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PREDICTING IMPACT OF FERTILIZER USAGE ON WATER QUALITY, SUTAMI RESERVOIR, INDONESIA

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Nutrients are an important water quality concern in the Sutami reservoir basin, East Java, Indonesia, due to high reservoir eutrophication. Nitrogen and phosphorous are the two nutrients derived from intensive agriculture the upstream basin. This work investigates the effect of fertilizer application rates on nutrient transport to the reservoir. The ArcView Interface of Soil and Water Assessment Tool 2000 (AVSWAT) was used. It was calibrated using measured flow rates and nutrient concentrations between 1990-2002 and validated for 2003-2005. Model predictions generally performed well on both an annual and monthly basis. Four scenarios were used: no fertilizer application, normal application, and a 50 and 100 percent increase over normal. Results show the SWAT model can be efficiently used for identification of critical subbasins that have higher nutrient loads to develop a priority watershed management plan to reduce nutrient pollution losses.

INTRODUCTION

Surface water contamination by non-point and point source pollution is a major concern for public and government agencies in Indonesia. Water quality issues are of interest to people because it is an important resource for any community for life support, economic development, recreation facilities and aesthetic values. Agriculture and urban activities are major sources of phosphorous (P) and nitrogen (N) to aquatic ecosystems. Nitrogen (N), phosphorus (P) and potassium (K), as essential macronutrients, are required for growth by all animals and plants. Farmers regularly apply fertilizers containing N, P and K to crops to increase yield. Eutrophication caused by excessive input of P and N are the common impairments of surface water and reservoirs in East Java Indonesia, (Soekistijono, 2005). Non-point source inputs are the major sources of water pollution because they accelerate eutrophication of surface water, lakes and reservoirs. The eutrophication problem currently exists in the Sutami reservoir, the largest reservoir in the Brantas river basin. It has been proposed for water supply, irrigation, flood control, electrical power and tourism. The 2005 water quality inventory of Perum Jasa Tirta (PJT) reports that approximately 60% of the river miles being monitored (including the Sutami reservoir) were impaired due to either high sediment loads or nutrient concentrations (Ramu, 2004).

The effectiveness of non-point source pollution control can be evaluated through a monitoring and modeling approach. Monitoring practices are applied to an area and the impact is evaluated with real-time sensors or through sample collection and analysis. The modeling approach provides a number of advantages over monitoring. Mathematical models have become widespread tools to aid management due to the high costs of monitoring discharges into water bodies. Some models capable of simulating watershed-scale pollutant transport include Soil and Water Assessment Tool (SWAT) (Arnold, 1998), MIKESHE (Danish Hydraulic Institute, 1999), Watershed Analysis Risk Management Framework (WARMF) (Chen et al., 1999) and Hydrologic Simulation Program – Fortran (HSPF) (Bicknell et al., 1996).

The aim of this research work is to investigate the effect of fertilizer application rates on nutrient transport to the Sutami reservoir. For this purpose the ArcView Interface of the Soil and Water Assessment Tool 2000 (AVSWAT) was used (Di Luzio et al., 2002). The AVSWAT is a model developed to predict the effect of different land management scenarios on water quality, pollutant loading and sediment yield in catchments (Srinivasan and Arnold, 1994). ArcView-SWAT was used for this effort because it is a public-domain model that can incorporate large amounts of data and simulate many hydrologic processes.

STUDY AREA

The Brantas river basin is located within the province of East Java Indonesia (see Figure 1). It is divided into three sub-basins; upstream (the Sutami reservoir basin), the middle basin (the Ngoro and Selorejo rivers) and downstream (the Porong and Surabaya rivers). The focus of this study is the Sutami reservoir which is the largest reservoir in the Brantas river basin. The Sutami reservoir basin is located between 112^{o} 25' and 112^{o} 50' East longitude and 7^{o} 35' and 8^{o} 05' South latitude (Figure 1). The maximum reservoir capacity is 253 million m^3. A detailed description of the Sutami reservoir is presented in Table 1. The Sutami Basin has an area of about 1.867,31 km^2 at the dam site. The catchment of the Sutami basin is bounded by Mt. Arjuno on the North and Mt. Semeru on the East.

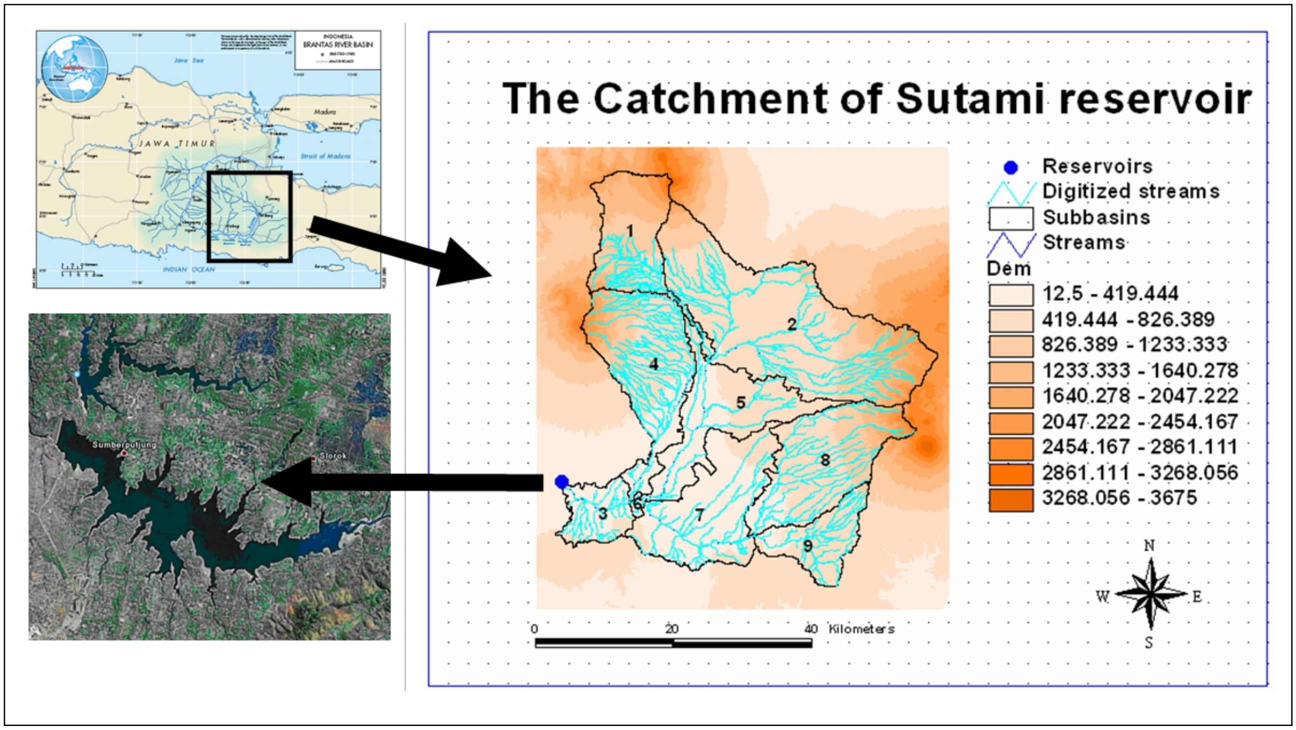

Figure 1. East Java, the Sutami reservoir and the Sutami reservoir basin.

The agricultural use area in the Sutami reservoir occupies the majority of the basin area (57.25%). The remaining uses are forestry (21.59%), residential (18.12%) and other (1.87%)(Table 2). The main soil types in the basin are latosols (20.05%), kambisols (13.41%), alluvial soils (29.01%), and andosols (20.12%)(Table 3). Annual precipitation is around 2,000 mm on average, with roughly 80% occurring in the wet season. Mean annual temperature is around 24.2^{o}C at Malang City (445 m above sea level). The NO_3 and NO_2 concentrations obtained during field work are shown in Figure 2. Land use/land cover can be seen in Figure 3, while Figure 4 shows the soil types in the Sutami river basin.

MODEL SETUP

AVSWAT is a hydrologic and water quality model developed by the U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS). It is a long-term continuous watershed scale simulation model that operates on a daily time step and is designed to assess the impact of different management practices on water, sediment, and agricultural chemical yields. The model is physically based, computationally efficient, and capable of simulating a high level of spatial detail. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. In SWAT, a watershed is divided into multiple sub-watersheds, which are further subdivided into unique soil/land use characteristics called hydrologic response units (HRUs). The water balance of each HRU is represented by four storage volumes:

Table 1. Description characteristics of the Sutami basin.

Reservoir	Type operation	FWL (m)	HWL (m)	LWL (m)	Function
Sutami	Annual	277.0	272.5	246.0	Flood control Irrigation water supply (76,651 ha) Hydropower generation 3 x 35 MW Domestic water supply Fisheries and tourism

Table 2. Land use in the Sutami basin.

Land use/land cover		Area (ha)	(%)
Agriculture	Rice field	46,389	24.84
	Dray land	46,635	24.97
	Mix garden	11,666	6.25
	Vegetable plant	1,265	0.68
	Coy plantation	473	0.25
	Apple plantation	467	0.25
Sub total		106,895	57.24
Forestry		40,314	21.59
Reservoir		1,420	0.76
Residential		33,859	18.13
Others		4,243	1.11
Total Area		186,731	100.0

Table 3. Soil types in the Sutami basin.

Soil type	Area (%)	(%)
Latosol	37,434	20.05
Kambisol, Mediteran	5,135	2.75
Kambisol	25,044	13.41
Lithosol, Andosol	2,705	1.45
Lithosol, Mediteran	3,720	1.99
Mediteran, Lithosol	2,600	1.39
Mediteran	2,446	1.31
Alluvial	54,178	29.01
Andosol	37,571	20.12
Regosol	9,515	5.10
Lithosol, Vertisol	2,609	1.40
Andosol, Kambisol	1,339	0.72
Vertisol	2,435	1.30
Total Area	186,731	100,00

snow, soil profile, shallow aquifer, and deep aquifer. Flow generation, sediment yield, and pollutant loadings are summed across all HRUs in a subwatershed, and the resulting loads are then routed through channels, ponds, and/or reservoirs to the watershed outlet.

AVSWAT simulates the complete nutrient cycle for nitrogen and phosphorus. The nitrogen cycle is simulated using five different pools; two are inorganic forms (ammonium and nitrate) while the other three are organic forms (fresh, stable, and active). Similarly, SWAT monitors six

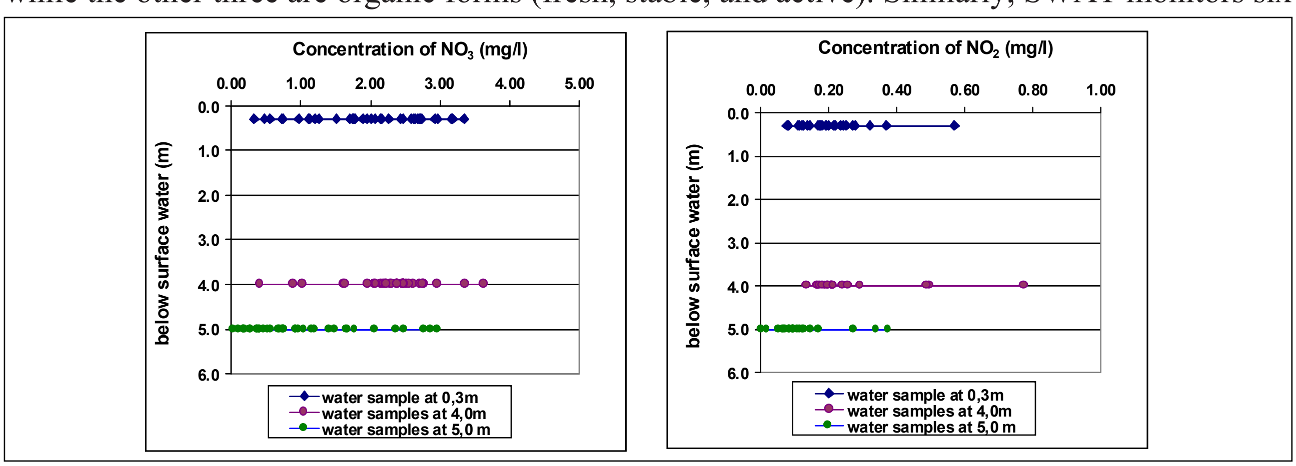

Figure 2. Distribution of NO_3 and NO_2 concentration in the Sutami Reservoir.

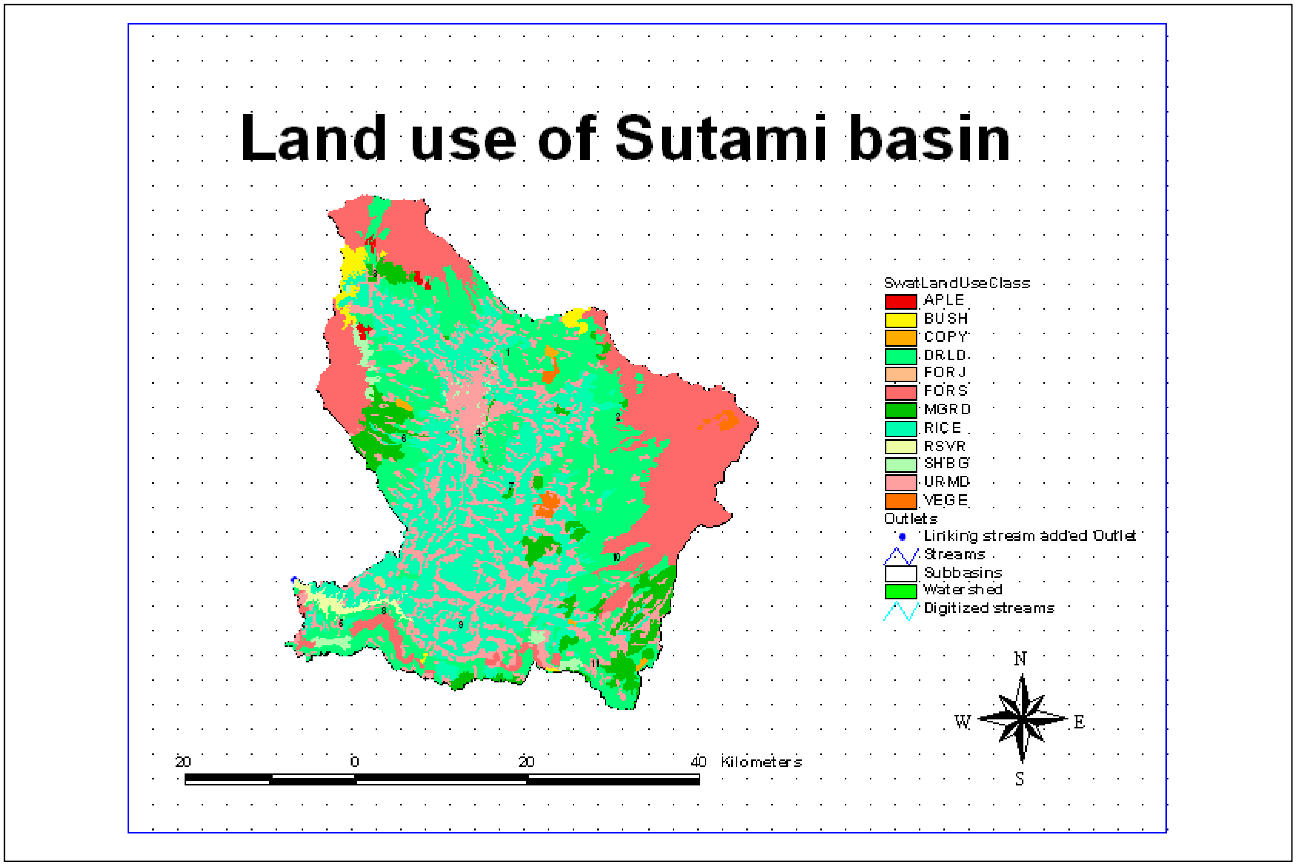

Figure 3. Land use/land cover of the Sutami basin.

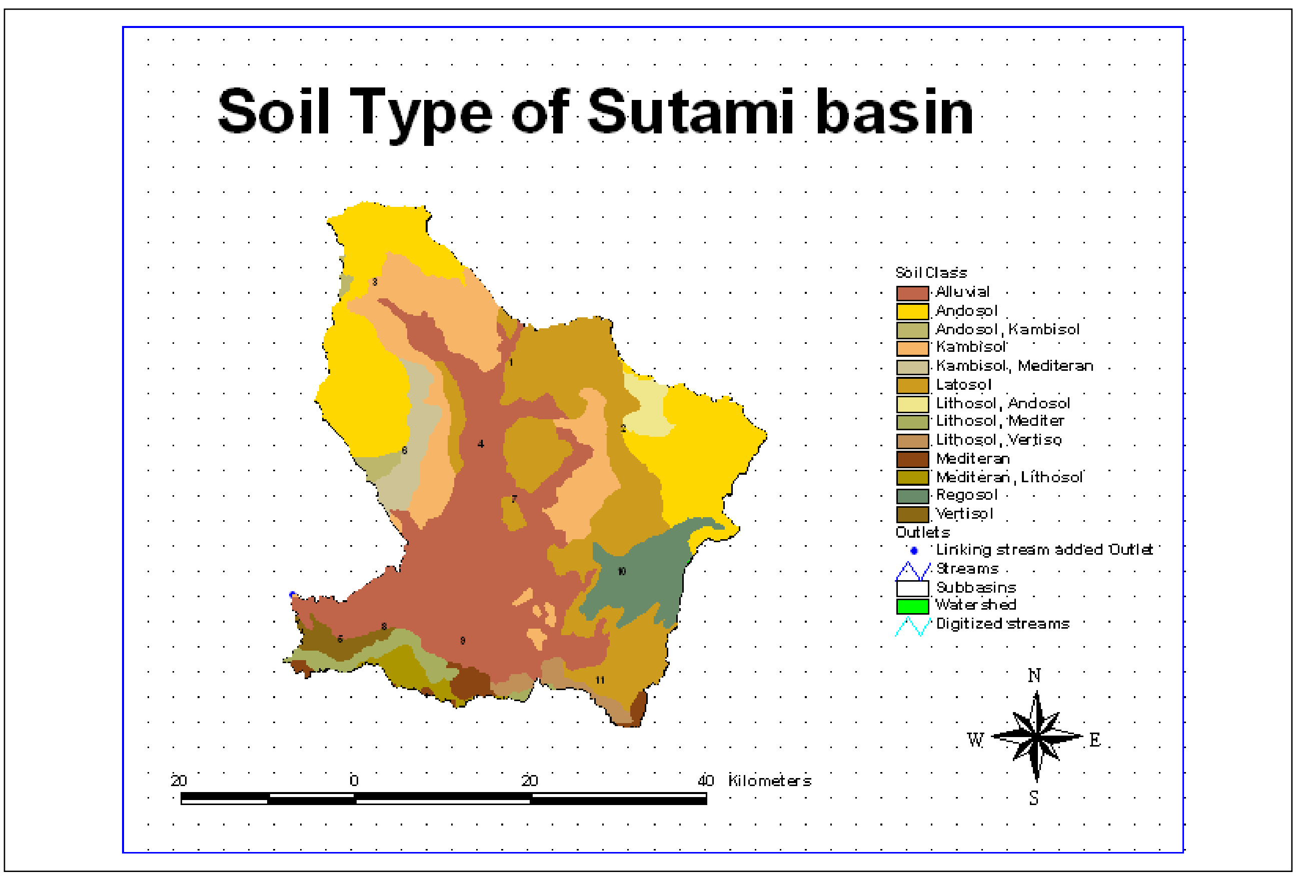

Figure 4. Soil types of the Sutami basin.

different pools of phosphorus in soil; three are inorganic forms and the rest are organic forms. Mineralization, decomposition, and immobilization are important parts in both cycles. These processes are allowed to occur only if the temperature of the soil layer is above 0ºC. Nitrate export with runoff, lateral flow, and percolation are estimated as products of the volume of water and the average concentration of nitrate in the soil layer. Organic N and organic P transport with sediment is calculated with a loading function developed by McElroy et al. (1976) and modified by Williams and Hann (1978) for application to individual runoff events. The loading function estimates daily organic N and P runoff loss based on the concentrations of constituents in the top soil layer, the sediment yield, and an enrichment ratio. The amount of soluble P removed in runoff is predicted using labile P concentration in the top 10 mm of the soil, the runoff volume and a phosphorus soil partitioning coefficient. In-stream nutrient dynamics are simulated in SWAT using the kinetic routines from the QUAL2E in-stream water quality model (Brown and Barnwell, 1987).

The land-use information was derived from 1:250,000- scale Landuse/Landcover Landsat TM spatial data and land use/land cover manual data were collected by the Ministry of Agriculture, Indonesia Government. This information was used when simulating infiltration, runoff, ET, and natural sources of nutrients. The soil data were obtained from both Ministry of Forestry and Ministry of Agriculture. The climate data used in AVSWAT were obtained from the Meteorological and Geophysical Agency (MGA). Daily precipitation and temperature data from fifteen weather stations were used in this model. A digital elevation model (DEM) was used to delineate the watershed boundaries. The DEM used in the study was obtained from the National Coordination Agency for Survey and Mapping (NCASM).

FERTILIZER INPUT

The fertilizer type and application amount differs for different farms due to soil conditions, specific farm management and the farmer's daily income. The main type of fertilizers used in the agriculture area are Urea (46% N), ZA (20% N), SP-36 (36% P2O5; 15.48% P) and KCl (50% K2O; 41.50% K), respectively. The common fertilizers used in agriculture are summarized in Table 5

Table 5. Fertilizer use by different plants.

Plant	Fertilizer (Kg/ha) *)			
	Urea	TSP	KCL	ZA
Rice	250	100	80	100
Corn	200	100	50	100
Soybean	50	50	50	50

SIMULATION SCENARIOS

Water quality in the reservoir is mainly affected by different human daily activities in the catchment. In order to know the significance of different fertilizer applications in the agricultural areas, four scenarios were chosen. The first scenario assumed no fertilizer loading. The second scenario assumed a normal, recommended rate of fertilizer application. The third and fourth scenarios increased fertilizer application by 50% and 100%. Each scenario is presented in Table 6.

MODEL CALIBRATION AND VALIDATION

Model calibration and validation are necessary and critical steps in any model application. For most models, calibration is an iterative procedure of parameter evaluation and refinement, as a

Table 6. Scenario of fertilizer usage in each basin and amount.

	Sub basin	Fertilizer usage		Kg/ha		
Scenario 1	All sub basin	Not used		Urea	KCL	ZA
Scenario 2	Highland	Urea-KCL-ZA	Normal rate	250	80	100
	Middle land		Normal rate	250	80	100
	Near Reservoir		Normal rate	250	80	100
Scenario 3	Highland	Urea-KCL-ZA	Increase 50%	375	120	150
	Middle land		Increase 50%	375	120	150
	Near Reservoir		Increase 50%	375	120	150
Scenario 4	Highland	Urea-KCL-ZA	Increase 100%	500	160	200
	Middle land		Increase 100%	500	160	200
	Near Reservoir		Increase 100%	500	160	200

result of comparing simulated and observed values of interest. Model validation is an extension of the calibration process. Its purpose is to assure that the calibration model properly considers all the variables and conditions which can affect the model results, and demonstrates the ability to predict field observations for periods separate from the calibration effort. Calibration of the SWAT model has been done in three steps; hydrology, sediment and nutrient. The stream-flow calibration (1992-1995) and validation (2000-2003) periods were also used for assessing the accuracy of the SWAT sediment and nitrate predictions. Stream-flow parameter calibration includes CN2, ESCO and SOL_AWC respectively. The values of sediment parameters calibrated include USLE_C, USLE_P, SLSUBBBSN, SLOPE and SPEXP, respectively. Nutrient value parameters calibrated include PPERCO, PHOSKD, SOL-OrgP, SOL-OrgN and RS5, respectively. Table 7 shows the final calibrated values for all parameters. The measured and simulated monthly flow at the Sutami hydrological station matches well (Figure 6). The statistical method was used to show the performance of the simulated results compared to the data recorded. The resulting statistical goodness-of-fit was evaluated with the Nash-Sutcliffe coefficient (Strobl, 2002), $R^2_{NS} = 0.32$ and the linear correlation was found to be, $R^2 = 0.85$ (Figure 7)

Table 7. AVSWAT calibration parameters and their final values for the Sutami Reservoir.

Parameter Name	Model Process	Description	Model Range	Actual Value
CN2	Flow	Curve number	± 10%	-6
ESCO	Flow	Soil evaporation compensation factor	0.00 t0 1.00	1
SOL_AWC	Flow	Soil available water capacity	± 0.04	+0.02
USLE_C	Sediment	Universal Soil Loss Equation C factor	0.0001 to 1	0.150
USLE_P	Sediment	Universal Soil Loss Equation P factor	0.1 to 1.0	0.6
SLSUBBSN	Sediment	Average slope length (m)	NA	-10%
SLOPE	Sediment	Average slope steepness (m/m)	NA	-10%
SPEXP	Sediment	Exponential factor channel sediment routing	1.0 to 1.5	1.0
PPERCO	Mineral P	Phosphorous percolation coefficient	10 to 17.5	10
PHOSKD	Mineral P	Phosphorous soil partitioning coefficient	100 to 200	200
FRY_LY1	Nutrient	Fraction of fertilizer applied to top 10mm soil layer	0.0 to 1.0	0.2
SOL_ORGP	Organic P	Initial organic P concentration in the upper soil layer	NA	0.2 mg/kg
SOL_ORG N	Organic N	Initial organic N concentration in the upper soil layer	NA	0.2 mg/kg
RS5	Total P	Settling rate organic P at 20^0C	0.001 to 0.1	0.1

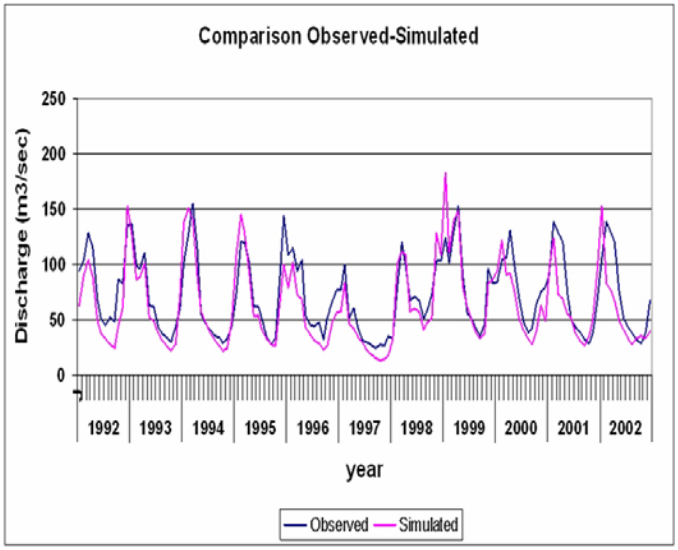

Figure 5. Comparison between observed and simulated flow.

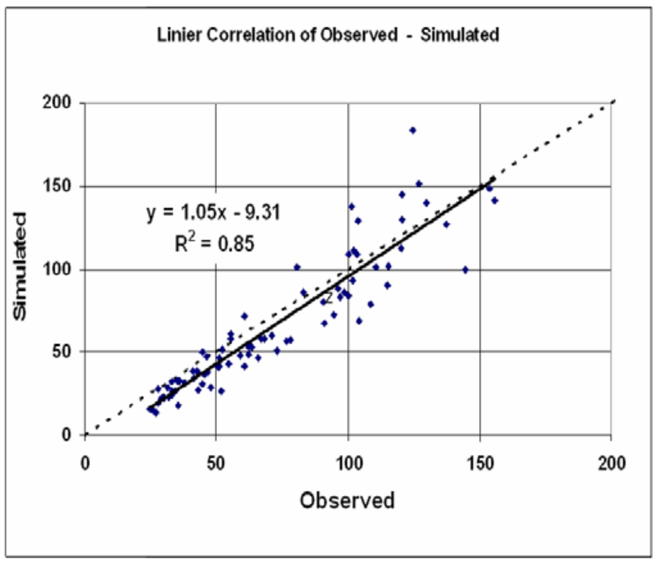

Figure 6. Linear correlation of observed and simulated flows.

RESULTS

The SWAT model was run using the model input and physical parameters were calibrated and validated in the field before the scenario simulation. The results from each scenario are as follows.

- Scenario 1: Nutrient load without fertilizer application

The result shows that the surface runoff of nitrate is highest in sub-basins in the highlands. In those areas, the existing natural nutrient levels are relatively high, which may be due to the rapid decomposition of fresh organic matter.

- Scenario 2: Nutrient load at normal recommended rates of fertilizer application

Nutrient load input to the stream was simulated in the model by considering the actual fertilizer amount used by farmers for their intensive agricultural farming. There is an increase of nitrogen of 21.82% (22.700 kg/year) due to application of fertilizer with surface runoff at paddy fields upstream. There is also a phosphorous load at the reservoir of 34.420 kg/year (increase of 31.66%). The load of NO_2, NO_3 and mineral P in the reservoir increases 59.90%, 30.08% and 50.55%, respectively.

· Scenario 3: Nutrient load by increasing normal rate fertilizer application by 50%

The result shows that the organic N and organic P increase 23.22% and 35.38% from the normal rate, respectively. The load of NO_2, NO_3 and mineral P in the reservoir increases 68.50%, 31.96% and 56.34%, respectively.

· Scenario 4: Nutrient load by increasing normal rate fertilizer application by 100%

The result shows that the organic N and organic P increase 24.00% and 38.90% from the normal rate, respectively. The loads of NO_2, NO_3 and mineral P in the reservoir increase 73.88%, 35.74% and 60.88%, respectively.

The increase in percentage nutrient load shows significant differences between scenario 1 and scenario 2; around 20% to 30% (organic N, organic P and NO_2) and 50% to 60% for NO_3 and mineral P. The increase in percentage nutrient load between scenario 1 and 2 was not significant for both organic N and organic P. The NO_3 and mineral P load increase was 73.88% and 60% respectively for scenario 4. Results of simulations with different scenarios is shown in Table 8 and Figure 7.

Table 8. Summary of simulations with different scenarios of fertilizer usage.

Parameters	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
	Nutrient Load	(Increase in %)	(Increase in %)	(Increase in %)
	Kg/year	Kg/year	Kg/year	Kg/year
Organic P	816,200	1,044,000	1,063,000	1,074,000
		(21.82%)	(23.22%)	(24.00 %)
Organic P	80,780	118,200	125,000	132,200
		(31.66%)	(35.38%)	(38.9%)
NO_3	1,319,000	3,289,000	4,187,000	5,049,000
		(59.9%)	(68.5%)	(73.88%)
NO_2	336,800	481,700	495,000	524,100
		(30.08%)	(31.96%)	(35.74%)
Mineral P	316,400	639,900	724,700	808,800
		(50.55%)	(56.34%)	(60.88%)

CONCLUSIONS

In order to increase the of productivity of paddy fields, the majority of farmers in the Sutami Basin use fertilizer at more than the recommended normal rate. The water quality status of the Sutami reservoir is at a critical condition. It has a mesotropic status condition according to the USPA water quality standard. The major agricultural pollutants detected in the reservoir were organic N (1.044 ton/year) and $N0_3$ (3.298 ton/year), respectively. Fertilizer use at the normal rate can cause an increase of nutrient load (organic N, organic P, NO_2, and NO_3) at the reservoir of 21% to 50%. Fertilizer use at a 100% increase of the normal rate can increase the nutrient load 25% to 74%, approximately. The agriculture pollutant load to the Sutami reservoir can be reduced by rescheduling fertilizer use in each subbasin. The time of application and cultivation in each sub

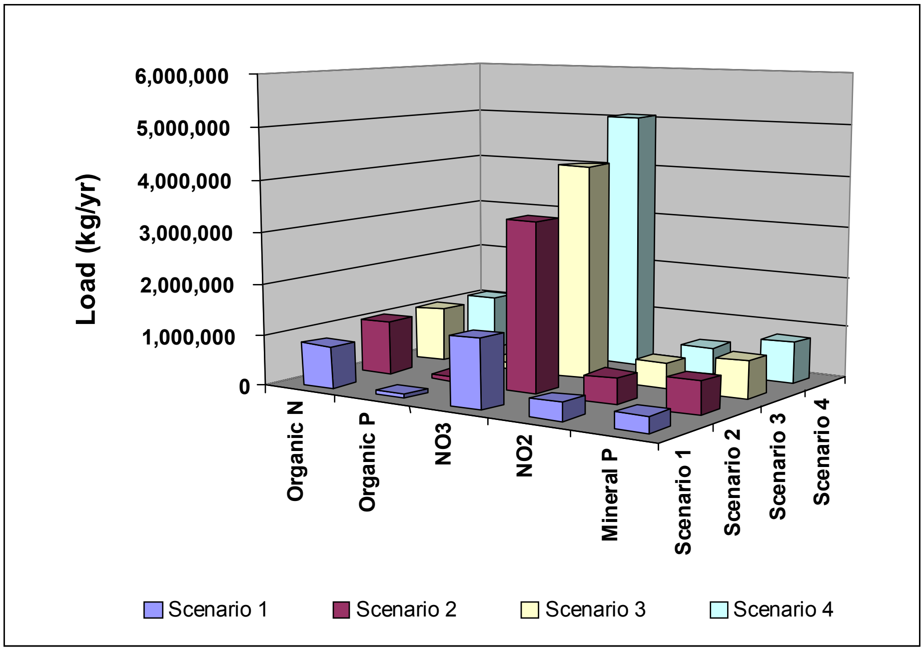

Figure 7. Graph of nutrient load in the Sutami reservoir with the four scenarios.

basin must be separated. The AVSWAT model can be effective for identification of critical subbasins that have higher nutrient loads in order to develop a priority watershed management plan to reduce nutrient pollution losses.

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