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Abstract

The purpose of this paper is to implement the "Soil and Water Assessment Tool" model to examine the effects of land use change scenarios exert on runoff discharge and sediment yield from Song Cau catchment in Northern Viet Nam. Prior to the scenarios, the particular hydrological and erosion regime of the catchment, representative of the tropical climate, was fully demonstrated. SWAT successfully predicted soil losses from different HRUs that caused significant sediment yield.

Facing the problem of reservoir inadequacy in the near future, this study attempted to assess the impact of pre-specified land use change scenarios, in terms of quantifying the results from the application of crop rotations and special cultivation techniques that was most susceptible to erosion. All scenarios resulted in a decrease in soil losses and sediment yield comparing to the current land use status. The model predicted explicitly the consequences of non-structural mitigation measures against erosion. The understanding of land use changes in relation to its driving factors provides essential information for land use planning and sustainable management of soil resources, under the special conditions of Viet Nam.

KEYWORDS: SWAT, Agricultural land, Sediment yield, Land use change scenarios

Introduction

Impact assessments of land use changes, population increases and urban development to water quantity and quality are one of the most important topics in a watershed management. Integrated management of water resource environment from river basin to downstream facilities such as dam or lake is also important for conservation and sustainable use of natural resources. Findings arising by catchment experiments provide clear evidence of the strong relation of erosion rates, land use, and human activities (Walling, 1999). Interventions along rivers, such as dams, clearly affect the dynamic equilibrium of materials exchanged between the land and the water body. Changes of the flow and sediment discharges can become influential in the evolution of the coastline, and sedimentation in reservoirs can rapidly decrease the dead storage capacities (Bonora *et al*, 2000). This is currently taking palce in Song Cau catchment in northern Viet Nam, where the sedimentation patterns of the downstream part of the catchment have significantly changed mainly due to land use change within the catchment. In addition, seasonal extreme meteorological phenomena have caused significant soil losses and sediment deposited in reservoirs has increased the operational inadequacy for water supply.

Facing the aforementioned problems, considerable efforts are needed to achieve the required improvements of surface water, primarily focusing on those areas likely to present the greatest risk. Agricultural land that is usually susceptible to soil losses is considered to be the most favorable land use type where low cost mitigation measures against erosion can be applied. Land use changes which are biophysically, or more commonly in the last years, artificially based (Skole and Tucker, 1993), often have significant effects on the surrounding environment and consequently on the hydrological cycle. Although the empirical knowledge of the consequences of a land use change is generally common (i.e. crops cultivation under rotations, strip-cropping, contours or terrace systems can decrease soil loss and sediment yield), it is often difficult to make an explicit quantification of these consequences.

The purpose of this study is to quantify the impacts of specific land use changes on runoff discharge and sediment yield through case study of Song Cau catchment in northern Viet Nam. Therefore, the objectives of this study are:

1. To apply SWAT in Song Cau catchment to analyze the impact of land use changes on runoff discharge and sediment yield, and;
2. To make policy recommendations for decision makers regarding the impacts of land use changes on runoff discharge and sediment yield.

Methodology

Study area

The Song Cau catchment is located in northern Viet Nam, between $21^0$07' – $22^0$18'N and $105^0$28' – $106^0$08'E (figure 1). The catchment has an area of 2940 km^2 and is predominantly agricultural land (arable and pasture). The elevation ranges from 24 to 1498m above sea level with the mean elevation being 284.8m. The length of the main stream is 125 km. High rainfall events in combination with less permeable soil formations cause significant runoff and subsequently high soil losses and sediment yield. Data from Thai Nguyen Meteorological and Gauging station show that the study area is influenced by tropical monsoon climate with an average temperature of 22^0C. The winter (dry) season (November to March) is cold and mostly dry with the average temperature under 15^0C and the lowest temperature during recent years is 3^0C. The summer (rainy) season (April to October) is hot with the average temperature of 26^0C while highest temperature is 39^0C.

The average annual rainfall is 2000 - 2500 mm. The highest rainfall usually occurs from June to August which occupies more than 70% total annual rainfall (GSOV, 2008).

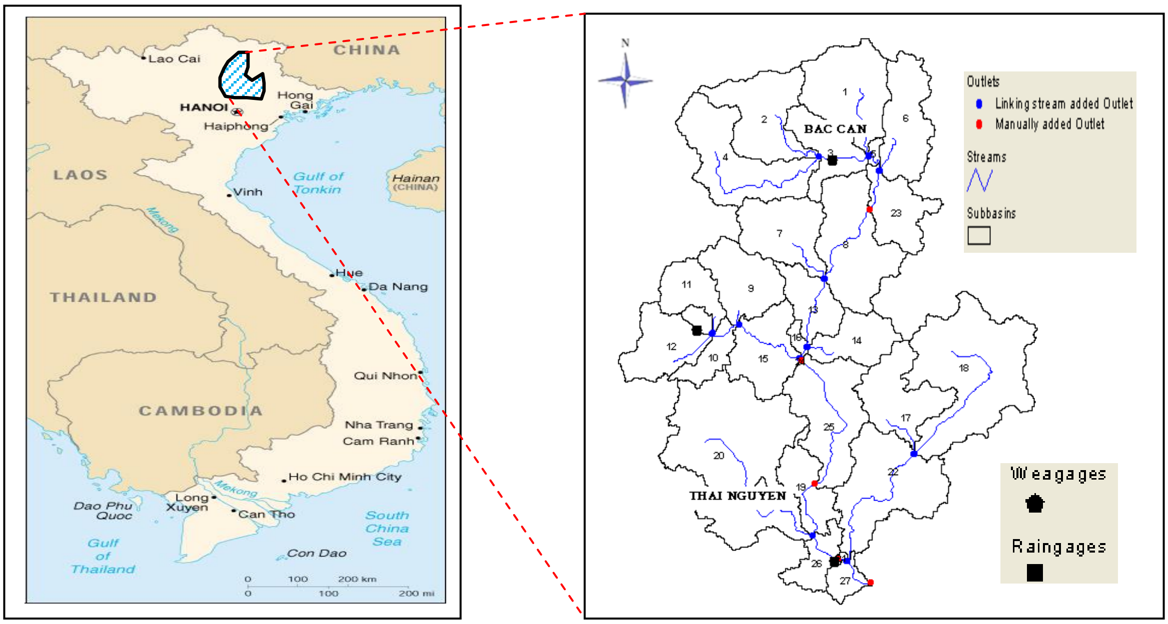

Figure 1. Location of Song Cau Catchment in Northern Viet Nam.

Brief descriptions of SWAT model

SWAT is a physically based, continuous-time hydrologic model with an ArcView-GIS interface developed by the Blackland Research and Extension Center and the United States Department of Agriculture – Agricultural Research Service (USDA-ARS) (Arnold *et al.*, 1998) to predict the impact of land management practices on water, sediment and agricultural chemical yields in large, complex basins with varying soil type, land use and management conditions over long periods of time (Mimikou *et al.*, 2000, Varanou *et al.*, and Panagopoulos *et al.*, 2007). The main driving force behind SWAT is the hydrological component. The hydrological processes are divided into two phases (Hiroaki, and Ikuo, 2009): 1) the land phase, which controls the amount of water, sediment and nutrients received by a water body and 2) the water routing phase, which simulates water movement through the channel network. SWAT considers both natural sources of nutrient inputs (e.g., mineralization of organic matter and N-fixation) and anthropogenetic contributions (fertilizers, manures, and point sources). SWAT delineates watersheds into sub-basins interconnected by a stream network. Each sub-basin is further divided into hydrologic response units (HRUs) based upon unique soil and land class characteristics separated from any specified location in the sub-basin. SWAT sums the flow, sediment and nutrient loading from each sub-basin HRU and the resulting loads are then routed through channels, ponds, and reservoirs to the watershed outlet (Arnold *et al*, 2001). A single growth model in SWAT, based on a simplification of Erosion Productivity Impact Calculator (EPIC) crop model, is used for simulating all crops (Williams *et al.*, 1984). Phenological development of the crop is based on daily heat unit accumulation. SWAT also uses WXGEN weather generator model (Sharpley and Williams, 1990) to generate climate data or to fill gaps in the measured records.

Data collection

SWAT requires meteorological data such as daily precipitation, maximum and minimum air temperature, wind speed, relative humidity, and solar radiation. Furthermore, spatial datasets including digital elevation model (DEM) as well as land cover and soil maps are required. We collected available data and information related to SWAT for Song Cau catchment including maps, statistic data, forest area, forest cover, precipitation, runoff discharge, sediment yield, and other related data. The sources and main types of data collected are shown in Table 1.

Table 1. Sources and Types of Data Collected for SWAT.

N^0	Types of data	Sources of data
1	Precipitation (rainfall)	Thai Nguyen, Bac Can, and Dinh Hoa weather stations
2	Temperature and others meteorological data	Thai Nguyen, Bac Can,and Dinh Hoa weather stations
3	Runoff discharge (observed data)	Gia Bay, Thac Buoi, and Thac Gieng gauging stations
4	Sediment yield (observed data)	Gia Bay gauging station
5	Topography (DEM)	Department of Information and Communication technology for Natural Resources and Environment, Ministry of Natural Resources and Environment
6	Soil map	Viet Nam Soil and Fertilizers Research Institute
7	Land use map	Department of Information and Communication technology for Natural Resources and Environment, Ministry of Natural Resources and Environment plus field survey data
8	Forest, Agricultural land	Department of Natural Resources and Environment of Thai Nguyen and Bac Can provinces

Land use scenarios

The principal objective of this case study was to assess an efficient land use planning for the future of Song Cau catchment. Therefore we formulated different planning scenarios based upon the recommendations addressed in "***Report on Land use planning***" (TNPC, 2008 and BCPC, 2008). Table 2 shows four land-use planning scenarios formulated for Song Cau catchment, and the baseline scenario is the land use currently implemented. (2008).

SWAT model requires methodological data such as daily precipitation, maximum and minimum air temperature, wind speed, relative humidity and solar radiation data (Nguyen *et al*., 2009). Spatial datasets including digital parameter layers such as topography (LS) and parameters R, K, C and P (Wischmeier and Smith, 1978) were digitized from the associated maps. The watershed LS factor was derived from digital elevation model (DEM) obtained from topography data.

Table 2. Land Use Planning Scenarios for Song Cau Catchment.

SWAT Code*	Baseline		Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
WATR	39948.11	13.58	39948.11	13.58	39948.11	13.58	39948.11	13.58	39948.11	13.58
URMD	16384.72	5.57	16384.72	5.57	16384.72	5.57	16384.72	5.57	43075.18	14.65
FRSD	15214.7	5.17	15214.70	5.17	15214.70	5.17	0.00	0.00	15214.70	5.17
FRSE	38391.23	13.05	38391.23	13.05	38391.23	13.05	38391.23	13.05	38391.23	13.05
FRST	17332.68	5.89	17332.68	5.89	84867.29	28.86	0.00	0.00	17332.68	5.89
RICE	26690.46	9.08	26690.46	9.08	26690.46	9.08	26690.46	9.08	0.00	0.00
PAST	135069.2	45.93	67534.61	22.96	67534.61	22.96	135069.21	45.93	135069.21	45.93
AGRL	126.82	0.04	126.82	0.04	126.82	0.04	126.82	0.04	126.82	0.04
AGRR	4928.73	1.68	72463.34	24.64	4928.73	1.68	37476.11	12.74	4928.73	1.68
	294086.66	**100**	**294086.66**	**100**	**294086.66**	**100**	**294086.66**	**100**	**294086.66**	**100**

* *SWAT code were based on Neitsch et al., 2002 with WATR: Water bodies including natural and manmade ponds and reservoirs, URMD: Urban residential medium density, FRSD: Forest-Deciduous, FRSE: Forest-Evergreen, FRST: Forest-Mixed, RICE: Rice cultivation, PAST: Pasture, AGRL: Agricultural Land-Generic, AGRR: Agricultural Land-Row Crops (almost occupied by Tea).*

Model performance evaluation

We used the Nash-Sutcliffe efficiency (NSE), root mean square error (RMSE), observation's standard deviation ratio (RSR) and percent bias (PBIAS) to evaluate model performance.

The NSE value is calculated using the following equation (1):

$$NSE = 1 - \left\{\sum_{i=1}^{n}(Q^{i}_{obs} - Q^{i}_{sim})^2\right\} \Big/ \left\{\sum_{i=1}^{n}(Q^{i}_{obs} - Q_{obs\text{-}mean})^2\right\} \quad (1)$$

Where: n is the number of registered data points, Q^{i}_{obs}, and Q^{i}_{sim} are the observed and simulated data, respectively, on the i^{th} time step, and $Q_{obs\text{-}mean}$ is the mean of observed data (Q^{i}_{obs}) across the n evaluation time steps.

The NSE value indicates how well the observed data versus simulated results fit the 1:1 line (Nash and Sutcliffe, 1970). NSE values range from $-\infty$ to one, with values less than or very close to zero indicating the unacceptable or poor model performance and values equal to one indicating perfect performance.

The RSR value is calculated as a ratio of the RMSE and standard deviation of the measured data (Moriasi *et al*., 2007). RSR incorporates the benefits of error index statistics and includes a scaling/normalization factor. The RSR value varies from the optimal value of zero, which indicates zero RMSE or residual variation, to a large positive value (Moriasi *et al.*, 2007). The RSR value is calculated using the following equation:

$$RSR = RMSE/STDEV_{obs} = \left\{\sqrt{\sum_{i=1}^{n}(Q^{i}_{obs} - Q^{i}_{sim})^2}\right\} \Big/ \left\{\sqrt{\sum_{i=1}^{n}(Q^{i}_{obs} - Q_{obs\text{-}mean})^2}\right\} \quad (2)$$

in which all parameters in the equation share the same definitions as that in Equation (1).

The PBIAS is used to determine if the average tendency of the simulated data is either larger or smaller than its observed counterparts (Gupta *et al.*, 1999). The optimal value of PBIAS is zero, with low-magnitude values indicating accurate model simulation. Positive PBIAS values indicate model underestimation bias, while negative values indicate model overestimation bias (Gupta *et al.*, 1999). PBIAS is calculated using the following equation:

$$\text{PBIAS} = \left\{\sum_{i=1}^{n}(Q^{i}_{obs} - Q^{i}_{sim})\,x100 \Big/ \sum_{i=1}^{n}(Q^{i}_{obs})\right\} \quad (3)$$

Similarly, all parameters shares the same definitions as that shown in Equation (1).

Results and Discussions

Watershed Delineation

Model simulations were performed using a delineation consisting of 27 sub-basins to account for the climatic, soil, topographic, and land cover variations within Song Cau catchment (Figure 1). A total of 9 land covers and 5 soil types were employed in the project. Table 3 presents a listing of the respective land cover types, sub-basin areas, ranges in curve number values, and USLE C factors for each land cover type delineated.

Table 3: Areas, Land Cover Types, Range in Curve Number and USLE C Factor Delineated in the Song Cau Catchment.

SWAT Code	Land Use Type	Area (ha)	Area (%)	Curve Number Range	USLE C Factor
WATR	Water	39948.11	13.58	92 - 92	0.00
URMD	Urban	16384.72	5.57	74 - 92	0.008
FRSD	Forest-Deciduous	15214.7	5.17	45 - 83	0.001
FRSE	Forest-Evergreen	38391.23	13.05	25 - 77	0.001
FRST	Forest-Mixed	17332.68	5.89	36 - 79	0.001
RICE	Rice	26690.46	9.08	62 - 84	0.030
PAST	Pasture	135069.2	45.93	49 - 84	0.003
AGRL	Agricultural Land-Generic	126.82	0.04	67 - 87	0.200
AGRR	Agricultural Land-Row Crops	4928.73	1.68	67 - 89	0.200
	Total	**294086.66**	**100**		

Model Calibration and Validation

Based on available climatic, streamflow, and sediment data collected from the catchment, model parameters in SWAT were calibrated and validated using 44 years period of record, of which data collected from 1964 to 1984 was designated for model calibration, and a period of record from 1985 to 2008 was designated as the validation period for runoff discharge. For sediment, 19 years data recorded from 1972 to 1990 and 18 years from 1991 to 2008 for calibration and validation, respectively. To account for spatial variability in topographic, soil types, and land use factors among Song Cau catchment, parameters governing streamflow response in SWAT were calibrated in a distributed fashion. We used the model's manual calibration procedure in which observed and simulated outputs are compared at the same outlet points (Gia Bay) on the catchment.

Simulation Results

Streamflow

A comparison of measured versus simulated monthly hydrographs from the Gia Bay gauges on the main stem of Song Cau showed very good agreement as that shown in Figures 2 and 3. For the calibration period from 1964 to 1984, monthly Nash-Sutcliffe coefficient of efficiency (NSE) was 0.822, observation's standard deviation ratio (RSR) and percent bias (PBIAS) were 0.438 and -1.587. For the validation period (1985 – 2008) all the parameters (NSE, RSR, PBIAS) were little lower than calibration period with value of 0.767, 0.425 and 5.928, respectively (Table 4).

Table 4. Monthly streamflow Coefficient of Nash-Sutcliffe Efficiency (NSE), Observation's Standard Deviation Ratio (RSR), and Percent Bias (PBIAS) of Song Cau.

N^0	Items	Period of Record	Monthly NSE	RSR	PBIAS (%)
1	Calibration	1964 - 1984	0.822	0.438	- 1.587
2	Validation	1985 - 2008	0.767	0.425	5.928

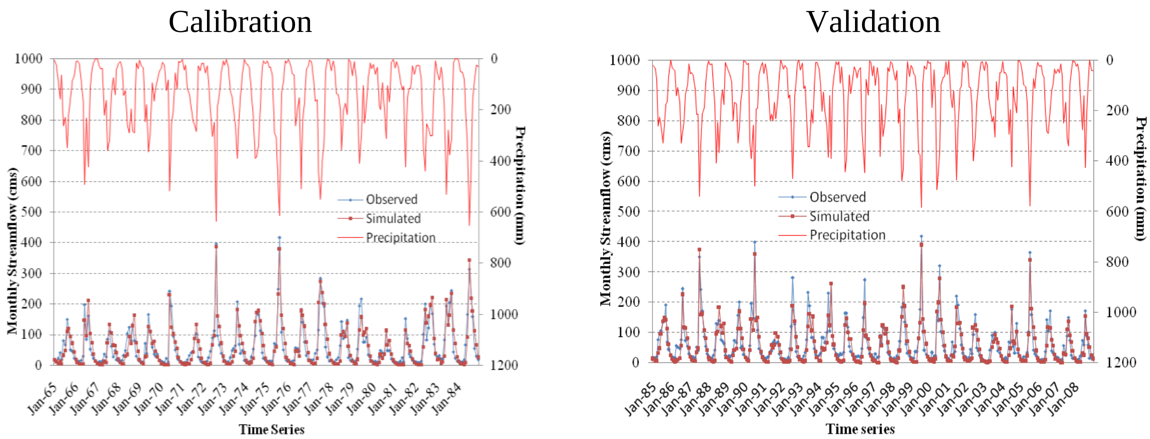

Figure 2. Observed versus Simulated Monthly Streamflow and Precipitation of Song Cau during Calibration and Validation Periods.

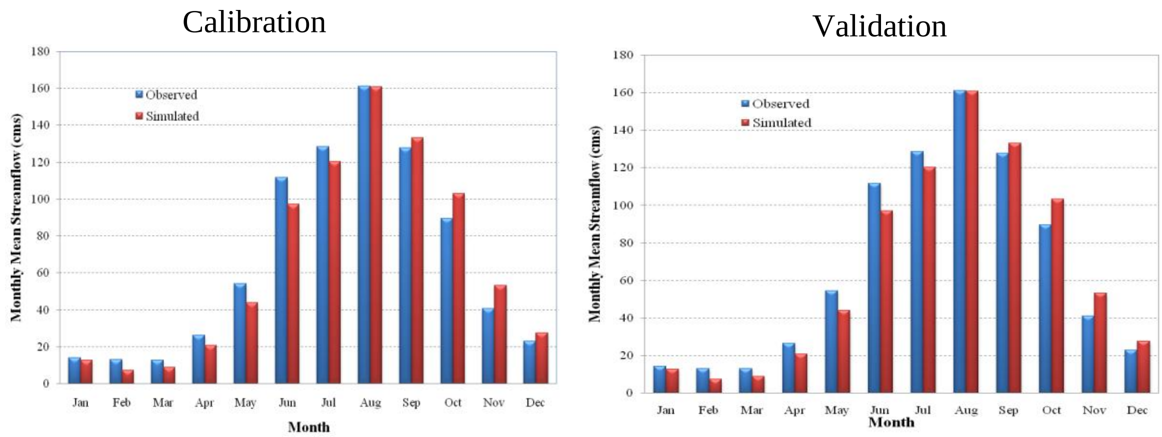

Figure 3. Observed versus Simulated Average Monthly Streamflow during the Calibration and Validation periods of Song Cau Catchment.

Sediment

The sediment data collected from 1972 to 2008 were used to compare with SWAT simulation results. In general, the simulation results showed that SWAT tended to overestimate sediment loads for all months of year, except the August of the validation period (Figure 4, and 5). SWAT performance in simulating sediment response in the watershed was considered good based on monthly NSE values for the calibration and validation periods, which were 0.660 and 0.690 respectively. The Percent Bias (PBIAS) value was satisfactory (-36.127%) for calibration and good (-26.443%) for validation period (Table 5).

Table 5. Sediment Load Percent Bias (PBIAS), Monthly Coefficient of Nash-Sutcliffe Efficiency (NSE) and Observation's Standard Deviation Ratio (RSR) of Song Cau.

N^0	Items	Period of Record	Monthly NSE	RSR	PBIAS (%)
1	Calibration	1972 - 1990	0.660	0.583	- 36.127
2	Validation	1991 - 2008	0.690	0.555	- 26.443

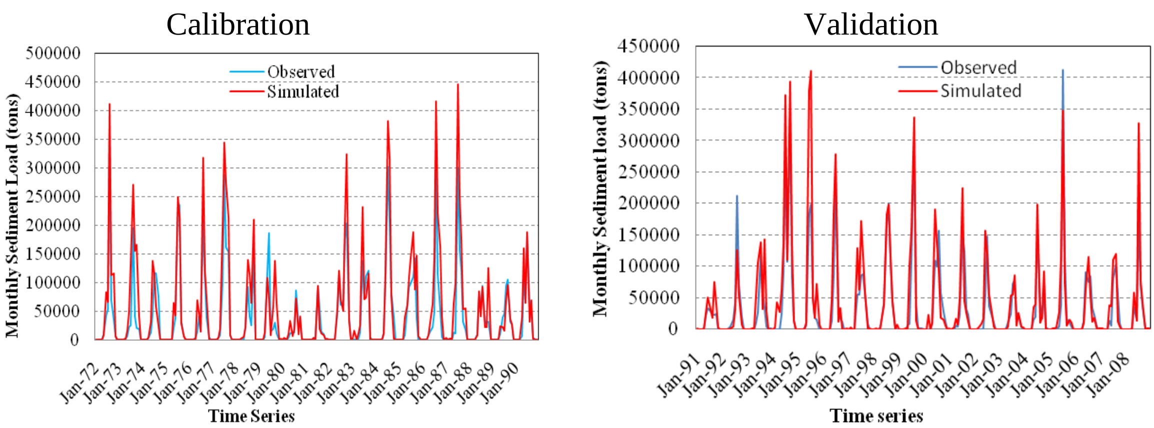

Figure 4. Observed versus Simulated Monthly Sediment Load of Song Cau during Calibration and Validation Periods.

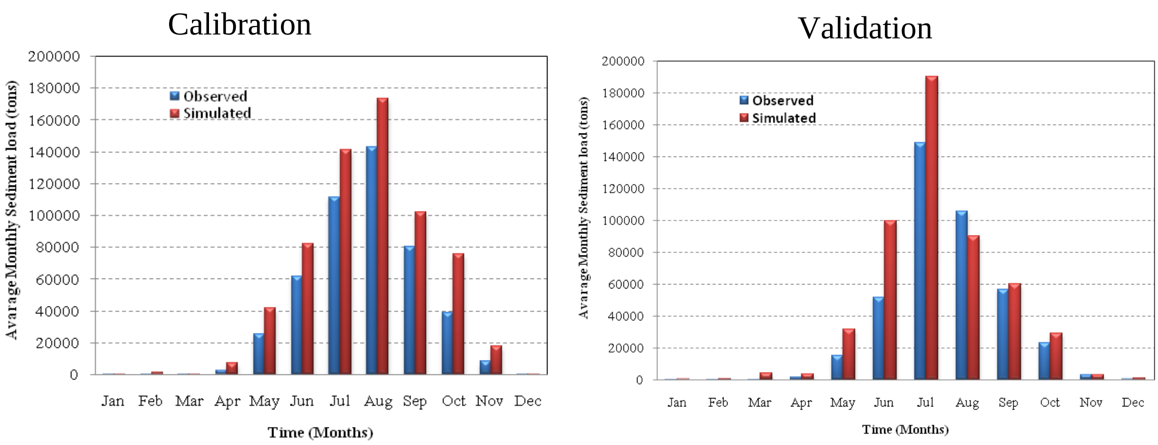

Figure 5. Observed versus Simulated Average Monthly Sediment Load during the Calibration and Validation periods of Song Cau Catchment.

Evaluation of model sensitivity to land use

Model's sensitivity to land use changes was tested using 4 hypothetic scenarios. Each scenario was generated based on Reports of land use planning of Bac Can and Thai Nguyen provinces (BCPC and TNPC, 2008). Current land use was considered as baseline scenario, and other scenarios include: (1). Scenario 1: converted 67534.61 ha (22.96%) Pasture land into Agricultural Land-Row Crops but other land uses remained unchanged; (2). Scenario 2: transferred 67534.61 ha (22.96%) Pasture land to Forest-Mixed land; (3). Scenario 3: converted 15214.7 ha (5.17%) Forest-deciduous and 17332.68 ha (5.89%) Forest-Mixed land into Agricultural Land-Row Crops; and (4). Scenario 4: transferred 26690.46 ha (9.08%) Rice land to Urban area (Table 2 and Figure 6). SWAT model was used to simulate basin hydrology under different land use scenarios using a common meteorological time series (i.e., time series of 1964~2008 for streamflow and 1972~2008 for sediment), from which impacts of land use changes on river flows and sediment loads were evaluated.

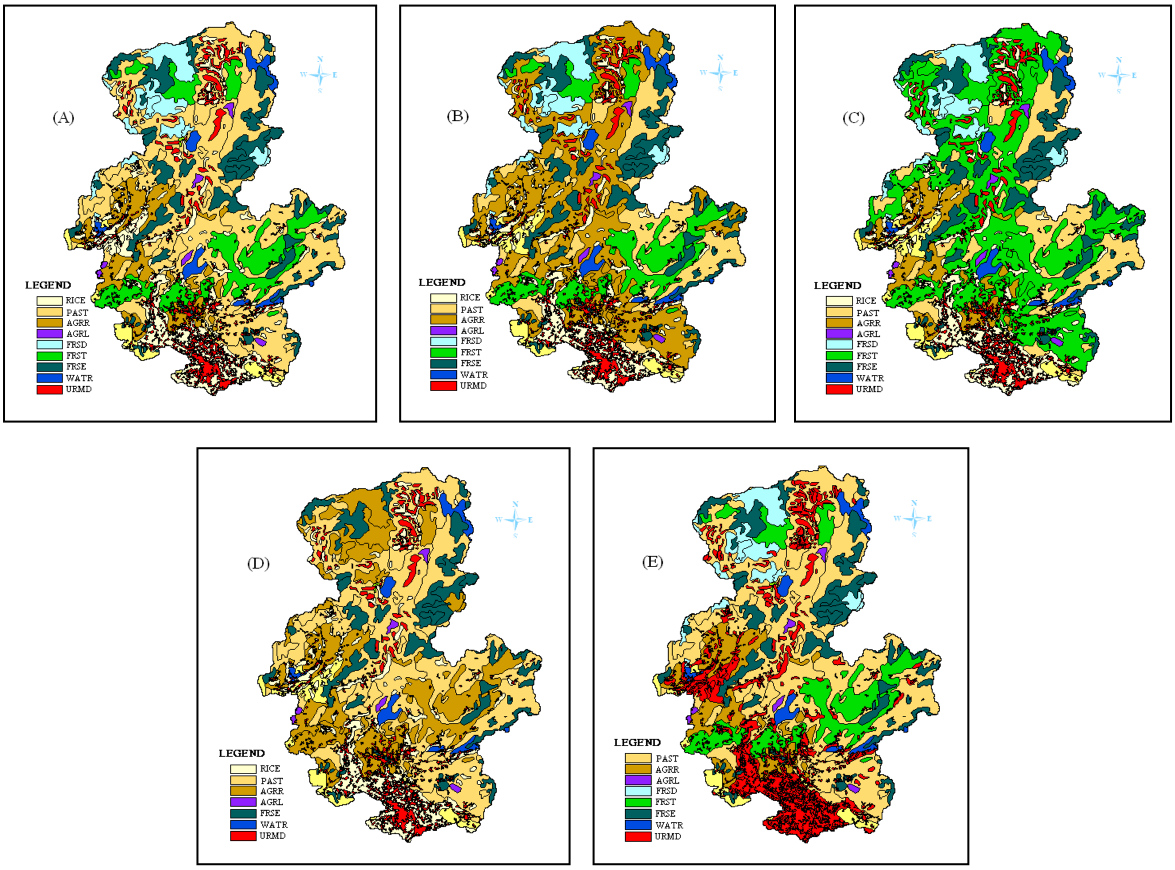

Figure 6. Different Land-use Scenarios Generated for Song Cau Catchment: (A) Baseline Scenario; (B) Scenario 1; (C) Scenario 2; (D) Scenario 3; (E) Scenario 4.

Table 6 and Figure 7 show that decreasing the area covered by forestry plantations will in general reduce the mean annual streamflow, whereas increasing the area under agriculture will increase mean annual flows. This result is consequent with that obtained by Thanapakpawin, *et al* (2007) and Stehr, *et al* (2007). The results from different scenarios that presenting the highest increase in mean annual streamflow was scenario 3, in which 11.07% of forestry (FRSD and FRST) areas were converted into agriculture land row crop (AGRR). Scenario 3 causes 3.93% increase in mean annual flows as compared to Baseline scenario. On the other hand, the lowest decrease of mean annual flows was occurred in scenario 2 with -1.37% decrease when 22.96% of pasture (PAST) was converted into forestry (FRST). Additionally, a specific comparison of simulated results for different scenarios was conducted for both dry (mean values for November to April) and wet period (mean values from May to October) as that shown in Table 6. It is worth of notice that scenario 2 produces -3.15% mean annual streamflow during mean wet season while 8.31% increase during mean dry season as compared to Baseline scenario. The effect of conserving water resources is mainly due to the significant role of forestry within catchment, which may avoid flood and drought in wet and dry season; respectively.

Table 6. Percentage (%) of Flow Change from Baseline (current land use) Scenario for Mean Annual, Wet Season (May – October) and Dry Season (November – April).

Items	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mean Annual	2.90	-1.37	3.93	1.61
Mean Wet season (5-10)	2.84	-3.15	5.08	2.41
Mean Dry season (11-4)	3.20	8.31	-2.32	-2.73

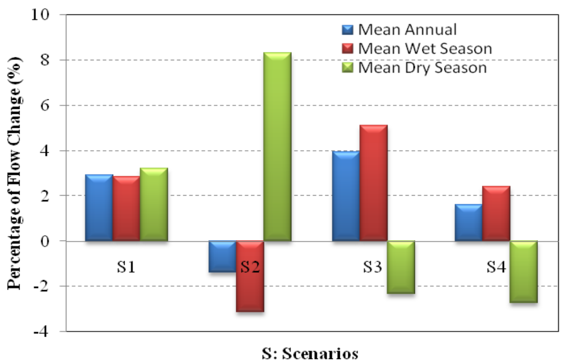

Figure 7. Percentage of Change in Mean Annual, Wet Season (May – October) and Dry Season (November – April) Flow with Respect to Baseline Scenario.

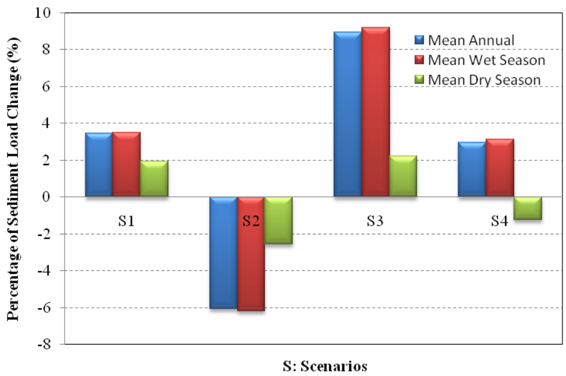

Figure 8. Percentage of Sediment Load Change in Mean Annual, Wet Season (May – October) and Dry Season (November – April) with Respect to Baseline Scenario.

Referring to sediment loads in Song Cau, three factors were mentioned, they were: Mean Annual, Mean Wet Season (May – October) and Mean Dry Season (November – April) (Table 7 and Figure 8). It can be seen that decreasing the area covered by forestry plantations will in general reduce mean annual sediment load (scenario 2), while an increase of area under agriculture will increase mean annual sediment loads (scenario 3). Results from 4 scenarios illustrate that scenario 2 produces a significant decrease in sediment loads with Mean Annual of -6.08%; Mean Wet Season of -6.21%, and Mean Dry Season of -2.56% as compared to Baseline scenario. Meanwhile, scenario 3 increases sediment loads with Mean Annual, Mean Wet Season, and Mean Dry Season 8.94%, 9.18%, and 2.21%, respectively. That illustrates the disadvantage of cultivated method on hillslopes in the mountain range of Vietnam.

Table 7. Percentage (%) of Sediment Load Change from Baseline Scenario for Mean Annual, Wet Season (May – October) and Dry Season (November – April).

Items	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mean Annual	3.45	-6.08	8.94	2.98
Mean Wet season (5-10)	3.51	-6.21	9.18	3.13
Mean Dry season (11-4)	1.92	-2.56	2.21	-1.25

Conclusions

SWAT was able to successfully simulate streamflow discharge and sediment loads for Song Cau catchment. The results showed that monthly Nash-Sutcliffe coefficient of efficiency (NSE) ranged from 0.66 to 0.822, observation’s standard deviation ratio (RSR) and percent bias (PBIAS) ranged from 0.425 to 0.583 and -36.127 to 5.928, respectively.

Land use change scenarios based on application of crop conversion on parts of the study catchment seemed to be an efficient mitigation measure to minimize soil loss. Although financial and social consequences of these changes were not taken into consideration in this study, the results strongly suggested the incorporation of pasture with forest-mixed (scenario 2) and pasture with agriculture land low crop (scenario 1) cultivation in the study catchment are among the lists of BMPs . Moreover, cultivation of pasture with forest-mixed resulted in the highest mean annual reduction in sediment yields (-6.08%), and 8.31% increase of stream flows in dry season.

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