Biofuel Expansion Impacts on Soil Loss in the US Midwest

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Executive Summary

In 2007, Congress passed the Energy Independence and Security Act (EISA 2007) which set targets for the proportion of transportation fuels that are to be renewable. EISA amended the Renewable Fuels Standard (RFS2) such that the total amount of renewable fuels targeted by 2022 would increase from 9 billion gallons in 2009 to 36 billion gallons or approximately 13% by volume of all transportation fuels. This mandate will necessitate increased cultivation of biomass, in particular of corn whose kernels are used for current first generation bioethanol production. A recent study by the National Exposure Research Laboratory or the US Environmental Protection Agency predicted that land use / land cover will change for around 13% of the area of the US Midwest, where most of the nation's corn is produced.

This study considered the implications of land use / land cover conversion on water-related soil erosion. Whereas biofuel expansion is generally perceived as deleterious to ecosystem services such as nutrient regulation and biodiversity, our results suggest that most of the US Midwest area will experience a *reduction* in soil loss under the forecasted scenario. This decrease in soil loss is mainly related to conversion of corn/soy rotation to monoculture corn, which has less erosion per hectare.

While our study predicts an overall 9.5% decrease in soil loss in the US Midwest, we predict a large spatial heterogeneity across the Midwest, with some watersheds experiencing increase of up to 35% in soil loss whereas in others soil loss will decrease by as much as 60%. The former watersheds are predominantly in the north (SD and ND) and south (KS, MO) of the US Midwest, suggesting targeted policy aimed at preventing soil loss in these areas, for example by promoting more conservation tillage practices in these states, should be considered.

This study opens promising opportunities for further research, in particular looking at the trade-off between soil loss and nutrient leakage, as well as including wind erosion and the impacts of agricultural tiling, cover cropping etc. into our modeling framework.

Introduction

Several forces have converged to motivate the federal government of the United States to reevaluate the nation's food and fuel production systems. Concerns about climate change, food security, fuel independence, and national security have all aligned to focus the attention of different government agencies on the allocation of private lands to agricultural systems for the purposes of both food and fuel production. The opportunity to address several of these issues simultaneously through agricultural policy led to regulatory action.

In 2007, Congress passed the Energy Independence and Security Act (EISA 2007) which set targets for the proportion of transportation fuels that are to be renewable, including conventional biofuels (e.g. corn-based ethanol) and "additional renewable fuels" (e.g. advanced biofuels, biomass-based diesel, and cellulosic). EISA also amended the Renewable Fuels Standard (RFS2) created as part of the 2005 Energy Policy Act such that the total amount of renewable fuels targeted by 2022 would increase from 9 billion gallons in 2009 to 36 billion gallons or approximately 13% by volume of all transportation fuels. Through this revised program, the U.S. Environmental Protection Agency established new statutory requirements in 2010 for the production of biofuels, including annual targets for individual fuels that initially consist entirely of corn starch-based fuels (9 billion gallons), but then shift to more advanced biofuels as we approach 2022 when the amount of conventional biofuels is estimated to reach 15 billion gallons, or roughly 42% of the total renewable fuels produced (U.S. EPA, 2010).

Water quality and quantity problems are expected to be exacerbated as rising grain prices and well-meaning government regulation spur a switch to monoculture cropping of corn on lands with competing crops (i.e., cotton and wheat), and potential conversion of Conservation Reserve Program (CRP) lands back to field crops (Westcott 2007). The pressure to increase corn production is also likely to affect already marginalized wildlife species reducing populations, thereby decreasing important ecosystem services such as the existence of native biodiversity, wildlife viewing opportunities and recreational use.

Biofuels pose a promising option for increased renewable energy production and national energy independence. The recent mandate for increasing bioethanol in transportation gasoline in the EISA will necessitate increased cultivation of biomass, in particular of corn whose kernels are used for current first generation bioethanol production. Increased corn production can be achieved for instance by conversion of land not used for production systems into agriculture, or conversion of one type of production system into another. The conversion of unmanaged prairie and forest systems into managed agricultural production systems is known to have environmental implications, including the loss of several ecosystem services, such as sediment retention (Haigh, Jansky et al. 2004, Tiner 2005). Erosion and sedimentation problems are often a high priority of watershed management initiatives in the US (United States. Environmental Protection and United States. Environmental Protection Agency. Office of 2007). The effects of soil erosion are far reaching; on site, soil erosion removes fertile topsoil, reducing crop productivity with an estimated loss of $27 billion (Jones, Lal et al. 1997). Off site, eroded soil reduces water quality and impairs ecosystem health (Newcombe and MacDonald 1991, Metzeling, Doeg et al. 1995), increases the cost of treatment for consumptive use, and accumulates in reservoirs reducing storage capacity and diminishing the efficiency of dams (ICOLD 2001). Such impacts are likely represents large environmental and social externalities in current energy policy.

Maintaining adequate vegetative cover is central to controlling the risk of erosion as vegetation reduces the likelihood of soil detachment, impedes overland flow energy and thus reduces export; and provides trapping of eroded sediment along the flow path. The sediment retention model in the InVEST software suite (Integrated Valuation of Ecosystem Services and Trade-offs) developed by the Natural Capital Project can be used to identify the impacts of land-cover and land-use change on the amount of sheetwash erosion originating from--and the amount retained by--different parts of the landscape (Nelson, Mendoza et al. 2009, Kareiva, Tallis et al. 2011) In this project, we applied the InVEST sediment retention model to contribute to a better understanding of how sedimentation process would change under different landscape patterns of agricultural production, focusing on the US Midwest region. Some key questions we address are:

1. Identify the implications for sediment delivery of the expected transitions in land use and land cover in the US Midwestern due to the increased demand for biomass and expected growth in urban areas
2. Identify sub-watersheds throughout the US Midwest where changes in land use and land cover are predicted to result in the greatest change (increase/decrease) in downstream sediment delivery
3. Separate the impacts of the new energy policy, and that of natural population growth and urbanization

In addition, this study addressed two methodological questions:

4. Identify best available data needed for such analysis, and point out future work needed to reduce uncertainties in results
5. Determine proper spatial scale of analysis for the US Midwest

Roadmap

This study builds upon the scenario development effort in EPA NERL and recently published by Mehaffey et al. (Mehaffey, Smith et al. 2012). Using projections for corn demand, based on new EISA, and natural population growth, this study developed a year 2020 land use/land cover (LULC) map. This future scenario complements a baseline dataset for year 2001, published in an earlier study by the same authors (Mehaffey, Van Remortel et al. 2011). Together, these two LULC maps were used in the present study as our current and future scenarios.

Our general approach estimates sediment production based on the Universal Soil Loss Equation (USLE). We show that the relative change in sediment delivery can be modeled using the USLE at an appropriate spatial scale.

In the next section, we detail some general comments regarding LULC change and its effect on soil loss. Next, we detail the InVEST sediment retention model, and describe our approach to parameterize it.

In the results section, we begin by studying six watersheds of varying areas spread across the US Midwest. Using available suspended sediment gauge data collected by the USGS, we calibrate the InVEST sediment model for each case. We use these watersheds to determine the appropriate spatial scale in which USLE gives adequate relative change prediction in sediment delivery. We then use the USLE approach to measure how LULC change impacts regional and spatial patterns of soil delivery at the US Midwest region.

Finally, the last section describes some key findings and proposes some promising future research directions.

Methodology

General Considerations

Land use / land cover (LULC) change affects many ecosystem functions, including water erosion (caused by rain) and wind erosion (caused by wind). While wind erosion has an important contribution to top-soil loss in the US Midwest (NRCS 2009), an analysis of the impacts of the new energy policy and/or urbanization on wind erosion is beyond the scope of this study. The total soil loss due to water erosion on the landscape is the sum of few key processes: splash, sheet, rill/gully and stream/bank erosion (Toy, Foster et al. 2002). The first stage of the erosion process occurs when raindrops hits the soil surface, causing the detachment of soil particles. Increased runoff accelerates the detachment of soil particles. Once in solution, the soil particles move across the landscape in a thin uniform layer referred to as sheet erosion. Along the flow path, soil particles can fall out of solution when runoff slows to a point where the particles can no longer remain in suspension, either via flow retardation due to interactions with vegetation or through geomorphological controls. Vegetation along the flow path can also mechanically trap eroded soil particles reducing sediment transport (Toy, Foster et al. 2002). When sheet wash begins to concentrate on the land surface, rill erosion occurs, and as the duration and intensity of rainfall continues and runoff volumes increase, rills eventually convert to gullies. Gully formation is dependent on the occurrence of rainfall events that completely saturate the soil profile; and gully development is widespread in upland areas, particularly those with mineral soils and steep slopes. Finally, stream/bank erosion occurs in channels as the stream bed erodes, banks destabilize and the channel deepens.

Factors affecting water erosion rates

Soil erosion rates are controlled by climate, topographic relief, soil properties, vegetative cover and human activity. In terms of management, a promising means of limiting soil erosion is taking advantage of the role of vegetation in the sediment erosion process. Vegetative decreases the rainfall energy arriving at the soil surface, helping reduce the detachment of soil particles. Vegetation helps retain sediments by increasing infiltration of the overland flow volume, reducing the flow velocity, and mechanically trapping eroded sediments (Wilson 1967). The capacity of sediment retention is different for different vegetation types.

A second key management factor is tillage -- the agricultural preparation of the soil for planting by mechanical agitation. Decreasing tillage intensity results in increase percentage of crop residue, reducing soil detachment and overland flow velocity (Mannering, Meyer et al. 1966). On the other hand, tillage is usually needed to create an aerated and fine seedbed for crop production. For row crops (crops planted in rows separated by some distance; most commercial crops including corn are row crops) the orientation of the rows with respect to the slope of the field also affects soil loss, with cross slope cultivation, contour farming and strip-cropping being common practices to cutoff runoff and decrease soil loss.

Many areas of the US Midwest have poorly drained soils. Excess water in the soil can hinder or even prevent growth of commercially important crops (Pavelis 1987). An extensive artificial drainage network has been installed starting in the 1870s. Studies estimate that extended areas in the US Midwest used for growing row crops and small grains and tile drained (between 50%-100%l see Figure 1 in (Jaynes). It is believed that the dead zone in the Gulf was caused by excess nitrates leaking from tile drained fields in the Midwest. Tile drainage increases infiltration, hence one expects to have less soil loss on tiled fields, all else being equal. A study performed in northern Ohio found 36% reduction in soil loss in tile drained fields compared to control fields which were only surface drained (Schwab, Nolte et al. 1977). Unfortunately, the last survey farmland drained by artificial means was done by USDA NRCS in 1992, and to our knowledge only few studies considered tiling impacts using an USLE approach. However, since tile draining is practiced for nearly all commercial crop types, we do not expect tiling to impact relative change of soil delivery, assuming most (if not all) of the fields that can benefit from tile drainage have already been using it by 2001.

Finally, many farmers plant “cover crops” after harvest, often with explicit purpose of reducing soil loss by storms that occur during the main-crop off season. The LULC layers used in this study were derived from the USDA Cropland Data Layer, which use classification of remote sensing data aimed at estimating in-season acreage of different crop types. Acquiring information on cover crop practices for the scale of US Midwest is beyond the scope of this study. Furthermore, few studies focused on the impact of cover crops in reducing annual sediment loss, which is modeled by the USLE, and this effect will be regional specific. Assuming that planting cover crops decreases soil loss by some percent, and that the LULC transitions will not increase/decrease the acreage where this practice is used, we do not expect relative change of soil delivery to be affected by cover cropping.

Model Details

The InVEST sediment model is based on the Universal Soil Loss Equation (USLE), thus it captures only the sheet wash component of the sediment budget. Modeling gully and bank erosion requires large amounts of local data (e.g. shape of existing gullies, slopes and curvature of river banks) that are typically not available across large spatial scales. Furthermore, the InVEST model is mainly focused on assessing the effects of land use change on soil loss from sheet erosion. Although sheet erosion may not necessarily be the dominant source of erosion, it can be a significant contribution to total sediment load. The InVEST sediment model, therefore, is useful mainly for estimating relative change in sediment entering the stream network.

InVEST models sheet wash as a two-step process (Figure 1) – generation of detached soil, modeled by the Universal Soil Loss Equation (USLE), and transport/deposition of soil particles on the landscape, modeled by a Sediment Delivery Ratio (SDR). There are now in-stream processes in our model. Unlike more detailed hydrological models such as SWAT (ref), InVEST distributes erosion generation and sediment delivery per pixel over an annual time step. A similar approach has been used in several other studies (Ferro, Porto et al. 1998, Ferro and Porto 2000, Bhattarai and Dutta 2007). The use of a fully distributed hydrological model allows quantitative valuation of the key factor in which we are interested: the effects of land use change on soil loss and soil retention. The InVEST sediment model is depicted below:

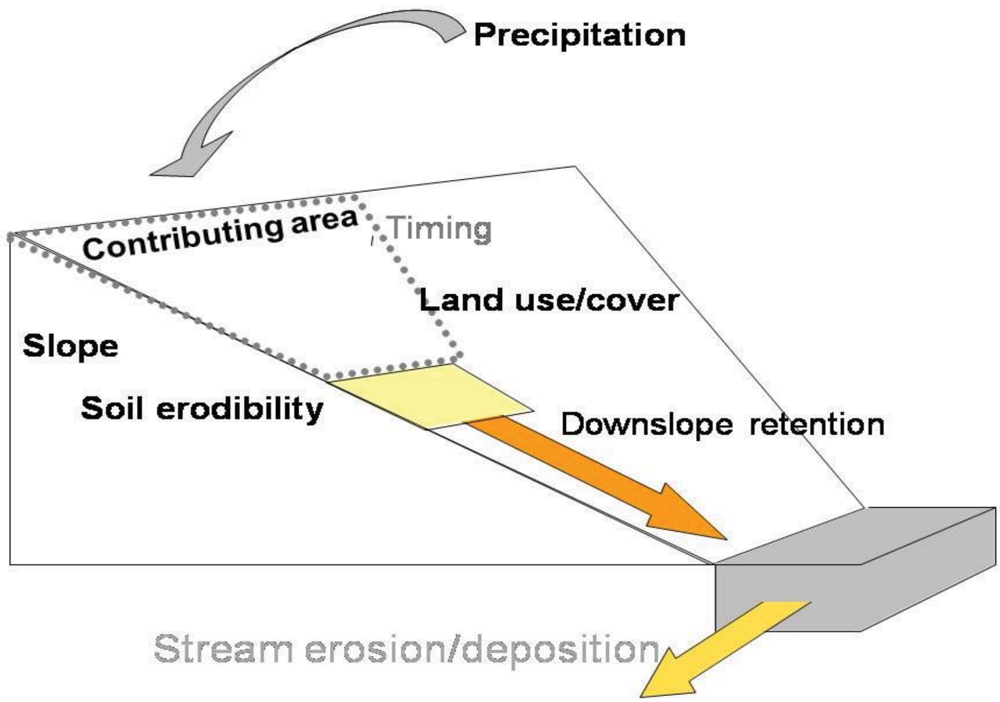

Figure 1: Schematic of the InVEST Sediment Retention Model. The model accounts for amount and intensity of precipitation, captured by the erosivity parameter in the USLE, land use/cover (affecting crop and support parameters as well as vegetation roughness), soil erodibilty, and local slope. The model is annual, and ignores in-stream erosion or deposition (gray).

<u>Generation of detached soil</u>

The Universal Soil Loss Equation (USLE), developed in 1978 by Wischmeier and Smith predicts the long-term average annual rate of erosion on a field slope based on rainfall intensity, soil characteristics, topography, crop cover management and support practices. The method provides a standardized approach to predict the amount of soil loss that results from sheet or rill erosion on a single gentle slope but does not account for additional soil losses that might occur from gully, stream/bank or wind erosion. The USLE equation is written as:

A = R x K x LS x C x P

A: The potential long-term average annual soil loss in mass per area per year basis

R: The Rainfall - runoff erosivity is a climatic–factor that accounts for the rainfall and runoff intensity -the greater the intensity and duration of the rain storm, the higher the erosive capacity and erosion potential.

K: The soil erodibility factor is a measure of the susceptibility of soil particles to detachment by rainfall and transport by runoff. Texture is the principal factor affecting K (soils with high clay content will have low K values), but structure, organic matter (high organic matter content promotes infiltration and reduces runoff) and permeability also contribute.

LS: The slope length-gradient factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 72.6 feet. Slope length is defined as the distance from the point of origin of overland flow to the point where deposition occurs or where the flow enters a defined channel. The steeper and longer the slope, the higher is the risk for erosion.

C: The crop and management factor is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The C factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss under tilled continuously fallow land.

P: The support practice factor is used to account for the positive impacts of support practices on annual soil loss. The value represents the ratio of soil loss by a support practice such as contouring, strip cropping, or terracing to that of straight-row farming up and down the slope.

Sediment transport/deposition over land

Soil retention is mainly an outcome of physical filtration and slowing down of overland flow by vegetation, causing deposition of sediment particles. Factors such as slope, soil permeability and area also play an important role in sediment transportation and deposition processes (Toy, Foster et al. 2002). The Sediment Delivery Ratio (SDR), which equals to the ratio of actual sediment load to gross erosion estimated from USLE equation, is included in our model to account for retention processes at the pixel scale. Many empirical equations have been developed to estimate SDR, the most commonly used ones are area-based equations at the catchment scale (Roehl 1962, Walling 1983). The sediment delivery approach in InVEST, uses a method developed by Ferro and Minnacapili (Ferro and Minacapilli 1995), which takes into account a catchment-specific parameter γ (related to particle size distribution) and the travel time in the flow path, estimated from the grid cell flow length (l), and roughness coefficient (α) which depends on land use/land cover, and slope (in %):

$$SDR = \exp\left(-\frac{\gamma \cdot l}{\alpha\sqrt{\frac{\min(slope, 0.1\%)}{100\%}}}\right)$$

<u>Transport of sediment in water</u>

The InVEST model does not include any in-stream processes of deposition. The model assumes soil reaching the "stream network" flows with the water to the outlet, and that the flux of sediment into the stream network is equal to the flux at the outlet. This stream network defines the physical location on the landscape where most of the soil transport is in concentrated flows, i.e. running surface water, during periods of rain. It is *not* necessarily the same as the location of perennial streams. The InVEST sediment model uses a fixed cutoff on the area drained into each pixel to delineate the stream network.

Data Sources and Parameterization

The study area for this work is the US Midwest. We used a 2001 LULC layer (aka "current scenario") and a predicted 2020 LULC layer (aka "future scenario") produced by Mehaffey et al. (Mehaffey, Smith et al. 2012). Table 1 below lists the data required to run the InVEST sediment model, and the sources used in this study:

Table 1: Summary of InVEST Sediment Model data sources used in present study

Input	Source
Land use/land cover	Mehaffey et al. LULC maps for 2001 and 2020, based on projected increase in corn production to meet EISA demands, and urbanization driven by population growth
Rainfall erosivity	USDA Isoerodent maps of the US (EPA 2012)†
Soil erodibility	STATSGO‡
Crop factor Management factor	See section 'Crop and Management Factor' below
Digital Elevation Map (DEM)	National Elevation Dataset 1/3 Arc-Second*
Roughness Coefficient for each land use/land cover	See section 'Roughness Coefficient' below
Flow accumulation threshold	See section 'Flow Accumulation Threshold' below

† Notice that original publication uses US Customary Units. Data was converted to SI units for this study.

‡ The use of STASTGO was preferred over the newer and more detailed SSURGO dataset. Although SSURGO is complete for the md-west region, generating raster datasets for erodibility proved impossible with the resources we had for this project.

* DEM was "filled" using ArcGIS to remove sinks

Crop and Management Factor

Factor C in the USLE is the ratio of soil loss from cropland under specific conditions to the corresponding loss from clean-tilled, continuous fallow. Hence the C-factor measures the combined effect of all the interrelated cover and management variables. Variables important for the C value determination include crop type and its canopy, residue mulch, and tillage among others (Wischmeier and Smith 1978). For agricultural production systems in the Midwest region, we used C factors from USLE implementation manuals published for different runoff erosivity index-EI distribution zones (Figure 2). We were able to obtain C-factor values only for EI 2, EI 3, EI 14, and EI 16 distribution zones. Since these regions are distributed across the study area, the C-values of these regions were averaged and used in estimating C values across the entire Midwest. For forest/shrub, pasture, alfalfa/hay and fallow we used generalized C factors from the literature (see Table 4 below).

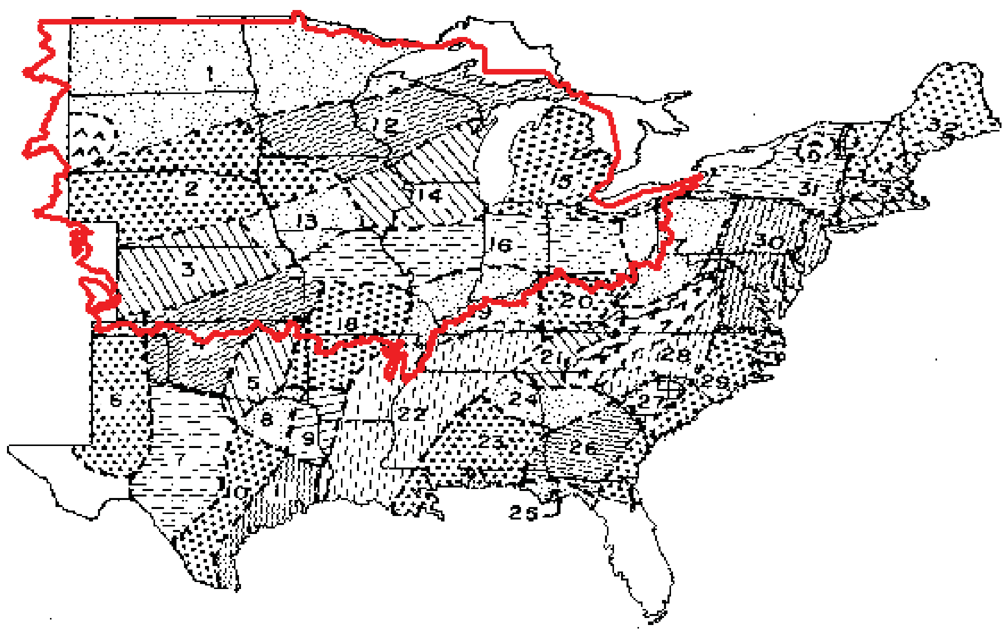

Figure 2. Runoff Erosivity Index distribution Zones. The Midwest is covered by EI regions 1, 2, 3, 4, 12, 13, 14, 15, 16, 17, 18 and 19. Boundaries of Midwest Region are in red. Adapted from (Wischmeier and Smith 1978)

The steps used to derive C-factors are detailed below:

1. As a first step, for each of the 12 states in the study region, (IA, IL, IN, KS, MI, MO, ND, NE, OH, SD and WI), data on extent of crop management, such as tillage and residue management were gathered from the annual Agricultural Resource Management Survey (ARMS) on-line database of the USDA Economic Research Service (USDA-ERS 2012). As an example, data gathered for corn production is presented in Table 2.
2. For specific crop type and tillage management in the study region, values of C were averaged from data reported for each of the four EI zones. C-factor values for crops in EI 3, EI 2, EI 14; and EI 16 were obtained from USDA Natural Resources Conservation Service, Field Office Technical Guide reports presented for each state. An example is presented in Table 3 for monoculture corn and corn-soybeans rotation under different tillage practices.
3. The final step was to estimate the average C-value for each state and crop by calculating weighed average of C values under different percentages of tillage management. Resulting C factors are listed in Table 4.

Table 2: Midwestern corn production and conservation practices data: data acquired from USDA Economic Research Service

States	Corn acres planted (1000 acres)*	Soil erosion controls used** (% of planted acres)	Tillage operations used (% of planted)			
			no-till	mulch till	Reduced tillage (15-30% residue)	Conventional tillage (<15% residue)
North Dakota	2,049.88	7	11%	25%	16%	48%
South Dakota	4,550.02	17	28%	18%	33%	22%
Nebraska	9,150.00	33	52%	25%	17%	6%
Kansas	4,800.13	56	47%	28%	12%	13%
Minnesota	7,700.06	15	6%	24%	35%	35%
Iowa	13,399.92	52	18%	48%	21%	13%
Missouri	3,200.02	65	16%	26%	31%	26%
Wisconsin	3,900.03	21	19%	19%	30%	32%
Illinois	12,600.00	18	9%	33%	26%	32%
Michigan	2,399.99	12	21%	10%	36%	33%
Indiana	5,900.10	6	25%	29%	12%	33%
Ohio	3,500.01	18	31%	15%	24%	31%

* 2010 data

**includes conservation buffer used

Table 3. C-factor values for corn-corn and corn-soybeans crops under different tillage practices for different Runoff Erosive Index zones.

Erosive Index (E I) distribution zone**	Tillage operations used			
	no-till (60% residue	mulch till (40% residue*)	Reduced tillage (20% residue)	Conventional tillage (7% residue)
Estimation of C- Factor for corn-corn				
2	0.08	0.15	0.17	0.34
3	0.08	0.16	0.17	0.48
14	0.08	0.15	0.21	0.34
16	0.09	0.15	0.21	0.36
Average	**0.083**	**0.153**	**0.19**	**0.38**
Estimation of C- Factor for corn-soybeans				
2	0.1	0.15	0.21	0.6
3	0.11	-	0.31	0.4
14	0.14	0.24	0.34	0.4
16	0.14	0.25	0.36	0.42
Average	**0.12**	**0.21**	**0.31**	**0.46**

* percent of residue values in parenthesis are typical values for the Midwestern states under different tillage systems obtained from the USDA Economic Research Service data.

** Erosive Index (EI) distribution zone for C-Factor presented in Figure 2.

‡ C-Factor values for crops in several EI distribution zones were obtained from USDA FOTE or documents from USDA Natural Resources Conservation Service, Field Office Technical Guide reports presented for States within these zones.Downloaded from:

http://www.agronomy.ksu.edu/extension/DesktopModules/ViewDocument.aspx?DocumentID=2126 (EI 3);

http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=2620&context=extensionhist (EI 2);

http://efotg.sc.egov.usda.gov/references/public/IA/Universal_Soil_Loss_Equation1.pdf (EI 14);

http://efotg.sc.egov.usda.gov/references/public/IL/ArchivedUSLE.pdf (EI 16)

Table 4: C-, and P- factor input data used in the InVEST Model for major land use/land covers in Midwest

Land Use/Land Cover Class†	P factor	C factor	Data source for C factor
New urban	1	0.001	It is not typical to model urban areas using USLE approach; however, for this study we assumed new urban construction sites are regulated and urban open areas are covered by grass vegetation
Developed open space	1	0.003	See above
Developed land	1	0.001	See above
Barren land	1	1	(Wishmeier and Smith, 1978) C value for bare ground
Deciduous, coniferous, and mixed forests	1	0.001; 0.003; 0,006	(Wischmeier and Smith 1978) Deciduous forest - average c value of 0.001 for undisturbed forest with 75-100% of area covered by canopy of trees and undergrowth; mixed forest - average c value of 0.003 for undisturbed forest with 45-70% of area covered by canopy of trees and undergrowth; Coniferous forest - average c value of 0.006 for undisturbed forest with 20-40% of area covered by canopy of trees and undergrowth
Shrub/scrub	1	0.008	Average c value for brushes with 50% of canopy cover and full ground cover (Wischmeier and Smith 1978)
Undefined pasture/Hay	0.89	0.02	Generalized C value for small grains following hay crops (Stewart, Woolhiser et al. 1975)
Pasture/Hay	0.89	0.02	Average C value for Meadow crops (Stewart, Woolhiser et al. 1975)
undefined crop	0.89	0.24	Average C value for small grains (Stewart, Woolhiser et al. 1975)
Wetland	1	0.003	Assumed value
Monoculture corn	0.89	0.21	Present study
Monoculture soy	0.89	0.28	Present study
Monoculture wheat	0.89	0.3	Present study
Monoculture cotton	0.88	0.42	Present study

Corn/soy	0.89	0.28	Present study
Corn/wheat	0.89	0.21	Present study
Corn/other	0.89	0.21	Present study
Corn/fallow	0.89	0.3	Present study
Soy/wheat	0.89	0.15	Present study
Soy/other	0.89	0.15	Present study
Soy/fallow	0.89	0.26	Present study
Wheat/other crop	0.89	0.24	Present study
Wheat/fallow	0.89	0.355	Present study
Cotton/other	0.88	0.42	Present study
Misc. grain/other	0.89	0.21	Present study; assumes conventionally tilled grain crops following other crops
Other crop/fallow	0.89	0.37	Present study; assumes conventionally tilled other crops following fallow land
Alfafa hay	0.89	0.02	Generalized C value for alfalfa (Stewart, Woolhiser et al. 1975)
Alfafa hay/other	0.89	0.004	Generalized C value for alfalfa hay mix (Stewart, Woolhiser et al. 1975)
Fallow	0.89	1	C value for bare ground (Wischmeier and Smith 1978)

† Some classes represent a crop rotation, e.g. 'corn/soy' is a rotation of one year growing corn, followed by a second year of growing soybeans, In absence of detailed information on crop rotation, we assumed a 2 year rotation period, although some farmers grow e.g. corn-corn-soy etc.

As shown in Table 4, generalized C-factor value for Monoculture corn was estimated to be 0.21 whereas a corn/soy rotation has a value of 0.28. Based on this estimation, corn crops grown following soybeans will produce higher erosion rates compared to corn crops following corn. The LULC dataset assigns a pixel to a corn/soy rotation whenever the two crops were grown on the same pixel between 2004 and 2007. In absence of detailed information on the frequency of planting each crop in a rotation, our analysis was based on a 2 year cycle (e.g. corn, soy then corn etc.).

Support practice factors (P-Factor) were estimated for the Midwest as follows:

P in the USLE is the support practice factor (also called Erosion Control Practice Factor, conservation practice factor). Conservation practices that reduce the P factor are contour farming, cross-slope farming, and strip-cropping. For the Midwest study region, a P value of 0.6 for row crops undergoing contour farming and strip-cropping with an average slope of 9-12% were assumed to represent control practices in the area (Wischmeier and Smith 1978). Based on the data acquired on crop production and managements (USDA-ERS 2012), support practices were used only on portions of crops planted. Thus, the P value was adjusted by the percent of crop area with soil erosion controls (Table 2) to estimate average value across the study area. A P value of 1 was used for all other land uses.

Roughness Coefficient

An empirical roughness coefficient, specific to each land use/land cover type, was determined using by inverting the SDR equation and collecting literature review of measured sediment retention efficiency (*R*) for different vegetation types (see Table 5 for a sample). Table 6 summarizes the literature derived retention coefficients used in this study. When literature data was unavailable for such data, roughness coefficient data for land covers from (Haan, Barfield et al. 1994) were used. The complete set of roughness coefficients for all LULC is listed in Table 7.

Table 5: Estimating roughness coefficient for various land cover types based on experimental studies of vegetated buffers.

vegetation type	width of filter strip (m)	average slope (%)	R = total sediment retention efficiency (%)	Retention ratio	SDR†	α
fescue (Festuca arundinacea)	0.7	5	82[1]	0.82	0.18	**0.18**
fescue (Festuca arundinacea)	4	4.9	93[1]	0.931	0.069	**0.68**
fescue (Festuca arundinacea)	8	4.9	97[1]	0.971	0.029	**1.02**
Ky-31 fescue	9.2	3.3	81[2]	0.811	0.189	**3.04**
Ky-31 fescue	4.6	3.3	71[2]	0.712	0.288	**2.03**
Ky-31 fescue	9.2	4	95[2]	0.947	0.053	**1.57**
Ky-31 fescue	4.6	4	77[2]	0.773	0.227	**1.55**
Ky-31 fescue	9.2	3.3	70[2]	0.704	0.296	**4.17**
Ky-31 fescue	4.6	4.5	49[2]	0.485	0.515	**3.27**
tall fescue (Festuca arundinacea)	0.5	3	88[3]	0.88	0.12	**0.14**
tall fescue (Festuca arundinacea)	1	3	93[3]	0.93	0.07	**0.22**
tall fescue (Festuca arundinacea)	2	3	94[3]	0.94	0.06	**0.41**
tall fescue (Festuca arundinacea)	3	3	96[3]	0.96	0.04	**0.54**
tall fescue (Festuca arundinacea)	4	3	98[3]	0.98	0.02	**0.59**

† By definition, the SDR is equal to 1 minus retention ratio

[1] Blanco-Canqui, H., Gantzer, C.J., Anderson, S.H., Alberts, E.E., Thompson, A.L. 2004. Grass barrier and vegetative filter strip effectiveness in reducing runoff, sediment, nitrogen and phosphorus loss. Soil Sci. Soc. Am. J. 68: 1670-1678.

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[3] Liu, X., Zhang, X., Zhang, M. 2008. Major factors influencing the efficacy of vegetated buffers on sediment trapping: a review and analysis. J. Environ. Qual. 37: 1667-1674.

Table 6: **Estimated Roughness coefficients for different land use/land covers**

Land uses	Roughness Coefficient	Land uses	Roughness Coefficient
Bare Ground	13.2	Tall grasses	1.4
Sugar Cane	1.9	Wetland(grassed & rush)	0.7
Corn planted across the slope	5.8	Logged forest	17.7
Grass + Trees (buffer)	3.3	Paved surface	20.3
Grasses	1.5	Hay: meadow	2.5
Legume + Grasses	2.5	Straight row cultivation	8.6
Mixed forest	2.6	Contour ; Strip cropped	5.1
Oatsplanted across slope	7.7	Forest with heavy ground litter	2.5
Sorghum contour plowed	4.0		

The roughness coefficients used in this study are given in Table 7.

Table 7: Roughness coefficient input data used in the InVEST Model for major land covers in Midwest

Land Use/Land Cover Class	Roughness Coefficient α	Data Source
New Urban	20.3	value for paved areas from Ham et al., 1994
Developed Open Space	20.3	value for paved areas from Ham et al., 1994
Developed land	20.3	value for paved areas from Ham et al., 1994
Barren land	13.2	value for bare land in Table 6
Forest	2.6	value for mixed forest in Table 6
Shrub/scrub	7	value for short grasses from Ham et al., 1994

Undefined pasture/hay	2.5	value for legume + grass in Table 6
Pasture/Hay	2.5	value for legume + grass in Table 6
Undefined crop	8.6	value for straight row cultivation from Ham et al., 1994
Wetland	0.7	value for wetland in Table 6
Monoculture corn	5.8	value for corn land in Table 6
Monoculture soy	5.8	value for corn land in Table 6
Monoculture wheat	7.7	value for oats in Table 6
Monoculture cotton	5.8	value for corn land in Table 6
Corn/soy	5.8	value for corn land in Table 6
Corn/wheat	5.8	value for corn land in Table 6
Corn/other	5.8	value for corn land: estimated from sediment retention percentages using an SDR equation
Corn/fallow	5.8	value for corn land in Table 6
Soy/wheat	5.8	value for corn land in Table 6
Soy/other	5.8	value for corn land in Table 6
Soy/fallow	5.8	value for corn land in Table 6
Wheat/other crop	7.7	value for oats in Table 6
Wheat/fallow	7.7	value for oats in Table 6
Cotton/other	5.8	value for corn land in Table 6
Misc. grain/other	5.8	value for corn land in Table 6
Other crop/fallow	5.8	value for corn land in Table 6
Alfafa hay	2.5	value for legume + grass in Table 6
Alfafa hay/other	2.5	value for legume + grass in Table 6
Fallow	8.6	value for straight row cultivation from Ham et al., 1994

Flow Accumulation Threshold

Our study examined the sensitivity of absolute and relative change in soil loss to the flow accumulation threshold parameter. As shown below, using sediment gauge data, one can adjust this parameter such that the modeled predicted soil export, corrected for estimated gully contribution (based on USDA State scale data; Table 8), matches the measured value. We analyzed 6 watersheds within the greater Midwest region in detail using time series data on suspended sediment load from the USGS National Water Information System. We found that the ratio of summed USLE contributions in current and future scenarios is a good proxy for the relative change in soil loss in watersheds roughly the size of a HUC8. A theoretical explanation is as follows; as watershed scale increases, more of the landscape is within a sufficiently short distance from the stream network to contribute to sediment delivery (areas far away from steams produce sediment, but it is retained within the landscape). Once the LULC change within a buffer around the stream network sufficiently samples the distribution of LULC transitions in the entire watershed, there is little further change in relative soil loss change with decreasing the flow accumulation threshold (making the stream network denser, and increasing total buffer area). Our analysis of the US Midwest was based on this observation – we neglect sediment retention and routing, since we find these processes are not changing much the relative change in soil loss at the HUC8 scale.

Table 8: Contribution of Gully Erosion to Suspended Sediment (USDA-NRCS 1997)

State	Estimated sheet erosion (tons/acre/year)	Measured ephemeral gully erosion (tons/acre/year)	Ephemeral gully erosion as percent of sheet
Illinois	7.1	5.2	73
Iowa	9.6	3	31
Kansas	21.98	8	36
Michigan	4.67	1.22	26
North Dakota	7.54	3.55	47
Wisconsin	7.87	4.19	53

Results

Identification of Scale of Analysis

As described in the Methodology section, we needed to find the scale of analysis for the Midwest where the USLE approach can be applied without an explicit stream network. Note that the lack of knowledge on the full stream network is common problem in all hydrological modeling, including those using more advanced models such as SWAT. We choose six watersheds which have at least 4 years of annual sediment load in the USGS National Water Information System, and represent different regions and scales across the Midwest. For these six watersheds, we could calibrate the InVEST sediment model, including the sediment retention part. We compare the relative change is soil loss across different parameterization of the model, as well as using the USLE approach. To illustrate this analysis, we start with a more detailed description of one watershed, namely Skunk River, and follow with the results for the remaining five watersheds in brief.

The Skunk River is a very large watershed (drainage area of 1,106,880 ha), comprised of three HUC8 regions (07080105, 07080106 and 07080107). The watershed has a USGS gauge station located on Skunk River at Augusta, IA (see Figure 3). We used InVEST sediment model, and varied the flow accumulation threshold over a 100 fold range. Figure 4 shows that predicted sediment load is proportional to the drainage density (we use total drainage length as proxy for density). The relation between the flow accumulation threshold and the total drainage length is determined by the watershed geomorphology. We find that a simple power law perfectly describes that relation, as seen in the linear fit on a double log scale of Figure 5. The two relations allow calibrating the cutoff value, based on the estimated sheet wash component of the measured suspended sediment time series data (corrected for gully erosion, as described in Methodology). For the Skunk River watershed, we find that a cutoff of 4845 pixels best agrees with the estimated sheet wash component of the measured sediment loading. As the difference between that and our 5k cutoff results was less than 3%, we used the 5k value for subsequent analysis.

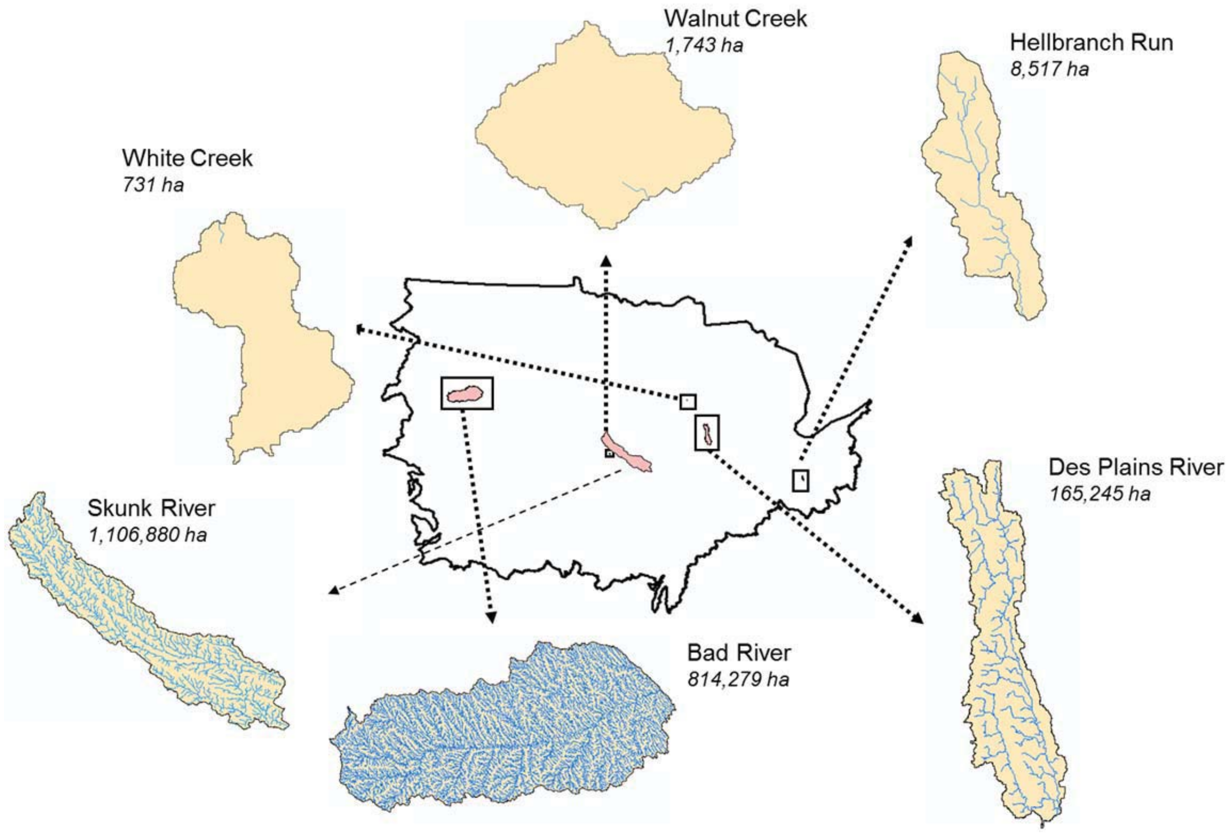

Figure 3: Watersheds used to study spatial scale of analysis. Six watersheds were chosen to represent different regions and scales (area) across the Midwest. The calibrated stream networks (drawings are not to scale) show substantial differences in drainage densities. Stream gauges data used for each watershed were taken from USGS website for stations 4073462 (White Creek); 5487540 (Walnut Creek); 3230450 (Hellbranch Run); 5532500 (Des Plains River); 6441500 (Bad River) and 5474000 (Skunk River).

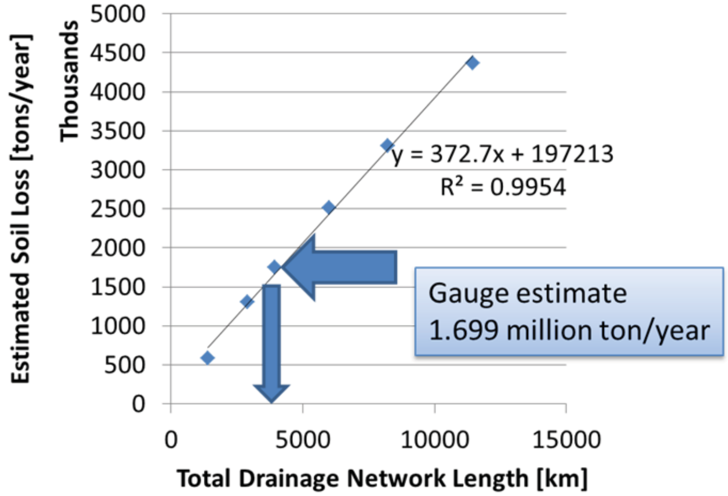

Figure 4: Relation between estimated soil export at the outlet and total drainage network length. Stream network was produced from raster area accumulation map, threshold at different cutoffs, and converted to vector form. Total drainage network length was calculated by summing individual river segment lengths. Correcting for gully erosion, the estimated sheet wash component based on the sediment data is 1.699 million ton per year, which can be used to identify the cutoff value which results agrees with measurements.

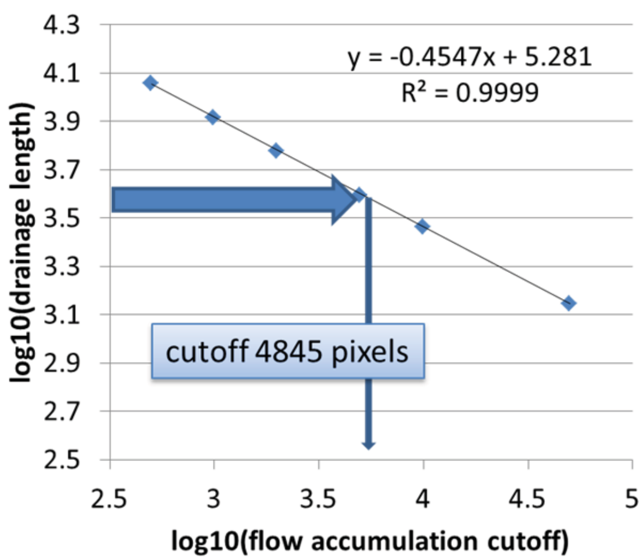

Figure 5: Relation between Total Drainage Network Length and Flow Accumulation Area parameter.

The calibration performed above highlights the critical dependency of the model on the flow accumulation cutoff for estimating absolute soil loss. In fact, we find that soil export (E) is a simple power law of the flow accumulation threshold (FT), namely $E = c\ FT^{-0.45}$ in this particular watershed, i.e. increasing flow threshold 4 fold, decreases soil export roughly by a factor of 2.

Once calibrated, we use the InVEST model for the current and future scenario, and evaluate the sensitivity of the absolute and relative change in soil loss. The results are summarized in Table 9. Evidently, absolute change is sensitivity to the stream network density, but relative change in soil loss shows no clear trend. This suggests that we can estimate relative soil loss without detailed data on suspended sediment, and indeed without calibration, for watersheds as large (or as little) as the Skunk River. Furthermore, we find that using only USLE, without running our full model (which includes sediment retention and routing), we can predict the relative change in soil loss within the same range as with the full model.

Table 9: Sensitivity of Absolute and Relative Soil Loss Change to Flow Accumulation Threshold

Flow Accumulation Threshold (pixels)	Absolute Change in Soil Loss (tons/yr) Basin-Wide	Relative Change in Soil Loss (%) Basin-wide
500	-946600	-22%
1000	-738360	-22%
2000	-583420	-23%
5000	-421400	-24%
10000	-305143	-23%
50000	-109382	-19%
USLE approach	N.A.	-20%

We repeat the same procedure for the other five watersheds. In two watersheds (Des Plains River and Hellbranch Run) we find similar power law dependence (albeit with different exponent and pre-exponent than in Skunk River). Table 10 summarizes for all six watersheds the relative change in soil loss predicted from our calibrated InVEST model to the value from using only the USLE:

Table 10: Absolute relative change in soil loss between current and future scenarios in the six watersheds.

Test watershed	Area (ha)	Predicted Soil Loss at outlet (tonnes/yr)			
		Current Scenario	Future Scenario	Change (%)	USLE only (%)
White Creek	731	745	744	0%	-8%
Walnut Creek	1,743	487	430	-12%	-24%
Hellbranch Run	8,517	3,072	408	-87%	-86%
Des Plains River	165,245	30,260	18,183	-40%	-49%
Bad River	814,279	591,246	579,164	-2%	-3%
Skunk River	1,106,880	1,745,180	1,323,780	-24%	-20%

We find that a to get a consistent estimate of relative change in soli loss using USLE approach, the spatial scale of analysis should be greater than 200,000 hectares. As 87% of all HUC8 units in the US Midwest are larger than this cutoff, we decide to use this scale in the Midwest scale analysis.

Relative Change in Soil Loss in the US Midwest

We now turn to the main questions of this study, namely estimating the impacts of biofuel expansion on the Midwest scale using the USLE approach. Our two goals are to identify the impacts of the new EISA on soil loss, and determine what areas of the Midwest would need more attention to prevent deleterious environmental impacts of the new energy policy.

Land Use/Land Cover Changes

As described in the Methodology, the current and future scenarios were taken from studies done by the National Exposure Research Laboratory (NERL) of the US EPA. The two main drivers used in predicting the 2020 scenario were increase in corn production, to comply with EISA mandate, and urbanization due to population growth. While a detailed analysis of predicted LULC changes is found in the original publication by Mehaffey et al. (Mehaffey, Smith et al.

2012), we assessed the LULC changes that would affect soil loss. Comparing the current and future LULC maps, we find that overall 13% of the land is predicted to undergo some LULC transition. Major LULC transitions and for each of 7 HUC2 sub-regions were analyzed using GIS, and are shown in Table 11; with a finer-scale spatial depiction of total LULC change (in %) throughout the region presented in Figure 6. Clearly, conversion of crop production systems to monoculture corn, or replacing wheat/soy by corn/soy are the major land use changes associated with biofuel expansion. In a few HUC2 units, the biggest driver of LULC change is urban expansion. Out of the total area of 231,261,166 hectares, monoculture corn is predicted to increase from 3.8% to 11%, 3% of the area will become urbanized, and corn/soy rotation will decrease from 14.4% to 9.5%. These changes will affect total crop production for individual agricultural sectors. Assuming a 2-year rotation period, we calculated the total area for each crop in the future. The future scenario predicts a 38% increase in corn production, 20% decrease in soybeans, 33% decrease in "undefined crops" (all other row crops, vegetables etc.), 22% decline in fallow area, and 10% less alfalfa. The soil loss implications for these crop production changes are described in the next section.

Relative Change in Soil Loss

Next we estimated the likely soil loss associated with the changes in land use and land cover outlined above. We use an aggregated USLE ratio to estimate relative soil loss change. Table 12 summarizes the relative change in soil loss in each HUC2 unit, as well as the entire mid-west. Overall, we predict a 9.5% decrease in soil loss in the future scenario. Only one region (Souris-Red-Rainy Region, HUC2 code 9) is predicted to have a slight increase in soil loss. This region has mostly wheat/other crop converting to soy/wheat, and almost the same area of soy/wheat converting to corn/soy (Table 11). The change in soil crop management factor (C factor) is relatively small for these LULC transitions (Table 4)—for example, wheat/other crop has a C factor of 0.24 and the C factor for corn/soy is 0.28.

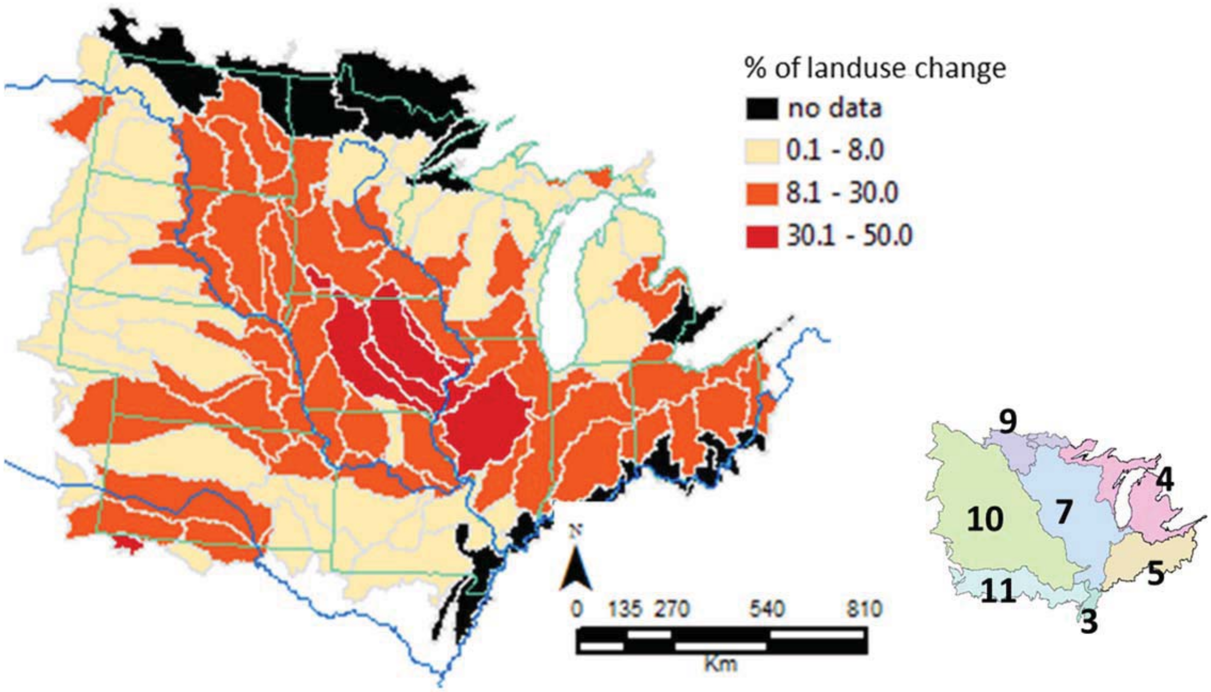

Figure 6: Map showing percent of land use change in each basin at the HUC 6 level. Basins with part of their drainage outside of EPA's land-use data set are shown in black, and could not be analyzed because of missing data. Insert shows the 7 HUC2 regions comprising the Midwest area - Arkansas-White-Red Region (HUC2 Code 11); Great Lakes Region (4); Lower Mississippi Region (3); Missouri Region (10); Ohio Region (5); Souris-Red-Rainy Region (9) and Upper Mississippi Region (7)

The finer-scale spatial pattern of relative soil loss shows a much greater variability in relative soil loss change (Fig. 7). Some sub-regions are predicted to exhibit up to 35% *increased* soil loss, whereas others are likely to experience up to 60% *decrease* in soil loss due to future changes in LULC. The spatial scale for this analysis is the HUC8 units, which we found in the individual watersheds analysis to be adequate for this analysis.

Finally, we divide the Midwest into areas where our model predicts an increase in soil loss (16% or the total land area), and areas where we predict a decrease (84% of the land area). Figure 8 shows that most of the area where soil loss is expected to increase is in Kansas, North and

South Dacota, and Missouri. In the state of Kansas, 50% of the land is expected to have some increase in soil loss by the new EISA energy policy.

Table 11: Major LULC Transitions in each HUC2 unit and the entire US Midwest. The dominant transitions in each HUC2 are in bold. Transitions sorted in descending order based on the maximal relative change among all HUC2 units. In all regions, over 80% of the total LULC change (last row of table) is captured by the 11 transitions listed.

LULC Transition		Percentage of given LULC transition in each HUC2							
Current	**Future**	**11**	**4**	**8**	**10**	**5**	**9**	**7**	**Midwest**
Corn/soy	Monoculture corn	0.0%	14.5%	0.0%	**35.5%**	**50.9%**	13.1%	**71.0%**	**40.7%**
Undefined crop	Monoculture wheat	**39.0%**	0.0%	0.0%	3.8%	0.7%	0.0%	0.2%	2.2%
Soy/wheat	Corn/soy	0.0%	0.0%	0.0%	3.7%	0.0%	**38.7%**	0.7%	4.7%
Wheat/other crop	Soy/wheat	0.0%	0.0%	0.0%	5.4%	0.0%	36.0%	0.0%	4.6%
Forest/shrub/grassland	New Urban	7.2%	**34.6%**	1.1%	5.8%	10.3%	2.3%	6.5%	10.2%
Undefined crop	New Urban	1.9%	6.0%	**24.9%**	0.9%	4.4%	0.6%	1.5%	2.2%
Soy/other	New Urban	0.8%	1.7%	20.2%	0.8%	1.6%	0.4%	0.9%	<2%
Undefined crop	Monoculture corn	19.1%	12.5%	13.0%	14.6%	17.3%	4.0%	6.3%	9.5%
Undefined crop	Soy/wheat	0.0%	16.1%	0.0%	5.9%	0.0%	0.0%	0.1%	2.9%
Corn/soy	New Urban	0.6%	1.3%	15.9%	3.3%	4.0%	0.6%	4.3%	2.9%
Pasture/Hay	New Urban	14.5%	4.3%	11.4%	2.6%	6.1%	0.2%	1.7%	2.9%
% of region undergoing LULC change		**6%**	**11%**	**3%**	**9%**	**20%**	**18%**	**22%**	**13%**

Table 12: Relative Change in Soil Loss for each HUC2 region and the US Midwest. Relative change is soil loss was estimated based on the ratio of aggregated USLE calculated for the current and future scenario.

Region Code	Name	Change in Soil Loss
11	Arkansas-White-Red Region	-7.3%
4	Great Lakes Region	-12.7%
8	Lower Mississippi Region	-4.6%
10	Missouri Region	-10.1%
5	Ohio Region	-7.4%
9	Souris-Red-Rainy Region	0.7%
7	Upper Mississippi Region	-10.0%
-	Entire Midwest Region	-9.5%

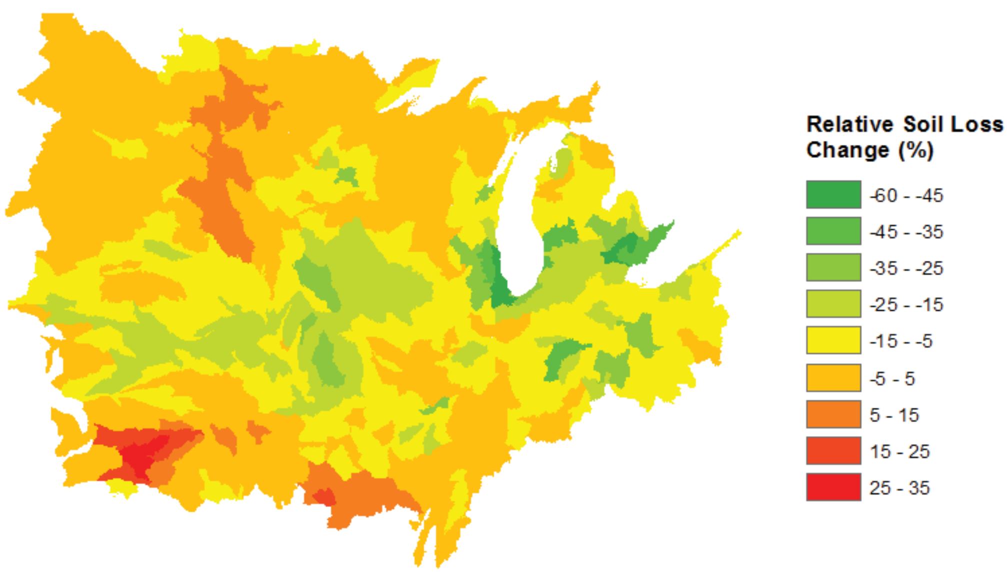

Figure 7: Relative Soil Loss Change at the HUC8 scale for the US Midwest

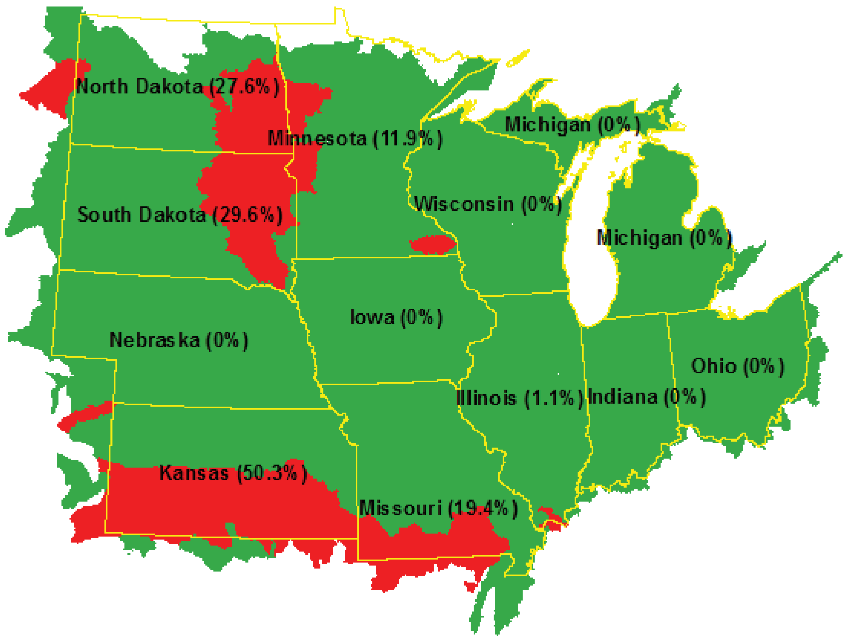

Figure 8: Relative area in each state expected to experience an increase in soil loss in future scenario.

Separating Biofuel Expansion and Urbanization Drivers

We found that two major drivers of LULC change, namely increased corn production for biofuels and increases in urban areas, tend to decrease soil loss in most HUC2 units. For the policy issue related to biofuel expansion, it is important to separate the two drivers. Ideally, a "business-as-usual" future scenario that has no biofuel expansion should be derived. Alternatively, since we use aggregated USLE ratio, we can computationally separate the impacts of biofuel expansion and urbanization. As Table 11 shows, most of the additional corn is assumed to come on the expense of soybeans, but other areas are predicted to start producing soybeans to compensate (partially) for that lost. Thus, the LULC transitions associated with the new energy policy are conversion of land to monoculture corn, or non-corn production systems converted to corn rotation (corn expansion), as well as conversion of land to monoculture soybean or non-soybean production systems converted to soy rotation (soybean displacement). As we highlight above, the future scenario predicts a net 20% decrease in soybean production, which will either go somewhere else within the US, or increase dependence on soybeans import (potentially causing land use change elsewhere on the globe). In Table 13 we break down the relative soil loss in Table 12 into these three drivers –expansion of corn production, soybean displacement and expansion of urban areas. These three drivers capture between 87% and 100% of the relative soil loss change. The results are shown in Table 13 for each HUC2 unit, as well as for the entire Mid-West. We find that in Arkansas-White-Red Region (#11), Great Lakes Region (#4) and Lower Mississippi Region (#8), the predicted decrease of soil loss is mainly because of new urban area. Urbanization is also the major driver in Ohio Region (#5). Biofuel expansion and urbanization are equally important in Upper Mississippi Region (#7), and contributes roughly 2/3 of the change in Missouri Region (#10). The only region where biofuel expansion will cause a net increase is Souris-Red-Rainy Region (#9), where we predict a net 2.6% increase due to biofuel (4.4% minus 1.8%), but urban expansion is predicted to cancel most of that change. In the mid-west scale, corn expansion is predicted to cause 5.2% decrease of soil loss, with urbanization contributing 3.8% to the total decrease.

Table 13: Breakdown of Relative Soil Loss Change to Major Land Use / Land Cover Change Drivers. The dominant factor in each HUC2 is highlighted in bold.

LULC Change Driver	Relative Change in Soil Loss per HUC2							
	11	4	8	10	5	9	7	**Midwest**
Corn expansion	-0.7%	-1.3%	-0.7%	**-7.2%**	-2.8%	4.4%	**-5.2%**	**-5.0%**
Soybean displacement	-1.7%	-1.3%	0.2%	0.0%	0.1%	-1.8%	0.1%	-0.2%
Urban expansion	**-4.3%**	**-8.4%**	**-3.8%**	-2.9%	**-4.7%**	-1.9%	-3.9%	-3.8%
Other	-0.5%	-1.7%	-0.2%	0.0%	0.0%	0.0%	-1.0%	-0.5%
Total (see Table 12)	**-7.3%**	**-12.7%**	**-4.6%**	**-10.1%**	**-7.4%**	**0.7%**	**-10.0%**	**-9.5%**

Key Findings, Remaining Uncertainties and Next Steps

This study analyzed the implications of the 2007 Energy Independence and Security Act (EISA) on soil loss in the US Midwest. In particular, we used a year 2020 land use/land cover (LULC) map, predicted based on expected demands for corn and urban population growth, that the EPA NERL produced, and compared it to a year 2001 baseline. Our study focused on the impacts of LULC change on water-caused sheet erosion. Our key findings were:

1. The overall soil loss across the Midwest is predicted to decrease by 9.5% by year 2020.
2. Whereas in all but one HUC2 regions we expect reduced soil loss, there is large spatial heterogeneity across the Midwest, with some HUC8 units experiencing increase of up to 35% whereas in some soil loss decrease by as much as 60%.
3. Separating biofuel expansion and urbanization driven LULC changes, we find that the impact of the new energy policy is a dominant factor in HUC2 regions 7, 9 and 10 (Upper Mississippi Region, Souris-Red-Rainy Region and Missouri Region) – namely in the “Corn Belt”.
4. Soil loss is predicted to increase in some HUC8 units in the far north and far south of the US Midwest, suggesting targeted policy aimed at preventing soil loss in these areas (for example by promoting more no-till/mulch till practices) should be considered.
5. Much of the US Corn Belt region is predicted to have less soil loss. This result is mainly driven by conversion of corn/soy rotation to monoculture corn. While this seems beneficial, we caution that other considerations need to be taken into account. In particular, combining this analysis with an estimate of Nitrogen leakage into waterways and the Gulf, which we expect to increase by this LULC transition, is a promising direction for future study.

Evaluating the impacts of a new energy policy, such as the mandate to increase the amount of bioethanol in transportation gas by 2020, requires careful consideration of scope, scale and methodology. Our analysis focused only on the impacts of LULC changes needed to produce corn for first generation biofuel. It would be very valuable to extend this to include different second generation biomass (e.g. corn stover, perennial switchgrass etc.) that can be grown on marginal land or, when managed properly, on Conservation Reserve Program areas. Furthermore, the new energy policy will necessitate construction of many new refineries, causing LULC change (e.g. construction of access roads and pipelines) that may also impact soil loss. Furthermore, this analysis focused on the US Midwest, but it is reasonable to expect that the predicted decrease in soy production (20%) and other crops (33%) will cause LULC change elsewhere in the continental US, potentially leading to increase soil loss elsewhere.

Significant methodological improvements were made in this project, in particular the quantitative derivation of crop management factor (C factor) from literature and the USDA annual Agricultural Resource Management Survey (ARMS) and derivation of roughness coefficients from meta-analysis of vegetation buffers. We have shown that when suspended sediment gauge data exists, and an estimate of gully erosion is available (even at a very coarse scale), we can get good agreement between modeled and average gauge data. We plan to proceed with improved validation of the model using a nested design where multiple gauges exist on the same stream. We also found the spatial scale that allowed using the USLE approach to give an adequate estimate over a region as large as the US Midwest.

As is the case with all modeling exercises, we used simplifying assumptions to complete our analyses, and summarize those and potential implications for findings in Appendix I. More detailed analysis and ground-truthing of the approach presented here would help illuminate local conditions that mediate sediment sources and reduce their transport into receiving water bodies. In general, we were unable to capture local effects of agricultural practices. For example, there is a lack of primary data on sediment delivery ratio for many types of buffers/strips, and the USLE parameters for “undefined crop” or “other crop”. In addition, we were not able to capture the effects of subsurface drainage (tiling) to increase productivity on poorly drained soils and the use of cover crops on soil loss. Ground-truthing estimated soil loss under specific agricultural practices and contexts would help calibrate our more generalized results.

This study can be extended into many promising new avenues for research. Some particular topics we would recommend to pursue are:

1. Including the “demand” side for soil retention, being any economic valuation for the impact of the EISA on operational costs of reservoir operators and water utilities, as well as potential productivity losses by farmers. This will require using the full model (which we expect to be able to do with the new InVEST version coming soon) and estimating the contribution sheet wash erosion compared to other sediment sources.
2. More careful analysis of urban areas soil delivery, as we find these have major impact in several HUC2 regions.
3. Trade-off analysis between change in soil loss and change in Nitrogen leakage into water bodies and the Gulf
4. Extending the analysis to include second generation biofuels
5. Use primary and secondary sources to study the impact of tiling and cover crop practices on USLE and sediment retention/transport.

Finally, much of the area studied suffers from wind erosion, which can even dominate over water erosion in some places. A promising direction for further research would be to build upon simple models developed by USDA to estimate annual wind erosion (e.g. the Universal Wind Erosion Equation). This will allow predicting how the 2007 Energy Independence and Security Act will impact both relative changes in water erosion and wind erosion.

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Appendix I

As with any modeling exercise, this study made many assumptions and simplifications. Some of these are listed below:

1. The C factors for particular crops were assumed to be identical over the entire Mid-West, despite being derived from different C factor values in EI 2, EI 3, EI 14 and EI 16. Since the different EI regions mainly differ by a factor affecting all crops, relative soil loss is not expected to be very sensitive to these differences. Thus, we don't expect this simplification to affect much our conclusions.
2. We compiled data on tillage practices from USDA ARMS hosted on the USDA website. The ARMS can be further stratified to get information on the correlations between previous year harvest and current year tillage practices. For example, it is known that corn after corn needs more intensive tillage than corn after soybean. Preliminary analysis we performed for corn/corn vs. corn/soy suggests this improved analysis will decrease slightly the difference between the two C factors, but the C factor for corn/soy remains higher than corn/corn. We expect this to change the magnitude of changes in Tables 12 and 13 as well as the values in Figure 7, but the spatial pattern in Figure 7 is likely to remain unchanged.
3. We used very rough estimates of gully to sheet wash components contribution to sediment gauges. Some studies showed this ratio can be measured using isotope analysis of sediments. Possibly, better and more spatially refined ratios can be found by scanning primary literature. Since this was used only in the individual watersheds analysis, we do not expect this will affect our conclusions.
4. The classification of LULC to "undefined crop" or rotation with "other crop" makes accurate estimate of C factor difficult. Potentially, one can use global datasets of 175 different crops production (Monfreda et al. (2008)) to stratify this "other crop" class, and improve the C factors for some of these. If there is no bias from the C factors we used in this study, we expect this to have minor effect at sufficiently large scales (where many different crops comprise the "other" class).
5. We used STASTGO dataset, whereas SSURGO is a newer and more detailed dataset that covers the entire Mid-West. However, SSURGO is distributed in legacy tile file format, and creating seamless spatial datasets from SSURGO was beyond the capabilities of our project. Since we report our results at the HUC8 or larger scales, we expect the differences between the two to be minor.

6. We find great variability of the calibrated flow accumulation threshold between watersheds. Finding some generalized model to predict this cutoff from watersheds characteristics might be possible, but was beyond the scope of this project. If successful, this would allow using the full InVEST sediment model at the Midwest scale.
7. We assumed a two-year rotation in all land use/land covers such as corn/soy etc. In many places, however, farmers use a rotation of 3, 4 or even 5 years. It is easy to extend our analysis to include more refined LULC classes, and use a more resolved version from the original 96,295 distinct crop combinations found by Mehaffey et al. Improving on this assumption will probably decrease the difference in C factor between corn/soy and corn/corn, and make the expected decrease in soil loss smaller.