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Predicting the impact of management practices on river water quality using SWAT in an agricultural watershed

Mei Liu[a], Jun Lu[a,b,*]

[a]*Department of Natural Resources, College of Environment and Natural Resources, Zhejiang University, 866 YuHangTang Road, Hangzhou 310058, Zhejiang Province, China, Tel./Fax: +86 571 88982661; email: jlu@zju.edu.cn*
[b]*China Ministry of Education Key Lab of Environment Remediation and Ecological Health, Zhejiang University, Hangzhou 310058, China*

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ABSTRACT

Since intensive farming practices are essential to produce enough food for the increasing population in China, farmers have been using more inorganic fertilizers and pesticides. In addition, rural areas were heavily populated and a large number of domestic sewage were discharged widespread. Agricultural land and residential land are two of the major sources of nonpoint source pollution. However, by changing farming practices in terms of tillage and reducing the fertilizer rate as well as improving domestic sewage treatments, the levels of contamination can be reduced and the quality of soil and water resources can be improved. Thus, there is a need to investigate the hydrologic effects on nutrient loss when various watershed managements are operated in tandem. In this study, the Soil and Water Assessment Tool (SWAT) was utilized to evaluate the individual and combined impacts of various management practices on total nitrogen (TN) and total phosphorus (TP) loads in the Changle River watershed. The model was calibrated and validated using the years 2004–2007 and 2008–2009 data sets, respectively. The simulated results revealed that the SWAT model provided a good simulation performance. For those tested watershed management scenarios, no-tillage (NT) offered more environmental benefits than moldboard plowing. In terms of reducing fertilizer rate or treating domestic sewage, they were also able to obviously reduce TN and TP loads. When the combined effects of the three practices were examined, it was found that the scenario of NT and reducing fertilizer rate by 30% without domestic sewage inputs could greatly restrain the loss of nutrients to waters and basically met the II grade water quality target, meanwhile it was also the best management practice that could be easily accepted by local farmers and government.

Keywords: SWAT; Nutrient loss; Farming practices; Domestic sewage; Fertilizer rate

1. Introduction

Nonpoint source (NPS) pollution results from anthropogenic activities such as excessive use of fertilizers, tillage measure, and discharge of domestic sewage into watershed [1–3]. Extensive application of fertilizer with about 200–500 kg N ha^{-1} to promote continuous supply of grains for increasing population needs in China has resulted in soil nutrient enrichment [4]. These nutrients (N and P) later entered the

*Corresponding author.

surface water such as lakes, rivers, and coastal oceans and caused eutrophication [5,6]. The lack of both land use planning and conservation practices may trigger environmental degradation processes in a watershed, such as increased runoff and sediment yield and nutrient losses, which can compromise the quality of the environment, and especially of the freshwater resources [7,8]. The increase in nutrient losses and river nutrient loads has caused the eutrophication of many coastal and freshwater ecosystems. To understand the influence of these anthropogenic activities on nutrient concentrations, varying in space and time may be a vital ingredient for successful water quality management. A watershed protection approach is an important strategy to effectively protect a watershed and thereby restore aquatic ecosystems. In watershed planning, mathematical models are useful tools which quickly and inexpensively provide information to guide decision-making processes. Several simulators based on mathematical methods that describe physical processes (natural and anthropogenic) have been developed in order to predict runoff, erosion, and transport of sediments and nutrients in watersheds subject to different management practices [9–11]. The Soil and Water Assessment Tool (SWAT) is one of the most complete models since it involves a large number of simulated components and can be used to predict over long periods of time, the impact of soil management practices in aquatic environments (surface and underground) in complex watersheds with variations in soil type, land use, application of fertilizers, and pesticides [12,13].

Many studies have been used SWAT to evaluate the impacts of watershed management practices on water quality [12–16]. In general, these studies showed that management practices, such as conservation tillage, fertilizer rate, filter strips, terraces, or grassed waterways, can lead to significant reductions of sediment and nutrient loads. Jha et al. [14] simulated the response of nitrate loads to fertilizer application rates in a watershed located in west-central Iowa. Santhi et al. [15] used SWAT to quantify the impacts of implementing best management practices (BMPs) on sediment and nutrients in Texas, USA. A comprehensive review of SWAT applications including BMPs impacts on pollutant losses can be found in Gassman et al. [17].

To protect the water resources, more research is needed to ascertain the environmental effects of agricultural practices. This is especially important for NPS polluted watersheds such as Changle River watershed in southeast China. In addition, Changle River watershed is densely populated area and rural population density is about 500 inhabitants per square kilometer. Survey showed rural domestic sewage including washes effluents and manure sewage which contained about total nitrogen (TN) 1,500 t year^{-1} and total phosphorus (TP) 400 t year^{-1} and a total of close to 80% were discharged widespread. Thus, any change in the anthropogenic activities may have significant impacts on river water quality. SWAT was employed to examine the hydrologic and water quality changes in Changle River watershed. Since previous researches mainly focused on predicting the effects of implementing conservation tillage and optimal fertilizer rate, predicting the effects of treating domestic sewage on water quality will provide valuable information to decision-makers for the design of NPS pollution control strategy.

The main objectives were firstly (1) to analyze the effect of runoff amount and land use types on NPS pollution, (2) to evaluate the performance of the SWAT model in the simulation of runoff and water quality in an agricultural watershed, China, (3) to model the relative background water quality without any anthropogenic inputs, and (4) to evaluate the individual and combined impacts of various watershed management scenarios, including two tillage systems (no-tillage (NT) and moldboard plowing (MP)) and reducing fertilizer rates by 30 and 60% as well as treating and untreating domestic sewage. We expected that the methodology presented in this paper would enhance the reliability of simulations for future SWAT applications and provide scientific support for decision-makers to achieve agricultural watershed management goals.

2. Materials and methods

2.1. Watershed description

The Changle River system (120˚35′56′′–120˚49′03′′E and 29˚27′98′′–29˚35′12′′S) is located in Zhejiang Province, eastern China (Fig. 1). It is one of the main tributaries of the Cao-E River, which ultimately flows into the QianTang Estuary and then East China Sea. The length of mainstream is about 44 km with an average slope of 0.36%. The Changle River catchment covers an area of 864 km^2 and has a population of about 500,000 persons, of whom some 38,000 live in the town city. It is consisted of five tributaries in the median-lower watershed and three headwater tributaries (Fig. 1). Long-term average annual rainfall from 1955 to 2010 is about 1,256 mm year^{-1}, and rainfall in wet season including April, May, June, July, August, and September is account for about 80%. The mean air temperature is about 17℃ with the lowest mean temperature 4℃ in January and the highest 28℃ in July. The main land use types in the catchment are

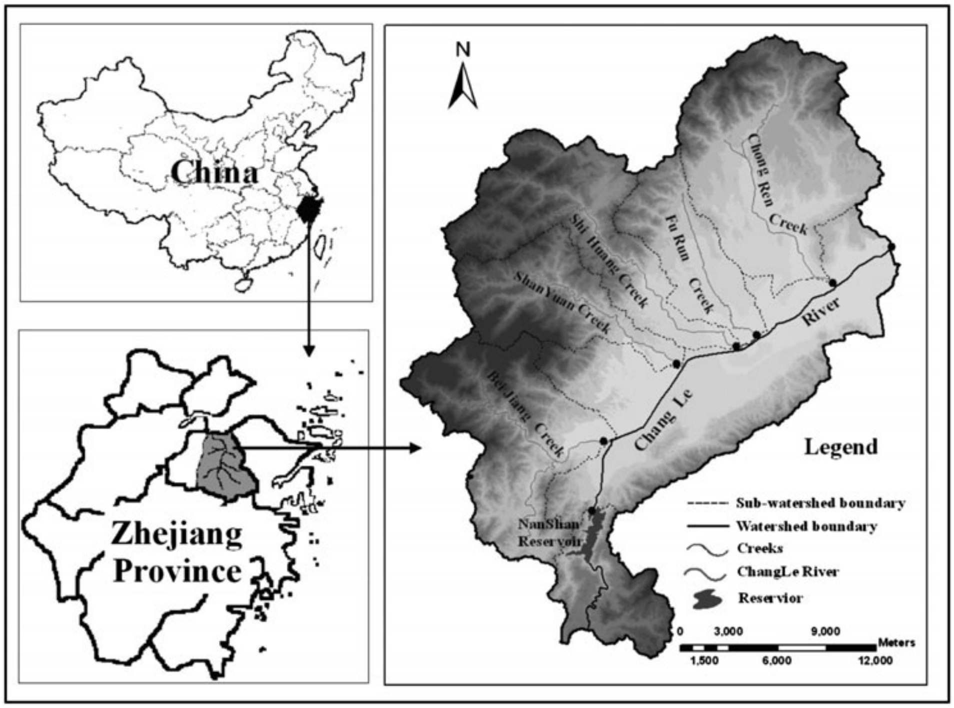

Fig. 1. Map of the surface waters and the watersheds used for the analysis.

agricultural land, including paddy field, dry land cropping, and plant nurseries, along with rural habitation. The Changle River is typical of agricultural drainage rivers in southeastern China that is being influenced by intensive farming practices causing serious water pollution problems from diffuse agricultural sources. The annual average precipitation is 1,194 mm with monthly variations of 26–215 mm in 2004–2006 for the catchment recorded at the weather station in Shengzhou city. The rainfall mainly occurs in May and June and during the typhoon season (i.e., September). Water drainage from the river headstream (Nanshan Reservoir, Fig. 1) is limited because it is the main local drinking water source, and rainfall is the main water source for the river. Point source pollution in the watershed (including waste water treatment plants and industrial sewage outlets) is negligible, with an annual TN discharge of only 0.3 ton in years 2004–2009.

2.2. Model description and available data

SWAT is a hydrologic and water quality model developed by the United States Department of Agriculture–Agricultural Research Service [17,18]. The model is a continuous-time, spatially distributed simulator of the hydrologic cycle and agricultural pollutant transport at a catchment scale. The main objective of SWAT is to predict the impact of agricultural or land management on water, sediment, and agricultural chemical yields in ungauged basins. The major components of SWAT include hydrology, weather, erosion, nutrients, and pesticide fate. SWAT takes into account surface runoff, percolation, lateral subsurface flow, groundwater return flow, evapotranspiration, and channel transmission losses. Runoff volume is estimated with the modified SCS curve number method. SWAT uses a storage routing technique to predict flow through each soil layers in the root zone. Downward flow occurs when field capacity of a soil layer is exceeded and the layer below is not saturated. SWAT partitions groundwater into two aquifer systems: a shallow unconfined aquifer which contributes return flow to streams within the watershed and a deep, confined aquifer that, besides pumping, is disconnected from the system. All parameters for groundwater were evaluated with particular attention to the "critical" parameters: alpha baseflow factor, groundwater delay, and groundwater evaporation. SWAT simulates the nitrogen and phosphorus wash out by runoff and leaching through the soil profile, while a fixed nitrate concentration of the shallow aquifer is used to estimate the groundwater contribution to the in-stream nitrogen load. The nitrogen and phosphorus transformation in stream water is based on QUAL2E model, which includes the major interactions of the nutrient cycles, algae production, and benthic oxygen demand. Runoff, sediments, and chemicals are simulated for each Hydrological Response Unit (HRU) and then aggregated for the sub-basin, and routed to the watershed outlet. The watershed concentration time is estimated using Manning's formula, considering both overland and channel flow. A detailed description of SWAT can be found in Nietsch et al. [18].

SWAT input parameter values such as topography, landscape, land use, and weather data were compiled using databases from various governmental agencies. Data included 1:50,000 scale land use data, 25 m resolution Digital Elevation Models (DEMs), and 1:50,000 scale stream network data from Zhejiang Bureau of Surveying and Mapping. Land use areas were defined based on the land use survey database developed by the Zhejiang Department of Water Resources during 1996–2004 under the assumption that agricultural land has not change since the survey was completed. Soil properties were extracted from the 1:25,000 Shengzhou Soil Survey Geographic (China, 1995) database based on soil surveys conducted in the study area. Daily precipitation and minimum and maximum temperature were retrieved from Zhejiang Meteorological Station in the study area. Monthly average streamflow was aggregated from daily data provided by Zhejiang Provincial Government Hydrology Office. Data on TN and TP sources (human population, quantity of poultry, and chemical fertilizer use) in the Changle River watershed were collected for each village in years 2004–2006. Appropriate nutrient generation coefficients for human and livestock poultry, and nutrient export ratios for domestic waste, livestock–poultry waste, and different fertilizers from the varying land uses in the catchment were obtained from the literature and used to estimate nutrient export loads from land into the Changle River [19].

Water quality was monitored once a month at five sampling sites along the Changle River from January 2004 to December 2009 (Fig. 1). Water samples were collected from the upper 30 cm of the water column in 2.0 l polyethylene bottles between 9:00 and 18:00. DO, water temperature (T), conductivity (EC), and temperature-corrected pH were measured using handheld multi-parameter 350i SETs (The Merck Co. Ltd, Germany). Chemical oxygen demand (COD_{Mn}) (GB11892), TN, and TP were measured according to the National Standard Method of China (GB 11893-89) in a laboratory within 8 h after sampling. Following filtration through a 0.45-μm filter, ammonium (NH_4-N) was measured using an Astoria Analyzer System (Brown Rupee Co. Ltd, Germany) and nitrate (NO_3-N) using the UV spectrophotometric method. Water quality indices in dry and flood seasons were statically summarized in Table 1.

2.3. SWAT calibration and validation

After prepared the necessary maps (land use, soil, and DEM) and database files (climate, soil properties, etc.), a new SWAT project was built for the Changle River watershed. Through delineating sub-watersheds and creating HRU, the SWAT project can simulate the water balance of the Changle River watershed. Model calibration is usually carried out by adjusting values of model parameters, but SWAT model has a large number of parameters; therefore, identification of the sensitive parameters to improve the calibration efficiency is necessary. Latin Hypercube sampling based on One Factor at a Time (LH-OAT) method [20], which is incorporated in SWAT as an extension, was used to identify parameters that have a significant influence on model simulations. LH-OAT starts with taking N Latin Hypercube sample points for N intervals and then varying each LH sample point P times by changing each of the P parameters one at a time. The method operates by loops and each loop starts with a Latin Hypercube point. Around each Latin Hypercube point j, a partial effect $S_{i,j}$ for each parameter e_i is calculated using Eq. (1):

$$S_{i,j} = \left| \frac{100 * \left(\frac{M(e_1, \ldots, e_i * (1 + f_i), \ldots, e_p) - M(e_1, \ldots, e_i, \ldots, e_p)}{[M(e_1, \ldots, e_i * (1 + f_i), \ldots, e_p) - M(e_1, \ldots, e_i, \ldots, e_p)]/2} \right)}{f_i} \right| \quad (1)$$

Table 1
Summary statistics for all original available water quality indices in the Changle River

Indices	Dry season Mean	Dry season Range	Wet season Mean	Wet season Range
TN (mg l^{-1})	4.13	0.76–9.55	3.11	0.92–8.43
TP (mg l^{-1})	0.15	0.02–0.46	0.19	0.06–0.0.51
DO (mg l^{-1})	11.65	4.04–19.63	8.6	2.02–15.69
NH_4-N (mg l^{-1})	0.31	0.02–1.66	0.17	0.02–1.19
NO_3-N (mg l^{-1})	1.28	0.28–5.41	2.26	0.31–6.03
COD_{Mn} (mg l^{-1})	3.52	0.66–13.5	3.88	0.67–15.8
T (℃)	12.45	4.2–20.4	28.4	11.5–37.1
EC (us cm^{-1})	141.5	39–305.6	134.5	28v387.6
pH	8.01	5.06–9.84	8.23	5.88–10.37

where M (…) refers to the model functions, f_i is the fraction by which the parameter e_i is changed (a predefined constant), and j refers to a LH point. A final effect is calculated by averaging these partial effects of each loop for all Latin Hypercube points. The final effects can be ranked with the largest effect being given rank 1 and the smallest effect being given a rank equal to the total number of parameters. Thus, the impacts of each parameter on the model results can be quantified, and the most sensitive parameters can be identified.

After identifying the sensitive parameters, model calibration can be carried out. Annual runoff of 2004–2007 was used for model calibration and annual runoff of 2008–2009 for model validation to further improve the performance of SWAT. It should be noted that calibration for runoff is first done for average annual conditions. Once completed, the calibrated values are used as first approximation and are fine tuned using monthly records until the simulated results are acceptable according to the model evaluation guidelines.

Nash–Sutcliffe model efficiency (*Ens*) [21] was used to assess the predictive power of the SWAT model. The equation was given as follows:

$$Ens = 1 - \sum_{i=1}^{n} (Q_{obs} - Q_{sim})^2 \Big/ \sum_{i=1}^{n} (Q_{obs} - \mathrm{mean}(Q_{obs}))^2 \qquad (2)$$

where Q_{obs} and Q_{sim} are the measured and simulated data, respectively, and n is the total number of data records. This coefficient (*Ens*) presented using Eq. (2) can vary between $-\infty$ and 1; $Ens = 1$ indicates a perfect adjustment. Moriasi et al. [20] analyzed results from several authors and considered appropriate *Ens* values greater than 0.5.

The r^2 (r is correlation coefficient) calculated using Eq. (3) evaluates how accurately the model tracks the variation of the observed values. It can reveal the strength and direction of a linear relationship between simulation and observation. The difference between the *Ens* and r^2 is that the *Ens* can interpret model performance in replicating individually observed values, while r^2 does not [22].

$$r^2 = \frac{\left(\sum (Y_{i,obs} - \bar{Y}_{obs})(Y_{i,sim} - \bar{Y}_{sim})\right)^2}{\sum (Y_{i,obs} - \bar{Y}_{obs})^2 \sum (Y_{i,sim} - \bar{Y}_{sim})^2} \qquad (3)$$

where n is the number of observation/simulation data points for comparison, $Y_{i,obs}$ and $Y_{i,sim}$ are observed and simulated data, respectively, on each time step i (e.g. day, month, or year), and $\overline{Y}_{obs}$ and $\overline{Y}_{sim}$ are mean values for observation and simulation, respectively, during the examination period.

2.4. Results of calibration and validation

In this study, the hydrology was calibrated first. The simulated monthly runoff based on year 2000 land use types and 2004–2007 weather data was compared with the monitored values. The input parameters were adjusted by trial and error until the simulated monthly flow was statistically close to observed data. Table 2 listed the simulation performance of SWAT. The results indicated that the model could simulate runoff and sediment over the 2004–2007 periods reasonably well. The mean observed monthly runoff was 11.64 $m^3 s^{-1}$, whereas the mean simulated value was 10.19 $m^3 s^{-1}$. This suggested that the model slightly underestimated the mean water flows by approximately 12.4%. Perhaps, one important reason for underestimating the peak flow during the flood period is the fact that the extra release of water from the upstream Nanshan Reservoir to avoid overfilling. Another reason may be related to the parameters dealing with the lesser understood processes such as groundwater recharge, and ground–river interaction was not as important as they would have been [16]. However, the over/underestimations did not occur systematically, although they tended to be underestimated in summer and early fall periods (July–October). Nonetheless, it can be seen from the hydrograph in Fig. 2 that the simulated runoff matched observed values quite well. This was confirmed by a highly significantly correlation coefficient ($r^2 = 0.901$, $n = 48$, $p < 0.01$) and *Ens* (0.768), as shown in Table 2.

After runoff had been properly calibrated, the next step was sediment calibration. This process is necessary because the amount of organic nutrients is directly affected by sediment load. If sediment load is not properly calibrated, it will be difficult to calibrate nutrient loads, such as TP. The mean simulated monthly sediment yield was 9.99 $mg\,l^{-1}$, and the observed value was 9.43 $mg\,l^{-1}$. The correlation between observed and simulated data was highly significant ($r^2 = 0.905$, $n = 48$, $p < 0.01$) meanwhile *Ens* is 0.784. Since the simulation results were within acceptable limits, the parameters for sediment calibration were applied to the model for the study area.

Two nutrients, TN, and TP in surface water were included in this study. The mean simulated monthly TN load was 143.1 $t\,month^{-1}$, which was 2.58%

Table 2
SWAT calibration and validation results

Index	Observed	Simulated	Difference[a] (%)	*Ens*	r^2
Calibration period					
Runoff ($m^3 s^{-1}$)	11.64	10.19	−12.39	0.768	0.901**
Sediment ($mg\,l^{-1}$)	9.99	9.43	−5.68	0.784	0.905**
TN ($t\,month^{-1}$)	146.8	141.3	−2.58	0.697	0.918**
TP ($t\,month^{-1}$)	3.99	3.73	−6.61	0.662	0.866*
Validation period					
Runoff ($m^3 s^{-1}$)	12.09	10.76	−10.98	0.791	0.877*
Sediment ($mg\,l^{-1}$)	9.59	9.06	−5.54	0.825	0.910**
TN ($t\,month^{-1}$)	150.3	136.3	−9.33	0.782	0.900**
TP ($t\,month^{-1}$)	4.19	3.73	−11.02	0.715	0.816*

[a]Relative error (%).
*$p < 0.05$.
**$p < 0.01$.

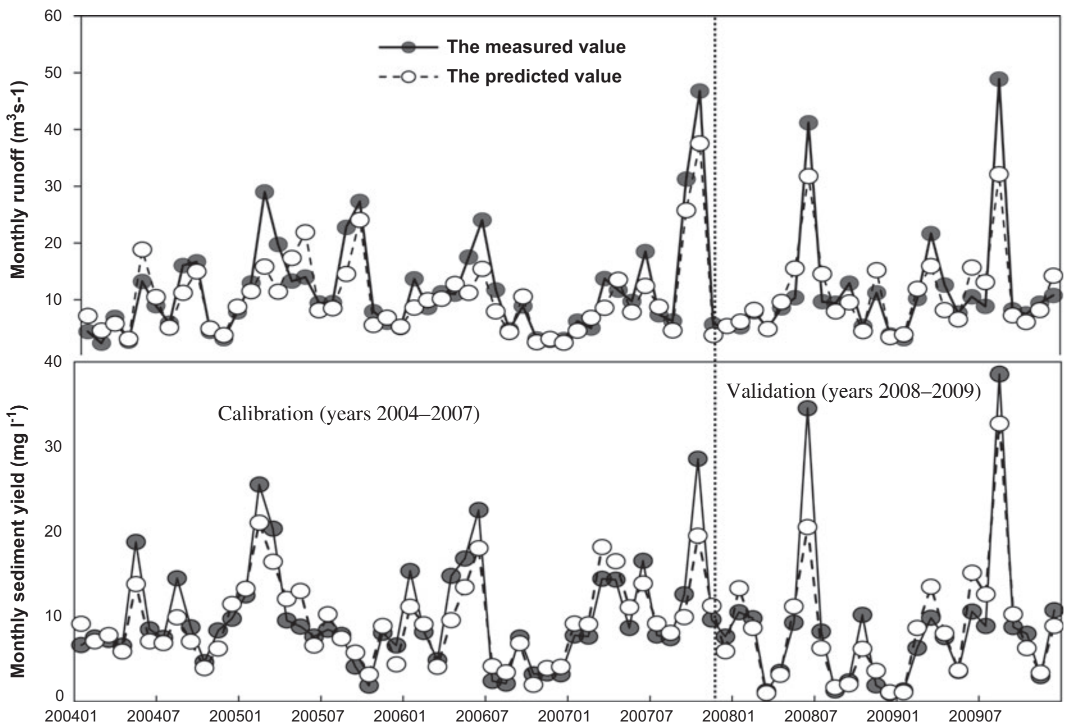

Fig. 2. Observed vs. simulated runoff and sediment in calibration (years 2004–2007) and validation (years 2008–2009) periods.

less than the mean observed monthly value ($146.8\,t\,month^{-1}$). TN loads tended to be underestimated (Fig. 3) especially when peak loads were predicted because of river flow (Q, $m^3 s^{-1}$) that is significantly correlated with TN loads (L_d, $kg\,d^{-1}$) ($L_d = 7.0885Q - 0.6704$, $R^2 = 0.8067$, $p < 0.05$) while as previously stated peak flow was underestimated. Despite this discrepancy, the general simulation results were reasonably close to observed values because the correlation between the simulated and observed values was 0.89, with $p < 0.05$, moreover the *Ens* is 0.697. The simulated monthly results of TP were also underestimated by 6.61% compared to the observed values. Likewise, TP loads (L_d, $kg\,d^{-1}$) were significantly correlated with river flow (Q, $m^3 s^{-1}$) ($L_d = 434.33Q - 741.38$, $R^2 = 0.9355$, $p < 0.01$).

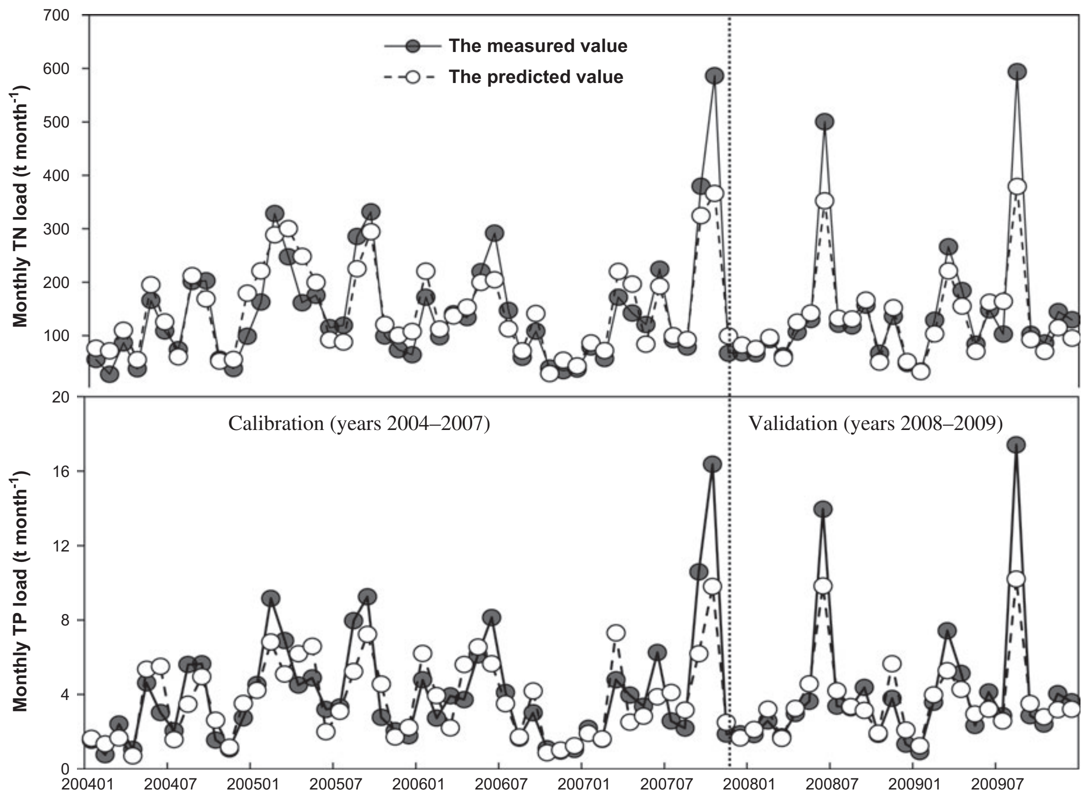

Fig. 3. Observed vs. simulated TN and TP load in calibration (years 2004–2007) and validation (years 2008–2009) periods.

The simulated monthly concentrations varied from 0.009 to 0.745 mg l^{-1}, whereas the observed values were from 0.005 to 1.12 mg l^{-1}. Since the correlations between the simulated and observed data of every variable were significant (Table 2), it was considered that the built SWAT for simulating Changle River watershed was properly calibrated.

The next step was validation. This step is important because it ascertains that the calibrated model is capable of portraying realistic conditions under different environments in the validation process, and the values of all input parameters from the calibration process were maintained the same, but a different data-set consisting of the 2008–2009 weather data was used. Without modifying any other input parameters, the model was run. If the results are unacceptable, then the model has to be recalibrated using 2004–2007 weather data until the criterion is met. If the results are satisfactory, then the model is expected to produce reasonable results and can be used to forecast future events. This procedure was repeated until the simulated data were in close agreement with the observed data in both the calibration and validation runs.

In this study, the validation results were generally acceptable. The differences between the validation and observation values were greater than those in the calibrations, varying from −9.33% (TN) to −5.54% (sediment), −10.98% (runoff), and −11.2% (TP). Nevertheless, the r^2 between the mean monthly observed and simulated values in the validation processes were still high, ranging from 0.816 to 0.91, with $p < 0.01$ and *Ens* is 0.782, 0.825, 0.791, and 0.715, respectively. These results showed that the validation was still reasonable (Table 2) and the compiled model was capable of predicting the hydrologic effects of different watershed management practices under current parameterization.

3. Results and discussion

3.1. The effect of rainfall or runoff on NPS pollution

NPS pollution is caused by water movement over and through the surface of the land. The runoff picks up and transports natural and man-made pollutants to water bodies when rainfall occurs especially storm events. Thus, NPS pollution load was mainly concentrated in the flood period [23,24]. Changle River watershed represents a typical agricultural watershed in southeast China and is characterized by a subtropical monsoon climate. Seasonal rainfall distribution is not even, there are two rain seasons all over the year (Fig. 4). One is from April to May which is mainly affected by plum rains and the second one is from July to September which is affected by typhoon. In general, the rainfall or runoff from April to September is above 80% of the whole year. TN loads in the two periods are 30.6 and 24.7% of the whole year, respectively. TP loads are 34.5 and 22.6% of the whole year, whereas NPS pollution loads of other months with little rainfall are relative small, for example, the TN NPS load in January is only 4.6% of the whole year. In addition, variance analysis showed that TN pollution load is significantly with month rainfall and runoff. The Pearson correlations are 0.66 and 0.78 with $p < 0.05$, respectively. According to China Technical Guideline for Delineating Source Water Protection Areas and Scheme for dividing the water environment of Zhejiang province, the Changle River watershed should belong to drinking water second-grade protection zone. The water quality should meet III grade. Meanwhile according to China's Surface Water Environment Quality Standards (GB3838-202), river TP concentration should be lower than $0.2\,\mathrm{mg\,l^{-1}}$. But there is no river TN criterion in the current

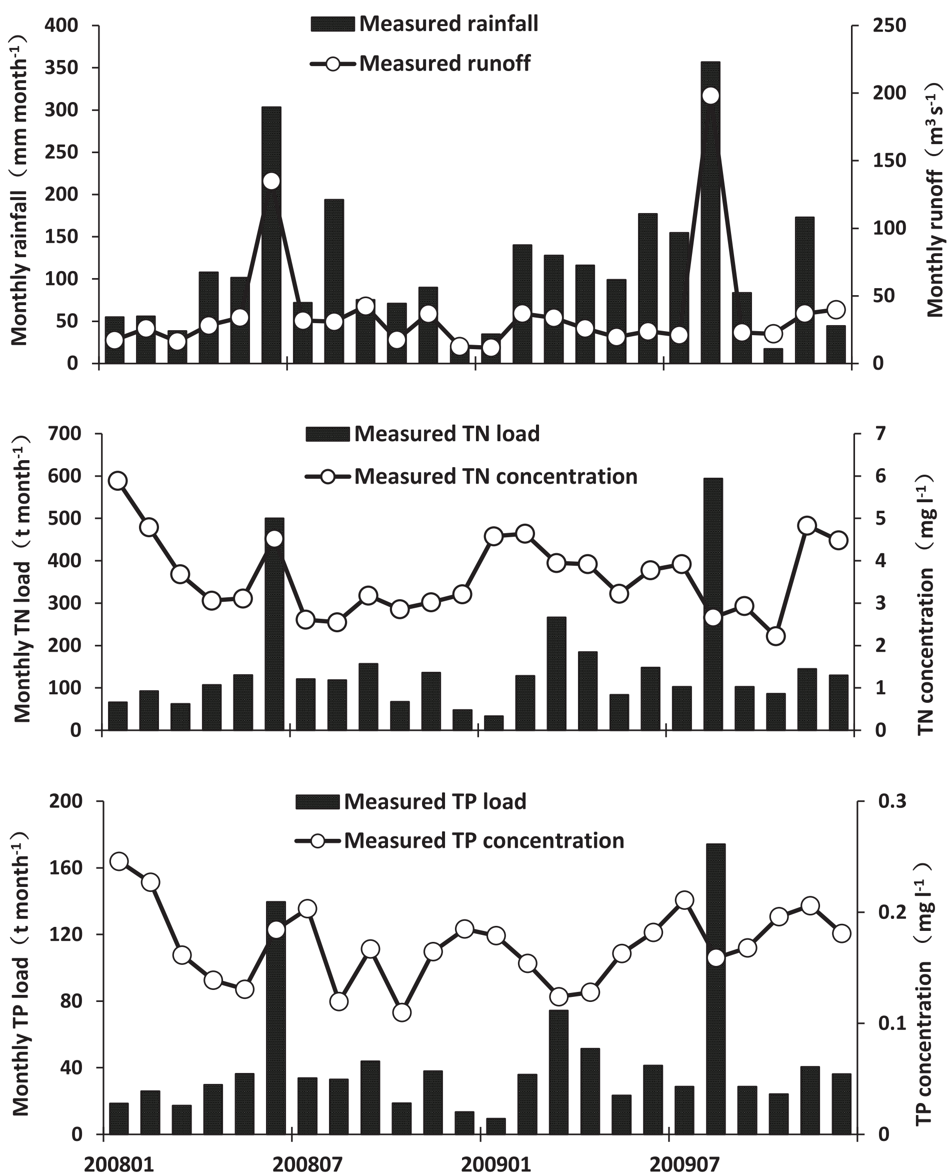

Fig. 4. (Top) Monthly mean rainfall and runoff in Changle River watershed, (Middle) monthly mean TN concentration and loads at outlet station, and (Bottom) monthly mean TP concentration and loads at outlet station.

standards of China. Thus, we referred to USEPA (2000) Ecoregional Nutrient Criteria [25,26], and the critical TN concentration for Changle River watershed is set to $2\,mg\,l^{-1}$. Average month TN concentration is $3.67\,mg\,l^{-1}$ that is far higher than the critical concentration $2\,mg\,l^{-1}$. And mean month TP concentration is $0.17\,mg\,l^{-1}$ ($<0.2\,mg\,l^{-1}$). Therefore, TN is the important control factor to improve the water quality. Whereas unlike TN or TP loads, there are not significantly correlations between TN or TP concentrations and runoff or precipitation since there is big seasonal and annual variance for runoff. TN and TP concentrations are relatively high in summer and winter. In summer, river TN and TP concentrations were high because heavy rain delivered more pollutants to rivers. Although TN and TP concentrations were high in winter, the load was still very low. There are two main reasons. First, little runoff in winter led to high nutrient concentrations to some extent. Second, perennial plants (such as wood) went into winter period after they have dropped their leaves. Therefore, nutrient elements of leaves went into the top soil layer and amount of nitrogen they needed would also decreased much.

There exited a significant correlation between TN load and runoff (0.87, $p < 0.01$). Consequently, some watershed practices should be adopted to reduce runoff amount together with sediment yield. Currently, conservation tillage such as NT is the most common practice at a catchment scale. Whereas in this study area, the most widespread tillage system in smallholder farming areas (i.e., communal, small scale farming and all resettlement areas) is still the conventional tillage (CT), which involves the inversion of the soil using a MP thereby leaving the soil loose, enhancing organic matter mineralization and resulting in poor soil structure and enhanced sheet erosion. Therefore, the effect of NT on the nutrient pollution is necessary to explore using SWAT in the following section.

3.2. The effect of different land use types on NPS pollution

The unit area outputs of runoff, sediment, and nutrient loads from different land use types were presented in Fig. 5. Many studies have reported that water quality will be better in the watersheds with mainly high forest than those with main agricultural land [27–30]. It is similar with the result of our study. As good forest coverage can provide high leaf interception and decrease the impact of raindrops on the soil, causing water and soil erosion, whatever runoff, sediment, or TN and TP load per unit area are the lowest, only $1.59\,mm\,hm^{-2}$, $1.11\,t\,hm^{-2}$, $15.19\,kg\,hm^{-2}$, and $0.11\,kg\,hm^{-2}$, respectively. While due to cultivation practice and applying large amount of fertilizer, sediment and nutrient loads except runoff per unit area for dry land were significantly higher than other four land use types. As for the orchard (garden land), the fruit trees and vegetation played the role of soil and water conservation; thus, the runoff and sediment per unit area were the second least just $2.4\,mm\,hm^{-2}$ and $10.9\,t\,hm^{-2}$. But TN and TP loads per unit area are very high and up to $72.7\,kg\,hm^{-2}$, $2.4\,kg\,hm^{-2}$. The result is reasonable because a large number of N fertilizer close to $500\,kg\,ha^{-1}\,year^{-1}$ were applied meanwhile most of them would be washed out by runoff. Residential land contributed the most to the runoff with the value of $8.74\,mm\,hm^{-2}$ because its high hardening surface prevented the infiltration.

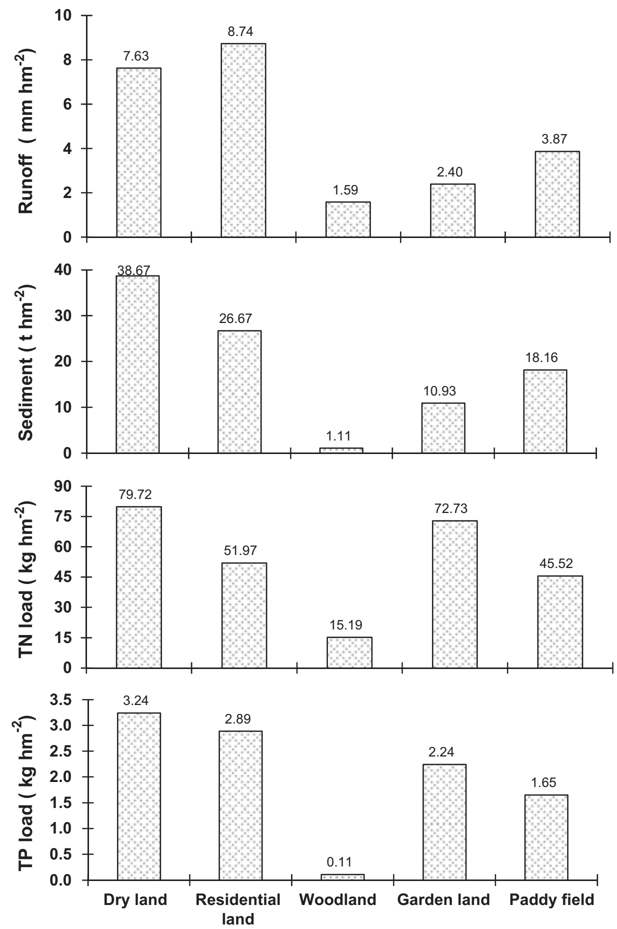

Fig. 5. Simulated surface runoff, sediment yield, TN loads, and TP loads per unit area from different land use types in Changle River watershed.

since a large amount of fertilizer was applied to agricultural land including dry land, paddy field and garden land, nutrient loss from these three land use types was the most serious. Accordingly, reducing fertilizer rates by 30 and 60% were investigated to explore the extent of decreasing NPS pollution. As for residential land, due to high population density and lack of sewage disposal system, its contribution on NPS pollution cannot be ignored. To quantify this effect on river water quality, it was assumed that after building sewage plants, treated wastewater would be discharged into water bodies within emission standard.

3.3. Model river nutrient background water quality

Nutrient background concentrations are an important index for evaluation of the extent of NPS pollution [31,32]. But absolute background concentrations cannot be directly monitored by chemical analysis method since the unpolluted river cannot be found especially in the agricultural watershed that has been intensely disturbed by human activities. As a result, only relative nutrient background concentrations could be simulated using SWAT under the condition that no anthropogenic N and P were delivered into the watershed. Fig. 6 showed that relative background TN concentrations at the watershed outlet were fluctuated at the level 2 mg l^{-1} that had met river water quality target in an agricultural watershed. In addition, with years increased, TN concentrations were slightly gradually decreasing. And at the year 2009, TN concentrations had been lower than 2 mg l^{-1}. The explanation was that although soil nitrogen content kept at a high level due to long-time agricultural activities such as application of fertilizer, when there was no any input even though soil organic released nitrogen by mineralization, yet, the soil residual nitrogen would decrease gradually with the washout of rainfall-runoff, and finally, the influence of soil nitrogen on nutrient concentrations of surface runoff was less and less. Increasing runoff would take up more TN and TP pollutants to the river, but at the same time, it also increased streamflow and enhanced river dilution capability. Consequently, the variation of background TN and TP concentrations is little.

3.4. The impacts of watershed management practices on NPS pollution

Development of watershed management practices to reduce N and P pollutants transfer from land to water is an essential component of the agricultural catchment planning required to achieve good ecological status under the legislative requirements [33]. Additionally, appropriate watershed management

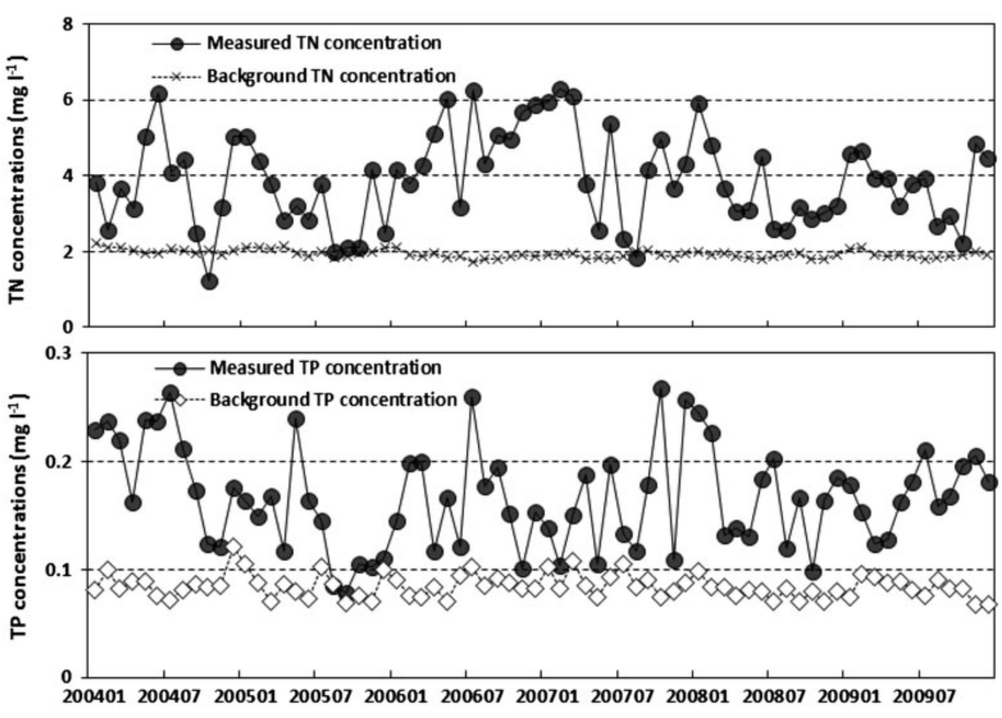

Fig. 6. Simulated TN and TP background concentrations in the watershed outlet without any anthropological pollutants inputs.

mode should not reduce crop yield and economic benefit and then adopt efficient management practices to reduce nutrient loss to the greatest extent.

According to factors as previously stated, eight scenarios were chosen to model the extent of reducing NPS pollution (Table 3) and the simulating results were shown in Fig. 7. When the fertilizer usage declined by 30 and 60% (scenarios 1 and 2), a total of 21.2% and 38.9% less in TN and 16.5% and 26.4% less in TP were not transported to the river from agricultural land. The population density in Changle River watershed is about 500 inhabitants per square kilometer, which is about 20 times higher than that in the USA. At the same time, most of inhabitants were living in the rural area where there was no public sewage system and rural domestic sewage was dispersed overspread, as a result, the amount of pollutants cannot be ignored. However, if domestic sewage was centralized to be treated, then the pollution from domestic sewage could be discharged within the standards. Therefore, the reduction ratios for TN and TP loads were 10.3 and 9.5% after domestic sewage was treated.

Surface runoff under NT was lower 18.6% than MP. The results are reasonable because other studies have also reported similar findings [7,8]. Alberts and Spomer [8] observed that from conservation tillage which was 4-year study, the decrease in runoff was mainly due to the fact that in NT crop residues were left undisturbed to cover the soil surface and protect soil erosion. With more litter in the surface, more water is retained. In time, most of the water will be infiltrated to the lower soil horizons instead of leaving the field as surface runoff. Annual sediment loads under NT were lower 12.3% than those under NT. Similar to runoff and sediments, the reduction rates for TN and TP were 13.9 and 12.1%, respectively.

More nitrogen from soil will be lost to river through runoff after plowing the farmland. Hence, NT will help in reducing nitrogen loss, providing a higher soil nitrogen level than CT. As for TP, close examination of Table 3 revealed that when combining the two farming practices, compared with scenarios 1–3 (only reduce fertilizer rate or only change tillage practices), the reduction rates were greater with 36.6% and 55.6% for TN and 29.9% and 40.4% for TP under scenarios 5 and 6. If three watershed management practices (scenario 7 and 8) were combined, TN and TP reduction rates were 49.8 and 34.8% for scenario 7 and 63.4 and 48.7% for scenario 8.

As previously mentioned, if river water quality was requested to meet II grade target, TN concentrations at the outlet should be lower than $2\,\mathrm{mg\,l^{-1}}$. It was found that the TN concentrations for all the months were lower than $2\,\mathrm{mg\,l^{-1}}$ only under scenario 8. But scenario 8 requests to reduce the fertilizer rate by 60% that will obviously reduce crop yield and affect the economic benefit. Thus, this practice will be hard to implement. Compared with scenario 8, TN concentrations of six months mainly focused on winter season were slightly higher than $2\,\mathrm{mg\,l^{-1}}$ in the scenario 7. But the average annual TN concentration ($1.96\,\mathrm{mg\,l^{-1}}$) was still lower than $2\,\mathrm{mg\,l^{-1}}$. The key point is only to request for reducing fertilizer rate by 30%. This will be not decrease the crop yield but also can improve the water quality to reach III grade target. As for TP, TP concentrations were fluctuated at the level $0.1\,\mathrm{mg\,l^{-1}}$, which is close to II grade water quality under scenario 7.

Table 3
The predicting reduction ratios of TN and TP load under eight scenarios

Scenarios	Reducing fertilizer rate (%)	N/P fertilizer rate ($\mathrm{kg\,ha^{-1}\,year^{-1}}$)	Tillage measure	Sewage[a] treatment ways	Amount of sewage (ton TN/TP $\mathrm{year^{-1}}$)	TN reduction (%)	TP reduction (%)
Scenario 1	−30	246/21	MP	Untreated	1,394/349	21.2	16.5
Scenario 2	−60	141/12	MP	Untreated	1,394/349	38.9	26.4
Scenario 3	−0	352/30	NT	Untreated	1,394/349	13.9	12.1
Scenario 4	−0	352/30	MP	Treated	320/54	10.3	9.6
Scenario 5	−30	246/21	NT	Untreated	1,394/349	36.6	29.9
Scenario 6	−60	141/12	NT	Untreated	1,394/349	55.6	40.4
Scenario 7	−30	246/21	NT	Treated	320/54	49.8	34.8
Scenario 8	−60	141/12	NT	Treated	320/54	63.4	48.7

[a]Included human and animal manure.

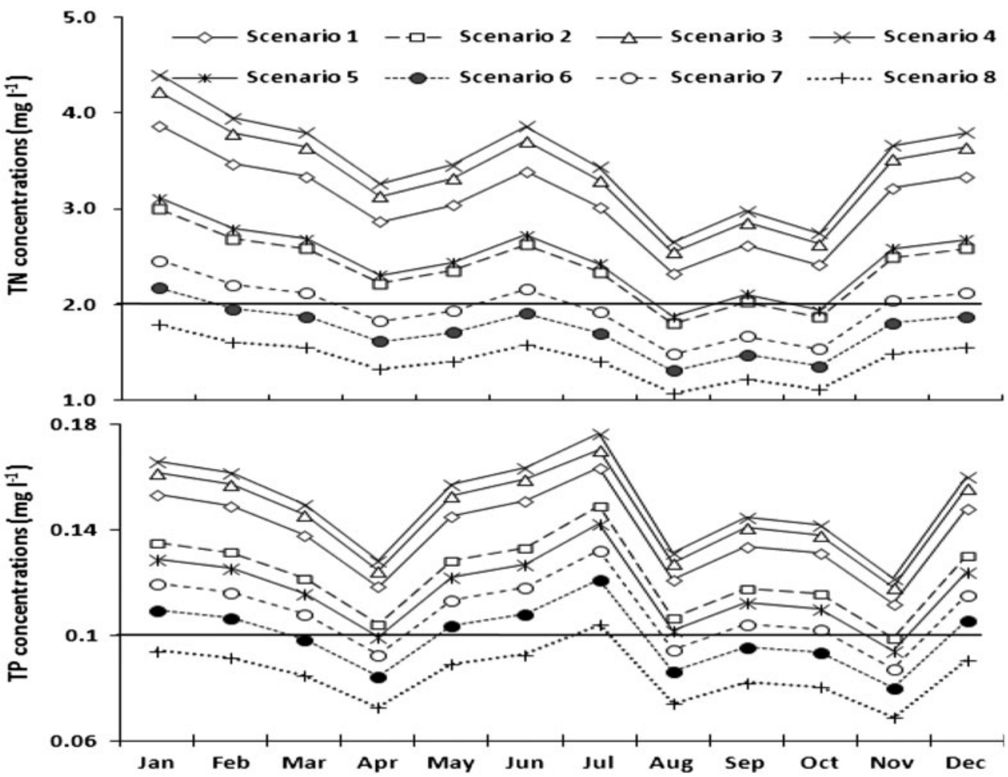

Fig. 7. Simulated mean monthly TN and TP concentrations under 8 scenarios at the watershed outlet. Solid lines represent the TN and TP concentration critical values with 2.0 and 0.1 mg l^{-1}, respectively.

4. Conclusions

The simulation results from both the calibration and validation processes demonstrated that SWAT could offer realistic simulations of water quantity and quality. This shows that SWAT is a reliable practical tool for water quality modeling. With little modification, other researchers may adopt a similar protocol as used in this research to compile a SWAT-based hydrologic and water quality model to assess and predict the impacts of alternative watershed management in their watersheds.

Regarding farming practices, the results for different tillage practices revealed that NT provided more beneficial environmental influence than MP in the Changle River watershed. Therefore, changing tillage practice from MP to NT can obviously improve water environmental quality in the study area. Except tillage practices, reducing fertilizer rate also can play a critical role in improving environmental quality. Among the tested fertilizer rate scenarios, less fertilizer rate applied in the soil, less TN and TP loads in river. While when the combined effects of those three watershed management practices were examined, it was found that scenario 7 could greatly restrain the loss of sediments and nutrients to water bodies and reach III grade water quality goal. In addition, the crop yield won't be affected, so this practice can be easily accepted and carried out by farmers.

This suggests that the practice of NT and reducing fertilizer rate by −30% with treated domestic sewage is a viable and low cost-high gain option for a successful farming system in this area. Nonetheless, different soil types, climate, and landscape (slope, aspect, etc.) may require different tillage measures and fertilizer rates. Each of these management systems has advantages and disadvantages. Therefore, farmers should consider all the benefits and drawbacks before selecting the practice that best suits their farmland. More research is needed to facilitate the decision-making processes.

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