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Application of the spatial distribution of nitrogen stable isotopes for sediment tracing at the watershed scale

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Summary Sediment tracing technology relies on the use of natural biogeochemical tracers to identify sediment sources in a watershed. This improves sediment tracer technology by presenting a method to model the spatial distribution of biogeochemical tracers. The nitrogen stable isotope of surface soils is modeled across the landscape and was chosen due to (i) its ability to reflect land management changes across the landscape, (ii) the lack of understanding regarding its distribution at the watershed scale, and (iii) its recent successful use within sediment tracer technologies and anticipated future use. Potential linkages between watershed variables that vary across the landscape and nitrogen stable isotopes are postulated based on assessment of the watershed variables in a geographical information system, field assessment, and review of biogeochemical processes. Thereafter field data collection and analyses of nitrogen stable isotope using an isotope ratio mass spectrometer are performed followed by statistical analyses and modeling of the tracer across the landscape. The nitrogen stable isotope is statistically dependent upon land management practices, geomorphologic landform and soil depth in the agricultural soils, which is a result of plant harvest as a nitrogen sink, fertilization and mineralization rates. Short-range variability of soil moisture and surface heterogeneity due to cobbles and gravel, woody debris and litter control nitrogen isotopic variability in the forest and only a small portion of the total data variance is dependent upon the watershed variables. The spatially distributed model of nitrogen stable isotope of surface soils is presented and is expected to provide further pin-pointing of sediment sources using natural tracer technology.

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Introduction

Surface erosion of soils depletes the fertility of agricultural lands with the removal of organic rich soils and impacts water quality through particle disaggregation and leaching. Measuring erosion at the watershed scale is a task facing both the agriculture, forestry and water resources communities. In recent years, the use of natural sediment tracer studies has gained application for measuring surface erosion across a watershed. Tracer studies use physical, chemical and biological properties of soils (e.g., isotopic signature, size, density, color, mineralogy), termed biogeochemical tracers (De Boer and Crosby, 1995; Collins et al., 1998; Walling and Amos, 1999; Gruszowski et al., 2003; Fox and Papanicolaou, 2007). Tracers are used to allocate more than one erosion source, such as agricultural fields and disturbed forests, from the total sediment load. The applicability of natural sediment tracers relies on accurate modeling the spatial distribution of the tracers. In this context, 'modeling the spatial distribution' refers to the broad task of creating representations or maps of sediment tracers across erosion sources in a watershed in order that the maps can be used within the sediment tracer studies.

Generation of models of the spatial distribution of the tracers has not been included into protocols for sediment tracer studies (Davis and Fox, 2007). For natural biogeochemical tracers that have been the focus of recent technology, their spatial distribution is dependent upon watershed variables related to geomorphologic form of the landscape (e.g., hillslope and floodplain geomorphic landforms), soil morphology (e.g., soil profile development) and anthropogenic disturbances (i.e., land-use and land management practices). To model tracers, it is necessary to assess the distribution of watershed variables which can control tracer variability. The need to assess watershed variables and their link to natural tracers comes at a time when geospatial data are freely available and easy to transform within a geographical information system (GIS). After potential linkages between watershed variables and tracer signature are postulated, tracer field sampling can be performed followed by biogeochemical analyses (e.g., analysis of isotopic and elemental composition using an isotope ratio mass spectrometry), statistical modeling and finally spatial modeling of tracers in a GIS.

At the present time, a method to develop a spatially distributed model of natural sediment tracers has not been detailed in the literature. We focus on developing this method and model the spatial distribution of a natural sediment tracer known as the nitrogen stable isotope or $\delta^{15}N$. $\delta^{15}N$ is a soil property proportional to the $^{15}N/^{14}N$ isotopic ratio and has been used most prominently by environmental scientists to study nitrogen pollution in the hydrosphere and atmosphere and for studying eco-environmental problems such as nitrogen cycling in vegetation and nitrogen cycling in lakes and coastal regions (Heaton, 1986; Lojen et al., 1997). Only a small number of studies have used $\delta^{15}N$ for studying soil erosion and sediment transport (Bellanger et al., 2004; Fox and Papanicolaou, 2007), thus information about $\delta^{15}N$ spatial variability related to geomorphologic form of the landscape, soil morphology and anthropogenic disturbances is needed for the community at the watershed scale where sediment tracing is performed. $\delta^{15}N$ of surface soils is controlled by organic matter derived from decaying vegetation and plant roots and thus is indicative of plant management (Papanicolaou et al., 2003; Fox, 2005). $\delta^{15}N$ has sediment tracing capability to distinguish sediments derived from sources with unique land-uses, land management, geomorphology and depth in the soil column (Fox, 2005). Modeling $\delta^{15}N$ across a watershed will help meet the need to use the tracer within sediment tracing.

The objective of this study is to (i) present a methodology for developing a spatially distributed model of natural sediment tracers that takes advantages of statistical modeling, field sampling, biogeochemical analyses and GIS, and (ii) use the methodology and present the results for modeling $\delta^{15}N$ across multiple land-uses, land management, geomorphology and depth in the soil column. The method is applied here to the Upper Palouse Watershed in Northwestern Idaho–a watershed with soil erosion problems defined by the dominance of forest and agricultural land-uses for which the nitrogen tracers have shown the capability to distinguish land-uses and be used within sediment tracing (Fox, 2005; Fox and Papanicolaou, 2007).

The steps to the tracer modeling methodology include the following: (1) assessment of the spatial distribution of watershed variables using geospatial modeling and field assessment. (2) Review of the processes and variables controlling $\delta^{15}N$. (3) Field data collection and biogeochemical analyses of $\delta^{15}N$. (3) Statistical analysis of $\delta^{15}N$ dependence upon watershed variables. (5) Explanation of $\delta^{15}N$ variability and dependence upon watershed variables. (6) Modeling of $\delta^{15}N$ in a geographical information system to produce a spatially distributed model of $\delta^{15}N$ for sediment tracing.

Assessment of the distribution of watershed variables

Geospatial modeling and field assessment were used to examine the spatial distribution of the watershed variables in the Upper Palouse. Models of land cover were generated. In addition, the Universal Soil Loss Equation (USLE) was considered as an erodibility model and was used to investigate the importance of the distribution of the variables upon surface erosion. The models were generated in a GIS at a 30 m resolution (i.e., 30 m × 30 m grid cells) for the entire 600 km^2 watershed. Table 1 compiles land cover, topography and soil geospatial data and its sources used to generate the models. GIS modeling was performed in *ArcView 8.1* by

Table 1 Data used for modeling watershed variables

Data type	Data sources
Land-use/vegetation data	USGS National landcover dataset 1 m digital orthophot quadrangles Field assessment
Soil data	USDA-NRCS SSURGO Database Local XRCS office in Moscow, ID
Topography data	USGS 30 m digital elevation model Field survey