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Using SWAT to Assess the Critical Areas and Nonpoint Source Pollution Reduction Best Management Practices in Lam Takong River Basin, Thailand

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Abstract

Hydrological models are essential tools for water resource and nonpoint source pollution management. This study aimed to evaluate critical areas and best management practices (BMPs) of sediment and nutrient loads in Lam Takong River basin, Northeastern Thailand, using SWAT (Soil and Water Assessment Tool) model. The model was calibrated and validated using daily data of streamflow, sediment, NO_3-N and TP in Lam Takong River from 2007-2008 and 2009, respectively. In general, the simulated streamflow and sediment were in reasonable agreement with the measured values with coefficient of determination (R^2) and Nash-Sutcliffe model efficiency coefficient (NSE) greater than 0.50 and the percent bias (PBIAS) less than 25%. Additionally, nutrient loads showed a fair relationship between observation and simulation with R^2 values more than 0.6 and PBIAS values less than 25%. From simulation, September was the month with the highest sediment, NO_3-N and TP yields while January and December were the lowest months. From the model, SWAT identified 1 severe and 1 high soil erosion subbasins. Two subbasins were classified into medium loading for NO_3-N. However, 9 subbasins were classified into high loading rate of TP. For BMPs, the 30-m wide filter strip was the best scenario reducing 100% of both sediment and TP, and 97.27% of NO_3-N. These results could be a useful tool for water resources managements and soil conservation planning in Lam Takong River basin.

Keywords: hydrological model; nitrate; phosphorus; soil erosion; watershed

1. Introduction

Nonpoint source (NPS) pollution of streams, lakes and estuaries has created a critical concern throughout the world. Agricultural activities have been identified as the primary sources of NPS pollutants. In Thailand, water pollution is largely associated with urbanization, industrialization and agricultural activities. The main pollutants for surface water quality problems are sediments, nutrients and other chemical substances (Office of Natural Resources and Environmental Policy and Planning, 2012). However, the governing policies on watershed management in the past, did not appreciate the importance of NPS pollution (Simachaya, 2003) and few strategies exist for remediating the issue (Babel *et al*., 2004; Pollution Control Department, 2006).

Lam Takong River basin is crucial to the Northeastern region of Thailand. More than 880,000 people reside within Lam Takong River basin. The river is 220 km long and originates from Sangampang Range in Khao Yai National Park. It covers about nine districts of three provinces including Pracheenburi, Nakhon Nayok and Nakhon Ratchasima provinces. The dominant land use is agriculture land. Many organizations, such as the Hydrology and Water Management Center for the Lower Northeastern Region, the Pollution Control Department (PCD), Regional Environmental Office 11 and Municipality of Nakhon Ratchasima, have studied hydrology and water quality of Lam Takong River. Water quality degradation has been observed for more than two decades, as a result of urbanization and intensive farming (Pollution Control Department, 2008). Previous studies did not evaluate temporal and spatial sediment and nutrient loads at basin level which can sufficiently reduce NPS pollution.

Continuous water quality monitoring is very expensive, time consuming and spatially impractical at the watershed level. Therefore, mathematical modeling has become a primary technology for analyzing NPS pollution and its spatial distribution (Chu *et al*., 2004). Examples of these models are: the physically based event Areal Non-point Source Watershed Environment Response Simulation (ANSWERS) model, the physically based Dynamic Watershed Simulation Model (DWSM) model and the Soil and Water Assessment Tool (SWAT) model. When comparing the models, SWAT is the most capable for long-term simulations in watersheds dominated by agricultural land (Arnold and Fohrer, 2005; Arnold *et al*., 1998). It is designed to assess the impact of land use and management practices on water, sediments and agricultural chemicals. The model has proven to be an effective tool for assessing NPS for a wide range of scales and environmental conditions (Gassman *et al*., 2007). The United States (Arabi *et al*., 2006); Europe (Panagopoulos *et al*., 2011) and other parts of the world have incorporated SWAT into NPS assessment on a broad scale (Bouraoui *et al*., 2005; Cheng *et al*., 2007). In Thailand, SWAT was successfully used to study water flow in Lam Sonthi watershed, the Pasak watershed (Phomcha *et al*., 2011), Upper Mae Tuen basin (Thanasiriyakul, 2003) and Chaophraya River basin (Vathananukij, 2006); water supply for irrigation in the Songkhla Lake basin (Prachayasittikul, 2006); water use efficiency for agriculture in Mae Tha watershed (Keawmuangmoon, 2009); effect of land use changes on runoff in the Upper Nan basin (Vesurai, 2005) and Mae Jang basin (Intaruksa, 2012). Suspended sediment at Thoung-naklang and Failuang weirs, Uttraradit province, using SWAT,but only temporal variation was apparent (Suwanlertcharoen, 2011). However, SWAT was also unsuccessfully used to evaluate nutrients in Utapao River Basin to Songkhla Lake (Punyawattano, 2010).

In this paper, the SWAT2009 model was used to study temporal and spatial variability of watershed characteristics, and then identify critical areas in Lam Takong River basin. Moreover, the best management practices (BMPs) were used to evaluate the reduction of NPS pollution to meet water quality criteria without disturbing environmental quality. The results may be incorporated into BMP planning for water resource management and soil conservation in Lam Takong River basin.

2. Materials and methods

2.1. Study area

Lam Takong River basin is a part of the Moon watershed, in the Northeastern region of Thailand (Fig. 1). The basin has a total area of 3,518 km^2, covering nine districts of three provinces including: Prachantakham district in Pracheenburi province, Pak Plee district in Nakhon Nayok province, Pak Chong, Sikhio, Sung Noen, Kham Thale So, Dan Khuntod, Mueang Nakhon Ratchasima and Chaloem Phra Kiat districts in Nakhon Ratchasima province (Royal Irrigation Department, 2004). At Ban Kong Rae, Kham Thale So district, Lam Boriboon River diverges from Lam Takong River for 35 km and then rejoins Lam Takong River at Ban Kanphom before flowing into the Moon River at Tha Chang Sub district, Chaloem Phra Kiat district in Nakhon Ratchasima province (Nakhon Ratchasima Municipality, 2006).

Lam Takong River basin is influenced by the southwest and northeast monsoons. There are three seasons including rainy, winter and summer seasons. From May to October, the southwest monsoon brings moisture from the Indian Ocean that falls as rain, peaking in August and September. The average amount of rainfall is 1,454.3 mm. From October to February, the wind direction is reversed, and a cooler, drier northeast monsoon wind blows off the Asian landmass, bringing a cold season. Temperature then continuously rises with a slightly drop in a short transitional period between the monsoons during March and April. Lam Takong River basin has an average annual temperature of 25.4^{o}C, and a maximum and minimum relatively humidity of 83.4% and 47.8%, respectively.

According to Land Development Department (2009), land use Lam Takong River basin is dominated by agricultural land (55.73%), followed by forested areas (21.28%) and urban areas (11.81%) (Fig. 2). Various soil series are present, including Khao Yai, Kabinburi, Khorat and Lam Narai series. Soil drainage is medium to good. The soil layers alternate between shallow and deep areas with universally moderate fertility.

2.2. Model description

The United States Department of Agriculture and Agricultural Research Service (USDA-ARS) developed SWAT as a hydrologic/water quality model (Arnold *et al*., 1998). Outputs provided by SWAT include: streamflow and in-stream loading or concentration estimates of sediment, organic nitrogen, nitrate, organic phosphorus, soluble phosphorus and pesticides (Gassman *et al*., 2007). The SWAT model can predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land uses and management conditions over long periods of time (Neitsch *et al*., 2011).

In SWAT, a watershed is divided into multiple subbasins, which are further subdivided into hydrologic response units (HRU) that consist of homogeneous land use, management, and soil characteristics. In this study, the Lam Takong River basin was divided into

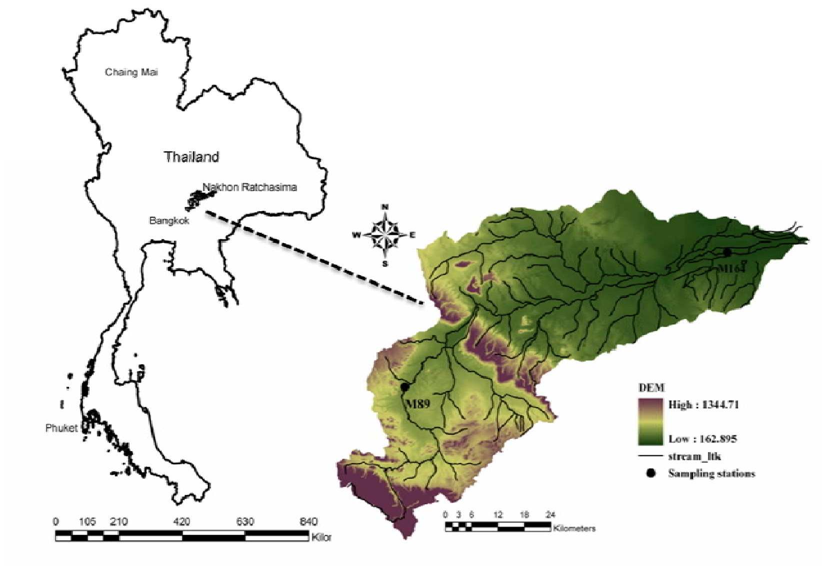

Figure 1. Lam Takong River basin and sampling stations

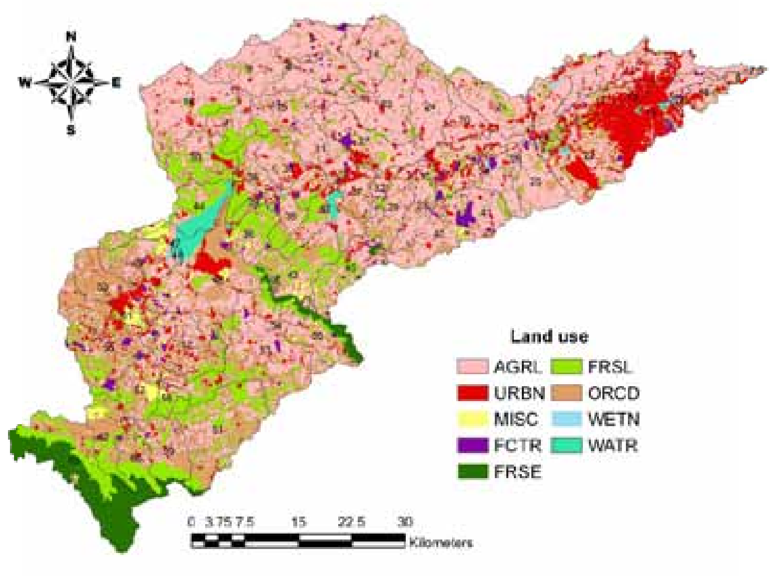

Figure 2. Land use types of Lam Takong River basin

63 subbasins, which in turn were subdivided into 308 HRUs. However, only the subbasins level was described in this study.

2.3. Input data

Lam Takong River basin information was obtained from various agencies as secondary data (Table 1). These data were input into SWAT to simulate streamflow, sediment and nutrient loads. In this study, we focus only on NPS pollution because it applies to the entire basin. The PS pollution locations are difficult to obtain, because most factories are far from Lam Takong River. The effect from factories, should be minimal except in the case of accidents. PS pollution effects in Lam Takong River basin were excluded from this study because they are already covered in previous studies.

There are 4 stations along Lam Takong River. Only 2 stations were used for this study because they have complete data of both sediment and water quality for the period of study from 2007 to 2009. The other two, however, have incomplete or mismatched data; therefore, they are unusable. The M89 station in Pak Chong district is a representative of the Upper Lam Takong River which has been affected primarily by agriculture. On the other hand, the M164 station in Mueang Nakhon Ratchasima district was chosen to represent the Lower Lam Takong River which has been mainly affected by urbanization.

Two years (2007-2008) of data were used to calibrate SWAT, a single year (2009) was used to validate the model, by observing daily streamflow, sediment, NO_3-N and TP loads at M89 and M164 stations in Lam Takong River (Fig. 1). These data were

Table 1. Data inputs for Lam Takong River basin

Data type	Agency	Period of time
Digital Elevation Map (30 × 30 m^2 resolution)	Land Development Department	2004
Land use	Land Development Department	2008
Flow of water/run off	Royal Irrigation & Meteorology Department	1990 - 2009
Reservoir	Royal Irrigation Department	1990 - 2009
Wind	Thai Meteorology Department	1980 - 2005
Solar, humidity	Thai Meteorology Department	1980 - 2009
Rainfall	Thai Meteorology Department	1990 - 2009

obtained from the Hydrology and Water Management Center for the Lower Northeastern Region and Regional Environmental Office 11, Nakhon Ratchasima, Thailand.

2.4. Data analysis

A wide range of statistics has been used to evaluate SWAT hydrologic predictions. The most widely used statistics (Gassman *et al*., 2007) for hydrology calibration and validation are the: regression correlation coefficient (R^2), the Nash-Sutcliffe model efficiency (NSE) coefficient (Nash and Sutcliffe, 1970) and percent bias (PBIAS). They are calculated according to formula (1), (2) and (3):

$$\mathrm{R}^2 = \frac{\left(\sum_{i=1}^{n}(O_i - \overline{O})(P_i - \overline{P})\right)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2 \sum_{i=1}^{n}(P_i - \overline{P})^2} \quad (1)$$

$$\mathrm{NSE} = 1 - \left(\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2}\right) \quad (2)$$

$$\mathrm{PBIAS} = \left(\frac{\sum_{i=1}^{n}(O_i - P_i)^* \, 100}{\sum_{i=1}^{n} O_i}\right) \quad (3)$$

Where, n is the number of measured data, O_i and P_i are the measured and predicted data at time i, $\overline{O}$ and $\overline{P}$ are the means of measured and predicted data.

Soil Erosion is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). Then SWAT uses the modified Environmental Impact Policy Climate (EPIC) model (Izaurralde *et al*., 2006) to compute nutrient yield and cycling from the sub-watersheds. The nutrient concentration is converted to mass (kg/ha) by multiplying it by the depth of the soil layer and soil bulk density and performing appropriate unit conversions. SWAT is interfaced with ArcGIS (ArcSWAT), all soil sediment and nutrient loading results were classified in different levels and presented in maps.

2.5. Classification maps

Sediment load maps were built by using soil loss tolerance rate (Stone and Hilborn, 2000). NO_3-N load maps were classified according to Wu *et al*. (1997). Finally, TP load maps were classified according to the Gurung *et al*. (2013) standard.

2.6. Management scenarios

Watershed level reductions include cumulative load reductions considering overland pollutants and their routing through the stream network. Simulations of BMPs are a term used in the Lam Takong River basin to describe a type of water pollution control. BMPs are analyzed under alternative scenarios which simulate the effects of several specific scenarios. In this study, the analysis simulated the effects of 13 specific scenarios of change in land cover, filter strip, terrace and combination (Table 2).

Table 2. Scenario descriptions for Lam Takong River basin

Scenarios	Description
1	Agriculture → deciduous forest, if slope > 12°
2	Orchard→ agriculture, if slope > 12°
3	Agriculture → orchard,if slope > 12°
4	6-m filter strip
5	10-m filter strip
6	15-m filter strip
7	20-m filter strip
8	25-m filter strip
9	30-m filter strip
10	Terrace
11	Terrace, 6-m filter strip
12	Terrace, 50-m filter strip in Muang district, 6-m filter strip for the rest
13	50-m filter strip in Muang district, 6-m filter strip for the rest

Group A: Land use change. Since Land Development Department (2009) suggests that at slope > 12°, the recommended land use should be forest type. We evaluate different land use type changes in areas with this slope.

Group B: Filter strip. Filter strips are strips of herbaceous vegetation situated between cropland, grazing land, or any disturbed land and an environmentally sensitive area. Filter strips trap sediment, thereby reducing the sediment and sediment-bound contaminants in runoff. Filter strip was represented in terms of edge-of-field filter strip (FILTERW) variable in SWAT. In this study, filter strips with 6 different widths were evaluated including 6, 10, 15, 20, 25 and 30 m. The 6-m filter strip refers tothe ministerial regulations for Nakhon Ratchasima's principle city plan.

Group C: Terraces. Terraces are broad earthen embankments or channels constructed across the slope of a field to intercept runoff water and control erosion. Terraces effectively decrease hill-slope length, help prevent the formation of gullies, and redirect intercepted runoff to a safe outlet. In this study, terraces were represented by conservation support practice factor (P-factor) and CN. The P-factor (P_{USLE}) is defined as the ratio of soil loss with a specific support or conservation practice to the corresponding loss with cultivation up-and-down the slope. In the scenario basis condition, P-factor was set to 1.0 and 0.6 whereas in Scenario 10 condition P-factor of the terraced areas was set to 0.10, 0.12, 0.16, 0.18 and 0.2 depending on the average upland slope and also considering waterways or graded channel outlets in conjunction with terraces. Curve number values were reduced by 5 from the calibration CN values; this is a common practice and has been used by others such as Bracmort *et al*. (2006) and Secchi *et al*. (2007).

Group D: Combination scenario. We combined terrace and different filter strip widths here. The 1975 Town and Country Planning Act suggested using 6-m filter strip near the banks of every water way. The 2007 Ministerial Regulations for Nakhon Ratchasima's Principle City Plan also suggested 50-m empty space parallel to the sides of water bodies.

3. Results and discussion

3.1. Calibration and validation of SWAT model

Simulated values of both streamflow and sediment were very close to the observed values (Fig. 3) as R^2 and NSE were greater than 0.5 (Table 3) and PBIAS was less than 25% (Moriasi *et al*., 2007; Santhi *et al*., 2001). It indicated that this model was able to predict streamflow and sediment loads consistently. Although, NSE at M164 did not exceed 0.5 during the validation period, PBIAS was still less than 25%. Therefore, SWAT was successful in streamflow and sediment yields prediction for the entire period.

On the other hand, the model calibration and validation of NO_3-N and TP showed a fair relationship between observed and simulated NO_3-N and TP loads, with R^2 values greater than 0.6 and PBIAS values less than 25% (Table 3). The NSE was not used based on the insufficient, irregular data (only 10 samples). The simulated NO_3-N and TP loads were above or below the 1:1 line, indicating that the model did not exhibit any tendency to systematically overestimate or underestimate due to data limitations.

3.2. Temporal sediment and nutrient loads

For the simulation period (2007-2009), the model calculated a 616 mm mean annual evapotranspiration rate and an 1138.7 mm mean annual precipitation.

Sediment, NO_3-N and TP loads showed temporal fluctuation (Fig. 4). TP was closely linked to sediment in SWAT whereas NO_3-N was governed more directly by runoff. Overall, all parameters were very low in

Table 3. Summary of streamflow, sediment and nutrient calibration and validation

Period	Variable	M89			M164		
		R^2	NSE	PBIAS (%)	R^2	NSE	PBIAS (%)
Calibration (2007-2008)	Streamflow	0.69	0.61	0.02	0.68	0.50	1.32
	Sediment	0.65	0.54	0.75	0.64	0.63	1.87
	NO_3-N	0.84	-	1.42	0.60	-	0.63
	TP	0.94	-	1.82	0.91	-	2.96
Validation (2009)	Streamflow	0.72	0.58	8.72	0.49	0.40	17.39
	Sediment	0.80	0.80	6.74	0.52	0.47	1.08
	NO_3-N	0.95	-	6.29	0.66	-	5.07
	TP	0.96	-	14.25	0.67	-	9.85

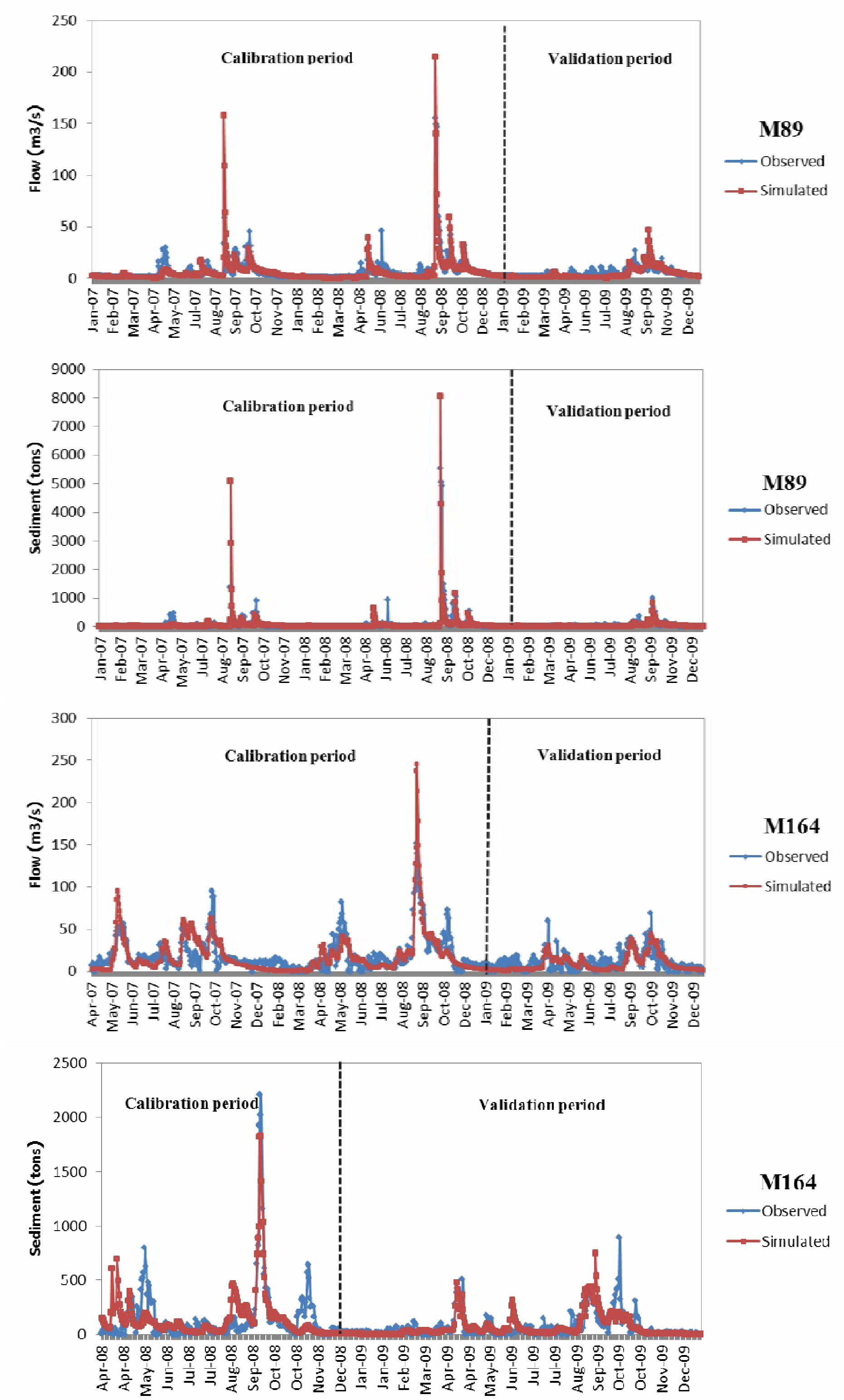

Figure 3. Comparison between the simulated and observed streamflow and sediment values of M89 and M164

the dry season (November to April) attributed to a significant reduction in runoff. They reached the first peak at the beginning of the wet season (May) from the first round of rain storms but went down during the intermittent dry season in June. Levels climbed up to the second and highest peak in September (3.47 ton/ha of sediment load, 0.20 kg/ha of NO_3-N load and 0.46 kg/ha of TP load). The significant loss of NO_3-N during the summer has been reported in agricultural catchments (Arheimer and Liden, 2000; Yevenes and Mannaerts, 2011). The presence of stagnating waters in the catchment stream network along with the sink of nitrogen from denitrification in high temperatures and low oxygen level condition may explain the observed

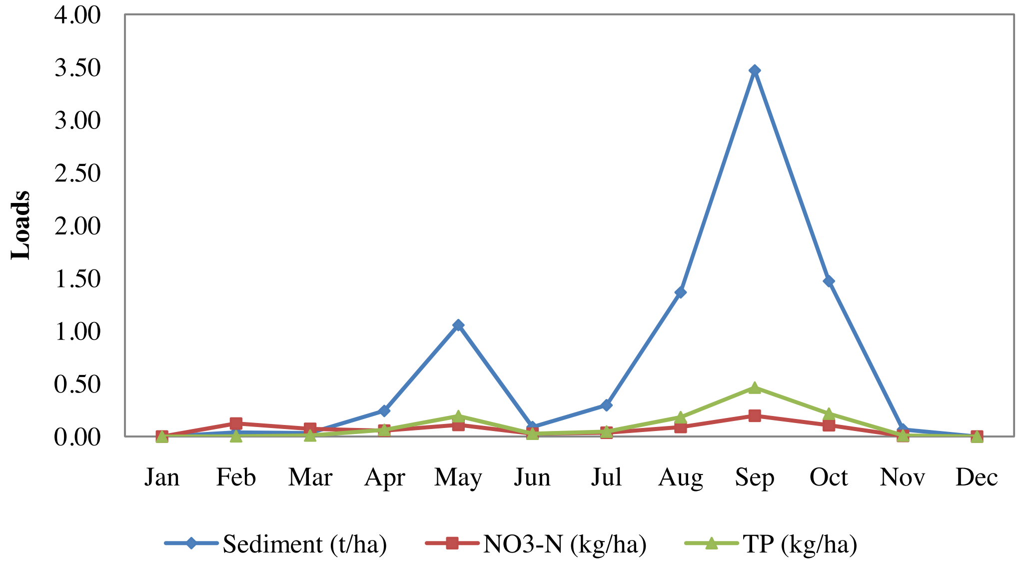

Figure 4. Temporal variation of sediment, NO3-N and TP yields at basin outlet

variation. Another explanation may be the increased plant uptake and removal by periphyton and plants (Flipo *et al*., 2007).

3.3. Sediment and nutrient load critical areas

Lam Takong River basin had an annual soil erosion of 8.134 t/ha which was identified as very low by using the soil loss tolerance rate (Stone and Hilborn, 2000). This value was less than 29.46 t/ha of Upper Lam Phra Phloeng watershed, the nearby basin (Ongsomwang and Thinley, 2009) due to hilly topography with undulating, steep slopes and significantly higher rainfall than in Lam Takong River basin. Other studies also reported soil erosion of 10.70 t/ha for Arnigad basin of Lower Himalaya (Tyagi *et al*., 2014) and 12.2 t/ha for Upper South Koel Basin in India (Parveen and Kumar, 2012). These values were higher than Lam Takong River basin because the former is in a mountainous region with higher elevation, while the latter has a greater proportion of agricultural area (84%). However, Lam Takong River basin's soil erosion was higher than in Mae Phun watershed at 5.4 t/ha (Suwanlertcharoen, 2011) because this basin has a larger percentage of forested area (89%) and Songkhram watershed at 3.59 t/ha has more flat area (Nontananandh and Changnoi, 2012).

The simulation results were able to identify areas of significant soil erosion based on the average annual sediment yield for the total hydrological period within each subbasin. Among 63 subbasins within the catchment, subbasin 48 (Lam Takong dam) had the highest sediment loading of 33.73 t/ha (Fig. 5). It was identified as a severe soil erosion area using the

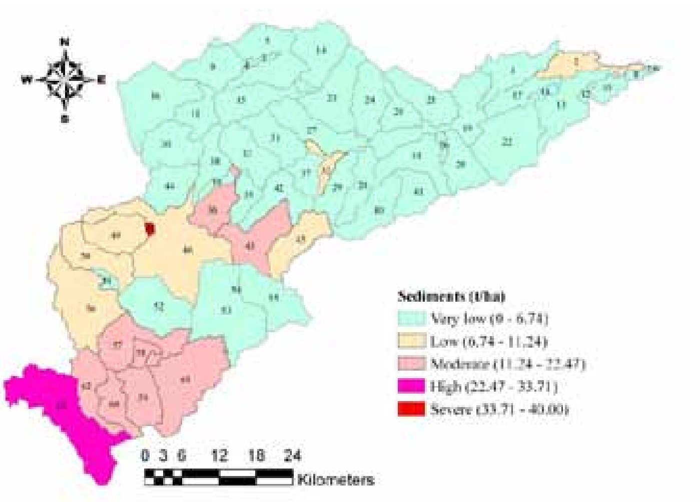

Figure 5. Vulnerability of different subbasins in sediment loads

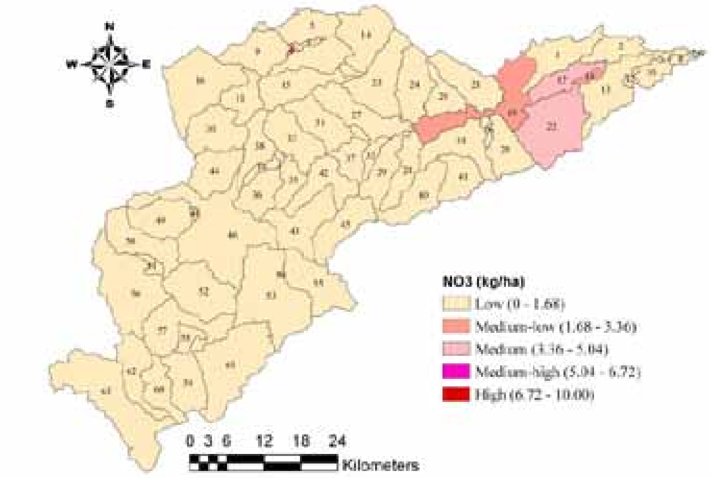

Figure 6. Vulnerability of different subbasins in NO_3-N losses

soil loss tolerance rate (Stone and Hilborn, 2000) because it received water and sediment of all basins above Lam Takong dam. In addition, basin 63 (Mu Si subdistrict) was identified as a high soil erosion area since it was located at high steep slopes (more than 55.95^o) upstream and subjected to tillage and many major rainfall events. Similarly, the study in the upper Mekong River concluded that the soil erosion was produced on land with a steepness reaching 59.7 t/ha when the slope was greater than 40° (Zhou *et al*., 2014). Therefore, appropriate strategies, such as land use changes, filter strips and terraces, should be devised to protect these critical areas for soil and water conservation practices.

The mean annual NO_3-N yield of Lam Takong River basin was only 0.879 kg/ha which waslow as classified by Wu *et al*. (1997). This value was lower than 2.57 to 4.52 kg/ha in Banha watershed, India (Mishra *et al*., 2010) where cattle and poultry farms are found in residential areas. However, the value was higher than those in Honey Creek watershed, Ohio (Grunwald and Qi, 2006) which has more forested area.

Subbasin 22 and 17 (Nai Mueang subdistrict) had the highest NO_3-N in the basin (Fig. 6). Similarly, the Pollution Control Department (2008) and Suwanwaree and Suwannarat (2010) reported water quality in Nai Mueang subdistrict as meso-eutrophic and deteriorating. However, both subbasins were classified as medium ranges following Wu *et al*. (1997).

Unlike NO_3-N, the mean annual TP yield of Lam Takong River basin was 1.213 kg/ha which was considered medium according to Gurung *et al*. (2013). This value was similar to the upstream Yellow River, China (Ouyang *et al*., 2009). However, it was greater than the Banha watershed, India (Mishra *et al*., 2010) where paddy-cultivation made up 31.49% of the total area.

Nine subbasins had high TP loading and were considered as eutrophic areas (Gurung *et al*., 2013). They were distributed all over the basin both in agricultural and urban areas (Fig. 7). Agricultural land, where chemical fertilizers or manure are deposited, is the main source of NO_3-N and TP losses (Panagopoulos *et al*., 2011).

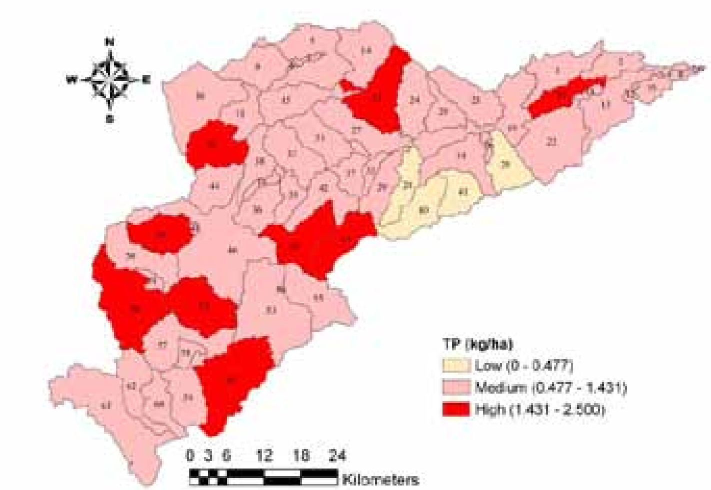

Figure 7. Vulnerability of different subbasins in TP losses

However, subbasins with very high vulnerability to TP losses might be of moderate vulnerability in NO_3-N losses. This can be attributed both to the uneven N and P input to this subbasin as well as to the different mechanisms governing N and P movement in the area, which are associated with surface and subsurface pathways of pollutant transport (Panagopoulos *et al*., 2011). Thus, such differences were crucial for the selection of appropriate management alternatives, which should be selected according to the environment target or type of pollutant.

3.4. Management scenarios

Filter strip was the most effective way to control nonpoint source pollution in the Lam Takong River basin, followed by terrace and land use change, respectively (Table 4). From 13 scenarios, the 30-m filter strip had the most effective BMP, it could reduce 100% of both sediment and TP, and 97% of NO_3-N. Reducing filter strip width would decrease the pollution reduction. Parajuli *et al*. (2008) found that about 73% of sediment yield was reduced with a 10 m filter strip. The 15 m removed up to 82% of sediment yield and the 20 m removed up to 89% of sediment yield at Upper Wakarusa watershed in Kansas. Moreover, they also concluded that 100% reduction of sediment yield needed a 30 m filter strip. Laurent and Ruelland (2011) studied alternative practices of nitrate flow in Oudon River, Western France. The results illustrated the efficiency of filter strips (5 m) was significant at the catchment scale as 11% nitrate reduction. Patty *et al*. (1997) showed that strips with widths of 6, 12 and 18 m reduced runoff volume by 43 to 99.9%, suspended solids by 87 to 100%, Nitrate and soluble phosphorus were reduced by 47 to 100% and by 22 to 89%, respectively.

Terraces were the second best method to control nonpoint source pollution. At the basin level, terraces curtailed sediment, NO_3-N and TP loads by 85.62%, 18.66% and 68.76%, respectively. It indicated that this scenario could reduce much of the sediment and TP loads, but moderate NO_3-N. However, previous study showed that the regulation of USLE C and P factors showed the greatest TN (36.5%) and TP (41.4%) reductions of among four BMPs scenarios including the application of vegetation filter strip, riparian buffer system, the regulation of Universal Soil Loss Equation P factor and the fertilizer control amount for crops (Lee *et al*., 2010).

Changing land use types in Lam Takong River basin did not affect nonpoint source pollution. A possible reason could be the size limitations of the area, which were too small to register. The change of agriculture to deciduous forest, if slope > 12^o was only 2.44% of total agricultural land. People rarely farm in areas with steep slopes. However, other studies found land use changes did indeed impact water pollution trends. For example, Liu *et al*. (2013) reported that the conversion of steep sloped arable land (25^o) to forests could reduce nitrogen, phosphorus and other nutrients in the Xiangxi River watershed by 20% or more. Yang *et al*. (2011) converted Eucalyptus plantations to natural forest, if the gradient > 25^o. The results showed that sediment and TP would reduce by 15.99% and 4.80%, respectively. Moreover, Betrie *et al*. (2011) simulated reforestation scenarios (altering cropland, shrub land,

Table 4. The simulated loads of the pollution and percentage reduction (in parenthesis) in different scenarios of Lam Takong River basin

Scenarios	Sediment (t/ha)	NO_3-N (kg/ha)	TP (kg/ha)
Present state	8.134	0.879	1.213
Scenario 1	7.987(1.81%)	0.877 (0.23%)	1.203 (0.82%)
Scenario 2	8.366 (-2.85%)	0.884 (-0.57%)	1.224 (-0.91%)
Scenario 3	8.070 (0.79%)	0.876 (0.34%)	1.204 (0.74%)
Scenario 4	3.054 (62.45%)	0.363 (58.70%)	0.455 (62.49%)
Scenario 5	2.223 (72.67%)	0.275 (68.71%)	0.332 (72.63%)
Scenario 6	1.467 (81.97%)	0.192 (78.16%)	0.219 (81.95%)
Scenario 7	0.873 (89.27%)	0.125 (85.78%)	0.130 (89.28%)
Scenario 8	0.376 (95.38%)	0.069 (92.15%)	0.056 (95.38%)
Scenario 9	0.000 (100%)	0.024 (97.27%)	0.000 (100%)
Scenario 10	1.170 (85.62%)	0.715 (18.66%)	0.379 (68.76%)
Scenario 11	1.525 (81.25%)	0.302 (65.64%)	0.211 (82.61%)
Scenario 12	1.415 (82.60%)	0.196 (77.70%)	0.174 (85.66%)
Scenario 13	2.856 (64.89%)	0.245 (72.13%)	0.378 (68.84%)

barren, mixed forest, and deciduous forest into evergreen forest), which showed that the least reduction of sediment loads was 11% reduction in the Blue Nile Basin.

The use of a 6-m filter strip alone had a moderate effect on three pollutants no greater than 62%. Terraces could significantly reduce both sediment (85.62%) and TP (68.76%) but not NO_3-N (only 18.66%). When combined, the 6-m filter strip could improve the reduction of NO_3-N (to 65.64%) and TP (82.61%) but decrease sediment reduction. When 50-m filter strips were added in subbasins of Muang District, this can improve much of NO_3-N up to 77.7% but only a little for sediment and TP due to small area size. However, when terraces were taken out, sediment and NO_3-N drastically dropped to 64.89% and 68.84%, respectively. Therefore, adding a filter strip has a greater impact on NO_3-N than terraces do in the Lam Takong River basin. The best combination would be scenario 12 when applying terraces with 6 and 50 m filter strips. However, it is not possible to apply 50-m filter strip in the Muang District due to the anthropogenic influence and previously established human dominated landscapes on the margins of Lam Takong River.

4. Conclusions

SWAT model was successfully used to evaluate sediment, NO_3-N and TP loads in Lam Takong River basin. The simulated flow, sediment and nutrient loads at the two stations in Lam Takong River were in reasonable agreement with the measured values with R^2 and NSE greater than 0.5 and PBIAS less than 25%. The simulation also showed that mean annual sediment, NO_3-N and TP at the outlet were 8.134 t/ha, 0.879 kg/ha and 1.213 kg/ha, respectively. Moreover, September had the highest sediment, NO_3-N and TP yields while January and December had the lowest, which can be accounted for by seasonal variation in rainfall. From 63 subbasins, SWAT identified 1 subbasin with severe soil erosion, 1 subbasin with a high soil erosion rate. There were no high NO_3-Nloading subbasins within this basin but 2 subbasins were classified as medium. However, 9 subbasins were classified as high TP loading.

The management scenario evaluation illustrated that the best scenario to reduce sediment, NO_3-N and TP loads was scenario 9 (30-m filter strip). Using scenario 9 could reduce 100% of the sediment and TP loads and 97.27% of NO_3-N loads. Terraces alone had greater effects on sediment and TP but adding filter strips could improve NO_3-N reduction further. In this study, however, the number of sampling stations (calibration sites) were too few. Therefore, the further works of calibrating and validating the models should follow up by increasing the number of sampling stations in future monitoring efforts. Moreover, the in-depth study of HRUs level and PS should be also considered to improve management efficiency.

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