lam Takong basin

Land use of Lam Takong Basin in 2008 (Department of Land Development, 2008) showed that the most of 1804.30 km^2 has been used for agricultural area (52.29%) followed by the forest (15.6%) of total area. The others Land use was shown in Table 4.6 and Figure 4.39.

Table 4.6 Land use of Lam Takong Basin in 2008.

Sequence	Land use Type	Area (km^2)	Percent (%)
1	Agricutural area	1,804.30	52.29
2	Forest	526.46	15.26
3	Mixed orchard	357.47	10.36
4	Urban	348.08	10.09
5	Scrub forest	153.45	4.45
6	Grassland	96.41	2.79
7	Industrial area	86.75	2.51
8	Waterbody	67.38	1.95
9	Flat area	10.34	0.30
	Total	3,450.65	100

4.5.2 Land use change (Change detection)

For study land use change, land use data file of Nakhon Ratchasima province in 2001 and 2008 (Department of Land Development) were compared by basin by using Arc view 9. Agricultural area is the most area follow by forest in both years. Area of each land use type showed in Tables 4.7. Mapping of land use type as shown in Figures 4.44 and 4.45

Table 4.7 Area of land use type in 2001 and 2008.

Land use type	2001 Area (km^2)	2008 Area (km^2)
Agricutural area	2,212.00	1,856.79
Forest	423.06	622.55
Mixed orchard	313.49	217.42
Urban	287.84	395.64
Scrub forest (deteriorated forest)	98.22	152.92
Grassland	39.09	96.54
Water body	38.84	67.61
Industrial area	33.96	34.50
Flat area	3.60	10.35

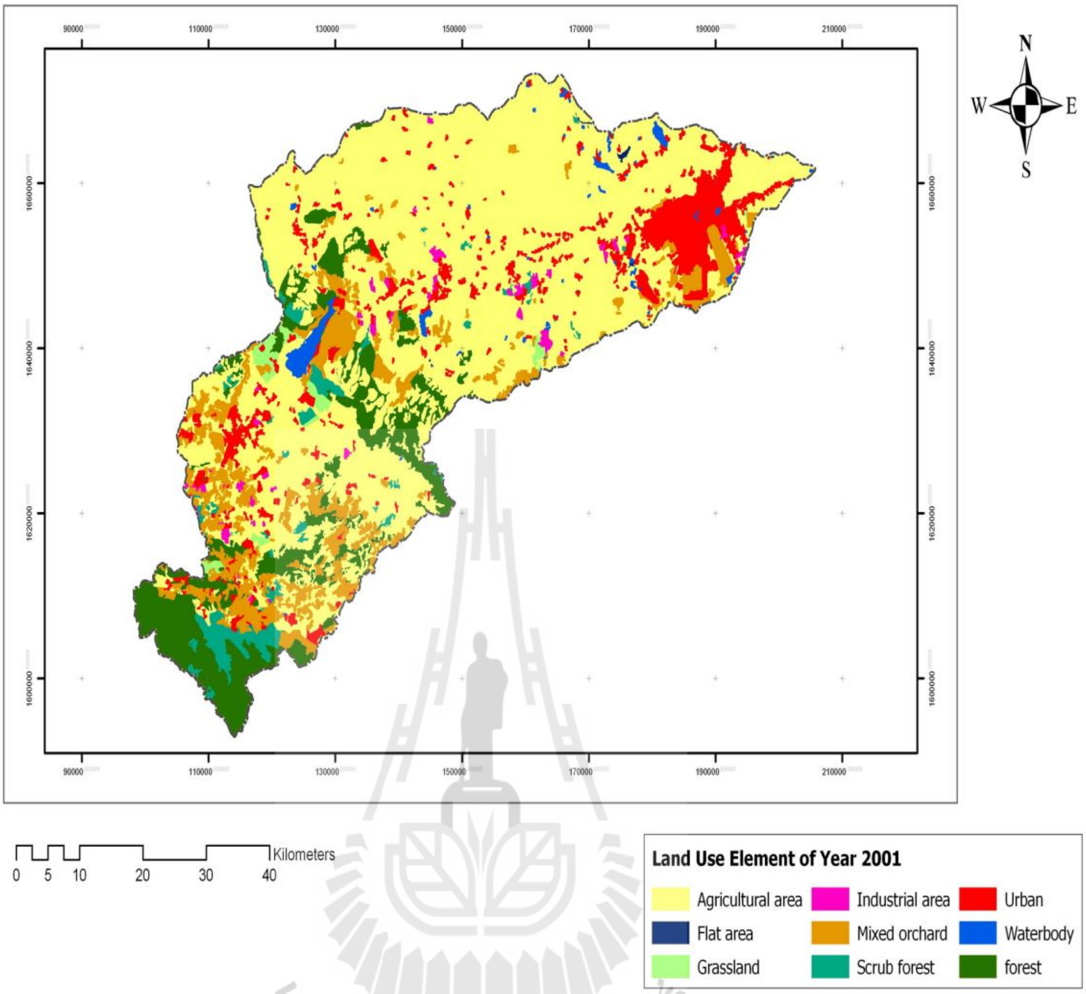


Figure 4.44 Land use type of Lam Takong basin in 2001.

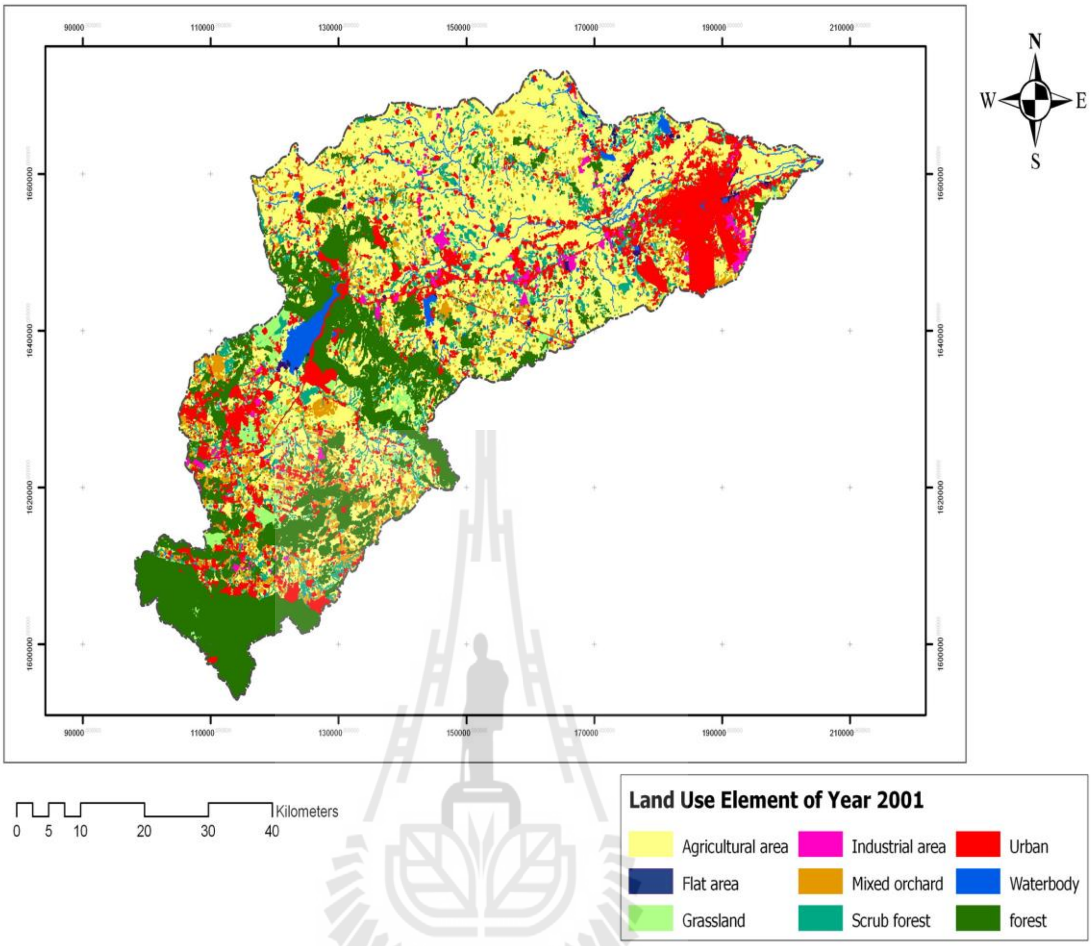


Figure 4.45 Land use type of Lam Takong basin in 2008.

Table 4.8 Land use (km^2)change in Lam Takong Basin from 2001-2008.

Land use in 2008	Land use in 2001									Total (km^2)
	Agricutural	Mixed orchard	Scrub forest	Grassland	Water body	Forest	Flat area	Urban	Industrial	
Agricutural	1675.3074	75.24	12.28	0.57	2.49	40.71	2.06	32.86	13.15	1854.6674
Mixed orchard	131.92	67.3578	0.9405	1.9148	0.2619	4.2768	0.0162	9.1332	1.5984	217.4196
Scrub forest	108.9	12.618	8.6112	1.4473	0.5643	7.9614	0.2169	10.4985	2.1042	152.9218
Grassland	54.28	4.1661	3.3597	22.1035	0.1062	7.9875	0.2169	3.9438	0.3798	96.5435
Water body	30.14	0.9036	0.1719	0.9537	31.2696	0.6714	0.5463	2.7279	0.2277	67.6121
Forest	86.52	103.7736	67.2885	0.5644	0.1656	356.5566	0	6.0984	1.584	622.5511
Flat area	0.03	0.0027	0.0963	7.0497	1.1592	0	0.5355	1.4814	0	10.3548
Urban	116.96	46.8729	4.842	1.1869	1.7703	4.4091	0.0054	216.1854	3.4047	395.6367
Industrial	10.06	2.5533	0.6264	3.3011	1.0548	0.4824	0	4.9122	11.5119	34.5021
Total (km^2)	2214.1174	313.488	98.2165	39.0914	38.8419	423.0552	3.5972	287.8408	33.9607	3452.2091

From Table 4.8 showed the comparison the area of land use change between in 2001 and 2008. The result show that the land use type which increasing in 2008 include scrub forest, grassland, water body, forest, flat area, urban area, and industrial area. Especially, urban area has the most area exchange. The comparison of urban change between in 2001 and 2008 showed the urban area was 287,8408 km^2 while in 2008 was 395,6367 km^2 increasing area came form agriculture 116.96 km^2, mixed orchard 46.87 km^2, scrub forest 0.63 km^2, grassland 3.30 km^2, water body 1.05 km^2,forest 0.48 km^2, industrial 3.40 km^2 .

4.6 Loading assessment

Sources of pollution in the area of Lam Takong Basin can be divided into 5 major sources including urban, industry, agriculture, livestock and aquaculture area. The mainly point sources of pollution in Lam Takong Basin is urban area following by livestock, industry, agriculture, and aquaculture. For non point source that can not be assigned points such as agricultural area, it is the second of major pollutant source in Lam Takong Basin while the first source is urban area. The contamination was calculated in term of BOD loading, the result showed that 46.05% of pollutant came from the urban area followed by agriculture area was 42.90% (Table 4.9).

Table 4.9 Proportion of pollution sources in Lam Takong Basin.

pollution sources	BOD loading (kg BOD/day)	Proportion (%)
Urban	30,637	46.5
Agriculture	28,540	42.90
Livestock (swine farm)	6,334	9.52
Industry	753	1.13
Aquaculture	264	0.40
Total	66,528	100

4.6.1 Urban

Number of population in 2008, rate of wastewater 180 L/capita/day and BOD concentration constant 193 mg BOD/L (Pollution Control Department, 2008) were use to calculated BOD loading. The volume of domestic wastewater in 6 districts of Lam Takong Basin showed that the total of population in 2008 was 882,376 (National Statistical Office, 2008), so can be released 158,828 m^3/day of wastewater. The contamination in term of BOD loading was 30,637 kg BOD/day. At Mueang Nakhon Ratchasima district has highest BOD Loading (49.17%) following by Pak Chong, Si Khio, Sung Noen, Kham Thale So district. For Chaloem Phra Kiat district, generally of pollutant will flow through Mool river because the most area of district is in Mool Basin than Lam Takong Basin (Table 4.10).

Table 4.10 BOD loading from 6 districts in Lam Takong Basin.

District	Population	BOD loading (kg BOD/day)	Proportion (%)
Pak Chong	184,427	6,404	20.90
Si Khio	121,637	4,223	13.78
Sung Noen	79,122	2,747	8.97
Kham Thale So	28,462	988	3.22
Mueang Nakhon Ratchasima	433,838	15,064	49.17
Chaloem Phra Kiat	34,890	1,211	3.95
Total	882,376	30,637	100

When the population in municipality around the river was considered (Table 4.10), the result indicated that the highest BOD loading was Nakhon Ratchasima city municipality which it was 5,062 kg BOD/day (66%) following by Pak Chong district municipality, Si Khio district municipality, Sung Noen subdistrict municipality, Chaloem Phra Kiat subdistrict municipality, and Kham Thale So subdistrict municipality, respectively.

4.6.2 Industry

The number of factory in Lam Takong Basin were 2,268 (National Statistical Office, 2008) Majority is Agro-process industry, while 1994 industries released wastewater to environment (Regional Environment Office 11) causing wastewater 37,627 m^3/day or 753 kg BOD/day which calculated by method from Pollution Control Department.

4.6.3 Agriculture

The generally cultivation in Lam Takong Basin were field crops, fruits, vegetables, and paddies. The mainly pollutants were fertilizer and Pesticide leaching to surface water by runoff. Actually, pollution point source can not be defined in this area that called non point source. For determination of BOD loading by assess the amount of runoff and rainfall data (Thai meteorological Department, 2008). The amount of runoff (mm) multiply by catchment area (km^2) and then multiply by BOD loading of runoff that flow pass agriculture (3.83 mg/l) were calculated (Intarapirat, 2009). The result showed the total agriculture area in Lam Takong Basin were 2,058.50 km^2 that refer to the BOD loading was 8,540 kg BOD/day.

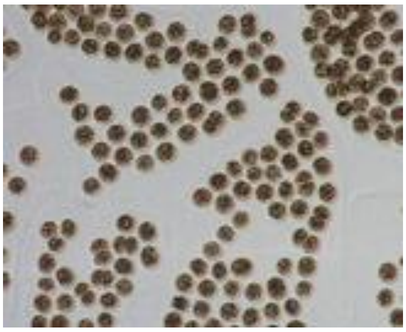
4.6.4 Livestock and Poultry

Lam Takong Basin was including poultry and livestock such as bovine, goat, sheep farms. By the report from Pollution Department Control in 2008 said that the mainly livestock pollutant was come from swine farm. The National Statistical Office was reported the total swine in Lam Takong Basin were 222,238 causing to 3,334 m^3/day of wastewater that is 6,334 kg BOD/day.

4.6.5 Aquaculture

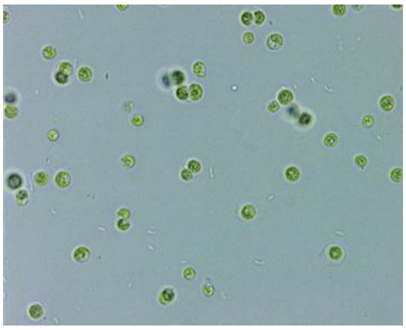
The aquaculture area was 1.6288 km^2 that discharged wastewater to environment 214 m^3/day or 264 kg BOD/day (Pollution Control Department, 2008). Pollution area of aquaculture were surveyed and found a lot of catfish ponds at Klong Yang upper the Lam Takong reservoir. In addition, the blue green algae were bloomed in ponds. During the heavy rainfall, pollutant from fish farms might be an important source of pollution that effected on water quality in Lam Takong reservoir.

Lam Takong reservoir



Microcystis sp.

Catfish pond



Chlorella sp.

Figure 4.46 Catfish ponds at the upper of Lam Takong Reservoir.

4.6.6 Point Sources in Lam Takong Basin

For this studied, Data of pollution source from any establishment (Regional Environment Office 11) were used. Mapping the point sources which far 0-1 km and 1-5 km from the river. The establishment is located 0-1 km is the major source while the establishment is located 1-5 km is secondary source of pollution shown in Table 4.11 and Figures 4.47-4.52. The result can be concluded that there are sources of pollution in both sides along the river. In radius1 km has 605 work places. The mostly of work places is industry followed by village and gas station. While in radius 5 km has 1,418 work places including 788 industries and 448 villages. Especially, work places in 0-1 km from river must be monitored urgently.

Table 4.11 Number of work places in the distance from Lam Takong 0-1 and 1-5 km.

Source of Pollution	**Distance from Lam Takong**		**Total**
	0-1 km	**1-5 km**	
Hospital	8	13	21
Market	16	24	40
Industry	328	788	1,116
Landfill center	2	11	13
Education institute	25	36	61
Slaughterhouse	3	5	8
Gas station	35	67	102
Swine farm	7	16	23
Village	174	448	622
Department store	7	10	17
Total	605	1418	2,023

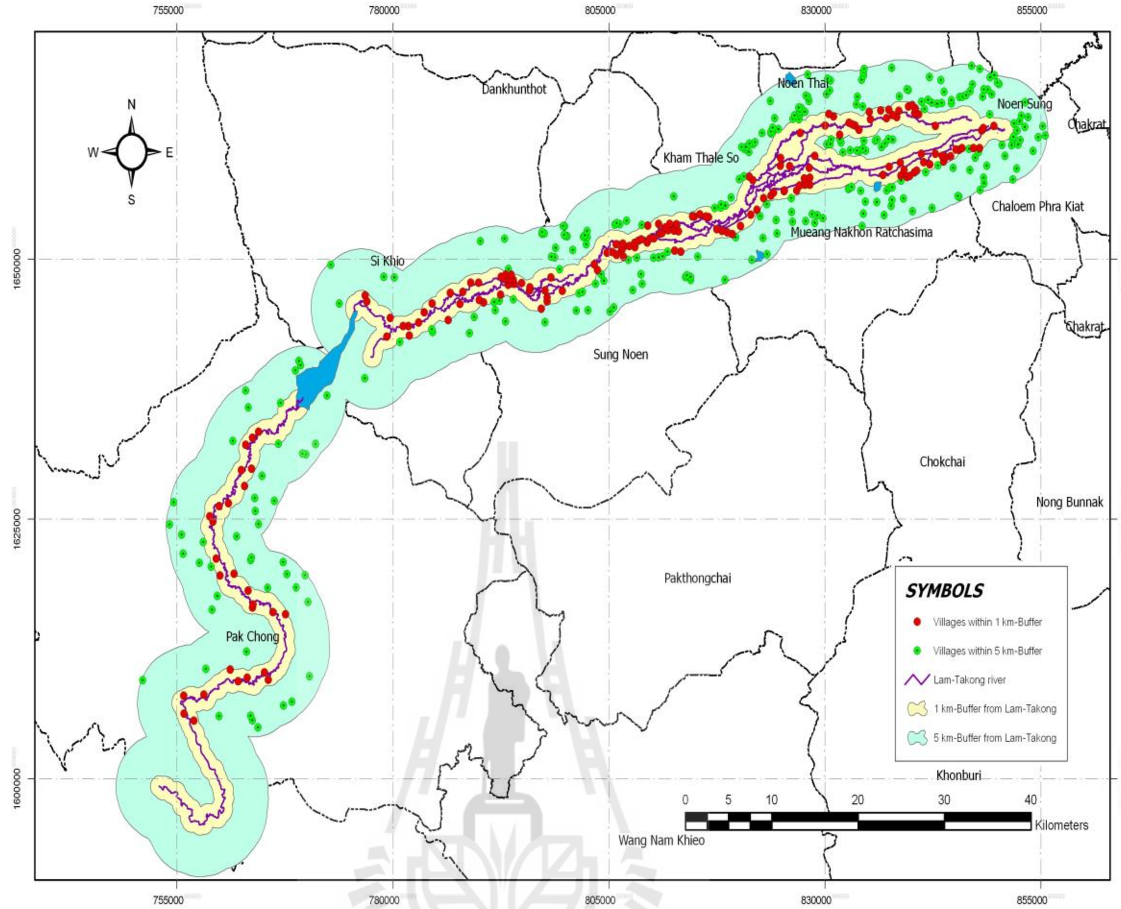


Figure 4.47 Villages in distance 0-1 and 1-5 km from Lam Takong River.

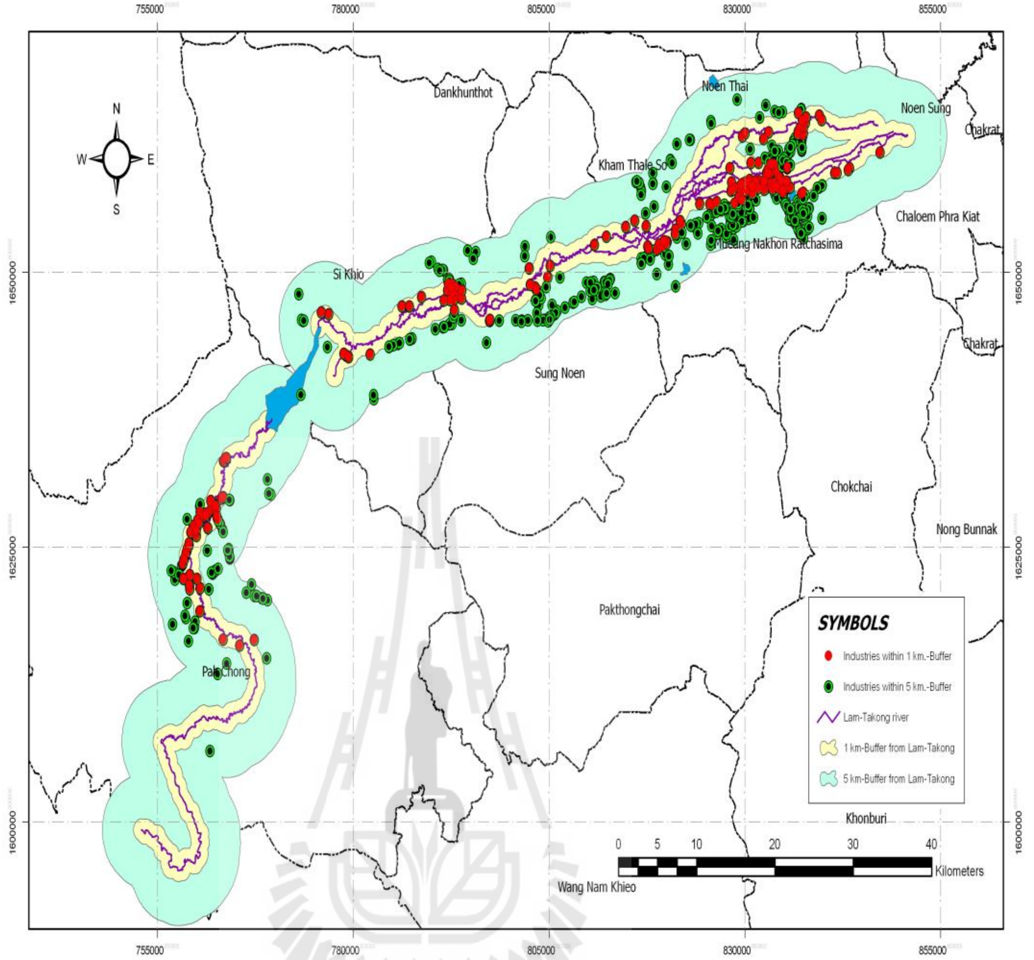


Figure 4.48 Industries in distance 0-1 and 1-5 km from Lam Takong River.

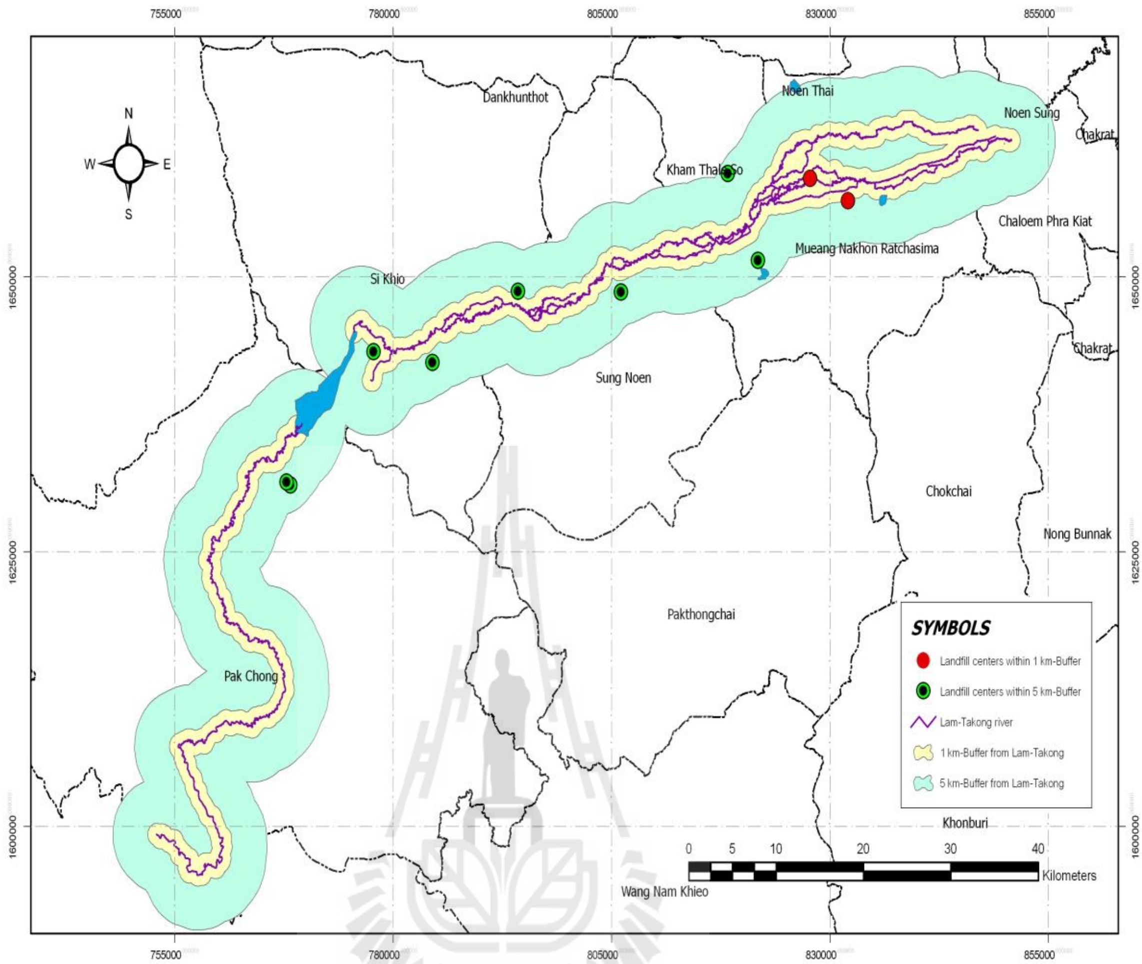


Figure 4.49 Landfill centers in distance 0-1 and 1-5 km from Lam Takong River.

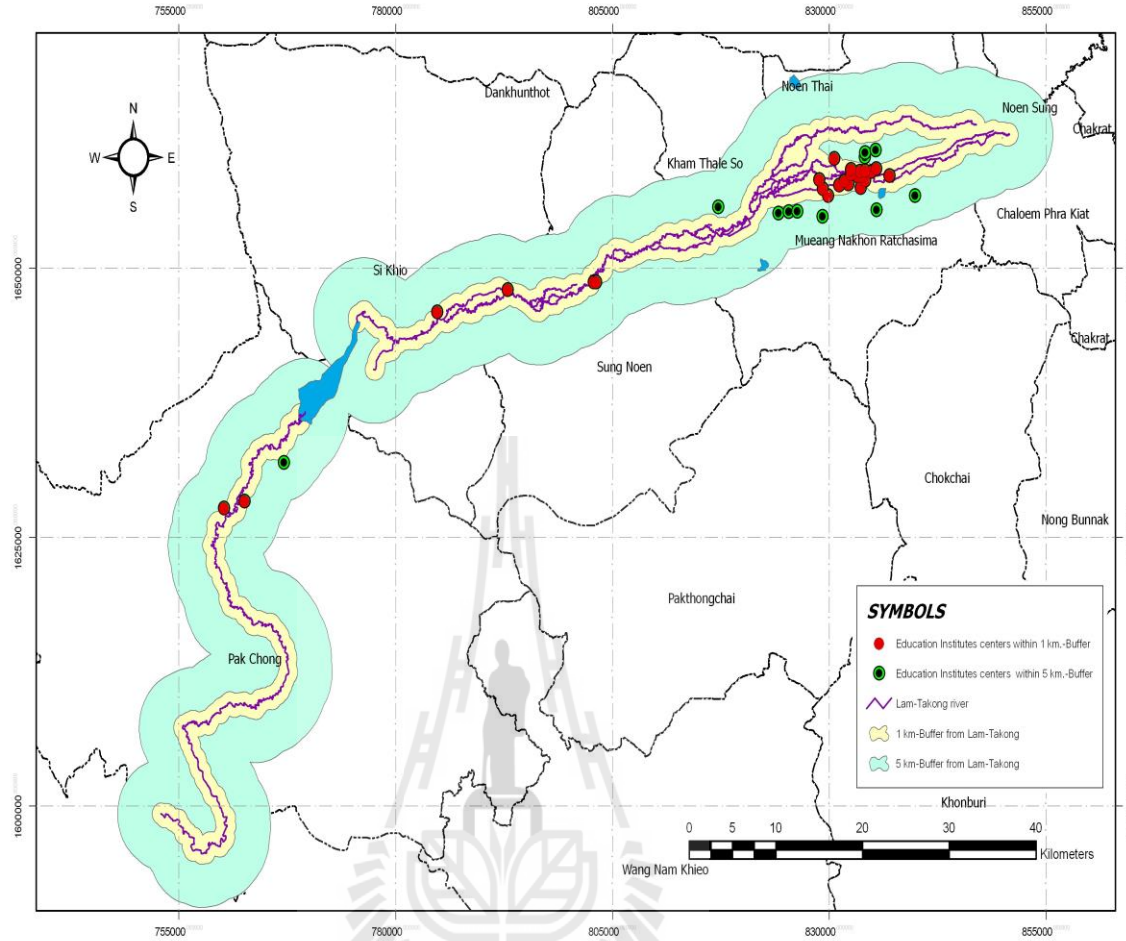


Figure 4.50 Education Institutes in distance 0-1 and 1-5 km from Lam Takong River.

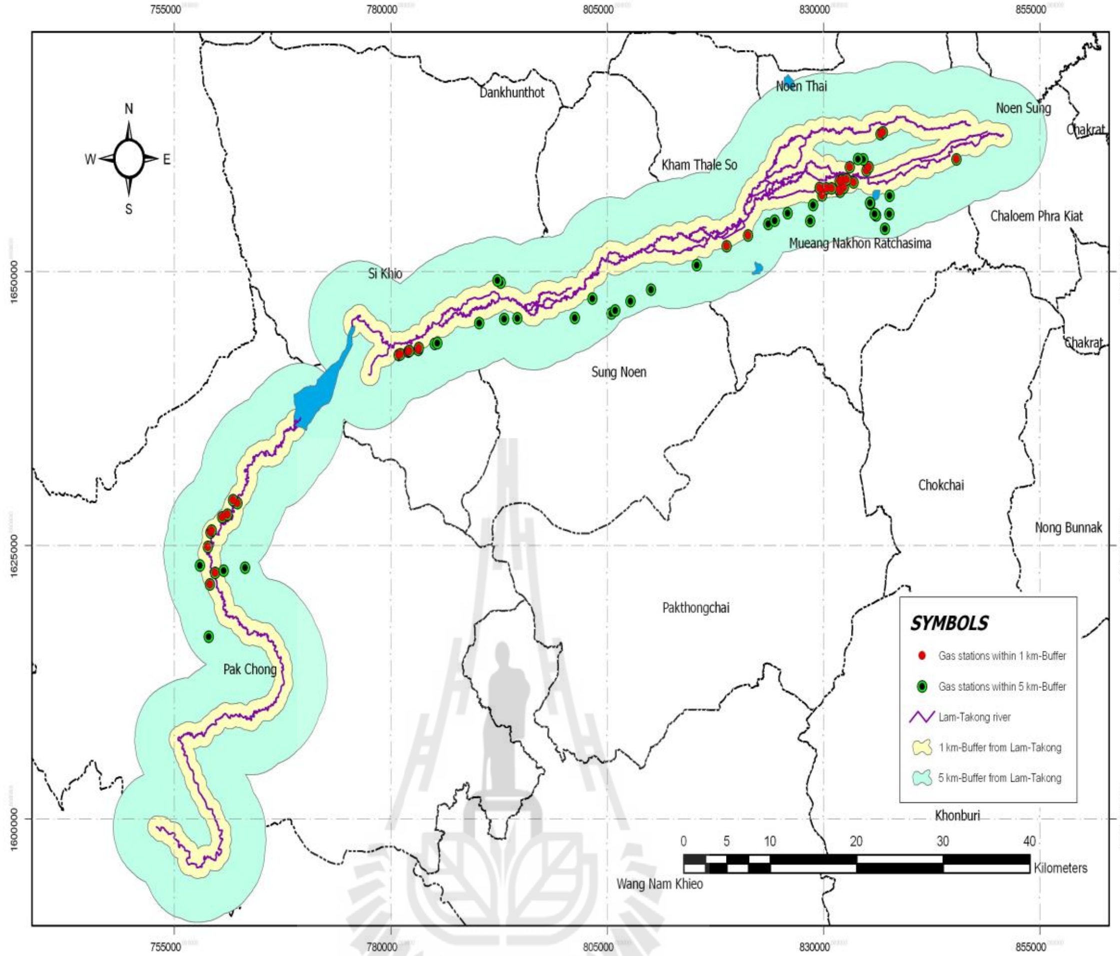


Figure 4.51 Gas stations in distance 0-1 and 1-5 km from Lam Takong River.

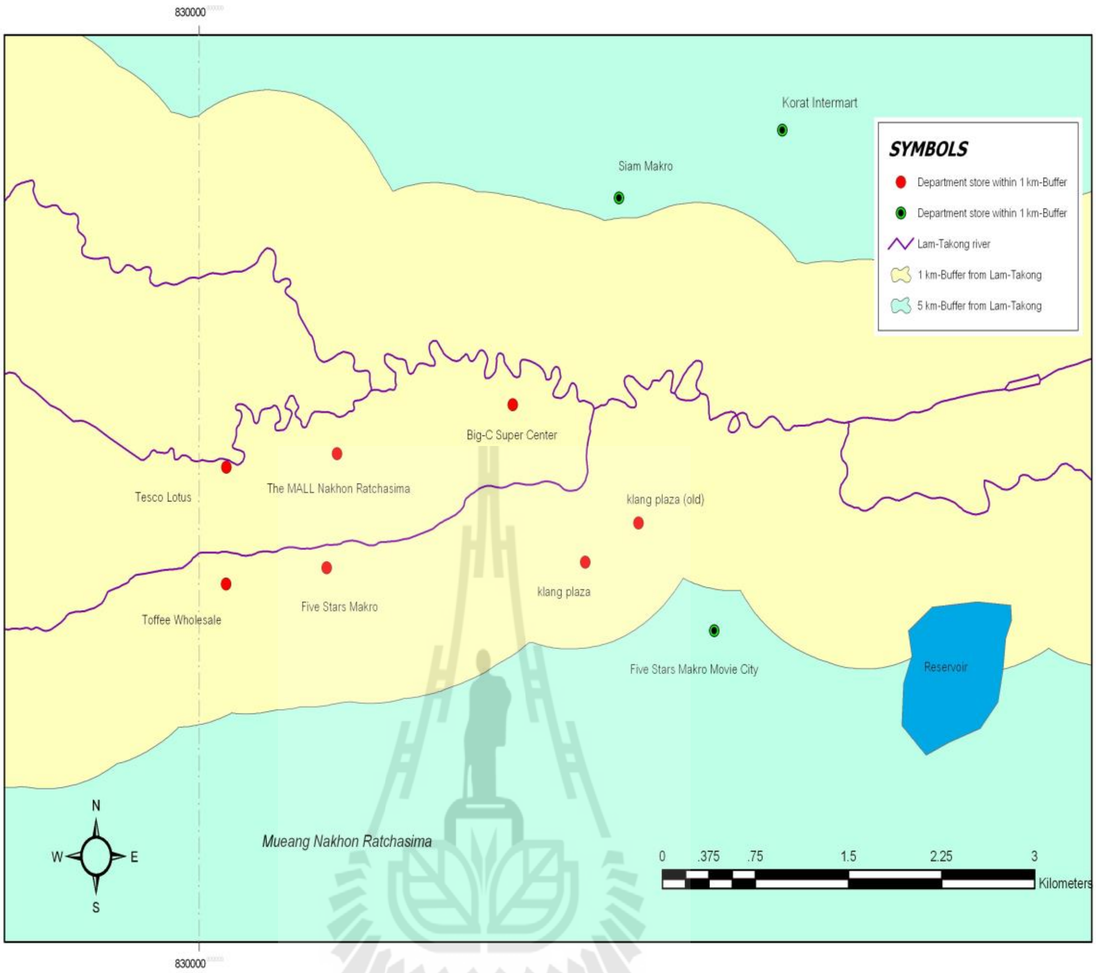


Figure 4.52 Department store in distance 0-1 and 1-5 km from Lam Takong River.

4.7 Effect of Land use on water quality

For studied the effect of land use on Lam Takong water quality, Data of land use type from Department of Land Development were used. Land use type and area in 2008 were classified (Table 4.7). Lam Takong subbasins were also classified by using data from Department of Land Development and Royal Irrigation Department (2008) (Figure 4.53). Correlation between Land use type and water quality parameter were determine for predicted which land use type has more effected on each parameter. The SPSS program version 16 was used for studied correlation.

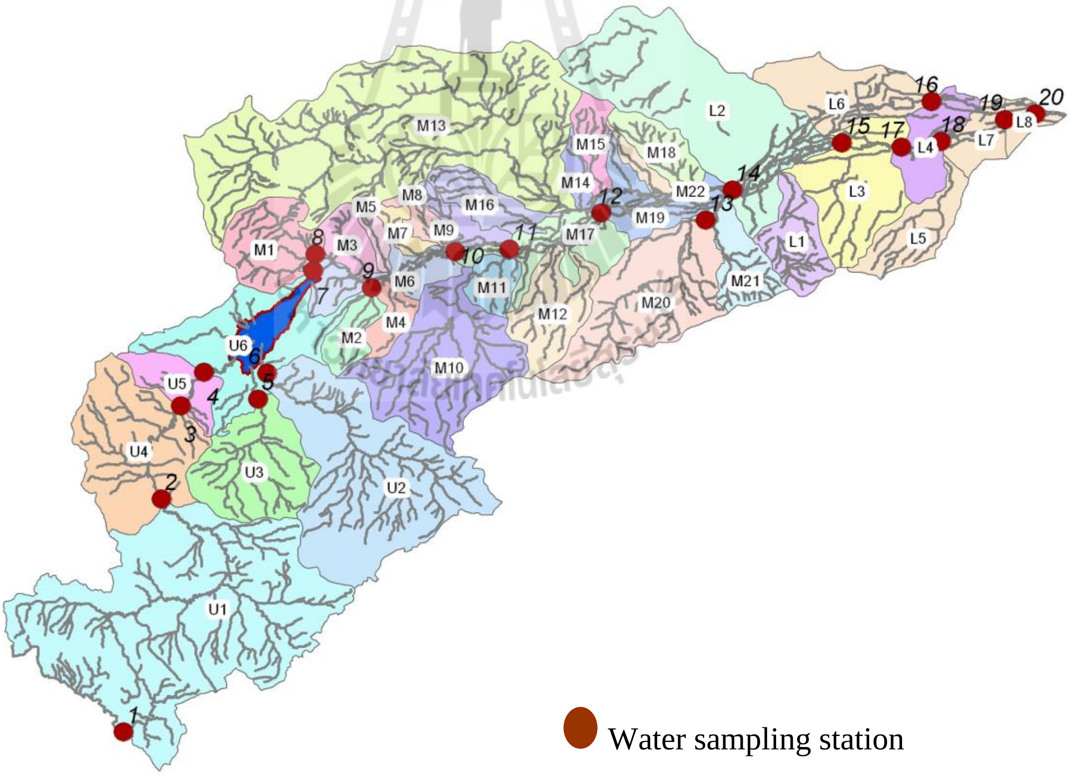


Figure 4.53 Subbasins of Lam Takong Basin.

Subbasins of Lam Takong Basin can be divided into 36 subbasins. In each subbasin has similar land use type but varies in area of each type of land use. BOD, DO, ammonia, nitrate, phosphate, and chlorophyll-a were representative of water parameters. The result of correlation between Land use type and water quality parameters (Table 4.12) showed that urban area was the most effected on BOD, DO, ammonia, phosphate, and chlorophyll-a followed by industrial area except chlorophyll-a that followed by scrub forest (deteriorated forest). For nitrate, waterbody or water resources was mostly effected might be coursing by nitrification and denitrification in water.

Table 4.12 Pearson's Correlations between land use types and water quality parameters.

Land use type	BOD	DO	NH_4	NO_3	PO_4	Chlo-a
Urban	.380	-.259	.445	-.121	.339	.425
Industrial area	.353	-.239	.364	-.161	.283	.335
Flat area	.107	.006	-.024	-.040	-.068	-.084
Waterbody	.135	-.019	-.028	.476	-.003	.064
Mixed orchard	.222	-.163	-.285	-.171	.245	.281
Agricultural area	-.240	0.80	-.193	.005	-.128	-.220
forest	.120	-.101	.221	-.217	.193	.208
Scrub forest (deteriorated forest)	.329	-.218	.348	-.157	.276	.347
Gassland	.234	-.170	.276	-.172	.240	.287

4.8 Prediction of water quality in Lam Takong Basin

Three types of land use that has mostly correlation with each water quality (Table 4.12) were determined water quality model prediction. Multiple regression analysis is the tool of SPSS program version 16 was used.

The prediction models were shown in Table 4.13. The model which has highly R^2 value is suit for prediction water quality of Lam Takong river. Although the R^2 value is nearly by other models, the model which has a few variables is better.

Table 4.13 The prediction model for Lam Takong water quality.

Parameter	Model prediction	R^2
BOD	BOD = (0.006 x urban) + 2.282	0.145
	BOD = (0.009 x urban) + (0.012 x industry) + 2.360	0.147
	BOD = (0.008 x urban) + (0.220 x industry) + (0.128 x scrub forest) + 2.516	0.229
DO	DO = (-0.003 x urban) + 6.705	0.067
	DO = (-0.005 x urban) + (0.008x industry) + 6.655	0.069
	DO = (0.004 x urban) + (0.154 x industry) + (0.089 x scrub forest) + 6.546	0.132
NH_4	NH_4 = (0.008 x urban) + 1.540	0.198
	NH_4 = (0.024 x urban) + (0.063 x industry) + 1.946	0.258
	NH_4 = (0.023 x urban) + (0.075 x industry) + (0.076 x scrub forest) + 2.038	0.281
NO_3	NO_3 = (0.010 x waterbody) + 1.107	0.226
	NO_3 = (0.010 x waterbody) + (0.001 x agricultural area) + 0.849	0.230
	NO_3 = (0.010 x waterbody) + (0.002 x agricultural area) + (0.000 xflat area) + 0.842	0.230
PO_4	PO_4 = (0.002 x urban) + 0.124	0.115
	PO_4 = (0.004 x urban) + (0.011 x industry) + 0.194	0.143
	PO_4 = (0.004 x urban) + (0.001 x industry) + (0.006 x scrub forest) + 0.202	0.145
Chlo-a	Chlo-a = (0.241 x urban) + (-3.051)	0.181
	Chlo-a = (0.004 x urban) + (0.918 x scrub forest) + 8.860	0.228
	Chlo-a = (0.659 x urban) + (0.883 x scrub forest) + (0.069 x industry) + 8.852	0.228

The model which fit for predict the effect of land use on water quality showed that:

BOD = (0.008 x urban) + (0.220 x industry) + (0.128 x scrub forest) + 2.516

DO = (0.004 x urban) + (0.154 x industry) + (0.089 x scrub forest) + 6.546

NH_4 = (0.023 x urban) + (0.075 x industry) + (0.076 x scrub forest) + 2.038

NO_3 = (0.010 x waterbody) + (0.001 x agricultural area) + 0.849

PO_4 = (0.004 x urban) + (0.011 x industry) + 0.194

Chlo-a = (0.004 x urban) + (0.918 x scrub forest) + 8.86 .

4.9 Water quality modeling in Lam Takong Basin

Prediction the amount of dissolved oxygen changed by pollution loading in Lam Takong river was determined by WASPs model. Complexity Level 2^c or Modified Streeter–Phelps with NBOD method was selected to consider the relationship between BOD-DO with SOD and NBOD. Mostly of variables and other constants were followed. Default of model and literature review were shown in Tables 3.6 and 3.7 (United States Environmental Protection Agency, 2010).

4.9.1 Model calibration and validation

WASP (Water Quality Analysis Simulation Program) was started with calibration each parameter after that validation for prediction the value of pollutant at that time (Tong and Chen, 2002). In addition, only DO value of ten water sampling stations in main river after Lam Takong Dam were used because DO can be the representative of water quality and can be used for prediction of aquatic ecosystem. The data in February 2009 were selected for model calibration until the simulated DO value is nearly by observed DO value in April 2009. Root mean square of error (RMSE) was 1.08 mg/L and relative error was 36% (Figure 4.54).

After model calibration, DO values were used for model validation by compare with DO value in August 2009. The result showed Root mean square of error (RMSE) was 0.68 mg/l and relative error was 19% (Figure 4.55). Simulated DO was rather differing from observed BOD due to limitation of model that has one constants for all segments, in fact in each segment was different.

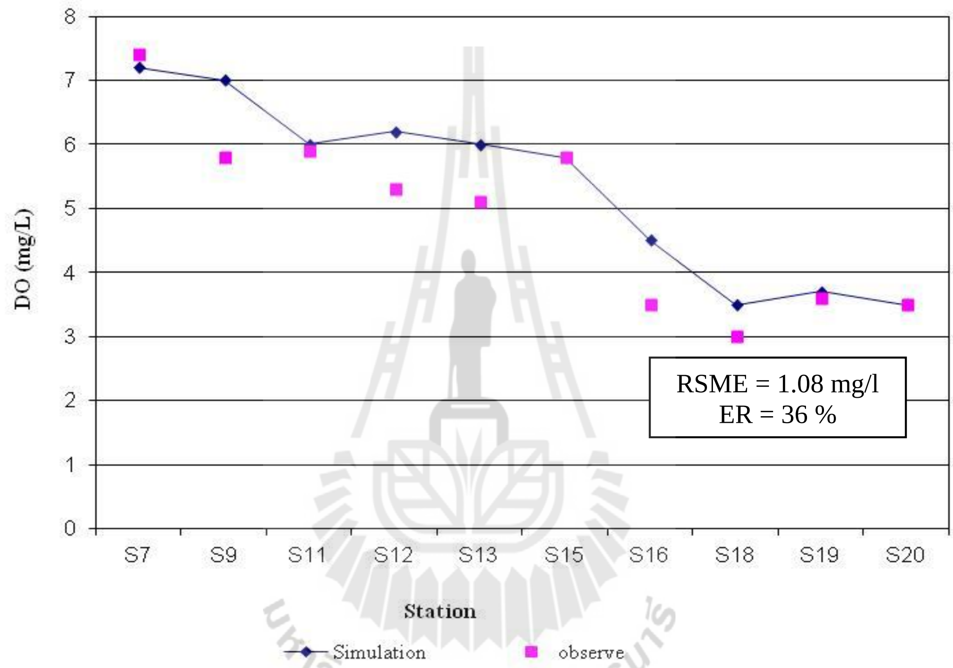


Figure 4.54 Lam Takong model calibration.

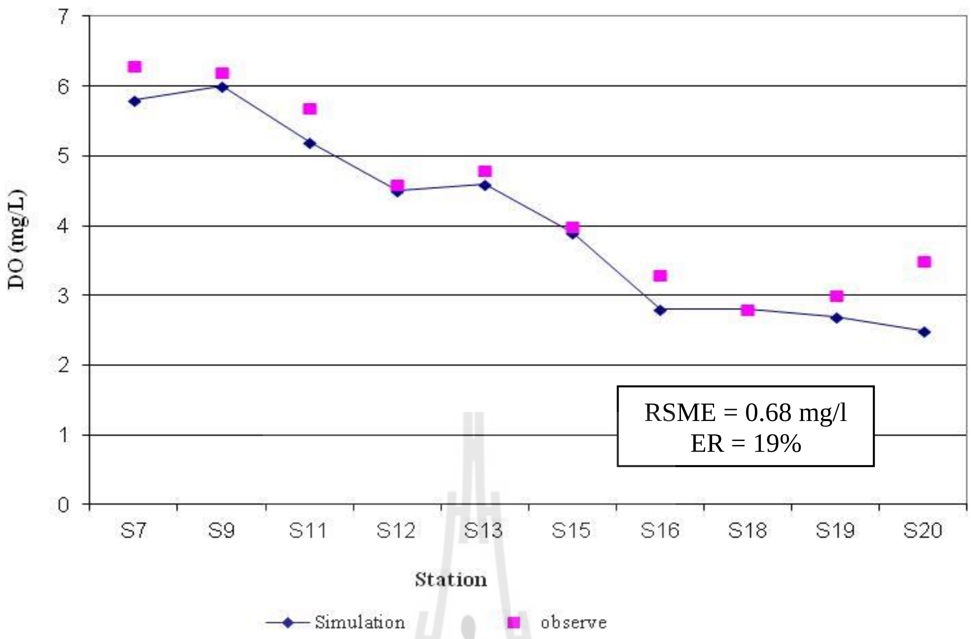


Figure 4.55 Lam Takong model validation.

4.9.2 Scenario setting

Interesting scenarios consist of basic case and reduce pollutant loading case. In this study, Three scenarios (Figure 4.56) as followed were applied :

<u>Scenario 1</u> Present situation (Lam Takong water quality in 2008.)

<u>Scenario 2</u> Future situation (Lam Takong water quality in 2018.)

<u>Scenario 3</u> Future situation (Lam Takong water quality in 2018 when reducing pollutant loading 25% off).

In scenario 3, the reason for setting the pollutant loading was 25% because the policy of Thai government assigned all districts must construct water treatment plants and every household should have septic tank. In fact, water treatment plant around Lam Takong could not be constructed in 10 years and there are many pipes directly drain wastewater into river.

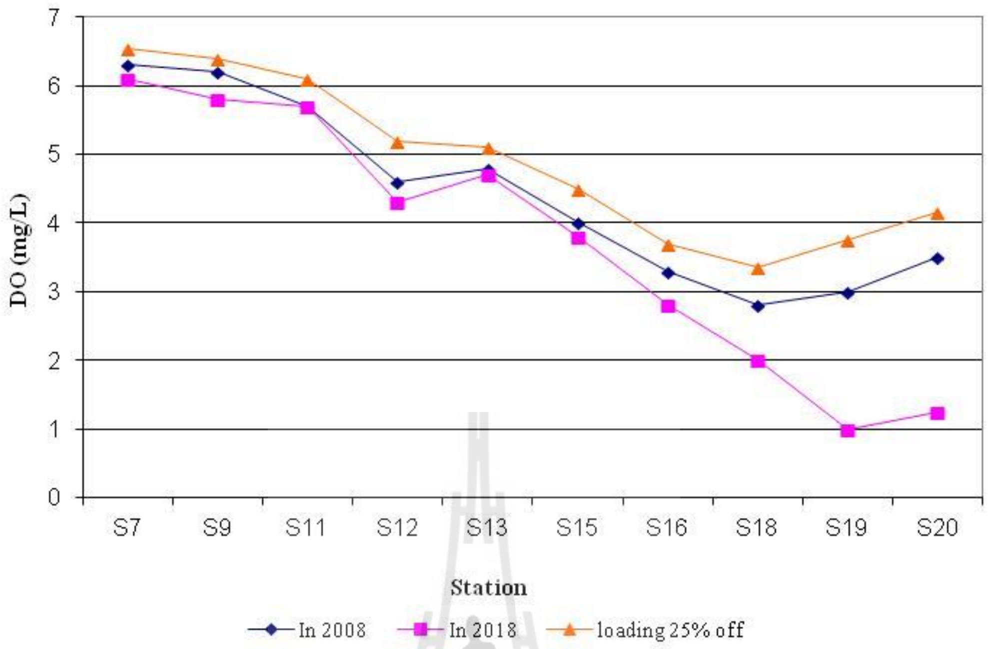


Figure 4.56 DO prediction scenario.

From scenario 1 and 2 showed water quality of Lam Takong was deteriorated at the lower part from the past to the present. In 2018, water quality was more deteriorate, especially, station 18 (Ban Thakrasang), station 19 (Ban Yongyang) and station 20 (Kunphum barrage). Other part of river will be deteriorated when the river flow pass urban area such as Sung Noen Municipality.

From scenario 3 showed the Do value will be increased when pollution loading was decreased. Reducing sewage in 25%, it allowed only water quality in sum parts of Lam Takong were better.

4.10 Discussion

Lam Takong water quality and land use type can be used to indicate water quality status, trophic level status, the seasonal effect and the effect of land use on water quality, and Lam Takong model prediction. The results of water analyses in Lam Takong river and tributaries in 6 months (October, November 2008; February, April, June, August 2009), water analyses in Lam Takong river of The Pollution Control Department in13 year period (1996-2008), and the effect of land use types in Lam Takong subasins on water quality can be summarized as follows.

4.10.1 Water quality in LamTakong in 13 years

The analysis of Lam Takong river from 7 stations of The Pollution Control Department in 13 years period. Only an important parameters for indicated water quality were considered. Dissolved oxygen (DO) value was well except at station LT6 (Wat-Samukkee) where Lam Takong river flow through the Nakhon Ratchasima Municipality. DO has low concentration in 1998, 1999, and 2005. From 2006 to present, DO was high value. When biochemical oxygen demand (BOD) was considered found station LT6 (Wat-Samukkee) and station LT7 (Ban Yongyang) has high value. In 1998-1999 water in Lam Takong was mostly deteriorated caused by urban expansion and established wastewater Treatment plant. For nutrients analysis, nitrate and ammonia were higher in year 1998, 1999, and 2005. It might be causing by high volume of wastewater drain into Lam Takong, especially in station LT6 (Wat-Samukkee) and station LT7 (Ban Yongyang) has highly ammonia concentration while nitrate concentration was highly at station LT2 (Ban Nong Salai), and station LT3 (Quartermaster Department Royal Thai Army Bridge) where crowded with agriculture area. The effect of fertilizer is mainly increasing nitrate factor and the other factor was community expansion along the river.

Total phosphorus was highly at station LT6 and station LT7 but the value found highly different in 2005 at station LT1 (Ban Bukachad) and station LT3

(Quartermaster Department Royal Thai Army Bridge). The investigators did not consideration these value. Conductivity at station LT6 (Wat-Samukkee) and station LT7 (Ban Yongyang) has highly value in 1998 and 2005.

Based on the result of parameters can be concluded that in the periods of 1998, 1999, and 2005 were the year of Lam Takong deterioration. The mostly deteriorated station is downstream where Lam Takong river flow through the Nakhon Ratchasima. Although, treatment plant of Nakhon Ratchasima Municipality was established and operated since 1990 (The Pollution Control Department, 2008) but Lam Takong water quality was still deteriorated causing by sewage pipes from residential area and other work places did not connect with collecting pipe of municipality. The amount of wastewater from urban area was drained into Lam Takong river caused Nakhon Ratchasima Municipality asked for Department of Science and Technology to supported money for expansion wastewater collecting pipes and finish in 2002. For this reason, water quality of Lam Takong is better. In addition, Nakhon Ratchasima municipality was establish central wastewater treatment plant phase II (2006-2009) for cover 90% of households but the operation of treatment plant did not complete because organic loading concentration was not suite for microorganism in plant growth.

4.10.2 Water quality in LamTakong and Tributaries from 2008-2009

Study of water quality in LamTakong and Tributaries from 20 station found the water quality in Lam Takong is moderate water quality except the water quality is quite bad when runs through the municipality of Nakhon Ratchasima. The results of water quality analysis showed that pH and temperature are different in each water station but slightly different based on monthly station which the value exceed the standard of surface water. as the same result of The Pollution Control Department from 1996-2008.

For conductivity and total suspended solid found higher in August which has a lot of water. Dissolved oxygen will be decrease when the river flow pass a big city include station 4 (Quartermaster Department Royal Thai Army Bridge), Station 18 (Ban Tha Krasang), station 19 (Yongyang Bridge) and its tributaries including station 5 (Klong Yang), station 9 (Huai Subwa), and station 13 (Huai Subtakhor).BOD found high value in tributaries at station 5 (Klong Yang) and where the river flow pass Nakhon Ratchasima Municipality, station 18 (Ban Tha Krasang) and station 19 (Yongyang Bridge).

Ammonia is exceed the standard of surface water quality, the highest value found at station 4 (Quartermaster Department Royal Thai Army Bridge), station 19 (Yongyang Bridge) where the river flow pass Nakhon Ratchasima Municipality. Total organic carbon will be high in April 2009 found at station 4 (Quartermaster Department Royal Thai Army Bridge), Station 15 (KonChum barrage) and station 17 (Wat-Samukkee Bridge) of main river and Station 6 (Huai Hinlub) of tributaries.

Nitrite, nitrate at station 4 (Quartermaster Department Royal Thai Army Bridge), station 18 (Ban Tha Krasang) and station 19 (Yongyang Bridge) are highest. Nitrogen were significantly related to vegetated coverage as the same Li *et al*. (2008), studied at upper Hua River Basin. For phosphate is found in April at station 7 (Lam Takong Dam) is high when considered with algae bloom in Lam Takong reservoir found that algae are rapidly growth at point where tributaries and main river flow into reservoir. Domestic waste increased phosphate concentration while filed crop cultivation increased nitrate concentration (Polpraprut, 1993)

The amount of chlorophyll-a found to be higher at station 5 (Klong Yang), station 12 (Kut Hin barrage), station 18 (Ban Tha Krasang) and station 20 (Kunphum barrage). When station 12 is considered, chlorophyll-a value might be from the water that release from station 7 (Lam Takong Dam) during the algae bloom. The current water flow through at this station which slow down the water by Kudhin barrage due to high value of chlorophyll-a. For station 18 (Ban Tha Krasang) where the river flow though Nakhon Ratchasima Municipality, activities around the river and effect from city and this station is behind Koyngam Barrage due to water slowly has speed of water and algae might be bloom. Station 20 (Kunphum barrage) where Lum Bariboon meet Lam Takong again before flow into Mool river. Algae bloom at this station might be flow from station 18 to accumurate in front of Kunphum barrage due to high concentration of chlorophyll-a at this station.

The trend of water quality status in Lam Takong River and tributaries in 2008-2009 still has the same quality that Pollution Control Department (2008) reported. Water quality in the upper part of Lam Takong is modurate while the lower part is modurate-polluted. Mae-ong (1986) and Lohkam (1999) were also reported that pH, total solids, turbidity and electrical conductivity in forest-agricultural watershed were less than in upland and lower agricultural watershed in Bang Pakong River Basin and Maetaeng Choen and Klong Yan Watershed.Water samples were taken from stations with forested catchments showed high level of dissolved oxygen but low level of turbidity, suspended particulate matter, total dissolved solids, ammonia-N and nitrate-N as Ngoye and Machiwa (2004) found in Ruvu River, Tanzania, and Ahern *et al*. (2005) found at watershed in Western Sierra Nevada, California.

Founding algae in Lam Takong Basin mostly occur in standing water such as water supply pump of Nakhon Ratchasima Municipality in Lam Takong dam, and in front of the barrage at the end of river from Konchum to Kunphum barrage. Human activities slow velocity of water and slow release water from barrage causing algae bloom. Blue green algae was mostly found such as *Microcystis* sp. and *Spirulina* sp. The accumulation of nutrient in surface water was increased caused wastewater from urban and agricultural area. At Nong Han, Sakon-Nakon Province, Kungkakat and Krutnoi (1990) showed that human activities led to the spread of aquatic weeds, such as water hyacinth and macro algae, over water body and increased water shallowness.

4.10.3 The seasonal effect on Lam Takong water quality

pH, DO, BOD and NH_3-N were significantly higher in dry season ($p<0.01$) while temperature, Salinity and TSS were significantly lower in dry season ($p<0.01$) Although, Turbidity, TOC, NO_3, NO_2 and Chl-a in rainy season were higher than dry season but not statistically different. Sliva and Williams (2001) and Ngoye and Machiwa (2004) also reported that the concentration of nitrate increased during rainy season.

4.10.4 Trophic level status in Lam Takong

Trophic level status in Lam Takong Basin in 2008-2009. The water quality of main river rater modurate (Oligotrophic-mesotrophic status) only at the upper part of Lam Takong river. But, the overall of Lam Takong main river and tributaries were moderate (Mesotrophic status). The water quality was quite poor (Mesotrophic-eutrophic status) at Station 18 when the river flow pass the Municipality of mueang Nakhon Ratchasima. The result as the same as trophic level of Lam Takong river in 13 years (1996-2008) which has Oligotrophic-mesotrophic status in the upper part and the river after release from dam, mesotrophic status when flow pass Pak Chong district and before the end of river, and The water quality was quite poor (Mesotrophic-eutrophic status) at Station LT6-LT7 when the river flow pass the Municipality of mueang Nakhon Ratchasima. Therefore, Urban area was effected on trophic level of Lam Takong from past to present.

4.10.5 Loading in Lam Takong Basin

BOD loadings were used for identify sources of pollution in basin showed that the pollution caused mainly by the urban following by agriculture, livestock, industry, and aquaculture, respectively. BOD loading of urban was 30,637 kgBOD/day, agriculture was 28,540 kgBOD/day, livestock (only swine farm) was 6,334 kgBOD/day, industry was 735 kgBOD/day, and aquaculture was 264 kgBOD/day which is nearly calculated by Regional Environmental Office 11 (2008) and found BOD loading of urban was 30,661 kgBOD/day, Actually the real loading was 11,063 kgBOD/day while loading of agriculture was 28,540 kgBOD/day, livestock (only swine farm) was 6,907kgBOD/day, industry was 690 kgBOD/day.

4.10.6 Effect of land use on water quality in Lam Takong Basin

Nine land use types and water quality in Lam Takong Basin were studied the correlation, the result found that urban area was the most effected on BOD, DO, ammonia, phosphate, and chlorophyll-a followed by industrial area except chlorophyll-a that followed by scrub forest (deteriorated forest). For nitrate, waterbody or water resources was mostly effected might be coursing by nitrification and denitrification in water. As the same as water quality in urban catchments as in the major mainland rivers of Scotland, England and Wales were also highly value of ammonium-N, orthophosphate-p and suspended solids (Ferrier *et al.*, 2000). There was a clear trend of increased wastewater with increasing urban land use intensity within a watershed (Sliva and Williams, 2001).

4.10.7 Prediction of water quality in Lam Takong Basin

After knew what land use type is mostly effected on water quality, multiple regression analysis was obtained the mathematic model for each parameter. The model which has highly R^2 value is suit for prediction water quality of Lam Takong river. Although the R^2 value is nearly by other models, the model which has a few variables is better. The result was showed that:

BOD = (0.008 x urban) + (0.220 x industry) + (0.128 x scrub forest) + 2.516

DO = (0.004 x urban) + (0.154 x industry) + (0.089 x scrub forest) + 6.546

NH_4 = (0.023 x urban) + (0.075 x industry) + (0.076 x scrub forest) + 2.038

NO_3 = (0.010 x water body) + (0.001 x agricultural area) + 0.849

PO_4 = (0.004 x urban) + (0.011 x industry) + 0.194

Chlo-a = (0.004 x urban) + (0.918 x scrub forest) + 8.86 .

4.10.8 Water quality modeling in Lam Takong Basin

Ramkomut *et al*. (2009) were used QUAL2K model for predict in crisis status in 2013 and 2018 found loading capacity along the river in 2013 was 102,724.04 kgBOD/day and in 2018 was 99,098.13 kgBOD/day due to increasing population and more increasing wastewater made less loading capacity. For this study, trend of DO was predicted by using WASP (Water Quality Analysis Simulation Program) which developed from US environmental protection agency. If the pollution loading was remained, the water quality would be deteriorated and value of DO would be decreased. DO value will be increase while pollution loading was decreased. 25% of decreasing could be slightly raise DO value. Reducing the pollution loading should be up to 50% for better water quality.

CHAPTER V

CONCLUSION

The effects of land use on the water quality in the Lam Takong Basin in Nakhon Ratchasima province were investigated.

5.1 Water quality and trophic status in Lam Takong basin in 13 years (1996-2008)

The analysis of Lam Takong river from 7 stations of The Pollution Control Department in 13 years period. The water quality of Lam Takong River, especially the lower reach, flowing through Mueang Nakhon Ratchasima, was very poor. Biological Oxygen Demand (BOD), Dissolved Oxygen (DO) and some parameters, such as Ammonia-N (NH_3-N), Nitrate-N (NO_3-N), Nitrite-N (NO_2-N), Total Phosphorus (TP) have been monitored. Most of parameters exceed the Surface Water Quality Standards of Thailand (Pollution Control Department,2005). water quality parameters in Lam Takong River from 1996 to 2008 can be classified class 3 in the upper reach (Headwater-Lam Takong Dam) and the middle reach (Lam Takong Dam-Mueang Nakhon Ratchasima) of Lam Takong River while the water quality in lower reach (Mueang Nakhon Ratchasima–Chaloem Phar Kiet) is class 4 by using the standard of surface water quality.

The nutrient level in water was oligotrophic-mesotrophic status in the upper reach and behind the dam. Nearly the big city such as Pak Chong, the status was mesotrophic. The mesotrophic-eutrophic status were found at the lower reach where the river flow through Nakhon Ratchasima municipality (Figure 5.1).

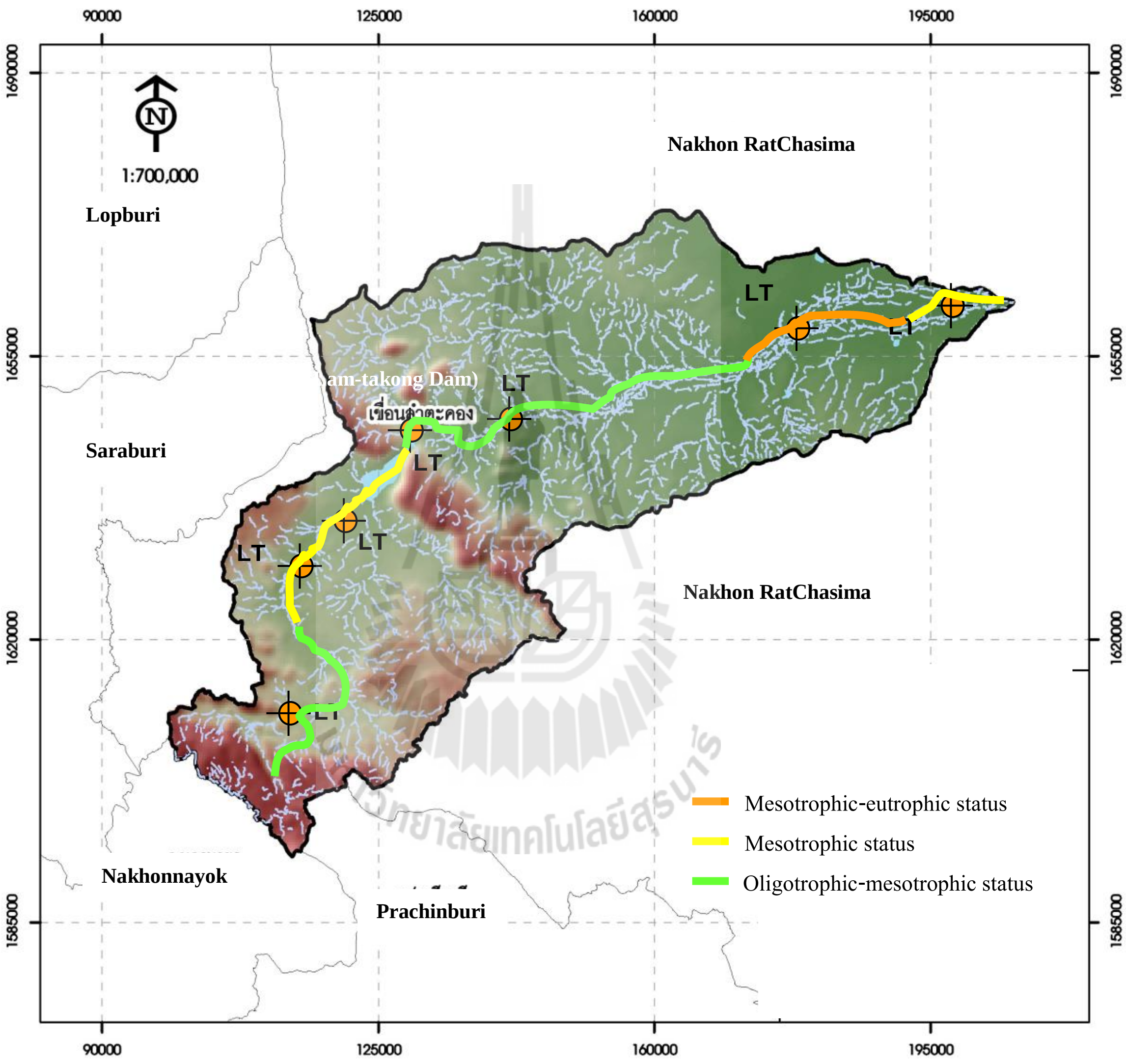


Figure 5.1 Trophic status in Lam Takong Basin in 13 years (1996-2008).

5.2 Water quality and trophic status in Lam Takong basin in 2008-2009

The study of water quality in Lam Takong basin from 20 stations of water sampling can be classified the water quality is class 3 in the upper reach (Headwater-Lam Takong Dam) and the middle reach (Lam Takong Dam-Mueang Nakhon Ratchasima) of Lam Takong river while the water quality in lower reach (Mueang Nakhon Ratchasima –Chaloem Phar Kiet) is class 4 by using Surface Water Quality Standards of Thailand. Class 3 is mean medium clean fresh surface water resources used for agriculture and consumption, but passing through an ordinary treatment process before using. Class 4 is mean Fairly clean fresh surface water resources used for industry and consumption, but requires special water treatment process before using.

The nutrient level in water caused by the activities along the river side, there are low activities at the Lam Takong upper reach. The overview of water quality by trophic level was oligotrophic-mesotrophic status. In the middle reach and tributaries, the trophic level is mesotrophic status where the activities were increased. The mesotrophic-eutrophic status were found at the lower reach which crowded of population, agriculture, industrial and residential area (Figure 5.2).

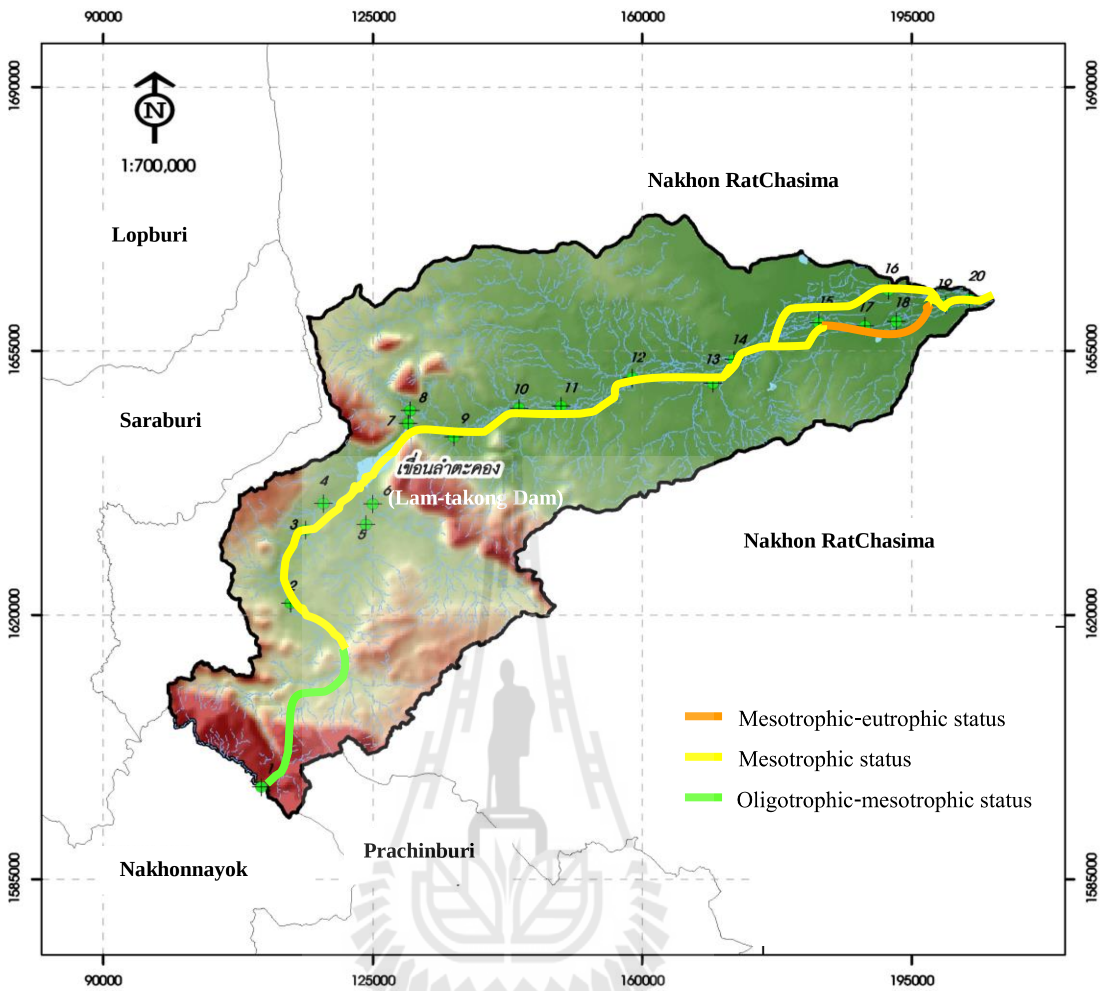


Figure 5.2 Trophic status in Lam Takong Basin in 2008-2009.

Because of population, economic and industrial expansion led to a deteriorated water quality in this basin. Even though the river can purify itself, high pollution loading, beyond the carrying capacity, can make it irreversible. For water quality and eutrophication monitoring, the station should be concerned were station 5, 6, 7, 12, 18 and 20 that there were Lam Takong tributaries and main river which flow passed urban area.

5.3 The seasonal effect on water quality in Lam Takong basin in 2008-2009

From studying, pH, DO, BOD and NH_3-N were significantly higher in dry season ($p<0.01$) while temperature, Salinity and TSS were significantly lower in dry season ($p<0.01$) as shown in Table 2. However, Turbidity, TOC, NO_3, NO_2 and Chl-a in rainy season were higher than dry season but not statistically different. Most water parameters were not exceed The Surface Water Quality Standards of Thailand except BOD, Nitrate and Ammonia. Normally, water quality of tributaries, the pass town river, and the end of river before entering to Mool River were very poor. Because of population, economic and industrial expansion led to a deteriorated water quality in this basin. Even though the river can purify itself, high pollution loading beyond the carrying capacity, can make it irreversible. The water management and monitoring is very important for Lam Takong main river and tributaries.

5.4 The effect land use on water quality of Lam Takong Basin

Land use type and Lam Takong subbasins area were also classified by using data from Department of Land Development and Royal irrigation department (2008). Correlation between Land use type and water quality parameter were determine for predicted which land use type has more effected on each parameter. The results of correlation between Land use type and water quality parameters showed that urban area was the most effected on BOD, DO, ammonia, phosphate, and chlorophyll-a followed by industrial area except chlorophyll-a that followed by scrub forest (deteriorated forest). For nitrate, waterbody or water resources was mostly effected might be coursing by nitrification and denitrification in water.

5.5 Prediction water quality

Three types of land use that has mostly correlation with each water parameter.The model which has highly R^2 value is suit for prediction water quality of Lam Takong river. Although the R^2 value is nearly by other models, the model which has a few variables is better.

5.6 Water quality modeling in Lam Takong Basin

WASPs model can be prediction the amount of dissolved oxygen changed by pollution loading in Lam Takong river. The DO value will be increased when pollution loading was decreased. Reducing sewage in 25%, it allowed only water quality in sum parts of Lam Takong were better.

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APPENDICES

APPENDIX A

AARL- PC SCORE

Appendix Table A.1 Assessment water quality in running water ecosystem using a simple sequence of AARL- PC score.

(AARL = Applied Algal Research Laboratory, PC = Physical and Chemical)

Standard score	DO (mg/L)	BOD (mg/L)	Conductivity (mS/cm)	NO_3 -N (mg/L)	NH_3 -N (mg/L)	Soluble reactive phosphorus (mg/L)
0.1	> 9	< 0.3	< 10	< 0.05	< 0.1	< 0.05
0.2	8-9	0.3-0.8	10-30	0.05-0.1	0.1-0.2	0.05-0.1
0.3	7-8	0.8-1.5	30-60	0.1-0.3	0.2-0.4	0.1-0.2
0.4	6-7	1.5-3.0	60-100	0.3-0.8	0.4-0.8	0.2-0.4
0.5	5-6	3.0-5.0	100-200	0.8-1.5	0.8-1.5	0.4-1.0
0.6	4-5	5.0-10.0	200-350	1.5-3.0	1.5-3.0	1.0-2.0
0.7	3-4	10.0-20.0	350-600	3.0-10.0	3.0-5.0	2.0-3.5
0.8	2-3	20.0-40.0	600-1,000	10.0-20.0	5.0-10.0	3.5-7.0
0.9	1-2	40.0-80.0	1,000-2,000	20.0-40.0	10.0-20.0	7.0-15.0
1.0	< 1	> 80.0	> 2000	> 40.0	> 20.0	> 15.0

Source: Applied Algal Research Laboratory (2006)

Appendix Table A.2 Water quality classified by AARL- PC score in running water.

Trophic level	Water quality	No. of Parameter			
		3	**4**	**5**	**6**
Ultraoligotrophic status	Very Clean	0.1-0.4	0.1-0.6	0.1-0.7	0.1-0.8
Oligotrophic status	Clean	0.5-0.9	0.7-1.2	0.8-1.4	0.9-1.6
Oligotrophic-mesotrophic status	Clean-Moderate	1.0-1.4	1.3-1.8	1.5-2.1	1.7-2.4
Mesotrophic status	Moderate	1.5-1.9	1.9-2.4	2.2-2.8	2.5-3.2
Mesotrophic-eutrophic status	Moderate -polluted	1.9-2.3	2.5-3.0	2.9-3.5	3.3-4.0
Eutrophic status	Polluted	2.3-2.6	3.0-3.5	3.6-4.2	4.1-4.8
Hypereutrophic status	Very polluted	> 2.6	> 3.5	> 4.2	> 4.8

Source: Applied Algal Research Laboratory (2006).

Appendix Table A.3 Assessment water quality by using AARL- PP score.

(AARL = Applied Algal Research Laboratory, PP = Phytoplankton)

Genus	Score	Genus	Score
Euglena	10	*Eudorina*	6
Merismopedia	9	*Gomphonema*	6
Nitzchia	9	*Gonium*	6
Oscillatoria	9	*Gymnodinium*	6
Phormidium	9	*Oocyctis*	6
Spirulina	9	*Pandorina*	6
Anabaena	8	*Peridiniopsis*	6
Cryptomonas	8	*Peridinium*	6
Gymnodinium	8	*Rhizosolenia*	6
Microcystis	8	*Surirella*	6
Phacus	8	*Synedra*	6
Rhodomonas	8	*Tetraedron*	6
Scenedesmus	8	*Volvox*	6
Strombomonas	8	*Actinastrum*	5
Synedra	8	*Acanthoceras*	5
Trachelomonas	8	*Aphanocapsa*	5
Ankistrodesmus	7	*Aphanothece*	5
Bacillaria	7	*Cymbella*	5
Coelastrum	7	*Fragilaria*	5
Crucigenia	7	*Golenkinia*	5
Crucigeniella	7	*Isthmochloron*	5
Cylindrospermopsis	7	*Kirchneriella*	5
Dictyosphaerium	7	*Meloseira*	5
Dimorphococcus	7	*Navicula*	5
Gyrosigma	7	*Nephrocytium*	5
Micractinium	7	*Pinnularia*	5
Monoraphidium	7	*Rhopalodia*	5
Pediastrum	7	*Stauroneis*	5

Appendix Table A.3 Assessment water quality by using AARL- PP score.

(AARL = Applied Algal Research Laboratory, PP = Phytoplankton) (Continued).

Genus	Score	Genus	Score
Planktolyngbya	7	*Botryococcus*	4
Pseudanabaena	7	*Centritractus*	4
Achnanthes	6	*Ceratium*	4
Amphora	6	*Elakatothrix*	3
Aulacoseira	6	*Euastrum*	3
Chlamydomonas	6	*Staurastrum*	3
Chlorella	6	*Staurodesmus*	3
Chroococcus	6	*Cosmarium*	2
Closterium	6	*Cyclotella*	2
Cocconeis	6	*Eunotia*	2
Encyonema	6	*Micrasterias*	2
Epithemia	6	*Dinobryon*	1

Source: Applied Algal Research Laboratory (2006).

From 1-10 score above can be divided into 6 sub class, as shown below.

Appendix Table A.4 Trophic level and water quality by using phytoplankton score.

Score	Trophic level	Water Quality
1.0-2.0	Oligotrophic status	Clean
2.1-3.5	Oligo-mesotrophic status	Clean-moderate
3.6-5.5	Mesotrophic status	Moderate
5.6-7.5	Mesotrophic-Eutropic status	Moderate-polluted
7.6-9.0	Eutrophic status	Polluted
9.0-10.0	Hypereutrophic status	Very polluted

Source: Applied Algal Research Laboratory (2006).

Appendix Table A.5 Surface Water Quality Standards of Thailand.

Parameter	Units	Statistic	Standard Value for Class Class 1	Class 2	Class 3	Class 4	Class 5	Methods for Examination
1. Colour,Odour and Taste	-	-	n	n*	n*	n*	-	-
2. Temperature	ºC	-	n	n*	n*	n*	-	Thermometer
3. pH	-	-	n	5-9	5-9	5-9	-	Electrometric pH Meter
4. Dissolved Oxygen (DO)2/	mg/L	P20	n	6.0	4.0	2.0	-	Azide Modification
5. BOD (5 days, 20°C)	mg/L	P80	n	1.5	2.0	4.0	-	Azide Modification at 20°C , 5 days
6.Total Coliform Bacteria	MPN/ 100 ml	P80	n	5,000	20,000	-	-	Multiple Tube Fermentation Technique
7. Fecal Coliform Bateria	MPN/ 100 mL	P80	n	1,000	4,000	-	-	Multiple Tube Fermentation Technique
8. NO_3 -N	mg/L	-	n		5.0		-	Cadmium Reduction
9. NH_3 -N	mg/L	-	n		0.5		-	Distillation Nesslerization
10. Phenols	mg/L	-	n		0.005		-	Distillation,4-Amino antipyrene
11. Copper (Cu)	mg/L	-	n		0.1		-	Atomic Absorption - Direct Aspiration
12. Nickle (Ni)	mg/L	-	n		0.1		-	Atomic Absorption - Direct Aspiration
13. Manganese (Mn)	mg/L	-	n		1.0		-	Atomic Absorption - Direct Aspiration
14. Zinc (Zn)	mg/L	-	n		1.0		-	Atomic Absorption - Direct Aspiration
15. Cadmium (Cd)	mg/L	-	n		0.005* 0.05**		-	Atomic Absorption - Direct Aspiration
16. Chromium Hexavalent	mg/L	-	n		0.05		-	Atomic Absorption - Direct Aspiration
17.Lead (Pb)	mg/L	-	n		0.05		-	Atomic Absorption - Direct Aspiration
18.Total Mercury (Total Hg)	mg/L	-	n		0.002		-	Atomic Absorption- Cold Vapour Technique
19.Arsenic (As)	mg/L	-	n		0.01		-	Atomic Absorption - Direct Aspiration
20.Cyanide (Cyanide)	mg/L	-	n		0.005		-	Pyridine-Barbituric Acid
21.Radioactivity - Alpha - Beta	Becqurel /L	-	n		0.1 1.0		-	Gas-Chromatography
22.Total Organochlorine Pesticides	mg/L	-	n		0.05		-	Gas-Chromatography
23.DDT	µg/L	-	n		1.0		-	Gas-Chromatography
24.Alpha-BHC	µg/L	-	n		0.02		-	Gas-Chromatography
25.Dieldrin	µg/L	-	n		0.1		-	Gas-Chromatography
26.Aldrin	µg/L	-	n		0.1		-	Gas-Chromatography
27.Heptachlor & Heptachlorepoxide	µg/L	-	n		0.2		-	Gas-Chromatography
28.Endrin	µg/L	-	n		None		-	Gas-Chromatography

Remar : P Percentile value

k n naturally

n' naturally but changing not more than 3°C

* when water hardness not more than 100 mg/l as $CaCO_3$

** when water hardness more than 100 mg/l as $CaCO_3$

Based on Standard Methods for the Examination of Water and Wastewater recommended by APHA : American Public Health Association, AWWA : American Water Works Association and WPCF : Water Pollution Control Federation.

Source : Notification of the National Environmental Board, No. 8, B.E. 2537 (1994), issued under the Enhancement and Conservation of National Environmental Quality Act B.E.2535 (1992) , published in the Royal Government Gazette, Vol. 111, Part 16, dated February 24, B.E.2537 (1994).

Appendix Table A.6 Water quality classification.

Classification	**Objectives/Condition and Beneficial Usage**
Class 1	Extra clean fresh surface water resources used for : (1) conservation not necessary pass through water treatment process require only ordinary process for pathogenic destruction (2) ecosystem conservation where basic organisms can breed naturally
Class 2	Very clean fresh surface water resources used for : (1) consumption which requires ordinary water treatment process before use (2) aquatic organism of conservation (3) fisheries (4) recreation
Class 3	Medium clean fresh surface water resources used for : (1) consumption, but passing through an ordinary treatment process before using (2) agriculture
Class 4	Fairly clean fresh surface water resources used for : (1) consumption, but requires special water treatment process before using (2) industry
Class 5	The sources which are not classification in class 1-4 and used for navigation.

Source : http://www.pcd.go.th/Info_serv/reg_std_water.html.

APPENDIX B

THE WATER QUALITY ANALYSIS IN

OCTOBER 2008-AUGUST 2009

The results of the analysis of water samples from the Lam Takong watershed at 20 point of 6 districts of Nakhon Ratchasima province sample collection was in from October and December, 2008 and in February, April, June, and August, 2009.

The physical analysis of water quality

Appendix Table B.1 Monthly pH of Lam Takong River and tributaries.

station	pH						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	8.03	6.43	6.65	6.58	5.59	5.59	6.48
2	7.92	7.26	7.72	7.07	7.19	6.17	7.22
3	8.01	7.32	7.41	7.08	6.29	6.11	7.04
4	7.93	7.91	7.89	7.47	6.89	6.69	7.46
5	7.99	6.11	7.41	5.93	5.95	4.85	6.37
6	8.04	8.08	7.91	7.72	6.45	6.79	7.50
7	7.94	8.40	8.22	7.74	7.40	8.50	8.03
8	7.97	7.73	7.25	6.59	5.79	6.93	7.04
9	7.74	7.46	5.15	6.25	6.18	6.51	6.55
10	7.85	7.99	7.10	7.91	6.93	7.35	7.52
11	7.76	8.10	7.40	7.82	6.45	6.80	7.39
12	8.02	8.22	6.40	7.12	6.67	5.08	6.92
13	7.20	6.35	6.02	5.80	5.45	6.58	6.23
14	7.58	6.87	6.41	6.63	6.59	5.97	6.68
15	7.76	7.41	5.91	6.38	6.76	6.38	6.77
16	7.53	6.87	6.05	6.85	5.90	6.49	6.62
17	7.54	6.83	6.29	6.54	6.74	6.54	6.75
18	7.58	7.30	7.10	6.76	7.22	6.79	7.13
19	7.68	7.15	7.28	6.47	6.75	6.73	7.01
20	7.56	7.83	8.14	7.58	7.19	6.67	7.50

Appendix Table B.2 Monthly Temperature of Lam Takong River and tributaries.

Station	Temperature (°C)						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	23.9	18.0	25.1	26.5	24.7	23.8	23.7
2	25.9	20.6	24.3	26.1	27.2	26.5	25.1
3	26.9	21.2	20.8	27.4	27.8	28.8	25.5
4	26.5	21.5	25.8	27.9	28.9	30.2	26.8
5	26.9	20.6	23.8	23.1	27.6	25.9	24.7
6	29.1	22.9	26.0	27.9	28.7	28.0	27.1
7	26.9	23.7	27.7	29.5	30.5	30.6	28.2
8	27.8	20.2	27.6	27.0	28.2	27.6	26.4
9	28.6	20.9	24.0	27.3	28.4	29.2	26.4
10	28.8	23.1	26.4	29.8	30.8	31.5	28.4
11	29.1	22.1	25.8	28.8	29.8	31.1	27.8
12	26.5	23.4	28.1	29.3	30.4	29.6	27.9
13	29.9	22.2	28.5	29.3	29.9	31.5	28.6
14	30.2	23.3	28.1	29.9	30.9	30.9	28.9
15	29.9	23.9	27.9	29.5	31.5	28.0	28.5
16	30.9	24.4	28.8	31.3	31.8	30.1	29.6
17	30.1	23.8	28.7	30.0	31.0	29.0	28.8
18	31.4	25.2	29.0	30.3	31.0	29.7	29.4
19	30.8	24.5	28.9	30.2	31.5	30.5	29.4
20	30.2	24.5	30.4	31.5	31.8	30.0	29.7

Appendix Table B.3 Monthly Conductivity of Lam Takong River and tributaries.

Station	Conductivity (mS/cm)						Average
	Oct 08	**Dec 08**	**Feb 09**	**Apr 09**	**Jun 09**	**Aug 09**	
1	450	363	74	640	38	93	276
2	374	405	451	423	275	394	387
3	957	403	438	398	286	381	477
4	443	408	477	453	300	864	491
5	768	237	663	60	666	638	505
6	292	534	501	454	492	806	513
7	208	245	269	254	247	327	258
8	645	205	356	181	204	331	320
9	291	182	168	266	235	242	231
10	306	235	327	305	249	383	301
11	329	267	304	336	258	388	314
12	136	270	308	264	263	370	269
13	404	575	310	384	322	364	393
14	368	254	302	296	278	328	304
15	590	285	303	296	296	519	382
16	430	454	408	571	668	894	571
17	397	365	357	334	392	364	368
18	427	526	419	348	467	371	426
19	436	433	437	387	473	378	424
20	439	438	458	430	455	376	433

Appendix Table B.4 Monthly Turbidity of Lam Takong River and tributaries.

Station	Turbidity (NTU)						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	8.44	4.83	3.62	18.10	10.00	24.20	11.53
2	12.10	2.31	1.47	40.00	5.00	19.80	13.45
3	20.90	1.77	2.19	120.00	15.00	132.00	48.64
4	11.30	2.51	4.56	22.90	9.00	164.00	35.71
5	23.00	4.59	11.30	16.00	5.00	4.56	10.74
6	6.44	3.37	17.10	43.00	14.00	1.60	14.25
7	28.40	6.10	3.23	4.82	6.00	13.40	10.33
8	18.90	13.50	7.31	86.00	19.00	28.90	28.94
9	21.30	92.40	20.50	53.20	31.00	42.20	43.43
10	35.80	12.50	14.60	20.30	13.00	6.05	17.04
11	26.50	15.10	14.70	20.90	11.00	7.27	15.91
12	38.90	21.00	31.10	32.00	19.00	11.70	25.62
13	23.20	27.70	9.64	9.80	22.00	4.73	16.18
14	27.80	27.70	62.30	81.00	25.00	8.98	38.80
15	25.00	20.90	50.20	54.00	38.00	14.80	33.82
16	28.20	18.50	37.50	46.80	14.00	12.60	26.27
17	38.50	10.80	29.00	35.50	13.00	16.20	23.83
18	20.90	12.00	13.80	16.40	9.00	9.65	13.63
19	44.10	18.20	17.90	14.30	14.00	15.10	20.60
20	26.90	17.10	10.50	14.80	11.00	13.20	15.58

Appendix Table B.5 Monthly Salinity of Lam Takong River and tributaries.

Station	Salinity (ppt)						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	0.0	0.0	0.0	0.3	0.0	0.0	0.1
2	0.0	0.2	0.2	0.2	0.1	0.2	0.2
3	0.0	0.2	0.2	0.2	0.1	0.2	0.2
4	0.0	0.2	0.2	0.2	0.1	0.4	0.2
5	0.0	0.3	0.3	0.0	0.3	0.3	0.2
6	0.0	0.3	0.2	0.2	0.2	0.4	0.2
7	0.0	0.1	0.1	0.1	0.1	0.1	0.1
8	0.0	0.1	0.2	0.1	0.1	0.2	0.1
9	0.0	0.1	0.1	0.1	0.1	0.1	0.1
10	0.0	0.1	0.2	0.1	0.1	0.2	0.1
11	0.0	0.1	0.2	0.2	0.1	0.2	0.1
12	0.0	0.1	0.2	0.1	0.1	0.2	0.1
13	0.0	0.3	0.1	0.2	0.1	0.2	0.2
14	0.0	0.3	0.1	0.1	0.1	0.1	0.1
15	0.0	0.3	0.2	0.1	0.1	0.2	0.2
16	0.0	0.2	0.2	0.2	0.3	0.4	0.2
17	0.0	0.2	0.2	0.1	0.2	0.2	0.2
18	0.0	0.2	0.2	0.2	0.2	0.2	0.2
19	0.0	0.2	0.2	0.2	0.2	0.2	0.2
20	0.0	0.2	0.2	0.2	0.2	0.2	0.2

Appendix Table B.6 Monthly Total Suspended Solid of Lam Takong River and tributaries.

Station	Total suspended solid (mg/L)						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	1.0	2.0	0.5	10.5	52.5	41.0	17.9
2	3.0	5.5	2.0	26.5	29.0	33.0	16.5
3	18.0	1.5	2.0	80.0	78.5	602.0	130.3
4	5.0	1.5	4.5	63.5	348.0	1325.0	291.3
5	37.5	5.0	6.0	12.0	17.5	10.0	14.7
6	6.0	6.0	11.0	22.5	98.0	19.0	27.1
7	6.5	2.5	4.5	4.0	6.0	713.0	122.8
8	21.5	2.5	6.0	31.0	108.0	22.5	31.9
9	9.0	47.5	14.0	33.0	393.0	317.5	135.7
10	13.0	13.0	3.0	5.0	27.0	316.0	62.8
11	11.0	18.5	3.5	7.0	764.0	540.0	224.0
12	19.5	32.5	10.5	14.0	54.5	83.0	35.7
13	7.0	22.0	8.0	3.5	9.0	10.5	10.0
14	17.5	42.5	15.5	37.5	65.5	37.5	36.0
15	12.0	23.0	16.5	56.5	17.5	44.0	28.3
16	10.5	23.0	16.0	23.5	21.0	55.0	24.8
17	26.0	15.0	8.5	16.0	190.0	20.5	46.0
18	12.0	15.0	7.5	6.5	3.0	50.5	15.8
19	17.0	34.5	9.5	7.0	55.0	49.0	28.7
20	21.0	24.5	16.5	10.0	9.5	44.0	20.9

Appendix Table B.7 Monthly Total Dissolved Solid of Lam Takong River and tributaries.

Station	Total dissolved solid (mg/L)						Average
	Oct 08	**Dec 08**	**Feb 09**	**Apr 09**	**Jun 09**	**Aug 09**	
1	164.5	198.0	40.0	342.0	19.3	48.9	135.5
2	215.0	215.0	239.0	226.0	146.0	208.0	208.2
3	202.0	215.0	233.0	213.0	152.0	204.0	203.2
4	184.0	217.0	255.0	239.0	160.0	461.0	252.7
5	295.0	337.0	364.0	319.0	354.0	339.0	334.7
6	68.0	284.0	267.0	242.0	262.0	426.0	258.2
7	198.5	131.0	143.0	134.0	131.0	175.0	152.1
8	213.5	110.0	185.0	97.0	108.0	176.0	148.3
9	218.0	99.0	90.0	141.0	125.0	128.0	133.5
10	219.5	125.0	168.0	161.0	132.0	205.0	168.4
11	490.0	141.0	167.0	179.0	137.0	205.0	219.8
12	187.0	142.0	195.0	140.0	140.0	197.0	166.8
13	478.5	306.0	164.0	204.0	171.0	194.0	252.9
14	221.5	134.0	161.0	158.0	148.0	177.0	166.6
15	384.0	152.0	165.0	157.0	156.0	278.0	215.3
16	146.0	242.0	218.0	304.0	355.0	480.0	290.8
17	104.0	193.0	190.0	177.0	210.0	194.0	178.0
18	322.5	281.0	226.0	185.0	252.0	197.0	243.9
19	145.5	230.0	232.0	206.0	253.0	201.0	211.3
20	153.0	234.0	244.0	228.0	242.0	200.0	216.8

The chemical analysis of water quality

Appendix Table B.8 Monthly Dissolved Oxygen of Lam Takong River and tributaries.

Station	Dissolved Oxygen (mg/l)						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	8.0	8.2	5.0	5.9	8.7	7.9	7.3
2	7.6	7.6	6.9	6.4	8.1	7.3	7.3
3	7.4	7.4	6.9	6.1	7.8	8.2	7.3
4	7.0	7.2	7.0	3.2	8.0	6.9	6.5
5	7.2	7.5	2.7	5.6	6.4	4.7	5.7
6	7.6	7.8	7.7	6.7	5.7	5.1	6.8
7	7.8	7.2	8.7	7.2	8.8	8.0	7.9
8	7.9	7.7	4.5	6.2	6.2	7.4	6.7
9	6.5	8.2	3.6	4.4	2.1	4.8	4.9
10	6.0	7.8	5.9	4.5	4.5	5.1	5.6
11	7.1	7.8	7.0	6.0	6.9	5.7	6.7
12	6.9	8.2	6.9	6.3	7.3	7.2	7.1
13	3.2	6.1	8.0	4.9	6.2	5.7	5.7
14	5.7	5.7	6.9	4.5	6.5	5.1	5.7
15	6.0	8.2	6.4	5.9	9.2	7.1	7.1
16	5.5	7.4	6.4	5.9	6.7	6.3	6.3
17	5.2	3.8	3.8	4.3	4.9	4.3	4.4
18	5.3	5.0	3.0	6.1	4.1	4.0	4.6
19	4.9	6.4	6.1	5.5	5.2	5.0	5.5
20	5.1	8.7	9.3	4.3	9.0	4.4	6.8

Appendix Table B.9 Monthly BOD of Lam Takong River and tributaries.

Station	BOD (mg/L)						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	0.1	0.1	0.1	0.6	0.8	0.2	0.3
2	1.4	0.3	1.4	1.6	0.4	0.4	0.9
3	2.5	4.2	1.1	2.5	1.6	1.1	2.2
4	3.6	5.2	1.7	2.4	0.8	0.9	2.4
5	8.1	4.2	8.0	8.1	1.8	1.8	5.3
6	3.6	4.8	2.6	2.5	0.6	0.5	2.4
7	1.2	3.3	2.0	1.4	0.9	0.6	1.6
8	4.5	3.6	4.1	2.1	1.8	1.7	3.0
9	2.1	3.9	2.4	3.6	4.2	2.8	3.2
10	4.8	4.8	1.4	1.6	1.4	1.1	2.5
11	2.4	1.5	4.1	2.4	2.4	2.4	2.5
12	2.4	4.2	2.6	1.8	2.6	2.6	2.7
13	3.0	4.8	2.4	1.6	3.5	2.6	3.0
14	3.6	4.5	7.2	1.4	3.2	2.6	3.8
15	1.8	4.8	2.9	2.3	3.0	3.0	3.0
16	4.2	5.4	3.2	3.6	4.2	2.8	3.9
17	5.1	5.4	4.6	6.0	2.0	4.0	4.5
18	7.8	6.0	8.7	4.8	3.4	5.1	6.0
19	3.9	6.2	4.0	3.4	5.0	8.0	5.1
20	3.0	4.5	2.0	1.4	2.8	2.9	2.8

Appendix Table B.10 Monthly NH_3 of Lam Takong River and tributaries.

Station	NH_3 (mg/L)						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	2.38	1.40	1.96	2.24	0.20	0.21	1.40
2	0.00	0.70	1.96	0.98	1.26	1.40	1.05
3	3.64	1.54	1.96	1.40	0.84	1.12	1.75
4	12.60	1.68	2.10	2.66	1.12	1.12	3.55
5	1.68	1.12	1.82	3.64	0.84	2.24	1.89
6	6.30	1.26	1.54	1.82	0.84	2.10	2.31
7	2.24	1.12	0.84	2.52	0.70	1.26	1.45
8	1.68	1.82	2.24	1.68	0.80	1.54	1.63
9	6.02	2.10	1.26	5.32	1.54	0.98	2.87
10	2.10	1.54	1.96	3.22	0.80	2.38	2.00
11	4.34	2.10	1.54	2.10	0.98	0.98	2.01
12	7.70	0.98	3.22	2.38	0.70	1.54	2.75
13	5.74	1.82	3.36	1.54	0.42	0.42	2.22
14	3.78	1.12	1.26	0.84	0.70	1.12	1.47
15	1.96	1.54	2.10	3.66	0.56	1.68	1.92
16	2.24	1.96	2.24	0.98	3.36	2.66	2.24
17	4.34	2.52	3.36	0.98	1.26	1.96	2.40
18	8.68	8.96	5.60	3.50	3.36	2.94	5.51
19	9.80	7.00	3.92	4.08	4.48	2.66	5.32
20	7.70	3.78	4.20	5.74	3.92	3.50	4.81

Appendix Table B.11 Monthly NO_2 of Lam Takong River and tributaries.

Station	NO_2 (mg/L)						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	0.00	0.00	0.00	0.06	0.00	0.00	0.01
2	0.00	0.00	0.00	0.22	0.00	0.00	0.04
3	0.04	0.00	0.06	0.40	0.07	0.07	0.11
4	0.00	0.33	0.00	0.62	0.15	0.06	0.19
5	0.00	0.00	0.00	0.00	0.00	0.06	0.01
6	0.00	0.05	0.00	0.00	0.24	0.10	0.07
7	0.16	0.00	0.00	0.04	0.00	0.02	0.04
8	0.00	0.10	0.00	0.05	0.13	0.07	0.06
9	0.00	0.13	0.00	0.00	0.28	0.00	0.07
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.08	0.00	0.00	0.02	0.13	0.01	0.04
12	0.23	0.00	0.00	0.00	0.09	0.00	0.05
13	0.00	0.00	0.00	0.00	0.15	0.07	0.04
14	0.00	0.00	0.02	0.00	0.00	0.02	0.01
15	0.00	0.00	0.00	0.04	0.00	0.03	0.01
16	0.00	0.00	0.00	0.00	0.05	0.00	0.01
17	0.12	0.31	0.28	0.13	0.19	0.02	0.17
18	0.24	0.00	0.25	0.34	0.53	0.02	0.23
19	0.34	0.09	0.36	0.40	0.02	0.00	0.20
20	0.41	0.60	0.41	0.53	0.70	0.02	0.44

Appendix Table B.12 Monthly NO_3 of Lam Takong River and tributaries.

Station	NO_3 (mg/L)						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	0.00	0.45	0.32	1.21	0.43	0.94	0.56
2	0.27	5.69	5.21	0.42	0.16	2.65	2.40
3	0.30	5.75	4.42	0.41	0.16	3.04	2.35
4	0.31	5.51	4.86	0.25	4.27	3.57	3.13
5	0.49	1.23	0.80	0.37	1.09	1.27	0.88
6	0.98	31.06	0.11	0.60	34.30	22.59	14.94
7	1.57	2.53	0.36	0.06	0.25	0.36	0.85
8	0.44	5.63	0.66	0.11	1.10	16.50	4.07
9	1.52	2.08	0.32	0.42	1.83	0.00	1.03
10	1.73	1.08	0.65	0.91	0.49	0.81	0.94
11	2.11	1.40	0.58	1.40	1.04	1.47	1.33
12	1.69	1.37	0.86	0.97	0.99	0.00	0.98
13	0.44	0.95	0.62	0.72	1.14	0.56	0.74
14	0.05	1.37	1.18	0.73	0.82	1.28	0.90
15	0.85	1.04	1.79	0.80	0.64	1.12	1.04
16	0.76	0.78	0.92	1.32	1.42	0.00	0.87
17	1.01	1.54	1.98	1.44	1.02	1.64	1.44
18	1.12	1.03	1.23	8.08	1.96	2.28	2.62
19	1.24	1.36	0.92	1.17	1.02	0.00	0.95
20	1.40	1.97	0.78	1.48	1.87	2.20	1.61

Appendix Table B.13 Monthly PO_4 of Lam Takong River and tributaries.

Station	PO_4 (mg/L)						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	0.66	0.00	0.00	0.00	0.00	0.00	0.66
2	0.57	0.00	0.00	0.59	0.00	0.00	0.57
3	0.71	0.00	0.13	0.80	0.10	0.07	0.71
4	0.84	0.00	0.29	1.20	0.06	0.00	0.84
5	0.98	0.00	0.00	0.20	0.10	0.05	0.98
6	0.00	0.00	0.00	1.77	0.00	0.00	0.00
7	0.00	0.00	0.00	2.70	0.00	0.00	0.00
8	0.35	0.00	0.01	0.66	0.00	0.66	0.35
9	0.26	0.16	0.00	1.31	0.09	0.23	0.26
10	0.25	0.11	0.00	0.00	0.00	0.00	0.25
11	0.23	0.42	0.00	0.00	0.00	0.19	0.23
12	0.71	0.38	0.00	0.00	0.00	0.00	0.71
13	0.24	0.00	0.00	0.00	0.00	0.00	0.24
14	1.04	0.19	0.00	0.00	0.00	0.00	1.04
15	0.47	1.61	0.09	0.01	0.00	0.00	0.47
16	0.19	0.00	0.00	0.00	0.67	0.00	0.19
17	0.09	0.49	0.15	0.00	0.10	0.14	0.09
18	0.29	1.91	1.64	0.00	0.73	0.37	0.29
19	0.00	2.21	1.82	0.70	0.72	0.46	0.00
20	0.00	1.10	1.70	0.58	0.09	0.56	0.00

Appendix Table B.14 Monthly SO_4 of Lam Takong River and tributaries.

Station	SO_4 (mg/L)						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	1.12	2.56	2.23	3.35	2.02	1.55	2.14
2	0.66	6.56	6.80	35.94	5.26	3.71	9.82
3	0.00	11.54	11.71	0.00	7.79	5.41	6.07
4	0.05	12.92	17.78	4.53	9.34	5.39	8.33
5	0.07	16.08	8.59	8.64	11.24	11.44	9.34
6	7.31	27.14	13.98	0.05	25.08	18.45	15.34
7	3.10	14.55	7.03	19.46	5.78	8.11	9.67
8	0.05	5.13	5.45	4.26	3.97	8.87	4.62
9	6.20	3.34	1.85	3.91	3.49	7.87	4.44
10	6.99	8.86	8.01	8.90	8.03	7.84	8.11
11	6.38	8.82	8.05	8.39	8.04	8.32	8.00
12	2.75	8.62	7.78	5.00	6.68	6.88	6.29
13	7.42	62.07	18.15	20.75	16.98	11.61	22.83
14	3.52	9.28	16.66	4.26	10.56	16.92	10.20
15	4.97	154.84	13.34	5.56	6.52	12.42	32.94
16	5.83	15.99	20.43	12.60	21.71	11.26	14.64
17	4.60	13.40	13.19	8.31	6.78	14.93	10.20
18	6.31	16.10	17.82	5.13	15.07	16.26	12.78
19	6.11	17.14	19.19	10.43	13.27	15.87	13.67
20	6.20	15.65	18.94	11.43	11.97	16.67	13.48

Appendix Table B.15 Monthly Total Organic Carbon of Lam Takong River and tributaries.

Station	Total organic carbon (mg/L)						Average
	Oct 08	**Dec 08**	**Feb 09**	**Apr 09**	**Jun 09**	**Aug 09**	
1	3.87	0.12	1.71	4.64	3.17	0.00	2.25
2	6.93	7.12	20.81	18.92	1.54	0.00	9.22
3	1.98	0.00	0.00	21.67	3.23	0.00	4.48
4	7.40	0.00	0.00	15.84	3.10	0.00	4.39
5	12.15	0.78	3.37	26.60	3.24	0.00	7.69
6	3.29	0.00	0.79	23.91	0.60	0.00	4.77
7	2.93	3.26	3.26	11.96	2.52	3.00	4.49
8	2.26	4.45	5.88	3.44	2.69	5.63	4.06
9	5.11	2.20	3.35	3.99	6.60	8.22	4.91
10	5.28	2.42	3.44	12.03	1.90	2.78	4.64
11	6.25	3.40	3.27	4.15	2.76	1.32	3.53
12	6.08	2.24	3.39	4.72	2.85	1.70	3.50
13	14.69	15.34	5.63	6.55	4.28	1.53	8.00
14	4.57	3.75	3.08	0.00	3.84	2.04	2.88
15	9.05	2.84	4.79	32.77	3.48	3.32	9.37
16	8.56	3.82	5.17	22.10	6.66	3.02	8.22
17	6.92	4.64	4.72	15.11	2.23	3.61	6.21
18	8.40	5.36	5.76	5.59	5.25	4.03	5.73
19	8.30	4.66	5.13	5.18	7.27	5.58	6.02
20	7.95	4.05	5.09	5.75	5.16	3.01	5.17

Appendix Table B.16 Monthly Chlorophyll a of Lam Takong River and tributaries.

Station	Chlorophyll a (µg/L)						Average
	Oct 08	Dec 08	Feb 09	Apr 09	Jun 09	Aug 09	
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.72	0.00	3.30	81.18	59.88	59.70	34.13
6	81.32	0.00	12.32	20.72	41.62	22.64	29.77
7	6.36	37.46	37.22	47.24	127.18	104.62	60.01
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	70.84	25.76	35.12	4.38	309.80	19.18	77.51
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	32.40	0.00	73.90	100.54	299.28	35.58	90.28
19	8.78	105.40	104.52	56.00	98.22	5.98	63.15
20	17.32	146.26	382.62	133.56	325.82	15.84	170.24

APPENDIX C

POPULATION IN LAM TAKONG BASIN

Appendix Table C Population in Lam Takong Basin in 1996-2008.

District	Population												
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Pak Chong	172,502	172,141	174,342	175,060	176,515	178,595	180,504	182,670	180,346	181,444	182,831	182,588	184,427
Pak Chong Subdistrict municipality	43,750	40,908	41,093	39,982	40,216	40,309	40,177	39,930	36,746	36,547	36,492	36,351	37,062
Keang Dong subdistrict munipality	_	_	_	_	_	5,193	5,216	5,272	5,254	5,254	5,243	5,185	5,273
Rural	128,752	131,233	133,249	135,078	136,299	133,093	135,111	137,468	138,346	139,643	141,096	141,052	142,092
Si Khio	117,639	117,685	119,067	119,817	120,808	121,625	122,435	122,997	120,822	121,626	122,061	120,817	121,637
Kong Pai subdistrict munipality	_	_	_	_	_	4,375	4,368	4,333	4,195	4,165	4,099	3,849	3,851
Lad baokeaw subdistrict munipality	_	_	_	_	_	3,707	3,817	3,850	3,903	3,961	4,085	4,059	4,049
Si khio subdistrict munipality	_	_	_	_	_	19,181	19,282	17,795	19,176	19,139	19,042	18,663	18,689
Rural	_	_	_	_	_	94,362	94,968	97,019	93,548	94,361	94,835	94,246	95,048
Sung Noen	73,331	74,505	75,271	75,511	76,006	76,773	77,634	78,331	77,743	78,120	78,610	78,503	79,122
Kud Jik subdistrict munipality	_	_	_	_	_	2,522	2,557	2,593	2,585	2,589	2,627	2,624	2,623

Appendix Table C Population in Lam Takong Basin in 1996-2008. (Continued).

District	Population												
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Sung Noen Subdistrict municipality	_	_	_	_	_	10,582	10,208	10,219	10,262	10,254	10,239	10,156	10,171
Rural	_	_	_	_	_	63,669	64,869	65,519	64,896	65,277	65,744	65,723	66,328
Kham Thale So	27,555	27,720	27,820	27,750	28,089	28,242	28,311	28,425	27,745	27,864	28,112	28,314	28,462
Kham Thale So Subdistrict municipality	_	_	_	_	_	3,874	3,913	3,811	3,917	4,033	4,042	4,089	4,067
Rural	_	_	_	_	_	24,368	24,398	24,614	23,828	23,831	24,070	24,225	24,395
Nakhon Ratchasima District municipality	426,053	421,739	427,191	425,592	429,689	434,567	437,386	442,675	418,411	421,653	427,099	429,853	433,838
Nakhon Ratchasima City municipality	187,021	175,956	176,497	173,321	174,057	174,322	173,826	173,123	153,435	151,454	148,609	146,201	145,793
Kok Graw Subdistrict municipality	_	_	_	_	_	7,053	7,182	7,069	7,148	7,151	7,165	7,132	7,204
Jo Ha Subdistrict municipality	_	_	_	_	_	12,484	12,889	13,237	13,136	13,682	14,006	14,421	14,731
Nong Pailom Subdistrict municipality	_	_	_	_	_	_	_	_	20,656	19,766	20,491	21,004	20,171

Appendix Table C Population in Lam Takong Basin in 1996-2008. (Continued).

District	Population												
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Hao Tala Subdistrict municipality	–	–	–	–	–	–	–	–	20,550	21,578	22,402	22,903	23,543
Pho keaw Subdistrict municipality	–	–	–	–	–	–	–	–	–	–	–	24,815	24,940
Nong Kai nam Subdistrict municipality	–	–	–	–	–	–	–	–	–	–	–	–	5,835
Rural	239,032	245,783	250,694	252,271	255,632	240,708	243,489	249,246	203,486	208,022	214,426	193,377	191,621
Chaloem Phra Kiat Subdistrict municipality	32,184	32,493	32,825	33,058	33,087	33,274	33,543	33,775	34,010	34,133	34,377	34,637	34,890
Ta Chang Subdistrict municipality	–	–	–	–	–	4,552	4,595	4,637	4,668	4,732	4,751	4,832	4,897
Rural	–	–	–	–	–	28,722	28,948	29,138	29,342	29,401	29,626	29,805	29,993

Source : Department of Provincial Administration (2008).

APPENDIX D

THE AMOUNT OF RAIN FALL IN LAM TAKONG BASIN 1996-2008

Appendix Table D The amount of rain fall in Lam Takong Basin 1996-2008.

Station	Rain fall (mm)												
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Pak Chong	1,292.7	707.4	1,043.4	1,269.7	1,501	1,100.6	1,085.2	1,263.3	967.4	1,092.4	1,207.4	1,155.8	1,371.7
Si Khio	1,181.1	835.5	883.4	1,128.8	1,173.05	809.8	867.65	1,057.5	646.3	868.55	828.25	1,124.05	1,268.8
Sung Noen	905.9	594.8	644.9	716.7	915.5	467.3	635.7	713.3	551.1	900.6	1,006	1,267.4	1,282
Kham Thale So	1,173.9	624	932.7	1,153.3	1,348.4	824.4	1,013.5	933	980	1,380.4	991.8	1,178.4	1,375.7
Mueang Nakhon Ratchasima	1,173.9	624	932.7	1,153.3	1,348.4	824.4	1,013.5	933	980	1,380.4	991.8	1,178.4	1,375.7
Chaloem Phra Kiat	1,170.2	631.5	904.4	1,324.3	1,419.1	1,003.1	1,046.4	1,134.2	963.6	971.7	1,200.4	1,185.6	1,307.4

Source : Thai Meteorological Department (2009).

APPENDIX E

DRAINAGE AREA OF EACH WATER SAMPLING STATION

Appendix Table E Drainage area of each water sampling station.

Land use type	Drainage area (km2)/Station									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Urban Builtup land	15.87	15.87	38.40	43.50	9.68	18.36	82.16	86.34	86.39	99.93
Factory/farm house	6.14	6.14	13.80	15.65	5.93	4.17	28.57	28.98	30.67	34.48
Marsh and Swamp	0.00	0.00	0.00	0.00	0.00	0.03	1.46	1.46	1.46	1.68
Institutional land	1.11	1.11	1.72	1.77	0.64	0.93	33.17	33.74	33.82	35.12
Mixed perennial/Mixed orchard	80.71	80.71	140.89	150.54	19.59	39.03	226.64	231.17	233.62	248.80
Agricultural land	100.97	100.97	140.79	159.09	59.36	137.49	391.57	420.31	431.51	508.08
forest	263.43	263.43	273.72	275.02	6.88	64.22	368.35	399.39	411.27	439.62
Scrub	16.63	16.63	25.01	28.60	6.88	9.13	52.66	55.33	55.87	62.30
Grass/Pasture	17.30	17.30	28.06	29.30	5.48	10.05	64.45	65.00	65.90	68.70
Sum	502.15	502.15	662.40	703.48	114.45	283.40	1,249.03	1,321.72	1,350.51	1,498.70

Appendix Table E Drainage area of each water sampling station. (Continued).

Land use type	Drainage area (km2)/Station									
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Urban Builtup land	112.66	147.95	9.07	167.24	202.45	11.80	274.70	330.01	346.57	348.08
Factory/farm house	39.10	57.01	12.00	70.64	76.42	1.08	77.84	85.17	86.68	86.75
Marsh and Swamp	1.98	2.30	1.01	3.36	6.67	0.82	6.89	8.78	10.34	10.34
Institutional land	40.81	48.48	2.46	52.70	60.27	3.42	61.28	62.85	66.86	67.38
Mixed perennial/Mixed orchard	273.94	306.39	12.31	323.38	338.84	2.49	346.61	352.33	357.07	357.47
Agricultural land	623.56	1,177.02	106.70	1,414.87	1,647.23	59.50	1,674.63	1,709.10	1,790.11	1,804.25
forest	486.22	515.21	5.00	523.61	526.13	0.19	526.20	526.23	526.42	526.45
Scrub	70.56	107.99	7.37	123.64	139.23	5.77	142.87	145.40	152.35	153.43
Grass/Pasture	75.86	81.29	3.21	85.19	90.09	3.01	91.85	92.45	96.40	96.40
Sum	1,724.70	2,443.64	159.14	2,764.63	3,087.34	88.09	3,202.87	3,312.32	3,432.80	3,450.57

Source : Department of Land Development (2008).

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Publications

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Awards -

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