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Validating the Soil Vulnerability Index for a claypan watershed

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ABSTRACT

Assessment studies of conservation efforts have shown that best management practices were not always implemented in the most vulnerable areas where they are most needed. While complex computer simulation models can be used to identify these areas, resources needed for using such models are beyond reach for most water resources managers. Soil and water conservationists need simple, spatially explicit tools such as the USDA-NRCS's Soil Vulnerability Index (SVI) to evaluate the inherent vulnerability of soils and the risk they pose to water quality when used for row crop agriculture. In this study, the SVI was evaluated in the Goodwater Creek Experimental Watershed (GCEW), a claypan watershed in Missouri, using three methods: professional judgment, comparison to the Conductivity Claypan Index (CCI) developed specifically for claypan soils, and comparison to model results. Factors affecting the critical areas identified by each method were assessed and classified areas were compared. Slope and depth to claypan had the most variability in GCEW and were found to be influential in determining area classification by each index. While the original definition of SVI included the soil type representative slope from the USDA SSURGO database, slope values provided by a Digital Elevation Model (DEM) improved the index usefulness by classifying visibly degraded and non-degraded areas in different categories. High and moderately high vulnerability areas identified with SVI, CCI and model results with DEM slopes were consistent and matched professional judgment. Additional testing of SVI is recommended in areas characterized by soils of different permeability and under different climates.

1. Introduction

Non-point source (NPS) pollution from agricultural activity is a major problem in the United States (Shortle et al., 2012). Common pollutants include nutrients such as phosphorus (P) and nitrogen (N), pesticides and herbicides, and sediment. Pollutants are typically transported away from fields via surface runoff or leaching, leading to downstream problems such as contamination of drinking water, damage to aquatic ecosystems, and sedimentation (Baker, 1992). The transported pollutants also affect farmers in the form of lost inputs that can affect future crop yields.

Use of conservation practices in the U.S. became more prevalent after the Dust Bowl crisis of the 1930s led to the government taking a more active role in soil conservation and related activities (Baveye et al., 2011). At that time, the focus for implementing conservation practices was more on reducing soil erosion than reducing agricultural pollution, an additional focus of current policy. Since then, the goal has also included protecting streams and water bodies downstream of agricultural areas from the negative effects associated with agricultural NPS pollution through the use of grassed waterways, contour farming, buffer strips, conservation tillage, and nutrient management plans among other best management practices.

Despite billions of dollars spent on conservation programs and a large increase in funding in the 2002 farm bill, skepticism has been expressed by many about the environmental benefits obtained from additional funding allocated to conservation programs, and especially obtained at watershed and regional scales (Mausbach and Dedrick, 2004). Research has typically shown conservation practices to be effective in reducing NPS pollution at field scales (Jokela et al., 2004; Sharpley et al., 2006; Nangia et al., 2010; Douglas-Mankin et al., 2013). In contrast, effectiveness in reducing NPS pollution in larger watersheds has been found to be minimal (Park et al., 1994; Inamdar et al., 2002; Chaubey et al., 2010; Tomer and Locke, 2011). One potential reason is that conservation practices have not been targeted to critical areas that contribute the most contaminants to receiving water bodies (Gale et al., 1993; Strauss et al., 2007; Tomer and Locke, 2011). It is therefore very important that these critical areas are identified.

Modeling, indices, and geographic information systems (GIS) can be used to identify and delineate critical areas (Meals et al., 2012). The

Abbreviations: CCI, Conductivity Claypan Index; CD, depth to claypan; DEM, digital Elevation Model; GCEW, Goodwater Creek Experimental Watershed; HRU, hydrologic response unit; KSAT, hydraulic conductivity; NPS, non-point source; NRCS, Natural Resources Conservation Service; SL, Slope; SSURGO, Soil Survey Geographic Database; SVI, Soil Vulnerability Index; SWAT, Soil and Water Assessment Tool; USDA, US Department of Agriculture.

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Agricultural Policy Environmental eXtender (APEX) model is a field scale hydrologic model that can simulate a variety of management operations (Gassman et al., 2010) and has been used to identify critical areas for sediment, runoff, and atrazine in a field located in Northeast Missouri (Mudgal et al., 2012). The Soil and Water Assessment Tool (SWAT) model is a watershed scale model that has also been used, sometimes in combination with APEX, to quantify contaminant delivery to a water body and identify the critical areas (Srinivasan et al., 2005; Busteed et al., 2009; White et al., 2009; Douglas-Mankin et al., 2010; Ghebremichael et al., 2010; Rabotyagov et al., 2015; White et al., 2014). These models are complex and analyses using these tools require significant resources that are beyond those of a state, county, or other local resource management authority. Thus tools that are simpler to implement within a GIS platform are being considered for local or regional analyses.

The phosphorus index (PI) and topographic wetness index (TWI) are examples of index approaches to identifying critical areas. The PI is used to assess phosphorus losses at a field level (Lemunyon and Gilbert, 1993). The TWI identifies areas in a watershed where saturation excess overland flow is likely to occur by estimating the saturation potential of soils (Beven and Kirkby, 1979). Methods based on GIS technology are often used in conjunction with modeling or index methods to display critical areas on watershed maps (Hamlett et al., 1992; Tim et al., 1992). Zollweg et al. (1995) demonstrated the use of a GIS-based tool to identify critical areas responsible for a majority of phosphorus loss in a studied watershed, and Nelson et al. (2011) combined GIS technology with a model based on the Revised Universal Soil Loss Equation (Revised USLE) to identify critical areas for soil loss in a watershed in Kansas.

The Soil Vulnerability Index (SVI) was developed by the NRCS as part of the CEAP cropland study (USDA-NRCS, 2012) to rank soils nationwide in terms of their inherent vulnerability to contaminant transport by surface runoff or by leaching when cropped. Vulnerability to contaminant transport by surface runoff was determined based on soil properties that were found to promote surface runoff and erosion, while vulnerability to contaminant transport by leaching was based on soil properties found to promote infiltration. No consideration is given to vegetation or management. Relevant soil properties were determined based on APEX model results for sediment and nutrient losses by surface runoff and percolation in the Upper Mississippi River Basin (USDA-NRCS, 2012). The model was run for a subset of the National Resources Inventory cropland sites throughout the Upper Mississippi River Basin, using the NRCS soil survey database, a climate database, and operator surveys about land management. Each site was ranked as having high, moderately high, moderate, or low soil erosion or nutrient loss, and nitrogen leaching potential based on its output of sediment and nutrient yield and percolation. With all sites ranked, soil properties that correlated well with the risk classes were determined. Hydrologic soil group, erodibility factor, and slope were the top properties for surface runoff and soil erosion, while the same properties plus coarse fragment content were the top properties found to affect infiltration and contaminant leaching. Ranges of values for slope, erodibility factor, and coarse fragment content were statistically determined for each hydrologic soil group to determine criteria to classify areas into different vulnerability classes. The final ranking criteria were then used to classify all soils within the U.S. so that regional comparisons could be conducted (USDA-NRCS, 2012).

Compared with using models, using indices to identify critical areas can be a simpler approach requiring fewer input parameters and less preparatory work such as model calibration. However, indices do need to be validated before they can be used to make decisions on conservation efforts. Validation of the SVI within and outside the Upper Mississippi River Basin is necessary before this index is widely used to guide policy. The overall goal of this study was to validate the SVI within the Goodwater Creek Experimental Watershed (CGEW), a Missouri watershed where contaminant transport has been monitored and simulated in detail (Blanchard and Donald, 1997; Donald et al., 1998; Lerch et al., 2011; Baffaut et al., 2015b). The dominance of soils with a restrictive layer causes a high potential for surface runoff and transport of sediment and nutrients to water bodies, and makes this watershed a good candidate for validation of a targeting index. The specific study objectives were to 1) evaluate the ability of the SVI to classify critical areas in terms of vulnerability to contaminant transport by surface runoff in the GCEW, and 2) assess how input parameters used by the SVI affect vulnerability classifications in this watershed. The evaluation was based on professional judgment, comparison with another targeting index developed specifically for soils with a restrictive layer, and comparison with the results of a hydrologic model.

2. Materials and methods

2.1. Study area

The Goodwater Creek Experimental Watershed (GCEW; Sadler et al., 2015b) is in Major Land Resource Area 113, Central Claypan Areas (Fig. 1): 4 Mha of primarily agricultural land use that cover a portion of Missouri and Illinois and where claypan soils dominate (USDA-SCS, 1981). Claypan soils are characterized by a shallow, low permeability clay layer, the claypan, that limits percolation and available water capacity, resulting in a high potential for surface runoff and other surface runoff induced problems. Excessive soil erosion and herbicide transported in surface runoff are known problems throughout the region (Lerch et al., 2008). The GCEW itself covers 72 km^2 in Boone and Audrain County in Missouri. Long-term (1970–2010) data from a weather station and a network of rainfall gauges in the watershed show annual precipitation ranging from 569 mm to 1620 mm, averaging 981 mm per year (Sadler et al., 2015a). Average annual air temperature was 12 °C, ranging from a January average of −2.7 °C to a July average of 25.0 °C (Sadler et al., 2015a). Over the same period, average annual discharge per unit area was 310 mm, or 32% of the average annual precipitation (Baffaut et al., 2015a).

2.2. SVI vulnerability classification

Risk classification for the SVI was based upon criteria specified by the USDA-NRCS (2012) shown in Table 1, which are based on soil hydrologic group, USLE soil erodibility (K-factor), and slope information for each SSURGO soil polygon in the watershed. Inputs were processed using ArcMap resulting in maps showing risk classifications throughout the GCEW.

Hydrologic soil group, slope, and K-factor were determined from SSURGO data publicly available online at the Geospatial Data Gateway website, http://datagateway.nrcs.usda.gov/ (January 2013). The hydrologic soil group status was determined from the Revised USLE, Version 2, Related Attributes report. When the hydrologic group was dependent on the drainage status, soils were assumed to be undrained based on knowledge of the watershed. As a result, all non-floodplain soils in GCEW had a hydrologic soil group D. K-factor values were determined from the surface layer Kw values in the Physical Soil Properties report. Slopes values were the representative slope value of each soil type (Lee Norfleet, USDA-NRCS, personal communication, 10 July 2012). As an alternative to representative slope values, vulnerabilities were also calculated based on slopes derived from a 10-m digital elevation model (DEM).

2.3. SVI evaluation

Index validation can involve professional judgment, comparison with other indices, comparison with field data, or comparison with results from well calibrated models (Tomer et al., 2003; Dosskey et al., 2011; Chan et al., 2013; Dosskey et al., 2013). In this study, the SVI was validated using professional judgment, comparison with the