Journal of Environmental Management 128 (2013) 735–748

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

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

Evaluating the impact of field-scale management strategies on sediment transport to the watershed outlet

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ARTICLE INFO

Article history:
Received 26 March 2013
Received in revised form
10 June 2013
Accepted 17 June 2013
Available online 12 July 2013

Keywords:
RUSLE2
SWAT
SEDMOD
EQIP
Best management practices

ABSTRACT

Non-point source pollution from agricultural lands is a significant contributor of sediment pollution in United States lakes and streams. Therefore, quantifying the impact of individual field management strategies at the watershed-scale provides valuable information to watershed managers and conservation agencies to enhance decision-making. In this study, four methods employing some of the most cited models in field and watershed scale analysis were compared to find a practical yet accurate method for evaluating field management strategies at the watershed outlet. The models used in this study including field-scale model (the Revised Universal Soil Loss Equation 2 – RUSLE2), spatially explicit overland sediment delivery models (SEDMOD), and a watershed-scale model (Soil and Water Assessment Tool – SWAT). These models were used to develop four modeling strategies (methods) for the River Raisin watershed: Method 1) predefined field-scale subbasin and reach layers were used in SWAT model; Method 2) subbasin-scale sediment delivery ratio was employed; Method 3) results obtained from the field-scale RUSLE2 model were incorporated as point source inputs to the SWAT watershed model; and Method 4) a hybrid solution combining analyses from the RUSLE2, SEDMOD, and SWAT models. Method 4 was selected as the most accurate among the studied methods. In addition, the effectiveness of six best management practices (BMPs) in terms of the water quality improvement and associated cost were assessed. Economic analysis was performed using Method 4, and producer requested prices for BMPs were compared with prices defined by the Environmental Quality Incentives Program (EQIP). On a per unit area basis, producers requested higher prices than EQIP in four out of six BMP categories. Meanwhile, the true cost of sediment reduction at the field and watershed scales was greater than EQIP in five of six BMP categories according to producer requested prices.

1. Introduction

Non-point source (NPS) pollution from agricultural lands poses a significant threat to water quality in the United States. Agricultural runoff is the main cause of water quality problems in rivers and lakes; a major component of this pollution is excess sediment runoff driven by rainfall events (EPA, 2005). Many publicly sponsored programs are aimed at reducing sediment runoff in an effort to protect and preserve water resources (Shortle et al., 2012). However, efforts to reduce water pollution have been mainly aimed at point sources, while NPS pollution remains largely uncontrolled (Thomas and Froemke, 2012). Limited success in NPS pollution control is primarily due to the difficulty of identifying specific problem areas that are significant sources of pollution (White et al., 2009) and lack of NPS pollution regulation and enforcement (EPA, 2005).

Monitoring projects aimed at quantifying water quality usually involve high implementation and operation costs and require long periods of time and extensive data to form conclusions. To address these difficulties, models can be employed to gain valuable knowledge faster than monitoring at lower costs. Watershed models provide a way to quantify NPS pollution, identify critical source areas of pollution, and compare management strategies (Daggupati et al., 2011). Therefore, these models are useful and often necessary tools in the planning and evaluation stages of water quality improvement projects.

Several studies have addressed the applicability of watershed models for quantify NPS pollution. For example, Shen et al. (2009)

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http://dx.doi.org/10.1016/j.jenvman.2013.06.019

evaluated the performances of the Water Erosion Prediction Project (WEPP) and the Soil and Water Assessment Tool (SWAT) for soil erosion prediction in the Zhangjiachong watershed. Both models produced satisfactory results, although the the WEPP model provided slightly better predictions. Parajuli et al. (2009) used the Annualized AGricultural Non-Point Source (AnnAGNPS) model and the SWAT model to predict sediment yields (among other outputs) in the Cheney Lake watershed located in Kansas. SWAT preformed better than AnnAGNPS for sediment yield prediction over the 45-month evaluation period. Im et al. (2007) compared predictions of sediment yield from the Hydrological Simulation Program-Fortran (HSPF) and SWAT models in the Polecat Creek watershed in Virginia. Both HSPF and SWAT produced satisfactory results, with HSPF performing slightly better for time steps greater than a month. However, all of the above models were found effective in NPS quantification. In addition, watershed models are widely used to identify critical source areas. For example, Nejadhashemi et al. (2011) compared the applicability of the Spreadsheet Tool for Estimating Pollutant Load (STEPL), the Long-Term Hydrologic Impact Assessment model (L-THIA), the PLOAD model, and the SWAT model to identify the critical source areas. They concluded that SWAT was the only model capable of identifying critical source areas. In addition, Giri et al. (2012) performed a comprehensive study to compare different targeting techniques (based on various factors such as pollutant concentration, load, and yield) to identify the critical source areas using the SWAT model. They concluded that concentration based targeting is the most effective in reducing nutrients, while load based targeting techniques are more effective in reducing sediment at the watershed outlet. Finally, watershed-scale impacts assessment of best management practice (BMP) implementation strategies have been extensively studied (Gitau et al., 2008; Ullrich and Volk, 2009; Lee et al., 2010; Tuppad et al., 2010; Gassman et al., 2010; Betrie et al., 2011; Giri et al., 2012, 2013), demonstrating that a watershed-scale model is a powerful tool for use in management plan development.

The aforementioned modeling exercises are essential for making informed watershed management decisions. However, execution of large-scale BMP implementation plans is infeasible due to a lack of rigorously enforced NPS regulations. In reality BMPs are implemented on individual fields, and due to the voluntary nature of these programs, installation of many BMPs covering a significant portion of a watershed is unlikely. Under these conditions, understanding the true cost and effectiveness of individual BMPs both at the field and watershed scales is important to guide informed decision-making for conservation programs such as the BMP Auction (Smith et al., 2009).

Many field-scale models are available for evaluation of BMP effectiveness, such as the Revised Universal Soil Loss Equation 2 (RUSLE2) and Agricultural Policy Environmental Extender (APEX). Although very useful for field-scale analysis, watershed-scale impacts cannot be quantified. Meanwhile, results obtained from watershed scale models such as SWAT are unreliable for field-scale study due to the limitations of land use, topography, and soil input data resolutions (Daggupati et al., 2011). Therefore, there is a need for an integrated modeling framework capable of assessing the impact of field-scale management strategies at the watershed scale, which is the main objective of this study. Four techniques were tested to evaluate watershed scale sediment reduction loads from 80 field-scale BMP scenarios. The methods tested were using: (1) predefined field-scale subbasin and reach layers in the SWAT model; (2) subbasin-scale sediment delivery ratio; (3) results obtained from the field-scale RUSLE2 model as point source inputs to the SWAT watershed model; (4) a hybrid solution combining analysis from the RUSLE2, the Spatially Explicit Delivery Model (SEDMOD), and SWAT models. The applicability, advantages, and disadvantages of these approaches are discussed. Finally, cost analysis was performed to compare producer requested prices versus the prices defined by the USDA's Environmental Quality Incentives Program (EQIP) for BMP implementation.

2. Materials and methods

2.1. Study area

The River Raisin watershed (Hydrologic Unit Code 04100002) is located approximately 97 km southwest of Detroit, Michigan (Fig. 1). The watershed is contained primarily in Michigan, with a small portion residing in Ohio. The watershed is located in six counties: Hillsdale, Jackson, Lenawee, Monroe, Washtenaw, and Fulton, with most of the area in Lenawee County. The River Raisin flows east into Lake Eire near Monroe, Michigan. Sixty-six percent of the total watershed area (268,100 ha) is allocated for crops and pastureland according to the Cropland Data Layer (CDL, 2007). The remaining land cover is 13% forest, 12% urban, 7% wetlands, 1% range grass and brush, and 1% water. Major crops in the watershed include corn, soybeans, and wheat. Mean elevation is 300 m above sea level with a maximum elevation of 391 m, and a minimum of 12 m, according to the United States Geological Survey.

2.2. Data inventory

In this study, a wide range of data was required for the modeling practices. The following is a summary of all data collected:

Mean daily streamflow data was available from January, 1990 through December, 2009 from USGS station number 04176500 located on the River Raisin near Monroe, Michigan. A total of 7305 records were collected. The United States Environmental Protection Agency (EPA) Storage and Retrieval (STORET) database contained

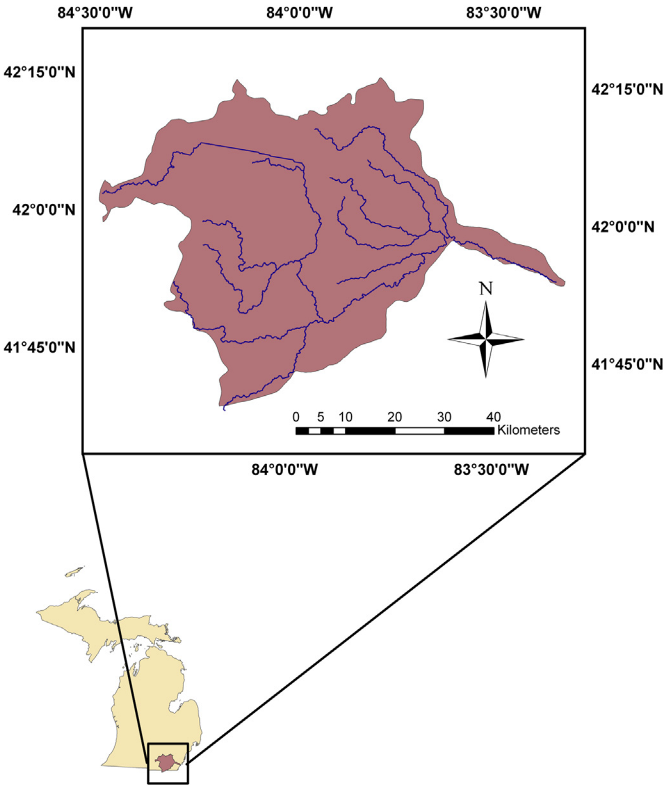

Fig. 1. Study Area – River Raisin Watershed.