Assessment of Agricultural NonPoint Source Model for a Watershed in Tropical Environment

Mukand Singh Babel1; Mohamed Mujithaba Mohamed Najim2; and Rainer Loo3

Abstract: Very little work on the application of watershed modeling has been done in the tropical climatic conditions of Thailand to explore the nature of environmental problems arising from nonpoint source pollution due to agricultural activities, and to evaluate possible remedial measures and strategies. The present study attempts to verify the suitability of a nonpoint source pollution model, the Agricultural NonPoint Source model, for the Huai Nong Prong watershed in Southeastern Thailand. Extensive fieldwork was carried out to collect data and information needed for the model preparation and application. The study has revealed that simulated runoff volume, sediment, and nutrient yield from the watershed with mixed land use and relatively high slopes match favorably with observed data. For the ten rainfall events simulated, the coefficient of performance, a measure of model efficiency (equal to zero for a perfect match), was 0.09, 0.47, 0.09, and 0.03 for runoff volume, sediment yield, total nitrogen, and total phosphorus, respectively. The model, however, could not accurately simulate peak flow rates, suggesting the need for changes in the modeling approach or governing equations and relationships to calculate peak discharges in a tropical environment.

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Introduction

Land resources are very important in Asia as the land to man ratio is very low, 0.87 ha/person in Thailand, for example. High population pressure on land has led to degraded and limited resources. In the past 4 decades, deforestation in Thailand has been very rapid and the forestland has been converted into agricultural land, which has increased erosion from these watersheds. Soil erosion from agricultural areas results in loss of not only productive soil, but also, plant nutrients, and organic and inorganic matter causing reduction in soil fertility. Sediment, a product of soil erosion, becomes a pollutant. Also, the increased use of agro-chemicals has deteriorated the quality of water generated from such watersheds.

According to the Land Development Department (LDD) of Thailand, some 33% of the 51.3 million ha of the total geographical area is moderately to severely eroded. Thailand is next only to India and Laos in Asia and the Pacific Region in the percentage of the total land area that is degraded. Suspended sediments from all the watersheds in Thailand are estimated to be 27 million t annually. Cropland expansion through exploitation of forested hilly regions in the North, and the utilization of the marginal uplands in the East and Northeast, have been major contributors (Dent 1984). About 12% of the total eroded land is under very severe erosion conditions and primarily under field crops with shifting cultivation. Lands with moderate to severe erosion are under land uses such as field crops (upland), or rubber and orchards. Studies from the hilly northern region of Thailand revealed annual soil losses of 0.28 t/ha from undisturbed forests, but with values of 14, and as high as 100, t/ha in deforested area (Sumrit 1993).

Soil erosion in Southeastern Thailand where the study watershed is located is designated as severe, where 62.2% of the forested area has been encroached upon, during the last 30 years, and used for agricultural activities. These lands are mainly cultivated with crops such as cassava and sugarcane, which accelerate soil erosion and deplete soil fertility. The predicted soil loss in the area is 34 t/ha/year. The loss of soil has caused nutrient losses, mainly of nitrogen, phosphorus, and potassium. This has decreased cassava yields from 30 to 16 t/ha during the past 30 years (Sukviboon et al. 1999).

Recently, water and land quality related issues have been analyzed and evaluated with the aid of computer models. In the United States, Canada, and Europe, substantial efforts have been put forward in the last 2 decades towards developing watershed-scale nonpoint source pollution models. As a result, several computer models such as CREAMS (Knisel 1980), HSPF (Johnson et al. 1980), ANSWERS (Beasley et al. 1980), EPIC (Williams et al. 1984), SWRRB (Williams et al. 1985), AGNPS (Young et al. 1987), GLEAMS (Leonard et al. 1987), WEPP (Nearing et al. 1989), EUROSEM (Morgan et al. 1998), and others have been developed for predicting erosion, sediment, nutrient, and chemical transport from watersheds. These water quality models are effective and very useful tools in watershed planning, development, and management, and can also play a significant role in

1Associate Professor, Water Engineering and Management Program, School of Civil Engineering, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand. E-mail: msabel@ait.ac.th
2Lecturer, Dept. of Agricultural Engineering, Faculty of Agriculture, Univ. of Peradeniya, Peradeniya, Sri Lanka. E-mail: mnajim@pdn.ac.lk
3Adjunct Associate Professor, Water Engineering and Management Program, School of Civil Engineering, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand. E-mail: loof@ait.ac.th

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evaluating possible remedial measures and strategies for soil, water, and nutrient conservation to improve watershed health.

The Agricultural Non-Point Source (AGNPS) pollution model presents a means of objectively evaluating nonpoint source pollution from agricultural watersheds and abatement strategies (Young et al. 1987). This model has been the subject of research by several scientists and engineers. Young et al. (1989) used data from seven watersheds in Minnesota, to test the chemical component of the AGNPS model and found realistic predictions of nutrient concentration in runoff water. Bingner et al. (1989 and 1992) used several nonpoint source models including AGNPS, to simulate runoff and sediment yields from three small watersheds in Mississippi and found that AGNPS provided better results than the other models investigated. A study done by Di Luzzio and Lenzi (1995) in Italy integrating geographic information system and AGNPS revealed that the model outputs of runoff, sediment yield, and nutrients load [nitrogen (N) and phosphorus (P)] are sensitive to rainfall spatial variability. Macalpine et al. (1995) used AGNPS for Pine Lake Watershed in Canada and they revealed that prediction of phosphorus concentrations by AGNPS was 10–100 times higher than that observed. Fisher et al. (1997) analyzed AGNPS in terms of spatial sensitivity of soil properties and land use categories on the model output and concluded that chemical discharge outputs from AGNPS has little or no sensitivity to the spatial distribution of these input data. Mostaghimi et al. (1997) concluded from their study that runoff, sediment yield, and N and P loading predicted by the AGNPS model compared favorably with the observed values. Perrone and Madramootoo (1997 and 1999) used the AGNPS model to evaluate the effectiveness of best management practices on water quality improvements.

Table 1 presents several of the past AGNPS applications in different environments. In most of the previous work the AGNPS model was applied to relatively flat or moderate slopes on predominantly agricultural watersheds and in temperate and humid continental climates. Also, the AGNPS model is based on the equations and methodologies developed in temperate soil and climatic conditions and as such its applicability and suitability in tropical environments needs to be assessed. Moreover, watershed modeling in developing countries is relatively new and not much modeling effort has been expended to make use of the predictive power of models in watershed management. The primary purpose of this study was to verify the applicability of the AGNPS model for the simulation of runoff, sediment, and nutrient yields from a watershed in Thailand that has a mixed land use and relatively higher slopes (Table 1).

Although, the continuous version of AGNPS model, the annualized AGNPS pollution model with the capability of simulating additional processes and incorporating geographical information systems was available (Cronshiey and Theurer 1998), the present study applied the event-based AGNPS model (version 5.0).

### Simulation Model

The AGNPS model is an event based, distributed parameter computer simulation model developed by the Agricultural Research Service in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service (Young et al. 1995). The model subdivides the watershed into uniform grids called “cells.” Potential pollutants are routed through cells in a stepwise manner, proceeding from the headwaters of the watershed to the outlet. The model can be used to predict runoff volume, peak flow, as well as sediment, nutrient, and pesticide yields for single storm events at any point in a given watershed (Young et al. 1987, 1995). The nutrients considered include nitrogen (N) and phosphorus (P), both essential plant nutrients and major contributors to surface water pollution. In addition, the model considers point sources of water, sediment, nutrients, and chemical oxygen demand (COD) from animal feedlots, and springs (Young et al. 1995).

Basic model components of AGNPS include hydrology, erosion, and sediment and chemical transport. Model components use equations and methodologies that have been well established and are extensively used by agencies such as the USDA Natural Resources Conservation Service.

In hydrology component of the model, the runoff is estimated based on the Soil Conservation Service (SCS) curve number method. Peak flow from each cell is estimated using the CREAMS equation

\[
Q_p = 3.79A^{0.7}CS^{0.16}(Q/25.4)^{0.903}LW^{-0.19}
\]

where \(Q_p\) is peak flow rate (m³/s); \(A\) = drainage area (km²); \(CS\) = length weighted channel slope (m/km); \(Q\) = runoff volume (mm); \(LW\) = watershed length width ratio; and \(L\) = watershed length.

The modified form of the universal soil loss equation (USLE) is used to estimate upland erosion for single storms. Detached sediment is routed from cell to cell through the watershed to the outlet. The steady state continuity equation used in sediment transport and depositional relations is

\[
Q_s = Q_{so} + Q_{sl}(x/L_s) = \int_0^x D(x)w \, dx
\]

where \(Q_s\) = sediment discharge at the downstream end of the channel reach; \(Q_{so}\) = sediment discharge into upstream end of the channel reach; \(Q_{sl}\) = lateral sediment inflow rate; \(x\) = downstream distance; \(w\) = channel width; and \(D(x)\) = depositional rate.

Soluble nutrients contained in runoff are estimated as follows:

\[
Nut_{sol} = C_{nut}Nut_{ext}Q
\]

where \(Nut_{sol}\) = concentration of soluble N or P in runoff; \(C_{nut}\) = mean concentration of soluble N or P at soil surface during runoff; \(Nut_{ext}\) = extraction coefficient of N or P for movement into runoff; and \(Q\) = total runoff.

Further details on the theoretical background of AGNPS can be found in Young et al. (1989).

### Data Collection and Analysis

The study watershed, Huai Nong Prong (latitude 12°33′–12°36′ N and longitude 101°53′–101°55′ E) with an area of 285 ha, is located in Chanthaburi Province in the Southeastern region of Thailand (Fig. 1). The area is under increasing pressure from agricultural and resources development activities leading to resource use conflicts including various land use planning and water allocation problems and modification and/or destruction of near-shore marine habitats such as mangroves. The landforms in the area are classified into four geomorphic units: hills, plains, intertidal zone, and near-shore zone. The study watershed, typical of the area, falls in the geomorphic unit of hills and is presently covered with a mixture of land uses due to encroachment by the local population for cultivation.

The climate of the area is tropical monsoon type, characterized by heavy rainfall and hot weather. It is influenced by the south-
western and northeastern monsoon. The area receives moisture mostly from the southwestern monsoon and is also affected by coastal climate due to its proximity to the Gulf of Thailand. The rainy season, mainly controlled by southwestern monsoon, lasts for 6 months, from mid May to mid November. The cold season, from mid November until mid February, is influenced by the northeastern monsoon. The annual maximum and minimum temperature of 28 and 25.2°C is observed in April and December, respectively, with an average of 26.8°C. The area has an average annual rainfall of 2,874.0 mm, 90% of which falls during May to October (Table 1). The annual rainy days are 170.

The LDD has been collecting rainfall, runoff, sediment and nutrient data from the study watershed since 1998. The rainfall is measured by a siphon type recording rain gage. A “V notch” weir is installed at the outlet of the watershed to measure the flow using a water stage recorder. Runoff samples are collected at the watershed outlet and brought to the LDD laboratory for analysis of total nitrogen, total phosphorus, and sediment. However, the rainwater samples are not collected by the LDD.

An extensive investigation, using both field observations and 1,992 areal photographs, was carried out to determine land use, channel network, channel types, and their dimensions, and the conservation measures being practiced within the watershed. The average land slope of the watershed is 9% with some area having steep slopes, up to 20% with dense forest. Analysis of the data shows that the watershed is covered with 41% of agricultural lands, 26% of natural and planted forest, 25% of mangrove forests, and 8% of other land uses. The main cropping systems in the study watershed are rubber plantation (27%), orchard (9%), and Cassava (5%). The farmers residing in the watershed were interviewed to get information on kind, dosage, and time of application of fertilizers and pesticides in their fields. The study area was carefully examined for the presence of point sources of pollution, additional erosion sources, and impoundments.

The semidetailed soil map developed by Rimchala et al. (1983) for the study area was used in identifying and sampling the major soil types and to measure the field slope. A representative soil sample was collected from each soil type and was analyzed for particle size distribution, total nitrogen, total phosphorus, and organic matter contents. A rainwater sample in the middle of the rainy season was also collected and analyzed for nitrogen concentration. This sample was considered as representative of the 1998 and 1999 rain events analyzed in the study. In order to confirm the assumption five rainwater samples were taken during the 2000 rainy season, which showed slight variation in the nitrogen concentrations.

The kinetic energy of rainstorm was calculated from the daily recording rain chart by subdividing the rain into specific intensity ranges (Lal 1988). The energy of the storm was calculated using the following equation (Morgan 1996):

\[ KE = 11.87 + 8.73 \log I \] (4)

in which \( KE \) = kinetic energy \((J \, m^{-2} \, mm^{-1})\) and \( I \) = intensity \((mm/h)\). The product of the total kinetic energy of storm times its maximum 30 min intensity \((I_{30})\) gives the \( E_{L30} \). \( E_{L30} \) divided by 1,000 gives the energy intensity (EI) or the rainfall erosive index of individual rainstorms.

The water stage records were converted to discharge data using the rating curve developed by the LDD. As the streams in the watershed are ephemeral and intermittent streams, the straight-line method was used in base flow separation to produce the direct runoff hydrograph. The runoff volume generated by each rainfall event was calculated using the direct runoff hydrograph. Details of calculations and results of EI and runoff are given in Najim (2000).

The soil erodibility factor \((K)\) for each soil type in the watershed was found from nomograph using measured soil textural parameters and organic matter contents. The SCS curve number \((CN)\), crop management factor \((C)\), supporting practice factor \((P)\), surface condition constant, COD factor, Manning’s roughness coefficient for overland, and channeled flows were taken from the literature and are given in Najim (2000). The CNs were adjusted for wet and dry moisture conditions as specified in the AGNPS users’ guide (Young et al. 1994).

Model Application and Evaluation

A uniform grid system superimposed on the watershed consists of 114 base cells, each with an area of 2.5 ha. However, to better represent the variation in model parameters such as the land use, soil, and slope differences, some of these base cells were divided into smaller areas leading to a total of 309 cells with 70 base cells, 155 subcells each representing one quarter of a cell, and 84 subsubcells each representing 1/16 of the base cell. The grid system overlain on the watershed is shown in Fig. 2.

The measured nitrogen concentration of the rainfall was 0.77 mg/L. Observed rainfall depth and the corresponding calculated EI values were input to the model. Flow directions identified from the areal photographs and the field visits were assigned to the cells. The SCS CNs were assigned to each cell according to the land use and the initial SCS antecedent moisture condition (AMC) selected for the event. A weighted average value of the crop factor, surface condition constant, and COD factor were calculated if there is a variation in land use within a particular unit. \( P \) factors were assigned based on the conservation measures adopted. Actual fertilizer application was considered in the simulation. Similarly, the actual channel type for each cell was assigned. In total, 22 input data are required for each cell.

In all, ten rainfall events were simulated. The four rainfall events observed in 1998 were used for model calibration. The six rainfall events in 1999 were used for model validation purpose. Table 2 lists the rainfall events and the calculated values of EI.

The model performance was evaluated by comparing the simulated and observed parameters in terms of the relative error (RE) and the coefficient of performance (CP). The percent RE is defined as

\[ \% RE = \left( \frac{\text{simulated} - \text{observed}}{\text{observed}} \right) \times 100 \] (5)

The percent RE is negative for underprediction and positive for overprediction. The CP is calculated using the following equation (James and Burgess 1982).

\[ CP = \frac{\sum_{i=1}^{N} \left[ S(i) - O(i) \right]^2}{\sum_{i=1}^{N} \left[ O(i) - O_{avg} \right]^2} \] (6)

where \( S(i) \) = ith simulated parameter; \( O(i) \) = ith observed parameter; \( O_{avg} \) = mean of the observed parameter; and \( N \) = total number of events. The CP approaches zero as the differences between observed and simulated values decreases.

In addition to the above two model performance indicators, the \( p \) value was calculated with the assumption, although the sample is of small size, that the simulated and observed parameters follow a standard normal distribution. The null hypothesis \( H_0 \) is defined as: the mean of the simulated data and the mean of the
observed data are equal. If the p value is less than a specified significance level (generally 5%), the $H_0$ is rejected; and if it is greater than a specified significance level, then $H_0$ is not rejected (Devore 1991). In other words, statistically, the p value is the smallest level of significance at which $H_0$ is rejected.

## Results and Discussion

### Rainfall–runoff Relationship

Fig. 3 is a plot between the measured rainfall and runoff. There is a strong linear relationship between the rainfall and runoff with the coefficient of determination ($R^2$) of 0.93. About 20% of the rainfall converts into runoff, indicating a large amount of initial losses and infiltration taking place in the watershed.

### Model Calibration

The model was calibrated using the four rainfall events observed in 1998 (Table 2). The rainfall events were selected for model simulations considering the availability of all the relevant data for these events. The surface runoff component of the model was calibrated by varying the CN parameter for the cells, as it is the single input parameter that influences runoff. All the other input parameters such as average land slope, slope shape factor, average field slope length, average channel slope, average channel side slope, Manning’s roughness coefficient for channels, and impoundment factor in the hydrologic characterization for a particular cell or a subcell are based on measured data and parameters from the field or suitably taken from the literature. The sediment yield estimation was improved by varying the cropping factor ($C$) in the USLE and the hydrographic shape factor (Perrone and Madramootoo 1997). The other soil erosion coefficients such as soil erodibility factor ($K$), practice factor ($P$), surface condition constant, and soil texture for a particular cell or subcell are assigned according to the field observations or analyses based on the observed data or suitably taken from the literature. The nutrient yields generated by the watersheds were calibrated by defining a user assigned factor representing the decay of the nutrients within the cells and specifying fertilizer levels during the event.

The calibrated CN values for the average moisture condition varied from 50 to 100 based on the observed land use in the study watershed. The hydrograph shape factor of 595.67 was found suitable during the calibration process. The calibrated cropping factor ($C$) values over the watershed varied from 0.00092 (for natural dense forest) to 0.92 (for bare land). Eight % decay for nitrogen and 13% decay for phosphorus yielded best fits for nutrient simulation. Chemical oxygen demand was not calibrated due to nonavailability of data. These calibrated parameters were then used for all the simulations.

The calibration results for the hydrology component are presented in Table 3. The simulated runoff volume reasonably matched the observed runoff volume with a CP of 0.09. The percent RE for the rainfall events considered varies from as low as 2.7 to 47.8%. The highest RE was from the rainfall event that occurred on 13 October 1998 and may be due to improper representation of the AMC as there is a gap of about 1 month between the last two events. The AMC was adjusted and the model was rerun, which yielded improved simulation results of runoff volume. The p value (two-tailed test) of 0.8180 clearly indicates that the model simulates the runoff process at an acceptable level.

The peak flow generated by the model is between 5 and 6 times of the observed peak discharge except for rainfall Event 4.

## Table 1. Comparison of Study Watershed with Other Agricultural NonPoint Source Applications

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Perrone and Madramootoo (1997)</th>
<th>Table 1. Comparison of Study Watershed with Other Agricultural NonPoint Source Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (ha)</td>
<td>Present study</td>
<td>285</td>
</tr>
<tr>
<td>Agricultural land</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Major crop</td>
<td>Rubber, orchard</td>
<td>Corn</td>
</tr>
<tr>
<td>Average rainfall (mm)</td>
<td></td>
<td>1,153</td>
</tr>
<tr>
<td>Residential area</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>Rainfall distribution</td>
<td></td>
<td>412</td>
</tr>
<tr>
<td>Soil</td>
<td></td>
<td>Corn, soybean, oats</td>
</tr>
<tr>
<td>Depth to sand</td>
<td></td>
<td>56.5</td>
</tr>
<tr>
<td>Point-source pollution</td>
<td></td>
<td>45</td>
</tr>
<tr>
<td>Average slope (%)</td>
<td></td>
<td>61</td>
</tr>
<tr>
<td>Climate</td>
<td></td>
<td>Humid continental</td>
</tr>
<tr>
<td>Average temperature °C</td>
<td></td>
<td>26.8</td>
</tr>
<tr>
<td>Maximum temperature °C</td>
<td></td>
<td>31.0</td>
</tr>
<tr>
<td>Minimum temperature °C</td>
<td></td>
<td>9.0</td>
</tr>
<tr>
<td>Data not available.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
where the ratio of simulated to observed peak flow is 2.85 (Table 3). It has been reported in the literature that the AGNPS model has overpredicted peak flow on several occasions. For example, Rode and Frede (1997) applied the model in Germany and found that the peak flow is overestimated by a factor of 3. However, the AGNPS model predicted the peak flow reasonably well for watersheds in the United States (Young et al. 1989; Mostaghimi et al. 1997).

The present study opted for the CREAMS equation to calculate peak flow rates as the other option in the model, the SCS TR55 method, required data that were not available for the study watershed. Bonta and Rao (1992) applied the CREAMS model to a watershed in Ohio and found that CREAMS slightly overpredicted peak flows. This may be a reason for the overestimation of the peak flows in this study. However, at the same time, the runoff volume calculated by the model is within the acceptable limits. The inability to predict peak flow accurately is a major limitation of AGNPS model and that may be due to the empirical nature of the relationships developed mainly in the United States that are used in the model to calculate peak flow. Therefore, there is a need to consider a different but suitable approach to determine peak flow rates that can be applicable to different hydrologic and geographical conditions. Alternatively, there could be an option in the AGNPS model where users can change the exponents and parameters of the equations to calibrate the peak flow part of the model.

Table 4 presents the results of the calibration exercise for sediment, nitrogen, and phosphorus. The model underpredicted sediment yield for the first rainfall event and overpredicted for the following three rainfall events. The RE of overprediction is as high as about 200%. This may be explained by the fact that the model overpredicted peak discharges, an error that carried over to the erosion and sediment yield components. The CP and $p$ value for the sediment yield calibration is calculated as 0.44 and 0.6456, respectively. The model output for the nitrogen is higher in the first three events and lower in the fourth rainfall event than the observed nitrogen concentration with the CP of 0.50. The model outputs are quite satisfactory with respect to phosphorus prediction.

**Model Validation**

The calibrated model was used in the validation process with a new data set of six rainfall events, Events 5–10 in Table 2. In the model validation process, it was required to modify the input data files to accommodate for variability in fertilizer application and land use changes.

The model validation results in Table 5 indicate that the model can reasonably simulate surface runoff volume with RE of less than 25% in the prediction. The runoff volumes generated by the validation process gives the CP as 0.38, which is larger than the CP (=0.09) and for the calibration process (Table 3).
events used for the calibration and validation are considered, the CP for the runoff volume becomes 0.09, which is much more satisfactory. The results show that the rainfall events on 13 October 1998 and 16 June 1999 are poorly simulated. Again, the peak flow is overpredicted several fold (Table 5), very similar to the simulation results obtained in the calibration process (Table 3). The peak flow simulations are not accepted as the calculated p value of zero indicates that two means are not the same.

Table 6 compares the observed data and the model outputs for the pollution parameters, sediment, nitrogen, and phosphorus for the validation period. The model overpredicted the sediment yields by about less than 25%, except the simulation results for the rainfall Event 7 on 18 June 1999 with about 36% of RE. These results are well within the acceptable limit in watershed modeling where the variability of input parameters is quite large. The sediment yields generated by the validation process give the CP as 0.76, which is larger than the CP from the calibration process (0.44) for the calibration process (Table 3). When all ten rainfall events are considered, the CP for the sediment yield becomes 0.47. These results prove that the AGNPS model is capable of simulating sediment yield for the study watershed, however, with lower accuracy than the runoff volume. This is also supported by the p value of 0.1528.

The nitrogen yields generated by the validation process give the CP as 0.09, which is much smaller than the CP from the calibration process (0.47). The CP for the phosphorus yields is 0.03, which is very close to the results from calibration (0.00). The validation results show that the model simulated the nitrogen and phosphorus yields within 25% of RE, except for the rainfall Event 5 on 16 June 1999 for phosphorus. Overall, the model performance in predicting nitrogen and phosphorus from the study watershed is within acceptable ranges with CP of 0.09 and 0.03, respectively. However, it should be noted here that the phosphorus results given by the model are in the increment of 0.01 mg/L, whereas the detection level was 0.001 mg/L. Therefore, the simulated and observed phosphorus concentrations are reported in increments of 0.01 mg/L, which might have influenced the statistical evaluations of the phosphorus results.

### Comparison of Simulated and Observed Parameters

Fig. 4 shows the observed and predicted runoff volume for all the rainfall events. The coefficient of determination ($R^2$) of 0.91 and the fitted regression line falling near the 1:1 line shows that there is a strong linear relationship and the model performance in predicting the runoff volume is acceptable.

The linear relationship between the simulated and observed sediment yield shown in Fig. 5 has a slope of 0.57 and an intercept of 0.62, indicating that the sediment yield was not close to the ideal 1:1 correlation as in the case of the runoff volume. The study watershed has 41% of agricultural lands, 26% of natural and planted forest, and 25% of mangrove forests. This may be one of the reasons that the AGNPS has not provided good results for sediment yields.

Both nitrogen and phosphorus predicted by the model compared favorably, showing a nearly one to one correlation with the observed data. As shown in Figs. 6 and 7 the model results are

### Table 2. Rainfall Events Simulated for Agricultural NonPoint Source Model Calibration and Validation

<table>
<thead>
<tr>
<th>Process</th>
<th>Event</th>
<th>Date</th>
<th>Rainfall (mm)</th>
<th>EI ($J m^{-2} mm^{-1} h^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration</td>
<td>1</td>
<td>11/Sep/1998</td>
<td>44.8</td>
<td>7.38</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>16/Sep/1998</td>
<td>56.6</td>
<td>5.73</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>17/Sep/1998</td>
<td>43.5</td>
<td>2.08</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>13/Oct/1998</td>
<td>35.2</td>
<td>2.17</td>
</tr>
<tr>
<td>Validation</td>
<td>5</td>
<td>16/Jan/1999</td>
<td>38.4</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>17/Jan/1999</td>
<td>43.5</td>
<td>4.78</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>18/Jan/1999</td>
<td>33.9</td>
<td>4.15</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>05/Jul/1999</td>
<td>42.5</td>
<td>1.40</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>14/Oct/1999</td>
<td>32.2</td>
<td>4.29</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>29/Oct/1999</td>
<td>38.4</td>
<td>2.89</td>
</tr>
</tbody>
</table>

### Table 3. Agricultural NonPoint Source Model Calibration Results for Runoff Volume and Peak Flow

<table>
<thead>
<tr>
<th>Event</th>
<th>Depth (mm)</th>
<th>Rainfall</th>
<th>Runoff volume</th>
<th>Peak flow</th>
<th>% relative error</th>
<th>Coefficient of performance</th>
<th>% relative error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Observed (m$^3$)</td>
<td>Simulated (m$^3$)</td>
<td>% relative error</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>44.8</td>
<td>27,125</td>
<td>21,564</td>
<td>-20.5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2</td>
<td>56.6</td>
<td>37,092</td>
<td>38,097</td>
<td>2.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>43.5</td>
<td>18,759</td>
<td>20,126</td>
<td>7.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>35.2</td>
<td>6,881</td>
<td>3,594</td>
<td>-47.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Coefficient of performance=0.09

$p$ value (two-tailed test)=0.8180

<table>
<thead>
<tr>
<th>Event</th>
<th>Observed (m$^3$)</th>
<th>Simulated (m$^3$)</th>
<th>Ratio $^a$</th>
<th>% relative error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.695</td>
<td>4.298</td>
<td>6.18</td>
<td>518.4</td>
</tr>
<tr>
<td>2</td>
<td>1.296</td>
<td>7.186</td>
<td>5.54</td>
<td>454.5</td>
</tr>
<tr>
<td>3</td>
<td>0.615</td>
<td>4.020</td>
<td>6.54</td>
<td>553.7</td>
</tr>
<tr>
<td>4</td>
<td>0.278</td>
<td>0.792</td>
<td>2.85</td>
<td>184.9</td>
</tr>
</tbody>
</table>

Coefficient of performance=110.49

$p$ value (two-tailed test)=0.0104

$^a$Simulated/Observed.
scattered about the linear regression line, with slopes of 0.77 and 0.99 and intercepts of 0.09 and −0.001 for nitrogen and phosphorus, respectively.

Table 7 compares model performance in the present study with the past AGNPS applications in different environments. It is seen that the model performed well and with similar level of accuracy in simulating runoff, sediment and nutrients. But, the peak flow simulated in the present study is about five times that of the observed compared to about 2.2–2.7 times in Mostaghimi et al. (1997) and about 1.4–2.1 times in Perrone and Madramootoo (1997). This indicates that the model computations for peak flow need to be modified for tropical climate. It is suggested to estimate the coefficients and constants of the empirical relationship [Eq. (1)] used in the model for local conditions. Another promising alternative could be to consider incorporating locally developed peak flow relationships, if available, in the AGNPS model.

Conclusions

The AGNPS model assessment presented and discussed in this paper is based on 2 years of data from a particular watershed in Southeastern Thailand. The observed runoff volume shows a linear relationship with the rainfall depth. The model has simulated the runoff volume with good accuracy as reflected by the small value of the CP and the high p value. This indicates that the SCS curve number method used in the AGNPS model is suitable for runoff volume prediction under local conditions.

The peak flow is overpredicted by AGNPS, which shows that the CREAMS equation employed in AGNPS to calculate peak flow may not be suitable for watersheds with relatively steep slopes in a tropical environment. It is therefore suggested to modify the peak flow-calculating component in the model to suit different geographical and climatic conditions. Sediment yield predictions by AGNPS are possible with moderate accuracy, whereas the nutrient yields are simulated with relatively high accuracy. Observed and predicted runoff, nitrogen, and phosphorus yields show a 1:1 relationship for the study watershed.

The study therefore has revealed that, in general, the AGNPS model can be used in simulating runoff volume, sediment, and nutrient yields from the watershed in tropical environments with mixed land uses and relatively steep slopes even though the model is primarily developed for flat agricultural watersheds.

Acknowledgments

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Notation

The following symbols are used in this paper:

- $A$ = drainage area;
- $C_{me}$ = mean concentration of soluble N or P at soil surface during runoff;
- $CS$ = length weighted channel slope;
- $D(x)$ = depositional rate;
- $I$ = intensity;
- $I_{30}$ = maximum 30 min intensity;
- $KE$ = kinetic energy;

Table 5. Agricultural NonPoint Source Model Validation Results for Runoff Volume and Peak Flow

<table>
<thead>
<tr>
<th>Event</th>
<th>Rainfall Depth (mm)</th>
<th>Simulated runoff volume (m$^3$)</th>
<th>% relative error</th>
<th>Observed runoff volume (m$^3$/s)</th>
<th>Simulated runoff volume (m$^3$/s)</th>
<th>Ratio$^a$</th>
<th>% relative error</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>38.4</td>
<td>11,432</td>
<td>8,495</td>
<td>14,478</td>
<td>1,035</td>
<td>0.405</td>
<td>7.34</td>
</tr>
<tr>
<td>6</td>
<td>43.5</td>
<td>16,549</td>
<td>20,269</td>
<td>14,478</td>
<td>2,976</td>
<td>0.814</td>
<td>4.94</td>
</tr>
<tr>
<td>7</td>
<td>33.9</td>
<td>8,495</td>
<td>10,135</td>
<td>14,478</td>
<td>2,140</td>
<td>0.858</td>
<td>2.49</td>
</tr>
<tr>
<td>8</td>
<td>42.5</td>
<td>17,692</td>
<td>19,545</td>
<td>14,478</td>
<td>3,804</td>
<td>0.890</td>
<td>4.27</td>
</tr>
<tr>
<td>9</td>
<td>32.2</td>
<td>7,123</td>
<td>8,687</td>
<td>14,478</td>
<td>1,888</td>
<td>0.245</td>
<td>7.71</td>
</tr>
<tr>
<td>10</td>
<td>38.4</td>
<td>12,899</td>
<td>14,478</td>
<td>14,478</td>
<td>2,976</td>
<td>0.543</td>
<td>5.48</td>
</tr>
</tbody>
</table>

$^a$Simulated/Observed.

$^b$ Coefficient of performance=0.38

$^c$ Coefficient of performance=99.11

$^d$ Coefficient of performance=0.0000

$p$ value (two-tailed test)=0.2460

$p$ value (two-tailed test)=0.0000
Table 6. Agricultural NonPoint Source Model Validation Results for Sediment, Nitrogen, and Phosphorous

<table>
<thead>
<tr>
<th>Event</th>
<th>Rainfall Depth (mm)</th>
<th>Observed</th>
<th>Simulated</th>
<th>% relative error</th>
<th>Observed (mg/L)</th>
<th>Simulated (mg/L)</th>
<th>% relative error</th>
<th>Observed (mg/L)</th>
<th>Simulated (mg/L)</th>
<th>% relative error</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>38.4</td>
<td>1.075</td>
<td>1.297</td>
<td>20.7</td>
<td>0.49</td>
<td>0.38</td>
<td>-22.5</td>
<td>0.02</td>
<td>0.01</td>
<td>-50.0</td>
</tr>
<tr>
<td>6</td>
<td>43.5</td>
<td>1.556</td>
<td>1.887</td>
<td>21.3</td>
<td>0.41</td>
<td>0.36</td>
<td>-12.2</td>
<td>0.01</td>
<td>0.01</td>
<td>0.0</td>
</tr>
<tr>
<td>7</td>
<td>33.9</td>
<td>0.798</td>
<td>1.089</td>
<td>36.5</td>
<td>0.38</td>
<td>0.40</td>
<td>-4.3</td>
<td>0.01</td>
<td>0.01</td>
<td>0.0</td>
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<tr>
<td>8</td>
<td>42.5</td>
<td>1.309</td>
<td>1.415</td>
<td>8.1</td>
<td>0.45</td>
<td>0.37</td>
<td>-17.8</td>
<td>0.01</td>
<td>0.01</td>
<td>0.0</td>
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<tr>
<td>9</td>
<td>32.2</td>
<td>1.040</td>
<td>1.052</td>
<td>1.2</td>
<td>2.37</td>
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<td>0.10</td>
<td>11.1</td>
</tr>
<tr>
<td>10</td>
<td>38.4</td>
<td>1.290</td>
<td>1.379</td>
<td>6.9</td>
<td>1.78</td>
<td>1.71</td>
<td>-3.9</td>
<td>0.10</td>
<td>0.09</td>
<td>-10.0</td>
</tr>
</tbody>
</table>

Coefficient of performance = 0.76
p value (two-tailed test) = 0.1528

Coefficient of performance = 0.09
p value (two-tailed test) = 0.6242

Coefficient of performance = 0.03
p value (two-tailed test) = 0.9282

$L = $ watershed length;
$\text{L}_{\text{W}} = $ watershed length width ratio;
$N = $ total number of events;
$\text{Nut}_{\text{ext}} = $ extraction coefficient of $N$ or $P$ for movement into runoff;
$\text{Nut}_{\text{sol}} = $ concentration of soluble $N$ or $P$ in runoff;
$O_{\text{avg}} = $ mean of the observed parameter;
$O(i) = $ $i$th observed parameter;
$Q = $ runoff volume;
$Q_p = $ peak flow rate;
$Q_{i(o)} = $ sediment discharge into upstream end of channel reach;
$Q_{i(x)} = $ sediment discharge at downstream end of channel reach;
$Q_{i} = $ lateral sediment inflow rate;
$S(i) = $ $i$th simulated parameter;
$w = $ channel width; and
$x = $ downstream distance.

References


Table 7. Agricultural NonPoint Source Model Performance (Coefficient of Performance) in Various Applications

<table>
<thead>
<tr>
<th>Result</th>
<th>Present study</th>
<th>Wu et al. (1993)b</th>
<th>Mostaghimi et al. (1997)b</th>
<th>Perrone and Madramootoo (1997)c</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calibration</td>
<td>Validation</td>
<td>Calibration</td>
<td>Validation</td>
</tr>
<tr>
<td>Runoff volume</td>
<td>0.09</td>
<td>0.30</td>
<td>1.23</td>
<td>0.06</td>
</tr>
<tr>
<td>Peak flow</td>
<td>5.30</td>
<td>5.30</td>
<td>—</td>
<td>2.15</td>
</tr>
<tr>
<td>Sediment</td>
<td>0.44</td>
<td>0.76</td>
<td>0.88</td>
<td>0.06</td>
</tr>
<tr>
<td>(average ratio)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.47</td>
<td>0.09</td>
<td>—</td>
<td>0.32</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.00</td>
<td>0.03</td>
<td>—</td>
<td>0.59</td>
</tr>
</tbody>
</table>

a No calibration and validation reported.
b Coefficient of performance values calculated (not given by the authors).
c Coefficient of performance values given by the authors.
d Simulated/observed.


