Modeling Approach to Water Quality Management in the Lower Pong River, Thailand

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Abstract

A water quality modeling study was performed for water quality management in the Lower Pong River. The model is based on the modified GEP EPD-Riv1 in an integrated Geographical Information System (GIS). Hydrology was predicted using the conservation of momentum and continuity model, and surface water quality by the conservation of mass and biochemical kinetics model. The main input variables to the models were information on river branches, point source pollution, water quality and kinetic coefficients. Input data were both from field surveys and literatures. The model was calibrated with the field data of water quality sampling in December 2006. The simulating data was reasonably well fit with the field data. In this case, the river flow has great impact on DO in the river, due to the existing high background and non point source pollution. Based on the simulation performance, the lower Pong river could be divided into three sections based on its carrying capacity. At the critical section about 32-33 km downstream of Ubolratana dam, the flow should be discharged at 22.65 m^3/sec to maintain water quality suitable for aquatic organism (DO higher than 2 mg/l). This section is required for an intensive monitoring and strict mitigation measures of any activities of land use.

Keywords: The Pong River, Water Quality, Modeling, GIS

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Introduction

The Pong River is one of the most important water sources in the northeast, Thailand. The River served for domestic, industrial and agricultural sectors cover area about 400 km^2 with daily water usages of about 100,000 m^3 for communities, 40,000 m^3 for industries and 3,000,000 m^3 for irrigation, respectively. It has been more than thirty years that the land use of the Pong River basin has been transformed from forestry to agriculture area. The forest coverage area was reduced to approximately 15% of the total area in the basin. As a result, problems of flooding, soil erosion, sediment loading, salinity and non point source pollution have arisen. These problems have simultaneously effected to the quantity and quality of surface water, and caused a problem of water supply for domestic, industrial and agricultural consumption (Wirojanagud and Jensen, 2003).

During the past decades, water quality of the river is in poor condition. Natural fish die due to low level of dissolved oxygen occasionally occurred especially during the winter time. This is possibly due to over pollution load from both point source (effluent discharge) and non point source pollutions, as well as the water use in irrigation, industrial and communities (Sangsurasak and Wirojanagud, 2005). Thus, there is an urgent need for integration watershed management for the Pong River basin covering physical, biological and socio economic aspects. The sound management plan for the basin should not only be technically effective but also be accepted by the community through the public participatory approach. The strategic plan and policy should be established from the relevant agencies in order to attain the sustainable development of the basin.

Modeling is the main tool to accomplish the integrated-participatory function. It helps identify the sources and pathways of nutrient emissions into the river which is usefully to determine the cause of the impaired water quality. In addition, the model can helps visualizing a different scenario for the decision maker to evaluate the most effective measures. In this research, river modeling had been applied to reveal the path and source of pollutant and to evaluate the current situation of the Pong River. In addition, it is used to predict the management scheme in different scenario for the decision making in water management plan. Modified computer program EPD-Riv1 along with the data collected from the site had been used to create the model for the mentioned outcome.

Study Site Description

The Pong River Basin covers an area of about 12,560 km^2, partly in the provinces of Petchaboon, Loei, Chaiyaphum, Udon Thani and Khon Kaen. Geographically, it lies between 16° and 17°30′ N and 101°15″ and 102°45″ E. The River originates from Phu-Kra-Dueng and the Chi River sub-watershed. It flows from Loei province to Ubolratana Electricity Generation Dam in Khon Kaen Province. The dam was built in 1965 blocking natural water route between two hills creating large reservoir. The reservoir at its maximum storage elevation of 182 m above mean-sea level (MSL) is 2,550 million m^3 with a surface area of 410 km^2. This part of the basin is mountainous covered with different forest types.

For the lower Pong River, as shown in Figure 1, water discharged from the electricity generator spill gate enters Nong Wai diversion has been irrigated for the area of 500 km^2 along 34 km downstream. The weir covers irrigation area about 400 km^2. This lower part of the watershed consists mainly paddy fields, and is more heavily populated than the upper Pong River.

Downstream of Nong Wai Weir, the river flows to join the Chi River before reaching Mahasarakham Irrigation Dam. The dam irrigates for the area of 120 m^2. The distance between the two control structures is 150 km.

The water flow in the Pong River is restricted by three control structures which use water for electricity and irrigation. Water quantity and quality of the downstream river has been altered upon the land use and activities performed accordingly. Thus, in this model, boundary conditions were based on control structure of the river.

Methods

Mathematical Model

Computer program used in this study was modified from EPD-Riv1 developed by Georgia Environmental Protection Division, USA using Visual Basic 6.0. The model is one dimensional and consisted of Hydrodynamics model and Water Quality model (Martin and Wool, 2002).

Hydrodynamics model: The model predicts flows, depths, velocities, water surface elevations and other hydraulic characteristics. Basic equations used in the model are conservation of momentum and continuity. The model solves those equations using the four-point implicit finite difference numerical scheme. It is assumed that the water body is one-dimensional (longitudinal) and there is a homogeneity over the cross-section.

Water Quality model: The model can predict 16 water quality constitutes base on conservation of mass. The advection transport affected by biogeochemical interactions and diffusion is adapted to the equations. Hydraulic information received from the hydrodynamics model with mathematical specifications of the kinetics of, and interrelationships between water quality constitutes are used to simulate variations in water quality under highly unsteady flow conditions.

Geographic Information System (GIS): GIS is used to visualize the input/output data. It maps and analyse data in a coordinate system. Input for spatially distributes models, as well as their output, can be treated as map overlays and topical maps. Data input through GIS are locations of point source and none point source pollution, control structure and water sampling point. Output from GIS shows all input data and results from water quality model. The familiar format of maps supports the understanding of model results and a convenient interface to spatially referenced data.

Input Variable for the Model

The model requires input values reflecting the hydrology of the river and kinetics of the river. The hydrology data include:

Control Structures: Control Structures are required to create the computational grid of the model. The field surveys were made along with the standard 1:50,000 scale military topographic maps of Thailand since 2001.

Tributary: Location of tributary was made by field surveys along with the military topographic maps. Flow rate and cross section of each tributary were survey in the field.

Cross- section: River cross-section data was collected at 162 locations along the Pong River between October and December 2006. The profiles were created and used to determine water-surface elevations.

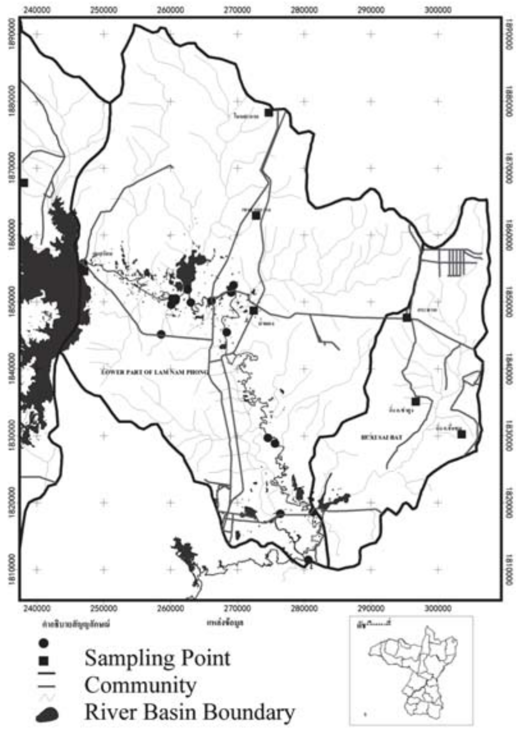

Figure 1. Study Area

The Pong river flow rate: The river flow rate obtained from major control structure includes Electricity Generating Authority of Thailand (EGAT), Ubolratana office, Nong Wai Irrigation Office and Mahasarakham Dam Irrigation office. Flow rate between October and December 2007 were used in the calculation.

The River Kinetics: The kinetic rate coefficients used can be either global value or site specific. Global kinetic values used are drawn from the previous work(Himesh et al., 2000; Thomas and Barnwell, 1985;Marty et al., 2003). For the site specific kinetics were obtained by field measurement which include, reaeration rate constant, the river productivity, sediment oxygen demand , biochemical oxygen demand (BOD) decay rate and nitrogenous biochemical oxygen demand (NBOD) decay rate. Details of kinetic measurement was reported elsewhere (Wirojanagud et al., 2007).

Pollution Source: Pollution sources including communities, agriculture and industrial were collected from various agencies. Data were collected and the field survey was made to confirm data. All data were input in water quality model and GIS. The duration of data collection was during June to December 2007.

Boundary Condition

Boundary condition was based on control structures of the river. Upstream boundary was controlled by amount of water release from Ubolratana Electricity Generation Dam. Downstream boundary was controlled by amount of water release from Mahasarakham irrigation Dam.

Model Calibration

Water quality model was constructed by using field data of 2007 for calibration and validation. Model calibration was performed over one month period of the average flow in December 2006 and focused on water quality parameters at 32 stations along the river during this time. Parameters used are 5-day biochemical oxygen demand (BOD_5) and dissolved oxygen (DO). Model validation was performed over a month period of the average flow in May the same year. Validation had been made by comparison of water elevations and water quality.

Water Quality Monitoring

Water samples from locations as shown in Figure 1 were collected on a weekly basis during 2007. Parameters included pH, Temperature, Dissolved Oxygen (DO), 5-days Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Ammonia Nitrogen (NH_3-N), Nitrate Nitrogen (NO_3-N), Nitrite Nitrogen (NO_2-N) and Phosphate (PO_4-P) were analyzed according to Standard Methods (APHA,1995). In addition, the historic data over 11 year's monitoring period from 1995-2006 were used to evaluate the river water quality.

Results

Pollution Source

There are various types of land use along the river, mostly agriculture. For the point source pollution, there are industries, communities and agriculture. There are four Factories along the lower Pong River of which water uses are : 1) Pulp and Paper Mill 32,000 m^3/day, 2) Combined Thermal Power Plant 5,000 m^3/day, 3 Distillery Factory 1,000 m^3/day, and 4) Sugar Mill 13,000 m^3/day. It is likely claimed that the factories have implemented zero discharge of effluent.

There are 17 communities with 53,935 households, 218,850 population with the equivalent BOD loading to the river of 12.6 g BOD/person/day (U.S. Environmental Protection Agency, 1985). Three major types of agriculture were found which are paddy fields, swine farm and fish cage farming. There are 259 swine farms along the river with total number of 1,931 pigs and the equivalent BOD loading to the river of 180 g BOD/pig/day (Rauch1 et al.,1998). There are 1,626 fish cages farming found in the river with BOD loading 250 g BOD/fish/day (Mungkarndee et al.,2005).

Status of River Water Quality

Based on the water quality data period from 1995-2006, it indicates that water quality in different section of river is different relevant to nutrient loading to the river. Water quality in the form of DO and BOD is shown in Figure 2. Change of BOD is low at difference distances along the river. However, there is dramatically change for DO, especially the low DO occurred at about 10 km before Nong Wai Wier. The Low DO found here is suspected from the discharge of nitrogen and phosphorus from the lagoon which has received runoff from the agriculture area nearby. The water quality at different segments show a little relation to the point source pollution. This might be related to the nonpoint source pollution and background pollution in the River.

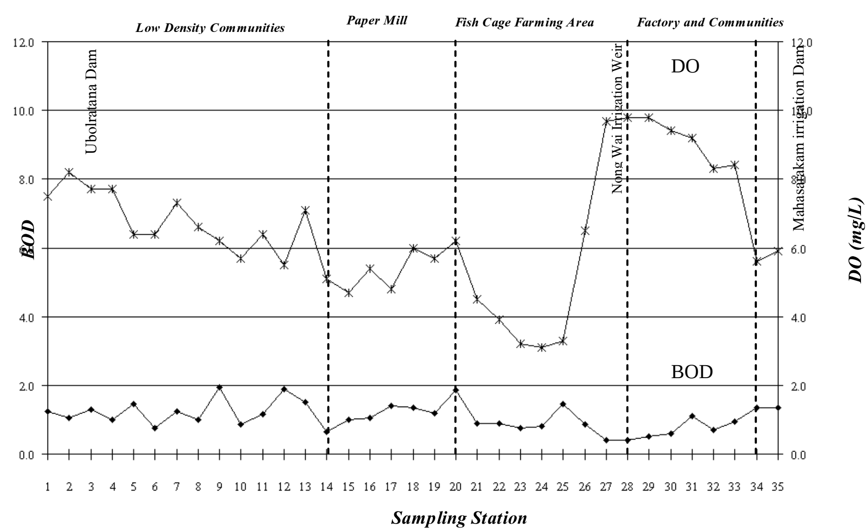

Figure 2. Water Quality

Model Calibration and Validation of Nutrients

Calibration process is mainly based on the field measurements. Calibration of the hydrodynamic part of the model was first carried out by comparing simulated hydrodynamic variables (depth and velocity) with the measured ones. The accuracy of the model in reproducing the hydrodynamics throughout the Pong River over the calibrating time periods show that the model can be used with confidence to simulate the water quality of point and non point source pollutants of the river and can assist as a tool for managing the impacts of such releases. Next, the calibration of the process compartment of the model was carried out sequentially by using transformation kinetic parameters. The order of calibration is; temperature, BOD and DO respectively. While calibrated water quality process part of the model, site specific kinetic parameters from field measurement are fixed, universal kinetics parameters are extracted from the standard modeling literature(REF), while the remaining parameters are obtained by tuning them till the observed and predicted results are closely matched. Under the dynamic conditions, the model's simulations "curve fit" are reasonably well with the observed values.

Model Application

The model application contains all the information for scenarios and criteria and gives a clear overview. Together with an analysis of the selected events, the evaluation approach will show which variable is mostly affected by which scenario. In this specific case, the scenario analysis illustrates that the river flow has great impact on DO of the river, due to the already high background pollution present. Different simulations at different flow rate were performed on the calibrated model. The assumption is base on the fact that flow rate of the river is controlled by Ubolratana Dam spill gate. The simulation was performed from the flow 22.65 m^3/sec to 31.15 m^3/sec. the result is shown in Figure 3. It reveals that the flow rate has significant impact on water quality at the critical point, 35 km from the Ubolratana Dam. The lowest flow rate that maintains water quality suitable for aquatic organism (DO>2 mg/l) was 22.65 m^3/sec.

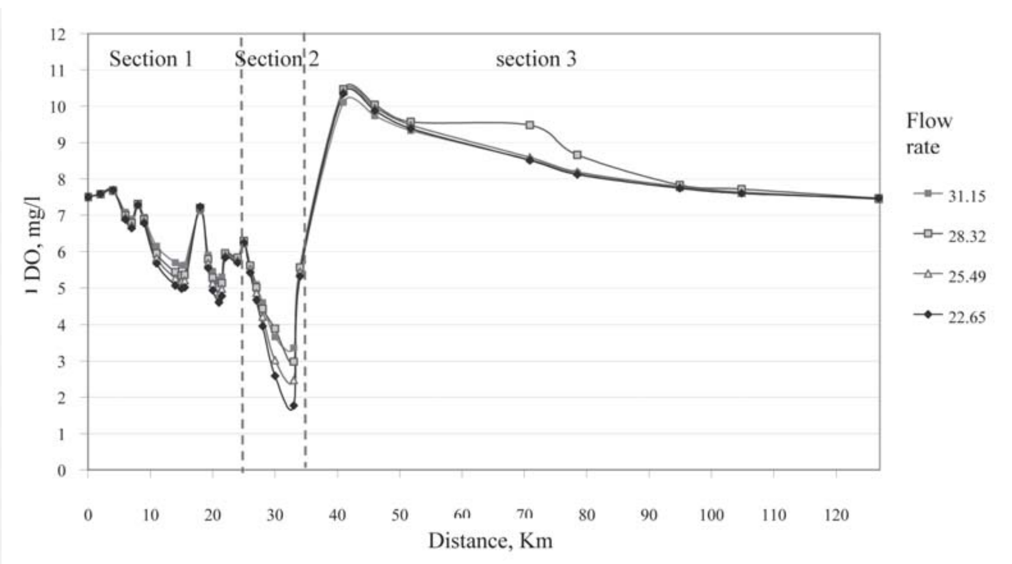

Figure 3. Simulation at Different Flow rate

In accordance with the simulation behavior, the river can be divided based on its carrying capacity into three sections.

Section 1: From Ubonratana Dam (0 km) to Km 25 (25 km), the carrying capacity is moderate since DO is in the range of 4-7 mg/l.

Section 2: From Km 25 downstream of Ubonratana Dam to Nong Wai irrigation Weir which is 35 km from Ubonratana dam, the carrying capacity of river is low especially at 32-33 km from Ubonratana dam. Thus, this area is needed to be closely monitored. Pollution source in the area should be strictly prohibited.

Section 3: From Nong Wai irrigation Weir (Km 35) to Mahasarakham Dam , which is 127 km from Ubonratana dam, the carrying capacity is quite high. DO ranges from 5-11 mg/l. The river in this section is shallow with rocks giving a high reareation rate. In addition, the low sediment existed in this section keep background pollution minimal.

Conclusion

One dimensional steady state water quality model was calibrated and validated. Model coefficients were estimated through field surveys and literatures. For the Pong River, it could be shown that water quality of the different segment of the river was evidently varied due to the background pollution from non point source pollution. At the critical point where DO was the lowest at 35 km from Ubonratana Dam, which might be due to the discharge from natural lagoon surrounded by paddy fields. In addition, water quality in the River is significantly dependent on the river flow rate. Based on the model simulation, the minimum flow that can maintain water quality above the critical point, where is the fish dead occurrence, is 22.65 m^3/sec. These findings should have to be taken into consideration for planning of mitigation measures.

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