Simulating the impact of flooding events on non-point source pollution and the effects of filter strips in an intensive agricultural watershed in China

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Abstract Non-point source pollution (NPSP) has become a critical pollution source after many improvements in point source pollution treatment have been made, particularly in China, due to intensive agricultural activities. Moreover, the impact of NPSP on surface water quality is significantly affected by extreme events, such as flooding. In this study, the soil and water assessment tool model was used to characterize the behaviours of NPSPs and to evaluate the effect of filter strips during flooding periods. The results showed that a flooding event in 2002 caused by a long duration of rainfall (event_1) contributed approximately 40 % of the annual sediment and organic N yield and 18.4 % of nitrate N yield. In 2007, more than 50 % of the annual sediment and organic N and 20 % of nitrate N export were caused by a flooding event due to heavy rainfall (event_2). The simulation results highlighted the severe threat of flooding events on aquatic environments. Furthermore, filter strips of different widths were simulated in these flooding scenarios to test their mitigation effects on the deterioration of surface water quality during these two events, and the 10-m filter strip did decrease more than 30–40 % of the loads of all NPSPs. Our study stresses that more attention should be paid to assessing the impact of flooding events on water quality management measures

and pollution loads, as well as the effect of management practices on both aquatic and terrestrial ecosystems to develop sustainable water and soil resources.

Keywords Extreme event · SWAT · NPSP · Filter strip · River

Introduction

In recent years, water quality has not improved significantly despite many efforts to control point source pollution, because non-point source pollution (NPSP) has become the main pollution source (Oeurng et al. 2011). The occurrence and intensity of NPSP have been shown to be closely related to hydrological behaviour and characteristics of the catchment, including the soil, land use, slope, and climate (Bernal et al. 2005; Shrestha et al. 2008). Moreover, NPSP is always characterized by random and intermittent occurrence, and generally originates from many diffuse sources (Shen et al. 2012; Zhang et al. 2010a), which makes it much more difficult to measure and control. Thus, NPSP control has been regarded as a major challenge for water quality management throughout the world.

Previous studies have noted differences in water quality between the dry season and rainy season (Li et al. 2009), implying a strong relation between rainfall and NPSP. Temporally, NPSP (e.g., nutrients and sediments) is always flushed out of the landscape during hydrologically active periods, such as the rainy season, and especially during flooding events (Nakashima and Yamada 2005; Rozemeijer and Broers 2007). It has been recognized that during extreme events such as extreme precipitation and the subsequent flooding events, pollutant fluxes vary greatly and

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could represent the majority of annual loads of nutrients and other pollutants (Cherifi and Loudiki 1999). Spatially, pollutants produced from agricultural areas were regarded as the major source of NPSP to streams and natural waterways (Prasuhn and Sieber 2005; Leu et al. 2004). Therefore, in China, which is a large agricultural country where the land use type in many watersheds is dominated by farmland, water quality management in agricultural watersheds, especially during extreme precipitation and flooding events, is key for researching and controlling NPSP.

This study was designed to identify the impacts of flooding events on water quality and the effects of watershed management measures. Previous studies reached a consensus that diffuse sources of nutrients and rainfall distribution in catchments are the key factors controlling the nutrient variability during flooding events (Oeurng et al. 2010). However, it is not easy to quantify the relations between flooding events and nutrients because it is difficult to predict extreme precipitation and flooding events to conduct field measurements (Zhang et al. 2007, 2008). Additionally, it is often challenging for researchers to collect and monitor frequently the spatio-temporal changes of climate and water quality on the watershed scale. Therefore, the mechanisms of nutrient export during flooding events are still relatively unknown (Weiler and McDonnell 2006).

Best management practices (BMP) have been developed as a series of effective surface water quality management measures to eliminate or mitigate NPSP loads. One common type of BMP used to intercept and remove nutrient pollutants is the construction of filter strips. Generally, 5- to 10-m-wide filter strips have been simulated along river channels in different watersheds worldwide, and their NPSP removal efficiency has been assessed (Volk et al. 2009; Parajuli et al. 2008; Lee et al. 2010). In China, the current principal objective for surface water management was put forward by the National Twelfth Five-Year Plan (2011–2015, hereafter called NTFYP), which has targeted 10 % reductions in ammonium and oxynitride loads by 2015. These targets, as annual averages, could be met by constructing filter strips (Chen et al. 2014). However, the effects of filter strips during flooding events have rarely been focused on. Therefore, the dynamic processes during flooding events and the different behaviours among various flooding events have still been undefined. In this study, we aimed to assess the effects of constructing filter strips during flooding events to identify whether filter strips could meet the “10 %” objective during extreme events.

The soil and water assessment tool (SWAT) developed by the United States Department of Agriculture (USDA) has been widely employed to simulate NPSP because this physics-based model incorporates land-cover, topography,

soil characteristics, climate conditions, and land use management, and can effectively simulate the transport of water, sediments and nutrients (Lee et al. 2010; Lam et al. 2010). However, very few studies have focused on flooding events, leaving a void for us to explore the nutrient transport mechanisms during these events. Because SWAT simulation is based on the level of hydrologic response units (HRUs), it allows researchers to analyse the nutrient export in different land use areas during flooding events. Furthermore, the management module embedded in the SWAT is also helpful for assessing the effects of filter strips during flooding events.

The Zhengshui watershed, which is characterized by intensive agricultural land use and abundant precipitation, was selected as a representative area for this study. This watershed is a tributary of the Xiangjiang River, which is one of the most polluted tributaries of the Yangtze River according to the National Environmental Quality Report (China Environmental Protection Bureau 2005). The objectives of this study were to (1) simulate the NPSP export patterns in the Zhengshui watershed with the available datasets; (2) estimate the impact of flooding events on NPSP loads; and (3) assess the efficiency of constructing filter strips in mitigating pollution during flooding events.

Area and method

Study area

The Zhengshui watershed is located in the middle reach of the Yangtze River and has a catchment area of 3,470 km². The watershed has a continental subtropical monsoon climate, with an average annual precipitation and temperature of 1,350 mm and 17.2–19.4 °C, respectively. The elevation of the watershed ranges from 40 to 1,112 m. The watershed consists of hills around the edge and plains in the middle and lower reaches. The majority of the land in the watershed is for agriculture (42.38 %) or covered by forests (52.19 %) (Fig. 1). The urban areas where most of the residents live are in Hengyang county in the middle reaches and Hengyang City at the outlet of the watershed.

Construction, calibration and validation of the SWAT model

In this study, the SWAT model was used to investigate the stream flow, sediments, and pollutants in the watershed. The basic inputs for the SWAT simulation included topography and climate data, as well as land use, soil and management data. A 90-m digital elevation grid and the land use and soil map for the year 2000 were used to

Fig. 1 Location, elevation, land use and slope of the Zhengshui watershed

delineate sub-basins, which were further subdivided into HRUs (Fig. 1c–e). In addition to the forest and agricultural land, small portions of the watershed are covered by shrubs (2.03 %), villages (1.64 %), water bodies (1.16 %) and grassland (0.60 %). Climate data, including daily precipitation, temperature, solar radiation, wind speed and relative humidity during the study period at five meteorological stations (Fig. 1b), were collected to structure the environmental characteristics. Additionally, agricultural data, including the cropping patterns, application of fertilizer and livestock manure in the watershed, were used in the model to accurately simulate nutrients. The fertilizer data were calculated from the Hunan Statistical Yearbook, and the livestock manure data were calculated from previous studies (Li 2003; Yi et al. 2007). Arcview3.3 and AV-SWATX were used to construct the model. The entire watershed was divided into 32 sub-basins and 626 HRUs. The modelling period was from 2000 to 2007, with the years 2000 and 2001 being considered the warm-up period. The period from 2002 to 2004 was used for calibration, while 2005 to 2007 was the validation period. The results of calibration and validation were evaluated using the Nash–Sutcliffe coefficient of efficiency (E_{ns}) and R^2 (Behera and Panda 2006).

The calibration and validation of the SWAT model should be conducted first for stream flow and sediment and then for nutrients (Pisinaras et al. 2010). The simulations of stream flow and sediment provide parameters for the hydrological process and sediment transportation, which were the basis for nutrient simulation. In this study, the simulations of stream flow and sediment were successively calibrated and validated with daily observations from the Shenshantou hydrometric station. For simulation of ammonium N, we first constructed a monthly model based on the validated parameters of flow and sediment because there were no complete daily observations available. Then, the model was calibrated and validated with the monthly ammonium N observations from the Hengyang water quality monitoring station. This monthly model was used to estimate the daily nutrient loads because the input data (meteorological data) was in daily steps and the flow and sediment had been validated daily. To test this rationale, the daily estimated results were compared with sporadic daily ammonium N records (53 records) collected from 2002 to 2007. Additionally, to evaluate the estimation ability in different hydrological conditions, we classified the daily records into two groups (group 1 for a normal flow, and group 2 for a high flow) according to the average

daily discharge ($50 \text{ m}^3/\text{s}$) of the base flow at the outlet of the watershed. In total, 32 daily ammonium N records belonged to group 1 with the discharges lower than $50 \text{ m}^3/\text{s}$ and the other 21 records belonged to group 2 with discharges above $50 \text{ m}^3/\text{s}$. Comparisons between the estimated and observed concentrations of ammonium N in the two groups were conducted separately and inclusively.

Regarding the nitrate N and organic N, no historical observations are available because they are not parameters typically monitored for surface water quality in China. This deficiency has been shown in many previous studies in China (Zhang et al. 2009, 2013). However, as nutrient transport depends largely on the runoff and sediment, we are sure that an accurate model based on the methods described above could provide key parameters to capture the inner mechanism and processes of environment behaviours in SWAT to some level (Zhang et al. 2007; Chen et al. 2014). Additionally, because of the importance of nitrate N and organic N for surface water quality, we estimated their outputs using the validated SWAT model.

Application of the validated model

The flood duration was defined as the period from the start date of a rain event to the date when the discharge at the outlet of the watershed fell to the average daily baseflow of $50 \text{ m}^3/\text{s}$. The analysis in HRU was then conducted using the validated model to investigate the pollutant export in different land use areas during these events. Furthermore, filter strips of different widths (1–10 m) at 1-m intervals were simulated to assess their pollution mitigation effects on the surface water during flooding events. The filter strips are generally recognized as an effective way to trap portions of sediment, nutrients, pesticides and bacteria loads in surface runoff as the surface runoff passes through them (SWAT theoretical documentation). The filter strip simulation can be performed by the management module of SWAT. To do this, the filter strips, which are a zone of some type of permanent vegetation, were assumed to be an additional vegetated area planted along the river banks during the hydrological process simulation. To evaluate the overall pollutant removal effect of the filter strips in the whole watershed, the pollutant and sediment reduction ratios at the outlet of the watershed were calculated using the following equation:

$$R = 1 - \frac{L_a}{L_b},$$

where R is the reduction ratio, and L_a and L_b are the pollutant or sediment loads at the outlet of the watershed before and after constructing the filter strips, respectively.

Results and discussion

Simulation results of SWAT analysis in the Zhengshui watershed

The results of daily and monthly calibration as well as validation of the SWAT model are shown in Figs. 2 and 3a. It is generally considered that E_{ns} is very good when it is larger than 0.75, satisfactory when it is between 0.36 and 0.75, and unsatisfactory when it is lower than 0.36 (Krause et al. 2005). The SWAT model generally requires that E_{ns} be larger than 0.5 and that R^2 be larger than 0.6 (Wang and Melesse 2006; Oeurng et al. 2011). As shown in Figs. 2 and 3a, all E_{ns} and R^2 values were satisfactory for conducting further analysis. Additionally, similar temporal variability was observed in the flow, sediment, and ammonium loads, with peaks appearing during flooding seasons (from May to August), while low values occurred during the dry seasons (winter and spring). Overall, these patterns supported the estimation of daily loads using the validated model.

Figure 3b shows the strong relations between the observed and simulated data during both flow conditions. Among 53 samples, most of the estimated ammonium N concentrations were distributed near the 1:1 line with a high R^2 of 0.73. Meanwhile, satisfactory results in both normal flow and high flow periods were also observed, with R^2 values of 0.69 and 0.60, respectively. These results substantiated the ability of the validated SWAT model to estimate daily concentrations of ammonium N. Thus, it was reasonable for us to further analyse the pollutant behaviours and effects of filter strips during flooding events based on the validated model. Additionally, these results also suggested an alternate method of performing SWAT simulations with limited data availability.

Data deficiency is the main limitation for model development and analyses, especially in China (Shen et al. 2012). The ability of SWAT to simulate other daily NPSPs (including nitrate N and organic N) could not be verified because of the lack of observations. Fortunately, as a type of physical process-based model, the ability of SWAT to estimate or predict nutrients under data deficiencies has been partly recognized in previous studies (Niraula et al. 2012; Glavan et al. 2011; Chu et al. 2004). Meanwhile, it was believed that the application of this model under data limitations could still facilitate the evaluation of management strategies if appropriately parameterized (Panagopoulos et al. 2011). Considering the satisfactory estimation of the SWAT model in this study, the results of nitrate N and organic N were estimated to assess the impacts of flooding events on pollutant loads and further to interpret the efficiency of filter strips.

Fig. 2 Simulation results for daily stream flow and sediment

Identification of flooding events

Two sample flooding events were selected based on the precipitation and discharge. The first occurred from 17 July to 30 August, 2002 (hereafter called event_1), and was characterized by its long duration of rainfall and the largest daily flow in the past 60 years. The precipitation in this event lasted from 17 July to 21 August, including 3 peaks larger than 50 mm (Fig. 4). The total rainfall was 507 mm and contributed 26.1 % of the annual precipitation in 2002. The continuous precipitation resulted in the large discharge of the stream. The highest flow ($1,270 \text{ m}^3/\text{s}$) was recorded on 19 August and was accompanied by the largest precipitation (95 mm) in 2002.

The other event took place from 22 August to 31 August, 2007 (hereafter called event_2). This event was selected because it started with the largest daily precipitation in the past 60 years, on 22 August. The 132.4 mm of precipitation on that day supplied 10.5 % of the total precipitation in 2007. During event_2, the total precipitation of 191 mm made up 15.2 % of the annual precipitation. Meanwhile, the average daily flow reached $158.8 \text{ m}^3/\text{s}$, with a peak discharge of $320 \text{ m}^3/\text{s}$ on 23 August.

During flooding events, nutrient loads in channels may increase greatly as new water sources are added, which can further mobilize large amounts of nutrients from many different sources into the catchment (Buda and DeWalle 2009). In this study, these two flooding events and two typical 1-day extreme events that occurred on 19 August 2002, and 22 August 2007, were analysed to evaluate their impacts on surface water quality.

Impacts of flooding events on pollutant yields at the HRUs

The HRU output in the SWAT model provided the simulated yields of sediment, nitrate N and organic N for each HRU. As ammonium N data were not provided by the HRU module, we took nitrate N and organic N as examples for assessing the impacts of flooding events on nutrient yields. Additionally, we focused more on the relative change ratio rather than the absolute value, because these two nutrients were estimated by the model. Average sediment and nutrient yields per km^2 per day in 2002 and 2007 for different land use types are shown in Table 1. It was observed that the agricultural land, including dry land and

Fig. 3 **a** Simulation results for monthly ammonium nitrogen, and **b** the comparison between daily estimates and observed concentration of ammonium nitrogen based on the sporadic daily records from 2002 to 2007

Fig. 4 Records of flow at the outlet of the Zhengshui watershed and average precipitation in the whole watershed during two flooding events

Table 1 Average sediment and nutrient loss for different land use types in 2002 and 2007

Land use types	Sediment (t/km ² /day)	Organic N (kg/km ² /day)	Nitrate N (kg/km ² /day)
2002			
Agricultural field	11.40	45.67	224.36
Forest	0.01	0.05	28.61
Grassland	0.03	0.16	17.72
Shrub	0.04	0.21	17.72
Wetland	0.02	0.13	18.26
Average in 2002	4.84	19.41	110.68
2007			
Agricultural field	4.00	15.75	165.89
Forest	0.00	0.02	15.95
Grassland	0.01	0.07	9.69
Shrub	0.02	0.11	9.72
Wetland	0.01	0.05	10.48
Average in 2007	1.70	6.70	79.00

paddy fields, showed the highest yields of NPSP in both years. Yields for sediment, organic N and nitrate N were all dozens of times larger in agricultural areas than yields from other land uses, especially as compared to sediment and organic N from forests and nitrate N from grassland. Fertilizer and manure use in agricultural areas has been recognized as the most important source of NPSP in the world (Rozemeijer and Broers 2007). In China, fertilizer and manure are generally applied directly on the surface. Accordingly, large amounts of soluble nutrients and sediment can be flushed away from the surface of the land and eventually enter into river channels during precipitation events. Conversely, fewer sediments and nutrients were lost from non-agricultural areas because they have good ground cover and fewer sources of pollutants.

HRU analysis during two flooding events was conducted to identify changes in sediment and nutrient yields. The simulation results showed that the impacts of flooding events were significant (Table 2), especially for event_2. Event_1 contributed 40.4, 42.2 and 18.4 % of the sediment, organic N and nitrate N yield of annual loads in 2002, respectively. During event_2, 55.1, 56.4 and 19.8 % of the sediment, organic N and nitrate N load in 2007, respectively, were generated in only 10 days. Moreover, 1-day extreme precipitation was shown to be a more severe threat to the water environment. For example, the yields of sediment, organic N and nitrate N were 10.9, 10.3 and 3.5 % of the annual load, respectively, on 19 August 2002, while these ratios were 38.4, 39.1 and 8.8 % on 22 August 2007. These results show that the majority of annual pollutant loads can export into the surface water during extreme events, highlighting the

Table 2 The simulation results of sediment and nutrient yields for different land use types during extreme events and the ratios of these yields to average annual yield shown in Table 1

Land use types	Sediment (t/km ² /day)	Ratios	Organic N (kg/km ² /day)	Ratios	Nitrate N (kg/km ² /day)	Ratios
Largest flow on Aug. 19th, 2002						
Agricultural field	451.84	39.63	1,709.13	37.42	2,864.43	12.77
Forest	0.84	107.81	5.05	108.48	337.78	11.81
Grassland	1.64	62.08	10.32	65.74	221.05	12.47
Shrub	2.48	67.05	14.48	67.48	221.52	12.50
Wetland	0.38	23.44	3.01	23.97	160.85	8.81
Flood event from Jul. 17th to Aug. 30th, 2002						
Agricultural field	36.57	3.21	153.00	3.35	329.67	1.47
Forest	0.03	4.32	0.20	4.35	40.35	1.41
Grassland	0.08	2.93	0.47	3.00	19.75	1.11
Shrub	0.12	3.14	0.68	3.18	21.09	1.19
Wetland	0.03	2.09	0.28	2.25	12.59	0.69
Average in event	15.71	3.24	65.75	3.39	163.31	1.48
Extreme precipitation event on Aug. 22nd, 2007						
Agricultural field	559.35	139.84	2,249.29	142.81	5,332.24	32.14
Forest	0.72	253.36	3.90	255.40	535.76	33.60
Grassland	2.97	205.04	13.94	197.62	177.27	18.28
Shrub	3.76	180.84	19.64	177.14	163.87	16.87
Wetland	0.95	130.36	6.94	128.99	122.73	11.71
Flood event from Aug. 22nd to 31st, 2007						
Agricultural field	73.12	18.28	294.77	18.72	1,118.34	6.74
Forest	0.07	23.81	0.37	18.65	88.45	5.55
Grassland	0.33	32.52	1.54	21.97	28.43	2.93
Shrub	0.45	22.32	2.37	21.55	28.99	2.98
Wetland	0.14	13.88	1.04	20.83	23.52	2.24
Average in event	31.10	18.30	125.38	18.72	521.16	6.60

necessity and significance of the study of water quality management during flooding events.

The ratios of yields from flooding events (storm yield) to the average annual yield were then calculated. Interestingly, higher ratios were found in non-agricultural areas, especially in forests (Table 2). The higher ratio may be attributed to the steeper terrain in the forest, which causes a larger portion of rapid surface runoff to enter the channel during storm rainfall events (Fig. 1c) (Zhang et al. 2008). In comparison, agricultural land is generally located in the medium or lower reaches of the watershed and has a flatter terrain (Fig. 1c). Despite the differences in ratios, the agricultural area is still the main source of NPSP due to the maximum loads during both normal and flooding periods. During flooding events, the much larger daily nutrient and sediment export, especially from agricultural areas, would cause the surface water quality to deteriorate. On the other hand, agricultural activities would also suffer from the severe soil erosion, fertility loss, and water logging.

It can be observed that the ratios of sediment behaved similarly to those of organic N from different land uses (the first two ratio columns in Table 2), while significant

differences were seen for nitrate N (the third ratio column in Table 2). These results imply a close relationship between the export of sediment and organic N. Many previous studies have demonstrated pollution export during flooding events and regarded hydrological processes as the main controlling factors (Zhang et al. 2007, 2008; Dai and Lu 2010). It is widely agreed that storm rainfall usually causes a rapid surface flow, which dissolves large amounts of nitrate N. Meanwhile, the flow also involves a large quantity of sediments, to which organic matter from the surface of the land adheres. Therefore, severe soil erosion and nutrient loss could be observed concurrently during flooding events, which would seriously threaten both agricultural production and the ecological environment (Coppus and Imeson 2002).

Comparison of two flooding events and their differences in NPSP loads

There were some consistent findings between the two events. For example, agricultural land was the main source

(more than 90 %) of sediment and nutrients. Additionally, wetlands had the smallest ratios of storm yield to average annual yield during both events. However, there were also clear differences between the two events. Event_1 was a long-term flood that lasted 45 days with continuous rainfall, while event_2 was triggered by extremely intense precipitation and lasted only 10 days. These distinct characteristics caused different impacts on the surface water quality.

In event_1, the total discharge was nearly 900 million m³. The estimated total average daily yields of sediment, organic N and nitrate N were 15.71 t/km²/day, 65.75 and 163.31 kg/km²/day, respectively. In event_2, the daily loads of sediment and organic N were 30.10 t/km²/day and 125.38 kg/km²/day, twice the daily loads seen in event_1; for nitrate N, the load was 521.16 kg/km²/day: more than 3 times the load in event_1. These huge differences might be ascribed to the differences in antecedent rainfall conditions, hydrological processes, rainfall features, etc. (Zhang et al. 2010b, 2013). The year 2007 was a dry year, and there was no rainfall for more than 1 month before event_2. Thus, a large amount of NPSP had accumulated on the land surface. The lack of precipitation and low flow conditions before the flooding events also made nutrient mobilization from the soil horizon difficult, thereby providing an abundant source of nutrients during the flooding events. When the extreme rainfall occurred on 22 August 2007, it induced a strong flushing of nutrients and sediments from the land surface into the river system. This type of “first flush” after a long dry period would lead to serious impacts on river nutrient loads (Ribarova et al. 2008), and similar phenomena have been observed in many studies conducted in different watersheds (Oeurng et al. 2010; Rusjan et al. 2008). In contrast, 2002 was a wet year. The antecedent monthly rainfall of event_1 was approximately 150 mm, which resulted in a wet antecedent condition and fewer nutrient sources. Therefore, the differences in antecedent conditions and consequently the available sources before the floods resulted in the huge differences in NPSP loads between the two flooding events.

Effects of filter strips on pollution mitigation

In this study, constructing a filter strip was considered as a management measure for mitigating sediment and pollutants. Figure 5 indicates a higher reduction ratio of NPSP with wider filter strips. The reduction efficiency for ammonium N (typically >50 %) was greater than that for sediment, nitrate N, and organic N during both events. The simulation results with 10-m filter strips led to significant reductions in the sediment, nitrate N, organic N, and ammonium N loads (event_1: 37.8, 55.3, 28.9, and 68.8 %, respectively; event_2: 53.4, 45.4, 45.9, and 71.2 %, respectively). The construction of filter strips showed a

Fig. 5 Effects of filter strips with different widths on pollutants

significant trapping of pollutants and sediments. Additionally, the 10 % reduction goal could be achieved with only 1-m-wide filter strips in the entire watershed (Fig. 5).

However, NPSP load reduction is not the only goal for clear water; satisfactory concentrations are also a consideration. According to the Environmental Quality Standards for Surface Water (GB3838-2002) in China, the standard level III for ammonium N is 1 mg/l, which is the highest acceptable level for basic living needs (there are no standard levels for sediment, nitrate N or organic N). With a 10-m-wide filter strip, the simulated concentration of ammonium N was 0.98 mg/l in event_1, and 1.43 mg/l in event_2. Thus, the concentration of ammonium N in event_1 would be below the acceptable limit, suggesting the utility of filter strips for dealing with potential pollution during flooding events to some degree. However, in event_2, the concentrations are above the acceptable level and cannot satisfy the basic living needs for local residents. It was found that the width of filter strip would need to be 19 m to meet the concentration requirement during event_2 (leading to an ammonium N concentration of 0.97 mg/l).

Some implications and limitations of the study

Our findings have substantiated the proposition that a filter strip is indeed an efficient way to mitigate the pollutant load in surface water. High ratios of pollutant loads could be intercepted by these permanent vegetation zones during flooding events. Considering the significant effects indicated by many previous studies (Betrie et al. 2011; Chen et al. 2014; Lee et al. 2010; Sahu and Gu 2009) that focused on annual or monthly loads, it is easily concluded that filter strips can improve the aquatic environment in different scenarios. However, the higher loads of NPSP, larger discharge and rapider flow during flooding periods will indubitably put larger requirement on the interception. Thus, in reality, wider filter strips are required to clear surface water during flooding events than in normal periods. Moreover, filter strips can indeed trap pollutants but do not control the sources of pollution because the sources are not actually removed. Flooding events account for approximately 20 % of the annual water and soil losses on average and consequently pose a severe threat to both the water environment and crop production. As such, more attention should be paid to the control of pollution sources during flooding events.

Generally, changes in land use and agricultural activities also influence water quality and quantity (Volk et al. 2009). By comparing the pollutant outputs from different land use areas, it was found that pollution from agricultural areas was unequivocally the most significant among all land use types during both flooding events and annual periods. Therefore, the results highlight that returning agricultural areas to land uses that contribute fewer pollutants (i.e., shrub, wetland, etc.) would reduce the pollutant source and is an alternative way to clear surface water. A previous study found that transforming 20 % of the forest to agricultural land would increase nitrate loads in the Kosynthos River watershed by nearly 100 % (Pisinaras et al. 2010). Meanwhile, significant reductions in nutrients loads (more than 11 %) in surface water have been observed after changing 7–10 % of agricultural fields in a watershed to forest or grassland (Volk et al. 2009). Additionally, these studies also stressed that the discharge would be significantly reduced with contracted agricultural areas, implying another method of water and soil conservation. Of course, other scientific agriculture measures such as fertilizer management and eco-agriculture have also been recognized as effective ways to mitigate NPSP from agricultural areas (Munodawafa 2007; Volk et al. 2009).

During the process of selecting suitable water treatment methods, other factors such as economic cost and the potential social impacts should be taken into account. For example, returning farm land into forest and grassland or reducing fertilizer application might impact farmers'

incomes, or even national food security, suggesting that it is hard to realize in the short-term. In comparison, constructing filter strips impacts farmers less and would be a relatively easy solution. However, filter strips just intercept the pollutants temporally and have a low cost efficiency because wider strips are required during flooding events than in normal periods (Lee et al. 2010; Chen et al. 2014). Thus, filter strips are palliative for mitigating the deterioration of water quality, while land use changes and improvements in agricultural technology will be more significant and critical long-term solutions for the control of pollution sources.

The study does have some limitations. First, although the simulated NPSP reductions from the model were comparable to the values available in the literature (10–60 %), overestimations were expected since the filter strip algorithm uses a uniform efficiency for all NPSP forms and does not consider or represent well some potential hydrological and physical processes in the field (including overland flow convergences and bypasses through ditches) (Verstraeten et al. 2006; White and Arnold 2009). Second, the monthly water quality dataset did show some effect on the model calibration and validation (verified by the strong link between the sporadic daily measures and estimated concentrations in different scenarios, Fig. 3b). However, more detailed datasets during flooding events would be beneficial to accurately describe NPSP behaviours. Finally, higher resolution observations (e.g., hourly) on climate, hydrology and hydrochemistry should be conducted to extend and expand our NPSP knowledge during extreme climate events.

Conclusion

In this study, the SWAT model was successfully applied to an agricultural watershed to explore NPSP behaviours and the effect of filter strips during flooding events. We investigated NPSP yields from different land use areas and compared their loads during different periods of flow using the validated SWAT model. We have shown that the estimated results based on the available datasets could reflect real environmental conditions to some degree. The results indicate a dramatic deterioration of surface water quality during flooding events, especially during extreme precipitation events. The yield of sediments and nutrients in flooding events were so large that their ratios to average annual yield were disproportionate to that of precipitation and runoff. Overall, these findings strongly substantiated that the severe soil erosion and nutrient loss from agricultural lands during flooding events has become another environmental problem, besides its potential feedback stress on agricultural production.

In addition, filter strips were shown to reduce NPSP, especially ammonium N, followed by nitrate N, sediment, and organic N. Although the 10 % N load reduction set by the NTFYP could be achieved with 10-m filter strips, the concentrations required for basic living were still exceeded. Thus, it will be wiser for decision-makers to consider both the load and concentration for water quality management. In addition, considering the large amount of water and soil erosion, more efficient countermeasures, such as land use changes and agricultural technology improvements, should also be taken to reduce the pollutant sources from agricultural land.

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