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EVALUATION OF POLLUTION IN NAKHON NAYOK RIVER USING QUAL2E-UNCAS AND GIS

Miss Patcharin Chatprasert

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พัชรินทร์ ฉัตรประเสริฐ:การประเมินภาวะมลพิษในแม่น้ำนครนายก โดยการใช้แบบจำลองคณิตศาสตร์ QUAL2E-UNCAS ร่วมกับระบบสารสนเทศภูมิศาสตร์. (EVALUATION OF POLLUTION IN NAKHON NAYOK RIVER USING QUAL2E-UNCAS AND GIS) อ. ที่ปรึกษา : อ.ดร.ศุภิชัย ตั้งใจตรง, อ. ที่ปรึกษาร่วม : ผศ.ดร. ทวีวงศ์ ศรีบุรี, 143 หน้า. ISBN 974-13-0821-3.

การศึกษาครั้งนี้ได้ประยุกต์ใช้แบบจำลองคณิตศาสตร์ QUAL2E-UNCAS ในการศึกษาคุณภาพน้ำในแม่น้ำนครนายก โดยพารามิเตอร์ที่ศึกษา ได้แก่ ออกซิเจนละลาย ค่าความต้องการออกซิเจนของสารอินทรีย์ แอมโมเนียไนโตรเจน ไนไตรท์ไนโตรเจน ไนเตรทไนโตรเจน ฟอสฟอรัสละลาย และอุณหภูมิ เพื่อให้ได้พื้นที่วิกฤต ของแม่น้ำนครนายก จึงทำการจำลองคุณภาพน้ำในช่วงฤดูน้ำน้อย คือ เดือนตุลาคมถึงเมษายน ผลการปรับเทียบออกซิเจนละลาย ค่าความต้องการออกซิเจนของสารอินทรีย์ แอมโมเนียไนโตรเจน ไนไตรท์ไนโตรเจน ไนเตรทไนโตรเจน ฟอสฟอรัสละลาย และอุณหภูมิระหว่างข้อมูลคุณภาพน้ำปี 2536-2542 จากกรมควบคุมมลพิษ และข้อมูลภาคสนามวันที่ 8 ธันวาคม 2000 พบว่าข้อมูลที่ได้จากการจำลองและที่ได้จากการวัดจริงมีความสอดคล้องกัน สำหรับผลการปรับเทียบระดับน้ำและปริมาณน้ำระหว่างข้อมูลที่ได้จากการจำลองและข้อมูลภาคสนามมีความสอดคล้องกันเฉพาะต้นน้ำ นอกจากนี้ ระบบสารสนเทศภูมิศาสตร์ยังสามารถใช้แสดงให้เห็นถึงพื้นที่วิกฤตได้ จากการศึกษาความไม่แน่นอนของแบบจำลองทำให้ทราบถึงการตอบสนองของข้อมูลนำออกต่อข้อมูลนำเข้า และสามารถนำไปใช้ในการวางแผนการใช้แบบจำลองเพื่อศึกษาคุณภาพน้ำได้

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QUAL2E-UNCAS was used to study Nakhon Nayok river water quality. Five simulated water quality parameters consist of Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), ammonia nitrogen (NH_3_N), nitrite nitrogen (NO_2_N), nitrate nitrogen (NO_3_N), dissolved phosphorous (Dis_P), and temperature. In order to get critical area of Nakhon Nayok river, water quality parameters were simulated during dry season, i.e. October-April. DO, BOD, Nitrogen Cycle, Phosphorous Cycle, and Temperature calibration results between water quality data of years 1993-1999 which are obtained from PCD and field survey data taken on December 8,2000, It was found that all simulated water quality parameters show the good agreement with measured values, while water level and flow from simulation agree with measured ones only at upstream. In addition, GIS was used to visualize critical area. Study on uncertainty analysis makes one realize the respond of output to input. It can be used to plan the using of model to further study on water quality.

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Abbreviations

BMP	=	Best management Practice
FOEA	=	First Order Error Analysis
MCS	=	Monte Carlo Simulation
DO	=	Dissolved Oxygen
BOD	=	Biochemical Oxygen Demand
NH_3_N	=	Ammonia Nitrogen
NO_2_N	=	Nitrite Nitrogen
NO_3_N	=	Nitrate Nitrogen
Dis_P	=	Dissolved Phosphorous

Conversion factor

1 rai	=	0.16 hectare

CHAPTER 1

INTRODUCTION

1.1 Background

The extent and complexity of water pollution problems are rapidly increasing throughout the world as population growth and industrialized system so the competing demand on water has affected not merely its supply and future availability but its quality also.

During dry season, flows of some rivers consist of almost entire of effluents while it also supplies water to other towns downstream. In essence, the effluents discharged into waterway must have high quality and the self purifying potential of the river must not be overloaded. In some watersheds, diversion and damming of rivers reduces streamflows, which decrease concentrated pollutants in a smaller volume of water.

The case presented in this study concerns Nakhon Nayok river with point and nonpoint source pollutants. This river provides water to more than two hundred thousands people and many industries distributing in the region. In addition, water is still used for water works and also irrigated projects. Along the riverbank, farming and agriculture are main activities. The river is also received pollution mostly from riparian and municipal sewage systems.

Wastewater is considered as a potential source of pollution when it is untreated or only partially treated. It contains organic and inorganic materials that can be hazardous to both human and aquatic lives. Naturally, wastewater makes amount of dissolved oxygen low in the receiving water.

Proper identification of water quality problem requires collecting data from the past and ongoing study water quality. Monitoring and measuring water constituents at different stations along the river give a synoptic view of the river quality.

The challenges in dealing with nonpoint pollution are to identify activities that result in significant impairment of water quality and to design control programs to minimize the problems by comparing the effect of different land uses to surface water quality. Water quality model can help us determine strategies and placement of Best Management Practices (BMP) which is designed to reduce, remedy, or retard pollutants. This study uses the modeling approach instead of taking experiment for assisting management decisions.

In response to water quality management problems, various models have been developed. But all of these water quality models, the QUAL series computer programs have a long history in system analysis in water quality management (Barnwell, 1987). QUAL2E model is widely used in Europe, Asia, North America, and South America (Smedt,2000).

The reasons to select **QUAL2E** for the present study as follows:

1) QUAL2E is basically a water quality planning tool which represents a state of the art in a steady state model.
2) Other software packages which help to make the work of QUAL2E and QUAL2E–UNCAS more faster, understandable, interpretable, and the likes are also available and incorporated into the program. These are the interactive data preprocessor program and the interactive graphics postprocessor program for QUAL2E.
3) Unlike some other models, the QUAL series is opened to the public which makes it much more easier to access and afford.
4) It is a model which allows the modeler to perform uncertainty analysis on steady state mode with three uncertainty options: sensitivity analysis, first order error analysis, and Monte Carlo simulations. Thus the modeler can assess the risk of imprecise forecast and recommend measures for reducing the magnitudes of imprecision.

1.2 Objectives

1.2.1 To study Nakhon Nayok river water quality with the following parameters: Temperature, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Nitrogen cycle (Ammonia (NH_3_N), Nitrate (NO_3_N), and Nitrite (NO_2_N)), and Dis_P with QUAL2E.

1.2.2 To study and analyze the existing water quality level of the river and predict its future trends.

1.2.3 To conclude and recommend improvement of Nakhon Nayok river water quality.

1.3 Scope of the study

1.3.1 The study area covers Nakhon Nayok river with a total length of 37 kilometers. The river flows through the following districts.

1) Muang district which the river passes 4 sub districts and 1 municipal: Ban Yai, Nakhon Nayok, Prom Mani, Wung Kra Jom, and Tha Chang municipal.

2) Ban Na district through which the river passes only Bang Or sub district.

The upper boundary is Khao Nang Buat Bridge in Muang district and the lower is Ampwan temple in Ban Na district.

1.3.2 QUAL2E will be used to simulate water quality constituents.

1.3.3 Only BMP concerning landuse will be considered.

1.4 Definitions

1.4.1 Best Management Practices (BMP), the best preventive measures sometimes called source controls, are management techniques that reduce the exposure of materials to stormwater, thereby limiting the amount of pollutants picked up by water (Park,S.W., 1994)

1.4.2 Critical area can be defined as areas where the potential contribution of pollutants to the receiving water is significantly higher than other areas (Sivertun et.al., 1988).

1.5 Expected Results

1) A critical area map in Nakhon Nayok river.

2) A conceptual plan for water quality management in the future.

3) Status of current water quality and future trend of the river.

1.6 Possible Benefit

Improvement of aquatic life and water quality through a proper management according to the existing information.

CHAPTER 2

LITERATURE REVIEW

2.1 Nonpoint Source Pollution

Point source and nonpoint source pollutions are distinct from each other in the means and extent that they are delivered to water bodies. Point sources enter the environment at discrete, identifiable locations. They can be measured directly or otherwise quantified. Pollutant from land-based point sources are usually delivered to water in almost the same concentrations. Samples of point source pollution are effluents from industrial and sewage treatment plants and from pipes of farm buildings or solid disposal sites. On the contrary, nonpoint sources enter the environment from diffuse sources, resulting in partial deposition of pollutant on land surfaces before delivering to receiving waters. Such sources are agricultural runoff, atmospheric deposition, contaminated sediments, and land use activities. Examples of agricultural pollutant are agricultural runoff, sediment, manure, chemical, and pesticide (Chester,G. and Linda, J.S., 1985).

2.2 Historical Development of Water Quality Models

The historical development of mathematical models of water quality is not attributed to just one time, one country, or a certain group of scientists. There are many models have already been developed and being developed by many scientists, group of professionals, or institutes. The development process is certainly presumed to continue in improving the models in the environmental sector which includes water quality. Water quality models commonly used are brief as follow.

DOSAG 1

It was originally developed by the Texas Water Development Board (TWDB) for use in simulating point sources and nonpoint sources of carbonaceous and nitrogenous oxygen demand and their impacts on the DO of a stream (Brown,2000).

DOSAG 3

Original DOSAG1 was modified for the United State Environmental Protection Agency (USEPA) by Water Resources Engineers (WRE). It was the same as DOSAG1 except the several additional constituents and the ability to use Tsivouglou technique for calculating reaeration rate (Brown,2000).

*WASP*5 *version* 4.20

Water Quality Analysis Simulation Program Version 4.20 was developed by USEPA in 1991. It was designed to provide generality and flexibility for analyzing a variety of water quality problems in a diverse set of water bodies (Ambrose et al., 1991). This model simulates the fate of contaminants both in steady state and dynamic mode in surface water and could be applied in one, two, or three dimensional cases. This modeling system consists of the hydrodynamic model DYNHYD5(http://www.scisoftware.com/products/wasp_details/wasp_details.html/ #wasp_intro).

HSPF

Hydrologic Simulation Program (HSP) is used for simulation of watershed hydrology and water quality for conventional toxic and organic pollutants (http://www.hydrocomp.com/HSPFinfo).

MIKE11

MIKE11, developed by Danish Hydraulic Institute (DHI), is a professional engineering software package for simulating surface runoff, flows, water quality, and sediment transport in estuaries, rivers, irrigation systems, channels, and other water bodies (http://www.dhi.dk/MIKE 11).

QUAL MODEL

The QUAL model generally developed by TWDB has passed through a series of development and improvement stages. It uses a finite difference solution technique to solve the differential equations representing one dimensional transport due to longitudinal dispersion and advection, so the history of QUAL model development is brief below.

QUAL I (1970)

- Developed by F.D. Mash and Association and TWDB,
- Simulated DO, BOD, and conservatives,
- Dynamic Numerical Solution.

QUAL II (1972)

- WRE modified for EPA,
- Simulate algae, nutrients, and non conservatives.

QUAL II / SEMCOG (1978)

- Camp,Dresser,McKee Inc;CDM/ WRE for South East Michigan Council of Governments (SEMCOG),
- Diurnal averaging for algae and temperature,
- Steady state solution.

QUAL II / NCASI (1980)

- Detail documentation and commentary,
- Correction to SEMCOG Code.

QUAL2E (1985)

- NCASI for USEPA,
- Enhancements to algae – nutrient – DO interactions,
- Microcomputer application.

QUAL2E – UNCAS (1987)

- Uncertainty analysis composes of Sensitivity Analysis, First Order Error Analysis, and Monte Carlo Simulation,
- Reach variable climatology.

QUAL2EU (1990)

- Pre processor (AQUAL) and Post processor (Q2PLOT).

QUAL2EU (1993)

- Fast version for 386/486 microprocessors (Brown, 2000).

2.3 The Enhanced Stream Water Quality Models QUAL2E

2.3.1 Overview of QUAL2E

The primary objective of any stream water quality model development is to produce a tool that has the capability of simulating the behavior of the hydraulic and water quality components of a stream system. The development of this tool to simulate prototype behavior by applying mathematical model on a digital computer proceeds through three general phases (WRE, Inc., 1967):

1) Conceptual Representation,

2) Functional Representation,

3) Computational Representation.

2.3.2 Conceptual Representation

QUAL2E simulates up to 15 water quality constituents in branching stream systems. The model uses a finite difference solution of the advective dispersive mass transport and reaction equations. The conceptual representation is illustrated in Figure 2.1. A stream reach is divided into a number of computational elements, and for each computational element a hydrologic balance is considered in terms of stream flow.

By operating the model dynamically, the user can determine a heat balance in terms of temperature and a material balance in terms of concentration. Both advective and dispersive transport processes are considered in the material balance. Mass is gained or lost from the computational element by internal sources and sinks such as benthic sources or biological transformations and external sources and sinks, e.g., discharges and withdrawals. The program simulates change inflow conditions along the stream by computing a series of steady state water surface profiles. The calculated stream flow rate, velocity, cross sectional area, and water depth serve as a basis for determining the heat and mass fluxes into and out of each computational element due to flow. Mass balance determines the concentrations of conservative minerals, coliform bacteria, and non conservative constituents at each computational element.

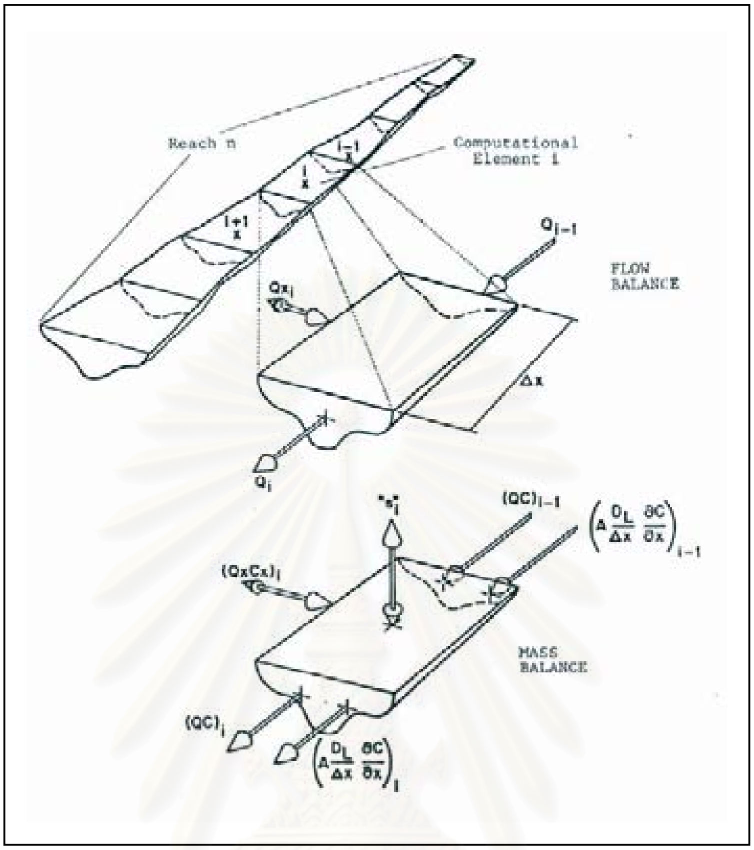


Figure 2.1 Discretized stream system

The model is applicable to dendritic streams that are well mixed. It assumes that advection and dispersion are significant only along the main direction of flow (the longitudinal axis of the stream or canal). It allows for multiple waste discharges, withdrawals, tributary flows, and incremental inflow and outflow. It also has the capability to compute required dilution flows for flow augmentation to meet any prespecified dissolved oxygen level.

Hydraulically, QUAL2E is limited to the simulation of time periods during which both the stream flow in river basins and input waste loads are essential constant. As a steady state model, it can be used to study the impact of waste loads (magnitude, quality, and location) on instream water quality. By operating the model dynamically, the user can study the effects of diurnal variations in meteorological data on water quality (primary dissolved oxygen and temperature) and can also study diurnal dissolved oxygen variations due to algal growth and respiration.

2.3.3 Functional Representation

2.3.3.1 Mass Transport Equation

The basic equation solved by QUAL2E is the one dimensional advective-dispersive mass transport equation, which is numerically integrated over space and time for each water quality constituent. This equation includes effects of advection, dispersion, dilution, constituent reactions and interactions, and sources and sinks. For any constituent, C, this equation can be written as

$$\frac{\partial M}{\partial t} = \frac{\partial\left(A_x D_L \frac{\partial C}{\partial x}\right)}{\partial x} dx - \frac{\partial\left(A_x \overline{U} C\right)}{\partial x} dx + \left(A_x dx \frac{dC}{dt} + S\right) \qquad (1)$$

Where

M	=	Mass [M]
x	=	Distance [L]
t	=	Time [T]
C	=	Concentration [ML^{-3}]
A_x	=	Cross sectional area [L^2]
D_L	=	Dispersion coefficient [L^2T^{-1}]
$\overline{U}$	=	Mean velocity [LT^{-1}]
S	=	External sources or sinks [MT^{-1}]

Because $M = VC$, we can write

$$\frac{\partial M}{\partial t} = \frac{\partial(VC)}{\partial t} = V\frac{\partial C}{\partial t} + C\frac{\partial V}{\partial t} \qquad (2)$$

Where

$V = A_x\, dx$ = *incremental volume*

If we assume that the flow in the stream is steady, i.e.

$$\frac{\partial Q}{\partial t} = 0$$

then the term

$$\frac{\partial V}{\partial t} = 0$$

and equation (2) becomes

$$\frac{\partial M}{\partial t} = V\frac{\partial C}{\partial t} \tag{3}$$

Combining the equation (1) and (3) and rearranging

$$\frac{\partial C}{\partial t} = \frac{\partial\left(A_x D_L \frac{\partial C}{\partial x}\right)}{A_x\,\partial x} - \frac{\partial\left(A_x \overline{U} C\right)}{A_x\,\partial x} + \frac{dC}{dt} + \frac{S}{V} \tag{4}$$

The terms on the right hand side of the equation represent dispersion, advection, constituent changes (e.g., growth and decay), and external sources/sinks and dilution, respectively. The term $\frac{\partial C}{\partial t}$ is the local rate of concentration change (time derivative of concentration).

Under steady-state conditions, the local derivative becomes equal to zero:

$$\frac{\partial C}{\partial t} = 0 \tag{5}$$

Changes that occur to individual constituents or particles independent of dispersion, advection, and waste inputs are defined by the term

$$\frac{dC}{dt} = \textit{individual constituent changes} \tag{6}$$

These changes include the physical, chemical, and biological reactions and the interactions that occur in the stream. Examples of these changes are reaeration, algal respiration and photosynthesis, and the coliform die-off (EPA,1987).

2.3.3.2 Constituent Reactions and Interrelationship

One of the most important considerations in determining the waste-assimilative capacity of a stream is its ability to maintain an adequate dissolved oxygen concentration. Dissolved oxygen concentration in streams is controlled by atmospheric reaeration, photosynthesis, plant and animal respiration, benthal demand, biochemical oxygen demand, nitrification, salinity, and temperature. In the most accurate oxygen balance, all significant factors would be considered.

The QUAL2E model includes major interactions of the nutrients cycle, algae oxygen uptake, atmospheric aeration, and their effects on the behavior of dissolved oxygen, see Figure 2.2.

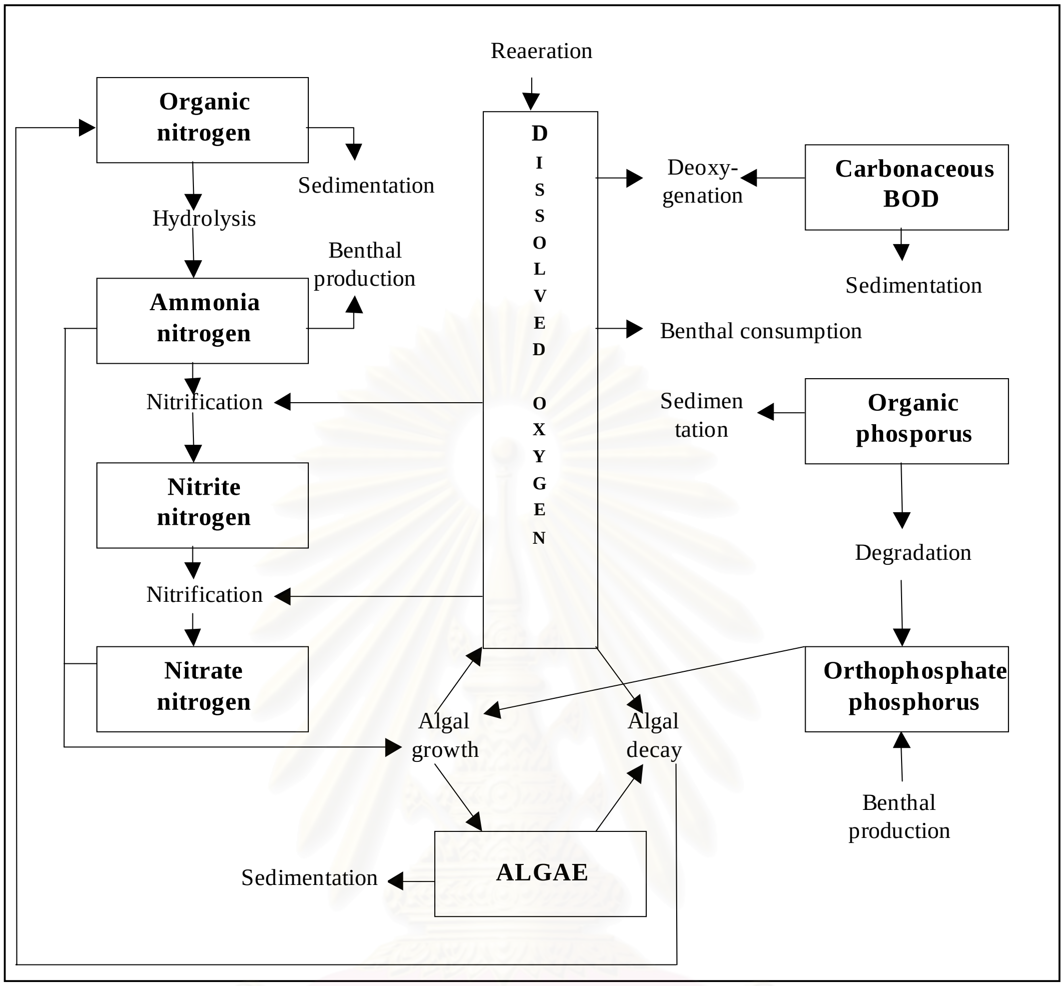


Figure 2.2 Major constituent interactions in QUAL2E (Smedt, 2000)

The mathematical relationship that describes the individual reactions and interactions are presented in the following.

Nitrogen Cycle

In natural aerobic waters, there is a stepwise transformation from organic nitrogen to ammonia, to nitrite, and finally to nitrate.

The nitrogen cycle in QUAL2E contains all four of these components, as shown in Figure 2.2. The differential equations governing transformations of nitrogen from one to another are shown below.

Organic Nitrogen

$$\frac{dN_4}{dt} = \alpha_1 \rho A - \beta_3 N_4 - \sigma_4 N_4 \qquad (7)$$

Where on the right hand side of the equation the gross explanation of the different forms is

N_4	=	Concentration of organic nitrogen,
β_3	=	Rate constant for hydrolysis of organic nitrogen to ammonia nitrogen, temperature dependent,
α_1	=	Fraction of algal biomass that is nitrogen,
ρ	=	Algal respiration rate,
A	=	Algal biomass concentration,
σ_4	=	Rate coefficient of organic nitrogen settling, temperature dependent,

Ammonia Nitrogen

$$\frac{dN_1}{dt} = \beta_3 N_4 - \beta_1 N_1 + \frac{\sigma_3}{d} - F_1 \alpha_1 \mu A \qquad (8)$$

Where

$$F_1 = \frac{P_N N_1}{\left[P_N N_1 + (1 - P_N) N_3\right]} \qquad (9)$$

N_1	=	The concentration of ammonia nitrogen,
N_3	=	The concentration of nitrate nitrogen,
N_4	=	The concentration of organic nitrogen,
α_1	=	Fraction of algal biomass which is nitrogen,
σ_3	=	The benthos source rate for ammonia nitrogen,
β_1	=	Rate constant for the biological oxidation of ammonia nitrogen,
β_3	=	Organic nitrogen hydrolysis,
d	=	Mean depth of flow,

F_1	=	Fraction of algal nitrogen uptake from ammonia pool,
μ	=	The local specific growth rate of algae,
A	=	Algal biomass concentration,
P_1	=	Preference factor for ammonia nitrogen.

Nitrite Nitrogen

$$\frac{dN_2}{dt} = \beta_1 N_1 - \beta_2 N_2 \tag{10}$$

Where

N_1	=	The concentration of ammonia nitrogen,
N_2	=	The concentration of nitrite nitrogen,
β_1	=	Rate constant for the oxidation of ammonia nitrogen,
β_2	=	Rate constant for the oxidation of nitrite nitrogen.

Nitrate Nitrogen

$$\frac{dN_3}{dt} = \beta_2 N_2 - (1 - F)\alpha_1 \mu A \tag{11}$$

Where

F	=	Fraction of algal nitrogen taken from ammonia pool,
α_1	=	Fraction of algal biomass that is nitrogen,
μ	=	Local specific growth rate of algae.

Phosphorous Cycle

The phosphorus cycle operates like the nitrogen cycle in many aspects. Organic forms of phosphorus are generated by the death of algae, which then are converted to the dissolved inorganic form, which it is available to algae for primary production. Phosphorus discharged from sewage treatment plants is generally in the dissolved inorganic form and is readily uptake by algae.

Below are the differential equations governing transformations between organic and dissolved phosphorus.

Organic Phosphorus

$$\frac{dP_1}{dt} = \alpha_2 \rho A - \beta_4 P_1 - \sigma_5 P_1 \qquad (12)$$

Where

P_1	=	The concentration of organic phosphorus,
α_2	=	Phosphorus content of algae,
ρ	=	Algal respiration rate,
A	=	Algal biomass concentration,
β_4	=	Organic phosphorus decay rate,
σ_5	=	Organic phosphorus settling rate.

Dissolved Phosphorus

$$\frac{dP_2}{dt} = \beta_4 P_1 + \frac{\sigma_2}{d} - \alpha_2 \mu A \qquad (13)$$

Where

P_2	=	Concentration of inorganic dissolved phosphorus,
σ_2	=	Benthos source rate for dissolved phosphorus,
d	=	Mean stream depth,
μ	=	Algal growth rate,
A	=	Algal biomass concentration.

Carbonaceous (CBOD)

The QUAL2E model assumes a first order reaction to describe deoxygenation of ultimate carbonaceous BOD in stream. The BOD function expressed in the model has taken into account additional BOD removal due to sedimentation, scour and flocculation, which do not exert an oxygen demand.

$$\frac{dL}{dt} = -K_1 L - K_3 L \qquad (14)$$

Where

L	=	The concentration of ultimate carbonaceous BOD,
K_1	=	Deoxygenation rate coefficient, temperature dependent,
K_3	=	The rate of loss of carbonaceous BOD due to settling.

Dissolved Oxygen (DO)

The oxygen balance in a stream depends on the capacity of the stream to reaerate itself. This capacity is a function of the advection and diffusion processes occurring within the system and the internal sources and sinks of oxygen. The differential equation used in QUAL2E to describe the rate of change of oxygen is shown below. Each term represents a major source and sink of oxygen.

$$\frac{dO}{dt} = K_2\left(O^* - O\right) + \left(\alpha_3\mu - \alpha_4\rho\right)A - K_1L - \frac{K_4}{d} - \alpha_5\beta_1N_1 - \alpha_6\beta_2N_2 \qquad (15)$$

Where on the right hand side of the equation the gross explanation of the different forms is

O^*	=	The saturation concentration of dissolved oxygen at the local temperature and pressure,
O	=	The concentration of dissolved oxygen,
α_3	=	The rate of oxygen production per unit of algal photosynthesis,
α_4	=	The rate of oxygen uptake per unit of algae respired,
α_5	=	The rate of oxygen uptake per unit of ammonia nitrogen oxidation,
α_6	=	The rate of oxygen uptake per unit of nitrite nitrogen oxidation,
μ	=	Algal growth rate, temperature dependent,
ρ	=	Algal respiration rate, temperature dependent,
A	=	Algal biomass concentration.
L	=	Concentration of ultimate carbonaceous BOD,
d	=	Mean stream depth,
K_1	=	Deoxygenation rate coefficient, temperature dependent,
K_2	=	The reaction rate in accordance with the Fickian diffusion analomy, temperature dependent,
N_1	=	The concentration of ammonia nitrogen,
N_2	=	The concentration of nitrite nitrogen,

β_1 = Rate constant for the oxidation of ammonia nitrogen,

β_2 = Rate constant for the oxidation of nitrite nitrogen.

2.3.3.3 Temperature

The input variables for temperature simulation are uniform over entire river basin. These input variables consist of climatological, geographical, and heat balance information as follows: basin elevation, dust attenuation coefficient, evaporation coefficient, dry and wet bulb air temperature, atmospheric pressure, cloud cover, and wind speed.

2.3.4 Computational Representation

2.3.4.1 Prototype Representation

Basically, seven types of computational elements are considered: head water element, standard element, element just upstream of a junction, junction element, last element in the system, input element, and withdrawal element. The fundamental reason for subdividing sections of the stream into “reaches” is that QUAL2E assumes that some 26 physical, chemical, and biological parameters (model input parameters or coefficients) are constant along a “reach”. The reason to define a “reach” is that stream has uniform hydraulic characteristics in it.

There is an explicit assumption of steady flow in all of the computer programs in the QUAL series. The only time varying forcing functions are the climatological variables that primarily affect temperature and algal growth. The forcing function used for estimating transport is the stream flow rate, which is assumed to be constant. Stream velocity, cross sectional area, and depth are computed from stream flow.

2.3.4.2 Forcing Functions

Forcing functions are user specified inputs that drive the system being modeled. These inputs which are specified in terms of flow, water quality characteristics, and local climatology are:

1) Headwater input

   Typically upstream boundary condition.

2) Point sources and/or withdrawals

   Representing point sources discharges into the system e.g., sewage, industrial waste or stream runoff, and losses from the system as a result of diversion.

3) Incremental inflow

   Flow uniformly added or removed along a reach.

4) Downstream boundary concentration (optional). This feature is very useful in modeling system with large dispersion in the lower reach such as estuary. Apart from these, local climatological data are also required for the simulation of algae and temperature.

2.3.4.3 Numerical Solution Techniques

At each time step and for each constituent, equation (4) can be written once for each of the computational elements in the network. Because it is not possible to obtain analytical solution to these differential equations under most prototype situation, a classical implicit backward finite difference method is used.

The general basis of a finite difference scheme is to find the value of a variable (e.g., constituent concentration) as a function of space at a time step (n+1), when its spatial distribution at the n^{th} time step is known. Time step zero corresponds to the initial condition. Backward difference or implicit schemes are characterized by the fact that all spatial derivatives are approximated in difference form at time step n+1.

Formulation of the Finite Difference Scheme

The finite difference scheme is formulated by considering the constituent concentration, C, at four points in the mnemonic scheme as shown in Figure 2.3.

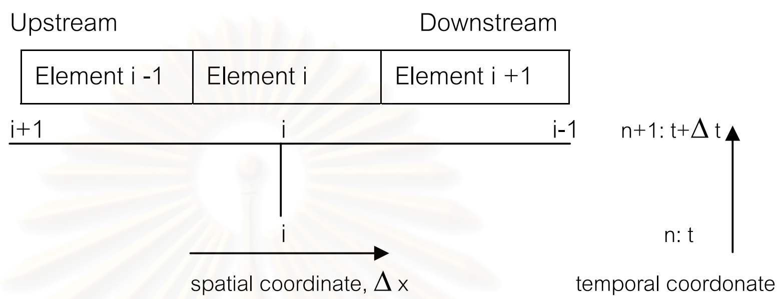


Figure 2.3 Classical Implicit Nodal Scheme

Three points are required at time n+1 to approximate the spatial derivatives. The temporal derivatives is approximated at distance step i and equation (4) could be written in finite difference form in two steps.

For the first step, advection and diffusion terms (differential with respect to x) are represented using finite difference scheme, giving:

$$\frac{\partial C_i}{\partial t} = \left[\left(AD_L \frac{\partial C}{\partial x}\right)_i - \left(AD_L \frac{\partial C}{\partial x}\right)_{i-1}\right]\frac{1}{V_i} - \left[(AVC)_i - (AVC)_{i-1}\right]\frac{1}{V_i} + \frac{dC_i}{dt} + \frac{S_i}{V_i} \qquad (16)$$

For the second step, an approximation to temporal and dispersion terms.

$$\frac{C_i^{n+1} - C_i^n}{\Delta t} = \frac{(AD_L)_i C_{i+1}^{n+1} - (AD_L)_i C_i^{n+1}}{V_i \Delta x_i} - \frac{(AD_L)_{i-1} C_i^{n+1} - (AD_L)_{i-1} C_{i-1}^{n+1}}{V_i \Delta x_i}$$

$$- \frac{Q_i C_i^{n+1} - Q_{i-1} C_{i-1}^{n+1}}{V_i} + r_i C_i^{n+1} + P_i + \frac{S_i}{V_i} \qquad (17)$$

In the above equation the term $\frac{dC}{dt}$ is expressed as:

$$\frac{dC_i}{dt} = r_i C_i^{n+1} + P_i \qquad (18)$$

where

r_i = First order rate constant,

P_i = Internal constituent sources and sinks (e.g., nutrient loss from algal growth, benthos source, etc.)

Note that, the $\frac{dC}{dt}$ term for every constituent modeled by QUAL2E can be expressed in this form.

Methods of Solutions

The above two finite difference equations could be arranged in terms of coefficients such that each representing a set of simultaneous linear equations whose solution provides the value of C_i^{n+1}, for all (i) and these sets of equation are expressed in tridiagonal matrix, an efficient method which readily lends itself to a computer solution.

Boundary Condition

In most situations of interest, transport is unidirectional in nature i.e., there is no significant transport in the upstream direction. Therefore, the concentration at some point just upstream from the beginning or end of the reach of interest can be used as a boundary condition.

The upstream boundaries are usually headwater elements. For headwater, there is no upstream, i-1 element, while at downstream boundary (last element in the system), QUAL2E has two options:

1) The zero gradient assumption,
2) The fixed downstream constituent concentrations.

2.4 Model Calibration and Verification

Calibration covered the processes for determining model parameters using measured waste loadings, stream flows, and water quality data. Calibrated parameters included DO, BOD_5, NH_3_N, NO_2_N, NO_3_N, and Dis_P. Verification was used to describe the situation where a model calibrated at one set of source inputs and receiving water conditions predicts successfully observed water quality and quantity under different sets of waste load and receiving water conditions. The effects of reaeration, BOD decay, and SOD were all examined during the calibration process. The same as calibration stream flow was considered from adjusting Manning's roughness coefficient (n).

In practice, the calibration and verification processes are such interactive procedures where output from model is checked against known data by comparative analysis. Errors in these elements of data are selected and corrected until the simulated and the measured are acceptable.

Two sources of data may be used in the verification process, historical data and field survey data. It is recommended that historical data records are used first for reliability, cost, time saving reasons.

There are a number of water quality model verification techniques. Some of these tools are described below.

2.4.1 Qualitative Measurement

The most direct and easy-to-understand measurement of model performance is comparing qualitatively of observed data and computed values. A plot of observed data versus theoretical one is a graphical measurement of model, giving credibility, understandability, and clear visualizability. However, the qualitative plot may not be enough and appropriate to some application especially water quality where a statistical method is more appropriate

2.4.2 Statistical Measurement

There are many statistical comparisons but those widely used to quantify the different between observed and computed values are as follows.

1. Regression Analysis
2. Relative Error
3. Comparison of Mean Value
4. Root Mean Square Error
5. QUAL2E Uncertainty and Sensitivity Analysis Techniques

   This last option containing three sub-techniques: Sensitivity Analysis, First Order Error Analysis, and Monte Carlo Simulation, is part of the QUAL2E-UNCAS program. It was used as a statistical analysis tool in this study.

2.5 Uncertainty Analysis with QUAL2E

Nowadays uncertainty analysis plays an important role in the field of water quality model simulation. One of the first steps in the analysis is to quantify the error in predicting water quality. Unfortunately, uncertainty analysis of water quality model has not received as much attention as it should be. However the water quality model QUAL2E has incorporated three uncertainty analysis techniques: Sensitivity Analysis, First Order Error Analysis, and Monte Carlo Simulation and model users can choose an appropriate option for their system.

The following are details of uncertainty analysis technique accompanying QUAL2E:

2.5.1 Sensitivity Analysis

This method is normally used to determine the changing of output variables when a single input or variable is changed or perturbed by a certain amount, say 5% or 10%. The result is typically expressed as a sensitivity coefficient $\frac{\Delta Y}{\Delta X}$, where ΔY and ΔX are the changing of output and input variables, respectively.

Anyway, as report in Charles S. Melching and Chun G. Yoon, 1996 this method is not appropriate for determining the sources of uncertainty that most affect model output. So Sensitivity Analysis was not taken into account in this thesis.

2.5.2 First Order Error Analysis (FOEA)

First Order Error Analysis (FOEA) is used to estimate the variance of an output variable as a linear approximation of the function of input variances which are assumed to act independently. The variance, *Var* (Y_i), of output variable, (Y_j), is computed as below.

$$Var(Y_i) = \sum_i Var(X_i)\left(\frac{\Delta Y_j}{\Delta X_i}\right)^2 \qquad (26)$$

Where

$Var\ (Y_j) =$ variance of output variable Y_j

$Var\ (X_i) =$ variance of input variable X_i

ΔX_i = magnitude of input perturbation n

ΔY_j = magnitude of output perturbation n

The input requirements for FOEA consist of the magnitude of the input perturbation, ΔX, and the variance of the input variable $Var\ (X_i)$. The value of ΔX_i (default value is 5%, i.e. $\frac{\Delta X_i}{X_i}$ = 0.05) is specified by the user and default values for input variances are provided with the QUAL2E-UNCAS model.

The output for FOEA from QUAL2E-UNCAS consists of a tabulation of normalized sensitivity coefficient $(S_{i\,j})$ which is computed as

$$S_{i\,j} = \frac{\Delta Y_j / Y_j}{\Delta X_i / X_i} \qquad (27)$$

Where

S_{ij} = normalized sensitivity coefficient for output Y_j to input X_i

X_i = base value of input variance

Y_j = base value of output variance

2.5.3 Monte Carlo Simulation (MCS)

Monte Carlo Simulation (MCS) is a method for numerically operating a system that has random components. Input variables are randomly sampled from a specified probability distributions and then, a frequency distribution of output variables is analyzed statistically.

The input requirements for the MCS in QUAL2E-UNCAS consist of the input variance, $Var\ (X_i)$, the probability distribution of input variable, only normal distribution being considered in this thesis, and the number of simulations to be performed.

The output of MCS in QUAL2E-UNCAS provides summary statistics and frequency distributions for the output variable at specific locations in the system.

2.6 Determining Coefficient Values for Modeling Parameters

There are factors affecting DO simulation as shown in the equation above. Methods to determine coefficient values relating to DO are tabulated in Table 2.1.

Table 2.1 Method for Determining Coefficient Values for Modeling Parameters

Model Parameters	Symbol	Method of Determination	Range
Dissolved Oxygen Parameters			
Reaeration rate coefficients	K_2	Compute as a function of depth and velocity using an appropriate formula, or measure in field using tracer techniques.	0.0-100.0
O_2 consumption per unit NH_3 oxidation	α_5	Constant fixed by biochemical stoichiometry	3.0-4.0
O_2 consumption per unit NO_2 oxidation	α_6	Constant fixed by chemical stoichiometry	1.0-1.14
O_2 production per unit photosynthesis	α_3	Literature values, model calibration and measurement by light to dark bottles and chambers	1.4-1.8
O_2 consumption per unit respiration	α_4	Literature values, model calibration	1.6-2.3
Sediment Oxygen Demand	K_4	In situ measurement and model calibration.	variable

Table 2.1 Method for Determining Coefficient Values for Modeling Parameters (cont.)

Model Parameters	Symbol	Method of Determination	Range
Carbonaceous BOD Parameters			
CBOD decay rate	K_1	Plot CBOD measurement on semi- log paper or measure in laboratory	0.02-3.4
CBOD settling rate	K_3	Plot CBOD measurement on semi- log paper and estimate from steep part of curve	-0.36-0.36
Nitrite Parameters			
Nitrite oxidation rate	β_2	Use literature values and calibration, since this rate is much faster than the ammonia oxidation rate	0.2-2.0
Ammonia Parameters			
Ammonia oxidation rate	β_1	Plot TKN measurements and NO_3 + NO_2 measurements on semi-log paper	0.1-1.0
Benthic source rate	σ_3	Model calibration	variable
Phosphate Parameters			
Benthic source rate	σ_2	Model calibration	variable

Source: EPA,1986

2.7 Geograhical Information System (GIS)

2.7.1 General Principles of GIS

A Geographical Information System is a computer–based system to capture, edit, manage, and display geographically referenced information. Due to the fast improvement of computer technology, the use of GIS is nowadays very popular in many field especially in hydrological research.

Federal Interagency Coordinating Committee (1988)

"A system of computer hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modullary, and display of spatially referenced data for solving complex planning and management problems."

Francis Hanigan (1988)

"Any information management system which can

- collect, store, and retrieve based on its spatial location
- identify locations within a targeted environment which meet specific criteria
- explore relationships among data sets within that environment
- analyze the related data spatially as an aid to making decision about that environment
- facilitate selecting and passing data to application-specific models capable of assessing the impact of alternatives on the chosen environment
- display the selected environment both graphically and numerically either before and after analysis"

2.7.2 Map Data Representation

Most of GIS system use one or a combination of the fundamental map representation techniques i.e., raster and vector.

Raster Data is data structure which is a cellular data or grid cell or grid data. It consists of rows and column as groups of cells showing feature. The value in the cell is the value of the feature. Vector Data is a data structure which is a coordinated-based data which is normally used to show linear map feature. Each linear feature show coordinate XY. Attribute data are linked to grid cell. Generally, vector data structure is meant to include polygon and arc-node model (John C. A., Brown, K., Croswell, P. L., Kevany, M. J., and Archer, H.,1991).

2.7.3 Geographic Information System Structure

The following components are involved in GIS:

- data input subsystem which collects or processes spatial data derived from existing maps, remote sensors, etc.
- data storage and retrieval subsystem which organizes the spatial data for being quickly retrieved by the user as well as permitting rapid and accurate updates and correction.

- data manipulation and analysis subsystem which change the form of the data or produce estimates of parameters and constrains for optimization or simulation models.
- Data reporting subsystem which can display all or part of the original database. The manipulated data and the output from spatial models in tabular or map form.
- User interface which consists of software capabilities in order to simplify and organize interactions between user and GIS software.

2.8 Overview of Nakhon Nayok Watershed

Nakhon Nayok river is one of tributaries of Bangpakong Basin that has a few small tributaries. It flows through different parts of the province and collects all solid and liquid wastes, including storm runoff. The river situates between 101°04'- 101°20' Longitude and 14°00'-14°24' Latitude. It has approximate length of 130 kilometers see Figure 2.4.

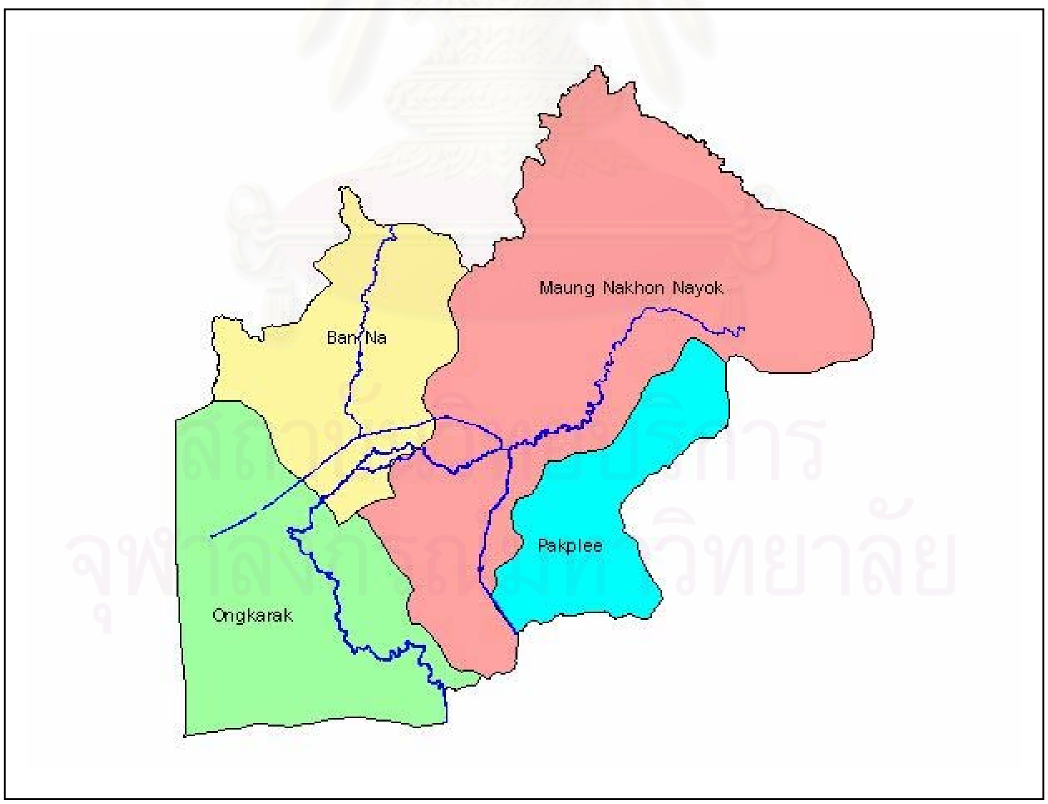


Figure 2.4 Map of Nakhon Nayok river

2.8.1 General

- *Population and Community*

Most settlements are in medium-community with 5,000-10,000 population and small community with population less than 5,000. Sub districts which have population over 10,000 are municipal and the surrounding like Prom Mani and Ban Prik. The average rate of population change during 1992-1997 was 1.01%. Population in downtown are 13.73% in 1997(KU,2000).

- Agriculture

Nakhon Nayok has 85.6% paddy field see Table 2.2. Agriculture in Eastern is influenced by slope, type of soil, and amount of rainfall. The amount of rainfall in Nakhon Nayok is 2,300-2,900 mm per year.

Table 2.2 Agricultural landuse of Nakhon Nayok in 1995

Landuse Type	Percent (%)
- Paddy field	85.6
- Plantation	0.4
- Tree Area	9.6
- Others	4.4
Total	100.0 = 595,000 rai

Source: Provincial Statistic. National Statistical Office (KU,1999).

The major agriculture in Nakhon Nayok watershed are detailed below.

1. *Major Rice*

There are differences in each area, cultivating period, and methodology depending on cultivable soil and amount of rainfall as described below.

1.1 *Lowland Rice*

Lowland rice is cultivated in lowland where water cannot be controlled. The most cultivation is found in Muang district, Ban Na district, and Pak Pli district. Cultivating period is in April while harvesting period is in October-January. It yields 450 kilograms per rai.

1.2 *Floating Rice*

Floating rice is cultivated in lowland where the water is controllable and is found in all dtstricts but in small area. Cultivating period is from April to May while harvest period is October-January. Yield is about 600 kilograms per rai.

1.3 *Upland Rice*

Upland rice is cultivated in lowland with flood area. The most cultivation is found in Ong Kalak district and Pak Pli district. Cultivating period is in May-June and October-January is harvesting period with yield of 250-350 kilograms per rai.

2. ***Second Rice***

Second rice is cultivated in irrigated area in November-December and the harvest time is February-March with yield of 600 kilograms per rai.

3. ***Fruit Trees***

Mango, orange, banana, and pomelo are widely cultivated.

4. ***Field Crops***

The most field crops are

- Mung bean with yield 122 kilograms per rai,
- Sweet corn with yield 1,094 kilograms per rai,
- Water melon with yield 2,631 kilograms per rai .

5. ***Vegetables***

Both vegetable and field crops are cultivated in dry period nearby water resource. The samples of them are cucumber, cantonese, chinese broccoli, etc.

6. *Livestocks*

At Ong Kalak district chicken farms are mostly found as chicken coops where fish pond are below. The fish get food from chicken waste. Besides, piggeries are mostly found both in Muang district and Ban Na district.

7. *Fisheries*

Fisheries are found both in Ong Kalak district and in Muang district.

- Industries

Nakhon Nayok watershed composes of 37 sub districts which have 215 factories. Most factories are in small and medium size. The factories are categorized as Table 2.3.

Table 2.3 The first five industries of Nakhon Nayok

Categories	Number of factories (amount)	Capital (million baht)	Number of employees (man)
1. Pulp industry	1	3,271	176
2. Machine repair and transport industry	39	948	626
3. Food processing industry	20	819	1,439
4. Agriculture processing product industry	39	257	436
5. Construction industry	33	159	431

Source: KU,2000

Factories concentrate in Ban Na sub district and Nakhon Nayok sub district. Industrial effluent of 10 factories are monitored by the office of provincial industry to conform effluent standard of Department of Industrial Works and eight of them locate in Muang sub district. Besides, half of them have treatment systems and can recycle the water, thus no wastewater is drained out of factories (Asdecon, Consultant of Technology, and TA&E,1994).

- **Tourism**

Nakhon Nayok has many attractive natural places. About 570,000 visitors coming here per year. Fifty seven percent are tourists which come and back in day and forty three percent staying in place day-long. Tourist seasons are in July- August and October-January.

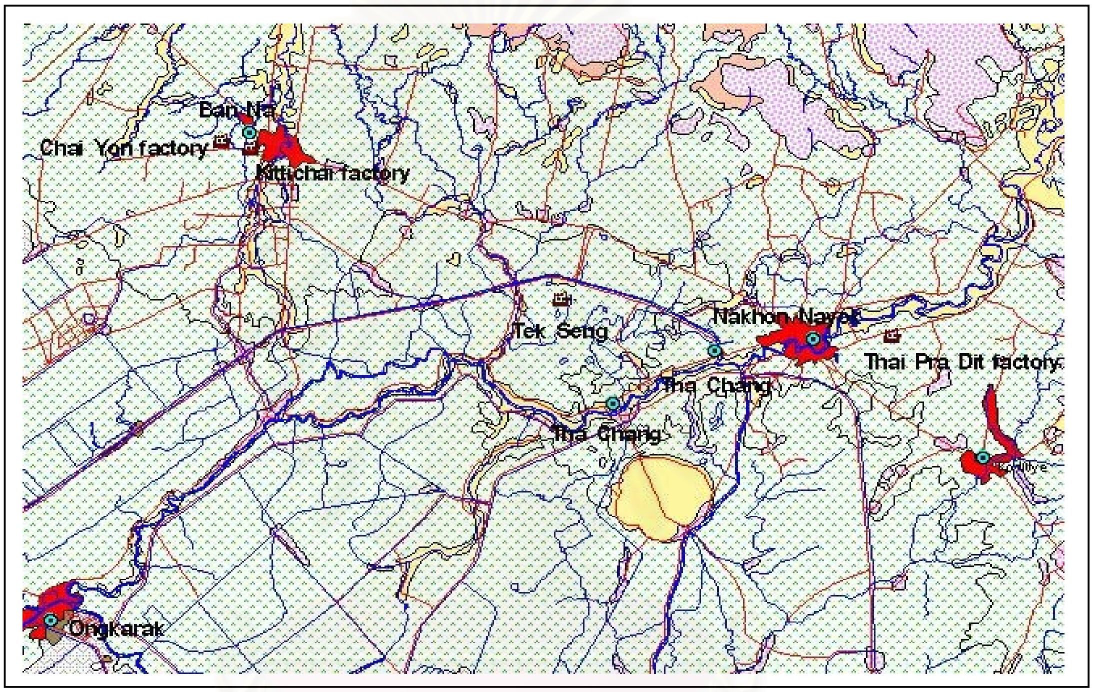


Figure 2.5 General of study area

2.8.2 Surface Water Quality

Faculty of Environmental and Resource Studies of Mahidol University studied water quality in 1991 and found that

- *Amphoe Muang Nakhon Nayok*

The water quality in upper boundary, from Tha Dan sub district to Tha Sai, was good. Water was still clean. The water was polluted and had bad smell due to fishes killed with chemical at Sri Nava sub district. At Nakhon

Nayok sub district wastewater was drained out from ice factory and community. Wung Kra Jom sub district has been full of moss and wastewater from both community and fresh market for 3 months long, so did Tha Chang. The water resource at Tha Sai sub district was polluted from piles of straw mushroom.

- *Amphoe Ban Na*

  At Ban Na sub district pesticide was poured in water. Salt water intrused to Bang Or sub district about one month long in May.

- *Amphoe Ong Kalak*

  Salt water intrused in dry season. Besides, it still had wastewater, accumulated herbicide, and herb spreading over river.

There are a number of water quality and relevant data collected by other government agencies. Because the data has continuity and sampling station cover study area, i.e upstream at Tha Dan station before Khao Nang Buat bridge which is the headwater, midstream at Nakhon Nayok bridge, and downstream at Ampwan temple. We choose collected data from PCD to show the change in water quality at the interval between 1993 - 1999 and located more points for collecting water quality in the study area of 12 in total points as in Figure 2.6.

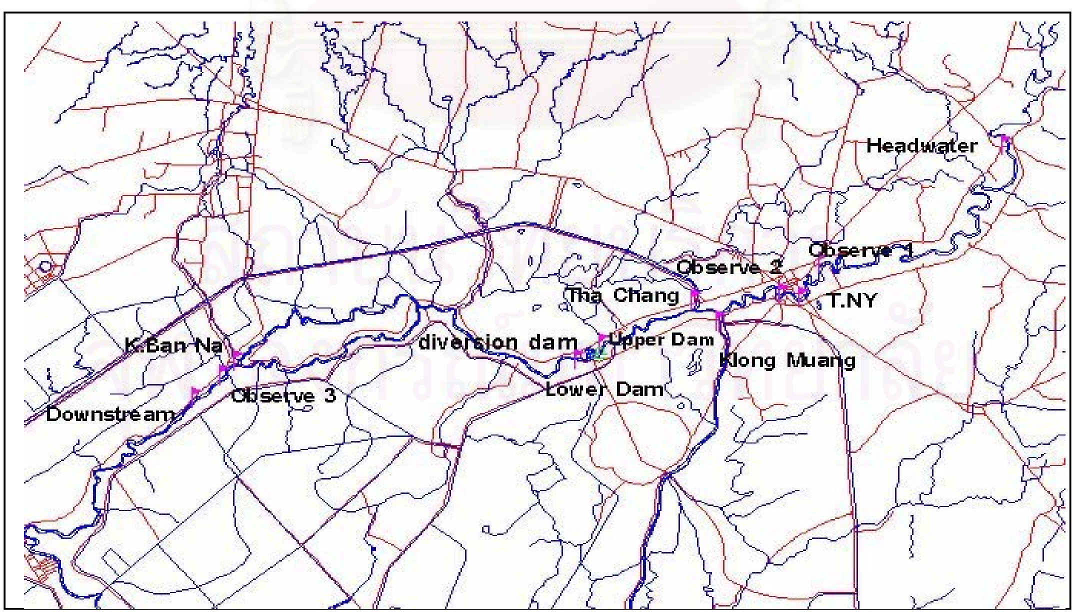


Figure 2.6 Sampling station in study area

The first station, Tha Dan, provided information of the upstream part of the river, see Figure 2.7.

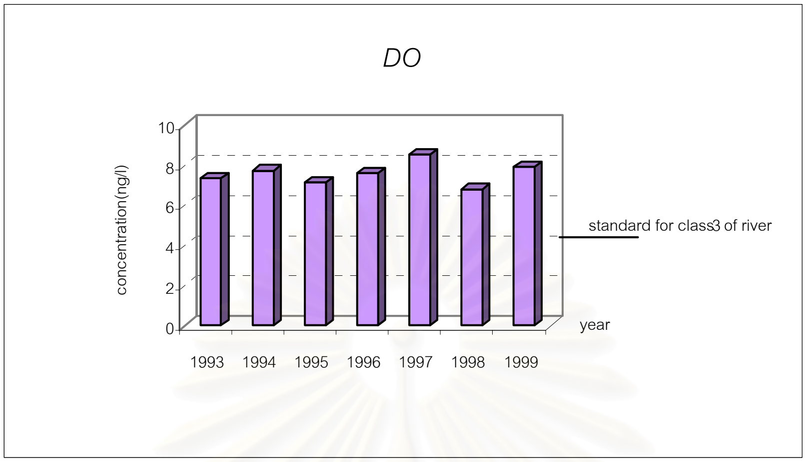


Figure 2.7 The contamination at Tha Dan sampling station

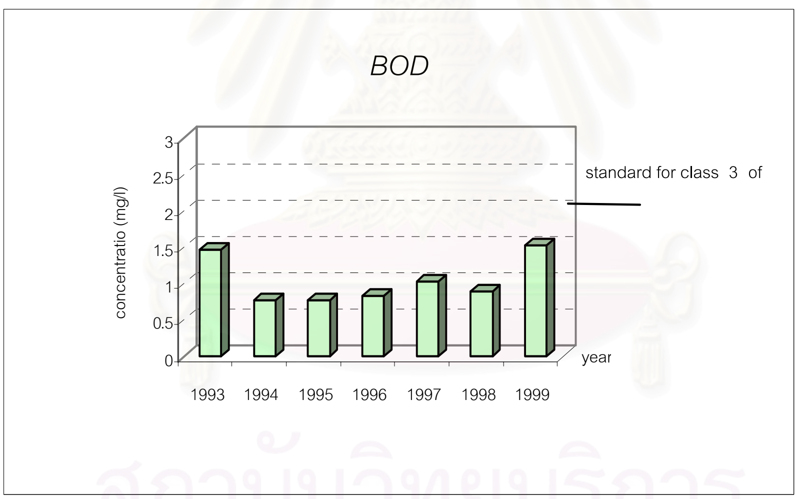


Figure 2.8 The contamination at Tha Dan sampling station (cont.)

From Figure 2.7 and 2.8, the concentration of DO and BOD in the beginning part of Nakhon Nayok river were still in the standard for class 3 of river. The standard concentrations of NH_3_N and NO_3_N are 0.50 and 5.00 mg/l, respectively, thus the contaminant of NH_3_N and NO_3_N are found to be in the standard eventhough the concentration of NH_3_N was higher in 1995 than in others and NO_3_N was rather high in 1993 and 1994, see Figure 2.9.

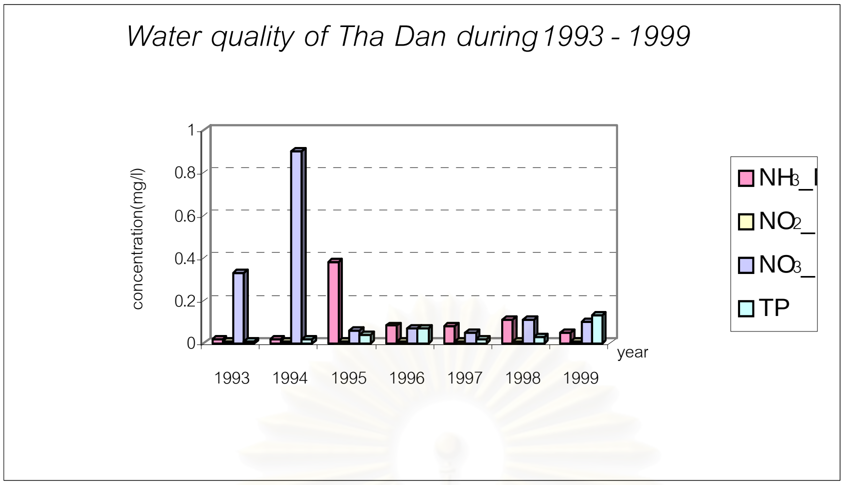


Figure 2.9 The contamination at Tha Dan sampling station (cont.)

The second station, Nakhon Nayok bridge, provided information of the midstream part, see Figure 2.10.

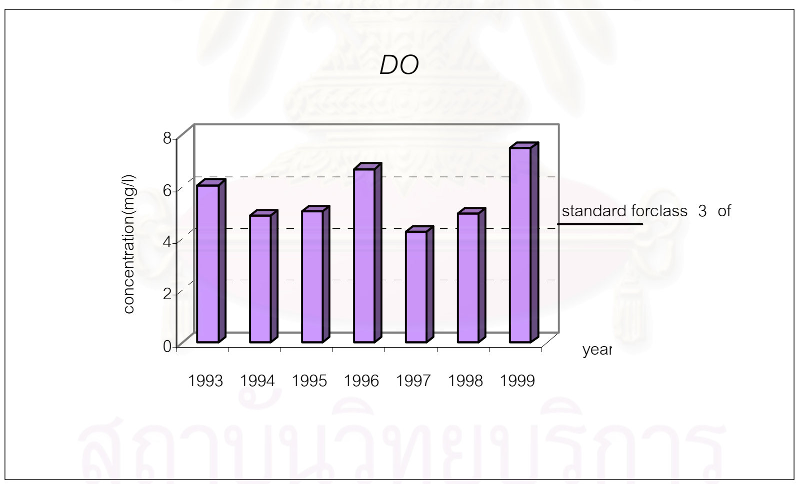


Figure 2.10 The contamination at Nakhon Nayok Bridge sampling station

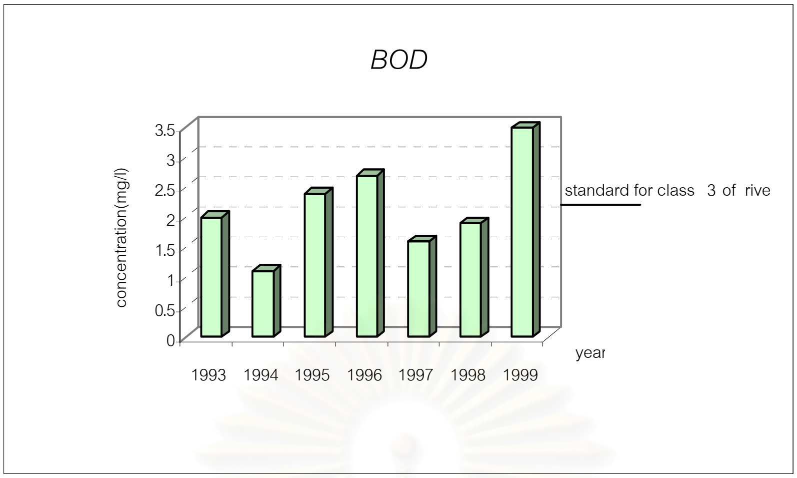


Figure 2.11 The contamination at Nakhon Nayok Bridge sampling station (cont.)

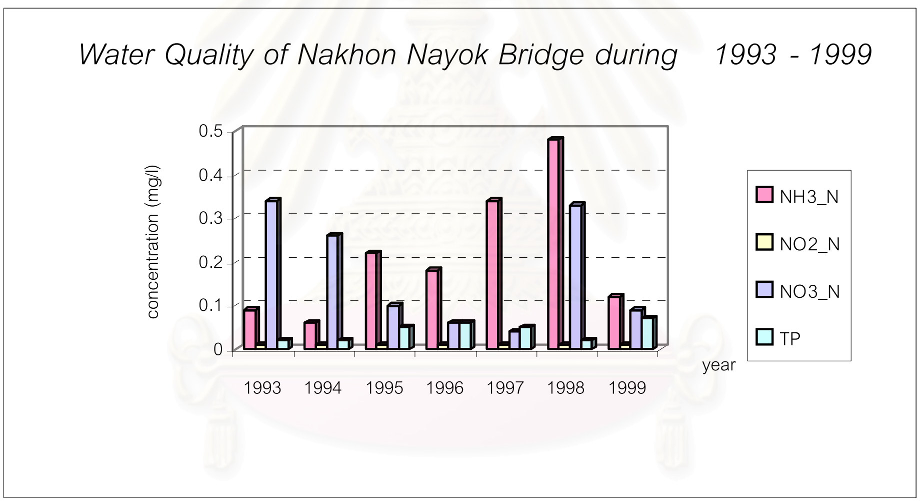


Figure 2.12 The contamination at Nakhon Nayok Bridge sampling station (cont.)

From Figure 2.10 to 2.12, at Nakhon Nayok bridge the concentration of DO was still in the standard eventhough the contaminant were rather high, in particular BOD which was over the standard in almost every year. The cause was due to high dense of population. Besides, wastewater was discharged through collecting pipes to the river directly. Other contaminants although not over the standard but were still high, in particular NH_3_N and NO_3_N.

The last station, Ampwan temple, gave information of the downstream part of the river, see Figure 2.13.

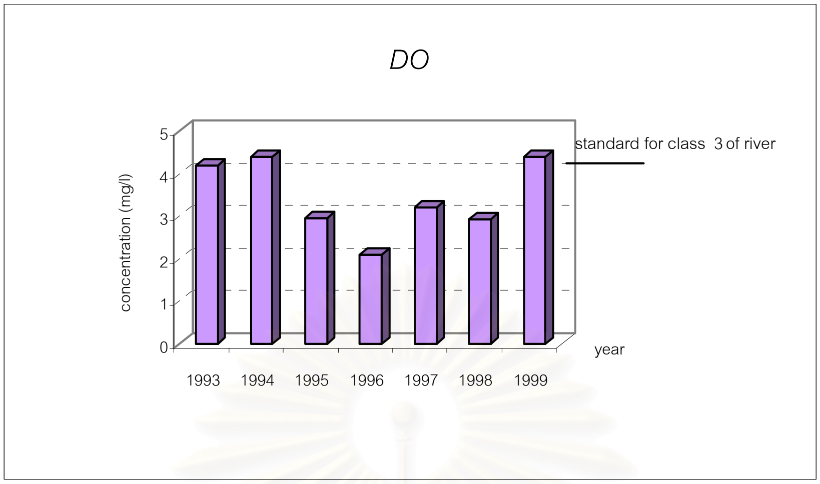


Figure 2.13 The contamination at Ampwan temple sampling station

Figure 2.13 shows the concentration of DO which is rather low and below the standard, in particular in 1996 the concentration was just 2.1 mg/l.

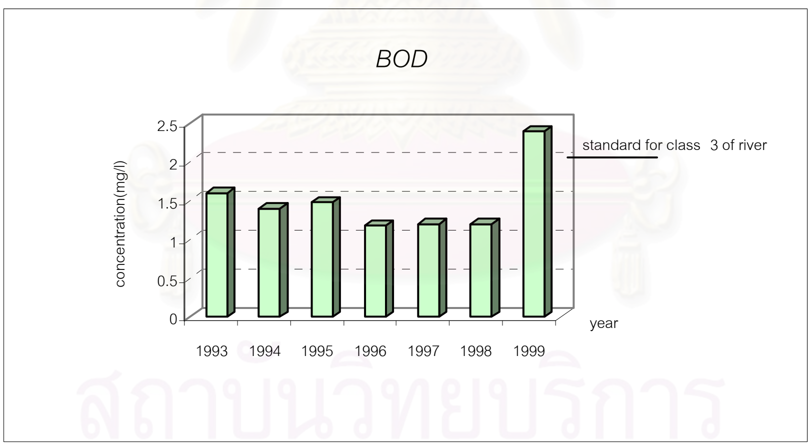


Figure 2.14 The contamination at Ampwan temple sampling station (cont.)

Figure 2.14 shows that the concentration of BOD was in the standard in almost every year, the exception was 1999 in which BOD was over the standard.

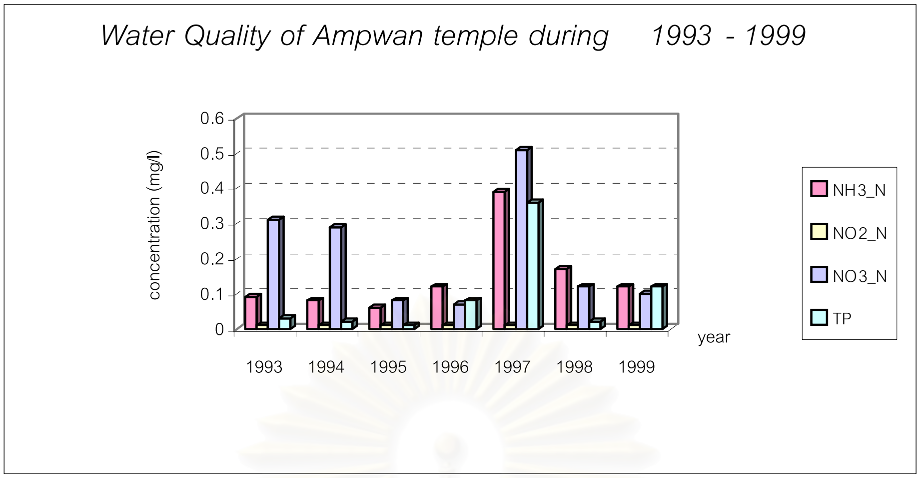


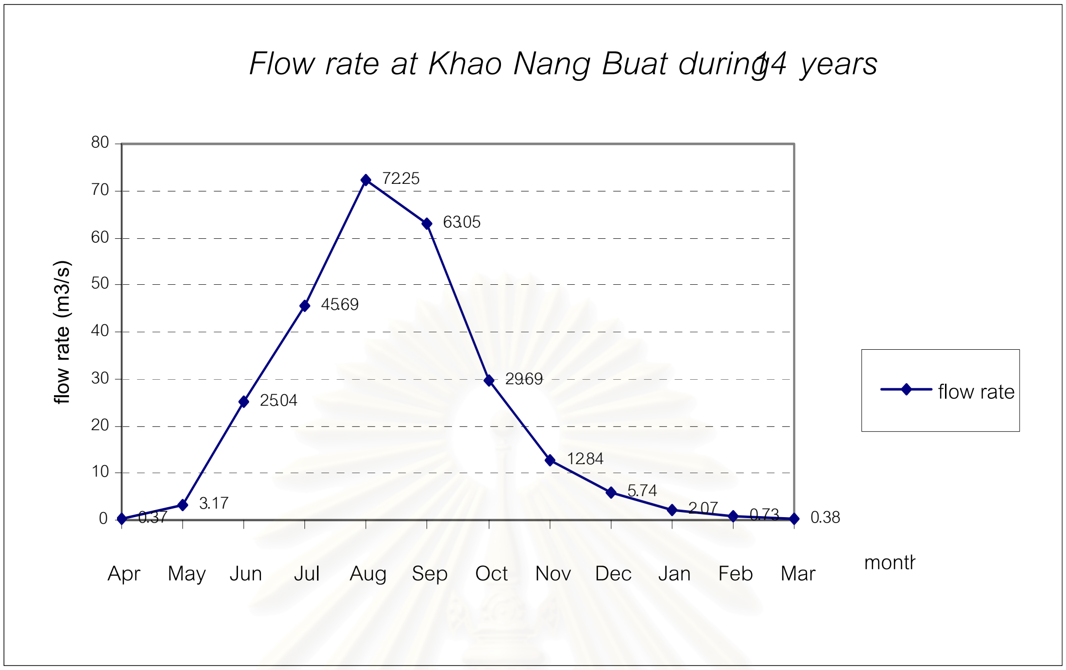
Figure 2.15 The contamination at Ampwan temple sampling station (cont.)

From Figure 2.15 the contamination of all pollutants were in the standard, although the concentrations of NH_3_N and NO_3_N, and total phosphate (TP) were rather high in 1997.

2.8.3 Flow Rate Data

Flow characteristics of river as the flow rate (volume of water passing through a cross section of the river in a unit of time) influences water quality. So in order to carry out a good model of water quality for a particular river, the flow rate must be defined.

It is usual to simulate critical condition occuring under an extremely low flow regime. As shown in Figure 2.16 flow rate recorded during December-May are too low. So one measurement is made in December see Figure 3.3.



Source: Average data during 1974-1980 and during 1991-1997 obtained from RID

Figure 2.16 Trend in flow rate data

2.9 Wastewater Loading Estimate

Presented in the following are population and loading estimate of point sources and nonpoint sources in the study area. These are input to the water quality model. So the assessment concerns 2 parts:

1.Type of pollutant sources,

2.Wastewater Loading estimates.

Pollutant sources are classified into 4 categories:

1. Communities

The effluents from communities include wastewater discharged from residential, which are domestic sewage. In this case we divide study area into 2 districts:

- Urban district,
- Rural district.

The wastewater loading is calculated from population densities, water supply and water consumption of the communities, which 96 percent of consumed water are total wastewater rate. Total wastewater rate is calculated from 80% of consumed water plus the seepage into pipes of underground water which is evaluted to be 20% of the former. The Table 2.4 and 2.5 show data used in the calculation.

Table 2.4 Rate of water consumption and BOD loading for communities estimation

Community	Population (capital)	Consumed Water Rate (l/cap/d)	Wastewater Rate (l/cap/d)
Urban district			
1.Municipal	>10,000	180	172.80
2.Sanitary	5,000-10,000	150	144.00
Rural district			
Sub districts and villages	<5,000	75	72.00

Source: Pollution Control Department; PCD (1998)

2. Industries

This type of wastewater includes a variety of chemicals whose quantity and characteristics depend on type, site, process, and size of industries. These industries are likely located outside colony and most of them consume less water (KU,1999). Only industries like machine repair and food processing that have caused high organic BOD loading and located along the river are considered. Almost industrial effluent have been pretreated before draining out to natural waterways, so their characteristics conform to the effluent standard of Department of Industrial Works. So these effluents have little impact on water quality.

3. Services and Commercials

Typically, effluent from this source almost occurs due to activities of human being and waste from these activities. Their characteristics compose of organic waste and chemical waste taken from many services. The services and commercial are of type hotels, hospital and sanitary services, education, fresh market, restaurants, slaughter house, and tourist places in jurisdiction of government, state enterprise, municipal, private and independent organization. Nakhon Nayok has many attractive tourist places but tourists likely come and back in day. Since the water use estimate are taken into account for only the tourist staying in place day-long, we can not estimate wastewater from this source.

Three categories mentioned above are point sources. Almost effluent have been treated and collected in sewer systems so the calculated flow rate is equal to the waste discharged from communities and industries.

Table 2.5 Rate of water consumption and BOD loading for services and commercials estimation

Places	Units	Consumed Water (l/unit/d)	Wastewater (l/unit/d)	BOD loading (g/unit/d)
Food center	Sq m	-	74	53.00
Fresh market	Sq m	-	16	21.00
Hospital	Beds	-	566	164.00
Hotel (>75 rooms)	Rooms	470	451.2	123.00
Government office	Capita	25	24	0.09
Education	Capita	25	24	0.09
Temple	Capita	200	192	0.09
Domestic	Capita	180	172.5	30.00

Sources: Thongchai et al., 1987 refered in Mingsarn,1996

The loading estimate of nonpoint source pollutant is done in order to be used in the water quality model as well. The nonpoint source pollutant includes nutrients and chemical waste from fertilizers, pesticides, and animal wastes. Typically, these pollutants enter the waterway through leaching, rainfall, and irrigation runoff. Nonpoint sources studied in this thesis are only from agriculture and riparian.

4. Agriculture

4.1 Crops

The most widespread land use is for rice paddy field, under fruit tree, and tree crops about 688,145 ,and 48,259 rai, respectively (PCD,1998).

To control agricultural nonpoint source pollution, we concentrate on chemicals, e.g. fertilizers and pesticides. Fertilizers contain nutrients mostly nitrogen and phosphorous. The nutrients are quite interesting from a water quality perspective. The type of fertilizer and usage depends on plant or crops, soil condition, and other environmental factors.

It is very difficult to predict the use of fertilizer in the future since type of crops changes annually and so does area during cultivation. The percentage of agricultural area has been steadily decreasing in recent decades due to the demand of land for urban and industrial development but the quantity of fertilizer use per unit area has been increasing because farmers drive to achieve higher crop yields (PCD,1997).

Frequency of draining consumed water depends on the type of cultivation such as paddy field. Consumed water in paddy field is drained during harvest period while that water from orchard is drained as runoff. Wastewater estimated from paddy field is considered from area multiplied by the height of consumed water before draining. Runoff from orchard is very little so it is ignored. Since water quality is minimum during dry period so only wastewater from second rice field is considered. The Table 2.6 and 2.7 are used in this assessment.

Table 2.6 Rate of water consumption and loading estimation for rice paddy field

Sources	Consumed water (m^3/rai)	Return flow (m^3/rai)	BOD loading (g/rai/crop)
second rice	1,563.20	150	3,830

Source: KU,1999

Table 2.7 Pollution loading from paddy field

Source	Temp(˚C)	Waste Loading (mg/l)						
		DO[(1)]	BOD[(1)]	BOD	NH_3_N	NO_2_N	NO_3_N	Dis_P
Paddy field	39.2	4.22	24.00	12.00	0.0960	0.0213	0.0085	0.0479

Source: field survey on December 8,2000

[(1)] Water that is being drained out from paddy field (KU,2000).

4.2 Livestocks

Livestock farming includes piggeries, poultry, and cattle. Pig farms are major pollutant sources which have a large impact on the river water quality and the wastes from other livestocks farming are consequently neglected due to its small scale and scattering of farms. The data used for the calculation is shown in Table 2.8.

Table 2.8 BOD loading for farming

Sources	Wastewater (l/cap/d)	BOD loading (g/cap/d)
Pig farms	40	136

Source: PCD (1997)

4.3 Aquacultures

There is a few aquaculture ponds, scattering in nature. Thus waterway can purify itself and loading estimate is not considered.

CHAPTER 3

METHODOLOGY

3.1 Data Collection

The information of the study area was collected as follows.

1) Cross section of Nakhon Nayok river at Khao Nang Buat Bridge in Muang district in 1997 surveyed by Royal Irrigation Department.
2) Discharge and water level from sampling stations during 1974-1980 and 1991-1997 observed by Royal Irrigation Department; the data include
    2.1 Discharge by year at Khao Nang Buat Bridge,
    2.2 Water level by month at Khao Nang Buat Bridge.
3) Water quality data at fixed sampling stations during 1993-1999 measured by Pollution Control Department,
4) Wastewater data including water consumption, BOD loading estimated from various studies.
5) Field survey conducted in this study; the data include
    5.1 Overview of study area on December 18,1999 and August 21, 2000,
    5.2 Cross section, flow rate, and water quality on December 8, 2000.

3.2 Materials, Equipments, and Chemical

3.2.1 Softwares

1) QUAL2E window version 1.0 software EPA-823-C-95-006 and documentation EPA-823-B-95-003 (EPA,1987)
2) MapInfo version 5.0 for editing Nakhon Nayok database from PCD.
3) ARC VIEW version 3.1
4) Topographic map 1:50,000 sheet 5237 II and 5237 III in 1992 (Royal Thai Survey Department)

3.2.2 Equipments:

1) GPS,

2) Thermometer,

3) Buoy, rope, length meter,

4) Glass and plastic bottles.

3.3.3 Chemicals:

- BOD and DO analytical technique
    1) $MnSO_4$ solution,
    2) Alkalini-iodine azide solution,
    3) Concentrated H_2SO_4
- Dissolved Phosphate analytical technique
    1) Ascorbic acid
    2) Concentrated sulfuric acid solution
    3) Potassium antimonyl tartate solution
    4) Ammonium molybdate solution
- Ammonia analytical technique
    1) Alkaline reagent
    2) Sodium hypochlorite
    3) Oxidizing reagent
    4) Sodium nitroprusside reagent
    5) Phenol reagent
    6) Standard ammonia
- Nitrite analytical technique
    1) Sulphanilamide solution
    2) N-(1-Naphyl)-ethylenediamine dihydrochloride solution
    3) Standrard nitrite
- Nitrate analytical technique
    1) Concentrated / dilute ammonium chloride solution
    2) Sulphanilamide solution
    3) N-(1-Naphyl)-ethylenediamine dihydrochloride solution
    4) Standard nitrate

3.3 Data Input

Although QUAL2E can simulate up to 15 water quality constituents, only ***dissolved oxygen (DO), biochemical oxygen demand (BOD_5), temperature, nitrogen cycle, and phosphorous cycle*** are selected to simulate in steady state mode with metric units. Running the model used input data which are based on practical assumptions, empirical equation, field measurements, and some values from literatures.

3.3.1 Number of Reaches

The first step to model this system is to divide the stream system into reaches which are stretches of stream that have uniform hydraulic characteristics. In this study the stream is divided into three reaches that contain 37 computational elements in total, see Figure 3.1.

3.3.2 River Kilometers

The river kilometers at the beginning and at the end of each reach are determined and entered as input data. The stream reach system in QUAL2E is identified by name and river kilometer by listing the reaches from the most upstream point in the system to the most downstream point. Information about this system is shown in Figure 3.2.

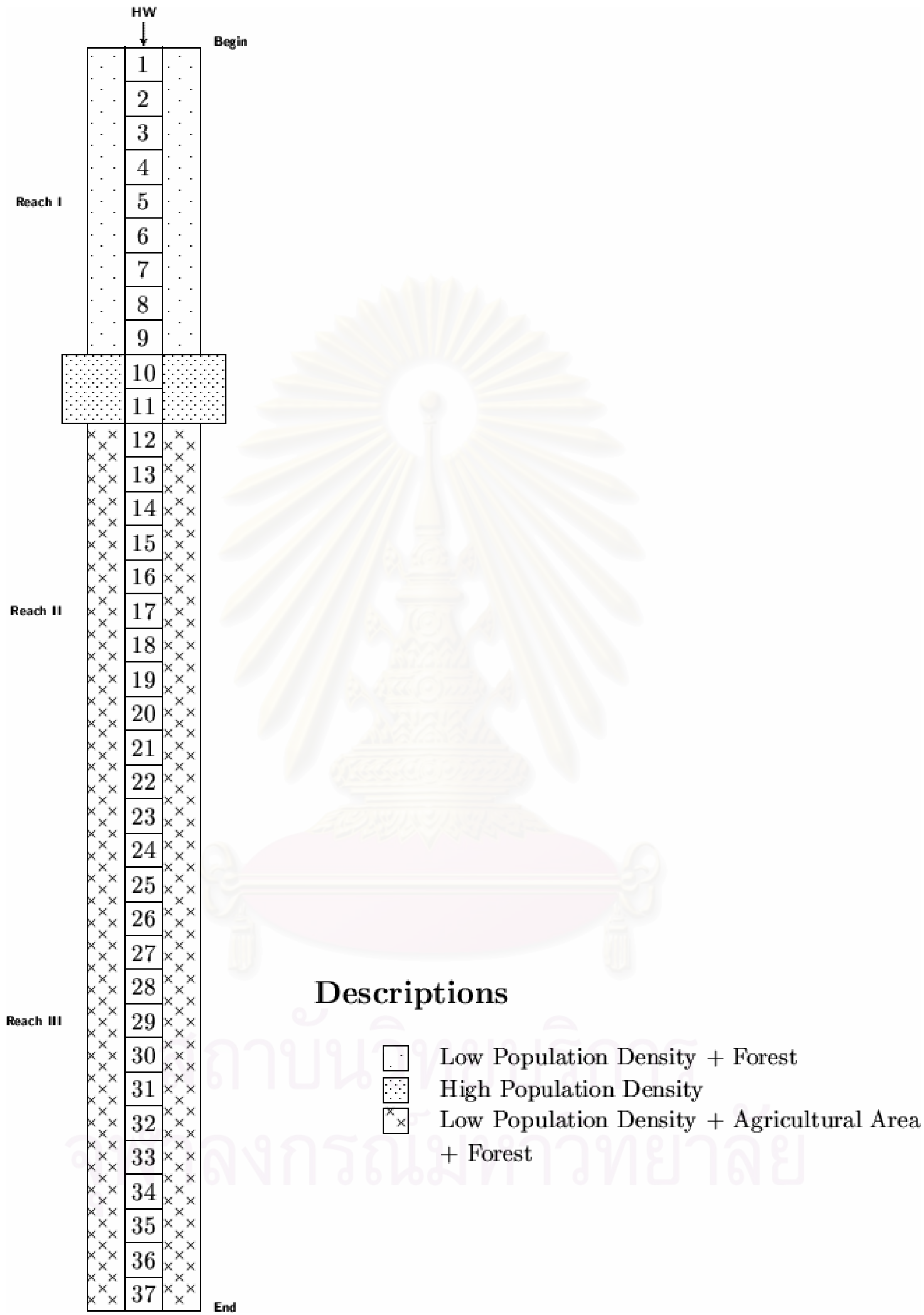


Figure 3.1 Schematic Representation of Study Area

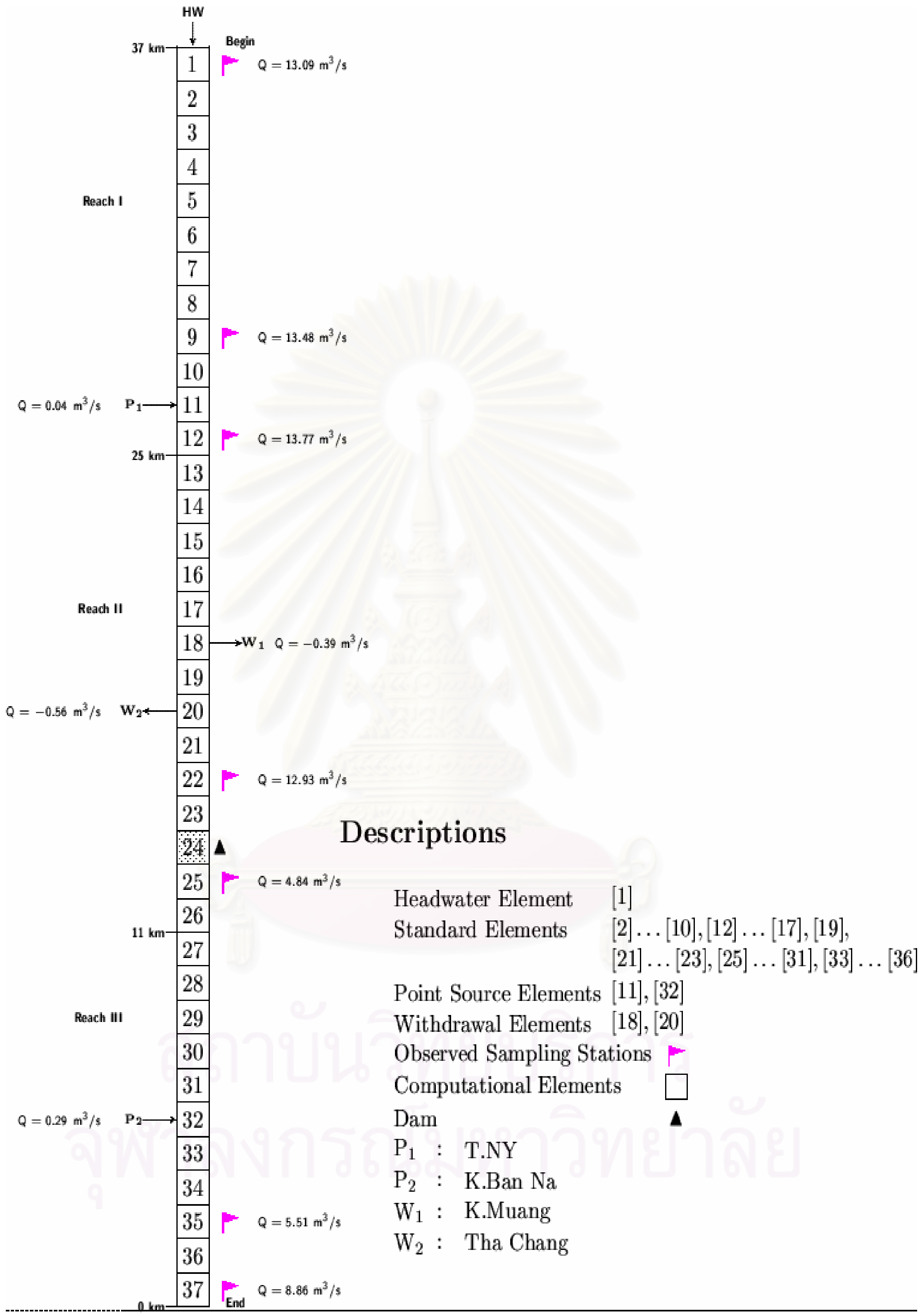


Figure 3.2 Stream network of computational elements and reaches for Nakhon Nayok river

3.3.3 Computational Element Length

After dividing the stream system into reaches, each reach is then subdivided into computational element of equal length. The computational element length has been computed from total length of the reach and the number of elements within each reach. Length of 1.0 kilometer of computational element is used in this study.

QUAL2E limit the maximum number of elements within a reach to be less than or equal to 20. The number of computational elements corresponding to each reach in the study is described in Table 3.1.

Table 3.1 Descriptions of the reaches.

Reach number	Reach name	Starting km	Ending km	No. of elements
1	Nang Buat	37	25	12
2	Klong Muang	25	11	14
3	Ampwan temple	11	0	11
			Total	37

3.3.4 Elements

The following different types of computational elements are identified:

- Headwater element (H) is element that begin every tributary as well as the main river system, and this is always the first elements in a head water reach.

  One of these elements is identified in this study.

- Element just upstream from junction (U) is used to designate elements on the main stream just upstream of a junction.

  One of these elements is identified in this study.

- The last element in a system or downstream element (E) identifies the last computational element in the river system.

  One of these elements is identified in this study.

- Point source element (P)

  Two of these elements are identified in this study, see Figure 3.2 and are described in more detail in item 3.3.7.

- Withdrawal element (W)

  Two of these elements are identified for this study.

- Standard element (S) are those that do not qualify as one of the remaining seven elements. Because incremental flow is permitted in all element types, the only input permitted in a standard element is incremental flow.

- Dam (D)

  One of these elements is identified in this study.

3.3.5 Hydraulic Characteristics

In the determination of the required hydraulic characteristics in QUAL2E model, there are two options available: the discharge coefficient option and the trapezoidal cross section. Cross sections of Nakhon Nayok river in study area have changed gradually, see Figure 2.10, so ***the second option*** is considered.

Each reach is represented as trapezoidal channel. These data are also used to specify the trapezoidal cross section (bottom width and side slope), the channel slope, and the Manning's "***n***" corresponding to each reach.

QUAL2E assumes that the stream hydraulic regime is steady state, i.e.

$$\frac{\partial Q}{\partial t} = 0$$

therefore the hydraulic balance for a computational element can be written simply as

$$\left(\frac{\partial Q}{\partial x}\right)_i = \left(Q_X\right)_i \qquad (19)$$

It means that the variation of Q along the streams is equal to the sum of external inflows and/or withdrawals to that element.

3.3.6 Estimation of Stream Flows

Flow Measurements

Along this stream system, there are no permanent flow measurement guages. However, some efforts were made to measure the flows for a typical dry season using a bouy. The flow rate recorded on December 8, 2000 is shown in Figure 3.3. The data reports indicated that the average flow rate of Nakhon Nayok river in the upstream and downstream were about 13.09 m^3/s and 8.86 m^3/s, respectively.

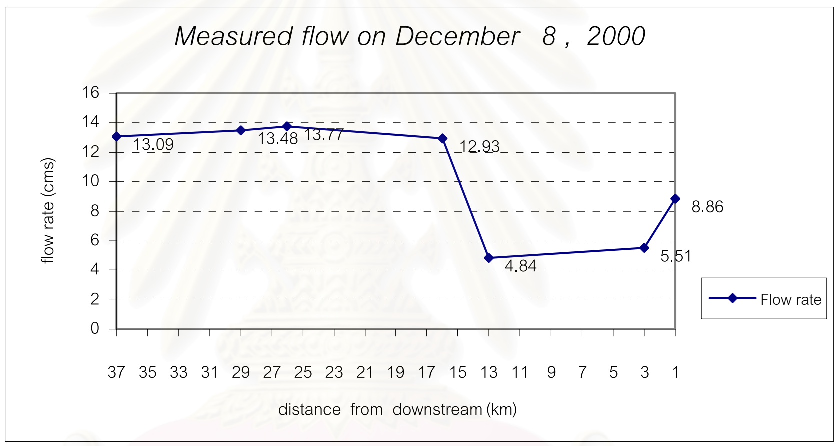


Figure 3.3 Measured flow on Nakhon Nayok river

Nakhon Nayok river Cross Section

The cross section of the sampling stations should be established on December 8, 2000 at the places where water is sufficiently well mixed to ensure the accuracy of the representative of parameters see Figure 3.4.

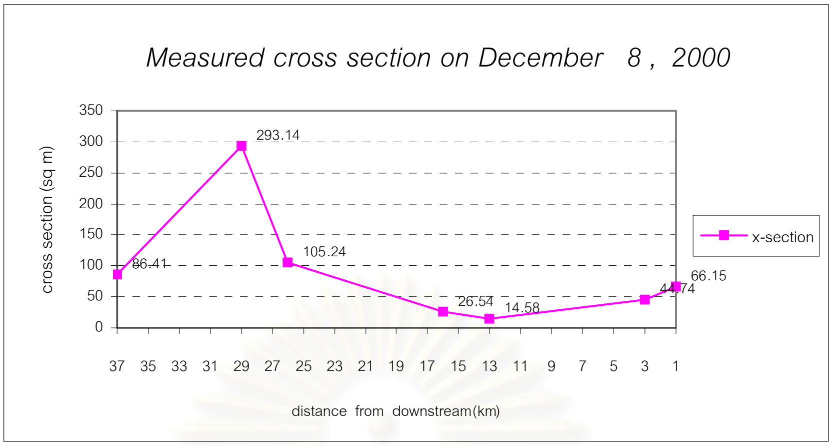


Figure 3.4 Measured cross section of Nakhon Nayok river

3.3.7 Estimation of Point Load Flow and Concentration

In general, stream water quality in the beginning of rainy season shows higher pollution concentrations for a period of time and then reduced significantly due to the apparent dilution effects (Smedt,2000). Thus, it would be a great interest to make simulation in early of rainy season. To determine the critical water quality we studied it at the time when water level was low, i.e. December. In the simulation we used point load flow and concentration from references and field study. Table 3.2 shows waste loading conducted on December 8, 2000.

Table 3.2 Waste loading estimation for communities

Community	Waste Loading (mg/l)			
	NH_3_N	NO_2_N	NO_3_N	Dis_P
Urban district	0.0765	0.0486	0.2341	0.0898
Rural district	0.1979	0.0161	0.7344	0.0843

Source: The results of grab wastewater sampling from field survey on December 8,2000

- **Point Load Flow**

Since point sources have an important role in the mass balance, their discharges are calculated as a function of the population densities, waste water rate, and water consumption of the communities. For Nakhon Nayok river the point load flow is combined with sewer system, so the flow may be calculated and set equal to the waste discharged from sewered communities and industries. Two point loads are identified.

An example of calculation of point load flow for a community (domestic sewage) is given below.

Nakhon Nayok municipal population = 17,883 capita

Water use per capita per day = 180 liters (see Table 2.4)

Waste water (96% of consumed water) = 172.80 liters (see Table 2.4)

$$waste\ \ flow = \frac{172.80l}{cap-day} \times 17{,}883\ cap \times \frac{1day}{86{,}400\,s} \times \frac{1m^3}{1000\,l}$$

$$= 0.0358\ m^3/s$$

Table 3.3 Point load flow estimation

Point load name	Flow rate (m3/s)							
	Domestic	Hotel	Hospital	Food center	Fresh market	Government office	Temple	Pig farm
T.NY (P_1)	0.0358	0.0027	0.0033	0.0001	0.0003	0.0003	0.0006	-
K.Ban Na (P_2)	0.0019	-	0.0004	0.00002	0.0001	0.0001	0.0003	0.0107

Source: calculation

Table 3.4 Total point load flow estimation

Point load name	Total flow rate (m^3/s)	
	Estimated *	Field study
T.NY (P_1)	0.0431	0.0400
K.Ban Na (P_2)	0.0028	0.0342

Source: * from Table 3.3

- **Point Load Concentration**

The point load concentration along the simulated river are also calculated from population, water supply, and water consumption. The estimate of concentration of BOD is based on BOD loading as described in chapter 2.

An example of calculation of concentration for BOD is given below.

$$BOD = \frac{30.00\left(\frac{g}{cap-day}\right)}{0.0358\left(m^3/s\right)}\times 17{,}883\ cap \times \frac{1\,day}{86{,}400\ s}\times\frac{1\,m^3}{1000\ l}\times\frac{1000\ mg}{1\,g}$$

$$= 173.42 \text{ mg/l}$$

Table 3.5 BOD concentration estimation

Point Load name	BOD concentration estimate (mg/l)							
	Domestic	Hotel(1)	Fresh(1) market	Hospital(1)	Food (2) center	Government office (3)	Temple(3)	Pig farm(2)
T.NY (P_1)	173.42	282.00	495.00	12.00	4.65	4.33	0.19	-
K.Ban Na (P_2)	285.84	-	259.25	10.00	0.89	2.64	0.21	118.0

Source: (1) PCD,1998

(2) Asdecon Corp, Consultant of Technology, and TA&E consultant, 1994

(3) Calculation

Table 3.6 Point load concentration estimation

Point load number	Point load name	Point load concentration (mg/l)				
		Total BOD_5[1]	NH_3_N[2]	NO_2_N[2]	NO_3_N[2]	Dis_P[2]
P_1	T. NY	971.50	0.42	0.27	1.28	0.49
P_2	K. Ban Na	558.83	0.40	0.03	1.50	0.17

Source: [1] from Table 3.4

[2] calculation

By surveying the area we found that wastewater from piggeries was drained to nearby area, so it was neglected in the calculation.

3.3.8 Estimation of Incremental Inflow and Concentration

- **Incremental Inflow**

Incremental inflow expressed in reach is an additional flow into the system not represented by point source inflow or headwater. This flow enters along the length of the stream such as ground water accretion and nonpoint sources. These flows are assumed to be uniformly distributed over the reach and constant through time. In order to calculate incremental inflow in reach, a mass balance of the system was made.

In this study the measured flow at a downstream location is higher than at an upstream location and there is no point source between the two locations. So the incremental inflow can be calculated from the difference of discharge between two measuring locations.

Table 3.7 Incremental inflow along this system

Reach No.	Name	Observe point	Inflow (m^3/s)	Point load flow (m^3/s)	Outflow (m^3/s)	Incremental Inflow (m^3/s)	Measured flow (m^3/s)
1	Nang Buat	Headwater	13.09	-	-	-	13.09
	NY. Bridge	Obs. DO 1	13.09	-	13.09	0.39	13.48
	T.NY bridge	Obs. DO 2	13.09	0.0431	13.13	0.64	13.77
2	Upper dam	Obs. DO 3	13.13	(-)0.949	12.18	0.75	12.93
	Lower dam	Obs. DO 4	-	-	-	-	4.84
3	Ban Na	Obs. DO 5	4.84	0.29	5.13	0.38	5.51
	Wat Ampwan	Downstream	5.13	-	5.13	3.73	8.86

Note: (-) withdrawal

- Incremental Inflow Concentration

Incremental inflow concentrations are calculated as nonpoint sources. Because we cannot identify clearly from where nonpoint sources come, we cannot quantify nonpoint sources certainly. Those of nonpoint sources are seepage water from agricultural area or vegetable garden, including forest, underground water, and waste water from riparian. In this study only waste water from riparian and seepage from agricultural area were considered.

An example of calculations of incremental inflow concentration for reach one which obtained from riparian is given below.

Population along the reach = 5,970 cap (20% of total population in reach)*

Waste flow from mass balance = 0.52 m^3/s

$$BOD = \frac{30.0\left(\frac{g}{cap - day}\right)}{0.52\left(m^3/s\right)} \times 5{,}970\ cap \times \frac{1\,day}{86{,}400\ s} \times \frac{1\,m^3}{1000\ l} \times \frac{1000\ mg}{1\,g}$$

= 3.99 mg/l

Note: * Surveying the study area found that people living along Nakhon Nayok river in reach 1 are about 20 percent of total people in reach, so in this study we assume riparian along the river in all reach is 20 percent of total people in reach.

Table 3.8 Riparian incremental inflow concentration of stream system

Reach number	Population (cap) *	Incremental inflow (m^3/s)	BOD[(1)] (mg/l)	NH_3_N[(1)] (mg/l)	NO_2_N[(1)] (mg/l)	NO_3_N[(1)] (mg/l)	Dis_P[(1)] (mg/l)
1	5,970	0.52	2.99	0.0040	0.0003	0.0149	0.0017
2	1,224	0.75	0.43	0.0028	0.0002	0.0103	0.0012
3	913	2.10	0.11	0.0004	0.0000	0.0037	0.0004

Source: * obtained from field survey

[(1)] from calculation

An example of calculations of incremental inflow concentration for reach two which obtained from paddy field is given below.

$$BOD = \frac{12.00\left(\frac{g}{cap-day}\right)}{0.75\left(m^3/s\right)} \times 6{,}500\ cap \times \frac{1\,day}{86{,}400\ s} \times \frac{1\,m^3}{1000\ l} \times \frac{1000\ mg}{1\,g}$$

$$= 1.20 \quad mg/l$$

BOD entering to stream (after 25% degradation) = 0.90 mg/l (Smedt,2000)

Table 3.9 Agricultural incremental inflow concentration of stream system

Reach number	Agriculture* (rai)	Incremental inflow (m^3/s)	BOD[(1)] (mg/l)	NH_3_N[(1)] (mg/l)	NO_2_N[(1)] (mg/l)	NO_3_N[(1)] (mg/l)	Dis_P[(1)] (mg/l)
1	-	-	-	-	-	-	-
2	6,500.00	0.75	0.90	0.0096	0.0021	0.0085	0.0048
3	9,430.00	2.10	0.46	0.0049	0.0011	0.0004	0.0025

Source: * obtained from field survey

[(1)] from calculation

3.3.9 Estimation of Model Parameters

Generally, for the proper determination of appropriate model parameters such as rate coefficients and constants, reliable laboratory, and field measurements should be made.

3.3.9.1 Longitudinal Dispersion

Dispersion is basically a convective transport mechanism. It is a result of the differences between local particle velocities and the average flow velocities. Dispersion is directed from high concentration to low concentration, which may be in the downstream direction or the upstream direction, depending on the concentration distributions.

For the determination of D_L, there are development of different methods and approaches which all have different limitations. The basic assumption is that if the concentration gradient is small enough, the dispersive transport is also small and perhaps negligible.

The dispersion constant for the reach is the value of K in the generation expression relating the longitudinal dispersion coefficient to the depth of flow and shear velocity. As shown in Table 3.10 the range of change of D_L depends upon area. Because there is no unique value for K, experiment should be taken.

The relation to determine the longitudinal dispersion (D_L) is

$$D_L = KdU^* \tag{20}$$

where d is the mean depth of the stream; K the dispersion constant;

$$U^* = C\sqrt{R\ S_e}$$

Where

U^*	=	the averaged shear velocity
C	=	Chezy's coefficient
R	=	the hydraulic radius
S_e	=	the slope of the energy grade line

Chezy's coefficient is given by

$$C = \frac{R^{1/6}}{n}$$

S_e the slope of the energy gradient given by

$$S_e = \left(\frac{\overline{U}n}{1.486 R^{2/3}} \right)^2$$

And D_L is from literature as follow:

Table 3.10 Longitudinal dispersion coefficient (D_L)

River	D (m)	W (m)	U (m/s)	U^* (m/s)	D_L (m^2/s) measured	D_L (m^2/s) Fisher (1975)	References
Missouri	2.70	200	1.55	0.074	1500	5290.8	Yotsukura Et al.,1970
Clinch,Tenessi	0.85	47	0.32	0.067	14	43.7	Godfrey and
	2.10	60	0.94	0.104	54	100.2	Rrederick,
	2.10	53	0.83	0.107	47	94.7	1970
Bayor Anacoco	0.94	26	0.34	0.067	33	13.6	
	0.91	37	0.40	0.067	39	39.5	
Noolsach	0.76	64	0.67	0.27	35	98.6	McQuivey
Wind/Bighom	1.10	59	0.88	0.12	42	224.6	And
John Day	2.16	69	1.55	0.17	16	342.7	Keefer
	0.58	25	1.01	0.14	14	86.4	1974
Yadkin	4.75	127	0.64	0.08	670	191.2	

Source: Biswas,1997

From Table 3.10 the dispersion coefficient (D_L) is not constant but depends upon flow direction, river geometry, and bottom friction characteristics. The dispersion in the direction of width and depth is of little important for water quality modeling because water quality parameters are usually evenly distributed over the cross section area. Consequently, only dispersion coefficient in the direction of the river course will be considered. For modeling purposes the dispersion coefficient is related to the average velocity in the following way.

$$D_L = 3.82 \alpha n U d^{5/6} \tag{21}$$

where

D_L	=	Longitudinal dispersion coefficient
n	=	Manning roughness coefficient (0.025-0.15)
$\propto$	=	Dispersivity constant
U	=	Mean stream flow velocity
R	=	d = Mean depth = hydraulic radius

In the calculation of the dispersion coefficient, the other important process would be the estimation of Manning's coefficient (n).

Table 3.11 Values of manning "n" roughness coefficient

Natural River Channels	Minimum	Optimum	Maximum
Clean and straight	0.025	0.030	0.033
Winding with pools and shoals	0.030	0.035	0.040
Very weedy, winding and overgrown	0.033	0.040	0.045
Clean straight alluvial channels	0.035	0.045	0.050

Source: Chow, 1959 refered In Patthra,1998

Nakhon Nayok river's characteristic is straight and clean so the suitable Manning's roughness coefficient (n) for Nakhon Nayok river which have numerical values in the range from 0.025 to 0.033.

Computing the dispersivity constant in equation (21) was carried out using trial and error technique for Manning's roughness coefficient and dispersion coefficient and values of V, d, and W were obtained from field survey. Manning's roughness coefficient is assumed constant for all reaches with a value of 0.030 see Table 3.12.

An example of calculated dispersivity canstant is tabulated below.

$$\alpha = \frac{50}{3.82 \times 0.030 \times 0.10 \times 1.68^{\frac{5}{6}}}$$

$$= \quad 2831.57$$

Table 3.12 Longitudinal dispersion constant for Nakhon Nayok river

Reach No.	Reach Name	Manning $s/m^{1/3}$ $(n)^{(1)}$	Velocity m/s $(U)^{*}$	Width m $(W)^{(2)}$	Depth m $(d)^{*}$	D_L m^2/s (1)	Dispersivity constant $(\alpha)^{(1)}$
1	Nang Buat	0.030	0.10	30	1.68	50	2831.57
2	Klong Muang	0.030	0.38	33	0.89	50	1265.25
3	Wat Ampwan	0.030	0.13	35	1.65	50	2211.08

Note: * obtained from field study

(1) model calibration

(2) RID

3.3.9.2 Reaeration

The important process in river water quality studies is reaeration. The dissolution of atmospheric oxygen into the river water is the primary source for dissolved oxygen in the river. Typically, the net transfer of oxygen is from the atmosphere to the water since dissolved oxygen concentration in most natural water bodies is below saturation level.

- *Reaeration rate constant*

The reaeration rate constant (K_2) is a function of the average water velocity, depth, and temperature. QUAL2E program offers eight different options for estimating or reading in reaeration rate constant (EPA,1987). In function of some experience, the most appropriate for this analysis refered to the O'Conner and Dubbin type of reaeration. O'Conner and Dubbin,1958 developed this equation based on the turbulence of the stream.

$$K_2^{20} = \frac{3.95\ U^{0.5}}{d^{1.5}} \tag{22}$$

Where

K_2^{20} = Reaeration rate constant (day^{-1})

U = Mean velocity (m/s)

d = Mean depth (m)

The reaeration rate constant increases with increasing water flow velocity and decreasing depth.

- *Dam Reaeration*

QUAL2E has the capability of modeling oxygen input to the system from reaeration over dams (EPA,1987). The following equation estimates oxygen input from dam reaeration.

$$D_a - D_b = \left[1 - \frac{1}{1 + 0.1abH(1 - 0.034H)(1 + 0.56T)}\right] D_a \tag{23}$$

Where

D_a = Oxygen deficit above dam, mg/l

D_b = Oxygen deficit below dam, mg/l

T = Temperature, °C

H = Height through which water falls

a = Empirical water quality factor

b = Empirical dam reaeration coefficients.

Nayok dam has a height of 6.0 meters and acts as sluice gate. According to the empirical formula, values of a and b must be set as

a = 1.60 for considering the slightly polluted water.

b = 0.05 for sluice gates with submerged discharge

3.3.9.3 Carbonaceous

Biochemical Oxygen Demand (BOD) is the utilization of available dissolved oxygen (DO) by aquatic microorganisms to decompose organic matter and to mineralize species such as ferrous ion in a biological way. This BOD decay process is considered to consist of two first order reactions, a fast reaction for the carbonaceous part of the BOD and a slower reaction for the nitrogeneous part, NBOD. CBOD is often influenced by a number of factors like temperature, stream geometry, and nature of the organic matter. CBOD is widely used as a measure of aquatic pollution.

The reaction rate constant is called deoxygenation rate constant (K_1) is in range 0.02-3.40 per day see Table 3.13. It can be determined as follows:

1. From results of field and laboratory measurements,
2. From quantification of K_1 as a function of hydraulic parameters (EPA,1985).

For this study K_1 is from calibration due to the limitation of time.

Table 3.13 Deoxygenation rate constant

Location	K_1 (d^{-1} at 20 °C)	Methodology	References
Holston River (Tennessy)	0.4-1.5	Calibration	Novotny and Krenkel,1975
New York Bight	0.05-0.25		O'conner et al.,1981
Willamette River	0.1-0.3	Field study	Baca et al.,1973
Chattagoocgee	0.16	Field study	Bauer et al.,1979
Onondaga Lake (NY)	0.1	Calibration	Freedman et al.,1980
Yampa River (Colorado)	0.4	Calibration	Grenney and Kraszewski,1981
Skravad River (Denmark)	0.15	Field study	Hvitved-Jacobsen,1982
Seneca Creel	0.008		Metropolitan Washington Council of Governments,1982

Source: Martin et al., 1990

3.3.9.4 Sediment Oxygen Demand (SOD)

Oxygen demand by benthic sediments and organisms can represent a large fraction of oxygen consumption in surface water (EPA,1985).

The oxygen utilized per unit area per time (gO_2/m^2.day) in SOD is

$$SOD = a\,C^{b} \qquad (24)$$

Where

b = 0.30

a = 0.09-0.16 function of the population density of benthic invertibrate.

C = Oxygen concentration in the overlying water (mg/l)

SOD used in this study is from calibration which is set to 0.80.

3.3.9.5 Temperature Information

A water body loses heat to the atmosphere by evaporation. The following data consist of geographical and meteorological data required for performing the energy balance for heat transfer across the air-water interface.

- *Evaporation Coefficient*

The default typical values for these coefficients are

AE = 6.2E-06 [(m/hr)/mbar]

BE = 5.5E-06 [(m/hr)/(mbar-m/sec)].

- *Dust Attenuation Coefficient*

Dust attenuation coefficient of the solar radiation flux varies with optical air mass, season of the year, and geographical location. WRE, Inc.,1967 gives a range of 0-0.13 for several locations. Value of 0.06 was used in this case.

- ***Location of Basin***

Nakhon Nayok river:

longitude	=	101°-12'-38" E
latitude	=	14°-14'-45" N.
Standard meridian	=	90
Basin elevation	=	6.556 MSL.

- ***Climatological Data***

There are two options for supplying the climatological data: reach variable temperature inputs and global values. For steady state simulation, the two options may be applied. In the reach variable inputs the values of the temperature simulation inputs for all reaches in the system must be explicitly specified.

In the global values, the option that has been chosen in this study, a single value was specified for each of the temperature simulation inputs and QUAL2E assumes that this value applies to all reaches in the system being modeled.

- ***Local Climatological Data***

Climatological data from 1981-1999 for Nakhon Nayok province obtained from Meteorological Department.

Cloundiness	=	0.39
Dry bulb temperature	=	31.6 °C
Wet bulb temperature	=	29.2 °C
atmospheric pressure	=	1009.78 mbar
and wind speed	=	0.42 m/s

- *Temperature Correction Factors*

The temperature values computed in QUAL2E are used to correct the rate coefficient in the source/sink terms for the other water quality variables (EPA,1987). These coefficients are input at 20°C and then are corrected to temperature using a Streeter-Phelps formulation.

$$X_T = X_{20}\,\theta^{T-20} \qquad (25)$$

where

X_T = The value of the coefficient at the local temperature (T)

X_{20} = The value of the coefficient at the standard temperature (20°C)

θ = An empirical constant for each reach coefficient.

There are two options for the temperature correction factor, default or user specified. Several processes represented in QUAL2E are affected by the temperature. The default value option is chosen in this study so they could not be changed. The most important default values used in QUAL2E are given in Table 3.14.

Table 3.14 The most important default values used in QUAL2E (EPA,1987)

Rate Coefficient	Symbol	Default Values of θ
BOD decay	K_1	1.047
BOD settling	K_2	1.024
Reaeration	K_3	1.024
SOD uptake	K_4	1.060
Organic Nitrogen decay	β_5	1.047
Organic Nitrogen settling	σ_4	1.024
Ammonia decay	β_1	1.083
Ammonia source	σ_5	1.074
Nitrite decay	β_2	1.047
Dissolved Phosphorous source	σ_2	1.074

3.3.9.6 Reaction Rates and Physical Constants

The chemical and biological reactions that are simulated by QUAL2E are represented by a complex set of equations that contain many system parameters; some are constant, some are spatially variable, and some are temperature dependent. Table 3.15 lists these system parameters and gives the usual range of values, units, and the values specified for this study.

Table 3.15 Typical ranges and values selected for QUAL2E reaction coefficient

Variable	Description	Units	Range of values [1]	Values used [2]
α_5	O_2 uptake per unit of NH_3 oxidation	mg-O/mg-N	3.00-4.00	3.50
α_6	O_2 uptake per unit of NO_2 oxidation	mg-O/mg-N	1.00-1.14	1.14
K_1	Carbonaceous deoxygenation rate constant	day^{-1}	0.02-3.40	0.30
β_1	Rate constant biol. Oxidation of NH_3 to NO_2	day^{-1}	0.10-1.00	0.06
β_2	Rate constant biol. Oxidation of NO_2 to NO_3	day^{-1}	0.02-3.00	0.50
β_3	Rate constant for hydrolysis of org_N to NH_3	day^{-1}	0.00-0.40	0.02
β_4	Rate constant for decay of org_P to Dis_P	day^{-1}	0.01-0.70	0.1=5
σ_2	Benthos source rate for Dis_P		Variable	2.00
σ_3	Benthos source rate for NH_3_N		Variable	0.00
σ_4	Org_N settling rate	day^{-1}	0.001-0.10	0.001
σ_5	Org_P settling rate	day^{-1}	0.001-0.10	0.10
	Nitrification inhibition coefficient	-	0.00-10.00	10.00

Source: [1] EPA,1987

[2] model calibration

3.4 Integration of QUAL2E Output and GIS

Step1 Create center line in stream.shp obtained from PCD with digitizing by using MapInfo software see Figure 3.5.

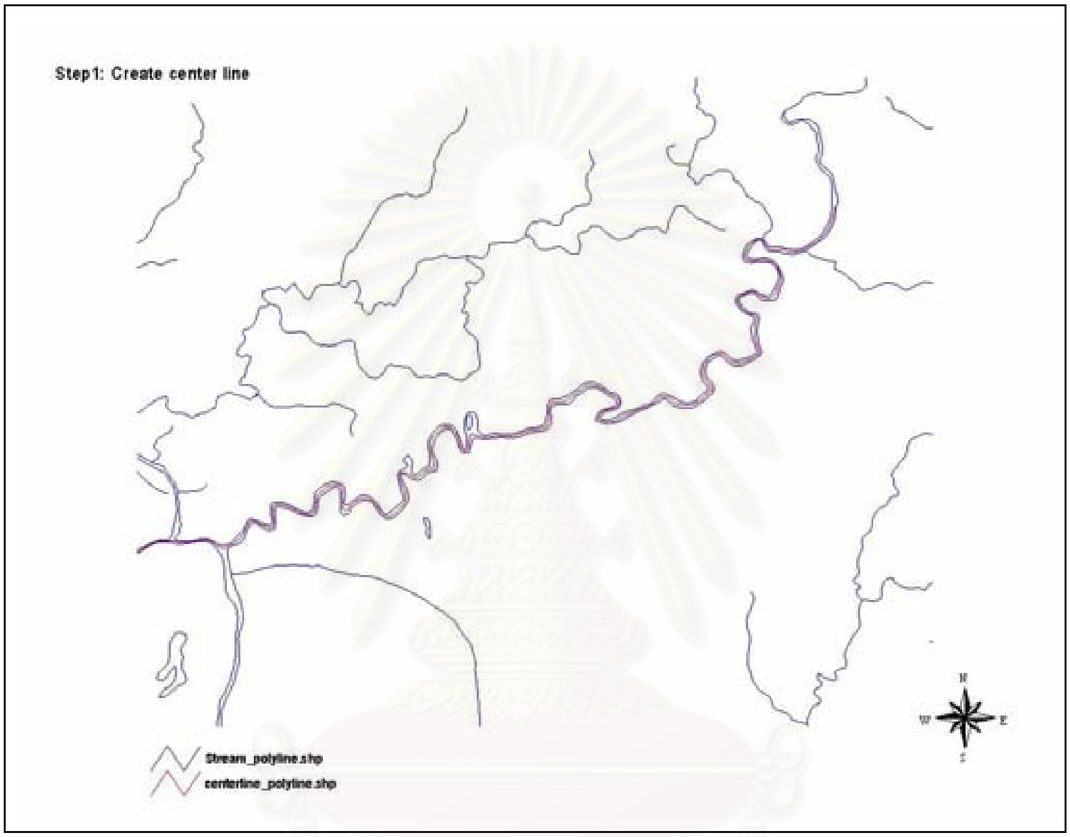


Figure 3.5 Sample of step 1

Step 2 Devide center line obtained from the first step into segment each with 1 km long in order to conform with computational element length of the model see Figure 3.6.

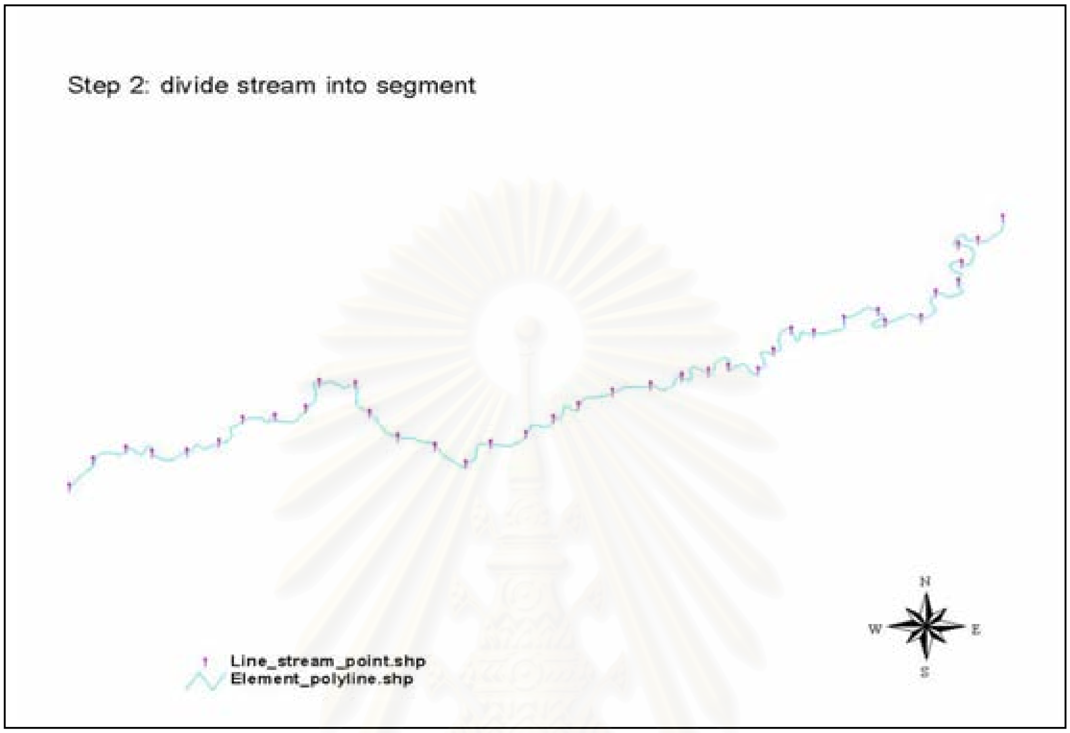


Figure 3.6 Sample of step 2

Step 3 Results of simulation are visualized through GIS software with inserting attributes to each segment see Figure 3.7.

Attributes of centerline_polyline.shp

Shape	Element	Do	Bod	Nh3_n	No2_n	No3_n	Dis_p
PolyLine	3/11	5.3800	3.1500	0.0900	0.0200	0.2100	0.0100
PolyLine	3/10	5.7200	3.5500	0.0800	0.0200	0.2100	0.0100
PolyLine	3/9	5.8200	3.7100	0.0800	0.0200	0.2200	0.0100
PolyLine	3/8	5.8900	3.8200	0.0800	0.0200	0.2200	0.0100
PolyLine	3/7	5.9600	3.9300	0.0800	0.0200	0.2200	0.0100
PolyLine	3/6	6.0300	4.0400	0.0800	0.0200	0.2200	0.0100
PolyLine	3/5	6.1100	3.0700	0.0800	0.0200	0.2200	0.0100
PolyLine	3/4	6.1900	2.9500	0.0800	0.0200	0.2200	0.0100
PolyLine	3/3	6.2600	3.0000	0.0900	0.0200	0.2300	0.0100
PolyLine	3/2	6.3400	3.0800	0.0900	0.0200	0.2300	0.0100
PolyLine	3/1	6.4300	3.1600	0.0900	0.0200	0.2300	0.0100

Figure 3.7 Sample of step3

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Qualitative Calibration and Verification of QUAL2E Simulation Results

4.1.1 Stream Flow Model Result

The first step of calibration of the flow rate was defining the geographical data, climatological data, and stream boundaries in such that upstream station was at Khao Nang Buat bridge, downstream station at Ampwan district, and station for calibration was at Nayok Dam. Next step was the calibration of Manning's roughness coefficient "n" in order obtain appropriate value for Nakhon Nayok river. The numerical values of "n" used in the calibration was obtained by the approximation from Table 3.7, yielding "n" = 0.025, 0.028, 0.030, 0.033, and 0.035 as in Figure 4.1.

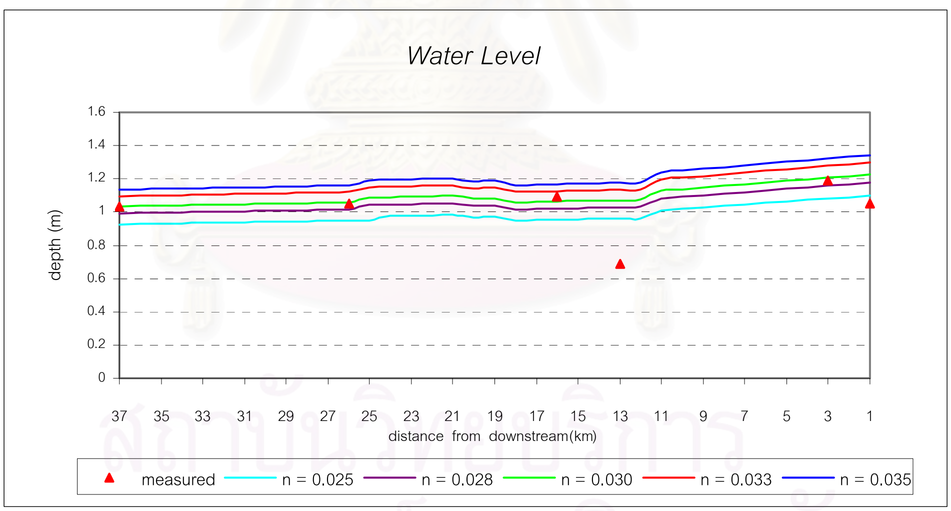


Figure 4.1 Comparison of water level at Nayok Dam versus changing of "n"

Because collecting observed data for calibration was taken at the beginning time of dry season where water was stored for use, making flow rate different from what it should be at the second reach and downstream see Figure 4.1.

From the calibration of water level at Nayok Dam, it is found that *"n"* appropriate for Nakhon Nayok river is 0.030 which satisfied those reported by a research of PCD, i.e. in the range 0.029-0.033.

Figure 4.2 shows a good agreement only in the first reach between the measured flow rate and simulated flow rate along 37 kilometers of Nakhon Nayok river. The initial flow rate measured about 13.09 m^3/s comes from headwater natural flow which located upstream of the system.

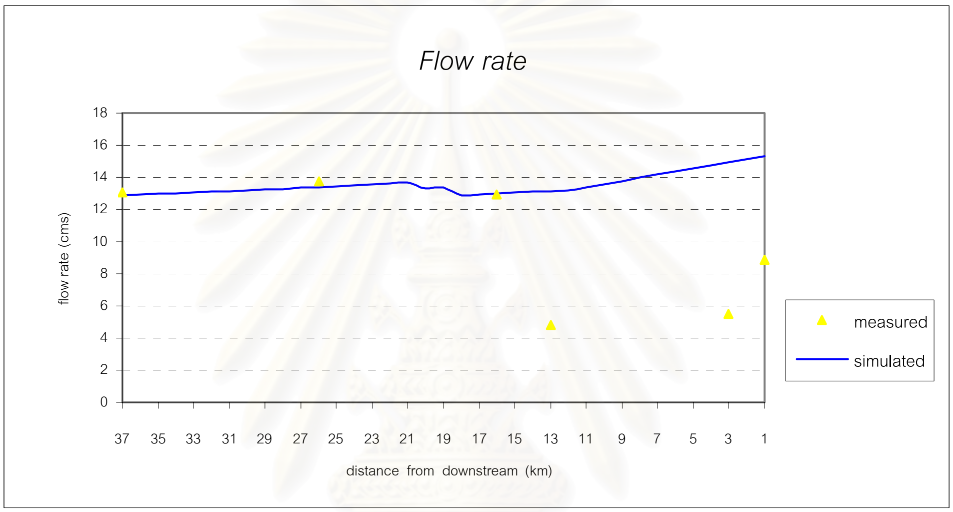


Figure 4.2 Simulated and measured flow rate

Incremental inflow might come from nonpoint sources of neighborhood area where most inflow are likely from both riparians and agricultural area especially those of second rice. Surveying the area and asking people living there for information found that in cultivated period, wastewater is not drained away. These paddy fields drain out water in the rainy season. So most incremental inflows are likely from seepage water from paddy field and activity of riparians.

Factors concerning to flow rate calculation, which depend on cross section, flow velocity, and incremental inflow and outflow, some unidentified point and diffused inflow and outflow along the stream system, can result in flow balance nevertheless.

4.1.2 Temperature Model Result

Temperature is the key factor controlling the concentrations of water quality parameters like DO, BOD, and capability to live of aquatic livings.

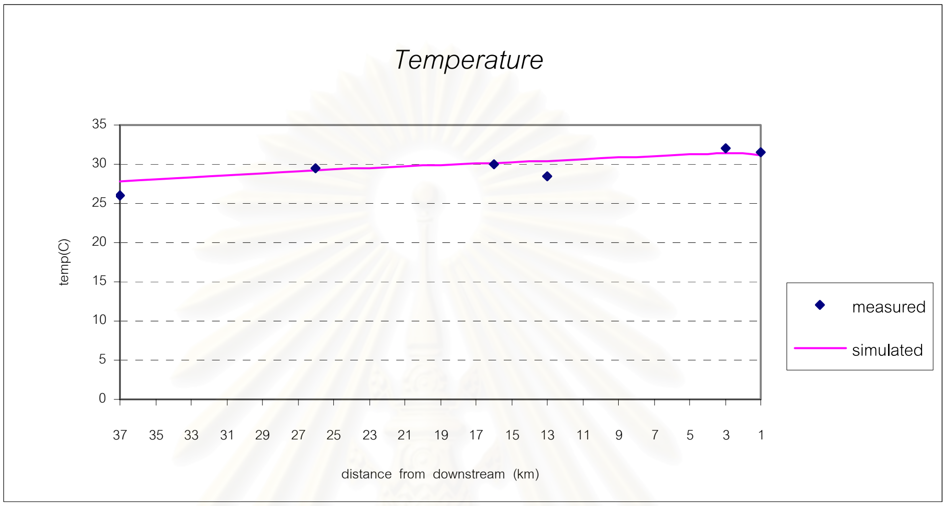


Figure 4.3 Simulated and measured temperature

From the simulation it was found that the trend of simulated temperature was agreed with the observed one. The first increasing temperature was due to wastewater from municipality and the second one was due to wastewater from Klong Ban Na. This shows that QUAL2E model can simulate the temperature of Nakhon Nayok river very well.

4.1.3 Water Quality Model Results

The water quality model was calibrated by defining boundary of the model as follows: Khao Nang Buat as upstream boundary, Wat Ampwan as downstream boundary, and calibrating stations along the river which included

- Observe DO2 station at Tambol Nayok bridge km 26,
- Observe DO3 station at Upper Dam km 16,
- Observe DO4 station at Lower Dam km 13,
- Observe DO5 station at Lower Klong Ban Na km 3.

Then made the calibration of model parameters as shown in Table 3.15. The water quality parameters from the model were all compared to those from PCD until their numerical difference was ignored small.

BOD Simulation

The method for determination of biochemical oxygen demand (BOD_5) depends on some bacteria action during incubation under 20 degree 5 days. Reaction rate depends on the quantity of bacteria and temperature. QUAL2E model is used for ultimate BOD simulation, where natural ultimate BOD is obtained from the combination of carbonaceous biochemical oxygen (CBOD) and nitrogenous biochemical oxygen demand (NBOD). But in this study only CBOD is considered.

Comparison was taken for deoxygenation rate constants (K_1) that resulted the simulated BOD close to the observe one. The K_1's were the following: 0.10, 1.00, 2.00, and 3.00 per day as in Figure 4.4.

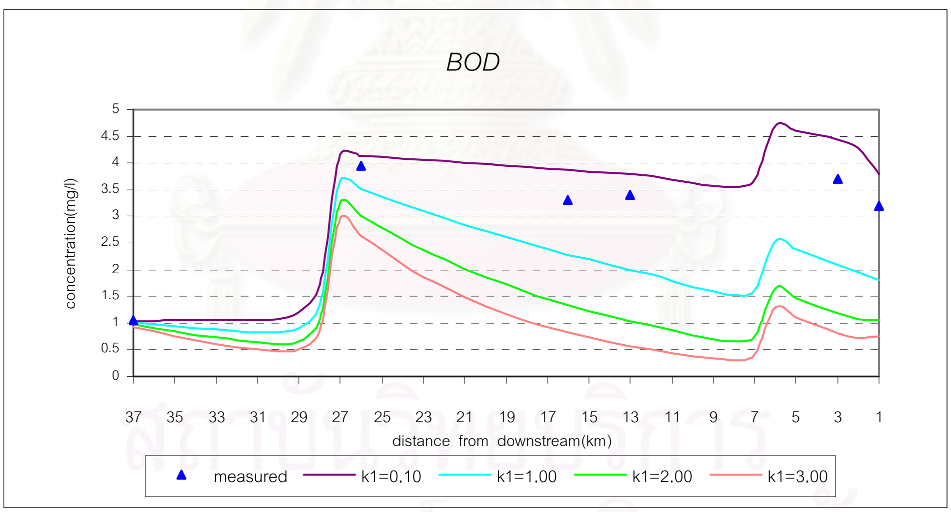


Figure 4.4 Results of comparison of BOD at calibrating stations when varying K_1

From Figure 4.4 it was found that K_1 is in the interval 0.10-1.00 day^{-1}. Adjusting K_1 one more so as to yield value appropriate for Nakhon Nayok river, it is as follow: K_1 = 0.10, 0.20, 0.30, 0.40, and 0.50 day^{-1}.

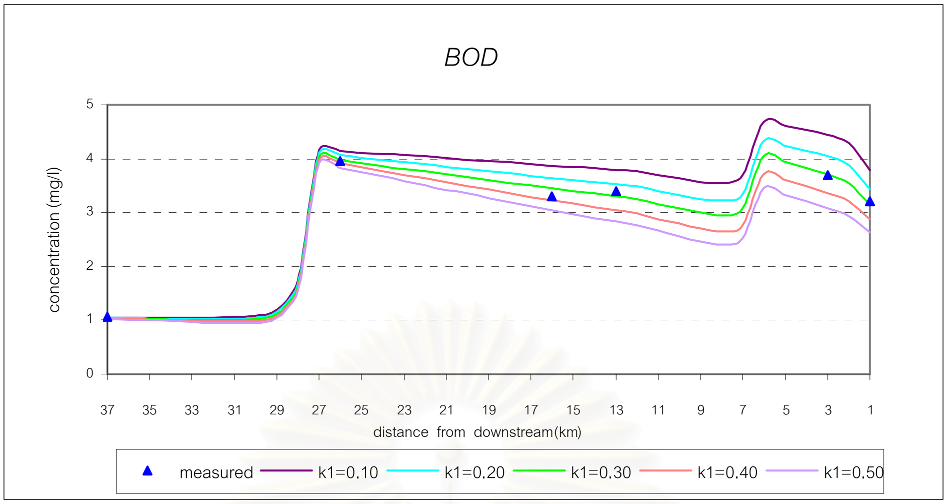


Figure 4.5 Result of calibrating K_1 in refine scale

From Figure 4.5 the constant K_1 appropriate to Nakhon Nayok river is 0.30 day^{-1}. From Table 3.13 it is found that K_1's differ each other as study area. Bowie (1985) proposed that K_1 should be in the interval 0.05-0.40 day^{-1}. Thomann and Mueller (1987) found K_1 also depend on depth with the requirement:

- depth <1.5 m, $0.5<K_1<3.0$ day^{-1}
- depth >1.5 m, $0.1<K_1<0.5$ day^{-1}

Comparing numerical values of K_1's find that K_1 appropriate for Nakhon Nayok river is 0.30 day^{-1}. Being in the refered interval, K_1 is acceptable.

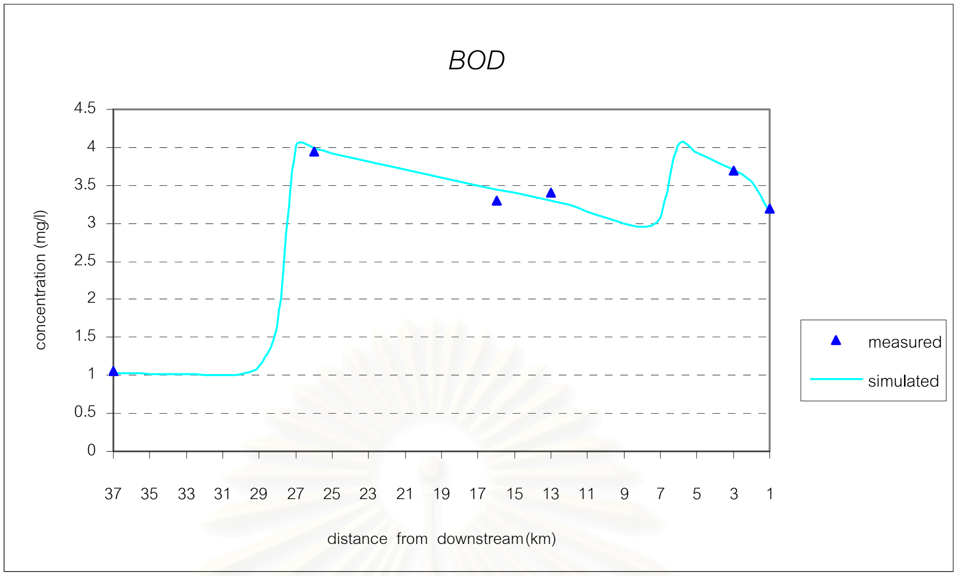


Figure 4.6 Simulated and measured BOD

Considering water quality along distance as in Figure 4.6 find that the critical points of water quality are in 26th km and 6th intervals which are the points the river obtains waste loads from municipality and Klong Ban Na, respectively. This makes the river have BOD concentration over the standard for water quality of class 3.

DO Simulation

Oxygen balance is influenced by many factors, e.g. factors that increase oxygen dissolving such as atmospheric reaeration, photosynthesis of aquatic plants, discharging water with high DO to the stream, and factors that decrease oxygen dissolving such as organic decay, aquatic living respiration, and sediment oxygen demand. The external factors affecting the capability of dissolving oxygen are temperature, pressure, etc.

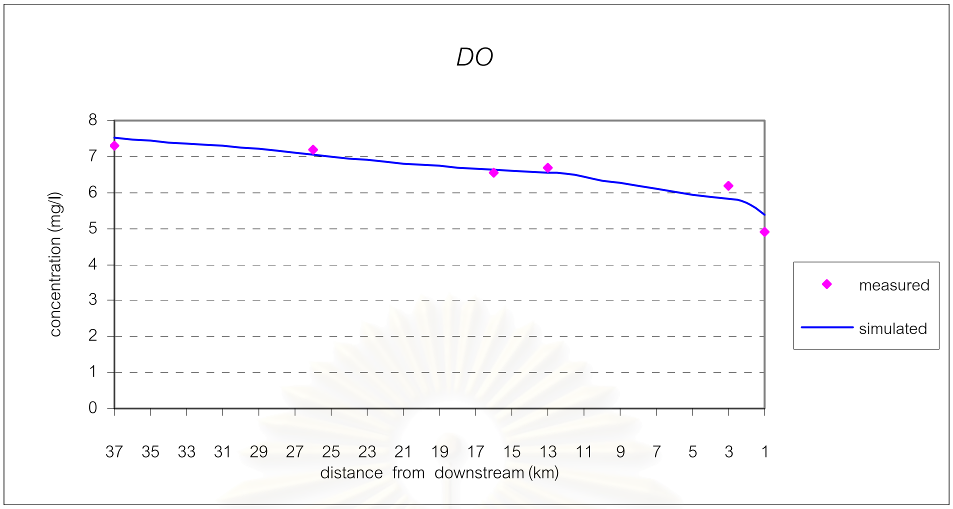


Figure 4.7 Simulated and measured DO

From comparing results we find that DO, BOD, temperature have a relation to each other, i.e. temperature has a trend of increasing along distance while DO has a trend of decreasing along distance and DO concentration is inversely proportional to BOD concentration.

Reviewing the literatures find that the reaeration equation of O'conner and Dubbin is the popular one and is used in general with the requirements:

1. use with the stream having depth from medium to high, $0.3<H<10.0$ m
2. use with the stream having flow rate $0.15<U<0.49$ m/s

These requirements satisfy the characteristics of Nakhon Nayok river, i.e. depth about 0.89 m and velocity about 0.40 m/s.

The reaeration coefficient computed with the equation is shown below,

$$K_2^{\,20} = 3.9\, U^{0.5} H^{-1.5} \text{ (in case of highest velocity)}$$

$$= 2.94 \quad \text{day}^{-1}$$

The reaeration coefficient should be in the interval 0.05-12.2 day^{-1} (Thomann and Mueller,1987). Comparing the coefficients from the simulation to those from calculating with O'conner and Dubbin's equation find that maximum K_2 = 2.31-3.14 day^{-1}, so K_2 is in the acceptable interval.

Nitrogen Cycle Simulation

The ammonia present in natural water is a result of either the direct discharge of material in wastewater or of the decomposition of organic matter in various form since it is a component of municipal or community waste.

Nitrification is the reaction that nitrogen compound is decomposed by bacteria, transforming pollutants as shown in equation below.

$$NH_4^+ + 1.5O_2 \xrightarrow{nitrosomonas} 2H^+ + H_2O + NO_2^-$$
$$NO_2^- + 0.5O_2 \xrightarrow{nitrobacter} NO_3^-$$

All reaction rates are known to be affected by such factors as: pH, oxygen, microorganisms, and temperature.

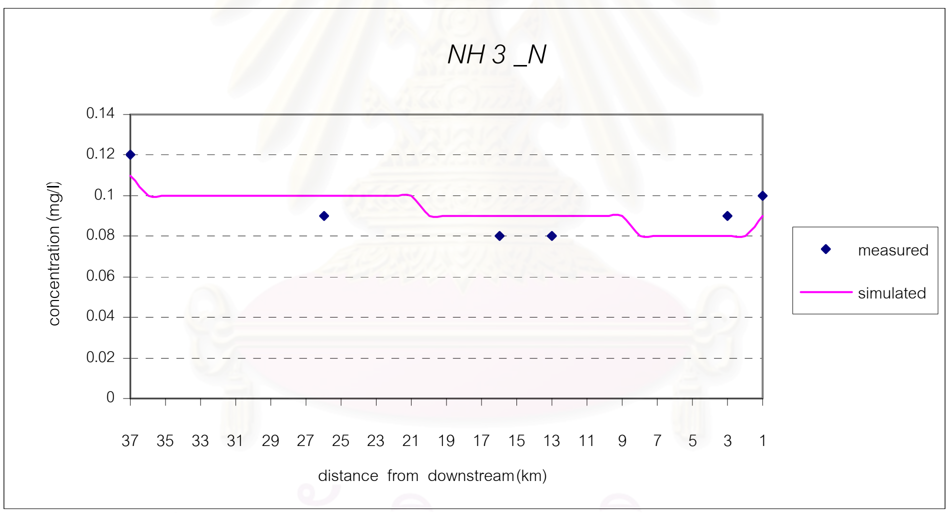


Figure 4.8 Simulated and measured ammonia nitrogen

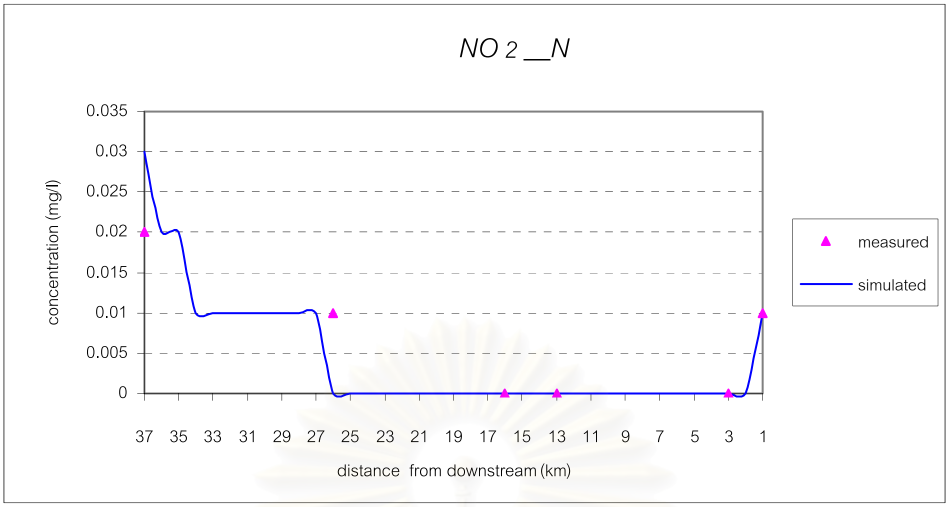


Figure 4.9 Simulated and measured nitrite nitrogen

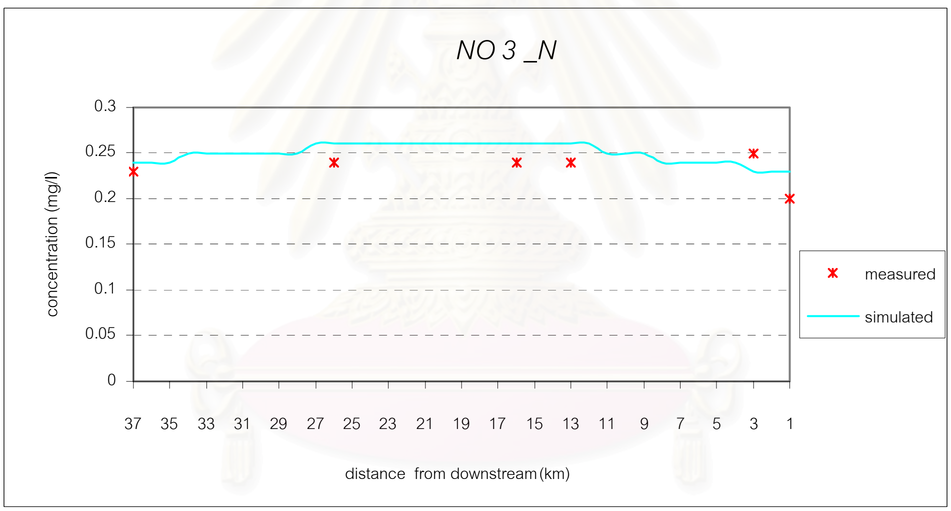


Figure 4.10 Simulated and measured nitrate nitrogen

Figure 4.8, 4.9, and 4.10 show the good agreement between simulated and measured nitrogen in ammonia, nitrite, and nitrate form. From Figure 4.8 and 4.10 we found that the increasing of ammonia and nitrate concentration at downstream is likely owing to wastewater from Klong Ban Na. Quering local people and studying from literatures found that most area in Ban Na district have been used for agriculture and the using of fertilizer increased every year. Nitrogen and phosphorous are essential nutrients to plants. Nitrogen is found in the form of NH_4^+ and NO_3^-, so it is possible that wastewater from Klong Ban Na has high NH_3_N and NO_3_N concentrations. Being easily transformable, nitrite is scarcely found.

Phosphorous Cycle Simulation

Phosphorous is an essential nutrient for living organisms and exits in water body both dissolved and particulate species. But in this study only dissolved phosphorous (Dis_P) is considered. Domestic effluent (particularly containing detergent) and fertilizer runoff contribute to elevate level in surface water. High concentration of phosphate can indicate the presence of pollution and largely contribution to eutrophication.

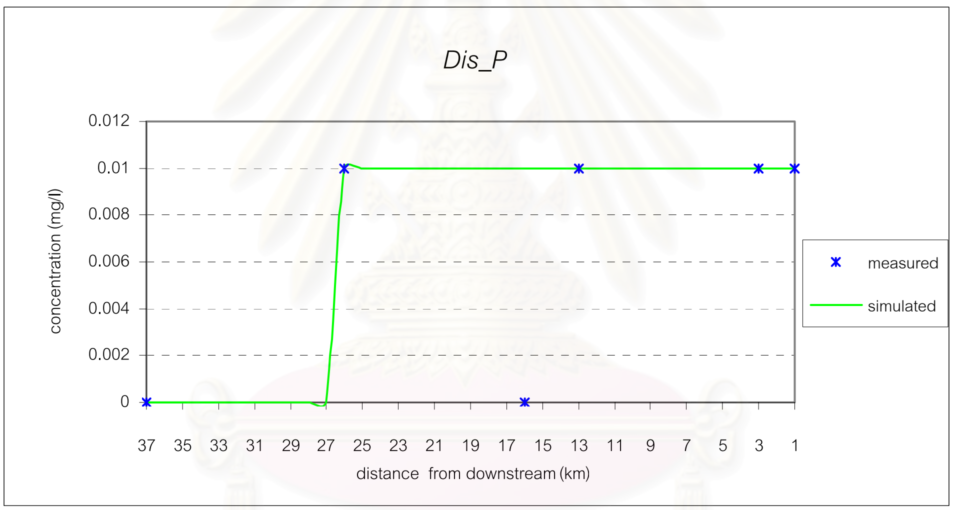


Figure 4.11 Simulated and measured dissolved phosphorous

From Figure 4.11 we found that Dis_P had a trend of increasing. Dis_P from the model is not so different from the observation. Dis_P concentration in the 26^{th} km and 6^{th} km intervals likely come from domestic effluent and waste water from Klong Ban Na, respectively. At the upper dam a little Dis_P concentration is found because this area is covered with aquatic plants and they use phosphate for their growth.

4.2 Results of QUAL2E-UNCAS Simulation

Performing uncertainty analysis must select the important variables and locations in stream network where uncertainty effects especially critical points. Thus, in this study only stream flow, DO, and BOD were performed at reach 1 and reach 3 respectively.

4.2.1 Stream Flow Model

- First Order Error Analysis

INPUT VAR	LOCATION	
	REACH 1 ELEMENT 12	REACH 3 ELEMENT 6
INCRFLOW		
VAR	0.8427	18.1903
VAR(%)	0.16%	3.40%
STDEV	0.918	4.265
HWTRFLOW		
VAR	514.0	514.0
VAR(%)	99.84%	96.15%
STDEV	22.671	22.671

The important parameters affecting flow variance are incremental inflow and headwater flow where the most contribution is from the headwater flow. The influence of headwater flow slightly decreases in the flow direction while that of incremental inflow is in reverse direction. For more simulation results see appendix G.

- Monte Carlo Simulation

The simulated mean and base mean values in Figure 4.12 and 4.13 show a good agreement at both locations. The small values of the magnitudes of skewness coefficient ≤ 0.008 (see appendix H) show that the distributions are well close to the normal. Thus this simulation model is able to represent the observed conditions with a higher degree of conformity

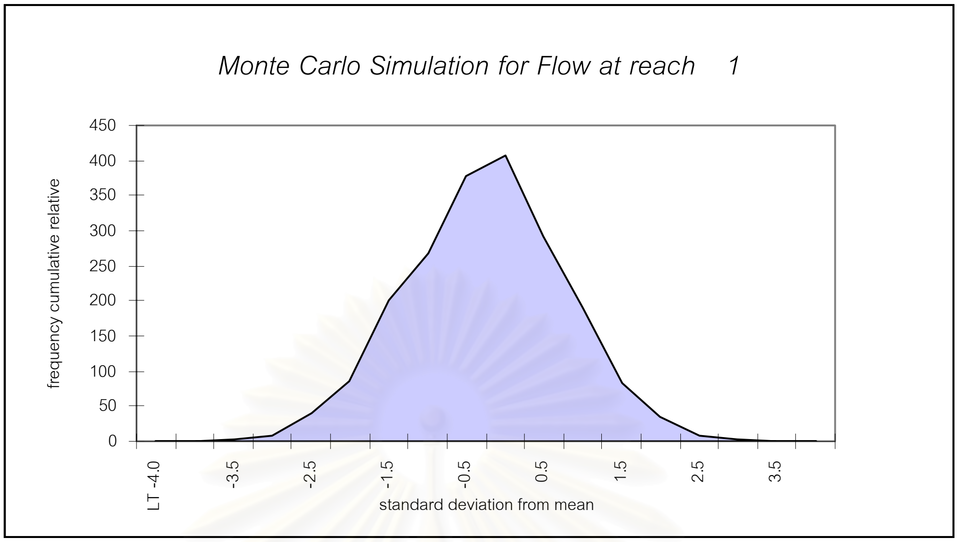


Figure 4.12 Monte Carlo Simulation 2000 for Flow at reach 1

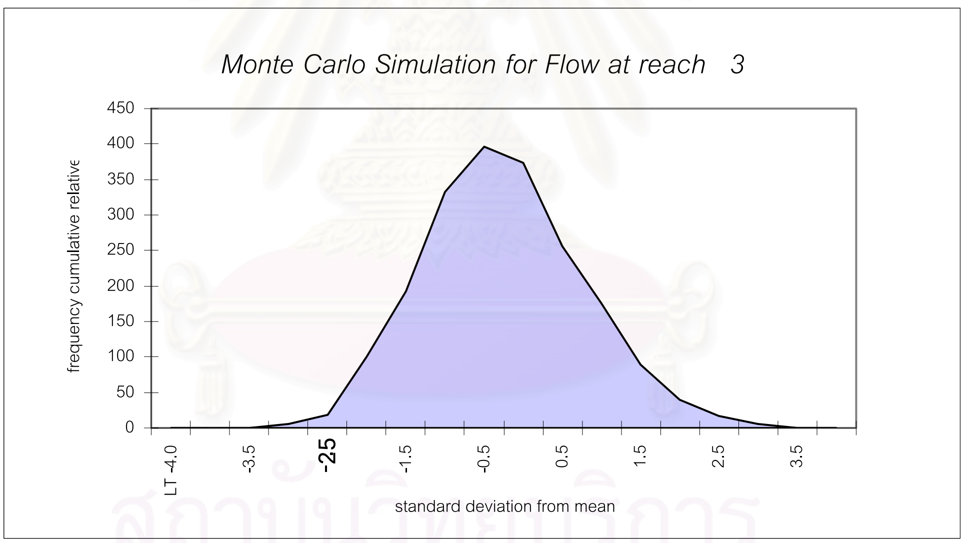


Figure 4.13 Monte Carlo Simulation 2000 for Flow at reach 3

4.2.2 Dissolved Oxygen

- First Order Error Analysis

INPUT VAR	LOCATION REACH 1 ELEMENT 12	 REACH 3 ELEMENT 6
MANNINGS		
VAR	0.0010	0.0061
VAR(%)	2.99%	16.93%
STDEV	0.032	0.078
TRAP-SLP		
VAR	0.0001	0.0004
VAR(%)	0.18%	1.02%
STDEV	0.008	0.019
DRYBULB		
VAR	0.0001	0.0006
VAR(%)	0.18%	1.79%
STDEV	0.008	0.025
WETBULB		
VAR	0.0003	0.0028
VAR(%)	0.79%	7.69%
STDEV	0.017	0.053
ATMPRES		
VAR	0.0023	0.0044
VAR(%)	6.70%	12.23%
STDEV	0.048	0.066
BOD DECA		
VAR	0.0006	0.0031
VAR(%)	1.72%	8.54%
STDEV	0.025	0.055
SOD RATE		
VAR	0.0031	0.0073
VAR(%)	8.85%	20.25%
STDEV	0.056	0.085

INPUT VAR	LOCATION	
	REACH 1 ELEMENT 12	REACH 3 ELEMENT 6
INCRFLOW		
VAR	0.0001	0.0007
VAR(%)	0.23%	1.81%
STDEV	0.009	0.026
HWTRFLOW		
VAR	0.0002	0.0012
VAR(%)	0.71%	3.36%
STDEV	0.016	0.035
HWTRTEMP		
VAR	0.0063	0.0067
VAR(%)	18.09%	18.55%
STDEV	0.079	0.082
HWTRDO		
VAR	0.0206	0.008
VAR(%)	58.96%	2.32%
STDEV	0.143	0.029
PTLDBOD		
VAR	0.0001	0.0012
VAR(%)	0.20%	3.24%
STDEV	0.008	0.034

Simulation above lists variances of DO output due to many input parameters see appendix G. At upstream location the most contribution is from headwater DO, and it decreases sharply along the river.

- Monte Carlo Simulation

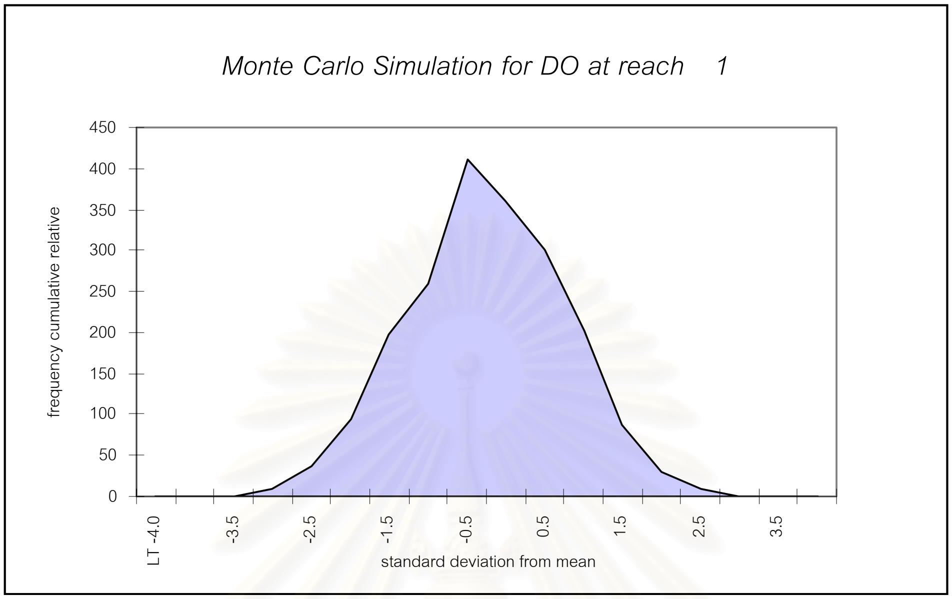


Figure 4.14 Monte Carlo Simulation 2000 for DO at reach 1

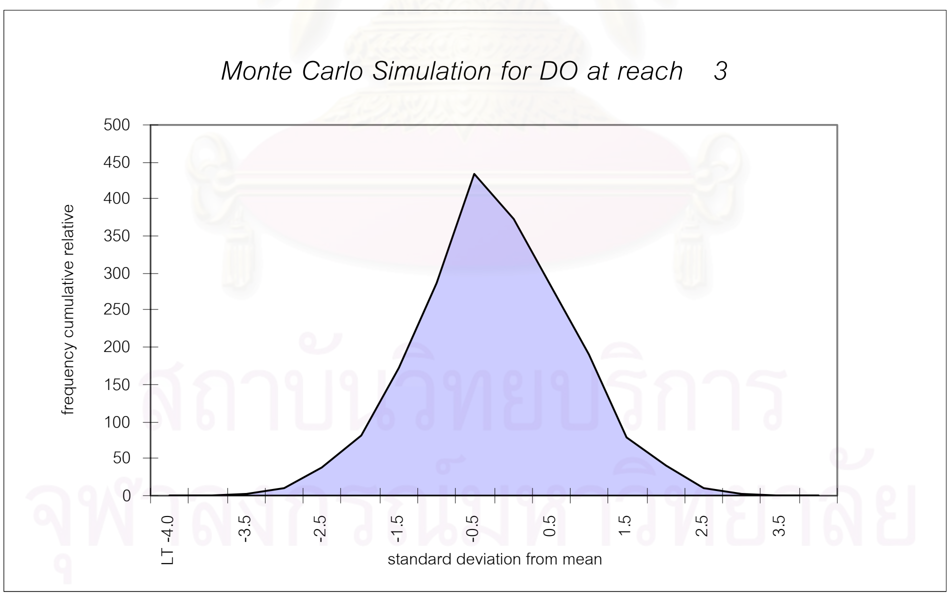


Figure 4.15 Monte Carlo Simulation 2000 for DO at reach 3

From Figure 4.14 and 4.15 the agreement between the base means and the simulated means is noticed at both locations. The skew coefficient is rather high at the downstream and the distribution has a peak and its shape slightly deviates from the normal. The distribution at upstream is still close to the normal. Anyway, the simulation model is still able to represent reliably the observed conditions. For more simulation results see appendix H.

4.2.3 Biochemical Oxygen Demand

- First Order Error Analysis

INPUT VAR	LOCATION	
	REACH 1 ELEMENT 12	REACH 3 ELEMENT 6
MANNINGS		
VAR	0.0003	0.0036
VAR(%)	0.24%	2.04%
STDEV	0.018	0.060
BOD DECA		
VAR	0.0012	0.0166
VAR(%)	0.85%	9.39%
STDEV	0.035	0.129
HWTRFLOW		
VAR	0.0187	0.0141
VAR(%)	13.21%	7.97%
STDEV	0.137	0.119
HWTRBOD		
VAR	0.0073	0.0032
VAR(%)	5.15%	1.83%
STDEV	0.085	0.057
PTLDFLOW		
VAR	0.0226	0.0279
VAR(%)	15.96%	15.74
STDEV	0.150	0.167
PTLDBOD		
VAR	0.0910	0.1091
VAR(%)	64.40%	61.59%
STDEV	0.302	0.330

From simulation results above, although many input parameters contribute to the variances of BOD, the most dominant one is point load BOD both at upstream and downstream locations with only slightly decreasing along the river. Another contribution is from point load flow which its values at upstream and downstream are nearly the same see appendix G.

- Monte Carlo Simulation

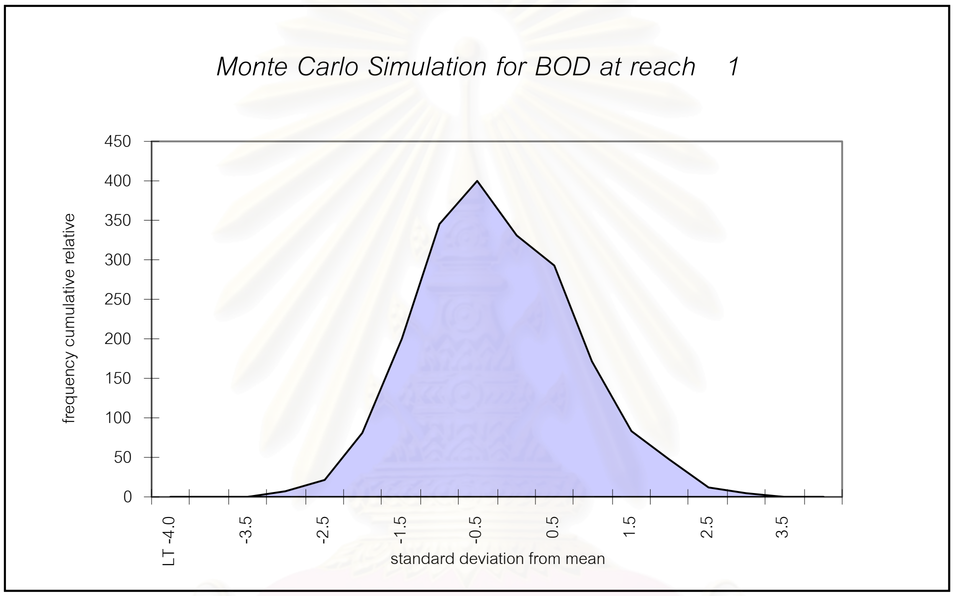


Figure 4.16 Monte Carlo Simulation 2000 for BOD at reach 1

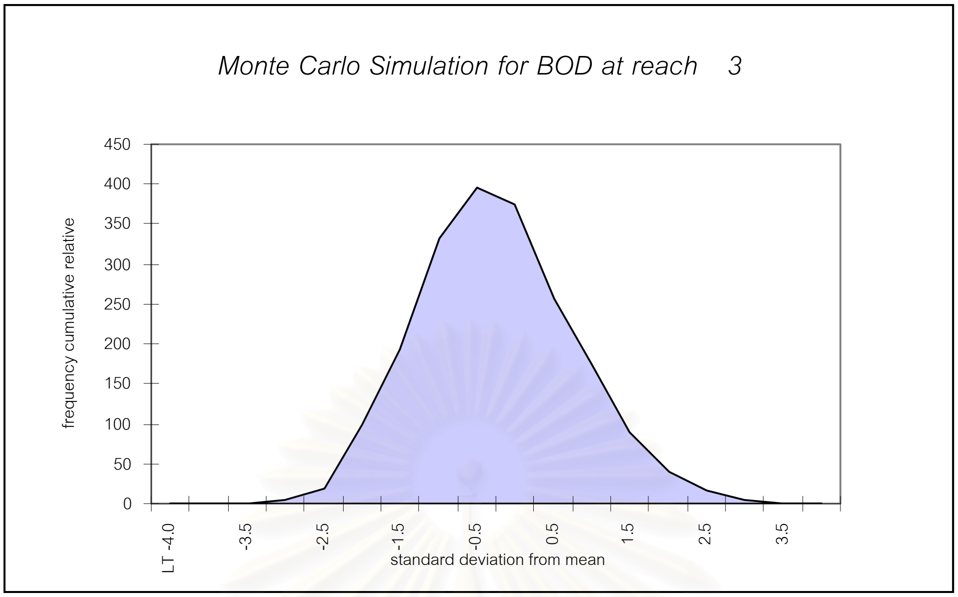


Figure 4.17 Monte Carlo Simulation 2000 for BOD at reach 3

From Figure 4.16 and 4.17 the bias between base and simulated means is acceptable. Both standard deviation and skew coefficient increase is from upstream to downstream. Although the skewness is rather high, the distribution is not so different from the normal. Thus, the simulation model conforms acceptably to the observation. For more simulation results see appendix H.

4.3 Application of The QUAL2E Model

4.3.1 Water Quality Standard

The main objective of the proposed schemes is to recommend improving Nakhon Nayok river water quality. The standard covers water use and criteria of water quality.

The water quality standard of Nakhon Nayok river is established into class 3. In this study all the proposed water quality improvement is to upgrade the river to classification 2 which are very clean and fresh water resources used for consumption which requires ordinary water treatment process before use, conservation of aquatic organism, fisheries, recreation (PCD, 1998).

Water quality standard in class 2

- *Temperature*

  Allowance level = natural
- *DO*

  No less than 6.0 mg/l at P20
- *BOD*

  No more than 1.5 mg/l at P80
- *NO_3_N*

  No more than 5.0 mg/l
- *NH_3_N*

  No more than 0.5 mg/l

Water quality standard in class 3

- *Temperature*

  Allowance level = natural
- *DO*

  No less than 4.0 mg/l at P20
- *BOD*

  No more than 2.0 mg/l at P80
- *NO_3_N*

  No more than 5.0 mg/l
- *NH_3_N*

  No more than 0.5 mg/l

4.3.2 Proposed Stream Water Quality Improvements

From literature and this study we found that Nakhon Nayok river has no serious wastewater and still conform to the standard of classification 3. Although the river sometimes encountered wastewater problems due to population increasing and illegal discharge of effluent without pretreatment to stream, it is able to recovery to its equilibrium. If we have no criteria for controlling wastewater, the river may fail to purify itself. So in this study the establishment of simply controlled measurement are considered.

4.3.2.1 Domestic Effluent Control Measurement

Since the organic contamination is the main problem in Nakhon Nayok river especial in municipal district (at P_1) because of no treatment system. The municipality has to treat their domestic waste before discharging into natural waterway. Implementing new domestic effluent control in municipality can certainly improve Nakhon Nayok river water quality. All proposed alternative schemes are expected to help forseeing water quality in the future when actual projects are applied.

4.3.2.2 Nonpoint Sources Control Measurement

A significant portion of all pollutants entering downstream of Nakhon Nayok river (at P_2) results from agricultural activities. In order to solve the water pollution problem, agricultural nonpoint source pollution will have to be controlled.

The first step in reducing agricultural NPS pollution is to focus on the primary water quality problem within watershed: the impairment of quality of water use must be identified and the type and source of pollutant must be defined. Once the problem has been clearly defined and documented, the critical area can be identified. Land treatment should then be implemented on these critical areas. Land treatment consists of the installation and utilization of best management practices (BMPs) which are used to control the generation and delivery of pollutants from agricultural activities to water resources and to prevent impacts to the physical and biological integrity of water surface. BMPs can be either structural (for example, waste lagoons, terraces, sediment basins, or fencing) or they can be managerial (for example, rotational grazing, fertilizer or pesticide management, or conservation tillage). Both types of BMPs require good management to be effective in reducing agricultural nonpoint source pollution. But only managerial BMPs are considered in this thesis.

The following schemes are proposed to improve the water quality to classification 2.

- Scheme One

Implementing a project with aim to reduce pollution loading with 60% treatment at both P_1 and P_2.

- Scheme Two

Implementing a project with aim to reduce pollution loading with 75% treatment at both P_1 and P_2.

- Scheme Three

Implementing a project with aim to reduce pollution loading with 90% treatment at both P_1 and P_2.

4.3.3 Results of Implementing Schemes

The QUAL2E model is considered to be an excellent DO/BOD model so only the effects of treatment on DO and BOD concentration have been considered.

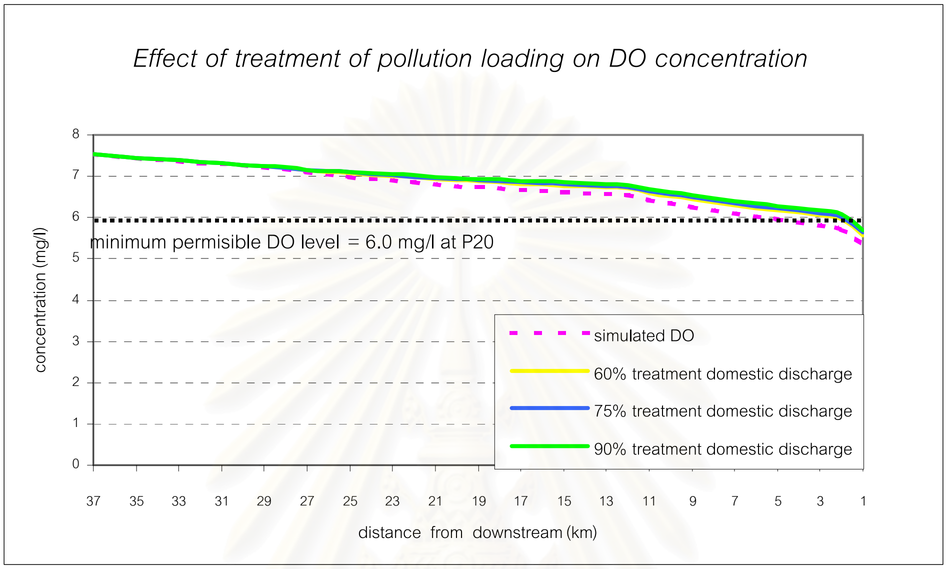


Figure 4.18 Integrated schemes for DO simulation

Figure 4.18 shows the effect of treatment of pollution loading on dissolved oxygen (DO) concentration. For all proposed schemes, DO along Nakhon Nayok river is in criteria of river class 2. It means that the recovery of DO concentration is enough and all of schemes are considered together with BOD simulation in considering the best one.

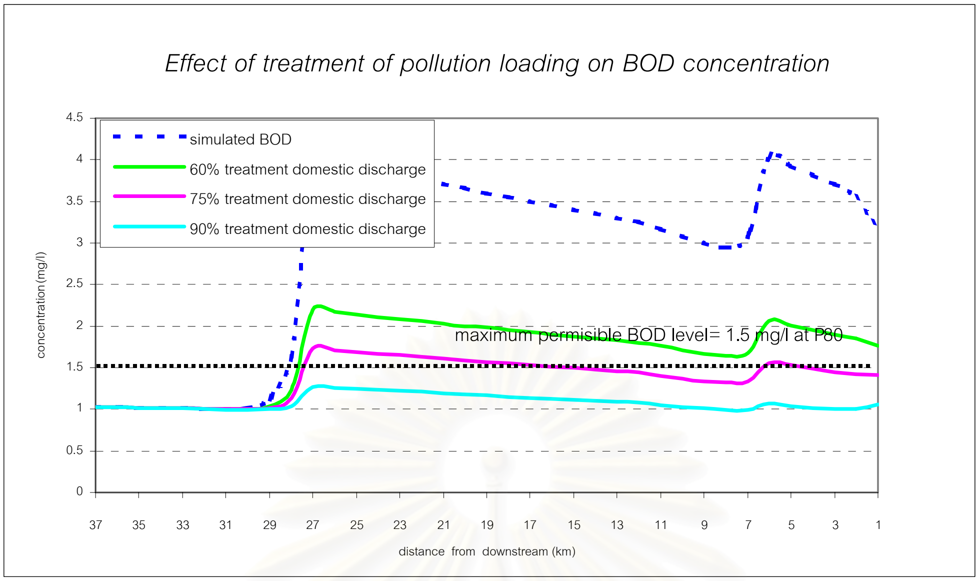


Figure 4.19 Integrated scheme for BOD simulation

Figure 4.19 shows the effect of treatment of pollution loading on biochemical oxygen demand (BOD) concentration. We chose percent treatment with BOD concentration acceptable to the proposed criteria. Last two schemes can be applied although the second gave BOD concentration over standard of the river class 2 and the third is the best. However what scheme to choose should be considered together with cost, the more pollution treatment the system can the more expensive it is.

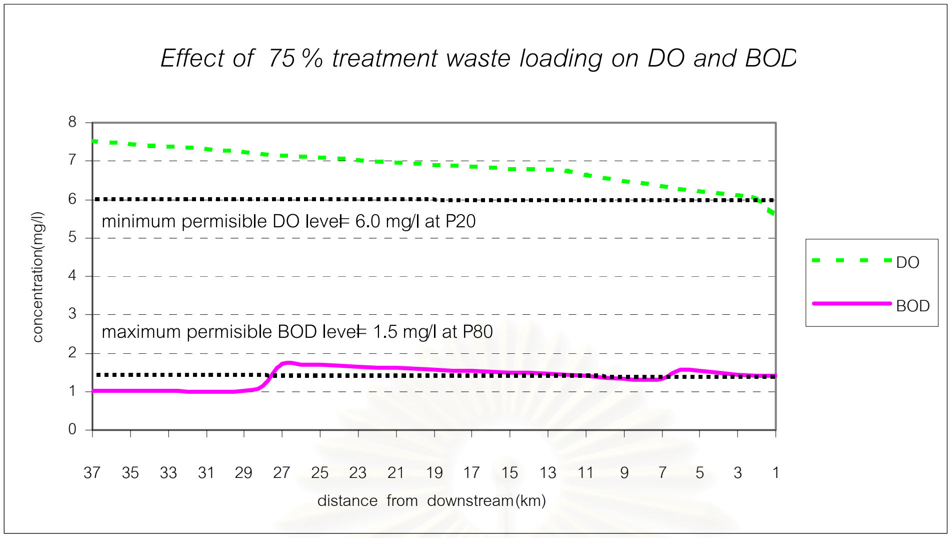


Figure 4.20 Integrated DO and BOD simulation for the second scheme

Having considered the result, the second scheme is the best for application see Figure 4.20. Water resources not only have good quality in class 2 but also waste loading capacity. Besides it saves the cost. Figure 4.21 and 4.22 show result of DO and BOD simulation without BMP respectively.

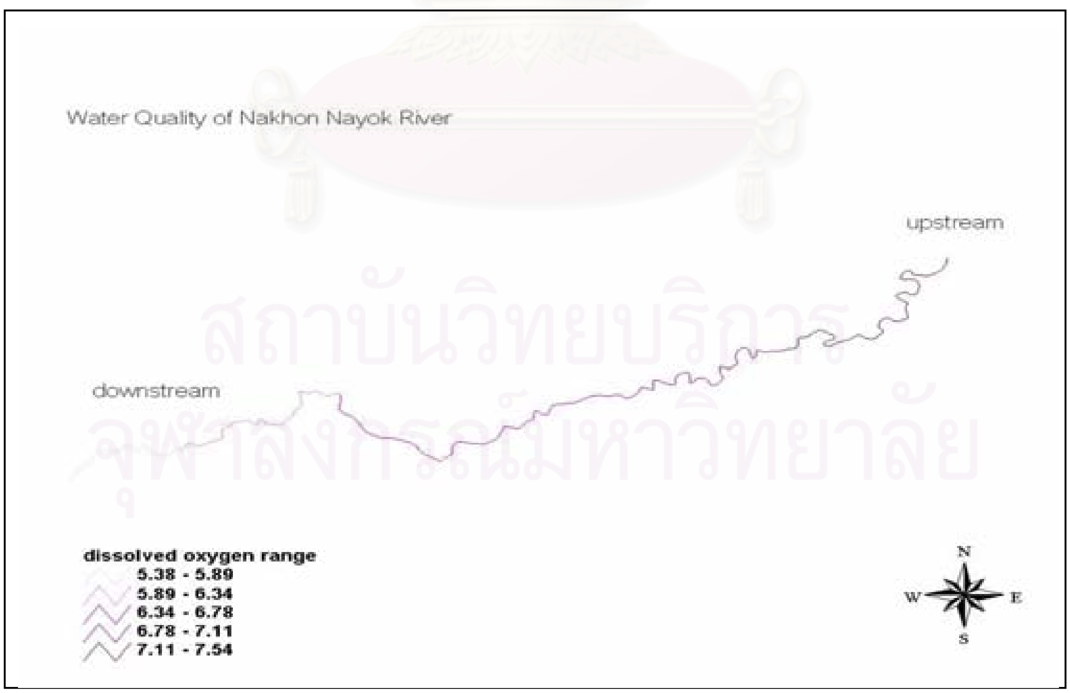


Figure 4.21 Result of DO simulation

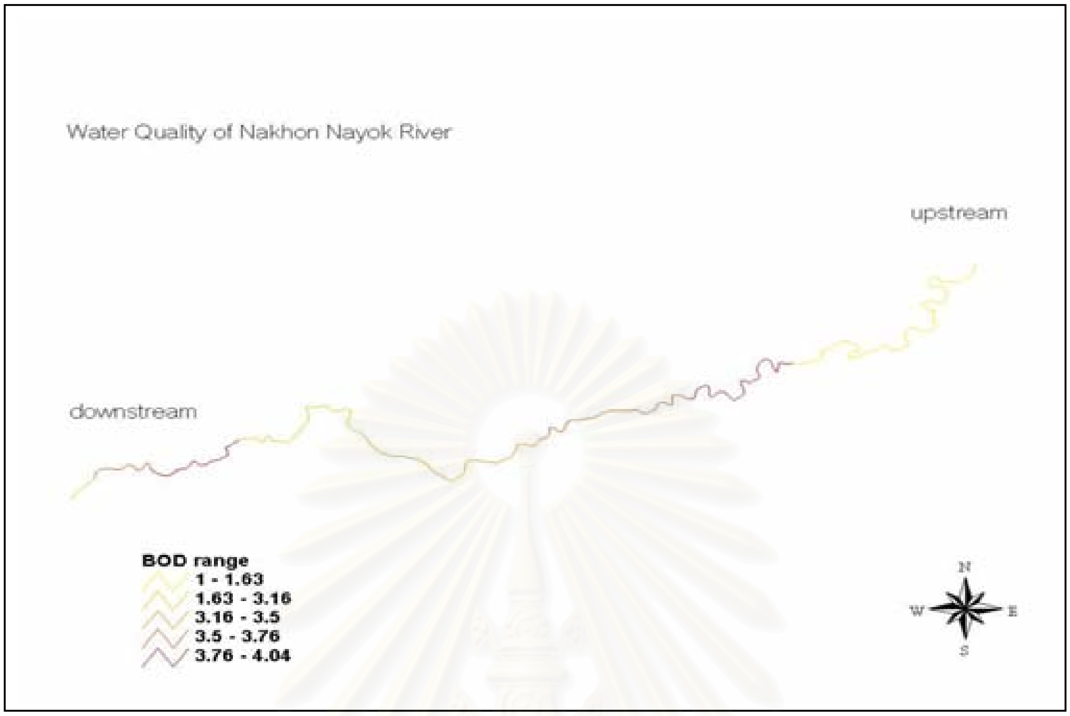


Figure 4.22 Result of BOD simulation

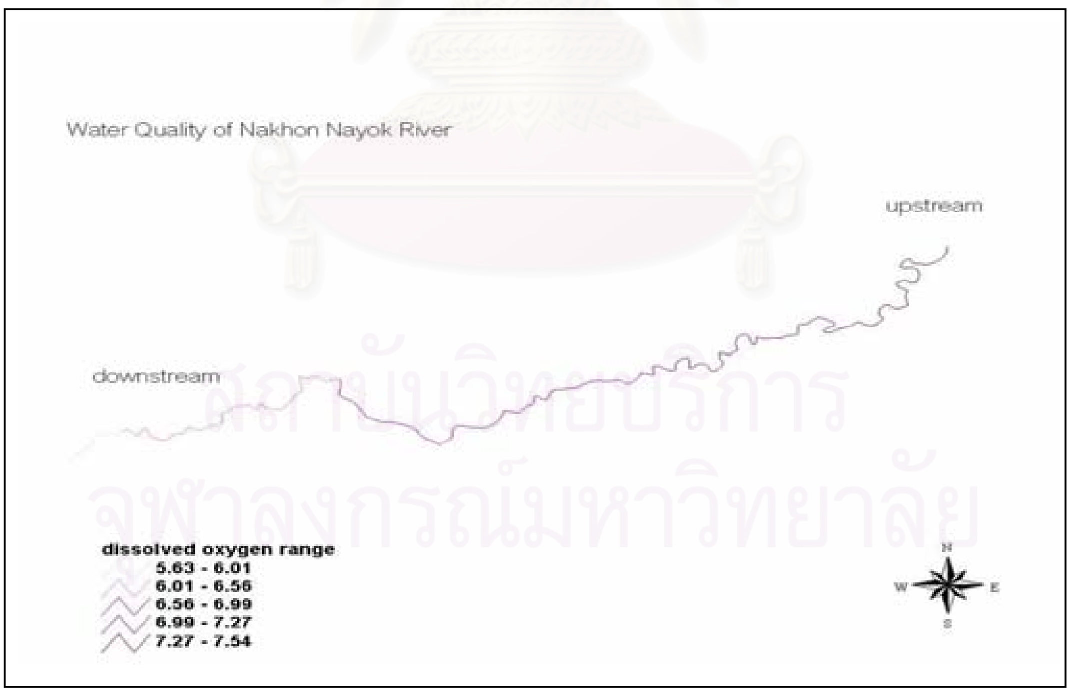


Figure 4.23 Result of DO simulation with chosen BMP scheme 2th

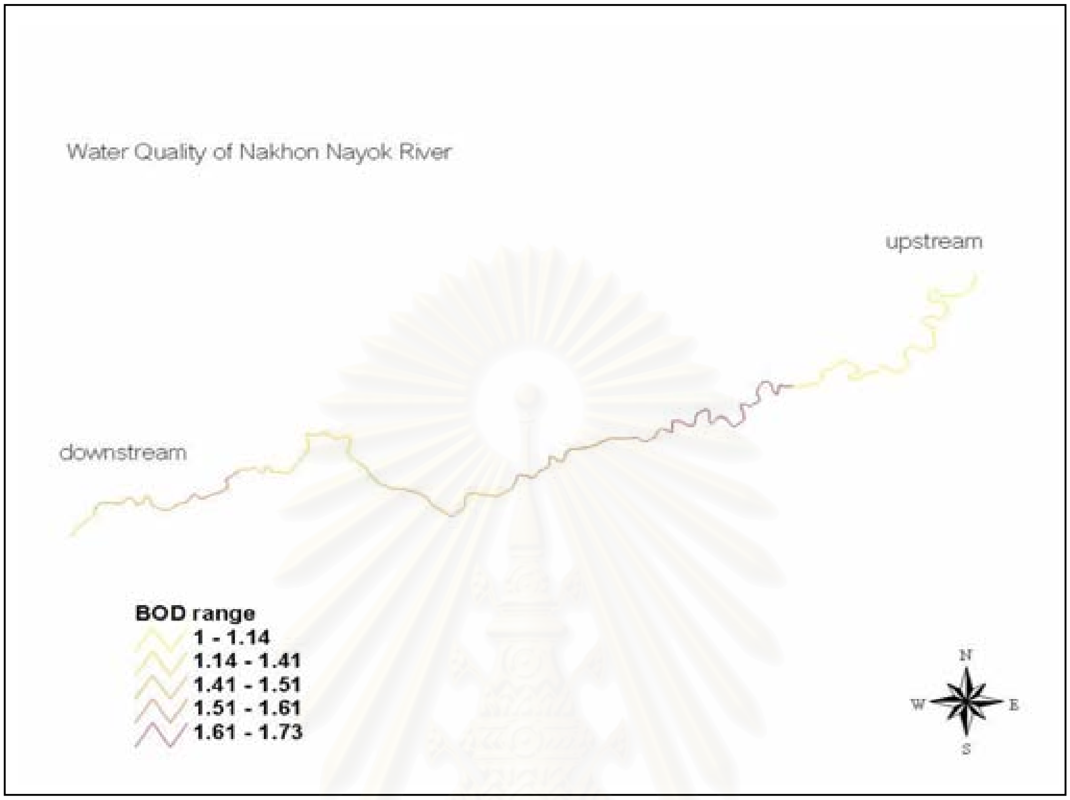


Figure 4.24 Result of BOD simulation with chosen BMP scheme 2^{th}

Figure 4.23 and 4.24 show that the second scheme should be applied for improving the water quality of Nakhon Nayok river.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Reviewing literatures and asking people living in the study area we found that Nakhon Nayok river has no serious water quality problem and it is in standard of water quality class 3. If there is no measurement to protect and control water consumption, water pollution may occur in the future. Thus in this study we concentrate on existing water quality and the water quality model QUAL2E is used as a planning tool to study existing water quality and recommend how to reduce pollution in order to save time and cost. Although the QUAL2E model does not simulate degradation of toxic materials. It can be used to trace them as conservative materials which should be useful in determining waste load allocations.

The necessary basic data in this study are water quality data, flow measurement, population, rate of water consumption, topographic maps, meteorological data, and digital database of Nakhon Nayok province. Water quality data, flow rate data, and cross section data, which are used to verify model, were done only once due to the limitation of time and fund. Besides, it was found unnecessary to fully calibrate the model because the water in dam was stored and acted unnaturally in km 24^{th}. From this study we found that critical areas locate at km 26^{th} which Nakhon Nayok river obtains point source from collecting system in Muang district and km 6^{th} it obtains nonpoint source from agricultural land use from Ban Na district.

QUAL2E-UNCAS has been shown to be a useful tool for performing uncertainty analysis in steady state water quality modeling. Two methods of uncertainty techniques, FOEA and MCS, have been performed with a data set from Nakhon Nayok river. FOEA gives results about output variances attributable to input variables, while MCS gives results about summary statistics and frequency distributions of the output variables that are not affected by model non-linearities. Uncertainty in water quality models causes the model equations imperfect of in representing the actual processes, as for instance, the real microscopic movement of dissolved constituents which is only modeled by advection and dispersion. It makes parameters appearing in the model equation, as for instance, dispersion coefficients or reaction rate constants, etc, are not known exactly. Then it is clear that water quality simulations yield simulated values not so equal to measured values, the error between them is unavoidable.

The general practice is to run a steady state model or a dynamic model several times for different sets of conditions expected over the period of interest. Enough data should be collected to characterize the seasonal variations, and to provide adequate data for calibrating and verifying the model.

This study can be used as a guide in preparing a plan to reduce water pollution, for instance, critical area gaining waste load from point source can be planed to reduce its pollution by designing the treatment at point load region before draining out waste to natural resource but if critical area has no point source one must consider the type of landuse. In this study, at km 6^{th} the type of landuse is mostly for agriculture, so we would like to recommend a way to reduce agricultural nonpoint source pollutions as follows: rotational grazing, fertilizer or pesticide management, or conservation tillage. Water supply in Muang district and Ong Kalak district was pumped to distribute to people, so we choose the second scheme as BMP because it can improve water quality class 3 into class 2 which conforms to standard water quality of Ministry of Science and Technology.

Percentage of reducible nonpoint source pollution in each type of landuse and application of structural BMP should be further studied to get best effective way in reducing nonpoint source pollution.

REFERENCES

Bowie. G. L., *et al*. 1985. Rate, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Report EPA/600/3-85/040). 2nd ed. Georgia: Environmental Protection Agency [EPA].

Brown, D. S., and Barnwell, T. O., Jr. 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual (Report EPA/600/3-87/007). Athens, Georgia: EPA.

Brown, L. C. 2000. Private Communication. (n.p.)

Chester, G. and Linda, J.S. 1985. A Primer on Nonpoint Pollution. Journal of Soil and Water Conservation 40(1): 9-13.

De Smedt, F. 2000. Private Communication. (n.p.)

De Smedt, F. 1989. Introduction to River Water Quality. Laboratory of Hydrology. Vrije University Brussel. Brussels, Belgium. pp. 1-62.

EPA. 1986. Stream Sampling for Waste Load Allocation Application. (Report EPA/625/6-86/013). Athens, Georgia: EPA.

EPA. 1995. QUAL2E Windows Interface User's Guide. (Report EPA/823/B/95/003). Athens, Georgia: EPA.

Gustavo, A. Alcala P. 1997. Application of The Stream Water Quality Model QUAL2E (Windows Version) Case Study: Cheliff Catchment in Algelia. Master Dissertation, Water Resources Engineering, Vrije Universiteit Brussel, VUB. Brussels, Belgium.

John C. A., Brown, K., Croswell, P. L., Kevany, M. J., and Archer, H. 1991. Geographic Information Systems: A Guide to the Technology. New York: Van Nostrand Reinhold. 301 p.

Melching C.S. and Yoon C.G. 1996. Key Sources of Uncertainty in QUAL2E Model of Passaic River. Journal of Water Resources Planning and Management. 3-4:105-113.

Park, S. W., Mostaghimi, S., Cooke, R. A., and McClellan, P. W. 1994. BMP Impacts on Wateshed Runoff, Sediment, and Nutrient Yields. Water Resources Bulletin. 30(6): 1011-1022.

Pengthemkeerati Patthra. 1998. Calibration of Mathematical Model MIKE 11 for Prediction of Water Quality in lower Maeklong River. Master's Thesis, Inter-department of Environmental Science, Graduate School, Chulalongkorn University (in thai).

Science, Technology and Environment, Ministry. Royal Irrigation Department 1993. Development of An Action Plan to Upper Nakhon Nayok Watershed Amphoe Pakplee Nakhon Nayok Province, Thailand (2/4). Bangkok (in thai).

Science, Technology and Environment, Ministry. Royal Irrigation Department 1993. Feasibilities and Environmental Impact Assessment to Upper Nakhon Nayok Watershed Amphoe Pakplee Nakhon Nayok Province, Thailand (1/4). Bangkok (in thai).

Science, Technology and Environment, Ministry. Pollution Control Department 1998. Development of An Action Plan to Improve Water Quality in The Eastern River Basin, Thailand (7/10). Bangkok: Thammasart University Press (in thai).

Science, Technology and Environment, Ministry. Pollution Control Department. 1997. Development of An Action Plan to Improve Water Quality in The Central River Basin, Thailand (14/24). Bangkok: Thammasart University Press (in thai).

Sivertun,Å.,Reinelt,E.L.,and Castensson,R., 1988. A GIS Method to Aid in Nonpoint Source

Critical Area Analysis. International Journal Geographical Information System. 2(4):365-378.

The National Research Council, Office. Water Quality, Department of Environmental Quality Standard. 1986-1987. Report of Water Quality Management of Bang Pa Kong, Prachin Buri, and Nakhon Nayok River (in thai)

Thomann, R.V., and J.A.Muller. 1987. Principles of Surface Water Quality Modeling. Harper&Row. New York.

Phunsawas Thongchai. 1987. Data for Preparing Management Strategy for Waste Water Treatment in Bangkok and its Neiborhoods. (in thai).

Computational Science Education Project. 1995. Introduction to Monte Carlo Methods. Available from: http://csep1.phy.ornl.gov/csep/MC/MC.html

Hydrologic Simulation Program - Fortran (HSPF). 2001. Overview. Available from: http://www.hydrocomp.com/HSPFinfo.

Number of Population. 1998. Available from: http://www.dola.go.th/local/nayok.html

Rivers, Channels and Reservoirs. 2001. Description. Available from: http://www.dhi.dk/ MIKE11.

WASP5, Water Quality Analysis Simulation Program. 2001. WASP5/DYNHYD5 OVERVIEW. Available from: http://www.scisoftware.com/products/wasp_details.html/#wasp_intro.

APPENDIXES

APPENDIX A

STANDARDS OF WATER QUALITY

INDUSTRIAL EFFLUENT STANDARDS

Items	Units	Standard Values	Remarks
BOD (5 day at 20°C)	mg/l	20	Depends on physical geography or official discretion but not more than 60 mg/l except #Fishery canning - Maximum 100 #Starch industry ● Centrifugal - Maximum 60 ● Sedimentation - Maximum 100 #Noodle industry - Maximum 100 #Tanning industry - Maximum 100 #Pulp industry - Maximum 100 #Frozen food industry – Maximum 100
Suspended solids (SS)	mg/l	Depends on dilution ratios of wastewater and receiving water	Ratio #1/8 to 1/150 - Maximum 30 #1/151 to 1/300 - Maximum 60 #1/301 to 1/500 - Maximum 150
Dissolved solids (DS)	mg/l	Maximum 2,000 or at official discretion but not more than 5,000	If the salinity of the receiving water is higher than 2,000 mg/l, DS in the effluent should not be higher than 5,000 mg/l of the DS in the receiving water.
PH		5-9	
Permanganate value		Maximum 60	
Sulphide as H_2S		maximum 1.0	
Cyanide as HCN	mg/l	Maximum 0.2	
Tar	mg/l	None	
Oil & Grease	mg/l	Maximum 5.0	Refinery and lubricant oil industry maximum 15.0
Formaldehyde	mg/l	Maximum 1.0	
Items	units	Standard Values	Remarks
Phenol & cresols	mg/l	Maximum 1.0	

INDUSTRAIL EFFLUENT STANDARDS (CONT.)

Items	Units	Standard Values	Remarks
Free Chlorine	mg/l	Maximum 1.0	
Insecticides		None	
Radioactivity	bq/l	None	
Heavy metals			
Zinc (Zn)	mg/l	Maximum 5.0	Zinc industry maximum 3.0
Chromium (Cr)	mg/l	Maximum 0.5	Zinc industry maximum 0.2
Arsenic (As)	mg/l	Maximum 0.25	
Copper (Cu)	mg/l	Maximum 1.0	
Mercury (Hg)	mg/l	Maximum 0.005	Zinc industry maximum 0.2
Cadmium (Cd)	mg/l	Maximum 0.03	Zinc industry maximum 0.03
Barium (Ba)	mg/l	Maximum 1.0	
Selenium (Se)	mg/l	Maximum 0.2	
Lead (Pb)	mg/l	Maximum 0.2	
Nickel (Ni)	mg/l	Maximum 0.2	Zinc industry maximum 0.2
Manganese (Mn)	mg/l	Maximum 5.0	Zinc industry maximum 0.002
Silver (Ag)	mg/l	-	
Temperature	°C		
Color and odor		Maximum 50 and not objectionable	

Source: Notification of the Ministry of Industry, No. 12 B.E. 2525 (1982), issued under the Factory Act B.E.2521 (1978), published in the Royal Gazette, Vol. 99, Part 33, dated March 5, B.E. 2525 (1982).

Notification of the Ministry of Industry, No. 10 B.E. 2521 (1978), issued under the Factory Act B.E. 2521 (1978), published in the Royal Gazette, Vol. 95, Part 132, dated November 28, B.E. 2521 (1978)

SURFACE WATER QUALITY STANDARDS

Surface Water Quality (Classification and Objectives) of Nakorn Nayok river Water Quality Standards

Parameters 1/	Units	Statistics	Class				
			1	2	3	4	5
Color, odor, Taste	-	-	n	n	n	n	-
Temperature	°C	-	n'	n'	n'	n'	-
pH	-	-	n	5-9	5-9	5-9	-
Dissolved Oxygen (DO)2/	mg/l	P20	n	6	4	2	-
BOD (5 days, 20°C)	mg/l	P80	n	1.5	2.0	4.0	-
Total Coliform Bacteria	mpn/100 ml	P80	n	5,000	20,000	-	-
Faecal Coliform Bacteria	mpn/100 ml	P80	n	1,000	4,000	-	-
NO_3 –N	mg/l	-	n	5.0			-
NH_3-N	mg/l	-	n	0.5			-
Phenols	mg/l	-	n	0.005			-
Copper (Cu)	mg/l	-	n	0.1			-
Nickel (Ni)	mg/l	-	n	0.1			-
Manganese (Mn)	mg/l	-	n	1.0			-
Zinc (Zn)	mg/l	-	n	1.0			-
Cadmium (Cd)	mg/l	-	n	0.005*,0.05**			-
Chromium hexavalent	mg/l	-	n	0.05			-
Lead (Pb)	mg/l	-	n	0.05			-
Total Mercury	mg/l	-	n	0.002			-
Arsenic	mg/l	-	n	0.01			-
Cyanide	mg/l	-	n	0.005			-

SURFACE WATER QUALITY STANDARDS (CONT.)

Parameters [1/]	Units	Statistics	Class				
			1	2	3	4	5
Radioactivity							-
- Alpha	bq/l	-	n	0.1			
- Beta	bq/l	-	n	1.0			
Total Organochlorine Pesticides	mg/l	-	n	0.05			-
DDT	μg/l	-	n	1.0			-
Alpha-BHC	μg/l	-	n	0.02			-
Dieldrin	μg/l	-	n	0.1			-
Aldrin	μg/l	-	n	0.1			-
Heptachor &Heptachlorepoxide	μg/l	-	n	0.2			-
Endrin	μg/l	-	n	Cannot detect by means of Gas Chromatography			-

Source: Notification of National Environmental Council of Thailand, No. 8 B.E. 2537 (1994), issued under the Factory Act B.E. 2521 (1978), issued under The National Environmental Quality Act B.E. 2535 (NEQA 1992) published in the Royal Gazette, Vol. 111, Part 16 , dated February 24, B.E. 2537 (1994).

Note:

[1/] Only standard values for river class 2-4.

[2/] Minimum standard value of DO

n Natural

n' Water temperature does not exceed 3 celcius of natural.

* Water hardness in $CaCO_3$ type not exceed 100 mg/l.

** Water hardness in $CaCO_3$ type exceed 100 mg/l.

P20 Percentile 20 from all effluent that checked continually.

P80 Percentile 20 from all effluent that checked continually.

mpn Most Probable Number.

SURFACE WATER QUALITY CLASSIFICATION AND OBJECTIVES

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

CLASSIFICATION OF NAKHON NAYOK RIVER

Controlled district of water quality standard	Classification
Distance from Tambol Bang Tan Amphoe Ban Sang Prachin Buri to Nakhon Nayok Bridge B.E. 1965 Tambol Nakhon Nayok Amphoe Muang Nakhon Nayok with 84 kilometers	3

Source: Notification of the Pollution Control Department, issued classification of Nakhon Nayok River, published in the Royal Gazette, Volume 111, Part 62, dated August 4, 2537 (1994).

APPENDIX B

WATER QUALITY OF NAKHON NAYOK STATIONS
FROM POLLUTION CONTROL DEPARTMENT

WATER QUALITY OF NAKHON NAYOK RIVER DURING 1993-1999
BY POLLUTION CONTROL DEPARTMENT

d/m/y	Tha Dan Station						
	DO (mg/l)	BOD (mg/l)	Temp. (°C)	NO_3_N (mg/l NO_3_N)	NH_3_N (mg/l NH_3_N)	NO_2_N (mg/l NO_2_N)	TP (mg/l P)
1/3/36	7.40	2.80	29.0	0.06	<0.01	-	0.01
20/9/36	7.70	0.60	29.0	0.59	0.03	0.14	0.01
20/12/36	7.00	1.00	24.0	-	0.01	-	0.01
Average	7.36	1.47	27.3	0.33	0.02	0.14	0.01
25/2/37	9.00	1.00	30.0	4.50	<0.01	<0.01	<0.01
19/4/37	7.00	1.60	30.0	<0.01	0.02	<0.01	<0.01
2/5/37	7.60	0.90	32.0	0.68	0.05	0.01	0.04
27/6/37	7.60	0.20	26.0	0.10	0.01	<0.01	0.02
29/8/37	8.20	0.40	-	0.10	0.02	<0.01	0.02
21/11/37	7.00	0.50	26.0	0.01	0.02	<0.01	<0.01
Average	7.73	0.77	28.8	0.90	0.02	0.01	0.02
20/2/38	5.90	1.10	28.0	0.05	0.04	<0.01	<0.01
3/5/38	7.50	1.30	30.0	0.06	0.08	<0.01	0.07
10/8/38	8.00	0.50	27.0	0.05	0.01	<0.01	-
24/11/38	7.20	0.20	25.0	0.06	0.02	<0.01	0.03
Average	7.15	0.77	27.5	0.06	0.375	0.01	0.04
20/3/39	7.60	1.90	31.0	0.02	0.16	<0.01	0.06
27/5/39	7.20	0.80	29.2	0.03	0.14	<0.01	-
17/7/39	7.70	0.20	27.3	0.08	<0.01	<0.01	0.01
5/11/39	7.90	0.40	26.0	0.14	0.02	<0.01	0.15
Average	7.60	0.83	28.4	0.07	0.083	0.01	0.07

d/m/y	Tha Dan Station (cont.)						
	DO (mg/l)	BOD (mg/l)	Temp. (°C)	NO_3_N (mg/l NO_3_N)	NH_3_N (mg/l NH_3_N)	NO_2_N (mg/l NO_2_N)	TP (mg/l P)
26/2/40	8.40	0.80	30.5	0.02	<0.01	<0.01	0.01
28/5/40	7.80	0.70	27.3	0.08	0.10	<0.01	0.03
25/11/40	9.40	1.60	25.8	0.06	0.12	<0.01	0.02
Average	8.53	1.03	27.9	0.05	0.08	0.01	0.02
2/4/41	5.70	1.60	27.0	0.01	0.03	<0.01	0.04
3/6/41	7.80	0.50	25.1	0.19	0.06	0.001	0.00
2/9/41	7.00	0.70	26.0	0.11	0.20	0.03	0.01
4/11/41	6.20	0.60	27.5	0.11	0.16	0.03	0.03
Average	6.80	0.90	26.4	0.11	0.112	0.035	0.03
13/1/42	5.90	1.30	28.30	0.01	0.003	0.01	0.01
22/3/42	9.00	0.30	31.00	0.04	0.07	<0.01	0.02
7/7/42	8.80	0.60	24.50	0.14	0.07	0.01	0.37
27/9/42	8.00	3.90	26.10	0.20	0.05	<0.01	0.11
Average	7.93	1.53	27.48	0.10	0.05	0.01	0.13

d/m/y	Nakhon Nayok Bridge Station (cont.)						
	DO (mg/l)	BOD (mg/l)	Temp. (°C)	NO_3_N (mg/l NO_3_N)	NH_3_N (mg/l NH_3_N)	NO_2_N (mg/l NO_2_N)	TP (mg/l P)
1/3/36	5.70	3.90	29.5	0.08	0.23	-	<0.01
20/9/36	7.30	0.50	29.0	0.59	0.03	0.14	0.01
20/12/36	5.20	1.60	28.0	-	0.01	-	0.03
Average	6.07	2.00	28.8	0.34	0.09	0.14	0.02
25/2/37	3.80	2.00	29.5	0.68	0.20	<0.01	0.03
19/4/37	7.00	1.30	30.0	<0.01	0.01	<0.01	0.03
2/5/37	3.70	0.60	32.0	0.66	0.09	0.01	0.04
27/6/37	6.70	0.40	28.0	0.12	<0.01	0.01	0.02
29/8/37	7.30	0.70	29.0	0.10	0.01	<0.01	<0.01
21/11/37	1.30	1.60	29.0	0.00	0.01	<0.01	0.01
Average	4.90	1.10	29.6	0.26	0.06	0.01	0.02
20/2/38	5.00	2.40	30.0	0.07	0.24	0.02	0.09
3/5/38	2.90	4.00	30.0	0.18	0.58	0.01	0.02
10/8/38	7.40	1.10	27.5	0.12	0.01	<0.01	-
24/11/38	5.00	2.00	27.0	0.04	0.05	<0.01	0.03
Average	5.06	2.40	28.6	0.10	0.22	0.01	0.05
20/3/39	7.60	7.50	31.0	0.02	0.47	<0.01	0.10
27/5/39	6.40	1.90	31.3	0.05	0.17	<0.01	-
17/7/39	5.50	0.80	29.2	0.05	0.07	0.02	<0.01
5/11/39	7.10	0.60	26.0	0.13	0.02	<0.01	0.08
Average	6.70	2.70	29.4	0.06	0.18	0.01	0.06

d/m/y	Nakhon Nayok Bridge Station						
	DO (mg/l)	BOD (mg/l)	Temp. (°C)	NO_3_N (mg/l NO_3_N)	NH_3_N (mg/l NH_3_N)	NO_2_N (mg/l NO_2_N)	TP (mg/l P)
26/2/40	4.90	2.00	30.5	0.02	<0.01	<0.01	0.06
28/5/40	3.10	1.50	30.2	0.05	1.00	<0.01	0.05
25/11/40	4.80	1.20	28.8	0.04	<0.01	<0.01	0.05
Average	4.27	1.60	29.8	0.04	0.34	0.01	0.05
2/4/41	3.20	4.30	30.3	0.38	1.00	0.05	0.19
3/6/41	4.40	0.60	26.2	0.65	0.09	<0.001	0.02
2/9/41	6.90	0.60	27.0	0.11	0.27	0.01	0.02
4/11/41	5.40	2.10	28.0	0.16	0.55	0.02	0.02
Average	4.98	1.90	27.9	0.33	0.48	0.02	0.02
13/1/42	5.30	2.10	26.7	0.04	0.29	<0.001	0.03
22/3/42	9.60	2.90	33.0	<0.01	0.07	<0.01	0.04
7/7/42	7.60	1.40	26.5	0.13	0.08	0.01	0.12
27/9/42	7.50	7.40	27.9	0.17	0.02	<0.01	0.09
Average	7.50	3.50	28.5	0.09	0.12	0.01	0.07

d/m/y	Wat Ampwan Station						
	DO (mg/l)	BOD (mg/l)	Temp. (°C)	NO_3_N (mg/l NO_3_N)	NH_3_N (mg/l NH_3_N)	NO_2_N (mg/l NO_2_N)	TP (mg/l P)
1/3/36	4.00	1.90	39.0	0.14	<0.01	-	0.05
20/9/36	5.30	1.00	30.0	0.48	0.06	0.15	0.02
20/12/36	3.40	2.00	28.0	-	0.20	-	0.01
Average	4.20	1.60	29.0	0.31	0.09	0.15	0.03
25/2/37	5.50	3.00	28.0	0.09	<0.01	<0.01	0.02
19/4/37	7.00	1.10	30.0	0.03	0.10	0.03	0.01
2/5/37	3.30	0.50	32.0	1.42	0.26	0.01	<0.01
27/6/37	4.10	0.40	29.0	0.10	0.09	<0.01	0.02
29/8/37	4.80	1.40	29.0	0.11	0.02	<0.01	0.03
21/11/37	2.90	2.20	28.0	0.00	0.02	<0.01	<0.01
Average	4.60	1.40	29.3	0.29	0.08	0.01	0.02
20/2/38	4.10	0.50	30.0	0.08	0.06	0.01	<0.01
3/5/38	2.50	0.80	30.0	0.14	0.05	<0.01	0.02
10/8/38	3.60	0.90	30.0	0.06	<0.01	<0.01	-
24/11/38	1.70	3.70	29.0	0.02	0.11	<0.01	0.01
Average	2.96	1.48	30.0	0.08	0.06	0.01	0.01
20/3/39	3.60	0.80	31.0	0.09	0.01	<0.01	0.05
27/5/39	2.60	0.80	31.5	0.02	0.34	<0.01	-
17/7/39	1.40	1.70	29.2	0.02	0.06	0.02	<0.01
5/11/39	2.80	1.40	27.5	0.13	0.06	<0.01	0.19
Average	2.60	1.18	29.8	0.07	0.12	0.01	0.08

d/m/y	Wat Ampwan Station (cont.)						
	DO (mg/l)	BOD (mg/l)	Temp. (°C)	NO_3_N (mg/l NO_3_N)	NH_3_N (mg/l NH_3_N)	NO_2_N (mg/l NO_2_N)	TP (mg/l P)
26/2/40	3.30	0.70	29.5	0.03	<0.01	<0.01	0.02
28/5/40	3.80	1.30	29.9	1.50	1.1	<0.01	0.05
25/11/40	2.50	1.60	30.6	0.01	0.07	<0.01	0.04
Average	3.20	1.20	30.0	0.51	0.39	0.01	0.36
2/4/41	1.00	1.30	29.9	0.08	0.11	<0.01	0.04
3/6/41	2.10	0.80	30.7	0.29	0.08	0.23	0.01
2/9/41	4.60	1.00	30.0	0.04	0.26	0.01	0.01
4/11/41	4.00	1.50	28.5	0.05	0.21	0.02	0.02
Average	2.93	1.20	29.8	0.12	0.17	0.07	0.02
13/1/42	4.30	2.60	28.2	0.08	0.19	0.003	0.01
22/3/42	8.10	3.90	31.0	0.05	0.09	<0.01	0.07
7/7/42	4.60	1.80	29.0	0.14	0.17	0.05	0.34
27/9/42	5.70	1.30	30.5	0.13	0.02	<0.01	0.06
Average	5.68	2.40	29.7	0.10	0.12	0.02	0.12

APPENDIX C

FIELD SURVEY DATA

NUMBER OF POINT SOURCES AND NONPOINT SOURCES

Places	Amphoe		Total
	Muang	Ban Na	
1. Domestic			
- number of population	17,883	2,305	20,188
2. Hotel			
- number of rooms	620	-	620
3. Hospital			
- number of beds	500	60	560
4. Food center			
- number of places	149	28	177
(average area per unit is 50 sq m)			
5. Education			
- number of students	17,821	5,609	23,430
- number of teachers	469	149	618
6. Fresh market			
- number of area (sq m)	1,100	320	1,420
7. Temple			
- number of monks	279	121	400
8. Government office			
- number of government officials	1,248	253	1,501
9. Pig farm			
- number of pigs	-	19,909	19,909
10. Paddy field			
- number of area (rai)	6,500	9,430	15,930

Source: Field study on October 21, 2000

NUMBER OF POPULATION IN EACH REACH

Reach number	Name of Tambol	Number of houses	Number of population (cap)	Total population (cap)
1	Hin Tang	9	5,481	29,850
	Sarika	12	7,488	
	Sri Nawa	8	3,970	
	Ban Hyai	7	2,191	
	Nakhon Nayok	12	8,028	
	Wand Kra Jome	7	2,692	
2	Tha Chang	12	3,692	6,120
	Tha Sai	7	2,428	
3	Bang Or	14	4,565	4,565

Source: http://www.dola.go.th/local/nayok.html

APPENDIX D

RESULTS OF WATER QUALITY ANALYSIS

WATER QUALITY ANALYSIS

Parameter	Preservation	Method	note
1. BOD	Ice	Azide modification method	-
2. DO	$MnSO_4$ 2 ml + alkali-iodine azide 2 ml + conc. H_2SO_4 2 ml		-
3. NH_3_N	Ice	Distillation nesslerization	-
4. NO_3_N	Ice	Cadmium reduction method	-
5. NO_2_N	Ice	Spectrophotometric method by using N-(1-Naphyl)-ethylenediamine	-
6. Dis_P	Ice	Ascorbic	-
7. Temp	-	Direct	Thermometer
8. Flow	-	Direct	Bouy

SURFACE WATER QUALITY ON DECEMBER 8, 2000

Indicators	Stations											
	1	2	3	4	5	6	7	8	9	10	11	12
Water temp (°C)	26.00	-	32.00	29.50	28.00	28.00	30.00	28.50	28.00	32.00	31.50	32.00
Flow rate (m^3/s)	13.09	13.48	0.04	13.77	0.39	0.56	12.93	4.84	0.29	5.51	8.86	-
DO (mg/l)	7.30	-	2.50	7.20	3.20	3.00	6.56	6.70	2.00	6.20	4.91	3.70
BOD (mg/l)	4.50	-	14.50	12.50	10.50	10.00	11.50	10.00	12.50	11.00	8.00	12.00
NH_3_N (mg/l)	0.1233	-	0.0765	0.0866	0.0888	0.0377	0.0782	0.0780	0.1979	0.0897	0.1230	0.0960
NO_2_N (mg/l)	0.0164	-	0.0486	0.0085	0.0015	0.0017	0.0093	0.0035	0.0161	0.0044	0.0114	0.0213
NO_3_N (mg/l)	0.2297	-	0.2341	0.2448	0.0275	0.0324	0.2421	0.2362	0.7344	0.2376	0.2075	0.0085
Dis_P (mg/l)	0.0028	-	0.0898	0.0076	0.0044	0.0060	0.0044	0.0047	0.0843	0.0108	0.0118	0.0479

Note:

Station 1	Khao Nang Buat bridge	(Headwater)	Station 7	Upper Dam	(Observe DO3)
Station 2	Nakhon Nayok bridge	(Observe DO1)	Station 8	Lower Dam	(Observe DO4)
Station 3	Tambol Nayok	(P_1)	Station 9	Klong Ban Na	(P_2)
Station 4	Tambol Nayok bridge	(Observe DO2)	Station 10	Lower Klong Ban Na	(Observe Do5)
Station 5	Klong Muang	(W_1)	Station 11	Wat Ampwan	(Downstream)
Station 6	Tha Chang	(W_2)	Station 12	Paddy field	(Sample)

APPENDIX E

INPUT DATA

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                    * * * QUAL-2E  STREAM QUALITY ROUTING MODEL * * *
                              Version 3.21  -  Feb. 1995

 $$$ (PROBLEM TITLES) $$$

CARD TYPE                           QUAL-2E PROGRAM TITLES
TITLE01              Nakhon Nayok Water Quality
TITLE02
TITLE03  NO          CONSERVATIVE MINERAL I
TITLE04  NO          CONSERVATIVE MINERAL II
TITLE05  NO          CONSERVATIVE MINERAL III
TITLE06  YES         TEMPERATURE
TITLE07  YES         BIOCHEMICAL OXYGEN DEMAND
TITLE08  NO          ALGAE AS CHL-A IN UG/L
TITLE09  YES         PHOSPHORUS CYCLE AS P IN MG/L
TITLE10                (ORGANIC-P; DISSOLVED-P)
TITLE11  YES         NITROGEN CYCLE AS N IN MG/L
TITLE12                (ORGANIC-N; AMMONIA-N; NITRITE-N;' NITRATE-N)
TITLE13  YES         DISSOLVED OXYGEN IN MG/L
TITLE14  NO          FECAL COLIFORM IN NO./100 ML
TITLE15  NO          ARBITRARY NON-CONSERVATIVE
ENDTITLE

 $$$ DATA TYPE 1 (CONTROL DATA) $$$

CARD TYPE                                   CARD TYPE
LIST DATA INPUT               0.00000                                   0.00000
WRITE OPTIONAL SUMMARY        0.00000                                   0.00000
NO FLOW AUGMENTATION          0.00000                                   0.00000
STEADY STATE                  0.00000                                   0.00000
TRAPAZOIDAL                   0.00000                                   0.00000
PRINT LCD/SOLAR DATA          0.00000                                   0.00000
PLOT DO AND BOD DATA          0.00000                                   0.00000
FIXED DNSTM CONC (YES=1)=     1.00000       5D-ULT BOD CONV K COEF   =  0.23000
INPUT METRIC            =     1.00000       OUTPUT METRIC            =  1.00000
NUMBER OF REACHES       =     3.00000       NUMBER OF JUNCTIONS      =  0.00000
NUM OF HEADWATERS       =     1.00000       NUMBER OF POINT LOADS    =  4.00000
TIME STEP (HOURS)       =     1.00000       LNTH. COMP. ELEMENT (DX)=   1.00000
MAXIMUM ROUTE TIME (HRS)=    30.00000       TIME INC. FOR RPT2 (HRS)=   0.00000
LATITUDE OF BASIN (DEG) =    14.00000       LONGITUDE OF BASIN (DEG)= 101.00000
STANDARD MARIDIAN (DEG) =    90.00000       DAY OF YEAR START TIME   = 342.00000
EVAP. COEF.,(AE)        =     0.00001       EVAP. COEF.,(BE)         =  0.00001
ELEV. OF BASIN (ELEV)   =     6.55600       DUST ATTENUATION COEF.   =  0.06000
ENDATA1                       0.00000                                   0.00000

 $$$ DATA TYPE 1A (ALGAE PRODUCTION AND NITROGEN OXIDATION CONSTANTS) $$$

CARD TYPE                                   CARD TYPE
O UPTAKE BY NH3 OXID(MG O/MG N)=   3.5000   O UPTAKE BY NO2 OXID(MG O/MG N)=   1.1400
O PROD  BY ALGAE (MG O/MG A)   =   1.6000   O UPTAKE BY ALGAE (MG O/MG A)  =   2.0000
N CONTENT OF ALGAE (MG N/MG A) =   0.0850   P CONTENT OF ALGAE (MG O/MG A) =   0.0140
ALG MAX SPEC GROWTH RATE(1/DAY)=   2.5000   ALGAE RESPIRATION RATE (1/DAY) =   0.0500
N HALF SATURATION CONST (MG/L) =   0.2000   P HALF SATURATION CONST (MG/L) =   0.0400
LIN ALG SHADE CO (1/M-UGCHA/L) =   0.0025   NLIN SHADE (1/M-(UGCHA/L)**2/3)=   0.0000
LIGHT FUNCTION OPTION (LFNOPT) =   1.0000   LIGHT SAT'N COEF (LANGLEYS/MIN)=   0.0299
DAILY AVERAGING OPTION (LAVOPT)=   2.0000   LIGHT AVERAGING FACTOR (AFACT) =   0.9200
NUMBER OF DAYLIGHT HOURS (DLH) =  14.0000   TOTAL DAILY SOLR RAD (LANGLEYS)= 352.8200
ALGY GROWTH CALC OPTION(LGROPT)=   2.0000   ALGAL PREF FOR NH3-N (PREFN)   =   0.9000
ALG/TEMP SOLR RAD FACTOR(TFACT)=   0.4400   NITRIFICATION INHIBITION COEF  =  10.0000
ENDATA1A                           0.0000                                      0.0000
```

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$$$ DATA TYPE 1B (TEMPERATURE CORRECTION CONSTANTS FOR RATE COEFFICIENTS) $$$

CARD TYPE      RATE CODE      THETA VALUE

THETA( 1)       BOD DECA        1.047     DFLT
THETA( 2)       BOD SETT        1.024     DFLT
THETA( 3)       OXY TRAN        1.024     DFLT
THETA( 4)       SOD RATE        1.060     DFLT
THETA( 5)       ORGN DEC        1.047     DFLT
THETA( 6)       ORGN SET        1.024     DFLT
THETA( 7)       NH3 DECA        1.083     DFLT
THETA( 8)       NH3 SRCE        1.074     DFLT
THETA( 9)       NO2 DECA        1.047     DFLT
THETA(10)       PORG DEC        1.047     DFLT
THETA(11)       PORG SET        1.024     DFLT
THETA(12)       DISP SRC        1.074     DFLT
THETA(13)       ALG GROW        1.047     DFLT
THETA(14)       ALG RESP        1.047     DFLT
THETA(15)       ALG SETT        1.024     DFLT
THETA(16)       COLI DEC        1.047     DFLT
THETA(17)       ANC DECA        1.000     DFLT
THETA(18)       ANC SETT        1.024     DFLT
THETA(19)       ANC SRCE        1.000     DFLT
ENDATA1B

 $$$ DATA TYPE 2 (REACH IDENTIFICATION) $$$

CARD TYPE           REACH ORDER AND IDENT              R. MI/KM           R. MI/KM
STREAM REACH     1.0  RCH=      Nang Buat    FROM        37.0     TO       25.0
STREAM REACH     2.0  RCH=    Klong Muang    FROM        25.0     TO       11.0
STREAM REACH     3.0  RCH=     Wat Ampwan    FROM        11.0     TO        0.0
ENDATA2          0.0                                      0.0               0.0

 $$$ DATA TYPE 3 (TARGET LEVEL DO AND FLOW AUGMENTATION SOURCES) $$$

CARD TYPE                    REACH  AVAIL HDWS TARGET      ORDER OF AVAIL SOURCES
ENDATA3                        0.        0.        0.0   0.   0.   0.   0.   0.   0.

 $$$ DATA TYPE 4 (COMPUTATIONAL REACH FLAG FIELD) $$$

CARD TYPE        REACH ELEMENTS/REACH              COMPUTATIONAL FLAGS
FLAG FIELD        1.        12.        1.2.2.2.2.2.2.2.2.2.6.2.0.0.0.0.0.0.0.0.
FLAG FIELD        2.        14.        2.2.2.2.2.7.2.7.2.2.2.2.2.2.0.0.0.0.0.0.
FLAG FIELD        3.        11.        2.2.2.2.2.6.2.2.2.2.5.0.0.0.0.0.0.0.0.0.
ENDATA4           0.         0.        0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.

 $$$ DATA TYPE 5 (HYDRAULIC DATA FOR DETERMINING VELOCITY AND DEPTH) $$$

CARD TYPE        REACH  COEF-DSPN     SS1       SS2      WIDTH      SLOPE     CMANN
HYDRAULICS        1.    2831.57      1.008     1.050    30.000     0.000     0.030
HYDRAULICS        2.    1265.25      1.009     1.051    25.000     0.000     0.030
HYDRAULICS        3.    2211.08      1.007     1.049    33.000     0.000     0.030
ENDATA5           0.       0.00      0.000     0.000     0.000     0.000     0.000
```

$$$ DATA TYPE 5A (STEADY STATE TEMPERATURE AND CLIMATOLOGY DATA) $$$

CARD TYPE	REACH	ELEVATION	DUST COEF	CLOUD COVER	DRY BULB TEMP	WET BULB TEMP	ATM PRESSURE	WIND	SOLAR RAD ATTENUATION
TEMP/LCD	1.	6.56	0.06	0.39	31.60	29.20	1009.78	0.42	1.00
TEMP/LCD	2.	6.56	0.06	0.39	31.60	29.20	1009.78	0.42	1.00
TEMP/LCD	3.	6.56	0.06	0.39	31.60	29.20	1009.78	0.42	1.00
ENDATA5A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 6 (REACTION COEFFICIENTS FOR DEOXYGENATION AND REAERATION) $$$

CARD TYPE	REACH	K1	K3	SOD RATE	K2OPT	K2	COEQK2 OR TSIV COEF OR FOR OPT 8	EXPQK2 SLOPE FOR OPT 8
REACT COEF	1.	0.30	0.01	0.800	3.	0.00	0.000	0.00000
REACT COEF	2.	0.30	0.01	0.800	3.	0.00	0.000	0.00000
REACT COEF	3.	0.30	0.01	0.800	3.	0.00	0.000	0.00000
ENDATA6	0.	0.00	0.00	0.000	0.	0.00	0.000	0.00000

$$$ DATA TYPE 6A (NITROGEN AND PHOSPHORUS CONSTANTS) $$$

CARD TYPE	REACH	CKNH2	SETNH2	CKNH3	SNH3	CKNO2	CKPORG	SETPORG	SPO4
N AND P COEF	1.	0.02	0.00	0.06	0.00	0.50	0.15	0.10	2.00
N AND P COEF	2.	0.02	0.00	0.06	0.00	0.50	0.15	0.10	2.00
N AND P COEF	3.	0.02	0.00	0.06	0.00	0.50	0.15	0.10	2.00
ENDATA6A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 6B (ALGAE/OTHER COEFFICIENTS) $$$

CARD TYPE	REACH	ALPHAO	ALGSET	EXCOEF	CK5 CKCOLI	CKANC	SETANC	SRCANC
ALG/OTHER COEF	1.	10.00	0.30	0.01	0.00	0.00	0.00	0.00
ALG/OTHER COEF	2.	10.00	0.30	0.01	0.00	0.00	0.00	0.00
ALG/OTHER COEF	3.	10.00	0.30	0.01	0.00	0.00	0.00	0.00
ENDATA6B	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 7 (INITIAL CONDITIONS) $$$

CARD TYPE	REACH	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INITIAL COND-1	1.	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	2.	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	3.	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENDATA7	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 7A (INITIAL CONDITIONS FOR CHOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INITIAL COND-2	1.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-2	2.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-2	3.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENDATA7A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 8 (INCREMENTAL INFLOW CONDITIONS) $$$

CARD TYPE	REACH	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INCR INFLOW-1	1.	0.520	32.00	0.00	2.99	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	2.	0.750	32.00	0.00	1.33	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	3.	2.100	32.00	0.00	0.57	0.00	0.00	0.00	0.00	0.00
ENDATA8	0.	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 8A (INCREMENTAL INFLOW CONDITIONS FOR CHLOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INCR INFLOW-2	1.	0.00	0.00	0.00	0.00	0.01	0.00	0.00
INCR INFLOW-2	2.	0.00	0.00	0.01	0.00	0.12	0.00	0.01
INCR INFLOW-2	3.	0.00	0.00	0.01	0.00	0.00	0.00	0.00
ENDATA8A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 9 (STREAM JUNCTIONS) $$$

CARD TYPE	JUNCTION ORDER AND IDENT	UPSTRM	JUNCTION	TRIB
ENDATA9	0.	0.	0.	0.

$$$ DATA TYPE 10 (HEADWATER SOURCES) $$$

CARD TYPE	HDWTR ORDER	NAME	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
HEADWTR-1	1.	Nang Buat	12.84	27.68	7.58	1.04	0.00	0.00	0.00
ENDATA10	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 10A (HEADWATER CONDITIONS FOR CHLOROPHYLL, NITROGEN, PHOSPHORUS, COLIFORM AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE	HDWTR ORDER	ANC	COLI	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
HEADWTR-2	1.	0.00	0.00	0.00	0.00	0.11	0.03	0.23	0.00	0.00
ENDATA10A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 11 (POINT SOURCE / POINT SOURCE CHARACTERISTICS) $$$

CARD TYPE	POINT LOAD ORDER	NAME	EFF	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
POINTLD-1	1.	T.NY	0.00	0.04	32.00	2.50	971.50	0.00	0.00	0.00
POINTLD-1	2.	K.Muang	0.00	-0.39	28.00	3.20	3.20	0.00	0.00	0.00
POINTLD-1	3.	Tha Chang	0.00	-0.56	28.00	3.00	2.40	0.00	0.00	0.00
POINTLD-1	4.	Ban Na	0.00	0.03	28.00	2.00	558.83	0.00	0.00	0.00
ENDATA11	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 11A (POINT SOURCE CHARACTERISTICS - CHLOROPHYLL A, NITROGEN, PHOSPHORUS, COLIFORMS AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE	POINT LOAD ORDER	ANC	COLI	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
POINTLD-2	1.	0.00	0.00	0.00	0.00	0.42	0.27	1.28	0.00	0.49
POINTLD-2	2.	0.00	0.00	0.00	0.00	0.09	0.00	0.03	0.00	0.00
POINTLD-2	3.	0.00	0.00	0.00	0.00	0.04	0.00	0.03	0.00	0.01
POINTLD-2	4.	0.00	0.00	0.00	0.00	0.40	0.03	1.50	0.00	0.17
ENDATA11A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 12 (DAM CHARACTERISTICS) $$$

	DAM	RCH	ELE	ADAM	BDAM	FDAM	HDAM
DAM DATA	1.	2.	12.	1.60	0.05	0.00	6.00
ENDATA12	0.	0.	0.	0.00	0.00	0.00	0.00

$$$ DATA TYPE 13 (DOWNSTREAM BOUNDARY CONDITIONS-1) $$$

CARD TYPE	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
DOWNSTREAM BOUNDARY-1	29.66	3.73	1.49	0.00	0.00	0.00	0.00	0.00
ENDATA13								

$$$ DATA TYPE 13A (DOWNSTREAM BOUNDARY CONDITIONS-2) $$$

CARD TYPE	CHL-A	ORG-N	NH3-N	NO2-N	NH3-N	ORG-P	DIS-P
DOWNSTREAM BOUNDARY-2	0.00	0.00	0.15	0.04	0.21	0.00	0.02
ENDATA13A							

APPENDIX F

EXAMPLE OF DATA OUTPUT

STREAM QUALITY SIMULATION
QUAL-2E STREAM QUALITY ROUTING MODEL

OUTPUT PAGE NUMBER 1
Version 3.21 - Feb. 1995

***** STEADY STATE SIMULATION *****

** HYDRAULICS SUMMARY **

ELE ORD	RCH NUM	ELE NUM	BEGIN LOC KILO	END LOC KILO	FLOW CMS	POINT SRCE CMS	INCR FLOW CMS	VEL MPS	TRVL TIME DAY	DEPTH M	WIDTH M	VOLUME K-CU-M	BOTTOM AREA K-SQ-M	X-SECT AREA SQ-M	DSPRSN COEF SQ-M/S
1	1	1	37.00	36.00	12.88	0.00	0.04	0.401	0.029	1.034	31.064	32.12	32.97	32.11	109.75
2	1	2	36.00	35.00	12.93	0.00	0.04	0.402	0.029	1.036	31.066	32.19	32.98	32.18	110.08
3	1	3	35.00	34.00	12.97	0.00	0.04	0.402	0.029	1.038	31.068	32.25	32.99	32.25	110.40
4	1	4	34.00	33.00	13.01	0.00	0.04	0.403	0.029	1.040	31.070	32.32	32.99	32.31	110.72
5	1	5	33.00	32.00	13.06	0.00	0.04	0.403	0.029	1.042	31.072	32.39	33.00	32.38	111.05
6	1	6	32.00	31.00	13.10	0.00	0.04	0.404	0.029	1.044	31.074	32.45	33.00	32.45	111.37
7	1	7	31.00	30.00	13.14	0.00	0.04	0.404	0.029	1.046	31.077	32.52	33.01	32.51	111.70
8	1	8	30.00	29.00	13.19	0.00	0.04	0.405	0.029	1.048	31.079	32.59	33.02	32.58	112.02
9	1	9	29.00	28.00	13.23	0.00	0.04	0.405	0.029	1.050	31.081	32.65	33.02	32.65	112.34
10	1	10	28.00	27.00	13.27	0.00	0.04	0.406	0.029	1.052	31.083	32.72	33.03	32.71	112.67
11	1	11	27.00	26.00	13.36	0.04	0.04	0.407	0.028	1.057	31.087	32.85	33.04	32.85	113.31
12	1	12	26.00	25.00	13.40	0.00	0.04	0.407	0.028	1.059	31.089	32.92	33.05	32.91	113.63
13	2	1	25.00	24.00	13.46	0.00	0.05	0.474	0.024	1.086	26.119	28.38	28.13	28.37	60.42
14	2	2	24.00	23.00	13.51	0.00	0.05	0.475	0.024	1.089	26.122	28.45	28.13	28.44	60.63
15	2	3	23.00	22.00	13.56	0.00	0.05	0.476	0.024	1.092	26.124	28.52	28.14	28.51	60.84
16	2	4	22.00	21.00	13.62	0.00	0.05	0.476	0.024	1.094	26.127	28.59	28.15	28.59	61.05
17	2	5	21.00	20.00	13.67	0.00	0.05	0.477	0.024	1.097	26.130	28.66	28.16	28.66	61.26
18	2	6	20.00	19.00	13.34	-0.39	0.05	0.473	0.024	1.081	26.113	28.22	28.11	28.22	59.95
19	2	7	19.00	18.00	13.39	0.00	0.05	0.473	0.024	1.083	26.116	28.29	28.12	28.29	60.17
20	2	8	18.00	17.00	12.88	-0.56	0.05	0.467	0.025	1.058	26.090	27.61	28.04	27.61	58.16
21	2	9	17.00	16.00	12.94	0.00	0.05	0.467	0.025	1.061	26.093	27.69	28.05	27.68	58.37
22	2	10	16.00	15.00	12.99	0.00	0.05	0.468	0.025	1.063	26.095	27.76	28.06	27.75	58.58
23	2	11	15.00	14.00	13.04	0.00	0.05	0.469	0.025	1.066	26.098	27.83	28.07	27.82	58.79
24	2	12	14.00	13.00	13.10	0.00	0.05	0.469	0.025	1.069	26.101	27.90	28.08	27.89	59.00
25	2	13	13.00	12.00	13.15	0.00	0.05	0.470	0.025	1.071	26.104	27.97	28.08	27.97	59.21
26	2	14	12.00	11.00	13.20	0.00	0.05	0.471	0.025	1.074	26.106	28.04	28.09	28.04	59.42
27	3	1	11.00	10.00	13.39	0.00	0.19	0.347	0.033	1.129	34.160	38.56	36.25	38.55	79.84
28	3	2	10.00	9.00	13.59	0.00	0.19	0.349	0.033	1.138	34.170	38.90	36.27	38.89	80.84
29	3	3	9.00	8.00	13.78	0.00	0.19	0.351	0.033	1.148	34.180	39.24	36.30	39.23	81.84
30	3	4	8.00	7.00	13.97	0.00	0.19	0.353	0.033	1.157	34.190	39.58	36.33	39.57	82.84
31	3	5	7.00	6.00	14.16	0.00	0.19	0.355	0.033	1.167	34.200	39.92	36.36	39.91	83.83
32	3	6	6.00	5.00	4.38	0.03	0.19	0.357	0.032	1.178	34.211	40.31	36.39	40.30	85.00
33	3	7	5.00	4.00	14.57	0.00	0.19	0.359	0.032	1.187	34.221	40.64	36.41	40.63	85.99
34	3	8	4.00	3.00	14.76	0.00	0.19	0.360	0.032	1.197	34.230	40.97	36.44	40.96	86.98
35	3	9	3.00	2.00	14.96	0.00	0.19	0.362	0.032	1.206	34.240	41.30	36.47	41.29	87.97
36	3	10	2.00	1.00	15.15	0.00	0.19	0.364	0.032	1.215	34.249	41.63	36.49	41.62	88.95
37	3	11	1.00	0.00	15.34	0.00	0.19	0.366	0.032	1.224	34.259	41.95	36.52	41.95	89.93

STREAM QUALITY SIMULATION
QUAL-2E STREAM QUALITY ROUTING MODEL

OUTPUT PAGE NUMBER 3
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***** STEADY STATE SIMULATION *****

** WATER QUALITY VARIABLES **

RCH NUM	ELE NUM	TEMP DEG-C	CM-1	CM-2	CM-3	DO MG/L	BOD MG/L	ORGN MG/L	NH3N MG/L	NO2N MG/L	NO3N MG/L	SUM-N MG/L	ORGP MG/L	DIS-P MG/L	SUM-P MG/L	COLI #/100ML	ANC	CHLA UG/L
1	1	27.82	0.00	0.00	0.00	7.54	1.03	0.00	0.11	0.03	0.23	0.37	0.00	0.00	0.00	0.00	0.00	0.00
1	2	27.96	0.00	0.00	0.00	7.49	1.03	0.00	0.10	0.03	0.23	0.37	0.00	0.00	0.00	0.00	0.00	0.00
1	3	28.10	0.00	0.00	0.00	7.45	1.02	0.00	0.10	0.03	0.23	0.37	0.00	0.00	0.00	0.00	0.00	0.00
1	4	28.24	0.00	0.00	0.00	7.41	1.01	0.00	0.10	0.03	0.23	0.36	0.00	0.00	0.00	0.00	0.00	0.00
1	5	28.37	0.00	0.00	0.00	7.38	1.01	0.00	0.10	0.03	0.23	0.36	0.00	0.00	0.00	0.00	0.00	0.00
1	6	28.50	0.00	0.00	0.00	7.34	1.00	0.00	0.10	0.03	0.23	0.36	0.00	0.00	0.00	0.00	0.00	0.00
1	7	28.63	0.00	0.00	0.00	7.31	1.00	0.00	0.10	0.03	0.23	0.36	0.00	0.00	0.00	0.00	0.00	0.00
1	8	28.76	0.00	0.00	0.00	7.27	1.02	0.00	0.10	0.03	0.23	0.36	0.00	0.00	0.00	0.00	0.00	0.00
1	9	28.88	0.00	0.00	0.00	7.23	1.12	0.00	0.10	0.03	0.23	0.36	0.00	0.00	0.00	0.00	0.00	0.00
1	10	29.00	0.00	0.00	0.00	7.19	1.63	0.00	0.10	0.03	0.23	0.36	0.00	0.00	0.00	0.00	0.00	0.00
1	11	29.13	0.00	0.00	0.00	7.11	4.03	0.00	0.10	0.03	0.23	0.36	0.00	0.01	0.01	0.00	0.00	0.00
1	12	29.24	0.00	0.00	0.00	7.06	3.98	0.00	0.10	0.03	0.23	0.36	0.00	0.01	0.01	0.00	0.00	0.00
2	1	29.34	0.00	0.00	0.00	7.01	3.92	0.00	0.10	0.03	0.23	0.36	0.00	0.01	0.01	0.00	0.00	0.00
2	2	29.44	0.00	0.00	0.00	6.96	3.87	0.00	0.10	0.03	0.23	0.36	0.00	0.01	0.01	0.00	0.00	0.00
2	3	29.53	0.00	0.00	0.00	6.91	3.81	0.00	0.10	0.03	0.23	0.36	0.00	0.01	0.01	0.00	0.00	0.00
2	4	29.63	0.00	0.00	0.00	6.86	3.76	0.00	0.10	0.03	0.23	0.36	0.00	0.01	0.01	0.00	0.00	0.00
2	5	29.72	0.00	0.00	0.00	6.82	3.71	0.00	0.10	0.03	0.23	0.36	0.00	0.01	0.01	0.00	0.00	0.00
2	6	29.81	0.00	0.00	0.00	6.78	3.66	0.00	0.09	0.03	0.23	0.36	0.00	0.01	0.01	0.00	0.00	0.00
2	7	29.90	0.00	0.00	0.00	6.74	3.60	0.00	0.09	0.03	0.23	0.35	0.00	0.01	0.01	0.00	0.00	0.00
2	8	29.99	0.00	0.00	0.00	6.71	3.55	0.00	0.09	0.03	0.23	0.35	0.00	0.01	0.01	0.00	0.00	0.00
2	9	30.08	0.00	0.00	0.00	6.68	3.50	0.00	0.09	0.03	0.23	0.35	0.00	0.01	0.01	0.00	0.00	0.00
2	10	30.17	0.00	0.00	0.00	6.65	3.45	0.00	0.09	0.03	0.23	0.35	0.00	0.01	0.01	0.00	0.00	0.00
2	11	30.26	0.00	0.00	0.00	6.62	3.40	0.00	0.09	0.03	0.23	0.35	0.00	0.01	0.01	0.00	0.00	0.00
2	12	30.35	0.00	0.00	0.00	6.59	3.35	0.00	0.09	0.02	0.23	0.35	0.00	0.01	0.01	0.00	0.00	0.00
2	13	30.44	0.00	0.00	0.00	6.56	3.30	0.00	0.09	0.02	0.23	0.35	0.00	0.01	0.01	0.00	0.00	0.00
2	14	30.52	0.00	0.00	0.00	6.53	3.25	0.00	0.09	0.02	0.23	0.35	0.00	0.01	0.01	0.00	0.00	0.00
3	1	30.64	0.00	0.00	0.00	6.43	3.16	0.00	0.09	0.02	0.23	0.34	0.00	0.01	0.01	0.00	0.00	0.00
3	2	30.75	0.00	0.00	0.00	6.34	3.08	0.00	0.09	0.02	0.23	0.34	0.00	0.01	0.01	0.00	0.00	0.00
3	3	30.86	0.00	0.00	0.00	6.26	3.00	0.00	0.09	0.02	0.23	0.33	0.00	0.01	0.01	0.00	0.00	0.00
3	4	30.96	0.00	0.00	0.00	6.19	2.95	0.00	0.08	0.02	0.22	0.33	0.00	0.01	0.01	0.00	0.00	0.00
3	5	31.06	0.00	0.00	0.00	6.11	3.07	0.00	0.08	0.02	0.22	0.33	0.00	0.01	0.01	0.00	0.00	0.00
3	6	31.15	0.00	0.00	0.00	6.03	4.04	0.00	0.08	0.02	0.22	0.32	0.00	0.01	0.01	0.00	0.00	0.00
3	7	31.25	0.00	0.00	0.00	5.96	3.93	0.00	0.08	0.02	0.22	0.32	0.00	0.01	0.01	0.00	0.00	0.00
3	8	31.33	0.00	0.00	0.00	5.89	3.82	0.00	0.08	0.02	0.22	0.32	0.00	0.01	0.01	0.00	0.00	0.00
3	9	31.41	0.00	0.00	0.00	5.82	3.71	0.00	0.08	0.02	0.22	0.31	0.00	0.01	0.01	0.00	0.00	0.00
3	10	31.43	0.00	0.00	0.00	5.72	3.55	0.00	0.08	0.02	0.21	0.31	0.00	0.01	0.01	0.00	0.00	0.00
3	11	31.20	0.00	0.00	0.00	5.38	3.15	0.00	0.09	0.02	0.21	0.32	0.00	0.01	0.01	0.00	0.00	0.00

END OF SYSTEM BOUNDARY CONCENTRATIONS

		TEMP DEG-C	CM-1	CM-2	CM-3	DO MG/L	BOD MG/L	ORGN MG/L	NH3N MG/L	NO2N MG/L	NO3N MG/L	SUM-N MG/L	ORGP MG/L	DIS-P MG/L	SUM-P MG/L	COLI #/100ML	ANC	CHLA UG/L
		29.66	0.00	0.00	0.00	3.73	1.49	0.00	0.15	0.04	0.21	0.40	0.00	0.02	0.02	0.00	0.00	0.00

APPENDIX G

RESULTS OF FIRST ORDER ERROR ANALYSIS

SUMMARY OF FIRST ORDER ERROR ANALYSIS INPUT VARIANCE CONDITIONS

RELATIVE STANDARD DEVIATION (%)		INPUT VARIABLE OR PARAMETER	INPUT DATA TYPE	MAGNITUDE OF INPUT PERTURBATION (%)
10.00	1	EVAPORATION COEF - AE	1	5.0
10.00	2	EVAPORATION COEF - BE	1	5.0
10.00	3	OXYGEN UPTAKE BY NH3 OXDTN	1A	5.0
10.00	4	OXYGEN UPTAKE BY NO2 OXDTN	1A	5.0
10.00	5	OXYGEN PROD BY ALGAE GRWTH	1A	5.0
10.00	6	OXYGEN UPTAKE BY ALGY RESP	1A	5.0
10.00	7	NITROGEN CONTENT OF ALGAE	1A	5.0
10.00	8	PHOSPHORUS CONTENT OF ALGY	1A	5.0
3.00	9	TEMP COEF BOD DECAY	1B	5.0
3.00	10	TEMP COEF BOD SETTLING	1B	5.0
3.00	11	TEMP COEF O2 REAERATION	1B	5.0
3.00	12	TEMP COEF SED O2 DEMAND	1B	5.0
3.00	13	TEMP COEF ORGANIC-N DECAY	1B	5.0
3.00	14	TEMP COEF ORGANIC-N SET	1B	5.0
3.00	15	TEMP COEF AMMONIA DECAY	1B	5.0
3.00	16	TEMP COEF AMMONIA SRCE	1B	5.0
3.00	17	TEMP COEF NITRITE DECAY	1B	5.0
3.00	18	TEMP COEF ORGANIC-P DECAY	1B	5.0
3.00	19	TEMP COEF ORGANIC-P SET	1B	5.0
3.00	20	TEMP COEF DISS-P SOURCE	1B	5.0
20.00	21	DISPERSION CORR CONSTANT	5	5.0
10.00	22	MANNING'S ROUGHNESS N	5	5.0
5.00	23	SIDE SLOPE 1	5	5.0
5.00	24	SIDE SLOPE 2	5	5.0
5.00	25	BOTTOM WIDTH	5	5.0
5.00	26	SLOPE OF CHANNEL	5	5.0
5.00	27	MEAN ELEVATION OF REACH	5A	5.0
5.00	28	DUST ATTENUATION COEF	5A	5.0
5.00	29	FRACTION OF CLOUDINESS	5A	5.0
5.00	30	DRY BULB AIR TEMPERATURE	5A	5.0
5.00	31	WET BULB AIR TEMPERATURE	5A	5.0
1.00	32	ATMOSPHERIC PRESSURE	5A	5.0
10.00	33	WIND VELOCITY	5A	5.0
15.00	34	CBOD OXIDATION RATE	6	5.0
15.00	35	CBOD SETTLING RATE	6	5.0
20.00	36	SOD UPTAKE RATE	6	5.0
20.00	37	ORGANIC-N HYDROLYSIS RATE	6A	5.0
20.00	38	ORGANIC-N SETTLING RATE	6A	5.0
20.00	39	AMMONIA-N DECAY RATE	6A	5.0
20.00	40	NITRITE-N DECAY RATE	6A	5.0
20.00	41	ORGANIC-P HYDROLYSIS RATE	6A	5.0
20.00	42	ORGANIC-P SETTLING RATE	6A	5.0
20.00	43	DISSOLVED-P BENTHAL SRCE	6A	5.0
5.00	44	INCREMENTAL FLOW	8	5.0
2.00	45	INCR-TEMPERATURE	8	5.0
10.00	46	INCR-BOD	8	5.0
15.00	47	INCR-AMMONIA-N	8A	5.0
15.00	48	INCR-NITRITE-N	8A	5.0

15.00	49	INCR-NITRATE-N	8A	5.0
15.00	50	INCR-DISSOLVED-PHOS	8A	5.0
5.00	51	HEADWATER FLOW	10	5.0
2.00	52	HWTR-TEMPERATURE	10	5.0
5.00	53	HWTR-DISSOLVED OXYGEN	10	5.0
10.00	54	HWTR-BOD	10	5.0
15.00	55	HWTR-AMMONIA-N	10A	5.0
15.00	56	HWTR-NITRITE-N	10A	5.0
15.00	57	HWTR-NITRATE-N	10A	5.0
15.00	58	HWTR-DISSOLVED-PHOS	10A	5.0
5.00	59	POINT LOAD FLOW	11	5.0
2.00	60	PTLD-TEMPERATURE	11	5.0
5.00	61	PTLD-DISSOLVED OXYGEN	11	5.0
10.00	62	PTLD-BOD	11	5.0
15.00	63	PTLD-AMMONIA-N	11A	5.0
15.00	64	PTLD-NITRITE-N	11A	5.0
15.00	65	PTLD-NITRATE-N	11A	5.0
15.00	66	PTLD-DISOLVED-PHOS	11A	5.0
10.00	67	DAM COEFFICIENT A	12	5.0
10.00	68	DAM COEFFICIENT B	12	5.0
10.00	69	FRACTION DF FLOW OVER DAM	12	5.0

2. FIRST ORDER ERROR ANALYSIS: RESPONSE NO. 1

A. TITLE OF DATA SET.

Nakhon Nayok Water Quality

B. RESPONSE VARIABLE: FLOW

C. NORMALIZED SENSITIVITY COEFFICIENT MATRIX: FLOW

INPUT VAR	LOCATION	
	REACH 1 ELEMENT 12	REACH 3 ELEMENT 6
INCRFLOW	0.039	0.168
HWTRFLOW	0.958	0.893

OTHER INPUTS WITH NORMALIZED SENSITIVITY COEFFICIENTS LESS THAN 0.10 EACH.

DISPSN-K MANNINGS TRAP-SS1 TRAP-SS2 TRAP-WTH
TRAP-SLP PTLDFLOW

D. COMPONENTS OF VARIANCE MATRIX: FLOW

INPUT VAR	LOCATION	
	REACH 1 ELEMENT 12	REACH 3 ELEMENT 6
INCRFLOW		
VAR	0.8427	18.1903
VAR(%)	(0.16%)	(3.40%)
STDEV	0.918	4.265
HWTRFLOW		
VAR	514.0	514.0
VAR(%)	(99.84%)	(96.15%)
STDEV	22.671	22.671
SUM		
VAR	514.8	534.5
VAR(%)	(100.00%)	(99.56%)
STDEV	22.69	23.12

OTHER INPUTS AFFECTING OUTPUT VARIANCE BY LESS THAN 1.0% EACH.

DISPSN-K MANNINGS TRAP-SS1 TRAP-SS2 TRAP-WTH
TRAP-SLP PTLDFLOW

2. FIRST ORDER ERROR ANALYSIS: RESPONSE NO. 12

A. TITLE OF DATA SET.

Nakhon Nayok Water Quality

B. RESPONSE VARIABLE: DO

C. NORMALIZED SENSITIVITY COEFFICIENT MATRIX: DO

INPUT VAR	LOCATION REACH 1 ELEMENT 12	 REACH 3 ELEMENT 6
MANNINGS	-0.046	-0.130
WETBULB	-0.047	-0.175
ATMPRES	0.685	1.102
HWTRFLOW	0.045	0.115
HWTRTEMP	-0.563	-0.678
HWTRDO	0.407	0.096

OTHER INPUTS WITH NORMALIZED SENSITIVITY COEFFICIENTS LESS THAN 0.10 EACH.

ECOEF-AE	ECOEF-BE	NH3OXYUP	NO2OXYUP	AGYOXYPR
AGYOXYUP	AGYNCON	AGYPCON	TC/BODDC	TC/BODST
TC/REAER	TC/SOD	TC/NH2DC	TC/NH2ST	TC/NH3DC
TC/NH3SC	TC/NO2DC	TC/PRGDC	TC/PRGST	TC/PO4SC
DISPSN-K	TRAP-SS1	TRAP-SS2	TRAP-WTH	TRAP-SLP
ELEVATIN	DUSTATTN	CLOUD	DRYBULB	WINDVEL
BOD DECA	BOD SETT	SOD RATE	NH2 DECA	NH2 SETT
NH3 DECA	NO2 DECA	PORG DEC	PORG SET	DISP SRC
INCRFLOW	INCRTEMP	INCRBOD	INCRNH3N	INCRNO2N
INCRNO3N	INCRDISP	HWTRBOD	HWTRNH3N	HWTRNO2N
HWTRNO3N	HWTRDISP	PTLDFLOW	PTLDTEMP	PTLDDO
PTLDBOD	PTLDNH3N	PTLDNO2N	PTLDNO3N	PTLDDISP
DAMSACOF	DAMSBCOF	DAMSFRAC		

D. COMPONENTS OF VARIANCE MATRIX: DO

INPUT VAR	LOCATION: REACH 1 ELEMENT 12	LOCATION: REACH 3 ELEMENT 6
MANNINGS		
VAR	0.0010	0.0061
VAR(%)	(2.99%)	(16.93%)
STDEV	0.032	0.078
TRAP-SLP		
VAR	0.0001	0.0004
VAR(%)	(0.18%)	(1.02%)
STDEV	0.008	0.019
DRYBULB		
VAR	0.0001	0.0006
VAR(%)	(0.18%)	(1.79%)
STDEV	0.008	0.025
WETBULB		
VAR	0.0003	0.0028
VAR(%)	(0.79%)	(7.69%)
STDEV	0.017	0.053
ATMPRES		
VAR	0.0023	0.0044
VAR(%)	(6.70%)	(12.23%)
STDEV	0.048	0.066
BOD DECA		
VAR	0.0006	0.0031
VAR(%)	(1.72%)	(8.54%)
STDEV	0.025	0.055
SOD RATE		
VAR	0.0031	0.0073
VAR(%)	(8.85%)	(20.25%)
STDEV	0.056	0.085
INCRFLOW		
VAR	0.0001	0.0007
VAR(%)	(0.23%)	(1.81%)
STDEV	0.009	0.026
HWTRFLOW		
VAR	0.0002	0.0012
VAR(%)	(0.71%)	(3.36%)
STDEV	0.016	0.035
HWTRTEMP		
VAR	0.0063	0.0067
VAR(%)	(18.09%)	(18.55%)
STDEV	0.079	0.082
HWTRDO		
VAR	0.0206	0.0008

```
  VAR(%)       ( 58.96%)      (  2.32%)
  STDEV             0.143          0.029

 PTLDBOD
  VAR              0.0001         0.0012
  VAR(%)       (  0.20%)      (  3.24%)
  STDEV             0.008          0.034


 SUM
  VAR               0.035          0.036
  VAR(%)       ( 99.61%)      ( 97.73%)
  STDEV             0.187          0.190
```

OTHER INPUTS AFFECTING OUTPUT VARIANCE BY LESS THAN 1.0% EACH.

ECOEF-AE	ECOEF-BE	NH3OXYUP	NO2OXYUP	AGYOXYPR
AGYOXYUP	AGYNCON	AGYPCON	TC/BODDC	TC/BODST
TC/REAER	TC/SOD	TC/NH2DC	TC/NH2ST	TC/NH3DC
TC/NH3SC	TC/NO2DC	TC/PRGDC	TC/PRGST	TC/PO4SC
DISPSN-K	TRAP-SS1	TRAP-SS2	TRAP-WTH	ELEVATIN
DUSTATTN	CLOUD	WINDVEL	BOD SETT	NH2 DECA
NH2 SETT	NH3 DECA	NO2 DECA	PORG DEC	PORG SET
DISP SRC	INCRTEMP	INCRBOD	INCRNH3N	INCRNO2N
INCRNO3N	INCRDISP	HWTRBOD	HWTRNH3N	HWTRNO2N
HWTRNO3N	HWTRDISP	PTLDFLOW	PTLDTEMP	PTLDDO
PTLDNH3N	PTLDNO2N	PTLDNO3N	PTLDDISP	DAMSACOF
DAMSBCOF	DAMSFRAC			

2. FIRST ORDER ERROR ANALYSIS: RESPONSE NO. 13

A. TITLE OF DATA SET.

Nakhon Nayok Water Quality

B. RESPONSE VARIABLE: BOD

C. NORMALIZED SENSITIVITY COEFFICIENT MATRIX: BOD

INPUT VAR	LOCATION REACH 1 ELEMENT 12	LOCATION REACH 3 ELEMENT 6
MANNINGS	-0.046	-0.149
BOD DECA	-0.058	-0.213
INCRFLOW	-0.013	-0.118
HWTRFLOW	-0.688	-0.588
HWTRTEMP	-0.111	-0.331
HWTRBOD	0.215	0.141
PTLDFLOW	0.756	0.827
PTLDBOD	0.759	0.817

OTHER INPUTS WITH NORMALIZED SENSITIVITY COEFFICIENTS LESS THAN 0.10 EACH.

ECOEF-AE	ECOEF-BE	TC/BODDC	TC/BODST	DISPSN-K
TRAP-SS1	TRAP-SS2	TRAP-WTH	TRAP-SLP	ELEVATIN
DUSTATTN	CLOUD	DRYBULB	WETBULB	ATMPRES
WINDVEL	BOD SETT	INCRTEMP	INCRBOD	PTLDTEMP

D. COMPONENTS OF VARIANCE MATRIX: BOD

INPUT VAR	LOCATION REACH 1 ELEMENT 12	LOCATION REACH 3 ELEMENT 6
MANNINGS		
VAR	0.0003	0.0036
VAR(%)	(0.24%)	(2.04%)
STDEV	0.018	0.060
BOD DECA		
VAR	0.0012	0.0166
VAR(%)	(0.85%)	(9.39%)
STDEV	0.035	0.129
HWTRFLOW		
VAR	0.0187	0.0141
VAR(%)	(13.21%)	(7.97%)
STDEV	0.137	0.119
HWTRBOD		
VAR	0.0073	0.0032
VAR(%)	(5.15%)	(1.83%)
STDEV	0.085	0.057
PTLDFLOW		
VAR	0.0226	0.0279
VAR(%)	(15.96%)	(15.74%)
STDEV	0.150	0.167
PTLDBOD		
VAR	0.0910	0.1091
VAR(%)	(64.40%)	(61.59%)
STDEV	0.302	0.330
SUM		
VAR	0.141	0.177
VAR(%)	(99.81%)	(98.56%)
STDEV	0.376	0.421

OTHER INPUTS AFFECTING OUTPUT VARIANCE BY LESS THAN 1.0% EACH.

ECOEF-AE	ECOEF-BE	TC/BODDC	TC/BODST	DISPSN-K
TRAP-SS1	TRAP-SS2	TRAP-WTH	TRAP-SLP	ELEVATIN
DUSTATTN	CLOUD	DRYBULB	WETBULB	ATMPRES
WINDVEL	BOD SETT	INCRFLOW	INCRTEMP	INCRBOD
HWTRTEMP	PTLDTEMP			

APPENDIX H

RESULTS OF MONTE CARLO SIMULATION

SUMMARY OF MONTE CARLO INPUT VARIANCE CONDITIONS 2000 SIMULATIONS

INPUT PDF		INPUT VARIABLE OR PARAMETER	INPUT DATA TYPE	RELATIVE STANDARD DEVIATION (%)
NM	1	EVAPORATION COEF - AE	1	10.00
NM	2	EVAPORATION COEF - BE	1	10.00
NM	3	OXYGEN UPTAKE BY NH3 OXDTN	1A	10.00
NM	4	OXYGEN UPTAKE BY NO2 OXDTN	1A	10.00
NM	5	OXYGEN PROD BY ALGAE GRWTH	1A	10.00
NM	6	OXYGEN UPTAKE BY ALGY RESP	1A	10.00
NM	7	NITROGEN CONTENT OF ALGAE	1A	10.00
NM	8	PHOSPHORUS CONTENT OF ALGY	1A	10.00
NM	9	TEMP COEF BOD DECAY	1B	3.00
NM	10	TEMP COEF BOD SETTLING	1B	3.00
NM	11	TEMP COEF O2 REAERATION	1B	3.00
NM	12	TEMP COEF SED O2 DEMAND	1B	3.00
NM	13	TEMP COEF ORGANIC-N DECAY	1B	3.00
NM	14	TEMP COEF ORGANIC-N SET	1B	3.00
NM	15	TEMP COEF AMMONIA DECAY	1B	3.00
NM	16	TEMP COEF AMMONIA SRCE	1B	3.00
NM	17	TEMP COEF NITRITE DECAY	1B	3.00
NM	18	TEMP COEF ORGANIC-P DECAY	1B	3.00
NM	19	TEMP COEF ORGANIC-P SET	1B	3.00
NM	20	TEMP COEF DISS-P SOURCE	1B	3.00
NM	21	DISPERSION CORR CONSTANT	5	20.00
NM	22	MANNING'S ROUGHNESS N	5	10.00
NM	23	SIDE SLOPE 1	5	5.00
NM	24	SIDE SLOPE 2	5	5.00
NM	25	BOTTOM WIDTH	5	5.00
NM	26	SLOPE OF CHANNEL	5	5.00
NM	27	MEAN ELEVATION OF REACH	5A	5.00
NM	28	DUST ATTENUATION COEF	5A	5.00
NM	29	FRACTION OF CLOUDINESS	5A	5.00
NM	30	DRY BULB AIR TEMPERATURE	5A	5.00
NM	31	WET BULB AIR TEMPERATURE	5A	5.00
NM	32	ATMOSPHERIC PRESSURE	5A	1.00
NM	33	WIND VELOCITY	5A	10.00
NM	34	CBOD OXIDATION RATE	6	15.00
NM	35	CBOD SETTLING RATE	6	15.00
NM	36	SOD UPTAKE RATE	6	20.00
NM	37	ORGANIC-N HYDROLYSIS RATE	6A	20.00
NM	38	ORGANIC-N SETTLING RATE	6A	20.00
NM	39	AMMONIA-N DECAY RATE	6A	20.00
NM	40	NITRITE-N DECAY RATE	6A	20.00
NM	41	ORGANIC-P HYDROLYSIS RATE	6A	20.00
NM	42	ORGANIC-P SETTLING RATE	6A	20.00
NM	43	DISSOLVED-P BENTHAL SRCE	6A	20.00
NM	44	INCREMENTAL FLOW	8	5.00
NM	45	INCR-TEMPERATURE	8	2.00

NM	46	INCR-BOD	8	10.00
NM	47	INCR-AMMONIA-N	8A	15.00
NM	48	INCR-NITRITE-N	8A	15.00
NM	49	INCR-NITRATE-N	8A	15.00
NM	50	INCR-DISSOLVED-PHOS	8A	15.00
NM	51	HEADWATER FLOW	10	5.00
NM	52	HWTR-TEMPERATURE	10	2.00
NM	53	HWTR-DISSOLVED OXYGEN	10	5.00
NM	54	HWTR-BOD	10	10.00
NM	55	HWTR-AMMONIA-N	10A	15.00
NM	56	HWTR-NITRITE-N	10A	15.00
NM	57	HWTR-NITRATE-N	10A	15.00
NM	58	HWTR-DISSOLVED-PHOS	10A	15.00
NM	59	POINT LOAD FLOW	11	5.00
NM	60	PTLD-TEMPERATURE	11	2.00
NM	61	PTLD-DISSOLVED OXYGEN	11	5.00
NM	62	PTLD-BOD	11	10.00
NM	63	PTLD-AMMONIA-N	11A	15.00
NM	64	PTLD-NITRITE-N	11A	15.00
NM	65	PTLD-NITRATE-N	11A	15.00
NM	66	PTLD-DISOLVED-PHOS	11A	15.00
NM	67	DAM COEFFICIENT A	12	10.00
NM	68	DAM COEFFICIENT B	12	10.00
NM	69	FRACTION OF FLOW OVER DAM	12	10.00

MONTE CARLO SIMULATION SUMMARY, RESPONSE NO. 1 FLOW

STATISTIC	LOCATION	
	REACH 1 ELEMENT 12	REACH 3 ELEMENT 6
BASE MEAN	473.308	507.906
SIM MEAN	472.952	507.577
BIAS	-0.356	-0.329
MINIMUM	394.612	423.412
MAXIMUM	559.523	597.425
RANGE	164.911	174.013
STD DEV	22.532	22.979
COEF VAR	0.048	0.045
SKEW COEF	-0.008	0.002

FREQUENCY
DISTRIBUTION
(STDV FROM MEAN)

FREQ	FREQ	CUM REL FREQ	FREQ	CUM REL FREQ
LT -4.0	0.	0.000	0.	0.000
-4.0 TO -3.5	0.	0.000	1.	0.001
-3.5 TO -3.0	2.	0.001	0.	0.001
-3.0 TO -2.5	7.	0.005	8.	0.004
-2.5 TO -2.0	39.	0.024	38.	0.023
-2.0 TO -1.5	87.	0.068	92.	0.069
-1.5 TO -1.0	200.	0.168	190.	0.164
-1.0 TO -0.5	268.	0.301	293.	0.311
-0.5 TO 0.0	379.	0.491	369.	0.495
0.0 TO 0.5	406.	0.694	397.	0.694
0.5 TO 1.0	293.	0.840	297.	0.843
1.0 TO 1.5	191.	0.936	182.	0.934
1.5 TO 2.0	82.	0.977	87.	0.977
2.0 TO 2.5	36.	0.995	38.	0.996
2.5 TO 3.0	7.	0.998	5.	0.999
3.0 TO 3.5	2.	0.999	2.	1.000
3.5 TO 4.0	1.	1.000	1.	1.000
GT +4.0	0.	1.000	0.	1.000

MONTE CARLO SIMULATION SUMMARY, RESPONSE NO. 12 DO

STATISTIC	LOCATION REACH 1 ELEMENT 12	LOCATION REACH 3 ELEMENT 6
BASE MEAN	7.056	6.028
SIM MEAN	7.062	6.040
BIAS	0.006	0.012
MINIMUM	6.525	5.220
MAXIMUM	7.652	6.664
RANGE	1.127	1.443
STD DEV	0.183	0.184
COEF VAR	0.026	0.030
SKEW COEF	-0.034	-0.114

FREQUENCY
DISTRIBUTION
(STDV FROM MEAN)

CUM REL FREQ FREQ	FREQ	CUM REL FREQ	FREQ	CUM REL FREQ
LT -4.0	0.	0.000	1.	0.001
-4.0 TO -3.5	0.	0.000	0.	0.001
-3.5 TO -3.0	0.	0.000	5.	0.003
-3.0 TO -2.5	10.	0.005	9.	0.007
-2.5 TO -2.0	37.	0.023	37.	0.026
-2.0 TO -1.5	93.	0.070	85.	0.068
-1.5 TO -1.0	197.	0.169	175.	0.156
-1.0 TO -0.5	260.	0.299	291.	0.301
-0.5 TO 0.0	412.	0.504	368.	0.485
0.0 TO 0.5	361.	0.685	405.	0.688
0.5 TO 1.0	301.	0.835	326.	0.851
1.0 TO 1.5	201.	0.936	176.	0.939
1.5 TO 2.0	88.	0.980	80.	0.979
2.0 TO 2.5	29.	0.994	32.	0.995
2.5 TO 3.0	10.	0.999	7.	0.998
3.0 TO 3.5	1.	1.000	3.	1.000
3.5 TO 4.0	0.	1.000	0.	1.000
GT +4.0	0.	1.000	0.	1.000

MONTE CARLO SIMULATION SUMMARY, RESPONSE NO. 13 BOD

STATISTIC	LOCATION REACH 1 ELEMENT 12	REACH 3 ELEMENT 6
BASE MEAN	3.976	4.040
SIM MEAN	3.987	4.057
BIAS	0.012	0.017
MINIMUM	2.858	2.828
MAXIMUM	5.275	5.543
RANGE	2.417	2.716
STD DEV	0.384	0.429
COEF VAR	0.096	0.106
SKEW COEF	0.254	0.276

FREQUENCY
DISTRIBUTION
(STDV FROM MEAN)

FREQ	FREQ	CUM REL FREQ	FREQ	CUM REL FREQ
LT -4.0	0.	0.000	0.	0.000
-4.0 TO -3.5	0.	0.000	0.	0.000
-3.5 TO -3.0	0.	0.000	0.	0.000
-3.0 TO -2.5	6.	0.003	5.	0.002
-2.5 TO -2.0	22.	0.014	19.	0.012
-2.0 TO -1.5	82.	0.055	100.	0.062
-1.5 TO -1.0	200.	0.155	193.	0.159
-1.0 TO -0.5	346.	0.328	332.	0.324
-0.5 TO 0.0	401.	0.529	396.	0.522
0.0 TO 0.5	330.	0.694	374.	0.709
0.5 TO 1.0	292.	0.840	256.	0.837
1.0 TO 1.5	172.	0.926	175.	0.925
1.5 TO 2.0	84.	0.968	89.	0.969
2.0 TO 2.5	48.	0.992	39.	0.989
2.5 TO 3.0	12.	0.998	17.	0.997
3.0 TO 3.5	5.	1.000	5.	1.000
3.5 TO 4.0	0.	1.000	0.	1.000
GT +4.0	0.	1.000	0.	1.000

BIOGRAPHY

Miss Patcharin Chatprasert, born March 21, 1974, got degree in BSc. (General Science) from Chulalongkorn University in 1997. Thereafter persued her graduate study in Inter-department in environmental science.