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Evaluation of targeting methods for implementation of best management practices in the Saginaw River Watershed

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ABSTRACT

Increasing concerns regarding water quality in the Great Lakes region are mainly due to changes in urban and agricultural landscapes. Both point and non-point sources contribute pollution to Great Lakes surface waters. Best management practices (BMPs) are a common tool used to reduce both point and non-point source pollution and improve water quality. Meanwhile, identification of critical source areas of pollution and placement of BMPs plays an important role in pollution reduction. The goal of this study is to evaluate the performance of different targeting methods in 1) identifying priority areas (high, medium, and low) based on various factors such as pollutant concentration, load, and yield, 2) comparing pollutant (sediment, total nitrogen-TN, and total phosphorus-TP) reduction in priority areas defined by all targeting methods, 3) determine the BMP relative sensitivity index among all targeting methods. Ten BMPs were implemented in the Saginaw River Watershed using the Soil and Water Assessment Tool (SWAT) model following identification of priority areas. Each targeting method selected distinct high priority areas based on the methodology of implementation. The concentration based targeting method was most effective at reduction of TN and TP, likely because it selected the greatest area of high priority for BMP implementation. The subbasin load targeting method was most effective at reducing sediment because it tended to select large, highly agricultural subbasins for BMP implementation. When implementing BMPs, native grass and terraces were generally the most effective, while conservation tillage and residue management had limited effectiveness. The BMP relative sensitivity index revealed that most combinations of targeting methods and priority areas resulted in a proportional decrease in pollutant load from the subbasin level and watershed outlet. However, the concentration and yield methods were more effective at subbasin reduction, while the stream load method was more effective at reducing pollutants at the watershed outlet. The results of this study indicate that emphasis should be placed on selection of the proper targeting method and BMP to meet the needs and goals of a BMP implementation project because different targeting methods produce varying results.

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1. Introduction

Maintaining proper water quality conditions is important to protect human, animal, and plant health, and is an ongoing concern in water resources (Pejman et al., 2009). Meanwhile, anthropogenic activities such as direct industrial discharges (point source pollution) and agricultural practices (non-point source pollution) significantly interfere with natural processes, which ultimately degrade water quality (Nouri et al., 2008; USEPA, 2009). The management of non-point source (NPS) pollution requires a strategic combination of practices to prevent their entry into receiving water bodies. Best management practices (BMPs) are widely accepted methods that minimize the impact of agricultural activities on both surface water and groundwater (Arabi et al., 2007). However, pollutant reduction efficiencies of BMPs fluctuate due to varying design methods, implementation, and maintenance frequency. Consequently, a thorough understanding of BMP mechanisms in pollution mitigation and uncertainty in BMP effectiveness are needed during the BMP selection process. Apart from BMP selection, placement in the watershed also plays a vital role in the pollution reduction, as the contribution of pollutants is disproportionate in the watershed (Maringanti et al., 2009). This means that potential BMP effectiveness is site specific. Therefore, an effective BMP implementation strategy for one site may or may not be useful in reducing and/or controlling pollution for other sites in a watershed (Tuppad and Srinivasan, 2008).

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Measuring pollution loads from all fields in a watershed and evaluation of BMP effectiveness through actual implementation at the field level is time consuming, expensive, resource intensive, and impractical. However, watershed/water quality models are efficient and provide accurate information needed for evaluating pollution loads and BMP implementation strategies at the field and watershed levels. Using watershed/water quality models allows for identification of critical source areas (CSAs), which are locations that contribute a significantly high pollution load per unit area. Using CSAs to prioritize placement of BMPs is called the targeting approach, which provides greater reduction of pollutants. Targeting CSAs in the watershed is a well-known procedure for implementing BMPs to control non-point source pollution and to improve environmental quality (Qiu, 2009; Gitau et al., 2004; Srinivasan et al., 2005; Tripathi et al., 2003; Yang et al., 2005). However, the comparison of different targeting techniques in identifying CSAs and the overall impacts of these techniques in reduction of NPS pollution at both the field and watershed levels are yet to be determined.

Among existing watershed/water quality models, the Soil and Water Assessment Tool (SWAT) has been widely used to evaluate the water quality impacts of different land use changes at watershed scale (Arnold et al., 1998; Gassman et al., 2007; Arabi et al., 2007). The SWAT model is capable of simulating various agricultural management practices such as tillage operations, fertilizer and pesticide applications, vegetative filter strips, crop rotations, etc., which makes it an ideal model for evaluation of agricultural watersheds. For this reason, several studies have used SWAT model to develop BMPs implementation strategies in conjunction with various targeting methods (Jha et al., 2010; Maringanti et al., 2009; Parajuli et al., 2008; Schilling and Wolter, 2009; Tuppad et al., 2010; White et al., 2009). Srinivasan et al. (2005) used SWAT to identify critical source runoff areas for phosphorus transport and compared the results with the Soil Moisture Distribution and Routing (SMDR) physically based model. Overall, it was determined that SWAT performed better than SMDR. Jha et al. (2010) studied the impacts of land use restoration to 1990 conditions and land use conversion in the CSAs (defined as highly erodible land areas, floodplain areas, and upper subbasin areas) to native grass in order to assess the effect of nitrate load reduction strategies in an Iowa agricultural watershed. Nitrate load reduction was determined to be 7% for the land use restoration and 47%, 16%, and 8% for the land use conversions in the highly erodible lands, upper subbasin areas, and floodplain areas, respectively. Tuppad et al. (2010) implemented various BMPs (reduced tillage, edge of field vegetative filter strips, and contoured terraced) on 10%, 26%, 52%, and 100% of total targeted cropland and compared the pollutant reduction efficiency at the outlet of the watershed using targeting and random placement. The results demonstrated that the targeting method is more effective than the random placement method. In both the Jha et al. (2010) and Tuppad et al. (2010) studies, CSAs were identified based on a total load per unit area at the subbasin basis. White et al. (2009) used SWAT to identify CSAs and quantify sediment and total phosphorus loads generated from five watersheds in Oklahoma. The identification of CSAs was based on the threshold unit area load at each hydrologic response unit (HRU). The HRUs were ranked based on sediment and phosphorus yields, and the highest-ranking fractions were defined as CSAs. They found that only 5% of agricultural land produced approximately 22% of sediment and phosphorus load. Schilling and Wolter (2009) used SWAT to evaluate nitrate load reduction in the Des Moines River in Iowa using four targeting methods. All targeting methods were based on CSAs that have the potential to generate greater than 15 kg/ha nitrate annually. Four different configurations were identified: all subbasins with the above criteria, only CSA subbasins within the Boon River basin, targeting CSA subbasins closer to the Des Moines Water Works, and targeting CSAs subbasins away from the Des Moines Water Works. Results showed that 95% of the total nitrate originated from non-point sources, and the greatest nitrate reduction was found when fertilizer application was reduced in subbasins closer to the watershed outlet. However, in all of the targeting strategies, the fertilizer application rate was reduced assuming that the difference of the fertilizer application rate compared to the base scenario would be compensated by different BMPs.

As it was discussed above, some studies exist that relate the effectiveness of targeting methods and BMP implementation strategies to environmental health and water quality improvement. However, these methods have not been comprehensively evaluated and compared for multiple pollutants. The objectives of this research are to (1) identify CSAs using multiple targeting techniques and pollutants, (2) assess the sensitivity of BMPs to different targeting methods, and (3) evaluate the impact of BMP application in CSAs at subbasin and watershed scales. The results of this study will aid policymakers and stakeholders in making informed decisions regarding BMP placement while maximizing the environmental benefits at a lower cost than current approaches.

2. Materials and methods

2.1. Study area

The Saginaw River Watershed (SRW) (hydrologic unit code-HUC 040802), located east-central Michigan, was selected for this study. The SRW consists of six sub-watersheds: Tittabawassee (HUC 04080201), Pine (HUC 04080202), Shiawassee (HUC 04080203), Flint (HUC 04080204), Cass (HUC 04080205), and Saginaw (HUC 04080206) (Fig. 1). The Saginaw River flows north towards Lake Huron. The total watershed area covers 22,260 km^2; of which 42% is forest, 23% is agriculture, 17% is pasture, 11% is wetlands, and the remaining is urban. Dominant agricultural crops in the watershed are corn and soybeans. Expansive wetland areas provide habitats to large populations of wildlife species. Average watershed elevation is 242 m above mean sea level; with the minimum elevation being 177 m, and the maximum elevation being 457 m.

2.2. Model description

Watershed/water quality models are useful tools to assess the effectiveness of BMPs on the watershed scale (Woznicki et al., 2011). The Soil and Water Assessment Tool (SWAT) was selected in this study to evaluate CSAs for sediment, total nitrogen (TN), and total phosphorous (TP). SWAT is a physically based, spatially distributed watershed scale model developed by the USDA-ARS (Arnold et al., 1998; Neitsch et al., 2005; Gassman et al., 2007). In SWAT, a watershed is divided into subbasins and further divided into hydrologic response units (HRUs) based on homogeneous land use, soil, slope, and management practices. The major components of the model consist of weather, hydrology, soil characteristics, plant growth, nutrients, pesticides, and land management practices (Gassman et al., 2007). Runoff volume in SWAT is calculated either by the SCS curve number or Green and Ampt infiltration method (Neitsch et al., 2005).

Soil erosion comprises of three processes (detachment, transport, and deposition/degradation) and is caused by two forces: raindrop impact and surface runoff. SWAT uses the Modified Universal Soil Loss Equation (MUSLE) to calculate erosion and sediment yield for each hydrologic response unit (HRU) within the watershed. In MUSLE, the average annual gross erosion is calculated as a function of runoff (where runoff is the function