

Empowering Water Quality Management in Lamtakhong River Basin, Thailand Using WASP Model

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Abstract: This research aimed at empowering local authorities on water quality management in the Lamtakhong river basin, Thailand with the assist of a water quality model, namely Water quality Analysis Simulation Program (WASP). Organic overcapacity and consequent dissolved oxygen depletion was recently the primary water quality issue of the river. WASP was successfully calibrated and validated using collected monthly hydrologic and water quality data from the year 2008 to 2009. The model was found to be capable of capturing variation and predicting the concentrations of dissolved oxygen for the river system. With the aid of the WASP simulation model, it was demonstrated that “business-as-usual” will seriously impact water quality in the future, causing dissolved oxygen levels to approach zero in some areas downstream. The model results were used in local communities hearing campaign in upstream, middle-stream and downstream communities to raise public awareness. Consensus was reached that household pollution reduction was needed and 5% should be a starting point. Pollution reduction of 5-20% will help improve water quality somewhat. However, a substantial 50% reduction in pollution would considerably improve the water quality of the river.

Keywords: Lamtakhong river basin, modelling, WASP, water quality

INTRODUCTION

Governmental policy on decentralization from central government to local authorities has been in-progress for a decade in Thailand. In the early stages, local administrations took charge of simple civil services with routine operations that may not require high technical skills. The decentralization had primarily provided an incentive in terms of local budget allocation (Lao-Araya, 2002). Pollution control and environmental management policy usually have lower priority due to lack of knowledge and technical expertise at local levels. Empowering local agencies, therefore, is an important mechanism to bring about effective management of their local resources.

This study was an attempt to enhance the capacity of local administrators on water quality management using a publicly available computerized model, developed by the United States Environmental Protection Agency (U.S. EPA) and known as the Water quality Simulation Program (WASP). The model has been successfully applied to various cases in the U.S. (Cerucci *et al.*, 2010; Narasimhan *et al.*, 2010; Johnson *et al.*, 2012) and Asia (Cho, 2010; Peng *et al.*, 2010; Yi-

Chu *et al.*, 2010; Hao and Lianbiao, 2012; Lai *et al.*, 2013). WASP was developed by Di-Toro *et al.* (1983) and capable of examining surface water quality. It is an important tool for the development of Total Maximum Daily Loads (TMDLs) assisting water quality decision-making process in the United States (Chin, 2006). The model was applied to the Lamtakhong river basin, located in the northeastern Thailand, in order to estimate cause-and-effect relationships between external influences, such as pollutant loadings, flows and used as a basic tool for predicting changes in future water quality due to changes in discharges of waste water. Results from the model were used to raise public awareness. The source of the river lies in a pristine national forest and World Heritage site, but the middle and lower parts of the river are deteriorating as a result of pollution discharges, mostly from communities, agricultural activities and industries. The river basin covers approximately 3,518 km² with more than 850,000 inhabitants. Over the last decade, increased population, together with industrial and urban establishment has facilitated economic and societal developments. Water quality monitoring data indicate that Dissolved Oxygen (DO) levels were declining

downstream, with the situation particularly serious during the dry season. In addition, land-use changes have increased the amount of impervious surface resulting in storm runoff events that negatively affect water quality. Between the years 2001 and 2007, the river has been considered as one of the most heavily polluted rivers as a result of contaminants accumulation from human activities (Regional Environment Office 11, 2008).

The present study sought to apply the WASP model to predict water quality of the Lamtakhong River over the next 10-years after consideration of a range of mitigation measures which are planned for the future. In addition, the participatory process of developing the model scenarios of pollution load reduction and model output could provide better understanding of water quality management to the stakeholders. The results of this study may help decision makers and city officers to evaluate pollutant reduction strategies and to alleviate the problem of water quality problems in the river.

MATERIALS AND METHODS

Study area and background: Lamtakhong river basin, located in Nakhon Ratchasima province in the northeastern region of Thailand, is a secondary order river with a total length of 220 km. It originates from the Khao Yai National Park and discharges into the Mun River. The river serves as a major source of domestic water supply for the third largest municipality in the country, Nakhon Ratchasima Municipality (NRM) and other smaller cities. DO is considered an important parameter for water quality management in Lamtakhong river. Average DO concentrations were in the range of 1.5-6.9 mg/L. Low DO concentrations

were found at locations downstream of the largest municipality in the study area, lower than the surface water quality standard of 2 mg/L, with the situation critical during the dry season. Organic content in terms of BOD₅ ranged from 1.5 mg/L at the upstream locations, to 8.3 mg/L downstream. High oxygen demand was associated with discharges from the municipality. NH₃-N concentration as high as 11.2 mg/L was found at locations receiving discharges from agricultural activities.

This study focuses on the middle and lower parts of the Lamtakhong River between Sikiu and Chalerm Prakiet districts (Fig. 1), which has the highest receiving pollutant loads from both point and non-point sources. Its water quality is considered as “moderate” (dissolved oxygen or DO ≤ 4 mg/L) and “poor” quality (DO ≤ 2 mg/L) according to the national surface water quality standards. The width of Lamtakhong River ranges from 10 to 42 m at different locations. The total length of the studied river section is approximately 120 km, divided into 14 segments according to hydraulic travelling time and segment characteristic. Figure 1 shows the arrangement of the segments in the study area.

Description of WASP 6.0 model: The WASP model Wool *et al.* (2003) was used for the simulation of water quality in Lamtakhong river. The development of the model started in the 1970s supported by the U.S. Environmental Protection Agency. WASP is a dynamic compartment-based model for aquatic systems that can be applied in 1-, 2- and 3-dimensions and is designed to permit easy substitution of user-written routines into the program structure. Problems studied using WASP include BOD and DO dynamics, nutrients and

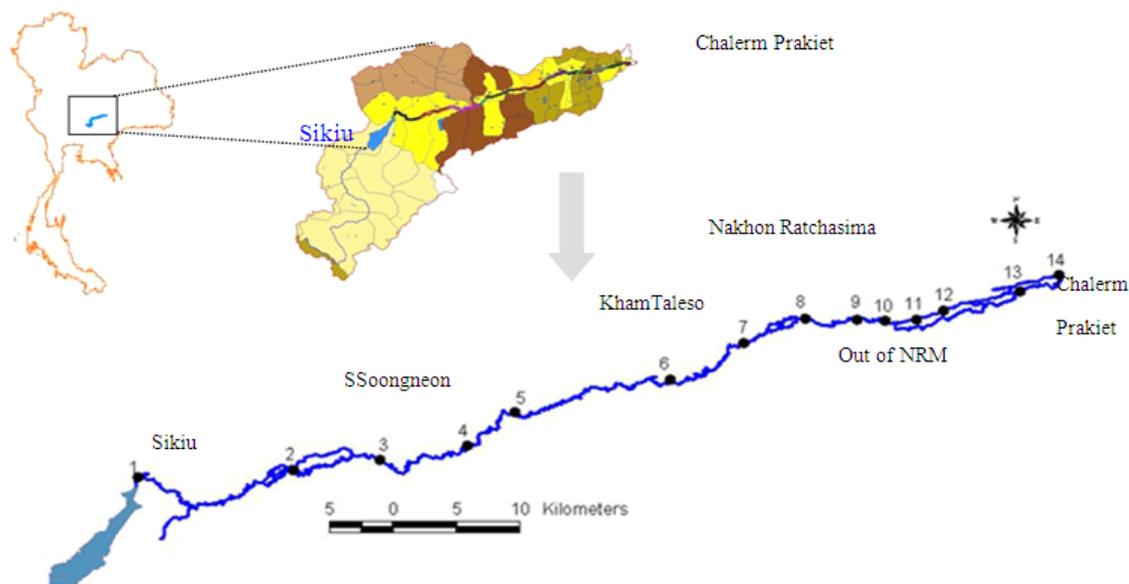


Fig. 1: Map of the Lamtakhong river basin and the river segments

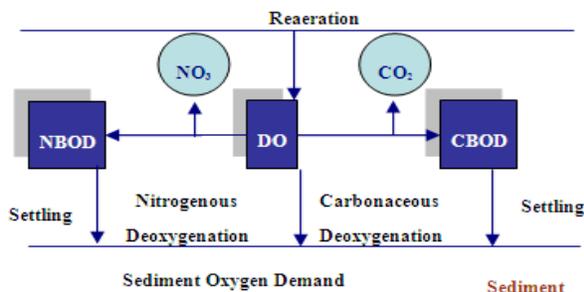


Fig. 2: Conceptual frame work of modified Streeter-Phelps in WASP

eutrophication, bacterial contamination and organic chemical and heavy metal contamination. The model operates on the principle of compartmentalization. The mass balance equation is written for every compartment. The advantage of this modeling approach is its flexibility in simulating almost any type of water body as well as most of the common water quality problems.

In this study, DO was selected as a major indicator of the water quality of Lamtakhong river. The EUTRO sub-model was applied for one dimensional flow and simulated under steady state conditions to compare the effect of pollutant loading changes on DO concentration. DO dynamics were simulated by using the modified Streeter-Phelps balance equations. In this conceptualization, while the re-aeration process at the

air-water interface acts to restore the thermodynamic equilibrium (saturation level), DO is consumed by the mineralization of particulate and dissolved organic matter, measured as carbonaceous and nitrogenous and by the oxidation processes occurring at the sediment-water interface as show in Fig. 2. The state variables activated are, therefore, CBOD, Nitrogenous Biochemical Oxygen Demand (NBOD), expressed as ammonia and DO. Model parameters are either estimated from data, obtained from the literature, or are calibrated. Parameter values, reported in Table 1, were chosen in agreement with the WASP documentation.

Hydrological and water quality data: Flow data with a sampling period of October 2008 to July 2009 are available for the discharge gauge stations at Sikiu and Chalerm Prakiet (Fig. 1). Water quality data were collected from fourteen stations designated to cover a wide range of determinants in the Lamtakhong River. Measurements of water quality parameters were conducted during a 10-month period (October 2008 to July 2009). Water pH, DO, EC and temperature were measured using calibrated handheld instruments. BOD was determined by the dilution method and NH₃-N was analyzed by the phenate method according to the Standard Methods for Examination of Water and Wastewater (APHA-AWWA-WEF, 2005). All the water quality parameters were expressed in mg/L, except pH, EC (μS/cm) and temperature (°C).

Table 1: DO module: state variables, parameters and functional groups description

DO model	Value
State variables and functional groups	
CBOD, carbonaceous biochemical oxygen demand	NR
Carbonaceous oxidation	NR
Settling of the particulate fraction of CBOD	NR
CBOD load in the element	NR
N-BOD measured as NH ₃ -N	NR
Nitrification	NR
Settling of the particulate fraction of N-BOD	NR
N-BOD load in the element	NR
Parameter description	
Nitrification rate constant @ 20°C (per day)	0.100
Nitrification temperature coefficient	1.080
Denitrification rate constant @ 20°C (per day)	0.050
Denitrification temperature coefficient	1.050
Dissolved organic nitrogen mineralization rate constant @ 20°C (per day)	0.001
Dissolved organic nitrogen mineralization temperature coefficient	1.050
Fraction of phytoplankton death recycled to organic nitrogen	0.500
Mineralization rate constant for dissolved organic phosphorus @20°C (per day)	0.220
Fraction of phytoplankton death recycled to organic phosphorus	1
BOD (1) decay rate constant @ 20°C (per day)	0.050
Bod (1) decay rate temperature correction coefficient	1.050
BOD (1) half saturation oxygen limit (mg O/L)	0.500
Phytoplankton light formulation switch (1 = ditoro, 2 = Smith)	1
Phytoplankton carbon to chlorophyll ratio	30
Phytoplankton optimal light saturation	300
Phytoplankton phosphorus to carbon ratio	0.025
Phytoplankton nitrogen to carbon ratio	0.250
Oxygen: carbon stoichiometric ratio	2.660
Re-aeration rate constant at 20°C, per day	0.220

NR: Not relevant

Pollution load estimation: The biggest polluting factors in the Lamtakhong River are organic substances originating from the domestic (resident and tourists), industries and intense agriculture. Unfortunately, direct measurements of these loads are not readily available. Therefore, loads discharged in the river were estimated on the basis of the type and the intensity of the economic activities taking place in the drainage basin. The drainage basin loads from agricultural activities were estimated using specific converting factors for each activity based on total area and type of area. Direct loads from the sewage treatment plants and industrial plants as well as untreated sewage from domestic sources were added to the model. Loading from domestic sources was estimated from the size of population who produced waste in the area of interest. Industrial loads were established using available data. The natural-purifying processes occurring in the river network were also considered. In addition, agricultural point sources, particularly swine and fish farms were also considered. BOD estimates given by the Pollution Control Department (2009) and ammonia nitrogen estimates given in Simachaya (1999) have been used to assess the pollution load. Pollutant load inputs in the river at the present time (2009), including a 10-year projection (to 2018), are summarized in Table 2.

Model scenarios: According to the concept of integrated water resources management, the participation of all stakeholders is necessary to establish the action plan for remediation as well as the activities required to restore and implement the integrated management of the Lamtakhong River. Model scenarios of various pollution-load reductions gathered from participatory process are as follows:

- Scenario 1:** The baseline case for current year (2009)
- Scenario 2:** A “do nothing” approach to wastewater management within the Lamtakhong river basin between the years 2009 and 2018
- Scenario 3:** Five percent reduction of waste load from all point sources between 2009 and 2018
- Scenario 4:** Ten percent reduction of waste load from all point sources between 2009 and 2018
- Scenario 5:** Twenty percent reduction of waste load from all point sources between 2009 and 2018
- Scenario 6:** Fifty percent reduction of waste load from all point sources between 2009 and 2018

Model calibration and verification: The objective of the model calibration is to adjust the input parameters so that there will be closer agreement between the simulated values and observed data (Ambrose *et al.*, 1992). Hydrologic and water quality inputs to the river during February 2009 were selected for model calibration. The evaluation of goodness-of-fit between

Table 2: Pollutant load inputs (kg per day) in the Lamtakhong river in two scenarios

Source of waste load	Year 2009		Year 2018	
	CBOD	NH ₃ -N	CBOD	NH ₃ -N
Drainage basin	2,692	62	2,692	62
Domestic	7,127	1,515	8,909	1,793
Industrial	386	232	1,782	440
Swine farm	3,498	255	5,222	381
Fish farm	278	36	569	73

field data and model simulation for DO was obtained by calculating the Root Mean Square of Error (RMSE) and Relative Error (RE) between these data. RMSE and RE are the most widely employed methods of evaluating the differences between simulated values and observed values during modeling calibration (Ambrose *et al.*, 1992). The equation for RMSE and RE determination may be illustrated in the following equations:

$$RMSE = \left(\frac{\sum (C_o - C_s)^2}{N} \right)^{0.5}$$

$$RE = \left(\frac{\sum \left(\frac{C_o - C_s}{C_o} \right)^2}{N} \right)^{0.5}$$

where,
 C_s = Simulated value
 C_o = Observed value
 N = Number of measurements

RESULTS

DO simulation: The model calibration for dissolved oxygen between observed and predicted values had a Root Mean Square of Error (RMSE) of 1.5 mg/L and Relative Error (RE) of 35%. The high RE results from non-uniformity of segmentation and considerable uncertainty in the estimation of discharges. The calibrated model was validated on the basis of a one month period. The results were compared with the field data collected during March 2009. It showed lower RMSE and RE, 0.65 mg/L and 19%, respectively as given in Fig. 3.

Quantification of oxygen demand: As was mentioned earlier, DO is the most important factor to be considered for water quality management in Lamtakhong river. The results from six-scenario simulations are described in the following paragraphs.

Scenario 1 represents the baseline case for the current year (2009) whereas scenario 2 is a “Do nothing” approach to wastewater management within

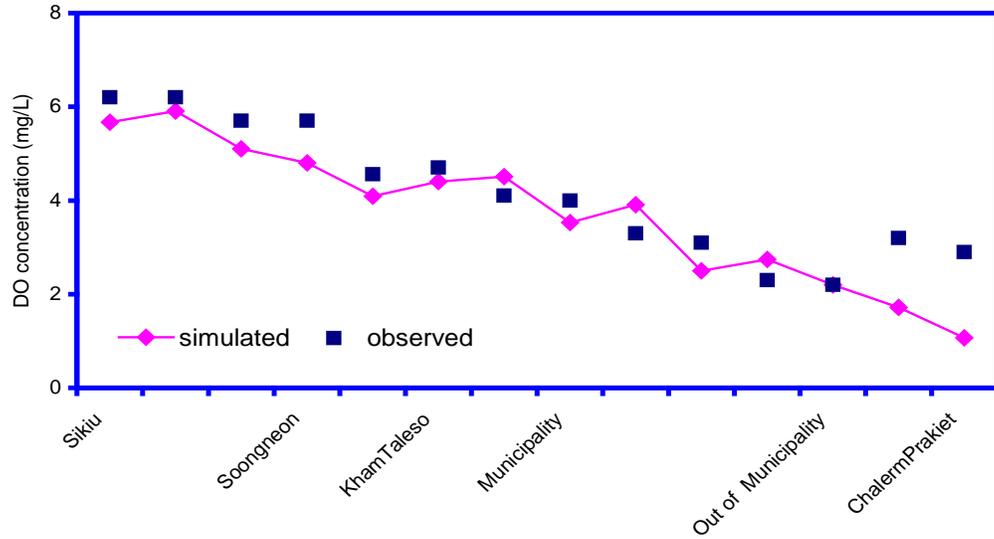


Fig. 3: WASP model validation of DO for March 2009

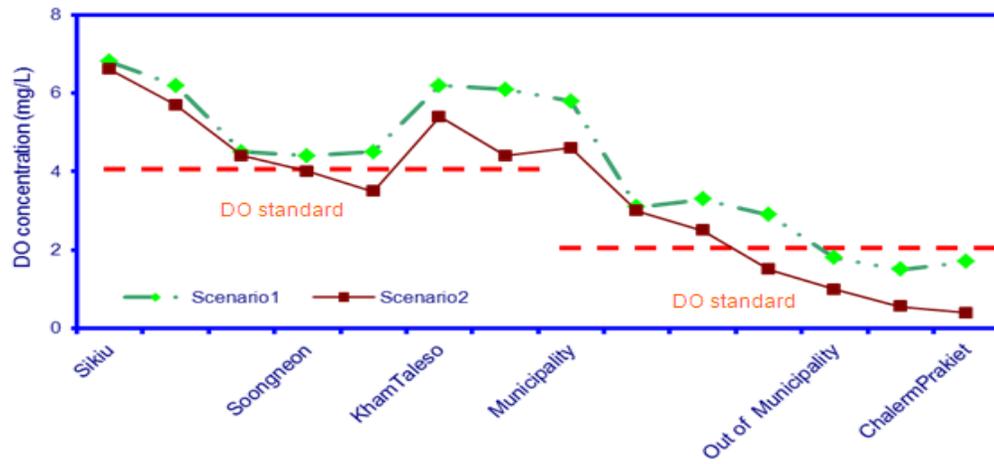


Fig. 4: Comparison of DO predictions for 2018 and present situation

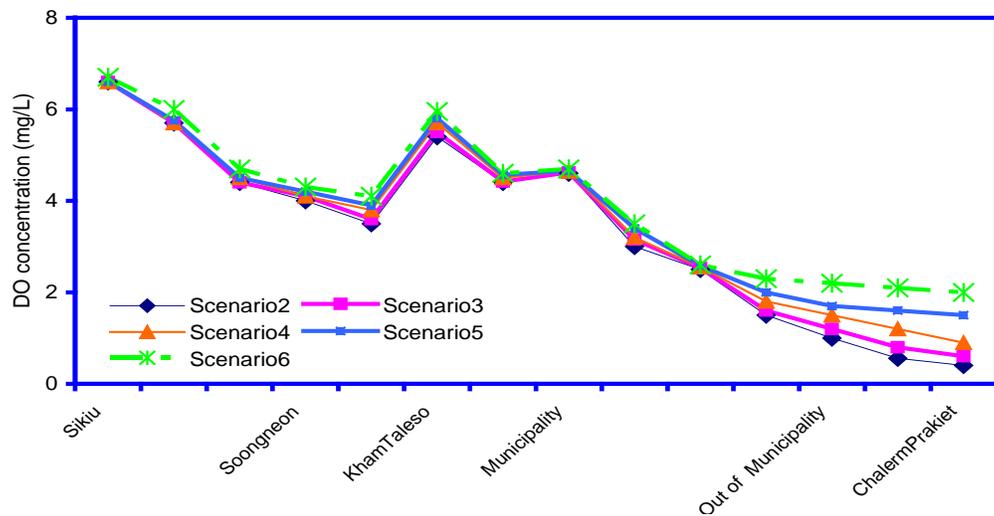


Fig. 5: DO predictions in various water quality management scenarios

the Lamtakhong river basin between the year 2009 and 2018. Waste loads are expected to increase by approximately 37% from the year 2009. This scenario projects the further decline of DO concentration in the river. Figure 4, extremely low DO concentrations are likely to extend to the lower reaches of segment 11 (Muang Nakhon Ratchasima district) to segment 14 (Chalerm Prakiet district). Particularly, segment 13 will have a DO as low as zero. Most DO in the lower portions was less than 2.0 mg/L (at or above the lowest allowable standard value of 2.0 mg/L).

Predicted DO values from scenarios 3, 4 and 5, which represent the 5, 10 and 20%, respectively reduction of waste load, respectively, were comparable. Under these scenarios, all point sources required reduction of 5 to 20% of total loads by appropriate treatment facilities involving the participation of all stakeholders. DO concentrations for all river reaches were improved, particularly DO values in the upper portion which were raised above 4.0 mg/L. However, these scenarios would have little influence on DO improvement in the lower portion of the river particularly in the segment 12 to 14, which DO concentrations would also be lower than the standard level (2.0 mg/L) as shown in Fig. 5.

Scenario 6 represents the 50% reduction of waste load from all point sources within 10 years. Under this scenario, DO concentrations would reach standard level for all river segments.

Preferred water quality management in the Lamtakhong river: In general, water quality management is a complicated issue that demands a multi-disciplinary approach involving scientific, economic and sociological analysis. The goals of Lamtakhong river management are to restore the river water quality to acceptable levels and to protect the river for various purposes. Scenario configurations included both existing conditions (2009) and a next ten years prediction. The results of scenario simulations implied that controlling waste water from domestic and swine farm, which are the major sources of in Lamtakhong river basin, are a top priority. In addition, the model result indicated that the lower sections of the Lamtakhong River will remain critical for water quality management. Results from the model were presented to upstream, middle-stream and downstream communities to raise public awareness. Since waste water collection and treatment exists in a few municipalities, preliminary treatment in household is needed. Thus, simple and inexpensive technologies and locally appropriate measures, such as on-site septic system or septic tank, grease trap installation, should be promoted alongside the education of local communities. The communities agreed that 5% pollution reduction in household would be a good starting point.

DISCUSSION

Water quality in the Lamtakhong River is in critical conditions especially the lower sections, downstream of NMR. Monitoring data used in WASP for simulating various management scenarios revealed a “do nothing” action will violate surface water quality standards if waste discharges could not be significantly reduced by the year 2018. The model was demonstrated that “business-as-usual” will seriously impact water quality in the future. Dissolved oxygen levels may approach zero in some areas downstream. Pollution reduction of 5-20% will help improve water quality. A substantial 50% reduction in pollution would considerably improve the water quality of the river. Currently, a biological waste water treatment plant is in operation for the municipality on the budget of more than US\$23.3 millions. Furthermore, the application of water quality modeling WASP is a useful tool to help local authorities understand the basin in a unified management approach. This tool can be used to identify problem areas and to evaluate water quality management alternatives.

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REFERENCES

- Ambrose, R.B., T.A. Wool and J.L. Martin, 1992. The Water Quality Simulation Program, WASP5: Model Theory. User's Manual and Programmer's Guide. U.S. Environmental Protection Agency, Athens, GA, USA.
- APHA-AWWA-WEF, 2005. Standard Methods for the Examination of Water and Wastewater. 21st Edn., American Public Health Association, Washington, DC, USA.
- Cerucci, M., G.K. Jaligama and R.B. Ambrose, 2010. Comparison of the monod and droop methods for dynamic water quality simulations. *J. Environ. Eng.*, 136(10): 1009-1019.
- Chin, D.A., 2006. Water Quality Engineering in Natural Systems. 2nd Edn., John Wiley and Sons, Hoboken, New Jersey, USA.
- Cho, J.H., 2010. Water quality modeling of a lake considering rainfall-runoff pollution loads and water quality improvement by diffuse pollution control. Proceedings of the 5th Conference on Water, Climate and Environment, Ohrid.

- Di-Toro, D., M. Fitzpatrick and J.J. Thoann, 1983. Documentation for Water Quality Analysis Simulation Program (WASP) and Model Verification Program. Office of Research and Development, U.S. Environmental Protection Agency, Minnesota, USA.
- Hao, L. and C. Lianbiao, 2012. Apply with WASP water quality model. Proceedings of the 2nd International Conference on Computer Application and System Modeling. Atlantis Press, Paris, France.
- Johnson, J.L., C. Wolfe and D. Waidler, 2012. An economic assessment of water quality improvement BMPs for the Eagle Mountain Lake Watershed. Proceedings of the 2012 Agricultural and Applied Economics Association Meetings. Seattle, Washington, USA.
- Lai, Y.C., Y.T. Tu, C.P. Yang, R.Y. Surampalli and C.M. Kao, 2013. Development of a water quality modeling system for river pollution index and suspended solid loading evaluation. *J. Hydrol.*, 478: 89-101.
- Lao-Araya, K., 2002. Effect of Decentralization Strategy on Macroeconomic Stability in Thailand. ERD Working Paper Series No. 17, Economics and Research Department, Asian Development Bank, Manila, Philippines.
- Narasimhan, B., R. Srinivasan, S.T. Bednatz, M.R. Ernst and P.M. Allen, 2010. A comprehensive modeling approach for reservoir water quality assessment and management due to point and nonpoint source pollution. *T. Am. Soc. Agri. Biol. Eng.*, 53(5): 1605-1617.
- Peng, S., G.Y. Fu and X. Zhao, 2010. Integration of USEPA WASP model in a GIS platform. *J. Zhejiang Univ.,-Sci. A*, 11(12): 1015-1024.
- Pollution Control Department, 2009. Mitigation measures for water quality control in Lamtakhong river basin. Nakhon Ratchasima, Thailand.
- Regional Environment Office 11, 2008. State of the Environment Report 2008. The Upper portion of Mun River basin (Nakhon Ratchasima Buriram Surin and Sri Saket). Ministry of Natural Resources and Environment (MONRE). Nakhon Ratchasima, Thailand.
- Simachaya, W., 1999. Integrated approaches to water quality management using geographic information systems and the wasp5 simulation model: Application to the Chin River Basin, Thailand. Ph.D. Thesis, the University of Guelph, Canada.
- Wool, T., R. Ambrose, L. Martin and E. Comer, 2003. Water Quality Analysis Simulation Program (WASP) 6.0, Draft: User's Manual. U.S. Environmental Protection Agency, Washington D.C., USA.
- Yi-Chu, H., Y. Chou-Ping and T. Pink-Kuei, 2010. Water quality management scenarios for the Love river in Taiwan. Proceedings of the International Conference on Challenges in Environmental Science and Computer Engineering (CESCE). Wuhan, China.