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Apportionment of suspended sediment sources in an agricultural watershed using sediment fingerprinting

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A B S T R A C T

Sediment fingerprinting techniques can provide valuable information on sources of suspended sediment to facilitate effective targeting of best management practices. Research was conducted in the Pleasant Valley watershed (50 km^2) in South Central Wisconsin to identify sources of suspended sediment during cropping season and snowmelt periods at a subwatershed scale. Results show that both stream banks and agriculture are important sources of suspended sediment. The contribution from agriculture and stream banks to suspended sediment at the watershed outlet ranged from 45 to 97% and from 3 to 47%, respectively. During periods of high sediment loading agriculture was the important source of suspended sediment at the majority of sites within this watershed, with the exception of snowmelt runoff, when stream banks were the dominant source of suspended sediment at the watershed outlet. The average annual erosion rates in croplands and pasture land-use determined from the Revised Universal Soil Loss Equation 2 (RUSLE 2) ranged from 0 to 0.00509 t m^{-2} yr^{-1}, indicating significant variability among fields. Conservation practices in this watershed should be targeted to stream banks or agriculture (prioritize fields based on RUSLE 2 average annual erosion rates) depending on the dominant source of suspended sediment within a subwatershed. The results of this study show that both temporal and spatial variability in suspended sediment sources should be considered to develop management strategies and sampling only at the watershed outlet or capturing a few storms might not be sufficient to target locations for best management practices.

1. Introduction

Eroded sediments are important non-point source pollutants causing degradation of surface water bodies. Loss of sediment-bound nutrients, such as phosphorus (P), from agricultural landscapes to surface waters results in growth of toxic algal blooms and eutrophication. To control excessive sediment delivery to streams and implement appropriate management practices effectively, sources contributing disproportionate amount of suspended sediment to streams must be identified.

Sediment fingerprinting technique has been successfully used in the past to identify sources of suspended sediment (Davis and Fox, 2009; Koiter et al., 2013a; Walling, 2013). This technique is based on linking the physical or geochemical properties of the suspended sediment to their corresponding sources within the watershed (Walling et al., 2008) and thereby quantifying relative contribution from different sources (Walling, 2013). Different types of sediment fingerprinting properties that have been used to identify suspended sediment sources include, but are not limited to, metals (e.g., Blake et al., 2012; Franz et al., 2014), fallout radionuclides (e.g., Huisman et al., 2013; Olley et al., 2013), stable isotopes (Mckinley et al., 2013), sediment color (Martínez-Carreras et al., 2010), and mineral magnetic properties (Walling et al., 1999). Sediment fingerprinting properties could be unique for a particular watershed (Walling, 2013). Therefore, a common approach used in sediment fingerprinting studies is to select a large number of fingerprinting properties and apply statistical procedures to optimize them to best apportion suspended sediment to different potential sources (Davis and Fox, 2009; Walling, 2013).

Sources, sinks and fluxes of sediment are highly variable in time and space (Trimble, 1999). The contribution from different sources to suspended sediment can change during crop growing season (Huisman et al., 2013). For example, in spring bare soils are more prone to erosion and susceptibility of soil movement in upland areas decreases as crop growing season progresses. Stream banks are more prone to soil erosion during freeze–thaw activity (Gellis and Noe, 2013). Similarly, sediment loading at the watershed outlet changes throughout a year. Therefore, identification of suspended sediment sources during periods of high sediment load would help prioritize the contributing source areas. In addition, there is a spatial dependence on the relative contribution from various sources within a watershed (Koiter et al., 2013b). Therefore, focusing efforts only at the watershed

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outlet can result in ineffective targeting of areas for best management practice (BMP) implementation.

Sediment fingerprinting technique using inorganic tracers can be used to prioritize upland sediment sources based on land-use types (e.g., croplands, pastures, woodlands), soil type, and geology. Management practices are typically implemented at the field-scale. In a watershed there could be several hundred to thousand fields under a particular land-use type. Therefore, an approach which can be used to prioritize fields within agricultural land-use will help in effective targeting of BMPs. A commonly used tool for field-level prioritization, using average annual soil erosion rate, is the Revised Universal Soil Loss Equation 2, RUSLE 2 (USDA-ARS, 2006). RUSLE 2 is readily available and fairly easy to use in comparison to other complex models such as Water Erosion Prediction Project (WEPP) (Flanagan and Livingston, 1995) and it is part of the P indices (Buczko and Kuchenbuch, 2007), such as, the Wisconsin P Index (Good et al., 2012). Therefore, combined use of RUSLE 2 with sediment fingerprinting could be effective in identifying specific fields for BMPs.

A study which considers both spatial and temporal aspects of suspended sediment transport, provides seasonal information on suspended sediment sources, and prioritizes fields based on average annual soil erosion rate is needed to obtain a comprehensive understanding of sediment transport in an agricultural watershed and to effectively target BMPs. Past efforts have focused on identifying sources of suspended sediment temporally (e.g., Gellis and Noe, 2013; Huisman et al., 2013) and at a subwatershed scale (e.g., Collins et al., 2013; Koiter et al., 2013b; Smith and Blake, 2014). However, limited work has been done to identify suspended sediment sources as a function of land-use during a growing season using sediment fingerprinting in conjunction with prioritization of fields for BMPs based on average annual soil erosion rates. Therefore, the objectives of this study were to: (a) determine relative contributions from different potential sources to fine suspended sediment at the subwatershed scale, (b) evaluate how these contributions from different sources change temporally at the subwatershed scale, and (c) prioritize fields for targeting BMPs within agricultural land-use category.

2. Methods

2.1. Study site

The 50 km^2 Pleasant Valley watershed is located in the non-glaciated area of South Central Wisconsin (Fig. 1a). The major land-uses in the watershed are cropland (34%), Conservation Reserve Program (CRP) grassland (unmanaged) (28%), woodland (22%), pasture (generally managed and grazed) (8%), and pastured woodland (4%) (Fig. 1b). The watershed has an average slope of 11% and consists primarily of silt loam soils. The average (October, 2006–September, 2012) flow and sediment load measured at the watershed outlet is 0.59 m^3 s^{-1} and 27.8 t km^{-2} yr^{-1}, respectively. The Pleasant Valley branch of this watershed is on the list of Wisconsin Impaired Waters due to degraded habitat from non-point source pollution contributions to sediment/total suspended solids (DNR, 2012).

2.2. Sample collection

Suspended sediment samples were collected at the outlet of three different subwatersheds and at the watershed outlet using time-integrated trap samplers (Fig. 1a) (Phillips et al., 2000). These time-integrated trap samplers collect fine suspended sediment (<63 μm) with particle size characteristics that are statistically representative of the ambient suspended sediment (Phillips et al., 2000; Russell et al., 2000) and have been successfully used in numerous previous studies (e.g., Huisman et al., 2013; Smith and Blake, 2014). At each site (i.e., monitored sub-watershed or overall watershed outlet), four time-integrated trap samplers were installed to ensure that sufficient sediment mass was collected for subsequent analyses. Suspended sediment samples were collected monthly (±5 days) during the entire

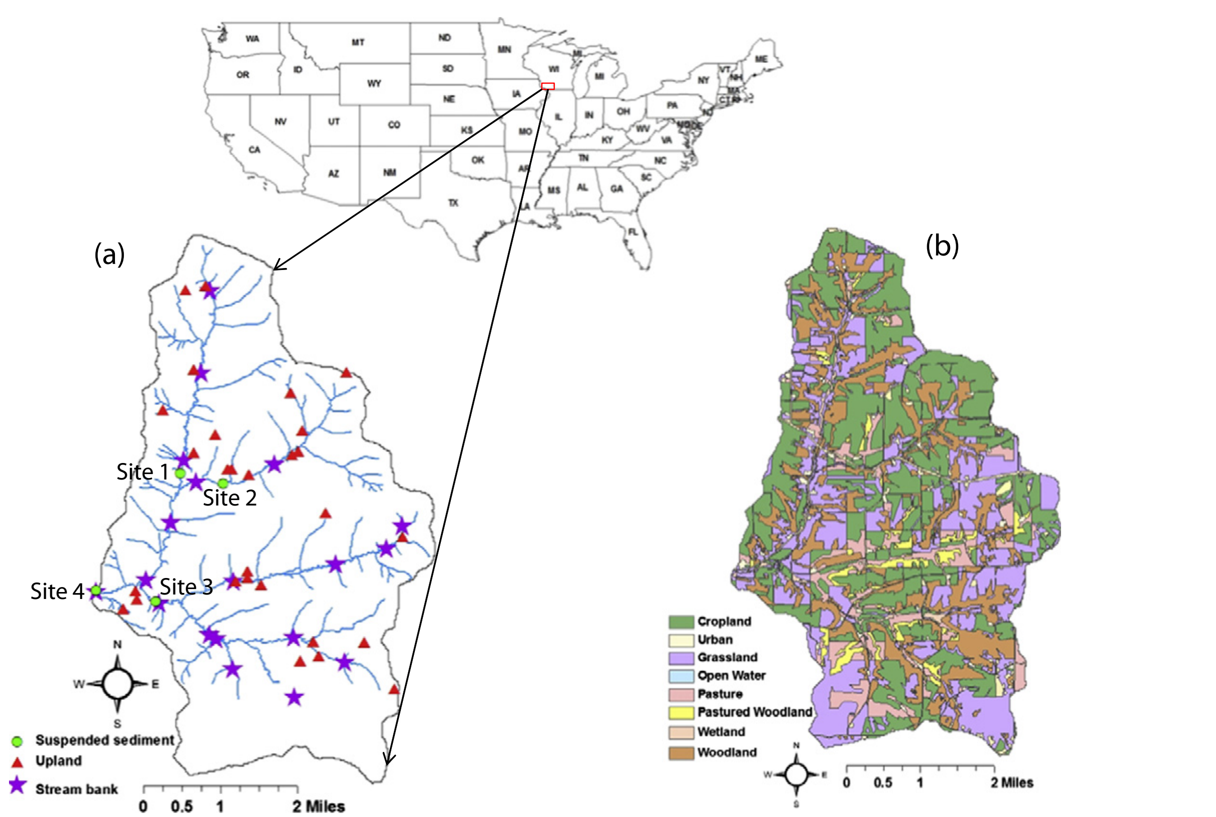

Fig. 1. (a) Location of the upland, stream bank and suspended sediment collection sites in the Pleasant Valley watershed. (b) Land-use distribution in the Pleasant Valley watershed.