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Ephemeral gullies and ecosystems services: Social and biophysical factors

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Ephemeral gullies and ecosystem services: Social and biophysical factors

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Chapter 1. General Introduction

Introduction and Project Description

Agricultural lands provide humans with an abundance of services. While they are currently primarily managed for the production of food (and to a lesser extent, fuel and fiber), agroecosystems can also provide many other beneficial ecosystem services, such as carbon sequestration, water quality enhancement, and wildlife habitat (Boody et al. 2005; Millenium Ecosystem Assessment 2005). Currently, the emphasis of Iowa's agricultural landscape is the provisioning of food. Often, this comes at the expense of other ecosystem services, such as provisioning of clean water. Agriculture is the leading source of water quality impairment in the state, and in the United States (US EPA 2010). Contamination by pathogens, nutrients, sediment, and heavy metals are all major causes of impairment (US EPA 2009).

Many management practices have been implemented to decrease water pollutants coming from agricultural fields. Both in-field and edge-of-field or after-field solutions have been used (Dabney et al. 2006). Decreasing the amount of tillage has been shown to decrease the amount of runoff and sediment from crop fields (Gebhardt et al. 1985). Cover crops can also decrease the amount of surface runoff and erosion (Hargrove 1991). Riparian buffers and grass filters have been used to reduce the amount of sediment and nutrients leaving agricultural fields (Dillaha et al. 1989; Daniels and Gilliam 1996; Dosskey 2001; Lee et al. 2003; Schultz et al. 2004; Lovell and Sullivan 2006). The restoration of wetlands can decrease nutrient concentrations in surface water (Zedler 2003).

While the ecological and technical understanding for limiting water pollution exists, the key challenge has been implementing these practices in the landscape. The majority of non-point source pollution comes from private lands, so the implementation of practices to limit it is voluntary. Regulating pollution or incentivizing conservation are two potential routes through which more conservation practices could be adopted on private lands.

Since the Clean Water Act, regulation has existed that could allow the Environmental Protection Agency (EPA) to create rules and regulations that would ensure water quality (U.S. Congress, 1972). However, the act as it applied to non-point source pollution was largely ignored until the 1990s (Shirmoahmmadi et al. 2006). Since then, various designated uses have been established for water bodies. Water bodies not meeting one or more designated use are placed on the Impaired Waters List (303d list). After being placed on the 303d list, the development of a Total Maximum Daily Load (TMDL) for sources of impairment, such as phosphates or sediment, are developed. Currently, these TMDLs merely serve as targets for watershed improvement projects, but this framework could be adapted for use as a regulatory framework. However, because most of these water quality issues are caused by non-point source pollution, enforcement by fines would be difficult. Therefore, most effort has been focused on incentives.

There exist many government programs that pay farmers to implement land use practices designed to improve water quality by decreasing the amount of sediment and nutrients leaving their farms. Regardless of the way water quality is achieved, the effectiveness hinges on monitoring. Because monitoring on the scale large enough to be effective for non-point source pollutants would be cost-prohibitive, the ability to estimate management effects on water quality through the use of modeling is necessary (Kroeger and Casey 2007). These models must not only be able to provide baseline estimates for the amount of soil erosion and sediment delivery occurring, but also be able to accurately reflect expected changes in water quality resulting from changes in management.

This study aims to build on the knowledge base necessary to improve the ability of agriculture to provide ecosystem services. The first portion of the study examines the ability of a model (the Water Erosion Prediction Project or WEPP model) to accurately predict soil loss and sediment delivery in watersheds with ephemeral gully erosion. This model includes the ability to estimate the effect of differing management practices on water quality, and could be an important tool in assessing ecosystem services. The second portion of the study examines the factors responsible for the connectivity of gullies in the agricultural landscape. Both in-field abiotic factors and edge-of-field vegetation characteristics are examined to attempt to identify key factors that could prevent the integration of gullies from fields to streams. Knowledge about how plants act as barriers to the transportation of sediment from fields to streams is important in determining practices to be incentivized in ecosystem service regimes. Finally, the third portion of the study seeks to provide a social context to the preceding chapters. In interviewing farmers about conservation practices, potential barriers to the increased adoption of practices crucial for ecosystem service provision are identified, areas where farmers may be open to new management practices that have the potential for increasing ecosystem service provision.

Thesis Organization

This thesis is arranged into five chapters. The first chapter is an introduction to the topics covered. The second chapter is entitled "WEPP and ephemeral gullies: predicted vs. observed sediment delivery" and has been modified from a manuscript prepared for submission to the *Journal of Soil and Water Conservation*. In this chapter, I evaluate the ability of the Water Erosion Prediction Project (WEPP) model to estimate sediment delivery related to ephemeral gullies. The third chapter is entitled "In-field and edge-of-field factors influencing ephemeral gully connectivity" and has been modified from a manuscript prepared for submission to the *Journal of Soil and Water Conservation*. In it, I identify the ecological factors contributing to the connectivity of gullies in the agricultural landscape based on field surveys. The fourth chapter is entitled "Ditches, washes, and decision making: Contextualizing the Lake Darling watershed project" and has been modified from a manuscript prepared for submission to the journal *Society and Natural Resources*. In this chapter, I interview some of the farmers on whose land the biophysical chapters were conducted in order to place that research into a social context.

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Chapter 2. WEPP and ephemeral gullies: Predicted vs. observed sediment delivery

Modified from a paper to be submitted to *Journal of Soil and Water Conservation*

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Abstract

Ephemeral gully erosion has been recognized as a significant erosion process for many years. Ephemeral gullies (EGs) are incised channels that form in the swales of agricultural fields in between tillage events. Factors such as soil type, rainfall, vegetation type, and management practices influence the size and location of EGs. The contribution of EGs relative to other forms of erosion varies throughout the world, but may increase in coming years due to climate change. Because EGs are an important erosion process, models to assess soil erosion need to accurately include it in their estimates. The Water Erosion Prediction Project (WEPP) includes an estimate of EG erosion. The objectives of this study were to measure annual soil loss from EG channels, sediment yield at the outlet of a small watershed (0.35 ha) containing an EG, and to assess the accuracy of WEPP at predicting both. Based on previous research on EGs and WEPP, we hypothesized that WEPP would not accurately predict EG erosion. To test the hypothesis, we measured the amount of soil lost from EG channels on six different farms in the Lake Darling watershed in southeast Iowa. A total of 79 metric tons of soil was observed to be lost in 2009 from the 20 EG channels measured. We also measured sediment yield at the outlet of a 0.35 ha subwatershed for individual rainfall events with an automated water sampling unit. For the 18 runoff events

measured in a small watershed containing an EG, a total of 50 metric tons of sediment was delivered to the outlet of the 0.35 ha watershed. These results were then compared to outputs from the WEPP model. Although the WEPP model performed well at predicting hydrological characteristics of rainfall events, it showed poor performance for predicting sediment loss and yield related to EGs. Its inaccuracy was probably related to its failure to account for dominant EG erosion processes. Headcut erosion is probably the most important of the processes missing from the model and its impact should be further studied. Unreliability of topographic maps due to subsurface drainage and microtopographical changes resulting from field work was also noted.

Introduction

Concern with ephemeral gully erosion has been growing since the mid-1980s, when it was first recognized by the scientific community as an erosion process separate from sheet and rill erosion (Foster 1986). Ephemeral gullies (EGs) are incised channels that form in areas of concentrated flow within agricultural fields. The word ephemeral is used because these channels are typically obliterated by tillage, leaving a depressional swale, and the gully re-forms in the subsequent year. EGs are distinguished from rills in that they form in swales rather than on planar areas, and by a critical channel cross-sectional area of one square foot (Poesen *et al.* 1996; Capra *et al.* 2009).

Along with being a significant sediment source (Valentin et al. 2002; Poesen et al. 2003), EG erosion decreases land value and reduces soil productivity. EGs hinder harvest because crossing them can damage farm equipment. Severe gullying necessitates disking or plowing in the gullies which takes time, increases cost, and moves more topsoil into erodible concentrated flow paths (Foster, 2005).

The threshold for ephemeral gully erosion initiation is influenced by a number of various factors (Horton, 1945; Poesen *et al.* 2003). Critical thresholds for channel initiation by concentrated overland flow have long been recognized. When the erosive power, or shear stress, of concentrated water reaches a certain level (critical shear stress), soil detachment occurs. Once detachment is initiated, EGs expand through gully sidewalls steepening and sloughing, bed incision, and headcut retreat (Bennett et al., 2000; Casali et al. 2000). While this can sometimes occur along linear landscape features, such as tractor ruts or old field drives (Poesen *et al.* 1998; Zhang *et al.* 2007), usually the concentration of water on the landscape is a function of slope gradient and upslope contributing area (Moore *et al.* 1988; Vandaele *et al.* 1996; Vandekerckhove *et al.* 1998; Desmet *et al.* 1999). Size and length of the watershed of the gully (gullyshed) can also influence the volume of runoff (Capra & Scicolone 2002). This threshold can change considerably, however, based on secondary factors, such as climate, soil type, vegetation type, and management practices.

Rainfall is the first of the secondary factors that can increase or decrease the critical threshold of gully formation. The amount and intensity of rain, its erosivity, and the antecedent soil moisture conditions all influence the runoff causing EG erosion (Capra *et al.* 2009). The size of rainfall event required to initiate gully formation has been shown to vary between 14 and 22 mm depending on soil type and moisture conditions (Poesen *et al.* 2003). One study found that a higher threshold for rain was required during summer months than later winter/early spring months because of lower antecedent soil moisture (Poesen *et al.*

2003). Soils that are thawing or that have recently thawed can be especially susceptible to EG erosion (Oygarden 2003; Poesen *et al.* 2003; Zhang *et al.* 2007).

While the assessment of the contribution of EGs to total soil erosion relative to sheet and rill erosion has been limited, estimates range from 10 to 94% throughout the world, and from 18-73% in the United States (Poesen *et al.* 2003). The most recent survey in the state of Iowa was in 1997, when it was estimated that EG erosion was responsible for 3 tons/acre/year or approximately 31% of total soil loss (USDA-NRCS, 1997). In the U.S., measured EGs ranged from losses of 1.22 tons/acre/year in Michigan to 12.8 tons/acre/year in Virginia (USDA-NRCS, 1997).

Climate change research is showing that rainfall amount and intensity has increased and is projected to continue to increase in the coming decades (Kunkel *et al.* 1999; Easterling *et al.* 2000; MacCracken *et al.* 2003). More unstable winter conditions such as more freezing and thawing and more intense rain are likely to increase the risk of ephemeral gullying (Poesen *et al.* 2003).

Currently, the USDA NRCS conducts the National Resources Inventory every five years to estimate the annual amount of soil erosion in the United States on private land (USDA-NRCS 2008). The survey estimates sheet, rill, and wind erosion using the Universal Soil Loss Equation (USLE) and the Wind Erosion Equation (WEQ). In Iowa, the dominant erosion processes are water erosion processes. In the past 25 years, based on the results of the NRI, water erosion has decreased by 43% (USDA-NRCS 2008). The NRI provides information to the USDA and the public about how changing management practices can affect soil erosion. However, because they use USLE, an empirically based model that doesn’t include estimates for EG erosion, the survey may underestimate the total amount of erosion. Furthermore, because climate change may increase the amount of EG erosion in the future, the model may become increasingly inaccurate.

The incorporating of a model that includes EGs in its erosion estimation may be one way of correcting that potential inaccuracy. The Water Erosion Prediction Project (WEPP) watershed model does incorporate an estimate of EG erosion (Ascough et al. 1997). The WEPP watershed model is a process-based model that continuously simulates loss and deposition for hillslopes, channels, and impoundments in a small watershed to create an estimate of sediment yield at the watershed outlet (Ascough et al. 1997). However, it is asserted that the WEPP model is not applicable for areas which have headcut erosion or the sloughing of sidewalls (Ascough et al. 1997), which are both dominant EG erosion processes (Bennett et al. 2000; Casali et al. 2000). The model’s ability to accurately measure soil lost from EGs or from small watersheds (<5 ha) that include EGs has not been tested.

In addition to estimating the total sediment yield from small watersheds containing ephemeral gullies, it is possible that the WEPP model could be used to estimate the amount of soil loss exclusively from EGs. The model returns outputs for sediment yield both at the end of each hillslope in a watershed, and at the outlet of the watershed. Therefore, it is possible to deduce the amount of erosion coming from the EG channel by subtracting the yield at the watershed outlet from the yield at the base of the hillslopes. However, because some aspects of the EG erosion process are unaccounted for in the WEPP model, it has been asserted that the WEPP model will not accurately predict soil loss from ephemeral gullies (Casali et al. 2006).

The first objective of this study was to measure soil loss from EG channels on an annual basis, and sediment yield on an individual rainfall event basis at the outlet of a 0.35 ha row-cropped watershed containing an EG. The second objective was to determine the effectiveness of WEPP at predicting the values in the first objective. We hypothesized that WEPP would not accurately predict soil loss or sediment delivery. These hypotheses were tested in the Lake Darling watershed by comparing field measurements with WEPP predicted results.

Materials and Methods

Site Description

Both parts of the study were located in the 5,128 ha (12,672 ac) Lake Darling watershed, which is located in Keokuk, Jefferson, and Washington counties in southeast Iowa within the Southern Iowa Drift Plain Level III Ecoregion (Griffith et al. 1994). The dominant land use in the watershed is a corn-soybean rotation, comprising over 50% of the total area (Downing and Poole 2008). Most parts of the watershed have a topography that is level to moderately sloping (0-9%) and soils that are primarily loess (74%) and till (11%) derived (Downing and Poole 2008). Based on personal observation and conversations with local farmers, a minimum tillage regime is common in the watershed, although areas containing EGs are commonly tilled annually. Sites for comparing measured vs. predicted sediment loss on an annual basis were located on several private farms throughout the watershed. Sites were also used for a related study, where edge-of-field vegetation was also measured, and the site selection process is described in Chapter 3 of this thesis (Ohde 2011).

Average annual precipitation for the area is 762-1016 mm (30-40 in), although average rainfall from 2008-2010 was 1412 mm (56 in).

Annual Soil Loss from Ephemeral Gully Channel

Field edges were walked in the early summer of 2009, and swales identified where EGs were expected to form. In late fall 2009, after harvest, we returned and measured the twenty EGs that had formed. Because the channels would have been smoothed out for planting in the spring, it can be deduced that gully volume represented soil loss in the year of 2009. Measurement at the end of the season ensured that the gullies were at their largest extent. Volume of each EG was determined by measuring length with a measuring wheel and depth/width cross-sections at least every 5 meters. This method allows for the most accuracy with the least amount of error (Casali *et al.* 2006). Soil loss was determined by multiplying the measured gully volume by the bulk density of the soil. Soil type and bulk density was determined from Soil Survey Geographic (SSURGO).

Sediment Yield per Event from Small Watershed containing Ephemeral Gully

To monitor runoff and sediment yield from a small watershed (0.35 ha) containing an ephemeral gully, permission was obtained from a local landowner to construct a semi-permanent runoff sampling site. This study includes results from 2008 and 2009. The sampling site was located at the edge of a field on an EG channel. The sampling system included a 0.46 m H-flume, sidewall stilling well, and 2.46 m long by 0.88 m wide level plywood approach. An ISCO 6712 (Teledyne ISCO, Inc.) automated water sampling unit interfaced with an ISCO 720 submerged probe module (located in the stilling well) was used to monitor depths, convert depths to flow, and collect water samples. Flow and water sampling data were recorded in one minute increments. The sampling unit was programmed to begin collecting samples after the initiation of runoff, when measured flow reached 0.2 l/s. The automated sample schedule was designed to collect samples throughout entire rainfall events. Samples were collected into 24 500 mL bottles.

Soon after each rainfall event, samples were retrieved and returned to the laboratory for analysis. Sediment concentration was measured using vacuum filtration with a 0.45 µm sterilized membrane filter. Sediment load was determined by multiplying concentration by flow at the time the sample was taken. Flow in between samples was split between temporally adjacent sample values. Flow after the sampling program had been completed was assigned the average concentration of the last five samples. To maintain accuracy, events where no samples were taken from the rising limb of the hydrograph were not considered.

Model Inputs

After collecting soil erosion data in the field, the WEPP watershed model was used to generate predictions to compare with the measured values. The WEPP watershed model requires five main inputs: climate, slope, soil, management, and channel input files. For this study, daily minimum and maximum temperatures were input from a NOAA (National Oceanic and Atmospheric Administration) weather station outside of Washington, IA located approximately 19 km away from the site. Wind direction and velocity, dew point, and solar radiation were generated by CLIGEN, the WEPP weather generator. Daily precipitation data was recorded using a HOBO (Onset Computer Corp.) tipping bucket rain gauge located at the sample site. However, the rain gauge malfunctioned for 10 of the measured events. For these events, daily rainfall data from the Iowa Environmental Mesonet was substituted. Iowa Environmental Mesonet data was also used for the annual estimates. Iowa Environmental Mesonet estimates rainfall based on the National Center for Environmental Prediction Stage 4 precipitation analysis, which combines data from NEXRAD radar and NOAA weather station rain gauges to provide rainfall estimates for any given geographic point (IEM 2010, NOAA 2009). Although these data could have been used from the local rain gauge for some of the events, intensity, duration, and peak intensity of storm events were generated by CLIGEN to maintain uniformity across data.

For the management input, WEPP provided values were adapted to represent the timing of the crop rotation and tillage regimes present in the watershed of the site. WEPP default values were used for parameters specific to each crop.

GeoWEPP, an interface linking WEPP with ArcGIS, was used to organize information for slope and channel parameters. Digital elevation models (DEMs) were created using 1-m resolution Light Detection and Ranging (LiDAR) data from 2007. The topographical analysis software TOPAZ (Topographic PArameteriZation) is integrated into GeoWEPP and uses DEMs to delineate channel networks and watersheds. The TOPAZ component of GeoWEPP was used in this study to create hillslope and channel models for use in WEPP. Due to lack of field surveying of soils, soil input was based on SSURGO data from the USDA-NRCS. All channel inputs used were GeoWEPP generated values based on the soil type and topography of the gully site. Once delineated, channel length and soil parameters remain static, while cross-sectional parameters update after each rain event (Ascough et al. 2007). The modified EPIC method for peak runoff calculation in the channel was used, as recommended by Ascough et. al (2007).

Model Evaluation

To determine how well the WEPP model accurately predicted observed data, we used the Nash-Sutcliffe (NS) model efficiency coefficient (Nash and Sutcliffe, 1970):

$$NS = 1 - \frac{\sum_{i=1}^{n}\left(Q_o^i - Q_m^i\right)^2}{\sum_{i=1}^{n}\left(Q_o^i - \bar{Q}_o\right)^2}$$

where Q_o^i is the measured value of sediment yield, total flow or peak flow rate either for an event or for the year, Q_m^i is the modeled value, and $\bar{Q}_o$ is the average of the measured values. The NS model efficiency coefficient is a widely accepted indicator of goodness-of-fit, and has been used extensively for evaluating the WEPP model (Perez-Bidegain et al., 2010, Risse et al., 1994, Pandey et al., 2008, Zhou et al. 2009). Coefficient values range from -∞ to 1. Values closer to one indicate good model performance, while negative values indicate that using the observation mean would have more accurately predicted the measured results. The coefficient of determination (r^2) was also used to evaluate the best fit line between observed and predicted values.

Results and Discussion

Annual Loss from Ephemeral Gully Channels

A total of 20 EGs were measured on seven farms in the watershed. EG volume ranged from 0.32 m^3 to 11.79 m^3 (Table 1). For the 20 EG sites measured, a total of 79 metric tons of soil loss was lost from the EG channels during 2009 (Table 1). For the gullies measured, the WEPP model underestimated sediment loss, on average, by 60% (Table 1). However, the average overstates the model's effectiveness. In fact, because of the extreme variability in the model results, the relationship between predicted and observed values was not linear (r^2<0.01) (Figure 1). Consequently, the Nash-Sutcliffe efficiency (<0) suggested that using the observational mean would have been a better predictor than the WEPP model.

According to laboratory experiments by Robinson et al. (2000) and Bennett et al. (2000), dominant ephemeral gully erosion processes are headcut migration, bed incision, channel widening, and bank steepening. Observations from several of the gully sites perhaps illuminate further the importance of headcut erosion. At three sites—gullies #7, 9, and 15 (Table 1), the model predicted a net deposition of sediment in the ephemeral gully channel. While some deposition was noted in these gullies, net loss was measured from each.

The over-prediction of deposition within the channel is probably a result of the inability of the model to predict changes in the channel length (headcut migration) over time. As a gully grows longer, the contributing area at the nick point or headcut becomes smaller, causing discharge to decrease and gully width to be reduced. This leads to decreased sediment loads from the upstream portion of the gully, and resulting increased transport capacity and the deposition from earlier events become sources for sediment (Gordon et al. 2007).

Yield per Event from Small Watershed with Ephemeral Gully

In 2008 and 2009, 18 rainfall events were sampled successfully. The 18 events yielded a total of 50 metric tons of sediment at the outlet of the 0.35 ha watershed (Table 2). However, it should be noted that many rainfall events occurred during this time period that were not successfully sampled.

Water related outputs of the WEPP model were well predicted, as expected based on previous studies. Liu et al. (1997) reviewed data from 15 watersheds in six locations across the United States and found an average r^2 of 0.74 for runoff. The result from this study of (r^2=0.82, NS=0.66) would indicate that the model performed well for total runoff (Figure 2). Peak runoff rate was also well predicted (r^2=0.56, NS=0.50), indicating that the hydrological portion of the model performed well (Figure 3).

Sediment yield on an event-by-event basis was underpredicted by an average of 92% (Table 2). Figure 4 shows that there was a very weak linear relationship between the predicted and observed values for sediment yield (r^2=0.16). A Nash-Sutcliffe efficiency <0 indicates that using the observational mean would have better predicted sediment yield than the model.

Transport capacity, which determines the amount of erosion or deposition in a given section, is primarily determined by soil characteristics and flow velocity (Casali et al. 2000; Toy et al. 2002). Therefore, it might be expected that if WEPP accurately predicts the characteristics of runoff, that it would also accurately predict the amount of soil erosion or deposition. However, while it does consider changes in cross-sectional geometry from event to event, WEPP does not consider headcut erosion when simulating ephemeral gully erosion (Ascough et al. 1997). Previous field assessments have shown a significant positive correlation between ephemeral gully length and volume, indicating that accurate prediction of length is crucial for accurately estimating the size of the gully (Nachtergaele et al. 2001). Failure to incorporate headcut migration could result in an inaccurate estimate of length, and explain some of the model inaccuracy. The use of a model explicitly designed to estimate EG erosion or one that has been modified to include specific EG erosion processes--such as headcut dynamics--could solve some of these problems, however these models tend to require very detailed inputs (Gordon et al. 2008; Capra et al. 2005).

While some of the inaccuracies at both temporal and spatial scales could be due to inadequate modeling of erosion processes, inaccurate topographic representation could also play a role. Zhang et al. (2008) found that differing resolutions and sources of DEMs input to GeoWEPP significantly affected the output of WEPP for small forested watersheds.

Using a LiDAR derived representation of topography to predict water flow also ignores the effect of subsurface flow via tile drainage, visually observed at several locations in this study, which could significantly affect the contributing area of an ephemeral gully. It has often been noted that linear landscape features, such as tractor ruts can affect the microtopography of the field (Poesen *et al.* 1998; Zhang *et al.* 2007). While this may be negligible on a larger scale, the effect on flow routing for a watershed <2 ha may be significant. In a related project described in chapter 4 of this manuscript, while interviewing farmers, it was clear that alteration of the gullysheds took place on a regular basis with bulldozers and other equipment (Ohde 2011). So even if the LiDAR data was accurate in 2007 when it was collected, its accuracy may have decreased by 2009 when we delineated the watersheds and measured soil loss. Therefore, the size and location of the gullysheds derived by LiDAR may be inaccurate for very small watersheds.

In addition to reducing the accuracy of topographic inputs, the aforementioned field work involving the tilling and filling of EGs could alter the particle size and therefore the critical shear stress of the channel sediment.

Summary and Conclusions

A total of 79 metric tons of soil was observed to have been lost in 2009 from the 20 EG channels measured. For the 18 runoff events measured in a small watershed containing an EG, a total of 50 metric tons of sediment was delivered to the outlet of the 0.35 ha watershed. Although the WEPP model performed well at predicting hydrological characteristics of rainfall events, it showed poor performance for predicting sediment loss and yield related to EGs. Its inaccuracy was related to its failure to account for dominant EG erosion processes. Headcut erosion is probably the most important of the processes missing from the model because of the importance of length in predicting sediment yield from EGs.

Compiling the topographic inputs to use WEPP on a farm scale could also be problematic. Intuitively, it would seem that with increased accuracy provided by high-resolution maps, corresponding improvements in the accuracy of remote delineation of watersheds could be made. But because of subsurface drainage, and microtopographical changes caused by routine field work, that may not be a realistic assumption.

While the WEPP model may be practical for large scale erosion estimation, such as with the Iowa Daily Erosion project (Cruse et al. 2006), it may not be applicable on a very small scale. However, programs that pay farmers for ecosystem services need a way to accurately monitor the conservation effects of individual farms, if not individual fields. More site specific efforts combining in-field surveys with more detailed models may be needed for such monitoring.

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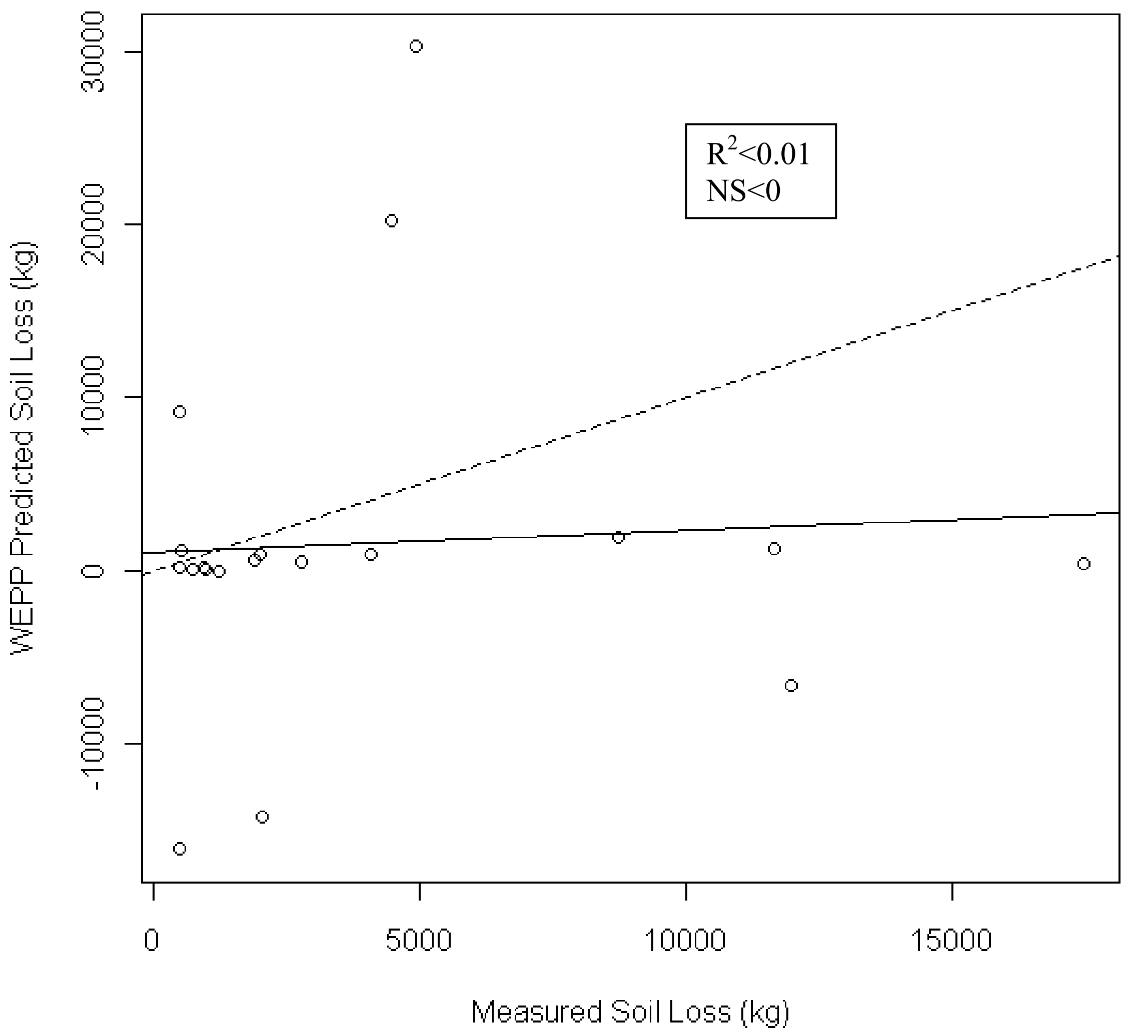

Figure 1. Measured versus WEPP-predicted sediment yield for 20 ephemeral gullies that developed in the Lake Darling watershed during 2009. The coefficient of determination (r2) and Nash-Sutcliffe (NS) index values were used to evaluate model performance. Dashed line represents 1:1 line.

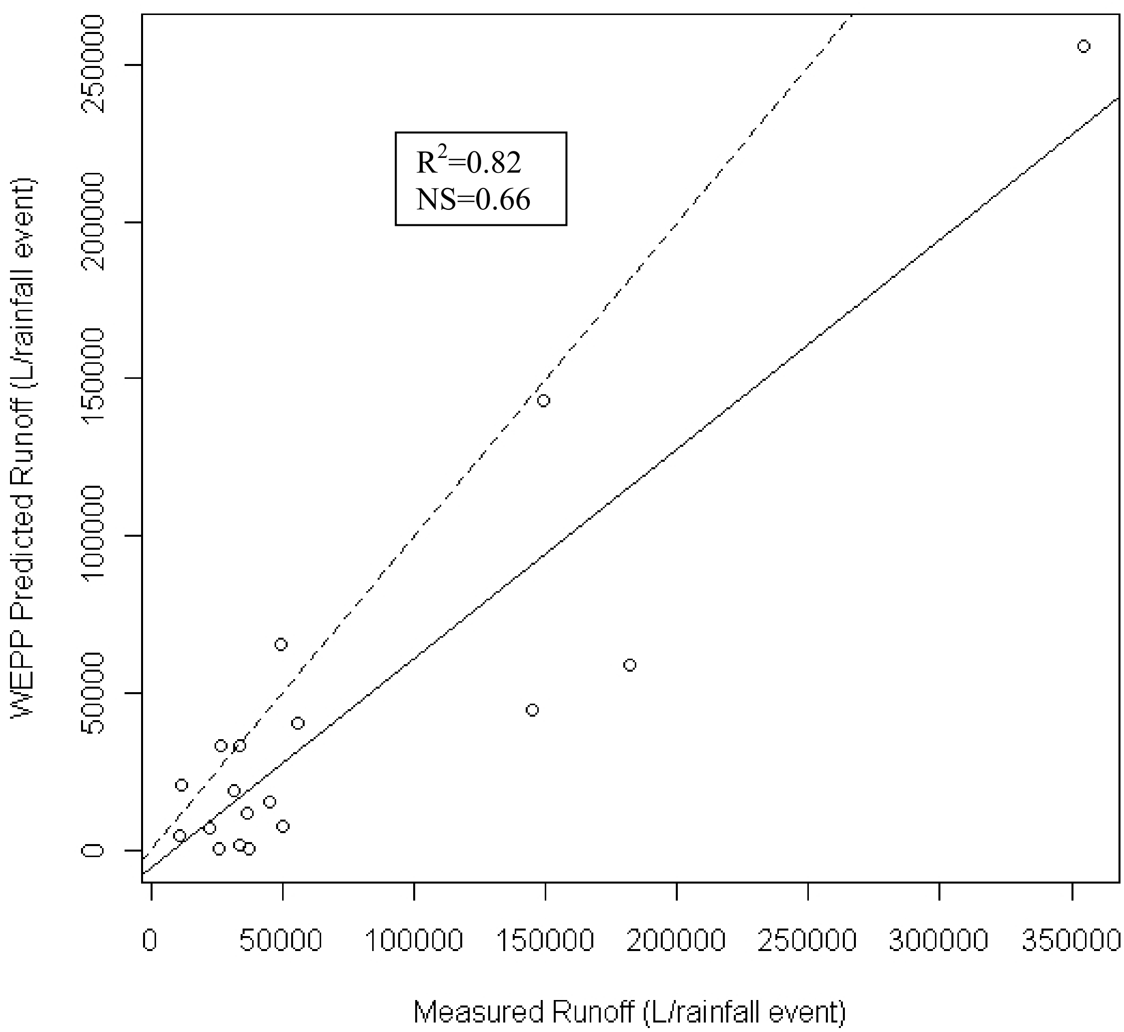

Figure 2. Measured versus WEPP-predicted runoff for 18 rainfall events during 2008-2009 from a 0.35 ha (0.86 ac) watershed near Lake Darling. The coefficient of determination (r2) and Nash-Sutcliffe (NS) index values were used to evaluate model performance. Dashed line represents 1:1 line.

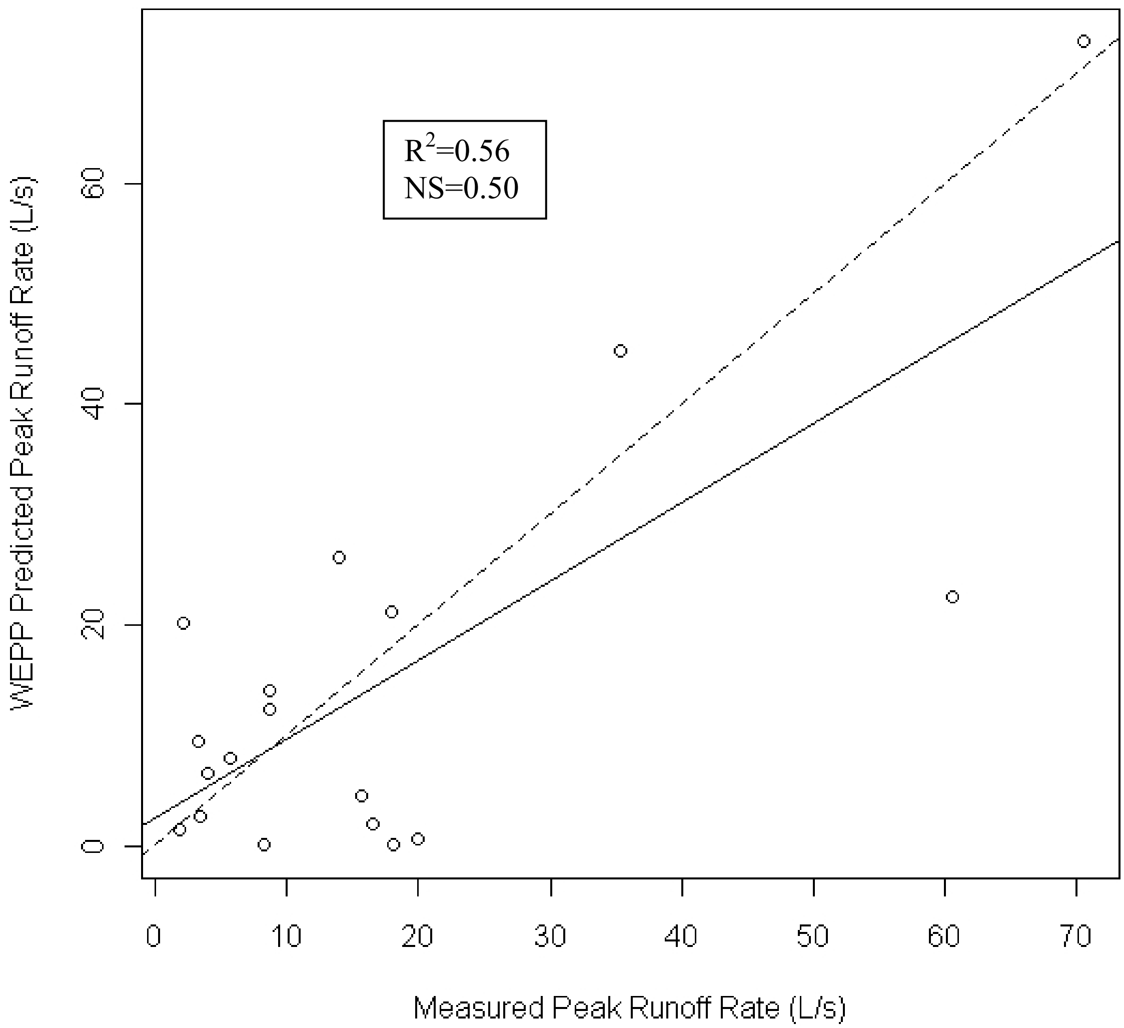

Figure 3. Measured versus WEPP-predicted peak runoff rate for 18 rainfall events during 2008-2009 from a 0.35 ha (0.86 ac) watershed near Lake Darling. The coefficient of determination (r2) and Nash-Sutcliffe (NS) index values were used to evaluate model performance. Dashed line represents 1:1 line.

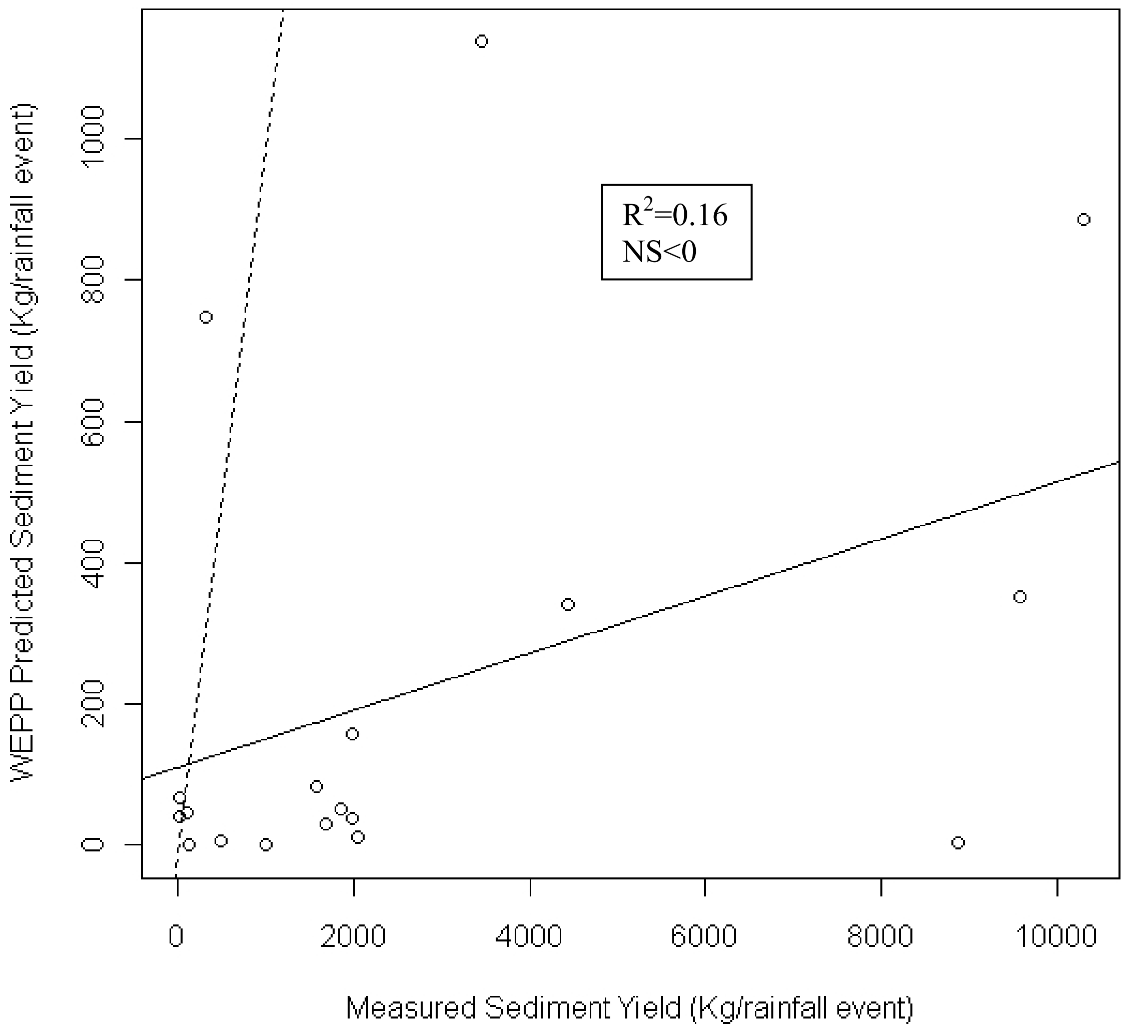

Figure 4. Measured versus WEPP-predicted sediment yield for 18 rainfall events during 2008-2009 from a 0.35 ha (0.86 ac) watershed near Lake Darling. The coefficient of determination (r2) and Nash-Sutcliffe (NS) index values were used to evaluate model performance. Dashed line represents 1:1 line.

Table 1. Volume, bulk density, and predicted and observed sediment loss from 20 ephemeral gully channels in the Lake Darling watershed in 2009. *Negative values indicate net deposition of sediment in ephemeral gully channel.

Gullies	Volume (m^3)	Bulk density (kg m^3)	Measured vs. Predicted	
			Measured sediment loss (kg)	WEPP sediment loss (kg)
1	0.92	1350	1242	15
2	8.64	1350	11664	1281
3	0.69	1350	932	156
4	0.73	1350	986	84
5	5.89	1480	8717	1892
6	0.33	1480	488	9129
7	1.48	1370	2028	*-14221
8	1.82	1520	2766	503
9	8.08	1480	11958	*-6671
10	0.35	1480	518	1209
11	0.32	1480	474	188
12	0.66	1480	977	72
13	11.79	1480	17449	406
14	3.37	1330	4482	20167
15	0.32	1520	486	*-16099
16	1.4	1350	1890	572
17	3.64	1350	4914	30253
18	0.50	1480	740	93
19	1.35	1480	1998	975
20	3.03	1350	4091	996
Total			78800	31000

Table 2. Predicted and observed total runoff, peak runoff rate, and sediment yield for 18 rainfall events in 2008 and 2009 at the outlet of a 0.35 ha watershed containing an ephemeral gully in Washington County, Iowa.

	Total Runoff		Peak Runoff Rate		Sediment Yield	
Date	WEPP Total Runoff (L)	Measured Total Runoff (L)	WEPP Peak (L/s)	Measured Peak (L/s)	WEPP Sediment Yield (kg)	Measured Sediment Yield (kg)
5.11.08	58,740	181,964	26.06	13.93	885	10,301
6.03.08	44,530	144,847	22.49	60.56	747	314
6.10.08	80	25,885	0.02	8.30	0	128
6.12.08	143,020	149,319	44.80	35.27	1,138	3,453
6.27.08	420	37,633	0.13	18.12	0.2	1,001
7.21.08	7,750	49,880	2.00	16.57	12	2,036
4.30.09	7,120	22,717	2.62	3.41	47	103
5.13.09	33,240	26,968	12.27	8.69	159	1,985
5.15.09	65,680	49,126	21.23	17.87	342	4,431
6.18.09	11,560	36,381	4.44	15.73	31	1,686
6.19.09	1,260	33,594	0.54	19.93	3	8,875
6.23.09	15,550	44,878	6.61	3.96	37	1,981
8.16.09	32,990	33,574	14.12	8.61	83	1,564
8.17.09	4,340	10,638	1.53	1.77	7	493
8.26.09	255,790	354,516	72.84	70.5	351	9,579
9.25.09	18,690	31,948	7.98	5.68	51	1,861
10.1.09	20,720	11,647	9.44	3.31	42	17
10.22.09	40,580	55,911	20.18	2.14	68	5

Chapter 3. In-field and edge-of-field factors influencing ephemeral gully connectivity

Modified from a paper to be submitted to the *Journal of Soil and Water Conservation*

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Abstract

Sediment is the most abundant water pollutant in the world, and each year it inflicts heavy costs on its citizens. There are many management practices, such as riparian buffers and grass filters, which exist to mitigate the amount of sediment that gets into water bodies. One soil erosion process, ephemeral gully erosion, which occurs in areas of concentrated flow, may deliver a disproportionate amount of sediment. When these in-field gullies are connected with gullies and streams outside of the field, they deliver much more sediment than if they were not connected. While the abiotic and biotic factors affecting sediment trapping ability for in-field and edge-of-field vegetation is well-studied, research is lacking on the factors discouraging the integration of gullies in the agricultural landscape. The objective of this study was to determine the characteristics of edge-of-field vegetation that effect the dispersal of concentrated flow paths and stop gully incision. We hypothesized that slope, hydraulic length, and size of the watershed of the ephemeral gully, gully volume, and shading at the field edge would be positively correlated with connectivity of ephemeral gullies. We also hypothesized that ground cover and plant biomass would be negatively correlated with connectivity of ephemeral gullies. To test these hypotheses, we carried out surveys to measure these in-field and edge-of-field factors. Twenty gullies were measured,

seven of which were connected to a perennial stream network. An estimated maximum of 34 metric tons of sediment had moved from the ephemeral gully to the stream since the last tillage in the connected gullies. Canopy density was the only factor significantly and positively correlated to gully connectivity. Root characteristics may play an important role in the stabilization of soil against gully incision and connection, and should be further studied. The results suggest that multispecies riparian buffers containing grass filters would be appropriate for addressing the many processes that contribute to gully connectivity.

Introduction

It has been estimated that soil erosion and the resulting sediment costs to the citizens of the United States is $16.05 billion per year (Osterkamp 1998). Soil erosion (on-site) costs are well-known to farmers, and have been decreased in the past few decades due to in-field practices such as minimum tillage and no-tillage regimes (USDA-NRCS 1997). In addition, sediment is the most abundant water pollutant in the world (Toy et al. 2002). While the sediment itself is of concern, it is also a concern because of the phosphorus that adheres to it, which is partially responsible for eutrophication in streams, lakes, and most notably in the Gulf of Mexico (Baker et al. 2008). Riparian buffers and grass filters have long been known to be an effective means of reducing the amount of sediment and nutrients leaving agricultural fields (Dillaha et al. 1989; Daniels and Gilliam 1996; Dosskey 2001; Lee et al. 2003; Schultz et al. 2004; Lovell and Sullivan 2006).

There are multiple biophysical factors that contribute to riparian buffers and grass filter's sediment trapping ability. Slope, soil type, sediment particle size, rainfall amount and intensity, and overland flow rates are several important abiotic factors (Dabney et al. 2006; Yuan et al. 2009). These are important for understanding and predicting sediment trapping, but are factors that are largely out of the control of the land manager. However, vegetation composition also plays an important role, and can be altered in accordance to NRCS standard practices, such as the Riparian Buffer (CP 22) or Grass Filter (CP 23) standards, or informally, through the strategic planting of specific perennial species.

There are various aspects of a plant community that contribute to the amount of sediment trapped in riparian buffers. Plant density, vegetation ground cover, and aboveground biomass can have a big impact on the amount of sediment trapped by vegetation (Pearce et al. 1998; Munoz-Carpena et al. 1999; Jin et al. 2002; Schoonover et al. 2006; Yuan et al. 2009). Numerous stems, thatch, and grass roots can help slow surface runoff, promote settling of suspended sediment, and prevent erosion from within the vegetative filter strip (Schmitt et al., 1999). While litter debris accumulated on the soil surface in wooded areas can create small terraces (<1 mm) that cause sedimentation (Leguedois et al. 2008), they may be easily moved by larger flow volumes (Daniels and Gilliam 1996). Shading could also have a negative effect on sediment trapping because of the prevention of continuous ground cover (Knight et al. 2010).

It has long been recognized that riparian buffers and vegetative filter strips become less effective as flow concentrates (Dillaha et al. 1989; Daniels and Gilliam 1996). Significant concentration of flow has been noted in numerous studies (Dillaha et al. 1989; Daniels & Gilliam 1996; Dosskey et al. 2002; Helmers et al. 2005a; Helmers et al. 2005b; Knight et al. 2010) More recently, the degree to which flow concentrates both in fields and in buffers has been studied more extensively (Dosskey et al. 2002; Helmers et al. 2005a; Helmers et al. 2005b). Often, if no conservation measure is taken, these areas of concentrated flow can turn into ephemeral gullies (Foster 2005). When integrated, gullies are effectively conduits that transfer sediment and runoff from upland areas where agriculture predominates to lowland stream channels. This increased connectivity in the landscape decreases the effectiveness of barriers to flow of sediment, nutrients, and other pollutants to downstream sources (Poesen 2003).

Knight et al. (2010) found that riparian buffers with grass filters dispersed more concentrated flow paths that those without. However, the biophysical mechanisms that contribute to concentrated flow dispersal in buffers have not been well studied. The processes of in-field vegetation's ability to disperse concentrated flow paths related to ephemeral gullies have been better studied in relation to vegetative barriers such as grass hedges and grass barriers.

Grass hedges or grass barriers are relatively narrow (<1.2 m), densely-spaced strips of grass planted perpendicularly across ephemeral gullies (Meyer et al. 1995). In research related to grass barriers, Dunn and Dabney (1996) found that the hydraulic resistance provided by stiff-stemmed grasses is critical for erosion control. This slowing of water caused by the hydraulic resistance allows water to pond and sediment to deposit uphill from the grass (Dabney et al. 1995; Meyer et al. 1995). Dabney et al. (2004) suggest that switchgrass barriers have potential for stabilizing gullies and reducing soil erosion by increasing the roughness of the channel.

Although the body of research describing in-field processes that mitigate ephemeral gully erosion, and in-buffer processes that promote sediment deposition identify some of the factors improving their efficacy, factors addressing the hydrologic connectivity of the agricultural landscape due to ephemeral gully erosion have not been studied extensively. To address this gap, there is a need to identify the factors that prevent connectivity of ephemeral gullies with perennial stream networks. For example, if vegetation can disperse concentrated flow from an ephemeral gully before it connects with a larger stream network, sediment delivery would be expected to be reduced (USDA-NRCS 1998).

The objective of this study was to determine the characteristics of edge-of-field vegetation that effect the dispersal of concentrated flow paths and stop gully incision. We hypothesize that slope, hydraulic length, and size of the watershed of the ephemeral gully, gully volume, and shading at the field edge will be positively correlated with connectivity of ephemeral gullies. We also hypothesize that ground cover and plant biomass will be negatively correlated with connectivity of ephemeral gullies. To test these hypotheses, we carried out surveys to measure these in-field and edge-of-field factors.

Methods and Materials

Site Description

The study was located in the 5,128 ha (12,672 ac) Lake Darling watershed, which is located in Keokuk, Jefferson, and Washington counties in southeast Iowa within the Southern Iowa Drift Plain Level III Ecoregion (Griffith et al. 1994). The dominant land use in the watershed is a corn-soybean rotation, comprising over 50% of the total area (Downing and

Poole 2008). Most parts of the watershed have a topography that is level to moderately sloping (0-9%) and soils that are primarily loess (74%) and till (11%) derived (Downing and Poole 2008). Based on personal observation and conversations with local farmers, a minimum tillage regime was common in the watershed, although areas containing ephemeral gullies were commonly tilled annually (Ohde 2011). Average precipitation for the area is 762-1016 mm (30-40 in), although average rainfall from 2008-2010 was 1412 mm (56 in).

Ephemeral Gully/Riparian Vegetation Surveys

In June of 2009, permissions were obtained from landowners with row-crop fields adjacent to stream networks within the Lake Darling watershed. Field edges on seven different farms were walked to identify locations for possible gullies. Areas of concentration of flow, i.e. potential sites for ephemeral gullies (EG)s, were mapped using GPS.

Both in late November 2009, after the crops were harvested, then again in late March 2010, before new crops were planted, characterization of EG sites was initiated. Volume of each EG that interfaced with riparian vegetation was determined by measuring length with a measuring wheel and depth/width cross-sections at least every 5 meters (Casali *et al.* 2006). At the interface between the field and riparian vegetation, vegetation was clipped and weighed from a 30 x 30 cm square PVC frame plot. It was also determined whether the EG directly connected with the larger stream network by visually examining to see if incision continued to the stream or stopped.

In July of 2010, cover surveys were conducted in the riparian vegetation at the field edge. Ground cover was determined in 1 m^2 plots. Cover type was identified and categorized in one of nine cover classes: 1 = 1-2 individuals, 2 = <5% cover, 3 = 5-10%, 4 = 11-15%, 5 = 16-20%, 6 = 21-30%, 7 = 31-50%, 8 = 51-75%, 9 =76-100%. Ground cover type was divided into woody (tree species), shrub, warm-season grass, cool-season grass, forbs, litter, and bare soil. Overstory canopy cover at the field edge was determined using a spherical densiometer.

GIS was used to further characterize each EG site. ArcSWAT, an extension of ArcMap, was used to delineate the "gullysheds" (contributing areas of the in-field portion of the gullies) based on Light Detection and Ranging (LiDAR)-derived 1-m resolution digital elevation models (DEMs). The slope and hydraulic length of the gullyshed was determined using ArcSWAT.

Data Analysis

Twenty ephemeral gully sites were characterized by survey and GIS analysis. Because the results of the study were expected to take on a binomial distribution (either the gully connects or it doesn't), we used logistic regression to identify factors correlated with gully connection. Statistical analysis was conducted using R (R Development Core Team 2010). We considered both gullyshed and edge-of-field vegetation related factors. Area, slope, and hydraulic length of the gullyshed, volume of the gully and crop type were the in-field factors considered in logistic regression. Edge-of-field factors included biomass, ground cover, and canopy cover.

Results and Discussion

We measured 20 ephemeral gullies ranging in volume from 0.32 m^3 to 11.79 m^3 (Tables 1 and 2). Seven of these gullies connected to the larger stream network. An estimated maximum of 34 metric tons of soil moved from gully to the stream since the last tillage from these gullies (Table 1). Thirteen gullies were stopped by edge-of-field vegetation. An estimated maximum of 45 metric tons of soil was prevented from being delivered downstream (Table 2). However, in addition to the soil that moved *from* the ephemeral gully channels, much more additional soil probably traveled *through* them (Poesen et al. 2003; Dosskey et al. 2002).

We also measured the area, slope, and hydraulic length of the gullyshed for each ephemeral gully. Gullysheds averaged 0.69 ha, 6.4 % slope, and 177 m for hydraulic length. Results from the GIS-derived gullyshed measurements are shown in Table 3.

Of the seven gullies that connected, canopy cover values ranged from 7 to 68%, but averaged 36%. Of the 13 gullies that did not connect, canopy cover ranged from 1 to 21%, and averaged 5% (Table 4). The amount of biomass at the field edge ranged from 11.6 g to 32.6 g where gullies connected, and averaged 19.9 g. Sites where gullies did not connect had 12.4 to 58.8 g of biomass, with an average of 34.2 (Table 4). Vegetation consisted largely of cool-season grasses, forbs, and litter/debris. Ground cover, on average, consisted of 21 to 30 % cool season grasses, 5-10% forbs, 16-20% litter/debris, and 21-30% bare ground (Table 5).

Based on the results of the logistic regression model we found that none of the gullyshed characteristics measured contributed significantly to the likelihood of gully connection. In fact, overstory canopy cover percentage was the only measured factor significantly ($P < 0.05$) and positively correlated with the connectivity of gullies (Figures 1-2). These results indicate that although the ground vegetation characteristics measured were not statistically significant, something about the effect of decreased shading led to a decrease in the connectivity of gullies.

While biomass was not statistically significant, a weak negative trend ($p<0.25$) between amount of biomass and decreased likelihood of gully connectivity indicated that it could have played a role (Figures 3-4). There was also a weak ($r^2=0.23$) negative correlation between canopy cover and biomass (Figure 5). A larger sample size may better elucidate these relationships.

In creating a methodology for selecting plants for gully stabilization De Baets et al. (2009) suggests several characteristics of plants important for gully erosion control. While above-ground characteristics like stem density and plant stiffness were identified, below-ground characteristics were also deemed to be very important. Because above-ground biomass is an indicator of belowground biomass, it may be suspected that root structure played a role in the preventing of gully connection. Root density and root diameter are both factors that contribute to how well different soil types respond to concentrated flow (De Baets et al. 2007). The fine, dense root systems of grasses have been found to increase soil cohesiveness more than tap roots (De Baets et al. 2008). This thick mat of roots has been found to provide more resistance to soil detachment under concentrated flow conditions (Gyssels and Poesen 2003). While no correlation was found between grass cover and gully connectivity in this study, the amount of grass present was limited (<30% of total ground cover on average) (Table 6). It is possible that a higher percentage of grass cover could prevent gully connection, but that relationship should be examined through further research.

In undisturbed Iowa forests, a shade-tolerant understory of native plants exists in the spring during likely times of larger runoff with abundant rooted components that could provide resistance to flow (Mabry et al. 2008). However, most of Iowa's forests have a land-use history of grazing (Jungst et al. 1998). Grazing may select for non-native annual plants because their high seed dispersal rate gives them a selective advantage in areas of disturbance (Mabry 2004). Based on personal communication with farmers in the area for a related study described in Chapter 4, a history of grazing can be expected in study woodlands (Ohde 2011).

Even in ungrazed areas, the number of species present at the edges of crop fields may have declined due to agrochemical drift (Kleijn and Snoeijing 1997). It was also observed that when initial tillage disturbed the soil, but was then unable to be planted, ephemeral gullies continued through the annual vegetation (mainly *Setaria sp.*, a summer annual) that grew in the place of the crop. Although a species survey was not conducted, most of the forbs observed growing at the edge of the field were non-native annuals. The fine, dense root systems of grasses have been found to increase soil cohesiveness more than tap roots, like most forbs possess (De Baets et al. 2008). For these reasons, shaded areas may have limited the amount of rooted vegetation present.

These results suggest that multispecies riparian buffers consisting of grass, shrub, and tree components would be appropriate for addressing the many processes that contribute to ephemeral gully network integration (Schultz et al. 2004). A warm-season grass filter could be expected to provide a stiff stemmed, dense barrier to runoff from the cropfield (Lee et al. 2000). Knight et al. found that 100% of EGs were stopped by riparian areas with grass filters, while only 80% of EGs were stopped by riparian forests alone (2010). Fine roots in the grass filter and slightly larger roots in the shrub and tree portions of the buffer could provide slope stabilization important to prevent headcut retreat and sidewall sloughing of larger gullies (De Baets et al. 2009; Bennett et al. 2000; Casali et al. 2000; Tufekcioglu et al. 1999).

It was observed at several different ephemeral gully sites that the headcuts of large classical gullies were retreating from the bottomland through the riparian vegetation towards the field. Often these were associated with concentrated flow areas protected with grass waterways. Although the grass waterways provided soil erosion protection in the field, this often meant a large volume of water being discharged into areas of riparian vegetation which does not have adequate rooted ground cover vegetation to prevent incision. This phenomenon has been noted in the past (Daniels and Gilliam 1996; Herring et al. 2006; Knight et al. 2010). A combination of in-field and edge-of-field practices has been shown to decrease the likelihood of this process occurring (Dabney et al. 2006; Blanco-Canqui et al. 2006).

Summary and Conclusion

The results of this study indicate that for these ephemeral gullies, overstory canopy cover was the biggest predictor of connection to the stream network. Characteristics of the watershed of the gully were not statistically significant factors for predicting connection. While not a significant factor, there was also a trend showing that sites with more biomass were less likely to be connected to stream networks. The presence of plant roots may play an important role in preventing the integration of gully networks, something that needs to be examined in the future.

Combining in-field and edge-of-field practices may be necessary to make net reductions in downstream sediment yields (Dabney et al. 2006). For areas with ephemeral gullies, practices such as grass barriers combined with multi-species riparian buffers may be advisable. For temperate areas where trees are the dominant riparian species, management to ensure adequate rooted vegetation growth is necessary. As shown by Knight et al., usually this will include a sufficiently wide grass filter upslope of the tree and shrub portion of a buffer (2010). The results of this study suggest that areas of concentrated flow need to be areas of management concern and further research focus.

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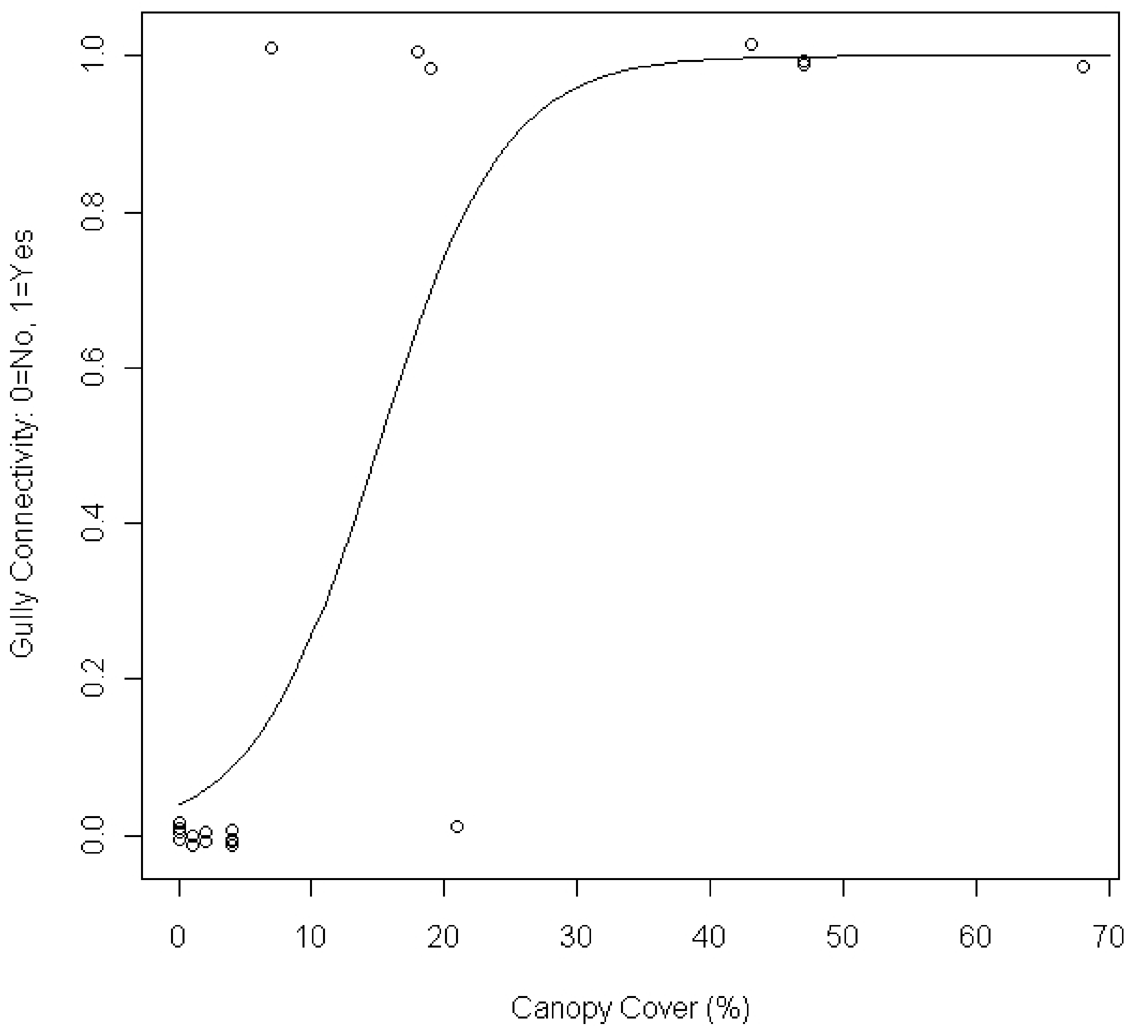

Figure 1. Logistic curve relating likelihood of ephemeral gully connectivity to overstory canopy cover. One indicates gully connection, zero indicates gully did not connect.

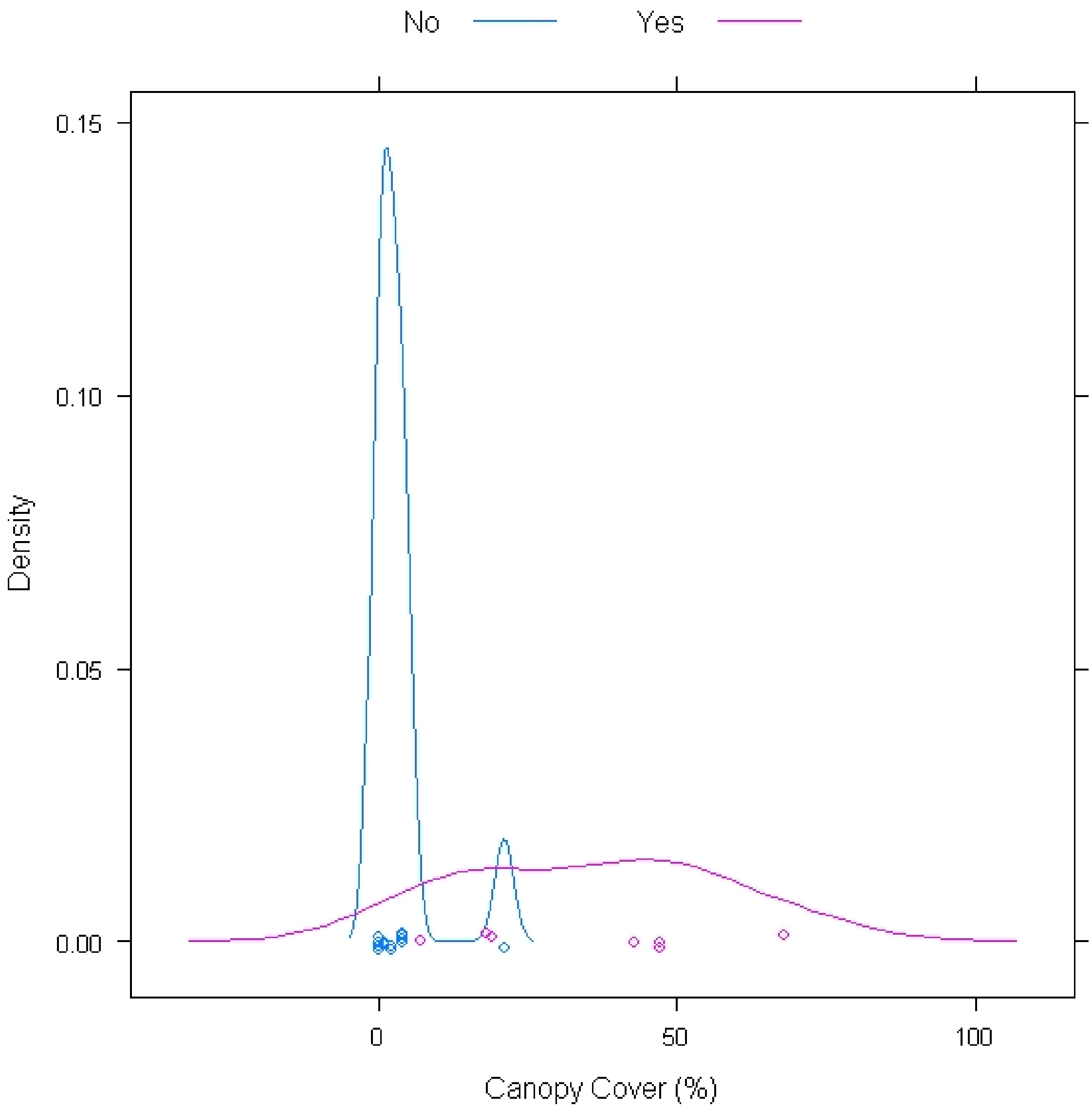

Figure 2. Ephemeral gully connectivity related to overstory canopy cover.

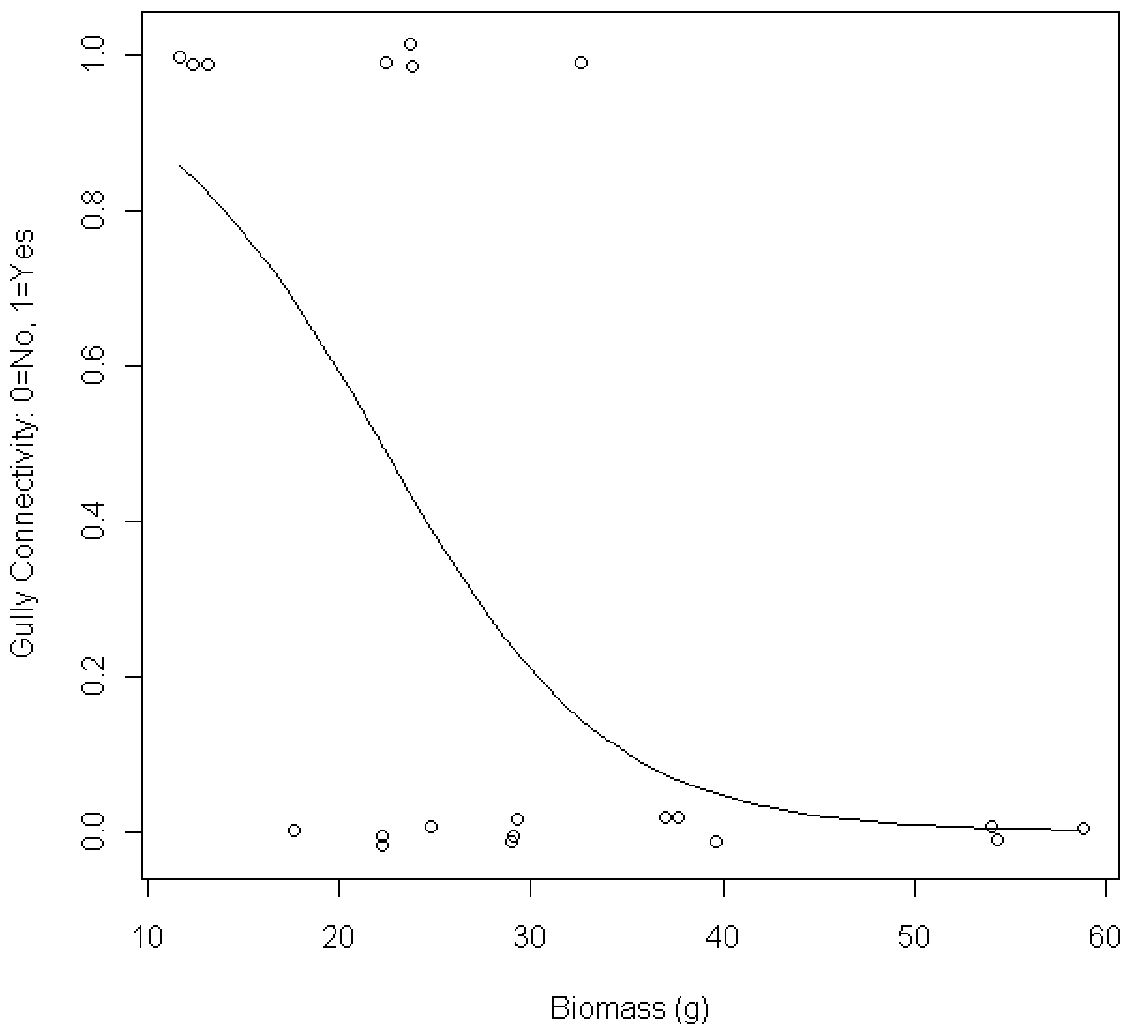

Figure 3. Logistic curve relating the likelihood of ephemeral gully connectivity to biomass amount. One indicates that the gully connected, while zero indicates that it did not.

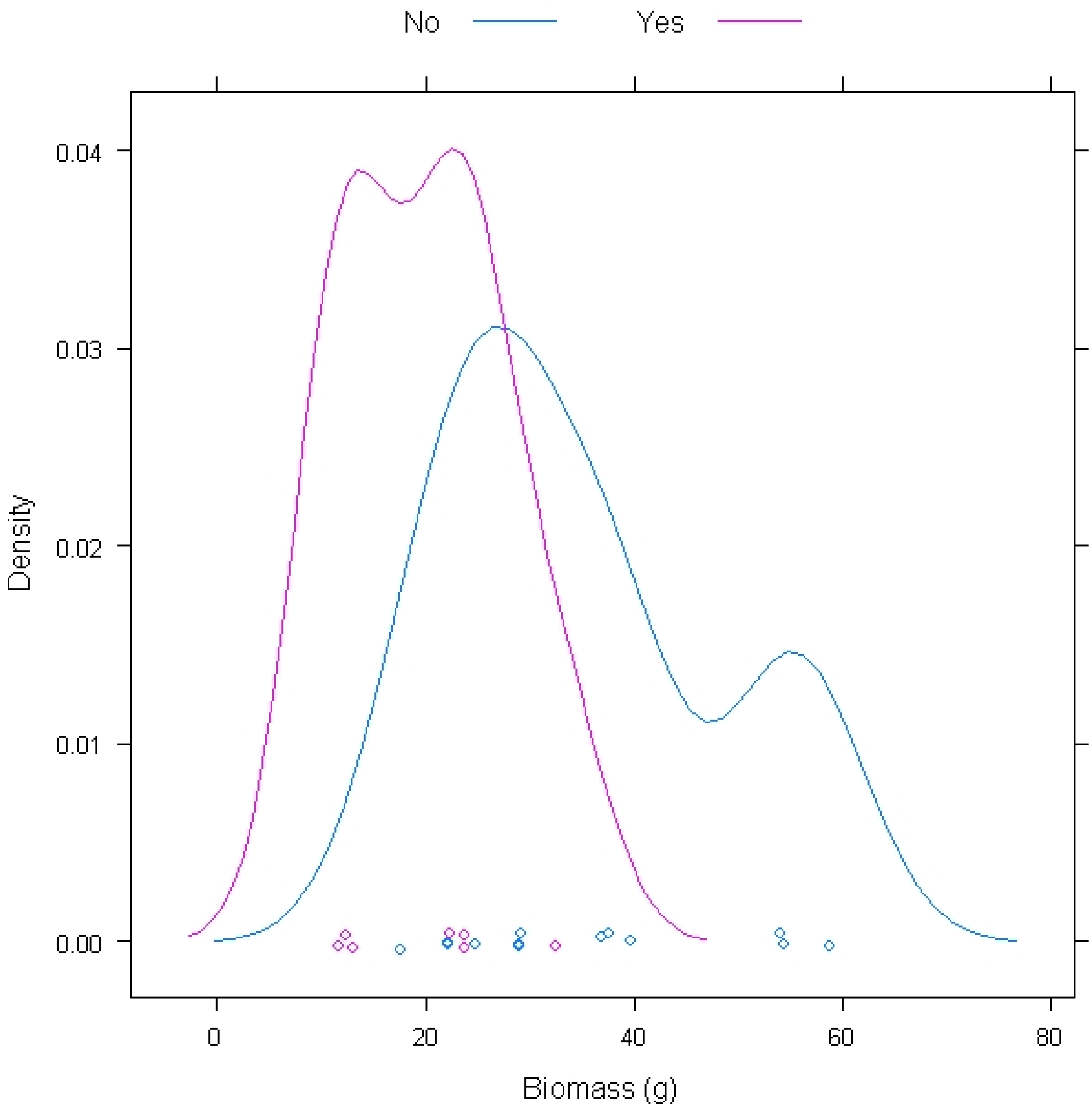

Figure 4. Ephemeral gully connectivity related to overstory canopy cover.

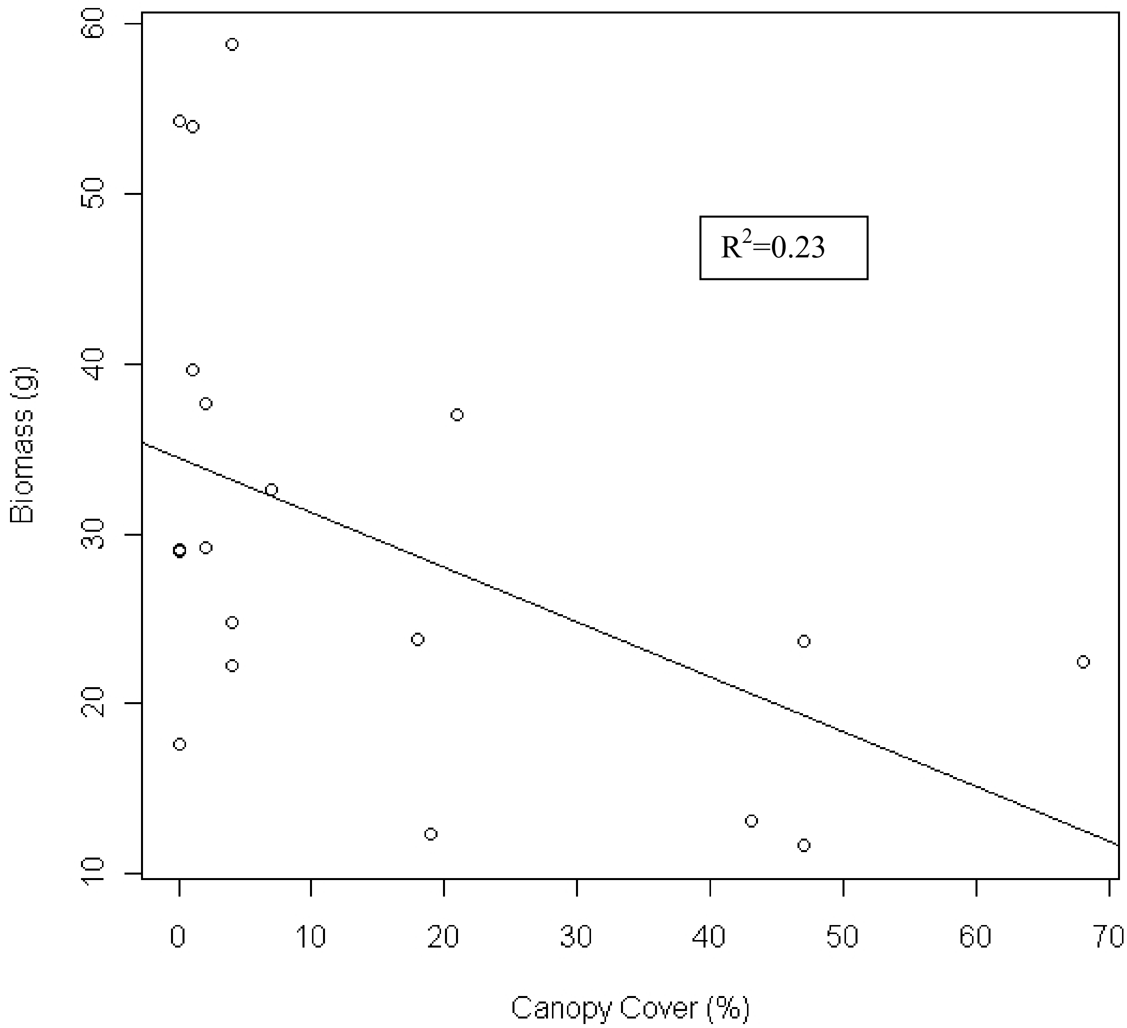

Figure 5. Linear regression of canopy cover on biomass.

Table 1. Volume and soil loss in 2009 from ephemeral gullies directly connected to stream channels in the Lake Darling watershed.

Gully	Volume (m^3)	Soil Loss (metric tons)
2	1.35	2.00
3	3.03	4.10
8	8.08	11.96
10	0.32	0.47
18	1.40	1.90
19	3.64	4.91
20	5.89	8.72
Total		34.04

Table 2. Volume and soil loss in 2009 from ephemeral gullies not directly connected to stream channels in the Lake Darling watershed.

Gully	Volume (m^3)	Soil Loss (metric tons)
1	0.50	0.74
4	0.32	0.49
5	0.33	0.49
6	1.48	2.03
7	1.82	2.77
9	0.35	0.52
11	0.66	0.98
12	11.79	17.45
13	3.37	4.48
14	0.92	1.24
15	8.64	11.66
16	0.69	0.93
17	0.73	0.99
Total		44.76

Table 3. GIS-derived area, slope, and hydraulic length of contributing areas for 20 connected and non-connected ephemeral gullies in the Lake Darling watershed in 2009.

Gully	Connects (yes/no)	Area (ha)	Slope (%)	Hydraulic length(m)
1	No	0.32	5.3	136
2	Yes	0.13	5.3	107
3	Yes	0.20	8.8	102
4	No	1.99	7.2	269
5	No	1.14	8.8	335
6	No	1.93	6.2	262
7	No	0.46	7.0	154
8	Yes	1.93	5.0	357
9	No	0.64	7.4	164
10	Yes	1.04	3.2	274
11	No	0.02	9.3	60
12	No	0.19	7.8	183
13	No	1.04	7.2	255
14	No	0.08	8.0	67
15	No	0.47	4.4	171
16	No	0.22	5.2	100
17	No	0.08	6.5	71
18	Yes	0.34	2.5	157
19	Yes	0.59	3.9	124
20	Yes	0.96	9.1	192
Average		0.69	6.4	177

Table 4. Overstory canopy cover and average biomass at the field-riparian zone interface for 20 connected and non-connected ephemeral gully sites in the Lake Darling watershed in 2009 and 2010.

Gully	Connects (yes/no)	Canopy Cover (%)	Biomass (g)
1	No	1	54.0
2	Yes	43	13.1
3	Yes	19	12.4
4	No	4	58.8
5	No	21	37.0
6	No	16	54.4
7	No	4	22.3
8	Yes	7	32.6
9	No	1	39.7
10	Yes	18	23.8
11	No	0	29.0
12	No	0	29.1
13	No	4	24.8
14	No	4	22.2
15	No	0	17.6
16	No	2	37.7
17	No	2	29.2
18	Yes	47	23.7
19	Yes	47	11.6
20	Yes	68	22.4
Average	Yes	36	19.9
Average	No	5	34.2

Table 5. Vegetation cover type and class at edge-of-field at connecting and non-connecting ephemeral gully sites in the Lake Darling watershed in 2010. Cover is categorized into one of nine cover classes: 1 = 1-2 individuals, 2 = <5% cover, 3 = 5-10%, 4 = 11-15%, 5 = 16-20%, 6 = 21-30%, 7 = 31-50%, 8 = 51-75%, 9 =76-100%.

Gully	Connects (yes/no)	Woody vegetation	Shrubs	Warm-season grass	Cool-season grass	Forbs	Litter/ debris	Bare ground
1	No	0	0	0	4	4	6	7
2	Yes	0	2	0	5	3	7	6
3	Yes	0	3	0	7	4	4	5
4	No	0	0	0	5	2	8	2
5	No	3	0	0	6	1	7	5
6	No	0	2	0	3	4	7	6
7	No	0	0	0	7	2	4	7
8	Yes	1	0	0	7	4	6	6
9	No	0	0	0	8	1	7	2
10	Yes	1	0	0	2	6	5	7
11	No	0	0	0	7	2	2	7
12	No	0	0	0	9	0	3	3
13	No	0	0	0	9	0	6	0
14	No	0	0	0	6	4	4	8
15	No	0	0	0	7	3	2	7
16	No	0	0	0	8	2	3	6
17	No	0	2	0	7	3	3	7
18	Yes	0	0	0	6	5	3	7
19	Yes	0	0	0	6	2	4	8
20	Yes	0	0	0	7	0	7	5

Chapter 4. Ditches, washes, and decision-making: Contextualizing the Lake Darling project

Modified from a paper to be submitted to the journal *Society and Natural Resources*

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Abstract

Diffusion of innovations theory has been extensively applied to the adoption of conservation practices. However, by itself it may be insufficient to explain why farmers choose to implement conservation agriculture on their land. Recent research on decision making attempts to understand farmers from their own perspective, rather than comparing their choices to “rational” decisions. The objective of this study was to provide a social context to two related studies in the Lake Darling watershed in southeast Iowa. We hypothesized that farmers decided to adopt conservation practices based on their knowledge and concern for the environment and because of their connections to social networks. Qualitative research interviews were conducted, the results were analyzed via coding, and major themes were identified. Major factors affecting conservation practice adoption were operating ease/maintenance, a concern for preserving in-field resources, and local leadership. We also identified the extreme rainfall of the past three years as a problematic event for farmers, and an area where farmers may be looking for solutions provided by new conservation measures. We learned from the study that farmers in our study area have an extensive knowledge of agroecological processes that affect soil erosion processes in the field, but are less concerned with areas outside of the field. In the future, plans to restore

ecosystem service functioning to this watershed, such as the ability to provide clean water to Lake Darling, need to provide incentives to farmers to be concerned with riparian areas on their farms.

Introduction

While initially used to explain the spread of agricultural production innovations, diffusion of innovations theory has also been applied to the adoption of conservation practices over the past 25 years (Ryan and Gross, 1943; Rogers, 1963; Napier 1991). While the field of diffusion of innovations research has evolved since the mid-20th century, it had/has an important premise that is made evident in its name—namely, researchers have a new and better technology, and they are curious about the ways they can spread the use of that technology (Rogers 2003). However, several studies have indicated that the diffusion of innovations framework is not by itself sufficient for explaining the adoption of conservation practices (Nowak 1983; van Es 1983).

Research into decision support systems in agriculture offers an alternative theoretical framework to understanding farm management. The historical trajectory of decision support research has followed a similar trend to that of diffusion of innovations research (McCown 2005), and examining its history provides important insights into the acceptance of practices intended to improve environmental conservation.

Initially, decision support research, much like early diffusion research, was based on scientific principles of management used by Frederick Taylor in the late 19th century to revolutionize the manufacturing sector (McCown 2005). Under this paradigm, intuitive, subjective judgment was seen as a problem to be overcome and something that needed to be replaced by a formal analysis that could tell a person what a “rational” person would do in that situation (McCown 2005).

This approach is based on a theory of behavior proposed by Lewin (1951) that human action can be distilled down to the equation B (Behavior)= f(P (Person),E (Environment)). While this seems like a relatively straightforward idea, it provides a good framework with which to discuss behavioral research. Management science has fluctuated between emphasizing that the P (knowledge of person) is more important or the E (environment) is more important (McCown 2005). In all cases, however, the person doing the behavior is judged against some standard of what a “rational” person would do in the situation.

The field of phenomenology rejects the idea that human behavior can be explained objectively and proposes an alternative philosophy for understanding human actions subjectively (Dreyfus 1992). With roots in phenomenological theory, McCown (2005) proposes an action-oriented model for understanding farmers’ decision making. McCown’s model draws not only on phenomenology but also theory in social psychology, cultural psychology, and cognitive science to come up with a slightly different framework for understanding farmer actions. This framework takes into account the goals of farmers, and how beliefs about the environment and beliefs about the tasks needed to be accomplished in order to achieve these goals influence decision making.

While many studies have focused on developing a theoretical explanation for acceptance and implementation of conservation practices, other studies have sought to understand the process empirically, by identifying determinants and factors. Prokopy et al.

(2008) reviewed 55 studies from 1982 to 2007 and identified education level, capital, income, farm size, access to information, positive environmental attitudes, environmental awareness, and utilization of social networks as factors that are more often positively associated with adoption rates. Another recent review found few universal variables that regularly explain the adoption of conservation practices (Knowler and Bradshaw 2007). Another review found strong community ties, face-to-face interaction with members of social networks, and familiarity with the innovation to be important factors (Wejnert et al. 2002). Camboni and Napier (1995) determined that the most important factor for adoption of conservation practices was economics. In contrast one study found that farmers are more likely to be motivated to practice conservation because of an attachment to the land than by economics (Ryan et al. 2003). As a whole, the body of literature based on empirical evidence seems to be inconclusive about what the barriers to the adoption of conservation practices are.

As part of a larger research project, we measured ephemeral gully erosion and the potential impact of riparian vegetation on sediment delivery on seven different farms. Four of the cooperating landowners were interviewed to provide a social context to our biophysical research. Details about the watershed are given in Chapters 2 and 3 of this thesis (Ohde 2011).

Conservation practices present in the study area include tile-outlet terraces, grassed waterways, grass filter strips, erosion control ponds, contour buffer strips, and sediment ponds. No-till practices were common.

The objective of the interview portion of the larger study was to understand why farmers of this study area decided to implement conservation practices. Drawing on theoretical and empirical literature regarding farmer decision making and conservation practice adoption, we hypothesized that farmers would have adopted conservation practices because of their knowledge of and concern for the environment, and their connection to social networks.

Methodology

To test the hypothesis, an ethnographic study (Robson 2002) was conducted in concert with two quantitative biophysical studies in the watershed. Attempts were made to interview each of the operators of the seven farms at which biophysical research was conducted. Four of the operators agreed to take part in the study. In a situation where the goal of the qualitative research is to contextualize and understand quantitative research, the qualitative interview is an optimal methodology (King 1994). We chose a semi-structured interview format in order to focus the general direction of the discussion, but also to be flexible and allow probing into differing perspectives (Robson 2002).

The interview questions were centered on a primary theme: why conservation practices were employed on their farm. These were subdivided into questions addressing two hypothesized reasons for conservation practice adoption—environmental awareness and concern, and social network factors.

Methodology for qualitative analysis of the interview results consisted of giving codes, identifying themes, and elaborating generalizations (Robson 2002). Specifically, we used an approach based on the template approach outlined by Crabtree and Miller (1992). Coding was conducted in three stages as described by Neuman (1997). The first stage, open coding, was the first pass, in which the primary focus was generating themes from the text of the interview. During the second stage, axial coding, we sought to identify categories, or groups of themes that were prominent in the data. In the final stage, selective coding, we identified areas that illustrated dominant themes or areas that offered comparisons and contrasts highlighting key issues in the data.

In order to assure validity and reliability, triangulation of analysis was employed (Denzin 1989). This was achieved by independent coding of the data by three researchers at the open and axial stage of the coding process, and by collaborative coding at the selective coding stage.

Conservation in Everyday Farming

Major categories identified as influencing farmer decision-making about conservation practices were *maintenance/operating ease*, an *in-field conservation ethic*, and *local leadership*. In addition, we noted that unusual rainfall throughout the last few years was an area where farmers expressed great concern, indicating a desire for potential solutions.

Maintenance/Operating Ease

The category of maintenance and operating ease permeated all of the interviews. Whether conservation practices resulted in additional time, or in time saved to make farming easier, the issue was always present. One farmer mentioned that one reason people don't install more conservation practices is that they “just don’t want to fool with it.” Most of the erosion problems in this watershed, as confirmed by the related biophysical survey, were related to ephemeral gully erosion—“ditches” or “washes” in the vernacular. Ephemeral gullies were not so much seen as a potential source of soil loss, but as a hindrance that caused operating obstacles. When asked why he had installed so many terraces, one farmer replied: “I don’t like crossing ditches!... I’d rather make three trips around the field and not have any washes than make just one and have one bouncing around.”

Atwell et al. (2009) found that for conservation practices to be desirable, they have to be compatible with the current farm practices and technologies—that for a practice to be adopted it has to fit into a farmer’s system. The prevalence of terraces with drainage tile inlets was noted during the biophysical study, and it is likely that this innovation was widely adopted throughout the study area because it worked. As one farmer put it, “When people build terraces they see how much it improves the farm, makes it easier to farm. You don’t have to worry about ditches, and it’s just better.”

The adoption of no-till farming appeared also to be heavily influenced by operating ease. “It helps us—we can run two machines--like in these late years we can be corn planting and bean planting at the same time and we don’t need all our equipment on corn, so we can get to planting our beans a little earlier.”

In-Field Conservation Ethic

All the farmers interviewed perceived themselves as being strong conservationists. It appeared, however, that this conservation ethic was for the most part limited to the boundaries of their farm. Where it may have been expected that a shared resource, such as a lake, would have inspired a shared responsibility for keeping it clean (Morton 2008), most of the conservation interest was related to keeping a valuable resource, their own farm soil, from washing away. That this conservation might also benefit the lake was secondary. When asked about Lake Darling, one farmer summed it up best:

> *I'm more interested in keeping the soil on the farm. I guess that is my primary interest. When it gets down in the lake it don't do anybody any good.*

Others elaborated on this issue for explaining the underlying reasons why they are soil conservationists. Another had a similar attitude when responding to why he enacts conservation practices:

> *Mainly because I didn't want to see the good dirt I've got washed down the river. It's a long range plan thing. That old saying that a good farmer likes to leave the land in better shape when's done then it was when he found it is kind of true. That's how most farmers think.*

Among farmers interviewed, a soil conservationist is identified as being concerned with soil and passing that resource base to the next person that's farming their land.

When further probed about conservation issues, these farmers were much more skeptical. They all were anxious about the thought of including wildlife habitat as a part of their farm. When questioned about the importance of wildlife, one farmer replied:

> *Well, if you've got too much of it, it can be real important because they'll eat up your profit… But you know, I like wildlife. I like to see them, I just don't like to see them costing me lots of money.*

On other issues, they weren't as ambivalent. One farmer, when asked what he thought about the issue of water quality, responded blatantly: "I think that's the biggest bunch of shit that's ever come… I ain't seen or heard of anybody die of water poisoning yet." Two of the farmers cited examples of living long, healthy lives drinking the local water.

While solutions to some problems, like the problem of ephemeral gullies creating maintenance difficulties, may lie in appealing to this common sense "I'll believe it when I see it" approach, larger scale problems like climate change or hypoxia are not likely to manifest symptoms that the farmer can experience in a direct way. However, the threat of water quality-related regulation has caught the attention of at least one farmer, who recognizes it as a definite possibility, if not a fair outcome for those downstream:

> *I think it's just a matter of time before we get more regulation on that, because water quality is, I mean it seems like we have a ton of water right now, but there're people who don't have enough water and as long as they're having problems down in the Gulf with runoff and things you can't just ignore that.*

Local leadership

Farmers can sometimes have an antagonistic relationship with government agencies that may provide incentives to adopt conservation practices. One farmer expressed his frustration: "Hell you could run it, I could run it, anybody could run this government as good as it's run." However, local leaders can be instrumental in bridging the gap between groups who otherwise may not interact and/or agree on most issues (Burt 1999).

In the case of the study area, the local watershed coordinator played a large role in the adoption of conservation practices:

> *[The installation of conservation practices] has come in part…a lot of it…a lot of that has come about because of [the watershed coordinator] working here in the Lake Darling*

watershed encouraging people to do these practices and so on. He deserves a lot of credit for that.

But perhaps the most important aspect of the local leader's work was that he was perceived as "getting help" for farmers. One farmer mentioned that "he tries his best to get all the help he can for farmers when they want to do a project, and that's important." Another furthered the notion that the local leader was instrumental in finding resources:

> *I mean he's always trying to find some extra money to do something around here. So yeah I'd say that's a major plus and success of what's been happening around here as far as soil conservation.*

Another way local leadership has contributed was by building relationships between the farm community and the rest of the Lake Darling watershed community, many of whom were interested in conservation:

> *[The watershed coordinator] has held several meetings down here at Brighton, over the years, in relation to the Lake Darling watershed, and that's made for a lot of goodwill too, I think. [He] gets along good with people.*

These findings are consistent with other studies from around the state of Iowa, which have found bridging boundaries and increased contact between farmers and communities are key factors in improving water quality though conservation (Atwell et al. 2009; Morton 2008; Morton and Weng 2009).

Change and Problematic Events

For most day to day decisions, people aren't constantly questioning what they've learned and analyzing each situation. Instead, they use mental models based on what they've learned in the past to "just do" the action, rather than consciously choose it (Lipshitz et al.

2001). It's not until a problematic event occurs that contradicts a held mental model that they question a belief, appropriateness of a task, or appropriateness of a goal. McCown (2005) included a quotation from a farmer to explain this, who said "You need a doctor when you're having problems, not when you're traveling well enough."

The area of this study experienced nearly double the average annual rainfall from 2008-2010. More rain and more frequent heavy rainfall events likely to cause erosion are outcomes predicted under current climate change scenarios (MacKracken 2003; Kunkel 1999). This caused some farmers to question how their tasks (methods of farming, conservation practices) could achieve their goals (operating smoothly, producing crops, conserving soil). It is in problematic situations like these that "naturalistic decision making" (Lipshitz et al. 2001) is interrupted, and a deliberation is engaged in based on beliefs and values (McCown 2005). One farmer's changing attitudes about the climate change provides an example.

> *I thought when they first started talking about [climate change] that it was just a hyped up Democratic scheme to impose more rules and regulations on everybody. And it probably still is, but I don't know these wild weather swings we've been having, it coincides with what they say.*

While observations of the environment play into this deliberation, so too, does a farmer's preconceived notions about the overarching goal.

> *Because there're so many people doing so many things to try and keep it from happening that if you get good weather, there's not going to be much soil erosion, you know, but when you get these crazy rainfall amounts like we've had the last three years, why it's going to be a problem, I don't care what you do. Unless you seed everything down to grass, that would be the only way of stopping it, but* ***the world can't live like that*** *(emphasis added).*

This vision of a farm as producing for “the world” influences ideas about how a changing climate may alter the ability of tasks (farming methods) to achieve goals. The producer goes on to mention that getting bigger equipment to be able to plant and harvest more efficiently in a shorter time period will be the only way to go.

While the current common agricultural practices were seen as ideal by one farmer, another had a more apprehensive view:

> *We didn’t used to farm this ground like we do now. We farm it so much more intensely than we used to. It used to be rotated and a lot of it would be in small grain and hay and pasture and so on you see and now most of it is farmed in corn and beans…it makes an all together different set up.*

The producer also mentioned “seeding it back to grass” as a potential solution to the problem of soil erosion in the face of climate change, but because they had different ideals about agriculture, their view on the reality of this suggestion was more optimistic than the previous farmer’s.

> *Well, you couldn’t farm it without these practices and get along. It’d be full of ditches. You’d have to seed it back to grass again and go back to a different way, method of farming, I think… it’s just amazing the amount of gullies some folks have got. And some of those are where they had some pretty sound practices, but it’s really wrecked a lot of those things in the past three years…. I think there should be some more cattle in this area than what there is. Some of these real steep slopes, poor soil, they need to be in grass. That’s my opinion.*

Contextualization of Biophysical Research

While conducting the related biophysical study, we found far fewer ephemeral gullies than we had expected. The prevalence of tile outlet terraces throughout the area probably played a significant role in reducing the number of ephemeral gullies. We found that ephemeral gully erosion was an area of concern for farmers because it causes difficulties in operating.

However, the results of the biophysical study also showed that a large amount of sediment likely travels through the existing gullies. These ephemeral gullies that are connected directly to gullies in the riparian areas and then with perennial streams are more likely to carry sediment and nutrients downstream. This suggests that strategic management of the riparian areas could result in significant reductions of sediment and nutrients delivered to the stream network.

However, based on these interview results, it is not likely that much concern or time is given by land managers to the management of riparian areas. One farmer referred to riparian areas as “wasteland… that’s never been cleared or anything.” A comment by another farmer suggested that streams were places where you dumped things you no longer wanted.

Furthermore, riparian gullies which were actively eroding and stream bank erosion appear to be major sources of sediment in this area. While one farmer tied the amount of runoff in fields to stream bank erosion rates, the other farmers interviewed didn’t perceive erosion in riparian areas to be a problem. These results suggest that the next step in conservation in the area will be made when farmers begin to become more concerned about their riparian areas.

Conclusions

If conservation practices are to be implemented, they need to fit into the farmer's current system. Because operating ease is one of the biggest day-to-day concerns for farmers, the success of a given conservation practice likely depends on its ability to make farming easier. Farmers in this study area have a good understanding of the local soil erosion processes and the land uses that could be put in place to slow it.

Extreme rainfall in recent years creates problems for farmers, causing them to reflect on their goals and practices. Research on decision-making indicates this could be an opportunity for implementation of new farming or conservation practices. If a new conservation practice is to be implemented, it needs to fit into the farmer's belief system. While climate change and water quality degradation weren't issues that these farmers even thought were real, for the most part, there was some acknowledgement of the benefit of incorporating perennial crops and livestock on the land. This opinion gap related to environmental issues between farmers and sustainable agriculture researchers may be bridged by local leaders with ties to both research/government organizations and with the local community.

Finally, this study provides additional insights to the related biophysical study conducted in the area. Farmers have a good grasp of the biophysical processes contributing to erosion and the practices that can be helpful in deterring it as determined in the other portions of this study. However, processes within the riparian area are places on the landscape where farmers underestimate the amount of erosion present.

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Chapter 5. General Conclusion

Summary of Results and General Discussion

The provisioning of clean water to downstream areas is an important ecosystem service that can be provided by healthy agroecosystems. However, agriculture is currently the leading source contributing to water quality impairment in the United States. Conservation practices exist that could substantially improve water quality. Because most agricultural land is privately owned, adoption of these practices is voluntary. Regulations and incentives have both been considered as options to improve water quality, but incentivizing conservation is the only approach currently used for non-point source pollution in the United States.

Regardless of the approach, monitoring the effectiveness of conservation practices is a key to achieving measured improvements. Because monitoring is not viable on the scale necessary for non-point source pollution, modeling the effects of changing management practice can serve as an estimate (Kroeger and Casey 2007). Different models may have differing degrees of accuracy. Previous research has identified ephemeral gully erosion as an area of potential weakness for model accuracy (Casali et al. 2006). The processes affecting the ability of ephemeral gullies to deliver sediment from in crop-fields to the stream network have not been well studied.

One part of this study sought to examine the effectiveness of the Water Erosion Prediction Project (WEPP) model to estimate soil loss and sediment delivery related to ephemeral gully erosion. A total of 79 metric tons of soil was observed to be lost in 2009 from the 20 ephemeral gully channels measured on six farms. For the 18 runoff events measured in a small watershed (0.35 ha) containing an ephemeral gully, a total of 50 metric tons of sediment were delivered to the watershed outlet. Although the WEPP model performed well at predicting hydrological characteristics, it was inaccurate for predicting soil loss and sediment delivery related to ephemeral gullies. These inaccuracies could be due to the failure of the model to include important erosion processes, such as headcut dynamics, and to the inaccuracy of topographical maps due to subsurface drainage and the alteration of field microtopography by routine field work.

The second part of the study examined the factors contributing to the connection of ephemeral gullies from field to stream. We measured both in-field and edge-of-field factors to identify those important for gully connection. Slope, hydraulic length, and size of the watershed of the ephemeral gully were measured using GIS. Ground cover, canopy density, and biomass at the field edge were the vegetation characteristics measured. We found that seven of the 20 gullies measured connected to the larger stream network and contributed 34 metric tons of sediment since the last tillage. Canopy density was the only measured factor significantly and positively related to gully connectivity. Root characteristics could play an important role in stabilizing soil against gully incision and connection, something that should be further studied.

Based on the results of this research, conservation practices that reduce and slow the volume of water both in the field and in riparian areas could reduce soil loss and sediment delivery. Grass barriers could be one economically viable in-field option (Meyer et al. 1995) and multispecies riparian buffers with grass filters could be installed at the edge of the field (Knight et al. 2010; Schultz et al. 2004).

The third part of the study provided insights into the factors influencing farmer decision making regarding conservation practices. In this study, qualitative interviews were conducted with some of the farmers who managed the land where the biophysical research took place. Important elements that factored into farmer decision making were maintenance and operating ease, an in-field conservation ethic, and strong local leadership. Concerns with soil loss and gully erosion were primarily related to concerns with loss of productivity and operating ease, and not to concerns for the adjacent environment or downstream areas.

Implications

This study reaffirms previous research that areas of concentrated flow should be of particular concern to conservation planners. Multispecies riparian buffers may be important to disperse these flow paths at the edge of the field before they connect to larger stream networks. An unshaded area of perennial grasses could provide a dense root system to stabilize soil. Other zones of vegetation including shrubs and trees could provide root systems that are appropriate for stabilizing existing gullies.

However, for these practices to be implemented on the landscape, significant changes will need to be made to address the social barriers. Because farmers are largely concerned with preserving their in-field resources, steps will need to be taken to motivate farmers to ascribe value to all the areas of their farm, especially those critical areas surrounding streams. Ecosystem service payments may be one option for achieving this goal. Before this can happen, however, a framework needs to be enacted to give values to the various functions of vegetation. Value could be estimated for the function of vegetation characteristics in providing ecosystem services. Some vegetation may provide more of one ecosystem service, such as wildlife habitat, and less of another, such as water purification. These functions should be quantified, so that appropriate choices can be made based on local priorities.

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