Agricultural Sciences, 2017, 8, 326-340
http://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

SWAT Modeling of Nitrogen Dynamics Considering Atmospheric Deposition and Nitrogen Fixation in a Watershed Scale

Chung-Gil Jung, Seong-Joon Kim

Department of Civil, Environmental and Plant Engineering, Konkuk University, Seoul, South Korea
Email: kimsj@konkuk.ac.kr

How to cite this paper: Jung, C.-G. and Kim, S.-J. (2017) SWAT Modeling of Nitrogen Dynamics Considering Atmospheric Deposition and Nitrogen Fixation in a Watershed Scale. *Agricultural Sciences*, **8**, 326-340.
https://doi.org/10.4236/as.2017.84024

Received: March 15, 2017
Accepted: April 27, 2017
Published: April 30, 2017

Abstract

The Soil and Water Assessment Tool (SWAT) nitrogen (N) water quality model considers the artificial inputs associated with human activities, including point and nonpoint source pollution loads. Although SWAT has the ability to simulate atmospheric N deposition and fixation, they were not considered in the modeling research. N deposition from the air is an important and considerable pathway for the input of N species into watersheds and water bodies, causing soil and water body acidification and the leaching of N into surface and groundwater, resulting in eutrophication and degraded water quality. The goal of this study is to assess the effects of atmospheric and agricultural N loads on stream water quality at the watershed scale. For a 6642 km^2 Chungju dam watershed, SWAT was calibrated for 4 years (2003-2006) and validated for another 4 years (2007-2010) using daily anthropogenic N data (sewage discharge pollutants and fertilizer) and monthly measured atmospheric deposition data for NO_3^-, NH_4^+, and dissolved organic N (DON). At the watershed outlet, the Nash-Sutcliffe (1970) efficiency (NSE) of daily streamflow during the validation period was 0.74. The coefficient of determination (R^2) of total N was 0.69 considering atmospheric deposition, whereas it was 0.33 when removing the deposition effect. The results of this study demonstrate the potential for using the N dynamics between the atmosphere and land for SWAT assessments of nonpoint source pollution and for modeling stream water quality.

Keywords

SWAT, Anthropogenic Nitrogen, Atmosphere Deposition, Fixation, Fertilizer, Manure, Sewage Discharge Nitrogen

1. Introduction

Human activities, such as agricultural cultivation and fossil fuel combustion, have dramatically increased the amount of reactive nitrogen (N), such as inorganic ammonium (NH_4^+) and oxidized (e.g., nitrate: NO_3^-) forms of N, as well as its movement through ecosystems [1] [2] [3]. The large magnitude of this N production is problematic, as excess reactive N can be extremely detrimental to the functioning of various ecosystems [4]. For example, excessive plant growth due to nutrient enrichment is the primary environmental issue facing surface waters worldwide [5] [6] [7] [8] because it not only results in many undesirable ecological (e.g., species or salt-marsh loss) [9] and water quality (e.g., algal blooms, hypoxia or dead zones) [8] [10] problems but also causes high economic costs [11]. The eutrophication process is accelerated by human activity in densely populated urban or agricultural regions, where point N sources discharged from sewage treatment plants supplement high levels of non-point N sources produced from vehicles or fertilization [5], which is also referred to as cultural eutrophication [8].

In South Korea, the annual N input and output of agricultural areas were reported to be 1,259,515 and 675,091 tons/yr, respectively. The annual N inputs of urban and forest area were 247,869 and 152,875 tons/yr, respectively, and the outputs were 90,319 and 65,794 tons/yr. For the past decade in South Korea, the N output of rivers and oceans was approximately 498,915 tons/yr, and the amount of nonpoint source pollutants equaled 367,640 tons/yr [12]. These phenomena can result in river and lake eutrophication due to excessive N.

Atmospheric deposition is an important pathway for the input of N species into watersheds and water bodies. Atmospheric N deposition can cause soil and water body acidification, as well as leaching of N into surface and ground waters, resulting in eutrophication and water quality degradation. Wet deposition occurs through rain and snowfall, whereas dry atmospheric deposition arises from gaseous and particulate transport from the air to the surfaces of aquatic and terrestrial landscapes. Atmospheric deposition of nitrate N and ammonium N has been identified as a major factor in the decline of water quality in the watershed. The water quality in large rivers has deteriorated because of land use development over the past several decades and the dust fall from the atmosphere. In particular, mineral aerosols are deposited on land and streams via rainstorms during the summer as a result of the monsoon climate in South Korea.

In general, surface water and groundwater are affected by agricultural anthropogenic pollution resulting from the excessive use of pesticides and fertilizers and inadequate irrigation techniques. Although nitrate leaching in regions appears to be an inevitable process, an improvement in management practices leading to higher N fertilizer use efficiency is thought to reduce the potential for groundwater nitrate contamination. The environmental impact of agricultural pollutants depends on many different factors, such as fertilizer type, fixation, crop type, hydro-meteorological conditions (climatology and hydrogeology), crop management practices and soil characteristics [13]. Several authors have demonstrated the effect of different types of land cover on the hydrology of watersheds [14], a factor that is also directly linked to the nutrient transport within a watershed, particularly within the root zone.

For the multiple environmental processes involved in the dynamics of N, such as atmosphere deposition and pesticide and fertilizer use, mathematical modeling is extremely valuable because it can help quantify the pollution, determine balances at the watershed scale and guide decisions to improve management [13] [15]. Thus, a model-based study is required to obtain information on the environmental effects considering anthropogenic data. The Soil and Water Assessment Tool (SWAT) model, which can be used for complex anthropogenic data, has been extensively applied in the literature. The SWAT model is considered one of the most useful models for long-term simulations in predominantly agricultural watersheds [16] and is robust in predicting nutrient losses at the watershed scale [15] [17].

In this study, among the available anthropogenic data (fertilizer, manure, fixation, sewage discharge and atmospheric deposition), the impact of the total N (T-N) load was evaluated to identify the effect of atmospheric, agricultural (fertilizer, manure, and fixation) and sewage discharge N loads on stream water quality at the watershed scale (**Figure 1**). The SWAT model was adopted and applied to a 6642 km^2 study watershed.

2. Materials and Methods

2.1. Description of the SWAT Model

SWAT [18] is a physically based and continuous, long-term, distributed-para-

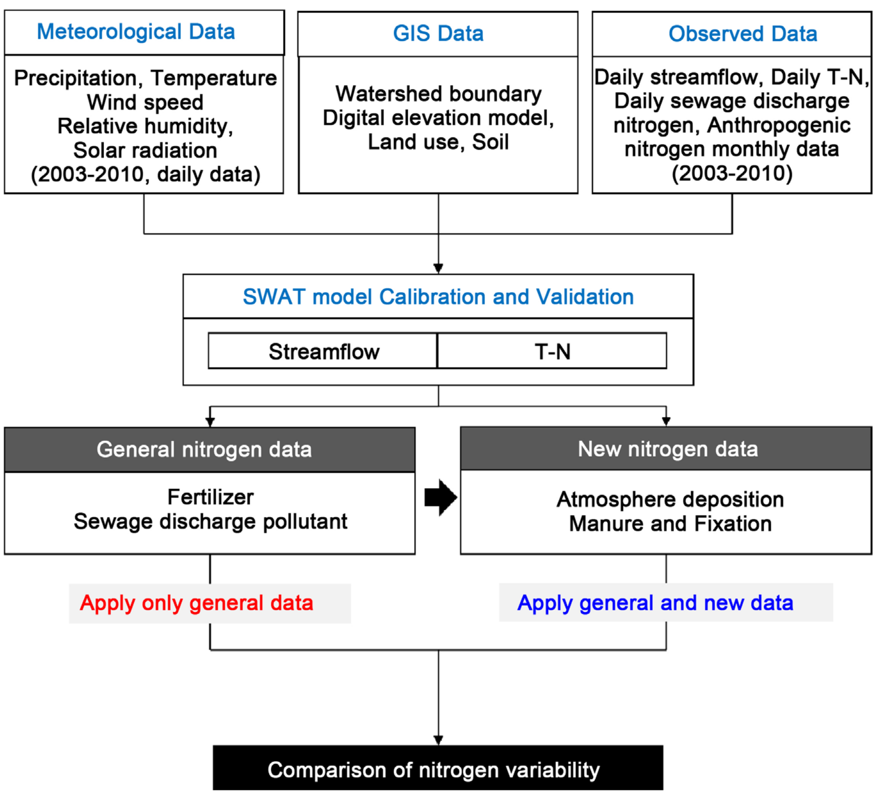


Figure 1. Flow chart of study process.

meter model designed to predict the effects of land management practices on the hydrology and sediment and contaminant transport in agricultural watersheds with varying soils, land uses, and management conditions [18]. SWAT is based on the concept of hydrologic response units (HRUs), which are the portions of a sub-basin that possess unique land-use/management/soil attributes. The runoff, sediment, and nutrient loadings from each HRU are calculated separately using input data regarding weather, soil properties, topography, vegetation, and land management practices and then summed together to determine the total loadings from the sub-basin [19].

SWAT uses a modified version of the SCS-CN method (USDA-SCS 1972) and the Modified Universal Soil Loss Equation (MUSLE) [20] to predict runoff and sediment generation, respectively. SWAT simulates the organic and mineral N and phosphorus fractions by separating each nutrient into component pools, which can increase or decrease depending on the transformation and/or additions/losses occurring within each pool [21]. Mass balance is calculated on a daily time scale to capture the series of changes addressed through the respective process equations. Further details of the water balance, soil erosion, and nutrient process equations can be found in the SWAT theoretical documentation [22].

Atmospheric deposition occurs when airborne chemical compounds settle onto the land or water surface. Some of the most important chemical pollutants are those containing N or phosphorus. N compounds can be deposited onto water and land surfaces through both wet and dry deposition mechanisms. Wet deposition occurs through the absorption of compounds by precipitation as it falls, carrying mainly nitrate and ammonium. Dry deposition is the direct adsorption of compounds onto water or land surfaces and involves complex interactions between airborne N compounds and plant, water, soil, rock, or building surfaces. The atmospheric deposition by SWAT model is based on the following equations:

$$NO_{3rain} = 0.01 \cdot R_{NO3} \cdot R_{day} \tag{1}$$

$$NH_{4rain} = 0.01 \cdot R_{NH4} \cdot R_{day} \tag{2}$$

$$NO_{3ly=1} = NO_{3ly=1} + NO_{3drydep} \tag{3}$$

$$NH_{4ly=1} = NH_{4ly=1} + NH_{4drydep} \tag{4}$$

where NH_{4rain} is the nitrate added by rainfall (kg N/ha), R_{NH4} is the concentration of ammonia in the rain (mg N/L), and R_{day} is the amount of precipitation on a given day (mm H_2O). The N in the rainfall is added to the ammonia pool in the top 10 mm of soil. $NO_{3ly=1}$ is the nitrate in the surface soil layer, $NH_{4ly=1}$ is the ammonium in the surface soil layer, $NO_{3drydep}$ is the daily nitrate dry deposition rate (kg/ha) and $NH_{4drydep}$ is the daily ammonium dry deposition rate (kg/ha).

2.2. Description of the Study Watershed

Figure 2 shows the Chungju dam watershed, which has a total area of 6642 km^2 and is located in northeast South Korea, within the latitudes of 127.9˚E to

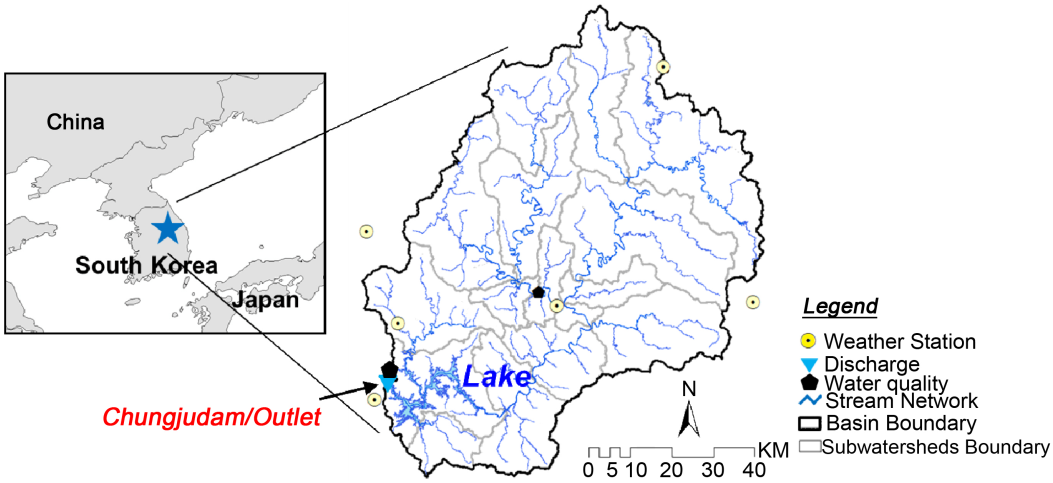


Figure 2. Location of study watershed and weather, streamflow, and water quality gauging stations.

129.0˚E and the longitudes of 36.8˚N to 37.8˚N. The elevation ranges from 112 to 1562 m, with an average slope of 37% and an average elevation of 609 m. The 30-year average annual precipitation is 1261 mm, and the mean temperature is 9.4˚C. More than 82.3% (5469 km^2) of the watershed area is forested, and 12.2% (811 km^2) is cultivated. The cultivated area consists of 728 km^2 of paddy fields and 83 km^2 of upland crops.

The elevation data were rasterized as a 100-m-resolution digital elevation model (DEM) from 1:5000 vector maps supplied by the Korea National Geography Institute. The soil data with respect to texture, depth, and drainage attributes were rasterized from 1:25,000 vector maps supplied by the Korea Rural Development Administration.

Thirty-four years (1977-2010) of daily weather data were collected from six ground weather stations. Daily streamflow data (2003-2010) at one location, located at the watershed outlet, were obtained from the Han River flood control office, and monthly water quality data at one location were obtained from the Korean Ministry of Environment to calibrate and validate the SWAT model.

The main indicator of stream water quality is the T-N (total N obtained as the sum of nitrate and particulate organic N losses) load. The eight-year (2003-2010) average sewage discharge N data for the modeling were prepared from each sewage discharge pollutant facility, including daily discharge rates and N load.

2.3. Definition of Anthropogenic N Data

2.3.1. Atmospheric Deposition

Table 1 shows the description of the N input data. To apply the anthropogenic data, the deposition, fixation, fertilizer, manure, and sewage discharge N were obtained from the Ministry of Environment, the Rural Development Administration (RDA), and the National Institute of Environmental Research (NIER). The obtained deposition N data were used to monitor acid deposition and to create the NEIR's impact assessment report (1999-2010). The dry and wet deposition N data were obtained from 39 stations in South Korea over a 12-year

Table 1. Description of the nitrogen input data.

Data		Source	Period
Deposition (dry and wet)	NO_3^-	Ministry of the Environment, National Institute of Environmental Research (NIER)	1999-2010
	NH_4^+		
	DON		
Fertilizer, manure, and fixation	NO_3^-	Ministry of the Environment, NIER, Rural Development Administration (RDA)	1999-2010
	NH_4^+		
	DON		
Sewage discharge	NO_3^-	Ministry of the Environment, NIER	2008-2010
	NH_4^+		
	DON		

period. The wet deposition N load (kg/m^2/year) was estimated by multiplying the wet deposition concentration (mg/L) and the annual mean precipitation from each station. The dry deposition N was distributed according to the ratio of urban to total dry deposition in South Korea. Total deposition N (wet + dry) was divided into NO_3^-, NH_4^+, and dissolved organic nitrogen (DON) according to Van Breemen *et al.* [23].

2.3.2. Fertilizer, Manure, and Fixation

Fertilizer and manure N data were obtained from the Statistical Yearbook of Agriculture and Forestry (1999-2010) of the RDA. The fixation N data used 35 and 15 kg/ha/yr [24] [25]. The fertilizer N data were obtained from administrative districts from the Statistical Yearbook of Agriculture and Forestry (Rural Development Administration, 1999-2010), and the manure N data were based on the Total Water Pollution Load Management Guidelines (1999-2010) from the NIER. The livestock waste pollutant load was estimated as follows:

$$\begin{aligned}&\text{Livestock wastewater pollutant load}\\&=\sum\left(\text{Livestock facilities numbers}\times\text{Livestock facilities wastewater pollutant unit load}\right)\end{aligned} \tag{5}$$

$$\begin{aligned}&\text{Livestock solid pollutant load}\\&=\sum\left(\text{Livestock facilities numbers}\times\text{Livestock facilities solid pollutant unit load}\right)\end{aligned} \tag{6}$$

$$\begin{aligned}&\text{Livestock pollutant load}\\&=\text{Livestock wastewater pollutant load}+\text{Livestock solid pollutant load}\end{aligned} \tag{7}$$

$$\begin{aligned}&\text{Final manure pollutant load}\\&=\text{Livestock pollutant load}\times\text{ratio of agriculture resource }(0.9)\end{aligned} \tag{8}$$

This study assumed that final manure pollutant load used only 90% of the livestock pollutant load considering agriculture resources. Thus, the final manure pollutant load was obtained according to Equation (8). Sewage discharge N data from the river were based on the daily N discharge data from 3227 stations in South Korea for 12 years (1999-2010).

3. Results and Discussion

3.1. Calibration and Validation of the SWAT Model

The SWAT model was calibrated based on 4 years (2003-2006) of daily streamflow data at the watershed outlet and then validated using another 4 years (2007-2010) of data. We used the same calibrated parameters as Park *et al.* [26] for both streamflow and T-N. The calibrated model parameters are shown in Table 2. Sensitivity Of parameters was analyzed by comparing ratio (%) of runoff changes. By comparing ratio (%) of changes simulated runoff from adjusted value, the ratio of change more than 70% or 50% defined high or medium sensitivity.The ESCO was sensitive to the peak flow and the amount of discharge. GW_DELAY and ALPHA_BF affected the recession phase of the hydrograph. These parameters were then used to validate the SWAT model to determine its efficiency. The decision process of the calibrated parameters and the sensitivity analysis are detailed in Park *et al.* [26]. A statistical summary of the 8 years of observed versus simulated streamflow is shown in Table 3. Figure 3

Table 2. SWAT calibrated parameters.

	Parameter	Definition	LB	UB	Sensitivity	Adjusted Value
Q	ESCO	Soil evaporation compensation factor	0	1	High	0
	ALPHA_BF	Baseflow alpha factor for land with slow response to recharge	0	1	High	0.05
	RCHRG_DP	Deep aquifer percolation fraction	0	1	Medium	0.6
	GW_DELAY	Groundwater delay	0	500	High	31
	GW_REVAP	Groundwater “revap” coefficient	0.02	0.2	Medium	0.02
SN	SMFMX	Maximum snowmelt rate	1.4	6.9	Medium	4.5
	SMFMN	Minimum snowmelt rate	1.4	6.9	Medium	4.5
	SMTMP	Snowmelt base temperature	−5	5	High	1.5

Q: Streamflow, SN: Snow parameter, LB: Lower bound, UB: Upper bound.

Table 3. Statistical summary of observed versus SWAT simulated streamflow for calibration (C) and validation (V) periods.

Year	PCP (mm)	Discharge (mm)		Runoff ratio (%)		NSE	R^2	Note
		Obs.	SWAT	Obs.	SWAT			
2003	1598.3	1051.1	811.4	65.8	50.8	0.77	0.79	C
2004	1542.0	911.5	714.9	59.1	46.4	0.74	0.74	C
2005	1494.4	743.1	626.2	49.7	41.9	0.74	0.76	C
2006	1348.0	954.6	826.6	70.8	61.3	0.75	0.75	C
2007	1475.6	1016.5	1009.1	68.9	68.4	0.71	0.75	V
2008	950.7	403.4	318.4	42.4	33.5	0.74	0.84	V
2009	1168.0	613.2	570.6	52.5	48.9	0.72	0.67	V
2010	1258.5	809.1	728.5	64.3	57.9	0.74	0.75	V
Mean	1354.4	812.8	700.7	59.2	51.1	0.74	0.76	-

PCP: Precipitation, Obs.: Observed, R^2: determination of coefficient, NSE: Nash-Sutcliffe efficiency, C: Calibration period, V: Validation period.

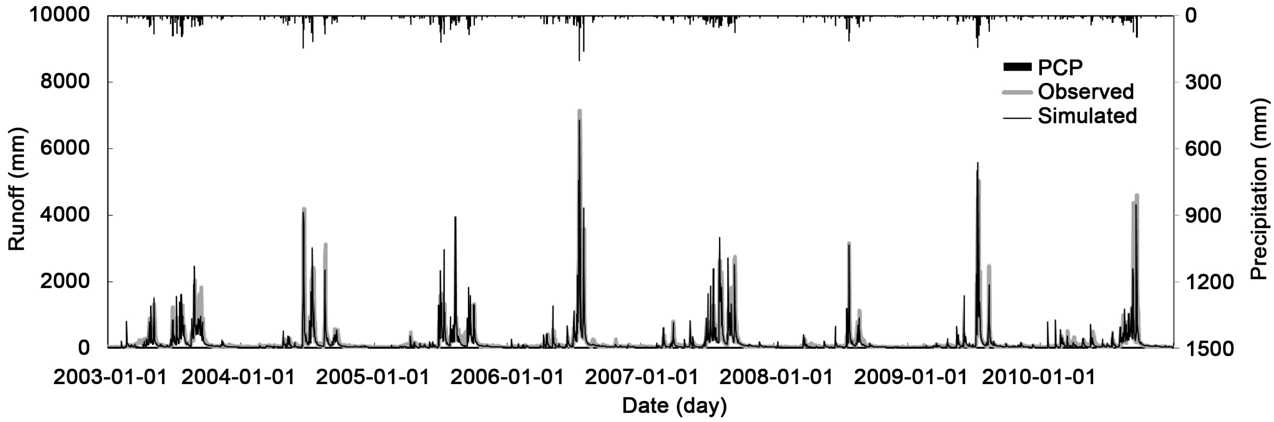


Figure 3. Comparison between observed and SWAT simulated streamflow results.

shows the observed versus simulated streamflow. The Nash and Sutcliffe [27] efficiency (NSE) for streamflow during the validation period was 0.74, and the coefficient of determination (R^2) was 0.76.

3.2. Comparison of the Nitrogen Dynamics

The N input datasets involve three anthropogenic N sources: atmospheric deposition, agriculture N (fertilizer + manure + fixation), and sewage discharge N. For each watershed, which consists of various land uses, the atmospheric deposition N input was applied to all the lands, whereas the agricultural N inputs were applied to only the upland crop and paddy lands. The sewage discharge N input was directly applied to the river reaches. Each of the N species for the three N sources was applied to the corresponding terrestrial and river pools.

Table 4 shows the SWAT-calibrated parameters related to anthropogenic N. Table 5 shows the T-N load (ton/year) that has a practical impact on the portion of input N in the watershed. The atmospheric deposition load comprised a large portion of the total input N. The deposition resulted in a large input N load into the watershed because wet deposition and dry deposition primarily decreased along with rainfall and yellow sand containing N particles through the total watershed in South Korea. The fertilizer, manure, and fixation were only consumed in the agriculture area during a specific period each year.

This study applied five cases based on the anthropogenic N data. Case 1 is scenario before all anthropogenic N data were applied, case 2 is a scenario after the sewage discharge N data were applied, case 3 is a scenario after the atmospheric deposition data were applied, case 4 is a scenario after the fertilizer, manure, and fixation data were applied, and case 5 is a scenario after all anthropogenic N data were applied. Figure 4 and Table 6 show the observed and simulated daily T-N at the watershed outlet. The average R^2 values of T-N during the calibration and validation periods were 0.33 (case 1) and 0.69 (case 5), respectively. The R^2 for the T-N results increased by 0.36 after the anthropogenic N data were applied. The results indicated that cases 2 and 3 affected the baseflow and recession of T-N, respectively.

Table 4. SWAT calibrated parameters related to anthropogenic nitrogen.

	Parameter	Definition	Default	Adjusted Value
Anthropogenic nitrogen	RAMMO_SUB	Atmospheric deposition of ammonium (mg/L) values for the entire watershed	0	3
	RCN_SUB	Concentration of nitrate in the precipitation (mg/L)	0	4.5
	DRYDEP_NH4	Nitrate dry deposition rate (kg/ha/yr)	0	4.3
	DRYDEP_NO3	Ammonia dry deposition rate (kg/ha/yr)	0	4
	FIXCO	Nitrogen fixation coefficient	0	1
	NFIXMX	Maximum daily N fixation (kg/ha)	0	3.3
	FRT_KG	Amount of fertilizer applied to the HRU (kg/ha)	0	257.4

Table 5. Process of calculating the average nitrogen input total load (tons/year).

N input	Calculation process	Total load (tons/year)
Deposition	dry deposition (8.3 kg/ha/yr) × total area (6642 km^2) wet deposition (3 mg/L) × total area (6642 km^2) × annual precipitation(1258.3 mm/yr)	30,589.7 (60.0%)
Fertilizer and Manure	fertilizer and manure nitrogen (257.4 kg/ha/yr) × agriculture area (783.5 km^2)	20,167.3 (39.0%)
Fixation	upland crop and paddy area (3.3 kg/ha/yr) × agriculture area (783.5 km^2)	
Sewage discharge	Sewage discharge nitrogen (126.0 kg/day) × year (365 days)	45.9 (1.0%)

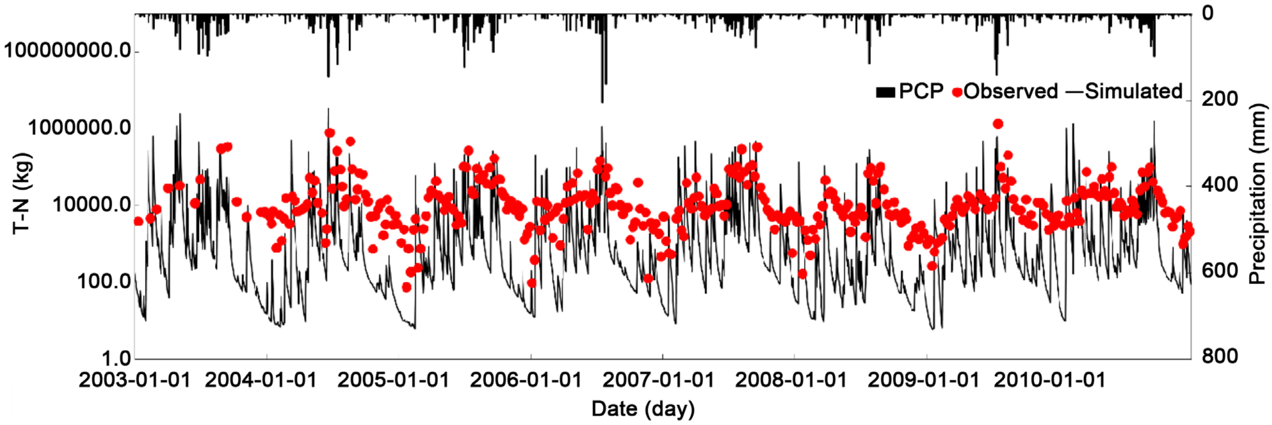
Table 6. Summary of yearly T-N loads for five cases.

Year	Observed	Case 1		Case 2		Case 3		Case 4		Case 5	
	Total (tons)	Total (kg)	R^2	Total (kg)	R^2	Total (kg)	R^2	Total (kg)	R^2	Total (kg)	R^2
2003	836.9	78.5	0.45	80.2	0.46	200.9	0.77	91.4	0.46	288.1	0.77
2004	2460.2	482.7	0.80	490.3	0.80	1224.3	0.67	539.1	0.84	1673.0	0.70
2005	1564.3	303.0	0.20	309.3	0.21	1083.0	0.60	417.4	0.18	1552.6	0.66
2006	954.2	133.6	0.27	139.1	0.29	568.5	0.77	206.8	0.44	847.5	0.82
2007	1848.3	384.2	0.19	390.6	0.22	1122.0	0.77	450.6	0.18	1565.4	0.78
2008	742.9	133.4	0.19	139.4	0.20	490.7	0.61	180.3	0.25	751.2	0.62
2009	2189.8	292.1	0.51	297.8	0.56	981.2	0.62	329.6	0.65	1335.8	0.65
2010	1092.9	1001.1	0.03	1007.0	0.01	1120.8	0.29	1087.5	0.02	1540.1	0.50
Mean	1461.2	351.1	0.33	356.7	0.34	848.9	0.64	412.8	0.38	1194.2	0.69

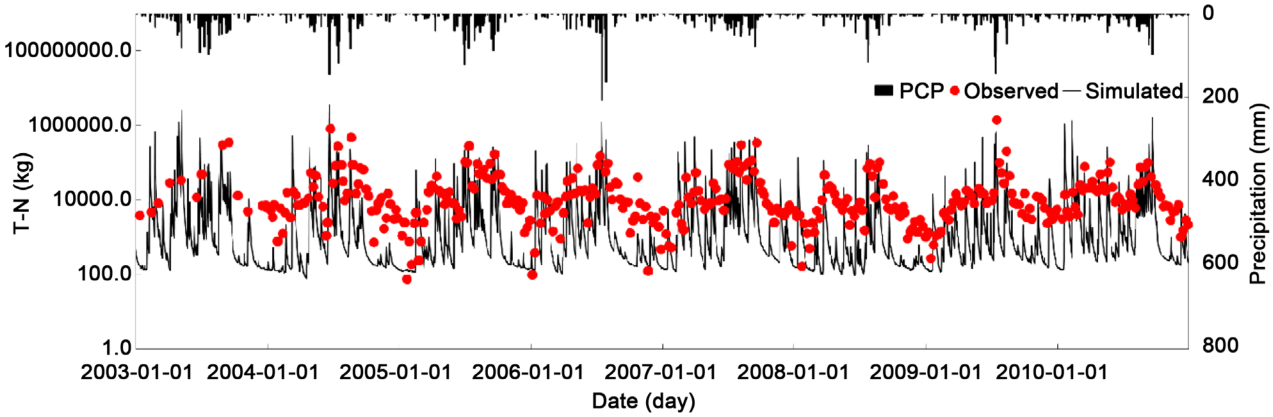
Case 1: scenario that excluded all anthropogenic N, Case 2: scenario that applied only sewage discharge N, Case 3: scenario that applied only atmospheric deposition N, Case 4: scenario that applied only agriculture N, Case 5: scenario that applied all anthropogenic N.

3.3. Analysis of the Nitrogen Changes

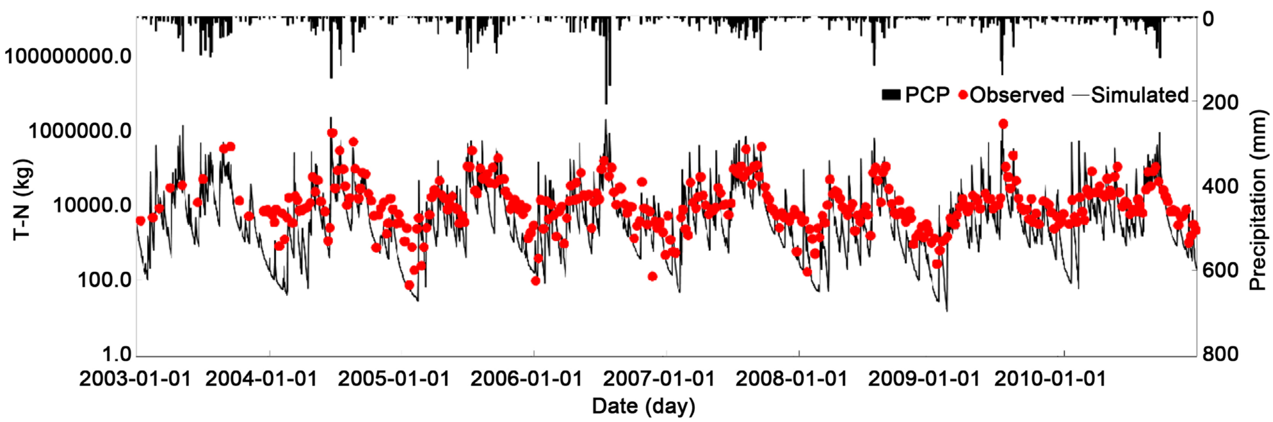
In this study, the load duration curve (LDC) method was used to determine the variability of T-N (Figure 5 and Table 7). The LDC method was used to describe the change in high, middle, and low T-N durations. Table 7 provides the monthly T-N loads and the percentage change by comparing the scenarios. Case 2, case 3, case 4, and case 5 exhibit percentage changes of 4.4, 112.3, 19.7 and 201.7%, respectively (Table 7). As a result, cases 3 and 4 tended to be affected by rainfall and the fertilizer period from April. The LDC graph in Figure 5 illustrates that the major differences between case 1 and case 2 appeared during the



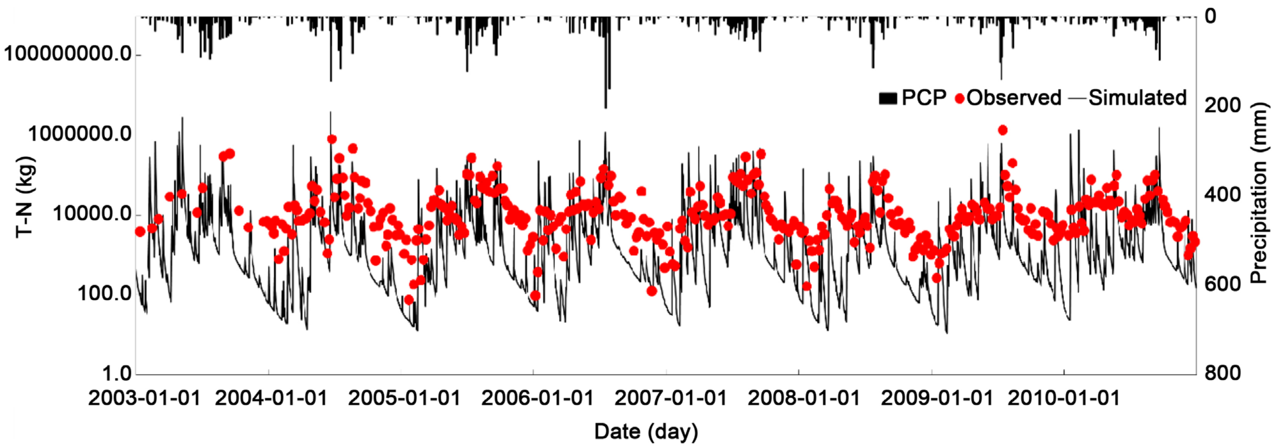
(a)



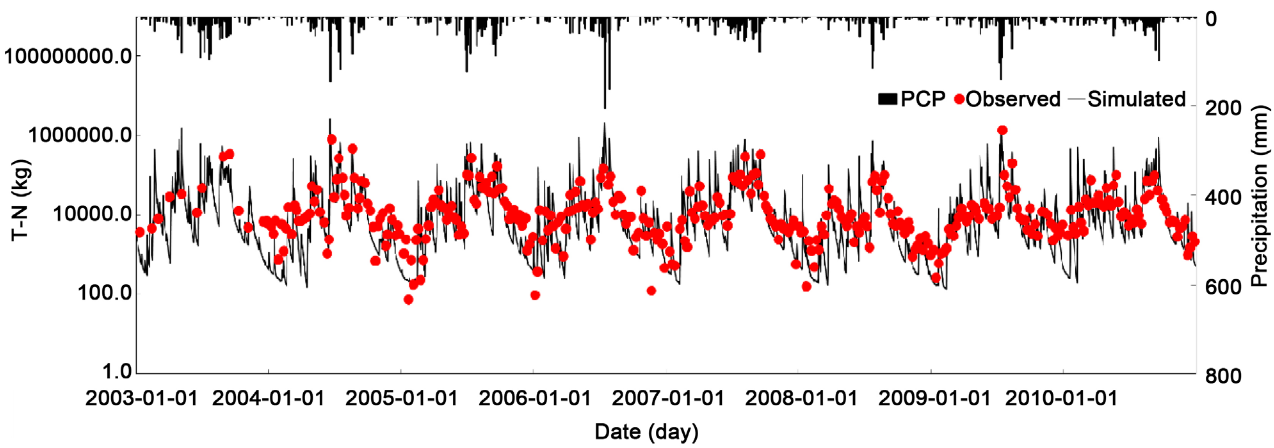
(b)



(c)



(d)



(e)

Figure 4. Comparison of observed and SWAT simulated T-N using anthropogenic data: (a) case 1, (b) case 2, (c) case 3, (d) case 4, and (e) case 5.

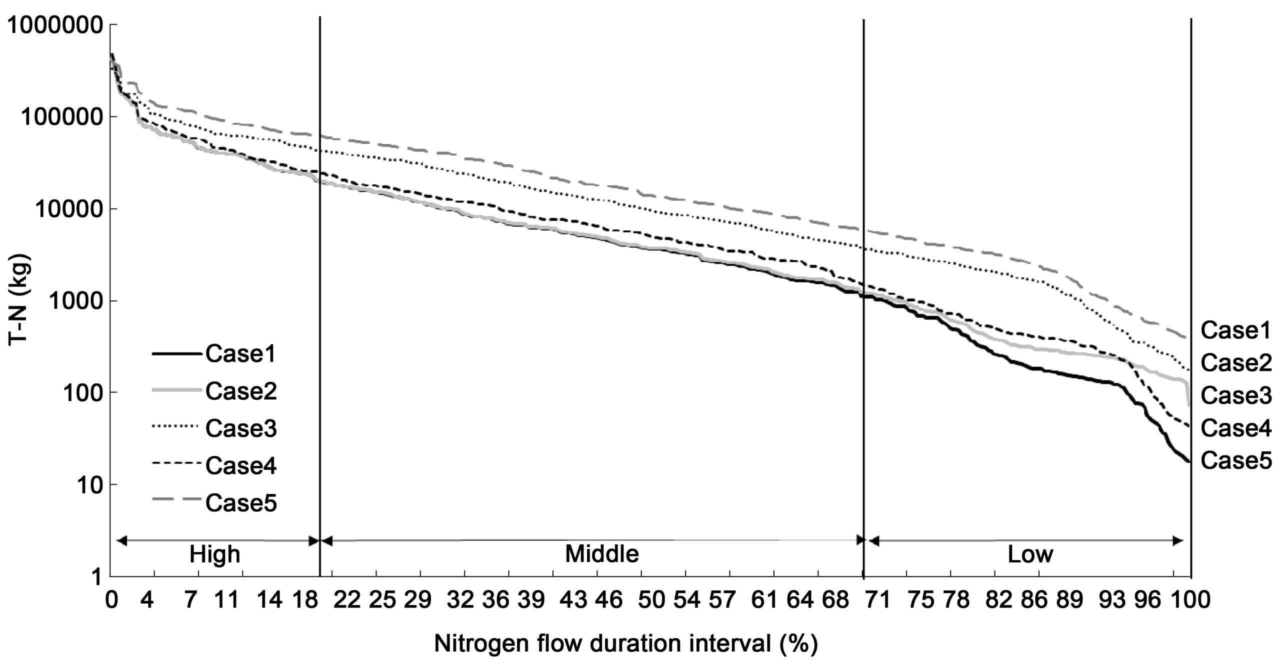


Figure 5. Comparison of T-N load duration graph for five cases.

Table 7. Percentage changes in monthly T-N for five cases.

Month	Case 1	Case 2		Case 3		Case 4		Case 5	
	Total (ton)	Total (kg)	Change (%)	Total (kg)	Change (%)	Total (kg)	Change (%)	Total (kg)	Change (%)
1	283.5	287.3	+1.3	133.6	−52.9	298.0	+4.5	154.9	−45.4
2	611.2	614.7	+0.6	361.8	−40.8	638.9	+6.1	436.3	−28.6
3	293.3	296.9	+1.2	399.5	+36.2	311.3	+6.7	498.3	+69.9
4	485.4	489.0	+0.7	656.4	+35.2	517.8	+53.9	824.4	+69.8
5	724.8	728.1	+0.5	824.5	+13.8	1115.2	+22.2	1405.5	+93.9
6	923.3	925.7	+0.3	898.1	−2.7	1127.9	+13.4	1359.1	+47.2
7	1163.6	1165.5	+0.2	3178.0	+173.1	1319.4	−5.2	4240.7	+264.5
8	569.4	572.7	+0.6	1713.0	+200.8	539.7	+0.8	2272.0	+299.0
9	750.8	753.9	+0.4	1291.7	+72.0	756.8	+29.7	1691.4	+125.3
10	30.6	34.2	+11.8	155.2	+406.6	39.7	+39.3	229.8	+650.3
11	20.8	24.4	+17.5	100.4	+383.0	29.0	+35.3	149.7	+620.1
12	21.1	24.8	+17.7	47.1	+123.5	28.5	+4.5	74.5	+253.8
Mean	489.8	493.1	+4.4	813.3	+112.3	560.2	+19.7	1111.4	+201.7

Case 1: scenario that excluded all anthropogenic N, Case 2: scenario that applied only sewage discharge N, Case 3: scenario that applied only atmospheric deposition N, Case 4: scenario that applied only agriculture N, Case 5: scenario that applied all anthropogenic N.

low T-N period in the dry season. When the results of case 1 and case 2 were compared, we found that sewage discharge pollution affected the T-N discharged with the baseflow during the low T-N period.

Compared to case 1, case 3 exhibited increases of 41.6% (high duration), 156.1% (middle duration), and 402.0% (low duration); case 4 exhibited increases of 10.8% (high duration), 27.7% (middle duration), and 55.9% (low duration); and case 5 exhibited increases of 87.3% (high duration), 272.6% (middle duration), and 677.9% (low duration).

4. Summary and Conclusions

In this study, the SWAT model was used to simulate the discharge and T-N load in the Chungju dam watershed outlet for the 2003-2010 period, and the impact of the T-N load was evaluated to identify the effects of atmospheric, agricultural (fertilizer, manure, fixation) and sewage discharge N loads on the stream water quality at the watershed scale. The SWAT model was established using all available data on the N stores in the fertilizer, manure, fixation, sewage discharge N, and atmospheric deposition. The SWAT model was prepared by calibrating and validating 8 years (2003-2010) of downstream streamflow and T-N data; the model can evaluate the N loads at depth considering atmosphere deposition. The N-input datasets were three anthropogenic N sources, namely, atmospheric deposition, agriculture N (fertilizer + manure + fixation), and sewage discharge N.

The SWAT model was calibrated for 4 years (2003-2006) of daily streamflow data at the watershed outlet and validated using another 4 years of data (2007-2010). The SWAT parameters were used to validate the SWAT model to determine its efficiency. The NSE for streamflow during the validation period was 0.74, and the R^2 was 0.76. This study applied five cases based on the anthropogenic N data to determine their impact on water quality. The LDC method and monthly T-N were analyzed for the variable T-N. The LDC method was used to describe the percentage change in high, middle, low T-N durations. Compared to case 1, the percentage changes for case 2, case 3, case 4, and case 5 were 4.4%, 112.3%, 19.7% and 201.7%, respectively. As a result, case 3 and case 4 tended to be affected by rainfall and the fertilizer period from April. The major differences between case 1 and case 2 appeared during the low-N period in the dry season. Atmospheric deposition data increased the overall T-N, following the rainfall trend.

The data collected from national reports and applied to the SWAT database can be utilized, and the N dynamics between the atmosphere and land were successfully determined even though SWAT uses data based on annual values. In the long term, N generally follows the trends in fertilization, atmospheric deposition, and sewage discharge N. The SWAT hydrological model was successfully used to produce the historical and future trends in N load. The achievement of this study has not been reported to date. The results of this study also indicate that the modeling of N dynamics at the watershed and small-scale sub-basin scales can provide a valuable link between the atmosphere and land.

Acknowledgements

This research was supported by a grant (16AWMP-B079625-03) from the Water Management Research Program funded by the Ministry of Land, Infrastructure and Transport of the Korean government.

References

[1] Galloway, J.N., Dentener, F.J., Capone, D.G., Boyer, E.W., Howarth, R.W., Seitzinger, S.P., Asner, G.P., Cleveland, C.C., Green, P.A., Holland, E.A., Karl, D.M., Michaels, A.F., Porter, J.H., Townsend, A.R. and Vöosmarty, C.J. (2004) Nitrogen Cycles: Past, Present, and Future. *Biogeochemistry*, **70**, 153-226. https://doi.org/10.1007/s10533-004-0370-0

[2] Galloway, J.N., Townsend, A.R., Erisman, J.W., Bekunda, M., Cai, Z., Freney, J.R., Martinelli, L.A., Seitzinger, S.P. and Sutton, M.A. (2008) Transformation of the Nitrogen Cycle: Recent Trends, Questions, and Potential Solutions. *Science*, **320**, 889-892. https://doi.org/10.1126/science.1136674

[3] Smil, V. (1999) Nitrogen in Crop Production: An Account of Global Flows. *Global Biogeochemical Cycles*, **13**, 647-662. https://doi.org/10.1029/1999GB900015

[4] Galloway, J.N., Aber, J.D., Erisman, J.W., Seitzinger, S.P., Howarth, R.W., Cowling, E.B. and Cosby, B.J. (2003) The Nitrogen Cascade. *BioScience*, **53**, 341-356.

[5] Howarth, R.W., Sharpley, A. and Walker, D. (2002) Sources of Nutrient Pollution to Coastal Waters in the United States: Implications for Achieving Coastal Water Quality Goals. *Estuaries*, **25**, 656-676. https://doi.org/10.1007/BF02804898

[6] Smith, V.H. (2003) Eutrophication of Freshwater and Coastal Marine Ecosystems:

A Global Problem. *Environmental Science and Pollution Research International*, **10**, 126-139.

[7] Smith, V.H., Joye, S.B. and Howarth, R.W. (2006) Eutrophication of Freshwater and Marine Ecosystems. *Limnology and Oceanography*, **51**, 351-355. https://doi.org/10.4319/lo.2006.51.1_part_2.0351

[8] Smith, V.H. and Schindler, D.W. (2009) Eutrophication Science: Where do We Go from Here? *Trends in Ecology and Evolution*, **24**, 201-207. https://doi.org/10.1016/j.tree.2008.11.009

[9] Vonlanthen, P., Bittner, D., Hudson, A.G., Young, K.A., Müller, R., Lundsgaard-Hansen, B., Roy, D., Di Piazza, S., Largiader, C.R. and Seehausen, O. (2012) Eutrophication Causes Speciation Reversal in Whitefish Adaptive Radiations. *Nature*, **482**, 357-362. https://doi.org/10.1038/nature10824

[10] Diaz, R.J. and Rosenberg, R. (2008) Spreading Dead Zones and Consequences for Marine Ecosystems. *Science*, **321**, 926-929.

[11] Pretty, J.N., Mason, C.F., Nedwell, D.B., Hine, R.E., Leaf, S. and Dils, R. (2003) Environmental Costs of Freshwater Eutrophication in England and Wales. *Environmental Science and Technology*, **37**, 201-208. https://doi.org/10.1021/es020793k

[12] National Institute of Environmental Research (2012) The Report on National Water Quality Evaluation 2012. Ministry of Environment, Seoul.

[13] Jégo, G., Martínez, M., Antigüedad, I., Launay, M., Sanchez-Pérez, J.M. and Justes, E. (2008) Evaluation of the Impact of Various Agricultural Practices on Nitrate Leaching Under the Root Zone of Potato and Sugar Beet Using the STICS Soil-Crop Model. *Science of the Total Environment*, **394**, 207-221. https://doi.org/10.1016/j.scitotenv.2008.01.021

[14] Pikounis, M. (2003) Application of the SWAT Model in the Pinos River Basin Under Different Land Use Cases. *Global Nest Journal*, **5**, 71-79.

[15] Cerro, I., Sanchez-Perez, J.M., Ruiz-Romera, E. and Antigüedad, I. (2014) Variability of Particulate (SS, POC) and Dissolved (DOC, NO_3) Matter during Storm Events in the Alegria Agricultural Watershed. *Hydrological Processes*, **28**, 2855-2867.

[16] Borah, D.K. and Bera, M. (2003) Watershed-Scale Hydrologic and Nonpoint-Source Pollution Models: Review of Mathematical Bases. *Transactions of the ASAE*, **46**, 1553-1566. https://doi.org/10.13031/2013.15644

[17] Gassman, P.W., Reyes, M.R., Green, C.H. and Arnold, J.G. (2007) The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. *Transactions of the ASABE*, **50**, 1211-1250.

[18] Arnold, J.G., Srinivasan, R., Muttiah, R.S. and Williams, J.R. (1998) Large Area Hydrologic Modeling and Assessment Part I: Model Development. *Journal of the American Water Resources Association*, **34**, 73-89.

[19] Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R. (2001) Soil and Water Assessment Tool Theoretical Documentation Version 2000: Draft-April 2001. Grassland, Soil and Water Research Laboratory, Temple.

[20] Williams, J.R. (1975) Sediment Routing for Agricultural Watersheds. *Journal of the American Water Resources Association*, **11**, 965-974. https://doi.org/10.1111/j.1752-1688.1975.tb01817.x

[21] Green, C. and Vangriensven, A. (2008) Autocalibration in Hydrologic Modeling: Using SWAT2005 in Small-Scale Watersheds. *Environmental Modelling & Software*, **23**, 422-434. https://doi.org/10.1016/j.envsoft.2007.06.002

[22] Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R. and King, K.W. (2002) Soil and Water Assessment Tool: Theoretical Documentation, Version 2000. TWRI Re-

port TR-191. Water Resources Institute, College Station.

[23] Van Breemen, N., Boyer, E.W., Goodale, C.L., Jaworski, N.A., Paustian, K., Seitzinger, S., Lajtha, L.K., Mayer, B., Van Dam, D., Howarth, R.W., Nadelhoffer, K.J., Eve, M. and Billen, G. (2002) Where Did All the Nitrogen Go? Fate of Nitrogen Inputs to Large Watersheds in the Northeastern USA. *Biogeochemistry*, **57/58**, 267-293. https://doi.org/10.1023/A:1015775225913

[24] Nam, Y., An, S. and Park, J. (2011) Nitrogen Budget of South Korea in 2008: Evaluation of Non-Point Source Pollution and N2O Emission. *Journal of Korean Society of Environmental Engineers*, **33**, 103-112.

[25] Parfitt, R.L., Schipper, L.A., Baisden, W.T. and Elliott, A.H. (2006) Nitrogen Inputs and Outputs for New Zealand in 2001 at National and Regional Scales. *Biogeochemistry*, **80**, 71-88. https://doi.org/10.1007/s10533-006-0002-y

[26] Park, J.Y., Park, M.J., Ahn, S.R., Park, G.A., Yi, J.E., Kim, G.S., Srinivasan, R. and Kim, S.J. (2011) Assessment of Future Climate Change Impacts on Water Quantity and Quality for a Mountainous Dam Watershed Using SWAT. *Transactions of the ASABE*, **54**, 1725-1737.

[27] Nash, J.E. and Sutcliffe, J.V. (1970) River Flow Forecasting Through Conceptual Models Part I—A Discussion of Principles. *Journal of Hydrology*, **10**, 282-290. https://doi.org/10.1016/0022-1694(70)90255-6