Journal of Hydrology 552 (2017) 105–120

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Evaluation of wetland implementation strategies on phosphorus reduction at a watershed scale

Mohammad Abouali [a], A. Pouyan Nejadhashemi [a,*], Fariborz Daneshvar [a], Umesh Adhikari [a], Matthew R. Herman [a], Timothy J. Calappi [b], Bridget G. Rohn [b]

[a] Department of Biosystems and Agricultural Engineering, Michigan State University, East Lansing, MI 48824, USA
[b] U.S. Army Corps of Engineers, 477 Michigan Ave., Detroit, MI 48226, USA

ARTICLE INFO

Article history:
Received 6 February 2017
Received in revised form 6 June 2017
Accepted 22 June 2017
Available online 24 June 2017
This manuscript was handled by Geoff Syme, Editor-in-Chief, with the assistance of Saeid Eslamian, Associate Editor

Keywords:
Targeting method
SWAT
Phosphorus
SUSTAIN
Random implementation

ABSTRACT

Excessive nutrient use in agricultural practices is a major cause of water quality degradation around the world, which results in eutrophication of the freshwater systems. Among the nutrients, phosphorus enrichment has recently drawn considerable attention due to major environmental issues such as Lake Erie and Chesapeake Bay eutrophication. One approach for mitigating the impacts of excessive nutrients on water resources is the implementation of wetlands. However, proper site selection for wetland implementation is the key for effective water quality management at the watershed scale, which is the goal of this study. In this regard, three conventional and two pseudo-random targeting methods were considered. A watershed model called the Soil and Water Assessment Tool (SWAT) was coupled with another model called System for Urban Stormwater Treatment and Analysis IntegratioN (SUSTAIN) to simulate the impacts of wetland implementation scenarios in the Saginaw River watershed, located in Michigan. The inter-group similarities of the targeting strategies were investigated and it was shown that the level of similarity increases as the target area increases (0.54–0.86). In general, the conventional targeting method based on phosphorus load generated per unit area at the subwatershed scale had the highest average reduction among all the scenarios (44.46 t/year). However, when considering the total area of implemented wetlands, the conventional method based on long-term impacts of wetland implementation showed the highest amount of phosphorus reduction (36.44 t/year).

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

Nutrient enrichment from intensive agricultural practices is considered the major cause of water quality degradation worldwide (Withers et al., 2014). Excessive nutrients have resulted in eutrophication of the freshwater and coastal ecosystems, harmful algal blooms, and alteration in aquatic food chains (Duan et al., 2012). Among the nutrients, phosphorus enrichment of water bodies has drawn considerable attention, as phosphorus is often the major growth-limiting factor in many terrestrial and aquatic ecosystems (Reddy et al., 1999). Studies have shown that minimizing phosphorus loading is critical for controlling lakes eutrophication, as controlling nitrogen alone has proven ineffective (Schindler et al., 2008; Wang and Wang, 2009). In this context, wetlands play an important role in mitigating phosphorus pollution as phosphorus sinks through non-saturating removal processes (Knight et al., 2003; Vymazal, 2007).

Wetlands are transitional lands between terrestrial and aquatic systems that provide a number of ecological functions and services including flood attenuation, pollutant reduction, carbon storage, groundwater recharge, and wildlife refuge (Zedler and Kercher, 2005; Yang et al., 2008; Kadlec and Wallace, 2008). Phosphorus removal in wetlands primarily occurs through peat accretion, adsorption, precipitation, and plant and microbial uptake (Vymazal, 2007). Among these processes, peat accretion, which constitute about 10–20% of the plant detrital, is a sustainable long-term phosphorus removal mechanism (Kadlec and Wallace, 2008). Thus, the phosphorus retention capacities of wetlands may play a key role in improving downstream water quality (Reddy et al., 1999).

Despite their valuable ecosystem functions and services, wetlands are vulnerable environmental systems and a substantial area of wetlands have been lost in the past century (Martinez-Martinez et al., 2014). At the global scale, it is believed that more than half of the original wetlands have been lost to human development and

* Corresponding author at: Department of Biosystems & Agricultural Engineering, Farrall Agriculture Engineering Hall, 524 S. Shaw Lane, Room 225, Michigan State University, East Lansing, MI 48824, USA.
E-mail address: pouyan@msu.edu (A.P. Nejadhashemi).

http://dx.doi.org/10.1016/j.jhydrol.2017.06.038
0022-1694/© 2017 Elsevier B.V. All rights reserved.

drainage projects (Mitsch, 2005), but the actual loss could be as high as 87% (Davidson, 2014). In the US, over 50% of original wetland areas were lost between 1780 and 1980 (Dahl, 1990). However, in recent years, there is a growing interest in restoring wetland functions through wetland creation and restoration (Dahl, 2000; Verhoeven et al., 2006).

Although wetland creation and restoration have garnered considerable interest, there is still a lack of knowledge on how to integrate wetlands into the landscape to achieve the best watershed scale management plan (Daneshvar et al., 2017a). As such, restored wetlands receive highly variable and unregulated inflows, making it harder to quantify their water quality improvement capabilities and incorporate the performance parameters in the design criteria (Jordan et al., 2003). Van der Valk and Jolly (1992) noted that for an effective wetland restoration at the watershed scale, development of site selection criteria is important, as wetland functions could be greatly enhanced when their spatial distribution within the landscape is considered (Moreno-Mateos and Comín, 2010). Research from the past two decades has also emphasized the need for a watershed scale approach to siting and designing wetlands in order to optimize performance and meet water quality goals (Goldman and Needelman, 2015). However, identifying potential sites that maximize the ecosystem services at the watershed scale still remain the greatest challenge in wetland creation and restoration (Babbar-Sebens et al., 2013; Zhang and Song, 2014), and is frequently overlooked (McAllister et al., 2000).

Models, such as the Soil and Water Assessment Tool (SWAT), are often used evaluate ecosystems. This is especially true for wetlands (Martinez-Martinez et al., 2014, 2015; Walters and Babbar-Sebens, 2016; Daneshvar et al., 2017a). However, SWAT is not limited to just wetland modeling, but can be used for a wide variety of ecological engineering and ecohydrological applications. For example, SWAT has been used to evaluate the implementation of best management practices (BMPs) within watersheds (Einheuser et al., 2012; Giri and Nejadhashemi, 2014; Sowa et al., 2016; Hall et al., 2017). BMPs are often implemented to improve ecosystem conditions within a region, this was the case for the study by Herman et al. (2015), in which BMP landscapes were evaluated with the goal of improving stream health while minimizing the implementation cost of the selected BMPs. SWAT can also be used to evaluate the implementation of bioenergy crops (Love and Nejadhashemi, 2011a; Einheuser et al., 2013; Herman et al., 2016; Giri et al., 2016). This was accomplished by developing unique bioenergy management rotations that could be applied to different regions within watersheds, which allowed for the accommodation of local practices within the model making it more realistic (Love and Nejadhashemi, 2011b). In regards to ecohydrological applications, SWAT has been used to evaluate the impacts of hydrological events such as droughts (Esfahanian et al., 2016, 2017) and floods (Ahiablame and Shakya, 2016; Lee et al., 2017). Furthermore SWAT has been used to analyze the impacts of climate change on many aspects of aquatic ecosystems, including the demand and availability of water resources (Woznicki et al., 2015; Adhikari and Nejadhashemi, 2016; Adhikari et al., 2016) and the conditions within aquatic ecosystems (Woznicki et al., 2016; Abouali et al., 2016; Daneshvar et al., 2017b).

In the past, few attempts have been made to incorporate spatial distribution within landscapes in wetland restoration. These studies include quantifying the marginal decrease in downstream flooding per restoration dollar spent (McAllister et al., 2000), GIS-based land score system to optimize nutrient abatement (Palmeri and Trepel, 2002), ranking approach to estimate the trade-off between competing restoration objectives (De Laporte et al., 2010); linking hydrological model with optimization algorithm to maximize peak flow reduction (Babbar-Sebens et al., 2013); understanding the importance of stream order for placement of wetlands to maximize peak flow reduction (Martinez-Martinez et al., 2014); and comparison of economic and environmental impacts to optimize sediment reduction (Martinez-Martinez et al., 2015). However, these studies are very limited regarding the identification of site selection/targeting techniques for wetland implementation, especially for development of watershed scale management plans for phosphorus mitigation, which is the goal of this study. In order to address this goal, the following objectives were investigated: 1) evaluating similarity between random and targeted wetland implementation strategies and 2) assessing the impacts of wetland sizes and targeting methods on watershed scale phosphorus reduction.

2. Materials and methods

2.1. Study area

The Saginaw River Watershed, which is located in Michigan, was selected for this study due to severe environmental degradation. This watershed was designated by the US Environmental Protection Agency as an area of concern (US EPA, 2015). The Saginaw River Watershed is the largest watershed in the state with the total area of 16,120 km^2, draining into Lake Huron (Fig. 1). Landuse in the Saginaw River Watershed is dominated by agricultural lands (36.2%), followed by forest (24.8%), water (14.3%), pasturelands (12.4%), and developed areas (12.3%). According to a study led by the Michigan Department of Environmental Quality (MDEQ), about 26% of the watershed (4292 km^2) is suitable for wetland restoration (MDEQ, 2016). As presented in Fig. 1, these areas are classified into different restoration potentials (highest, high, and moderate); however, only the areas with the highest potential were considered for the wetland restoration. This area is generally characterized by the existence of hydric soils and the presence of wetlands before European settlement in the region. The area with the highest potential for wetland restoration accounts for 6.5% (1056 km^2) of the study area.

2.2. Overall modeling process

Fig. 2 provides a schematic view of the modeling process. In order to understand the impacts of wetland restoration scenarios on phosphorus reduction, a watershed model was setup to established baseline sediment and phosphorus loads. Therefore, a watershed model called the SWAT was calibrated/validated using observed streamflow and sediment and phosphorus loads. However, due to limitations of the SWAT model in simulating wetlands (Martinez-Martinez et al., 2015), the SWAT outputs at the subwatershed scale (e.g., runoff, nutrient and sediment loads) along with temperature and precipitation records are converted to an appropriate format and then incorporated into another model called System for Urban Stormwater Treatment and Analysis IntegrationN (SUSTAIN) to simulate the impacts of wetland implementation at the subwatershed scale. The output of SUSTAIN is later converted to a format readable by SWAT and is provided as a point source at the outlet of the subwatersheds that are selected for wetland implementation. Next, the precipitation is forced to zero for that subwatershed to eliminate double counting the runoff and pollution loads. Such coupling of these two models allows incorporating the effect of wetlands into watershed modeling. Multiple different compositions of subwatersheds were selected using both conventional and pseudo-random targeting methods for wetland implementation. For the conventional methods, the wetland implementation scenarios were ranked based on: 1) the total phosphorus load at the subwatershed scale; 2) phosphorus

Download English Version:

https://daneshyari.com/en/article/5771148

Download Persian Version:

https://daneshyari.com/article/5771148

Daneshyari.com