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Research article

Examining water quality effects of riparian wetland loss and restoration scenarios in a southern ontario watershed

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ABSTRACT

Wetland conservation has two important tasks: The first is to halt wetland loss and the second is to conduct wetland restoration. In order to facilitate these tasks, it is important to understand the environmental degradation from wetland loss and the environmental benefits from wetland restoration. The purpose of the study is to develop SWAT based wetland modelling to examine water quality effects of riparian wetland loss and restoration scenarios in the 323-km^2 Black River watershed in southern Ontario, Canada. The SWAT based wetland modelling was set up, calibrated and validated to fit into watershed conditions. The modelling was then applied to evaluate various scenarios of wetland loss from existing 7590 ha of riparian wetlands (baseline scenario) to 100% loss, and wetland restoration up to the year 1800 condition with 11,237 ha of riparian wetlands (100% restoration). The modelling was further applied to examine 100% riparian wetland loss and restoration in three subareas of the watershed to understand spatial pattern of water quality effects. Modelling results show that in comparing to baseline condition, the sediment, total nitrogen (TN), and total phosphorus (TP) loadings increase by 251.0%, 260.5%, and 890.9% respectively for 100% riparian wetland loss, and decrease by 34.5%, 28.3%, and 37.0% respectively for 100% riparian wetland restoration. Modelling results also show that as riparian wetland loss increases, the corresponding environmental degradation worsens at accelerated rates. In contrast, as riparian wetland restoration increases, the environmental benefits improve but at decelerated rates. Particularly, the water quality effects of riparian wetland loss or restoration show considerable spatial variations. The watershed wetland modelling contributes to inform decisions on riparian wetland conservation or restoration at different rates. The results further demonstrate the importance of targeting priority areas for stopping riparian wetland loss and initiating riparian wetland restoration based on scientific understanding of watershed wetland effects.

1. Introduction

Wetlands provide important environmental and ecological functions including flow attenuation, sediment and nutrient retention, and wildlife habitats. However, majority of the wetlands in settled areas are lost due to agricultural activities and urban expansion (Douglas and Johnson, 1994; Dugan, 1992; Johnson, 2013). The value of wetlands has been gradually recognized and various wetland conservation initiatives have been established (Junk et al., 2013). Wetland conservation has two important tasks: The first is to halt wetland loss and the second is to conduct wetland restoration (Bendor, 1999; Schulte-Hostedde et al., 2007). In order to facilitate these tasks, it is important to understand the environmental degradation from wetland loss and furthermore, the environmental benefits from wetland restoration.

Watershed based hydrologic modelling is increasingly being developed and applied to examine water quantity and quality effects of wetlands and agricultural management practices (Fossey et al., 2015; Mahdizadeh et al., 2015; Valipour, 2015). One direction of the wetland modelling at watershed scale is to examine the hydrologic effects of isolated wetlands which are typically surrounded by upland (Leibowitz, 2003; Leibowitz and Nadeau, 2003; Leibowitz and Vining, 2003; Mushet et al., 2015). Wang et al. (2008) developed a hydrologic equivalent wetland (HEW) approach in the Soil and Water Assessment Tool (SWAT) to simulate wetland effects in a Minnesota watershed with extensive isolated wetland

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presence and demonstrated that wetlands have significant flow attenuation effects. In contrast, wetland modelling in another Minnesota watershed showed drastic increase in peak discharge and sediment and nutrient loadings from wetland loss in the watershed (Wang et al., 2010). Similarly, Yang et al. (2010) applied HEW based SWAT modelling to characterize potholes in a Canadian prairie watershed which are mostly isolated wetlands and showed that wetland restoration can generate considerable environmental benefits in terms of sediment and nutrient reductions. Furthermore, wetland modelling has been extended to examine the design of wetland restoration scenarios. Martinez–Martinez et al. (2014) applied wetland modelling to a Michigan watershed and revealed that increasing wetland area had greater flow attenuation effects than increasing wetland depth. Martinez–Martinez et al. (2015) developed the coupling of the SWAT and a field scale model SUSTAIN (Alvi et al., 2009) to examine various wetland restoration scenarios for sediment reduction in another Michigan watershed. Modelling results showed that wetland clusters near 150–200 stream km from the outlet had best performance in comparing to other locations and wetlands near the 4th order streams performed better at the watershed scale. These studies demonstrated the importance of wetland modelling in characterizing wetland processes, quantifying magnitudes of wetland hydrologic effects, and considering spatial variations of wetland effects when designing restoration scenarios.

Another direction of the wetland modelling at watershed scale is to examine the hydrologic effects of riparian wetlands which have interactions with stream channels. Arnold et al. (2001) modified the SWAT to allow ponded water interactions with soil profile and shallow groundwater and applied the model to examine water budget variations of a large riparian wetland complex in Texas. The results showed that during 60% of the 14-year simulation period, water budget in the wetlands should be maintained at 85% in order to perform its functions. Fossey et al. (2015) integrated both isolated and riparian wetland modules to a distributed hydrologic model HYDROTEL to examine flow attenuation effects of wetlands in a Quebec watershed in Canada and satisfactory model performance has been achieved. Particularly, Liu et al. (2008) developed a riparian wetland module in the SWAT to estimate runoff and sediment generated from upland drainage area and routed through riparian wetlands, and simulate the lateral exchange processes between riparian wetlands and their hydraulically connected streams. Modelling application to a southern Ontario watershed in Canada showed that the integration of the riparian wetland module in the SWAT improved model performance and riparian wetlands have considerable flow attenuation and sediment retention effects when comparing the scenarios without riparian wetlands. However, these studies did not simulate nutrient processes in the model, and therefore did not examine the effects of riparian wetland loss and restoration on nutrients yield at a watershed scale.

The purpose of this paper is to extend the SWAT riparian wetland module developed in Liu et al. (2008) to examine both sediment and nutrient retention effects of riparian wetland scenarios in the Black River watershed in southern Ontario of Canada. In addition, the updated SWAT modelling includes isolated wetlands in simulation to account for the effect of non-effective drainage areas in the watershed. The modelling is calibrated and validated based on available data collected from various sources. Extended from those studies that examined restoration of isolated wetlands (Wang et al., 2010; Yang et al., 2010; Martinez–Martinez et al., 2014), this study focuses on examining water quality effects of riparian wetland loss and restoration at a watershed scale. Nineteen riparian wetland loss and restoration scenarios are developed including the scenario under existing condition to account for different loss and restoration ratios and their spatial locations in the watershed. These scenarios are then simulated using the validated SWAT riparian wetland modelling. The modelling contributes to inform decisions on riparian wetland conservation or restoration at different rates subject to water quality objectives. The modelling results further support decisions on potential riparian wetland conservation or restoration in priority areas in order to mitigate adverse water quality impacts to the receiving water body.

2. Study area

The Black River flows into Lake Simcoe in southern Ontario, Canada (Fig. 1) with a drainage area of 323 km^2. Climate data from 1987 to 2008 show that the yearly average precipitation in the Black River watershed is 832 mm with a maximum of 1065 mm and a minimum of 643 mm and the yearly average temperature is 7.8 °C with a maximum of 9.5 °C and a minimum of 6.3 °C. The terrain in the watershed is relatively flat, 43% of the area has slopes less than 2%, 32% of the area has slopes between 2 to 5%, and 17% of the area has slopes between 5% and 10%. Agriculture including row crop, sod, hay, and pasture is the dominant landuse, occupies 44% of the watershed area. Other landuse types include 24% wetland, 15% forest, 10% urban and rural development areas, and 7% of managed woodland and meadow areas. According to Ontario soil classification, the main soil types in the watershed are BRIGHTON, MUCK, SARGENT, and GRANBY corresponding to Podzol, Histosol, Gleysol, and Podzol groups of Food and Agriculture Organization (2015) soil classification, and occupying 18.4%, 18.1%, 15.9%, and 10.8% respectively.

Based on 2008 data, the Black River watershed has 7721 ha of wetlands, of which 7590 ha or 98% of wetlands are riparian. Based on historical data, the watershed had 11,237 ha of riparian wetlands in the year 1800 (Fig. 1). The pattern indicates a 3647 ha loss of riparian wetlands, which is about half of the existing wetlands. Wetland loss coupled with agricultural development and urban expansion has considerably increased sediment and nutrient inputs to Lake Simcoe (Spaling, 1995). In recent decades, Lake Simcoe has been gradually experiencing eutrophication problems related to excess phosphorus loadings (Winter et al., 2011). As one of the key ecological components in the Basin, additional wetland loss will increase the likelihood of aggravating the eutrophication problem. On the other hand, wetland restoration offers the opportunity to combat the excess phosphorus loading problem.

3. Methods

This section introduces the wetland module, watershed-wetland modelling setup, calibration and validation, wetland scenario development, and model applications for examining wetland effects.

3.1. The wetland module

In 2008, Liu et al. developed a riparian wetland module in the SWAT to examine flow and sediment effects of riparian wetlands for the 53 km^2 Upper Canagagigue Creek watershed in southern Ontario. This study extends the SWAT-based riparian wetland module to simulate nutrient balance and transport for examining nutrient effects of riparian wetlands in the Black River watershed. In the wetland module, upland contribution areas to the riparian wetlands are calculated based on the procedure developed in Liu and Yang (2007) using ArcGIS (ESRI, 2011). The flow, sediment, and nutrients from these areas are then subtracted from SWAT subbasin output, and serve as the upland input to riparian wetlands. The initial mass of nutrients in the wetlands is calculated by