**M.L. 2011, First Special Session, Chp. 2, Art.3, Sec. 2, Subd. 03l Project Abstract**
For the Period Ending June 30, 2014

**PROJECT TITLE: Measuring Conservation Practice Outcomes**
**PROJECT MANAGER: Megan Lennon**
**AFFILIATION: Minnesota Board of Water and Soil Resources**
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**FUNDING SOURCE: Environment and Natural Resources Trust Fund**
**LEGAL CITATION: M.L. 2011, First Special Session, Chp. 2, Art.3, Sec. 2, Subd. 03l**

**APPROPRIATION AMOUNT: $ 340,000**

## Overall Project Outcome and Results

Accounting for on the ground outcomes and measureable environmental benefits to the quality of soil, water, and habitat is an essential component of implementing conservation projects. Local Government Units (LGUs), including Counties, Soil and Water Conservation Districts, and Watershed Districts, utilize pollution reduction estimators to quantify the outcomes of conservation projects. Board of Water and Soil Resources (BWSR) currently utilizes models or 'estimators' to measure the pollution reduction benefits of installed Best Management Practices (BMPs). Estimators quantify the outcomes of conservation practices in terms of reduced soil erosion, sediment and phosphorus reduction, carbon sequestered, etc. In order to improve the accounting of conservation practices and measurement of environmental benefits, existing estimators must be revised and new estimators developed.

Through a partnership with the University of Minnesota Department of Soil, Water and Climate, four new estimators were developed: Permanent Cover Erosion Reduction model, the Septic System Improvement Estimator, the Milkhouse Waste Practices Estimator, and the Hydrologic Soil Group – Knowledge Matrix tool. These estimators fill gaps where estimators did not exist previously. The existence of these estimators allows Local Government Units and other conservation partners to better quantify the environmental outcomes of conservation implementation. Training for LGUs and other conservation partners was conducted and made available in multiple formats (in-person, webinar, instructional videos). Many LGUs have already used the new estimators and we anticipate widespread adoption in the future.

Additional results include development of a framework to model and track movement of endocrine disrupting compounds and a data quality analysis of pollution reduction reporting. Three reports resulted from the work in the project. The reports are listed and briefly summarized below.

- *Modeling Soil Erosion with* $^{137}Cs$: This report explains the process of modeling landscape-scale soil erosion and provides instructions on using the model to estimate long-term average erosion rates.
- *eLINK Data Quality Control Analysis:* This report provides an overview of the pollution reduction estimates in eLINK and recommends actions to improve data quality and completeness.
- *Endocrine Disrupting Chemical Retention Framework*: This report explains the behavior of endocrine disrupting compounds in the environment and provides a framework for measuring the movement and transport of such chemicals.

**Project Results Use and Dissemination**

The estimators are used by LGUs and conservation partners to quantify outcomes of installed Best Management Practices. The measured outcomes are collected in BWSR's eLINK database. The associated *eLINK Data Quality Control Analysis* report helps BWSR improve reporting of conservation project outcomes by recommending actions for improving education and outreach and developing internal mechanisms for quality control. Work completed by the University of Minnesota has gained interest amongst the broader scientific community and has been presented at international conferences. All reports, estimators and training materials developed during this project are available on the BWSR website: www.bwsr.state.mn.us

Conference citations:

Dalzell, B. J., C. Fissore, E. Nater, K. Yoo, and A. Wu. 2011. Redistribution of Soil Organic Carbon in Agricultural Soils. Oral presentation given at the annual meeting of the Geological Society of America. October 2011. Minneapolis, MN

Dalzell, B. J., C. Fissore, E.A. Nater, and K. Yoo. 2010. Terrain Control on Soil Organic Carbon Distribution in Loess Soils with Varying Land Cover. Poster presentation given at the annual fall meeting of the American Geophysical Union. December 2010. San Francisco, CA

Dalzell, B.J., E.A. Nater, K. Yoo, and C. Fissore. 2013. Legacy of Topography and Land Use on Erosion and Soil Organic Carbon Burial over Decadal Timescales. Presented at the annual fall meeting of the Geological Society of America. October 2013. Denver, CO.

Nater, E. A., B. J. Dalzell, C. Fissore, A. Wu, K. Yoo, and P. Ginakes. 2012. Legacy of Topography and Land Use on Erosion and Soil Organic Carbon Burial. Oral presentation given at the annual fall meeting of the American Geophysical Union. December 2012. San Francisco, CA

Nater, E. A., B. J. Dalzell, C. Fissore, A. Wu, and K. Yoo. Distribution and Movement of Soil Organic Carbon in Grassland and Agricultural Landscapes. Poster presentation given at the annual fall meeting of the American Geophysical Union. December 2011. San Francisco, CA

# Environment and Natural Resources Trust Fund (ENRTF)
# M.L. 2011 Work Plan Final Report

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| **Date of Status Update:** | 09/15/2014 |  |
| **Date of Next Status Update:** | Final Report |  |
| **Date of Work Plan Approval:** | 6/23/2011 |  |
| **Project Completion Date:** | 6/30/2014 | **Is this an amendment request? no** |

**Project Title: Measuring Conservation Practice Outcomes**

**Project Manager:** Megan Lennon

**Affiliation:** Board of Water and Soil Resources

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**Location:**

**Counties Impacted:** Statewide

**Ecological Section Impacted:** Lake Agassiz Aspen Parklands (223N), Minnesota and Northeast Iowa Morainal (222M), North Central Glaciated Plains (251B), Northern Minnesota and Ontario Peatlands (212M), Northern Minnesota Drift and lake Plains (212N), Northern Superior Uplands (212L), Paleozoic Plateau (222L), Red River Valley (251A), Southern Superior Uplands (212J), Western Superior Uplands (212K)

|  |  |  |
|---|---|---|
| **Total ENRTF Project Budget:** | **ENRTF Appropriation $:** | 340,000 |
|  | **Amount Spent $:** | 340,000 |
|  | **Balance $:** | 0 |

**Legal Citation:** M.L. 2011, First Special Session, Chp. 2, Art.3, Sec. 2, Subd. 03l

**Appropriation Language:**
$170,000 the first year and $170,000 the second year are from the trust fund to the Board of Water and Soil Resources to improve measurement of impacts of conservation practices through refinement of existing and development of new pollution estimators and by providing local government training.

**I. PROJECT TITLE:** Measuring Conservation Practice Outcomes

## II. Final PROJECT SUMMARY:

### Overall Project Outcome and Results

Accounting for on the ground outcomes and measureable environmental benefits to the quality of soil, water, and habitat is an essential component of implementing conservation projects. Local Government Units (LGUs), including Counties, Soil and Water Conservation Districts, and Watershed Districts, utilize pollution reduction estimators to quantify the outcomes of conservation projects. Board of Water and Soil Resources (BWSR) currently utilizes models or 'estimators' to measure the pollution reduction benefits of installed Best Management Practices (BMPs). Estimators quantify the outcomes of conservation practices in terms of reduced soil erosion, sediment and phosphorus reduction, carbon sequestered, etc. In order to improve the accounting of conservation practices and measurement of environmental benefits, existing estimators must be revised and new estimators developed.

Through a partnership with the University of Minnesota Department of Soil, Water and Climate, four new estimators were developed: Permanent Cover Erosion Reduction model, the Septic System Improvement Estimator, the Milkhouse Waste Practices Estimator, and the Hydrologic Soil Group – Knowledge Matrix tool. These estimators fill gaps where estimators did not exist previously. The existence of these estimators allows Local Government Units and other conservation partners to better quantify the environmental outcomes of conservation implementation. Training for LGUs and other conservation partners was conducted and made available in multiple formats (in-person, webinar, instructional videos). Many LGUs have already used the new estimators and we anticipate widespread adoption in the future.

Additional results include development of a framework to model and track movement of endocrine disrupting compounds and a data quality analysis of pollution reduction reporting. Three reports resulted from the work in the project. The reports are listed and briefly summarized below.

- *Modeling Soil Erosion with* $^{137}$*Cs*: This report explains the process of modeling landscape-scale soil erosion and provides instructions on using the model to estimate long-term average erosion rates.
- *eLINK Data Quality Control Analysis:* This report provides an overview of the pollution reduction estimates in eLINK and recommends actions to improve data quality and completeness.
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### Project Results Use and Dissemination

The estimators are used by LGUs and conservation partners to quantify outcomes of installed Best Management Practices. The measured outcomes are collected in BWSR's eLINK database. The associated *eLINK Data Quality Control Analysis* report helps BWSR improve reporting of conservation project outcomes by recommending actions for improving education and outreach and developing internal mechanisms for quality control. Work completed by the University of Minnesota has gained interest amongst the broader scientific community and has been presented at international conferences. All reports, estimators and training materials developed during this project are available on the BWSR website: www.bwsr.state.mn.us

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Nater, E. A., B. J. Dalzell, C. Fissore, A. Wu, K. Yoo, and P. Ginakes. 2012. Legacy of Topography and Land Use on Erosion and Soil Organic Carbon Burial. Oral presentation given at the annual fall meeting of the American Geophysical Union. December 2012. San Francisco, CA

Nater, E. A., B. J. Dalzell, C. Fissore, A. Wu, and K. Yoo. Distribution and Movement of Soil Organic Carbon in Grassland and Agricultural Landscapes. Poster presentation given at the annual fall meeting of the American Geophysical Union. December 2011. San Francisco, CA

## III. PROJECT STATUS UPDATES:

**Project Status as of January 2012**: Outcome 1 of Activity 1 is complete. Several meetings were held with the UM research team to refine the list of estimators proposed for development. Discussions also included BWSR staff involved in selecting projects for Legacy funding. The many projects funded with the Clean Water part of Legacy funding has helped identify the need for new or revised estimators. Concerning Activity 2, the UM research team has made good progress determining sediment movement on the landscape. These findings, which are preliminary, show promise in developing estimators for Best Management Practices (BMP) associated with erosion and sediment. Moreover, since much non-point phosphorus loading is associated with sediment, the research may have help improve phosphorus estimators.

**Project Status as of September 2012:** University of Minnesota researchers made significant progress towards completing Outcome 2 of Activity 1. The University of Minnesota developed an estimator for septic system improvement projects. This estimator is currently in 'draft' format and is being reviewed by BWSR staff. The University of Minnesota continues to develop additional estimators for priority BMPs. In Activity 2, over 60 additional grassland and cropland sites were sampled for carbon and $^{137}$Cs analysis. Laboratory work is ongoing to prepare soil samples and run elemental analysis for organic carbon content and gamma spectroscopy for $^{137}$Cs. Outcome 3 of Activity 3 is underway. BWSR staff is conducting data analysis on reported pollution reductions thus establishing a baseline range of values for a subset of BMPs in eLINK. The data analysis serves as a foundation for development of quality control recommendations.

**Amendment Request (02/14/2013):** The University of Minnesota will develop and conduct a portion of the training sessions in Activity 3. A total of $19,500 will be shifted to the University of Minnesota contract from the following budget categories: TBD (competitive bid) - $8,000; Training Materials - $4,000; Printing - $2,000; Travel Expenses - $5,500.

Outcome end dates in all Activities are extended to reflect 1) the one year project extension due to the Minnesota Government shutdown in 2011 as well as 2) additional time needed to process samples in Activity 2. Approved by the LCCMR 2-28-2013

**Project Status as of March 2013**: University of Minnesota researchers continue making progress towards completing Activity 1 Outcome 2. New estimators will be deployed after the new eLINK system is launched in April 2013. Work on Activity 2 proceeds around the clock with $^{137}$Cs and organic carbon measurements. Fieldwork and sample processing is complete and analytical work remains. Activity 3 continues with curriculum development and quality assurance/quality control analysis.

**Project Status as of August 2013:** University of Minnesota researchers continue work on Activity 1 Outcome 2. The Septic System Improvement Estimator is complete and posted on the BWSR eLINK homepage. The Milk House Waste Water Improvement estimator is in development and the Knowledge Matrix – Hydrologic Soils Group estimator is in a final testing stage. Soil and Cesium – 137 analyses continue for Activity 2, Outcome 2 and a soil erosion/deposition model is in early stages of development. Model development will accelerate as additional Cesium data becomes available. As a component of Activity 3, training and education events are planned for October 2013 for the Septic System Improvement Estimator. Additional training and education events will be scheduled as the Milk House Waste Water Improvement and Knowledge Matrix – Soil Hydrologic Group estimators are finalized.

**Project Status as of February 2014:**
Activity 1 outcomes 2 and 3 are near completion. The Milk House Waste Water Improvement estimator is in a testing phase and will be finalized in the spring. Soil and Water Conservation Districts in Southeast Minnesota are testing the estimator and providing feedback. The Hydrologic Soils Group – Knowledge Matrix estimator is undergoing final changes to incorporate feedback from the testing process. Soil testing for Activity 2 is ongoing and soil movement models are being developed. Digital terrain attributes are being used to develop multiple regression approaches for predicting landscape-level distribution of $^{137}$Cs (which is used as a proxy for soil erosion and deposition.) Work continues on Activity 3 with training events, guidance development and eLINK data analysis. A University of Minnesota partner presented the Septic System Improvement Estimator at the 2013 BWSR Academy. The Hydrologic Soils Group – Knowledge Matrix instructional user guide is undergoing finalization following changes made after the beta testing process. The final user guide will be posted to the BWSR eLINK website in Spring 2014. eLINK data Quality Control and Quality Assurance review continues. In March 2014, work begins on Activity 4.

## IV. PROJECT ACTIVITIES AND OUTCOMES:

**ACTIVITY 1:** Develop new and improve existing pollution estimators

**Description:** Create a work team composed of BWSR staff and University of Minnesota researchers. The work team will identify BMPs requiring new estimator development and those requiring revision of current estimators. The team will work collaboratively to generate new estimators, improve existing estimators, and launch the new estimators for use by LGUs and other conservation professionals.

**Summary Budget Information for Activity 1:**

| | |
|---|---|
| **ENRTF Budget:** | **$ 86,000** |
| **Amount Spent:** | **$ 86,000** |
| **Balance:** | **$ 0** |

**Activity Completion Date:**

| **Outcome** | **Completion Date** | **Budget** |
|---|---|---|
| **1.** Work team develops recommendations for priority estimator development | December 2011 | $ 13,000 |
| **2.** Work team collaborates with the University of Minnesota and other soil and water conservation organizations to develop/revise priority estimators | December 2013 | $ 68,000 |

| | | |
|---|---|---|
| **3.** Deploy new estimators for outcome tracking in eLINK | December 2013 | $ 5,000 |

**Activity Status as of January 2012**: Outcome 1 of Activity 1 is complete. Several meetings were held with the UM research team to refine the list of estimators proposed for development. Discussions also included BWSR staff involved in Legacy funding. The many projects funded with the Clean Water part of Legacy funding has helped identify the need for new or revised estimators.

**Activity Status as of September 2012:** Staffs of the Department of Soil, Water and Climate and Bioproducts and Biosystems Engineering are leading the development of estimators. University of Minnesota researches made significant progress in developing an estimator for septic system improvement projects. This estimator is currently in 'draft' format and is being reviewed by BWSR staff. The University of Minnesota continues to develop additional estimators for priority BMPs.

**Activity Status as of March 2013**: The septic system improvement estimator is complete and training will begin in Spring 2013. Another calculator in development is the Milk House Waste Water Improvement pollution reduction estimator. A third estimator in development is a Soils add-on to the MPCA developed Minimum Impact Design Standards calculator.

**Activity Status as of August 2013:** The Septic System Improvement Estimator is posted on the BWSR eLINK homepage and is in use by Local Government Units. The Milk House Waste Water Improvement estimator remains in development at the University of Minnesota Water Resources Center. The Soils add-on to the Minimum Impact Design Standards calculator, titled *Hydrologic Soils Group – Knowledge Matrix,* is in a peer review process and beta tested by a subset of Local Government Units.

**Activity Status as of February 2014:** The Milk House Waste Water Improvement Practices estimator is in a testing phase and will be finalized in the spring. Soil and Water Conservation Districts in Southeast Minnesota are testing the estimator and providing feedback. The Hydrologic Soils Group – Knowledge Matrix estimator is undergoing final changes to incorporate feedback from the testing process.

**Final Report Summary:** Three new estimators were developed. Local Government Units (LGUs) and other partners use these estimators to quantify the benefits of conservation practices and provide measurable outcomes for grant reporting. The Septic System Improvement Estimator was launched in October 2013 and LGUs used it in the January 2014 reporting period. Reporting data shows that the quality of pollution reduction estimates improved after the estimator was made available. We believe this is directly attributable to the new estimator and estimator training at the BWSR Academy. The Milk House Waste Water Improvement estimator and the Hydrologic Soils Group – Knowledge Matrix were both launched in in June 2014. There has not been a reporting period since the launch and therefore cannot quantify their impact on pollution reduction estimates. However, we believe the estimators and associated training will improve pollution reduction estimates and provide measurable outcomes for conservation practices. See the eLINK Data Quality Control Analysis report (a component of Activity 3) for further discussion.

Milkhouse Waste Practices Estimator: Is a spreadsheet-based model that calculates annual pollutant loads from problematic milk house wastewater systems and accounts for the benefits of a range of milk house wastewater improvements. This tool estimates reductions in Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), Phosphorus, and Nitrogen. This tool is intended for use on projects where the producers cannot add the milk house wastewater to liquid manure storage. The user guide provides an introduction to the MWIE, as well as tips and instructions for using it. The user guide and model is available at www.bwsr.state.mn.us/outreach/elink. The Milk House Waste Water Improvement estimator was launched in June 2014.

Septic System Improvement Estimator: The Septic System Improvement Estimator (SSIE) is a spreadsheet-based model that calculates annual pollutant loads from problematic septic systems and accounts for the benefits of a range of septic system improvement, educational efforts and programs to identify the problematic systems. This tool estimates reductions in Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), Fecal Coliform bacteria, Phosphorus, and Nitrogen. The user guide provides an introduction to the SSIE, as well as tips and instructions for using it. The user guide and model is available at www.bwsr.state.mn.us/outreach/elink. The Septic System Improvement Estimator was officially launched in October 2013.

Hydrologic Soils Group – Knowledge Matrix: Provides a standardized decision support system to determine the appropriate Hydrologic Soils Group from a combination of off-site and field-determined soils information. A hydrologic soil group is used in a number of applications including the MPCA Minimal Impact Design Standards (MIDS) Calculator or sizing a stormwater features using the MPCA's Stormwater Manual (MPCA, 2013). This decision support tool improves the accuracy of MIDS calculations by updating Hydrologic Soil Group ratings to reflect current environmental conditions. The Hydrologic Soils Group – Knowledge Matrix tool was launched in June 2014.

**ACTIVITY 2:** Field Verification

**Description:**

Summary

A team of researchers (Nater, Fissore, Dalzell) at the University of Minnesota will directly measure and model sediment erosion and deposition on lands under annual row crop and perennial grassland management in order to determine the effectiveness of perennial grassland conservation management practices in limiting sediment production to streams. The activity includes development of estimators to quantify pollution reduction benefits of sediment-trapping BMPs. The new estimators will be used to initiate a framework for modeling the movement of a variety of land-applied chemicals to surface waters.

Background

Erosion of soils by water redistributes soil sediments within fields and can lead to increased sediment in adjoining streams and other surface water bodies. Because many chemicals adhere strongly to soil sediments, eroded sediments can carry these chemicals with them.

Conservation practices have been implemented over the years to reduce accelerated erosion and to protect sediments from entering surface waters. These include changes in tillage and residue management and the use of perennial grasses in grassed waterways, riparian buffers, and on steep slopes. While there is general agreement that these practices reduce erosion and sediment production, the actual quantities of sediment movement reduced by these practices is uncertain.

Erosion/Deposition Estimator Development

The erosion/deposition estimators will be based on the relationship between LIDAR-based Digital Terrain Attributes and a 50-year average of soil movement measured by the of Cesium-137 isotope method. Cesium-137 is a radioactive isotope that is produced only by nuclear fission; there are no natural sources. Large quantities of Cesium-137 were released into the atmosphere during above ground nuclear weapons testing and were carried into the stratosphere and distributed worldwide. Subsequent deposition (fallout) contaminated soils regionally with a small but relatively uniform dose of Cesium-137 which adheres tightly to surface soil particles, providing a measurable label for surface soils. Any redistribution of Cesium-137 since the cessation of above ground testing in 1963 is due to the physical movement of surface soil sediments by erosion, animal activity, or human activity. (Although Cesium-137 was released to the atmosphere during the Chernobyl explosion and is currently being released by the damaged reactors at Fukushima, Japan, the quantities deposited on Minnesota soils are negligible and will not interfere with these analyses). The total quantity of surface soil eroded from or deposited on any point in the landscape since the mid 1960s can be determined by measuring the activity of Cesium-137 in soils with a gamma ray spectrometer. Annual average rates of sediment movement can then be calculated and will be related to Digital Terrain Attributes to develop estimators of erosion/deposition and potential sediment production to surface waters.

LIDAR-based digital elevation models will soon be available for the entire state, providing the opportunity to enhance the estimation of erosion/deposition. Current estimates are developed using the RUSLE2 model, which is based on slope steepness and length, soil characteristics, and land use characteristics. Digital Terrain Attributes such as Compound Terrain Index and Stream Power Index also use slope steepness and length, but in addition include the curvature of the slope (which determines if runoff is focused or dispersed) and the area upslope of any point on the landscape that contributes runoff to that point. These attributes (and others) can be readily calculated from a LIDAR-based DEM and provide a better estimate of the potential for erosion or deposition at any point in the landscape, improving the accuracy of estimators based on them. (This approach was developed in collaboration with Dr. Kyungsoo Yoo and Joel Nelson).

**Summary Budget Information for Activity 2:**

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|---|---|
| **ENRTF Budget:** | **$ 196,000** |
| **Amount Spent:** | **$ 196,000** |
| **Balance:** | **$ 0** |

**Activity Completion Date:**

| **Outcome** | **Completion Date** | **Budget** |
|---|---|---|
| ***1.*** Identify sites on public lands or cooperating landowners that have either been continuously under tillage or have been continuously under perennial grassland for the last 50 years. Use LIDAR-based Digital Terrain Attributes (Compound Terrain Index [CTI], Stream Power Index [SPI]) of these sites to select sampling locations that encompass a broad array of Digital Terrain Attribute values. | November 2012 | $ 26,000 |
| **2.** Collect soil samples by depth increment for each site identified and analyze soil samples for total carbon, $^{137}$Cs (cesium-137) and $^{210}$Pb (lead-210). | December 2013 | $ 100,000 |
| ***3.*** Determine sediment movement as a function of Digital Terrain Attributes for both grassland and tilled sites. Report results and implement estimators. | January 2014 | $ 70,000 |

**Activity Status as of January 2012**: The UM research team has made good progress determining sediment movement on the landscape. These findings, which are preliminary, show promise in developing estimators for Best Management Practices (BMP) associated with erosion and sediment. Moreover, since much non-point phosphorus loading is associated with sediment, the research may have help improve phosphorus estimators.

**Activity Status as of September 2012:** Over 60 additional grassland and cropland sites were sampled for carbon and $^{137}$Cs analysis. Laboratory work is ongoing to prepare soil samples and run elemental analysis for organic carbon content and gamma spectroscopy for $^{137}$Cs.

**Activity Status as of March 2013**: Field work and sample processing has been completed for all grassland and cropland sites. In total, 220 sites were sampled during the field campaign for this project from 2010 through 2012 representing well over 2000 discrete soil samples for analysis. Crop and Grass sites were equally represented, with 111 and 109 sites sampled, respectively.

All samples have been dried, sieved and archived. Current efforts are focused on completing elemental analysis (C and N) of grassland samples that were collected in 2012 as well as $^{137}$Cs analysis of all soil samples. Thus far, measurements have been completed on approximately 750 and 1500 samples for $^{137}$Cs and organic carbon, respectively. Because $^{137}$Cs measurements are time-intensive (approximately 12-24 hours per sample), ongoing measurement of remaining samples is a round-the-clock operation that will likely extend well into 2013. Remaining soil samples for organic carbon determination are being prepared for analysis by Dr. Cinzia Fissore at Whittier College. While $^{137}$Cs analyses are ongoing, enough preliminary data points have been collected to proceed with our investigation of state-wide trends in the influence of land cover and soil movement on soil organic matter across landscapes representative of the southern 1/3 of Minnesota.

Ongoing and remaining tasks: Remaining analytical work is focused on completing instrumental analysis of soil samples (organic C and $^{137}$Cs). Existing data are currently undergoing quality control and being prepared for development of empirical models intended to quantify erosion effects on soil carbon across Minnesota's agricultural landscapes.

**Activity Status as of August 2013**

Recent efforts for Activity #2 have been focused on processing of $^{137}$Cs data including correcting collected energy spectra for instrument efficiency and determining appropriate minimum detectable activity (MDA) levels for each sample. (Instrument efficiency correction is based on a prepared mixture of known radioactivity; MDA levels vary with each sample based on acquisition time and background spectra characteristics.) Additional work has been performed to develop protocols and generate maps of digital terrain attributes for areas containing clusters of sample locations around the state. Current GIS-based work is focused on quality checking of digital terrain attribute products and filling missing gaps where LiDAR data were not initially available. Digital terrain attributes, $^{137}$Cs data, and soil organic carbon (SOC) data are being assembled into a master data file for final quality check and eventual input into development of empirical models of soil erosion for different regions of the state. Samples from grassland sites from scientific and natural areas (SNAs) are being prepared for both $^{137}$Cs and SOC analysis (smaller sample amounts from these sites requires different sample preparation protocols).

Ongoing and remaining tasks include finalizing analytical SOC and $^{137}$Cs work, data quality checks, and empirical model development. Due to the slow nature of $^{137}$Cs analysis, it is likely that outcome 2 will be ongoing until the completion of the project. Resulting from delayed $^{137}$Cs analysis, outcome 3 will be completed in Spring 2014.

**Activity Status as of February 2014:**

Digital terrain attributes are being used to develop multiple regression approaches for predicting landscape-level distribution of $^{137}$Cs. Preliminary results from these approaches show that $^{137}$Cs distribution is dependant upon both land use, slope steepness, and hillslope profile curvature. Regression model development is ongoing and current efforts are twofold:

1) Evaluating the differences in decadal-scale soil re-distribution across Southern Minnesota. Different study regions are being evaluated individually for model development based on digital terrain attributes. Following development of the best model for each region, resulting models will be compared to determine whether or not soil movement could be predicted with a more simple set of models that could be applied uniformly. This line of inquiry may also include adding climate factors as potential model variables.
2) Determining the difference in soil redistribution patterns between cropland and grassland landscapes. Different regression models are being developed based on land use. The resulting soil movement maps will be used to identify landscape segments that show the greatest difference between the two land uses. This will allow us to directly quantify how much soil

erosion may be prevented by implementing perennial vegetation on specific landscape segments.

In addition to model development of soil movement, $^{137}$Cs data are being used in conjunction with soil organic carbon (SOC) data to investigate the impacts of landscape-scale soil redistribution on decadal scale soil carbon cycling. Preliminary results suggest that soil erosion, followed by deposition in select landscapes can represent an important local sink of SOC via burial mechanisms. These conclusions are supported both by empirical (digital terrain attribute) based approaches as well as direct measurements of soil movement via $^{137}$Cs profiles.

**Final Report Summary:**

The University of Minnesota developed a new tool for measuring environmental outcomes for permanent vegetative cover practices like grassland restoration. The estimator is based on regression models and erosion maps and it will be useful for measuring outcomes and pollution reduction for conservation programs like RIM and the Conservation Reserve Program. Prior to the development of this estimator, there was not an easy to use, reliable model to estimate erosion reduction for conversion to perennial grasslands. The development of this estimator is timely and aligns with the increase in RIM project implementation.

The estimator has two components: GIS-based soil erosion maps and instructions for calculating the parcel-average erosion rate for a parcel of interest. The University of Minnesota and BWSR are in the process of selecting the best data delivery mechanism for users. The estimator and background data is scheduled for posting on the BWSR website by October 2014.. The exact blueprint of the estimator evolved throughout the project period. If given additional funding and time, it would have been beneficial to develop a user interface for the estimator to make it simpler to use. BWSR is dedicated to making the estimator as user-friendly as possible and will continue making improvements as staff time allows. The University of Minnesota developed a report for Activity 1 titled *Modeling Soil Erosion with $^{137}$Cs*

*Modeling Soil Erosion with $^{137}$Cs* Summary: In order to develop landscape-scale estimates of soil erosion in Minnesota's agricultural landscapes, we conducted a broad survey study of $^{137}$Cs in cultivated fields and uncultivated reverence sites located across the southern third of Minnesota. Produced during atmospheric testing of nuclear weapons in the 1950s and 1960s, $^{137}$Cs binds tightly to soils and serves as an effective tracer for soil movement on decadal timescales. A $^{137}$Cs conversion model was used to determine soil erosion rates for 107 locations in cultivated sites. Measured soil erosion rates ranged from 49 t ha$^{-1}$ yr$^{-1}$ (erosion) to -74 t ha$^{-1}$ yr$^{-1}$ (deposition). Based on these measured rates, regression models were developed with the goal of broadly predicting soil erosion rates based on topographic characteristics. Digital terrain attributes were calculated from LiDAR-derived (Light Detection And Ranging) digital elevation models and then used as predictor terms in regression model development. Resulting models showed that: (1) profile curvature, (2) planform curvature, and (3) slope steepness were significant model terms in predicting erosion rates for different Minnesota Major Land Resource Areas (MLRAs). The resulting regression models were able to explain 38% of the variability observed in measure soil erosion rates. When applied to cultivated landscapes, the regression models create maps of predicted long-term rates of soil erosion or deposition. These maps will be helpful to BWSR personnel, soil conservationists, and other local government unit personnel to help identify which portions of the landscape would benefit the greatest from perennial vegetation conservation practices. In a complementary manner, these maps may also be used to quantify the soil and water quality benefits of farm land enrollment into a conservation program (or, conversely, the environmental impact of converting perennially vegetated land for cultivation) like Re-Invest in Minnesota (RIM).

**ACTIVITY 3:** LGU Training and education

**Description:**
Develop and host training sessions for LGUs and other eLINK users on the newly revised and developed pollution reduction estimators. Training content will be developed in multiple platforms and available in alternative formats (i.e. video) that is widely accessible. A quality assurance and quality control assessment of LGU-reported pollution reduction values will verify the training was successful and LGUs are using the estimators correctly. Adjustments to estimation and reporting procedures following quality assurance and quality control review.

**Summary Budget Information for Activity 3:**

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|---|---|
| **ENRTF Budget:** | **$ 50,000** |
| **Amount Spent:** | **$ 50,000** |
| **Balance:** | **$ 0** |

**Activity Completion Date:**

| Outcome | Completion Date | Budget |
|---|---|---|
| **1.** Curriculum development for estimator training sessions | January 2014 | $ 15,000 |
| **2.** Host training sessions for new and revised estimators (in-person, webinars, instructional videos) | March 2014 | $ 25,000 |
| **3.** Quality control and quality assurance review of pollution reduction estimates | June 2014 | $ 10,000 |

**Activity Status as of January 2012**: N/A at this time.

**Activity Status as of September 2012:** Outcome 3 of Activity 3 is underway. Data analysis on reported pollution reductions was conducted to establish a baseline range of values for a subset of BMPs in eLINK. The data analysis serves as a foundation for development of quality control recommendations.

**Activity Status as of March 2013**: Curriculum development is underway for the Septic System improvement estimator. Quality control and quality assurance analysis on eLINK data continues. Sara Heger from the University of Minnesota presented the Septic System Improvement Estimator at the MN Onsite Wastewater Conference in Alexandria, MN 1/29/13 -1/31/13.

**Activity Status as of August 2013:** Training sessions for the Septic System Improvement Estimator are scheduled for October at the BWSR Academy – the annual training conference for local government staff. An instructional user guide for the Hydrologic Soils Group – Knowledge Matrix is in draft form and will be finalized this fall. Quality control and quality assurance analysis on eLINK data continues and will ramp up following the January 2014 eLINK reporting deadline when additional data is captured.

**Activity Status as of February 2014:** A University of Minnesota partner presented the Septic System Improvement Estimator at the 2013 BWSR Academy. The Hydrologic Soils Group – Knowledge Matrix instructional user guide is undergoing finalization following changes made after the beta testing process. The final user guide will be posted to the BWSR eLINK website in Spring 2014. eLINK data Quality Control and Quality Assurance review continues.

**Final Report Summary:** Training sessions were completed for three estimators: the Septic System Improvement Estimator, the Milk House Waste Water Improvements etimator and the Hydorlogic Soils Group – Knowledge Matrix tool. The training was delivered in multiple formats including in-person, webinar,and instructional videos or modules. The in-person training for the Septic System Improvement Estimator took place at the 2013 BWSR Academy (26 participants). Training evaluations showed that participants found the training and the estimator useful, particularly for studying proposed developments. The Milk House Waste Water Improvement webinar took place June 12, 2004 (28 participants). The training module (video tutorial) was also posted to the BWSR website in June. To date, there have been 7 page views. Participants reported the estimator was easy to use and would be helpful in LGUs outcome reporting. An additional piece of particularly useful feedback was a request to upgrade the tool to include pollution reduction estimates to water bodies. The current estimator is only an 'edge of field' model and does not address effluent after it leaves the field as defined in the estimator. The Hydrologic Soils Group – Knowledge Matrix training module (video tutorial) was posted in June 2014. To date, there are 15 page views. The number of website visits for both the Hydrologic Soils Group – Knowledge Matrix and the Milk House Waste Water Improvement estimator is low. The low traffic is likely due to the timing offset of estimator deployment and the timing of grant reporting. The Milk House Waste Water Improvement estimator and the Hydrologic Soils Group – Knowledge Matrix were first made available to LGUs in June 2014. The website visits reported reflect one month of activity. Also, LGUs most frequently use estimators in December and January of each year, the months immediately prior to grant reporting deadlines. As the next reporting period nears, we anticipate a spike in website visits for the online training tutorials.

The report *eLINK Data Quality Control Analysis* provides an overview of the pollution reduction estimates in eLINK and recommends actions meant to improve data quality and completeness.

*eLINK Data Quality Control Analysis* summary:

eLINK is a central database housing pollution reduction outcomes for BWSR's grants to local government units (LGUs). Since 2003 eLINK has tracked BWSR grants and project outcomes including pollution reduction estimates. The database contains gaps in pollution reduction reporting. These gaps exist for various reasons including:

- Insufficient models to estimate pollution reductions for all practices
- Inadequate enforcement of reporting requirements
- Inability to demonstrate benefits of preventative practices, e.g., Well Sealing, Nutrient Management Planning and Use Exclusion.

In an era of accountability and reporting of environmental outcomes, it is essential that BWSR demonstrates environmental benefit from BWSR-funded projects. The key to accountability and demonstrating outcomes is ensuring pollution reductions are 1) entered in the grant reporting process and 2) represent the best estimate for on the ground pollution reductions.

The Environment and Natural Resources Trust Fund provided funding as recommended by the Legislative Commission on Natural Resources to address BWSR's need for improved measurement of conservation practice outcomes. As a part of the *Measuring Conservation Practice Outcomes* project, BWSR and the University of Minnesota developed new pollution reduction estimators addressing eLINK's data gaps. Additionally, a quality control analysis was completed as a part of the *Measuring Conservation Practice Outcomes* project. The quality control analysis includes the following elements: 1) statistical analysis and interpretation of pollution reduction estimates derived from a newly developed estimator, 2) statistical analysis of reported pollution reduction from the most commonly-funded BMPs, 3) quality control recommendations, and 4) resources for internal quality control.

**ACTIVITY 4:** Develop framework for movement of chemicals and land-applied EDCs in soils
**Description:**
Summary
This activity combines the erosion/deposition estimator developed in activity 2 with partition coefficients for land-applied chemicals reported in published literature to create a pollution reduction estimator for

Atrazine (the most common land-applied EDC). Ideally this activity would include developing estimators for 9 of the most common land-applied EDCs (atrazine, daidzein, equol, genistein, 17-alpha-trenbolone, 17-beta-trenbolone, monensin, tylosin and virginiamycin) however existing research on these emerging chemicals is insufficient and partition coefficients are not currently available with the exception of atrazine. For the remaining land-applied chemicals without published partition coefficient values, a framework will be developed for modeling chemical movement when data become available. (This approach was developed in collaboration with Drs. Bill Koskinen and Pam Rice).

Background

Many chemicals adhere to surface soils, binding tightly to mineral and/or organic matter particles. Examples include phosphorus, numerous organic compounds (pesticides and herbicides, animal antibiotics, endocrine disrupting chemicals, natural chemicals), and many others. Transport of these chemicals occurs when soil particles are transported by erosion or other processes. Other chemicals such as nitrate, chloride, and sulfate, are soluble in water and do not adhere tightly to soil particles. Transport of these chemicals occurs with the movement of water, either as surface runoff or as subsurface flow to groundwater or in tile drainage.

A partition coefficient is a chemical term used to describe the relative affinity of a chemical for one phase (water) as opposed to another (soil). The relative affinity of a chemical for the soil phase is dependent on the nature of the soil (particularly the clay content and the organic matter content) and the structure of the chemical and how it interacts with the soil components. Partition coefficients for a chemical can be measured in the laboratory and are valid for a specific soil type.

If we know the concentration of a chemical in the field, the partition coefficient for a specific chemical/soil type combination, and we can estimate of the erosion/deposition rate, then we can estimate the movement of that chemical on the landscape and determine how effective conservation practices are at retaining it on the landscape. Consequently, a good erosion/deposition estimator provides a framework for estimating the movement of chemicals across the landscape if partition coefficients are available or can be determined. For a specific region where the clay and organic matter content and type are relatively uniform, partition coefficients can be applied across the region. For some well-studied chemicals, sufficient information may exist in the literature to allow a good prediction of the water-soil partition coefficient for a specific region. For most chemicals, and particularly for emerging chemicals such as many of the endocrine disrupting chemicals, existing data are insufficient. Our awareness of many of the endocrine disrupting chemicals is relatively recent and our understanding of their behaviors in natural systems is in its infancy.

The advantage of this method of estimating the movement of chemicals is that it is far more universal than field monitoring and measurement of the movement of chemicals where direct measurements are made for one chemical for only one or two years on a small number of fields or sites. Our approach can be applied to a much broader region and additional chemicals can be added as need or when data become available. An example of a similar type of estimator is the Minnesota Phosphorus Index, which is based in part on the movement of sediments as predicted by RUSLE2 and the strong affinity of phosphorus for soil particles.

**Summary Budget Information for Activity 4:**

| | |
|---|---|
| **ENRTF Budget:** | **$ 8,000** |
| **Amount Spent:** | **$ 8,000** |
| **Balance:** | **$ 0** |

**Activity Completion Date:**

| Outcome | Completion Date | Budget |
|---|---|---|

|  |  |  |
|---|---|---|
| **1.** Develop pollution reduction estimators for chemicals with known partition coefficients | June 2014 | $ 2,000 |
| **2.** Develop framework for measuring chemical movement in soils; including sample collection protocol and laboratory protocols. | June 2014 | $ 6,000 |

**Activity Status as of January 2012**: N/A at this time.

**Activity Status as of September 2012:** N/A at this time.

**Activity Status as of March 2013**: N/A at this time.

**Activity Status as of August 2013:** N/A at this time.

**Activity Status as of February 2014:** In March 2014, work begins on developing pollution reduction estimates and developing a framework for measuring and documenting chemical movement in soils.

**Final Report Summary:**
A framework was developed for modeling movement of endocrine disrupting chemicals. The document *Endocrine Disrupting Chemical Retention Framework* describes the technical background and framework development. This framework can be used as a springboard for additional research to track the movement and fate of endocrine disrupting compounds in the environment.

*Endocrine Disrupting Chemical Retention Framework* Summary:
A number of chemicals of emerging concern, including pesticides and herbicides, antibiotics used in animal agriculture, and growth-promoting hormones, are associated with agricultural activities. Many of these chemicals have, or are suspected of having, properties that affect or disrupt endocrine systems. These endocrine-disrupting chemicals (EDCs) may be applied directly to crops or the soil, or are present in manures that are applied to soils. Consequently they have the potential to be transported into surface waters by surface runoff or through tile drains.

Because many of these chemicals are strongly associated with soil solids, they are transported mainly as chemicals sorbed to suspended sediment, not as chemicals dissolved in water.

Many of these chemicals are hydrophobic and thus have a strong affinity for organic matter. This is expressed by the $K_{OC}$ value (the distribution coefficient between the aqueous phase and organic carbon (OC)). This is a commonly measured parameter for organic chemicals in soil environments because it normalizes sorption in soils having varying properties to a single value.. If you know the $K_{OC}$ value for a chemical and the OC of organic matter (OM) content of the soil, you can determine the distribution of the chemical between the aqueous phase and the soil-sorbed phase.

## V. DISSEMINATION:

**Description:**
Pollution reduction estimators developed, revised and verified in activities 1 and 2 will be made web available on the BWSR eLINK homepage (http://www.bwsr.state.mn.us/outreach/eLINK/index.html). Guidance documents and instructional materials developed in activity 4 will also be available on the eLINK homepage. In-person training sessions on pollution reduction estimators are planned throughout the State and specific dates and locations will be highlighted on the BWSR Training website (http://www.bwsr.state.mn.us/training/index.html) as well as in the *Train Tracks* training newsletter. The framework for estimating land-applied EDCs and protocols for sampling and analysis of EDCs will be available on the BWSR soils website (http://www.bwsr.state.mn.us/soils/index.html).

**Status as of January 2012**: Professor Ed Nater and his research team presented a poster entitled: “Distribution and Movement of Soil Organic Carbon in Grassland and Agricultural Landscapes” at the American Geophysical Union Annual Meeting in San Francisco, December 2011.

**Status as of September 2012:** No additional dissemination.

**Status as of March 2013**: An oral presentation, entitled *Legacy of Topography and Land Use on Erosion and Soil Organic Carbon Burial,* was given at the 2012 annual American Geophysical Union conference. Below is a summary of presentations associated with this project.

Nater, E. A., B. J. Dalzell, C. Fissore, A. Wu, K. Yoo, and P. Ginakes. 2012. Legacy of Topography and Land Use on Erosion and Soil Organic Carbon Burial. Oral presentation given at the annual fall meeting of the American Geophysical Union. December 2012. San Francisco, CA

Nater, E. A., B. J. Dalzell, C. Fissore, A. Wu, and K. Yoo. Distribution and Movement of Soil Organic Carbon in Grassland and Agricultural Landscapes. Poster presentation given at the annual fall meeting of the American Geophysical Union. December 2011. San Francisco, CA

Dalzell, B. J., C. Fissore, E. Nater, K. Yoo, and A. Wu. 2011. Redistribution of Soil Organic Carbon in Agricultural Soils. Oral presentation given at the annual meeting of the Geological Society of America. October 2011. Minneapolis, MN

Dalzell, B. J., C. Fissore, E.A. Nater, and K. Yoo. 2010. Terrain Control on Soil Organic Carbon Distribution in Loess Soils with Varying Land Cover. Poster presentation given at the annual fall meeting of the American Geophysical Union. December 2010. San Francisco, CA

**Status as of August 2013:** The Septic System Improvement Estimator is posted on BWSR’s eLINK grant reporting homepage (http://www.bwsr.state.mn.us/outreach/eLINK/SSIE_April_2013.xlsx). The Septic System Improvement Estimator was also posted on the scrolling Highlights section on BWSR’s homepage.

**Status as of February 2014:**

These results have gained interest amongst the broader scientific community and have been presented at two international conferences in 2013:

Dalzell, B.J., E.A. Nater, K. Yoo, and C. Fissore. 2013. Legacy of Topography and Land Use on Erosion and Soil Organic Carbon Burial over Decadal Timescales. Presented at the annual fall meeting of the Geological Society of America. October 2013. Denver, CO.

Dalzell, B.J., E.A. Nater, K. Yoo, C. Fissore, A. Wu. 2013. Terrain Influences on Soil Organic Carbon Translocation and Burial: Applications of High-Resolution Digital Elevation Models. Poster presentation given at the annual fall meeting of the American Geophysical Union. December 2013. San Francisco, CA

**Final Report Summary:**

Presentations at International conferences:

Dalzell, B. J., C. Fissore, E. Nater, K. Yoo, and A. Wu. 2011. Redistribution of Soil Organic Carbon in Agricultural Soils. Oral presentation given at the annual meeting of the Geological Society of America. October 2011. Minneapolis, MN

Dalzell, B. J., C. Fissore, E.A. Nater, and K. Yoo. 2010. Terrain Control on Soil Organic Carbon Distribution in Loess Soils with Varying Land Cover. Poster presentation given at the annual fall meeting of the American Geophysical Union. December 2010. San Francisco, CA

Dalzell, B.J., E.A. Nater, K. Yoo, and C. Fissore. 2013. Legacy of Topography and Land Use on Erosion and Soil Organic Carbon Burial over Decadal Timescales. Presented at the annual fall meeting of the Geological Society of America. October 2013. Denver, CO.

Dalzell, B.J., E.A. Nater, K. Yoo, C. Fissore, A. Wu. 2013. Terrain Influences on Soil Organic Carbon Translocation and Burial: Applications of High-Resolution Digital Elevation Models. Poster presentation given at the annual fall meeting of the American Geophysical Union. December 2013. San Francisco, CA

Nater, E. A., B. J. Dalzell, C. Fissore, A. Wu, K. Yoo, and P. Ginakes. 2012. Legacy of Topography and Land Use on Erosion and Soil Organic Carbon Burial. Oral presentation given at the annual fall meeting of the American Geophysical Union. December 2012. San Francisco, CA

Nater, E. A., B. J. Dalzell, C. Fissore, A. Wu, and K. Yoo. Distribution and Movement of Soil Organic Carbon in Grassland and Agricultural Landscapes. Poster presentation given at the annual fall meeting of the American Geophysical Union. December 2011. San Francisco, CA

Training events and modules:

BWSR Academy October 2013 – Septic System Improvement Estimator
Milk House Waste Water Improvement Estimator Webinar June 2014
Milk House Waste Water Improvement Estimator module – ongoing
Hydrologic Soils Group – Knowledge Matrix module - ongoing

Pollution reduction estimators and user guides are available on the BWSR eLINK homepage (http://www.bwsr.state.mn.us/outreach/eLINK/index.html). The Endocrine Disrupting Compounds framework developed in Activity 4 is available on the BWSR Soils webpage http://www.bwsr.state.mn.us/soils/index.html. Training modules and webinar recordings are available on the BWSR Training webpage http://www.bwsr.state.mn.us/training/index.html.

## VI. PROJECT BUDGET SUMMARY:

1 **ENRTF Budget:**

| Budget Category | $ Amount | Explanation |
|---|---|---|
| Personnel: | $ 55,000 | 1 BWSR classified staff (.25 FTE) to manage project address activities 1 and 3; 1 BWSR unclassified staff (.2 FTE) to address activities 1 and 3. |
| Professional/Technical Contracts: | $282,000 | Contract with University of Minnesota to develop and revise pollution reduction estimators, conduct field verification and to review land-applied EDCs. |
| Equipment/Tools/Supplies: | $3,000 | Software/licenses for training programs, supplies for workbooks, guidance documents and training packets, soil sampling and field verification supplies. |
| **TOTAL ENRTF BUDGET:** | **$ 340,000** | |

**Explanation of Use of Classified Staff:** LCCMR project funds do not supplant Agency general funds used for salary. Classified staff, Megan Lennon, is currently funded with special project funds devoted to conservation outcomes. These funds end 6/30/2011.

**Explanation of Capital Expenditures Greater Than $3,500:** N/A

**Number of Full-time Equivalent (FTE) funded with this ENRTF appropriation:** The ENTRF appropriation for the Measuring Conservation Practice Outcomes supports a total 6.44 FTEs over two years:

| | |
|---|---|
| Dr. Ed Nater | .05 FTE for 2 years |
| Cinzia Fissore | .1 FTE for 2 years |
| Brent Dalzell | .5 FTE for 2 years |
| Graduate Research Assistant 1 | .1 FTE for 1 year |
| Graduate Research Assistant2 | .5 FTE for 2 years |
| Graduate research assistant, undergraduate research assistants or research fellows (4 total) | .38 FTE for 2 years |
| Greg Larson | .2 FTE for 2 years |
| Megan Lennon | .25 FTE for 2 years |

**B. Other Funds:**

| **Source of Funds** | **$ Amount Proposed** | **$ Amount Spent** | **Use of Other Funds** |
|---|---|---|---|
| **State** | | | |
| BWSR In-kind services | $ 35,000 | $ 23,000 | BWSR IT staff support for Activity 3, specifically QA/QC and website development necessary for hosting web training. |
| **TOTAL OTHER FUNDS:** | **$ 35,000** | **$ 23,000** | |

## VII. PROJECT STRATEGY:

### A. Project Partners:

Paid in ENTRF funds: The project team includes Ed Nater (paid), Cinzia Fissore (paid), Brent Dalzell (paid) and two graduate students (paid), from the University of Minnesota's Department of Soil, Water and Climate, and Greg Larson (paid) and Megan Lennon (paid) from BWSR. Project partners from the University of Minnesota will conduct field research and collect and analyze data necessary for revision and development of new models to estimate environmental benefits of conservation practices. The University of Minnesota will receive a total of $262,500. Megan Lennon is the project manager, and Greg Larson will consult with University partners regarding research, and conduct training for local governments units on new and revised pollution reduction estimators.

Paid in-kind or unpaid: Additional project partners include Julie Blackburn (unpaid) and Conor Donnelly (paid in-kind) from BWSR. Julie Blackburn will consult on development of outcome measures and Conor Donnelly will provide IT support, outcome measure implementation, quality control/quality assurance, and training.

### B. Project Impact and Long-term Strategy:

The activities included in this proposal are critical to measuring the environmental outcomes and determining the effectiveness of conservation practices in Minnesota. BWSR's ongoing work with conservation programs necessitates assessments of practice effectiveness. With additional funding, this project could expand to include more comprehensive EDC research that is complimentary to both the 2010-2012 LCCMR project by Swackhammer, Koskinen and Rice and the 2011-2013 LCCMR proposal by Sadowsky. A mid-level analysis of land applied EDCs requires additional funding of $30,000 and would provide analysis of 5 EDCs (3 phytoestrogens, atrazine, and 1 growth hormone) on 3 soil types. A full scale analysis of land-applied EDCs requires additional funding of $88,000 and would provide analysis of 8 ECDs (atrazine, 3 phytoestrogens, 1 growth hormone, and 3 livestock antibiotics) on 8 soil types. The suite of EDCs chosen for both the mid-level and full scale analysis is identical to those in the Sadowsky and Swackhammer, Koskinen and Rice proposals. Analysis of the same suite of EDCs allows for inter-study comparability and lower analytical costs.

### C. Spending History:

| **Funding Source** | **M.L. 2009 or FY 2010** |
|---|---|
| Board of Water and Soil Resources - Clean Water Fund | $ 102,200 |

**VIII. ACQUISITION/RESTORATION LIST:** N/A

**IX. MAP(S):** N/A

**X. RESEARCH ADDENDUM:** N/A

## XI. REPORTING REQUIREMENTS:

**Periodic work plan status update reports will be submitted not later than January 2012, September 2012, and March 2013. A final report and associated products will be submitted between June 30 and August 1, 2013 as requested by the LCCMR.**

**Final Attachment A: Budget Detail for M.L. 2011 (FY 2012-13) Environment and Natural Resources Trust Fund Projects**

**Project Title:** Measuring Conservation Practice Outcomes
**Legal Citation:**
**Project Manager:** Megan Lennon
**M.L. 2011 (FY 2012-13) ENRTF Appropriation:** $ 340,000
**Project Length and Completion Date: 3** years; June 30, 2014
**Date of Update: August 14, 2013**

| **ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET** | **Activity 1 Budget** | **Amount Spent 02/28/2014** | **Balance 02/28/2014** | **Activity 2 Budget** | **Amount Spent 02/28/2014** | **Balance 02/28/2014** | **Revised Activity 3 Budget 02/28/2014** | **Amount Spent 02/28/2014** | **Balance 02/28/2014** | **Activity 4 Budget** | **Amount Spent 04/28/2014** | **Balance 04/28/2014** | **TOTAL BUDGET** | **TOTAL BALANCE** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **BUDGET ITEM** | **Develop new and improve pollution reduction estimators** | | | **Field Verification** | | | | | | ***Land-applied Endocrine Disrupting Compounds review*** | | | | |
| **Personnel (Wages and Benefits)** | | | | | | | | | | | | | | |
| Megan Lennon, classified staff, BWSR Soil Scientist: $35,000 (100% salary and fringe); .25 FTE for 2 years | 17,500 | 17,500 | 0 | | | | 17,500 | 17,500 | 0 | | | | 35,000 | 0 |
| Greg Larson, unclassified staff, BWSR soil scientist: $20,000 (100% salary and fringe); .2 FTE for 2 years. | 10,000 | 10,000 | 0 | | | | 10,000 | 10,000 | 0 | | | | 20,000 | 0 |
| **Professional/Technical Contracts** | | | | | | | | | | | | | | |
| University of Minnesota: for pollution reduction estimator development (activity 1) and field verification (activity 2). Contract includes:<br>• Brent Dalzell, Research Associate: $59,000 (75% salary, 25% fringe); .5 FTE for 2 years.<br>• Rebecca Beduhn, Research Scientist: $6,667 (80.5% salary, 19.5% fringe); 1 FTE for 3.3 months<br>• Cinzia Fissore, Research Associate (July - August 2011; Assistant professor starting September 2011): $26,881 (75% salary, 25% fringe); .5 FTE for 3 months<br>• 1 Graduate Research Assistant: $ 42,200 (80.5% salary, 19.5% fringe); .5 FTE for 2 years<br>• 2 Undergraduate Researchers: $10/hr (91% salary, 9% fringe). 1 FTE each for 5 months<br>• Ed Nater, Professor: $4,000 (75% salary, 25% fringe); .05 FTE for 1 year<br>• Graduate research assistants, undergraduates or research fellows: $62,500 (average 75% salary, 25% fringe).<br>• Soil sampling and field work equipment/supplies, $8000<br>• GIS laboratory fees, $1,500<br>• Travel expenses, $7,000 | 58,500 | 58,500 | 0 | 196,000 | 196,000 | 0 | 19,500 | 19,500 | 0 | 8,000 | 8,000 | 0 | 282,000 | 0 |
| **Equipment/Tools/Supplies** | | | | | | | | | | | | | | |
| Software programs and licenses for training and quality assurance/quality control review<br>• Camtasia 7.0 - Create Tutorials, Demos, Courses and Online Videos<br>• Statistica (or similar statistical analysis software) - QA/QC analysis of outcomes measured with pollution reduction estimators<br>• Raptivity - create learning interactions for online training sessions and webinars | | | | | | | 2,200 | 2,200 | 0 | | | | 2,200 | 0 |
| Training materials: Supplies for handouts/workbooks, binders, dividers, usb drives for storing data, postage for mailing training material. | | | | | | | 800 | 800 | 0 | | | | 800 | 0 |
| **COLUMN TOTAL** | **$86,000** | **$86,000** | **$0** | **$196,000** | **$196,000** | **$0** | **$50,000** | **$50,000** | **$0** | **$8,000** | **$0** | **$0** | 340,000 | 0 |

B31F-0374

UNIVERSITY OF MINNESOTA
Driven to Discover℠

# Distribution and Movement of Soil Organic Carbon in Grassland and Agricultural Landscapes

AGU Fall Meeting
December 2011

E. Nater[1], B. Dalzell[1,*], C. Fissore[1,2], A. Wu[1], and K. Yoo[1]
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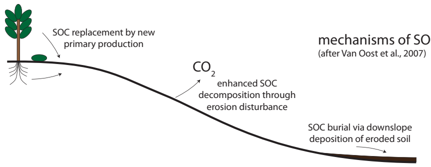
## abstract

In order to quantify land use impacts on the magnitude and landscape distribution of soil organic carbon (SOC) we are applying terrain attributes calculated from LiDAR-derived digital elevation models to predict SOC in the upper 1.5 m of soil at grassland and agricultural sites situated on loess soils in southeastern Minnesota. We developed separate regression models for surface (upper 25 cm) and deep (down to 1.5 m) soils and for grassland vs. agricultural sites. Key attributes were: profile curvature, slope, and compound topographic index. In addition to soil depth, these attributes were used to generate regression equations that were able to predict 82% and 77% of the observed variability in grassland and agricultural soils, respectively. While efforts to expand these relationships to perform landscape-scale SOC mass balance are ongoing, preliminary results suggest that agricultural landscapes don't necessarily have less SOC than grasslands. Observed SOC in the upper 10 cm of grassland soils is generally greater than in agricultural soils, this is in agreement with conventional thinking that conversion of grasslands to agriculture results in depletion of SOC. However, when SOC is quantified over the top 1.5 m of soil, agricultural sites show substantial SOC accumulation to deeper soil depths in downslope areas which can represent large pools of SOC in these landscapes. Ongoing efforts include dating of soil horizons via $^{137}$Cs analysis in order to assess rates of soil and SOC movement and potential loss in these landscapes.



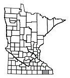
mechanisms of SOC loss or accumulation
(after Van Oost et al., 2007)

## introduction and background

In agricultural landscapes, erosion of SOC represents either a potential carbon source or sink depending on: (1) replacement of eroded soil organic matter via primary production, (2) enhanced degradation of SOC during erosion, and (3) deposition and burial of SOC at downslope locations (Van Oost et al., 2007). Different studies have identified agricultural erosion as either a global net source (Lal et al., 2004) or a net sink of carbon (Smith et al., 2005) with more recent studies indicating that agricultural soil erosion represents a small C sink (Van Oost et al., 2007). While valuable, these global estimates do not consider site-specific factors such as soil texture, climate, land management, and topography that are likely to influence the magnitude of soil erosion as a SOC source or sink. Improved local estimates are necessary to assess how landscape conversion and current land management practices may influence local and regional C budgets.

It is the overall goal of this study to evaluate how terrain attributes derived from digital elevation models can be used to predict SOC in agricultural and grassland soils across southern Minnesota and explore how these relationships may be used to evaluate potential conservation practices for reducing edge-of-field soil losses and enhancing SOC storage.

## study area



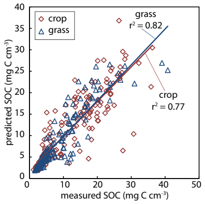
Samples presented here were collected from cropland and grassland sites located in southeastern Minnesota (Fillmore county). Soils in this region are typically Mollisols and Alfisols that are well-drained with moderate to good development. Topography in the eastern portion of the county is bedrock controlled with deeply incised streams and karst features overlain by deep (2 to 7 m) loess. Further west, soils are sandy loess with less relief over dense pre-Illinoian till. Sites were selected to represent soils that have been influenced by row crop agriculture as well as soils that are under perennial grasses (verified with historic aerial photographs).

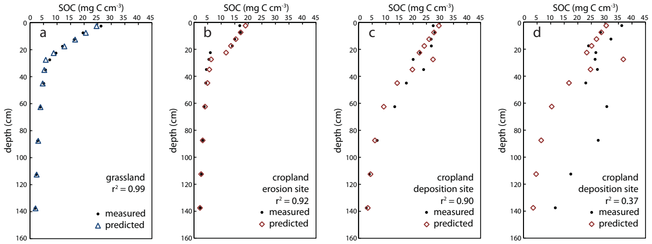
### sampling

Sample points were selected to represent the range of terrain attributes (slope, contributing area, curvature) at a site. Soil pits were used to sample the upper 50 cm of the soil profile at 5-10 cm intervals. Deeper soils were sampled with a multi-stage core sampler in 25 cm intervals down to 150 cm. Organic carbon content was measured via high-temperature combustion. SOC content was corrected for bulk density.

## results

SOC data were separated into grassland vs. cropland sites and further divided into samples representing the upper 25 cm of soil and samples from 25 to 150 cm. Separate regression equations were developed to predict SOC at each depth interval based on commonly available terrain attributes. Key attributes were slope (%), profile curvature, and compound topographic index. When tested against observed data, these regression equations were able to predict 82% and 77% of the observed variability in grassland and cropland soils, respectively.

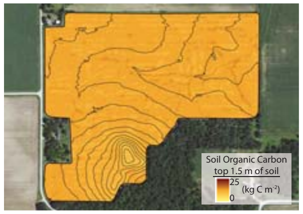




The regression equations developed from terrain attributes did a good job of representing SOC profiles for most grassland and cropland sites (a, b, c) and also captured the variability found in cropland sites (b, c). However, our regression approach did strongly under predict deep SOC accumulation at one of our cropland depositional sites (d). This site has experienced substantial soil accumulation over the past ~50 years (approx. 25 cm of soil accumulation indicated by the $^{137}$Cs profile - see ongoing work section).

## field application

The empirical relationships developed from field samples and terrain attributes were applied to selected farm fields to compare SOC distribution under cropped and grassland conditions.

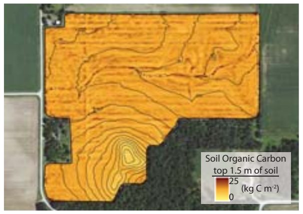


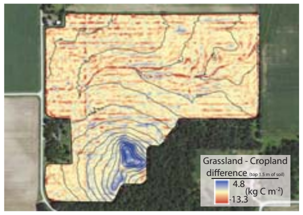
### grasslands SOC

Under grasslands, SOC was generally uniform throughout field sites with slight depletion in typical erosion sites and slight accumulation in downslope depressional areas.

### cropland SOC

Predicted SOC trends in the cropland landscape were more variable than those from the grassland landscape with greater SOC depletion and accumulation at erosional and depositional sites, respectively.





## comparing landscapes (cropland - grassland)

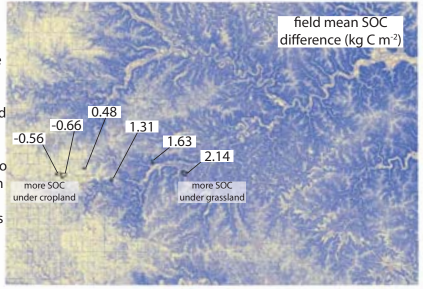
SOC pools in landscape elements with steep slopes and negative (convex) profile curvature was greater under grasslands (blue areas) while depressional areas with low slopes and positive (concave) profile curvature accumulated greater SOC under cropland (yellow to red areas).

## landscape trends

In the lower relief fields located in the western part of Fillmore county, our empirical models predict that more SOC would be present under cropland management.

In contrast, SOC pools are predicted to be larger under grassland scenarios in farm fields located in the central-to-eastern part of the county. Farm fields in this area tend to have steeper slopes.

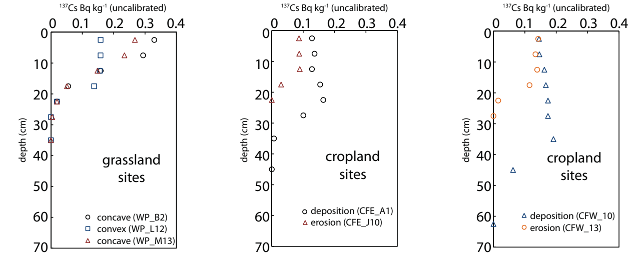
grassland - cropland difference for selected fields
Fillmore county, MN



These results (especially in lower relief landscapes) are consistent with the findings of Van Oost et al. (2007) which showed that agricultural erosion can be a net sink of SOC (especially in more flat landscapes). However, topographic variability within a region (or even within a single field) can ultimately determine the direction and magnitude of SOC source/sink relationships.

## ongoing work

We are currently performing similar analyses on samples collected across a wide range of parent materials and climatic conditions across the southern half of Minnesota. Further, we are complementing SOC data with measurements of $^{137}$Cs activity in order to quantify soil erosion and deposition in these landscapes. Combining $^{137}$Cs and SOC data will also allow us to assess the stability of SOC pools in erosion and deposition settings and quantify their relative importance in SOC dynamics over decadal time scales.



## acknowledgements

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# Endocrine Disrupting Chemical (EDC) Retention Framework

June 2014

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Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR

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## *Background and Theory*

A number of chemicals of emerging concern, including pesticides and herbicides, antibiotics used in animal agriculture, and growth-promoting hormones, are associated with agricultural activities. Many of these chemicals have, or are suspected of having, properties that affect or disrupt endocrine systems. These endocrine-disrupting chemicals (EDCs) may be applied directly to crops or the soil, or are present in manures that are applied to soils. Consequently they have the potential to be transported into surface waters by surface runoff or through tile drains.

Because many of these chemicals are strongly associated with soil solids, they are transported mainly as chemicals sorbed to suspended sediment, not as chemicals dissolved in water.

Many of these chemicals are hydrophobic and thus have a strong affinity for organic matter. This is expressed by the $K_{OC}$ value (the distribution coefficient between the aqueous phase and organic carbon (OC)). This is a commonly measured parameter for organic chemicals in soil environments because it normalizes sorption in soils having varying properties to a single value.. If you know the $K_{OC}$ value for a chemical and the OC of organic matter (OM) content of the soil, you can determine the distribution of the chemical between the aqueous phase and the soil-sorbed phase.

## *Calculations*

The distribution coefficient ($K_D$) is determined as:

$$K_D = K_{OC} * X$$

where

$X$ = the unitless fraction of organic C in the soil.

If the soil OM content is known, you can assume that OM is approximately 50% carbon by weight, and therefore OC ≈ OM/2. For example, if a soil has 4% organic matter, $X = 0.02$.

The distribution coefficient for a specific chemical can then be used to determine its distribution between the aqueous and sorbed phases at equilibrium:

$K_D = C_{sorbed} / C_{aq}$

where

$C_{sorbed}$ is the sorbed concentration (µg $kg^{-1}$),
$C_{aq}$ is the concentration in solution (µg $L^{-1}$), and
$K_D$ is the distribution coefficient (L $kg^{-1}$)

Typically we know the total concentration in the soil, not the concentration in either of the two phases. The following relationship then applies if the total concentration is on a soil dry weight basis:

$Q_{total} = Q_{sorbed} + Q_{aq}$

where

$Q_{total}$ is the total quantity (µg) of the EDC
$Q_{sorbed}$ is the quantity sorbed to soil, and
$Q_{aq}$ is the quantity dissolved in water

$Q_{total} = C_{sorbed} * Soil\ (kg) + C_{aq} * H_2O\ (L)$

If the total concentration is on a soil dry weight basis, then for 1 kg of soil (dry wt) we get:

$C_{total} = C_{sorbed} + C_{aq} * V$

where

$V$ is the volume of water associated with 1 kg of soil

rearranging the distribution equation, we get:

$C_{aq} = C_{sorbed} / K_D$

and can then substitute for $C_{aq}$

$C_{total} = C_{sorbed} + (C_{sorbed} / K_D) * V$

This can be rearranged to:

$C_{total} = (1 + V/K_D) * C_{sorbed}$

and solved for $C_{sorbed}$

$C_{sorbed} = C_{total} / (1 + V/K_D)$

which is the concentration of the chemical sorbed to the particulate phase.

For chemicals with high $K_{OC}$ values, $C_{sorbed} \approx C_{total}$

If we wish to know the concentration in the aqueous phase, we can go back to the distribution equation to get:

$C_{aq} = C_{sorbed} / K_D$

Once we know the concentration of a chemical on the particulate phase, we can proceed to determine the quantity of that chemical that is retained by conservation practices. The quantity of a chemical that is retained by perennial grassland conservation practices can be estimated by multiplying $C_{sorbed}$ times the mass of sediment retained by perennial grasslands. We can use the new erosion estimators developed in the ENRTF-funded project *Measuring Conservation Practice Outcomes* to determine the mean annual difference in sediment losses between a tilled field and the same field planted to perennial grasslands. Once we have obtained those values, we determine the difference between the two and multiply that by $C_{sorbed}$ to yield the quantity of chemical retained by conservation practices on an annual basis.

The associated spreadsheet, EDC Estimator.xls, provides those estimations if provided with the appropriate inputs.

## *Caveats:*

Although we now have an estimator to calculate the percentage or total quantity of EDCs applied to agricultural fields, there are limitations to its use and its capabilities.

*1. Hydrophilic compounds* - The distribution coefficient, $K_D$. can only be determined accurately from $K_{OC}$ values for hydrophobic organic chemicals. Chemicals that have more of a hydrophilic character will tend to distribute more to the aqueous phase unless they are retained by charged sites such as clay minerals. More accurate determination of the distribution coefficients of these chemicals may require actual determination of their $K_D$ s on a site-by-site basis.

*2. Determination of V, the effective water-to-soil ratio* - Determination of the ratio of water to soil used in the calculation is fairly subjective. Most individuals using these concepts are interested in the quantity of chemical in a known volume of water and simply view the soil as a source. Because we are interested in what remains on the soil and don't know the volume of water involved, it is more difficult to accurately pin down the water-to-soil ratio.

In general, hydrophobic EDCs are slow to reach equilibrium between the soil and aqueous phases when the solid phase is mixed with water or if additional water is added to a suspension. For soil water (water held within the pores of the soil), and perhaps drainage water that has slowly leached through the soil under the influence of gravity, EDCs may be in, or approaching, equilibrium with the soil-sorbed phase. This represents a fairly small water-to-soil ratio, however, as soil water generally constitutes less than 50% of the total volume of soil; on a volume-to-mass (L $kg^{-1}$) basis this would be approximately 0.77 L $kg^{-1}$ if we assume a bulk density of 1.3 for the soil.

Likewise, we seldom have more than 10 to 20 cm of water draining through our soils on an annual basis. If we assume 20 cm of drainage water, that would be the equivalent of 200 L $m^{-2}$ $yr^{-1}$. A square meter of soil 10 cm thick would weigh approximately 130 kg, so the combined ratio of water to soil would be 50 L soil water + 200 L drainage water divided by 130 kg soil, or a ratio of slightly less than 2 : 1.

Sediments eroded by water are much more dilute, with water-to-soil ratios as high as 100 : 1 or even higher. However, the contact time between erosive waters and sediment during transport is fairly short (often only a matter of minutes to hours) and it is unlikely that the eroding waters would come close to achieving equilibrium with the sediments they are transporting.

Because the large volume of water in contact with the soil during erosion does not maintain contact long enough for the EDCs to reach equilibrium with this large water-to-soil mixture, use of the actual water-to-soil ratio would greatly over-estimate $C_{aq}$, the concentration of EDCs in the aqueous phase. Based on these assumptions, this estimator uses an "effective volume of water", $V^{\dagger}$, to estimate the quantity of EDCs in the aqueous phase. The current figure for $V^{\dagger}$ is a water-to-soil ratio of 10 L : 1 kg. Further survey of the literature may yield a better estimate of the water-to-soil ratio, and the estimator can be modified accordingly.

*3. Chemical persistence* - The persistence (half life, $t^{1/2}$) of EDCs varies considerably. Some are highly persistent with half lives of many years, while others have half lives of less than a year. Consequently, the concentration that is applied may not represent the concentration in the soil at a later date when erosion might occur.

Transport in the aqueous phase must occur within a timeframe corresponding to the relative persistence of the compounds. However, since many of these chemicals are applied annually or more frequently, their concentrations are often maintained over long periods of time.

*4. Presence and concentration* - This is probably the single largest problem with use of the estimator. There are numerous agricultural chemicals that are applied at varying rates. Because record-keeping is not required for use of these chemicals, it is impossible to estimate the concentration of any specific chemicals or to determine where they have been applied. Regional usage figures may be available from the Minnesota Department of Agriculture or other sources, and application rate information is available for some of the chemicals from the manufacturers, so general estimates of usage and concentrations may be possible, but determination of site specific application rates or concentrations is not generally possible.

## *Data Requirements*

**Data required to determine quantities (mass) of EDCs retained by perennial grassland conservation practices:**

***General Parameters***

- % OM in surface soils (1)
- $V^{\dagger}$, the water to soil ratio (2)

***Site Specific Parameters***

- Quantity of sediment retained by conversion to perennial grasses (3)

***Chemical Specific Parameters***

- $K_{OC}$ (4)
- Mean concentration in soils (µg/kg) (5)
- $t^{1/2}$ (half life) (6)

(1) Can be estimated from Estimators data or can be determined from the NRCS Soil Survey.

(2) See discussion above.

(3) Main product of the Sediment Retention Estimator.

(4) From the literature.

(5) From literature or can be estimated from known application rates.

(6) From the literature. (Not a required parameter, but can be useful in estimating the mean concentration in soils)

The *relative potential reduction* in EDCs (% of applied EDCs that are retained by perennial grassland conservation practices) can be estimated without knowledge of either the concentration of EDCs applied or the mass of soil retained by the conservation practices. The attached spreadsheet, EDC Estimator 2.xls, provides those estimations.

# *Appendix 1*

$K_{OC}$ values for selected potential endocrine disrupting chemicals.

| **Chemical** | **$K_{OC}$** | **Reference** |
|---|---|---|
| | | |
| acetaminophen | 41 | Toxnet HSDB |
| | | |
| atrazine | 51-243 | Chen et al. (1984) reported in Agertved et al. (1992) |
| | 26-1,164 | Toxnet HSDB |
| | | |
| carbamazepine | 510 | Toxnet HSDB |
| | | |
| carbaryl | 290 | USDA ARS |
| | | |
| daidzein | 833 | EPI Suite estimate (KOW) |
| | 2,329 | EPI Suite estimate (MCL) |
| | 1 | Schenzel et al 2012 (expt, NOM) |
| | 6,500 | Toxnet HSDB |
| | | |
| equol | 23,988 | EPI Suite estimate |
| | 1,029 | Yost et al. (2013) (average of 6 measurements) |
| | | |
| erythromycin | 1,645 | Jones et al. (2002) |
| | | |
| 17-b-estradiol | 1,349-4,898 | Carballa et al. (2008) |
| | 3,981 | Lai et al. (2000) |
| | | |
| genistein | 6,500 | Toxnet HSDB |
| | | |
| metolachlor | 22-2,320 | Toxnet HSDB |
| | | |
| monensin | 10 | Toxnet HSDB |
| | | |
| oxytetracycline | 42,506 | Rabolle and Spliid (2000) |
| | 47,881 | Rabolle and Spliid (2000) |
| | 93,317 | Rabolle and Spliid (2000) |
| | 27,792 | Rabolle and Spliid (2000) |
| | | |
| 17-alpha-trenbolone | 588 | Blackwell et al. (2012) |
| | 420 | FDA Animal Veterinary Approval |
| | 477 | FDA Animal Veterinary Approval |
| | 1,100 | FDA Animal Veterinary Approval |
| | 400-9,500 | Syntex Material Safety Data Sheet |
| | | |
| 17-beta-trenbolone | 1,010-9,570 | Roche Safety Data Sheet |

| | | |
|---|---|---|
| tylosin | 7,988 | Rabolle and Spliid (2000) |
| | 771 | Rabolle and Spliid (2000) |
| | 5,664 | Rabolle and Spliid (2000) |
| | 553 | Rabolle and Spliid (2000) |
| | | |
| virginiamycin | 980 (M1) | Toxnet HSDB |
| (virginiamycin has two components: M1 and S1) | 160,000 (S1) | Toxnet HSDB |

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Rabølle, M., and N.H. Spliid. 2000. Sorption and mobility of metronidazole, olaquindox, oxytetracycline and tylosin in soil. *Chemosphere* 40(7): 715-722.

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http://www.roche.com/pages/csds/english/out/0491004.20051212.6299.pdf

Schenzel, J., K-U Goss, R.P. Schwarzenbach, T.D. Buchell, and S.T.J. Droge. 2012. Experimentally Determined Soil Organic Matter−Water Sorption Coefficients for Different

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# eLINK Data Quality Control Analysis

A component of the ENTRF-funded project *Measuring Conservation Practice Outcomes*

June 2014

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## Introduction

eLINK is a central database housing pollution reduction outcomes for BWSR's grants to local government units (LGUs). Since 2003 eLINK has tracked BWSR grants and project outcomes including pollution reduction estimates. The database contains gaps in pollution reduction reporting. These gaps exist for various reasons including:

- Insufficient models to estimate pollution reductions for all practices
- Inadequate enforcement of reporting requirements
- Inability to demonstrate benefits of preventative practices, e.g., Well Sealing, Nutrient Management Planning and Use Exclusion.

In an era of accountability and reporting of environmental outcomes, it is essential that BWSR demonstrates the environmental benefits of BWSR-funded projects. The key to accountability and documenting outcomes is ensuring pollution reductions are 1) entered in the grant reporting process and 2) represent the best estimate for on the ground pollution reductions.

The Environment and Natural Resources Trust Fund provided funding as recommended by the Legislative-Citizen Commission on Minnesota Resources to address BWSR's need for improved measurement of conservation practice outcomes. As a part of the *Measuring Conservation Practice Outcomes* project, BWSR and the University of Minnesota developed new pollution reduction estimators aimed at filling eLINK's data gaps. Additionally, a quality control analysis was completed as a part of the *Measuring Conservation Practice Outcomes* project. The quality control analysis includes the following elements: 1) statistical analysis and interpretation of pollution reduction estimates derived from a newly developed estimator, 2) statistical analysis of reported pollution reduction from the most commonly-funded BMPs, 3) quality control recommendations, and 4) resources for internal quality control.

## Data Analysis

Measuring the impact of deploying new pollution reduction estimators is accomplished by analyzing the estimated environmental outcomes before and after the estimator implementation. We expect improvement in data quality after a new pollution reduction estimator becomes available and LGUs are trained on proper use. In addition to looking at before/after scenarios, statistical analysis is also used for describing the business as usual scenario for BMPs without an associated pollution reduction estimator. Based on the data quality in the business as usual scenarios, quality control recommendations were developed for internal implementation aimed at improving eLINK data.

Data availability for the before/after analysis was limited by the timing of estimator development and grant reporting periods. A before/after analysis was feasible for only the Septic System Improvement BMP. The Milk House Waste Water Improvement estimator and Soil Hydrologic Group estimator were developed as a part of the project, but the eLINK database to date does not contain any pollution reduction estimates derived from these estimators. The eLINK database did not contain pollution reduction estimates using the Milk House Waste Water Improvement or Soil Hydrologic Group estimator because there has not been a reporting period since the estimator deployment. The Milk House Waste Water Improvement estimator and the Soil Hydrologic Group estimator were first made available to LGUs in June 2014. LGUs most frequently use estimators in December and January of each, the months immediately prior to grant reporting deadlines. We anticipate a rise in the use the estimators and outcome reporting by LGUs during the February 2015 reporting period.

New Estimators

## Septic System Improvement Estimator

| | Before | After |
|---|---|---|
| Data Completeness (%) | 15% | 84% |
| BOD$_5$ Mean (lbs/yr) | 329.0 | 372.9 |
| BOD$_5$ SD | 301.3 | 129.8 |
| Fecal Coliform Mean (CFU) | 1.4 x 10^$^{13}$ | 4.8 x 10^$^{13}$ |
| Fecal Coliform SD | 2.6 x 10^$^{13}$ | 2.4 x 10^$^{13}$ |
| Nitrogen Mean (lbs/yr) | 49.8 | 19.0 |
| Nitrogen SD | 58.6 | 11.9 |
| Phosphorus Mean (lbs/yr) | 15.9 | 9.6 |
| Phosphorus SD | 40.4 | 3.8 |

Figure 1: Before and after descriptive statistics for the Septic System Improvement Estimator

The analysis shows dramatic improvements in data completeness from 15% to 84% for septic system improvement projects after Septic System Improvement Estimator deployment and LGU training. Another positive trend is the standard deviation for all environmental indicators (BOD5, Fecal Coliform, Nitrogen, and Phosphorus) decreased after estimator development and training. Lower standard deviations indicate pollution reduction estimates are tightening up and LGUs are using consistent, appropriate methods for modeling pollution reduction.

## Milk House Waste Practices

| | Before | After |
|---|---|---|
| Data Completeness (%) | 42% | - |
| BOD$_5$ Mean (lbs/yr) | 1212.1 | - |
| BOD$_5$ SD | 855.5 | - |
| Nitrogen Mean (lbs/yr) | 93.6 | - |
| Nitrogen SD | 57.7 | - |
| Phosphorus Mean (lbs/yr) | 65.9 | - |
| Phosphorus SD | 40.5 | - |

Figure 2: Descriptive Statistics for pollution reduction for Milk House Waste Improvements

eLINK data on milk house waste improvement practices was not available after LGU training, therefore the analysis focuses on the quality of data prior to the new estimator development. Prior to the deployment of the new Milk House Waste Estimator, BWSR did not have a recommended model for LGUs to use. Each LGU likely approached pollution reduction estimates using unique methodologies and assumptions. The large standard deviations indicate a wide range in estimates for a given indicator (BOD5, Nitrogen, and Phosphorus). We expect the data completeness to increase and the standard deviations to decrease after LGUs enter data for the February 2015 reporting period.

Business as usual

**Critical Area Planting**

| | |
|---|---|
| Data Completeness (%) | 42% |
| Phosphorus reduction mean (lbs/yr) | 88.8 |
| Phosphorus reduction SD | 246.6 |
| Sediment reduction mean (Tons/yr) | 93.7 |
| Sediment reduction SD | 234.3 |
| Soil loss reduction mean (Tons/yr) | 125.2 |
| Soil loss reduction SD | 432.1 |

**Grade Stabilization**

| | |
|---|---|
| Data Completeness (%) | 52% |
| Phosphorus reduction mean (lbs/yr) | 75.1 |
| Phosphorus reduction SD | 246.5 |
| Sediment reduction mean (Tons/yr) | 84.9 |
| Sediment reduction SD | 303.1 |
| Soil loss reduction mean (Tons/yr) | 98.2 |
| Soil loss reduction SD | 346.0 |

**Streambank and Shoreline Protection**

| | |
|---|---|
| Data Completeness (%) | 63% |
| Phosphorus reduction mean (lbs/yr) | 184.3 |
| Phosphorus reduction SD | 1992.0 |
| Sediment reduction mean (Tons/yr) | 216.4 |

| | |
|---|---|
| Sediment reduction SD | 2354.5 |
| Soil loss reduction mean (Tons/yr) | 230.1 |
| Soil loss reduction SD | 2503.7 |

**Terrace**

| | |
|---|---|
| Data Completeness (%) | 70% |
| Phosphorus reduction mean (lbs/yr) | 59.5 |
| Phosphorus reduction SD | 513.8 |
| Sediment reduction mean (Tons/yr) | 53.0 |
| Sediment reduction SD | 454.0 |
| Soil loss reduction mean (Tons/yr) | 138.0 |
| Soil loss reduction SD | 1595.2 |

**WASCOB**

| | |
|---|---|
| Data Completeness (%) | 56% |
| Phosphorus reduction mean (lbs/yr) | 57.5 |
| Phosphorus reduction SD | 238.0 |
| Sediment reduction mean (Tons/yr) | 55.6 |
| Sediment reduction SD | 292.5 |
| Soil loss reduction mean (Tons/yr) | 48.2 |
| Soil loss reduction SD | 126.2 |

**Bioretention Basin**

| | |
|---|---|
| Data Completeness (%) | 52% |
| Phosphorus reduction mean (lbs/yr) | 5.8 |
| Phosphorus reduction SD | 17.3 |
| Sediment reduction mean (Tons/yr) | 32.1 |
| Sediment reduction SD | 164.2 |
| Volume reduction mean (Tons/yr) | 1.8 |
| Volume reduction SD | 4.3 |

## Quality Control Recommendations

Quality control measures for improving eLINK data fall into two general categories: 1) education and outreach to LGUs and 2) internal mechanisms for BWSR staff. Education and outreach involves many elements with a unifying theme of clear and frequent communication between LGU staff and BWSR grants and Board Conservationist staff. Internal mechanisms are tools for BWSR staff, particularly Board Conservationists, which help identify potentially inaccurate pollution reduction estimates given the site specific details of the project.

Recommended actions for improving eLINK data:

Education and Outreach

- Continued training on new and existing pollution reduction estimators
- Update reporting guidance and specify pollution reduction indicators required for individual BMPs

Internal Mechanisms

- Develop lookup references for Board Conservationists use in the grant review process
- Training for Board Conservationists on BMPs and expected pollution reduction

## Resources for Internal Quality Control

Three resources were developed to help Board Conservations review pollution reduction values. Board Conservationists can choose the resource that best fits the BMP and project they are reviewing. The first is a BMP effectiveness look up table reporting percent removal efficiencies for agricultural and stormwater practices. This lookup table is based on the literature cited in the Minnesota Department of Agriculture AgBMP handbook and the Minnesota Pollution Control Agency Stormwater Manual. The second resource identifies potential outliers for the most common BMPs reported in eLINK. It is important to note that the outlier ranges were calculated based on the data available in eLINK, not an independent dataset. The third resource outlines a Unit Area Loading methodology to estimate pollution reduction. Note the Unit Area Loading method estimates reductions reaching a water body, not edge of field calculations.

All internal control resources are found in Appendices A through D.

## Documentation

Quality Control Analysis documentation notes:

Removed all 2003 and 2004 data per the recommendation eLINK database manager.

This analysis included data in “Nitrogen” column and ignored “Nitrogen_calc_est” and “Nitrogen_Final”. “Nitrogen” is user entered and “Nitrogen_calc_est” is estimated by N = 2 x Phosphorus. “Nitrogen_Final” aggregates the data in both “Nitrogen” and “Nitrogen_calc_est”. If “Nitrogen” has a value, than that value is used in “Nitrogen_calc_est”. If not, the value in “Nitrogen_calc_est” is used.

This analysis included data in the “Phosphorus” column and ignored “Phos_calc_all”. “Phosphorus” is a user entered value and “Phos_calc_all” is populated using assumptions similar to those outlined above for Nitrogen.

For the septic system improvement estimator, this analysis assumed data from the “E_coli” indicator entered after October 2013 is actually “Fecal Coliform”.

For the milkhouse waste practices estimator, Total Suspended Solids is not an indicator in eLINK. The database manager was made aware of the issue and it was added. Data for Total Suspended Solids was not available because of the database omission and therefore was not used in the statistical analysis.

## Effectiveness Summary

The BMP effectiveness table for agricultural BMPs was populated using the following rules of precedence. 1) Data from the AgBMP handbook pertaining to Minnesota and the upper Midwest, 2) To fill the data gaps, data from the AgBMP appendix B (national sources) was included, 3) In cases where both the upper Midwest and national data existed, the Minnesota/upper Midwest data trumped national values.

Data from the Georgia manual (cited in the AgBMP handbook) was not included because it provided little in the way of references.

## Outliers

The Grubb's test could not be used for outlier identification because the data for individual BMP pollutant reductions are not normally distributed. The Inter Quartile Method was used instead because it does not require normal distributions. Also, the Inter Quartile Method is median based and is less subject to the problem of masking where a single outlier can inflate the standard deviation thus masking itself.

**Appendix A**

# BMP Effectiveness Summary - Agricultural

## BMP effectiveness estimate - % reduction

| BMP | Turbidity/ Sediment | Total Phosphorus | Soluble Phosphorus | Total Nitrogen | Nitrate Nitrogen | Ammonia Nitrogen | Pesticides | Herbicides | Bacteria | Dissolved Oxygen |
|---|---|---|---|---|---|---|---|---|---|---|
| Alternative Tile Intakes | | | | | | | | | | |
| Perforated Riser | 90% - 95% | 0.659 | | | | | | | | |
| Gravel (rock) inlet | 70% - 90% | 81.6% - 88.1% | | | | | | | | |
| Dense Pattern Tile | 1 | | | | | | | | | |
| Conservation Cover (327) | | | | | | | | | | |
| Conservation Crop Rotation (328) | 0.66 | 0.53 | 30% - 75% | 59%-62% | | | | | | |
| Conservation Tillage (329, 345 and 346) | 0.96 | 66% - 91% | 0.57 | 0.53 | 10% - 68% | -43% - 93% | | | | |
| Constructed (Treatment) Wetlands | 0.75 | 20% - 90% | 49% - 56% | | 40% - 90% | | | | | 70% - 92% |
| Contour Buffer Strips (332) | 83% - 91% | 49% - 80% | 20% - 50% | 27% - 50% | | | | 67% - 77% | 43% - 74% (fecal coliform) | |
| Contour Farming (330) | 28% - 67% | 10% - 62% | | 25% - 68% | | | | | | |
| Contour Stripcropping (585) | 43% - 95% | 8% - 93% | 20% - 93% | 20% - 55% | | | | | | |
| Controlled Drainage (554) | | 0.5 | | | 20% - 61% | | | | | |
| Cover Crops (340) | 32% - 92% | 54% - 94% | 7% - 63% | | 13% - 64% | 35% - 41% | | | | |
| Culvert Sizing/Road Retention/Culvert Downsizing | | | | | | | | | | |

# BMP Effectiveness Summary - Agricultural

**BMP effectiveness estimate - % reduction**

| | Turbidity/ Sediment | Total Phosphorus | Soluble Phosphorus | Total Nitrogen | Nitrate Nitrogen | Ammonia Nitrogen | Pesticides | Herbicides | Bacteria | Dissolved Oxygen |
|---|---|---|---|---|---|---|---|---|---|---|
| Feedlot/Wastewater Filter Strip (635) and Clean Runoff Water Diversion (362) | 0.79 | 0.83 | 10% - 45% | 0.84 | 0.93 | | | | | |
| Filter Strips (393) and Field Boarders (386) | 86% - 91% | 65% - 96% | 24% - 39% | 0.27 | -158% - 85% | -35% - 98% | 51% - 80% | 49% - 78% | | |
| Forest Buffer | 40% - 60% | 30% - 45% | 19% - 65% | | | | | | | |
| Grade Stabilization (410) | 0.99 | | | | | | | | | |
| Grassed Waterways | 94% - 98% | | | | | | | 70% - 96% | | |
| Livestock Exclusion/Fencing (382/472) | 82% - 84% | 0.76 | | -0.78 | 0.32 | | | | | |
| Nutrient Management (590) | | | 0.5 | 18% - 36% | 10% - 45% | | | | | |
| Pest Management (595) | | | | | | | | 17% -43% | | |
| Riparian and Channel Vegetation (332/390) | 53% - 99.7% | 41% - 93% | | 57.9% - 92.1% | | | | | | |
| Rotational Grazing | 0.49 | 0.75 | | 0.62 | | | | | | |
| Sediment Basin (350) | 0.84 | 0.5 | 0.8 | 0.3 | 0.82 | | | | 0.7 | |
| Streambank and Shoreline Protection (580) | 4% - 8% | | | | | | | | | |
| Terrace (600) | 80% - 95% | 70% - 85% | | 20% - 55% | | | | | | |
| Tile System Design | | | | | 0.47 | | | | | |
| Waste Storage Facility (313) | | 0.58 | | 0.52 | | | | | | |

# BMP Effectiveness Summary - Agricultural

**BMP effectiveness estimate - % reduction**

| | Turbidity/ Sediment | Total Phosphorus | Soluble Phosphorus | Total Nitrogen | Nitrate Nitrogen | Ammonia Nitrogen | Pesticides | Herbicides | Bacteria | Dissolved Oxygen |
|---|---|---|---|---|---|---|---|---|---|---|
| Water and Sediment Control Basin (638) | 79% - 99% | 12% - 526% | | 7% - 25% | | | | | | |
| Wetland Restoration (651) | > 75% | 0% - 50% | | 0.64 | 68% - >85% | 0.63 | | | | |
| Woodchip Bioreactor | | | | | 30% - 40% | | | | | |

Sources
AgBMP handbook - values specific to MN and upper Midwest
AgBMP handbook - values from other National sources

**Appendix B**

## BMP Effectiveness Summary - Stormwater

**BMP effectiveness estimate - % reduction**

| | TSS | Total Phosphorus | Total Nitrogen | Metals | Bacteria | Hydrocarbon | Data source |
|---|---|---|---|---|---|---|---|
| BMP | | | | | | | |
| Bioretention/raingarden | 85% - 90% | 50% - 100% | 0.5% | 0.95% | 0.35% | 0.8% | a,b |
| Sand or other media filter | 75% - 90% | 30% - 55% | 10% - 60% | 0.8% | 0.35% | 0.8% | a,b,e |
| Grass filter or dry swale | 40% - 87% | 0% - 55% | 0.35% | 0.8% | 0.35% | 0.8% | a |
| Stormwater pond | 60% - 90% | 34% - 73% | 30% - 55% | 0.6% | 0.7% | 0.8% | a,e |
| Pervious pavement | 0.9% | 65% - 80% | 0.6% | | | | b,e |
| Infiltration Trench | 85% - 100% | 25% - 100% | 0.55% | | | | b,e |
| Wet swale | 69-87% | 20-50% | | | | | b |
| Water and Sediment Control Basin / dry pond | 0.53% | 15% - 45% | | | | | c |
| Vegetated Filter Strips | 0.75% | 45% - 80% | 0.4% | | | | c,e |
| Forested Buffers | 40% - 60% | 30% - 45% | | | | | d |
| Stormwater Wetlands | 0.8% | 0.45% | 0.55% | | | | e |
| Tree Box Filter | 0.99% | | | | | | e |

Sources

a MPCA Stormwater Manual

b MIDS work group

c Weiss et al. 2005. The Cost and Effectiveness of Stormwater Mangament Practices. Prepared for the Minnesota Department of Transportation

d Chesapeake Bay Program, Phase 5.3 Watershed Model. Section 6: Best Management Practices for Nutrients and Sediment

e New Hampshire Department of Environmental Services 2008, New Hampshire Stormwater Manual, Volume 2 appendix B, BMP Pollutant Removal Efficiency

**Appendix C**

This table includes outlier ranges for common BMPs in eLINK. The outlier ranges identified below are provided for the express use as a method of flagging possible outliers in eLINK grant reporting. A value exceeding the outlier range does not automatically mean the reported value is erroneous. Projects reporting pollution reduction values exceeding the ranges should be looked at closer to identify site and project specific details explaining the estimate. Also, pollution reduction values not exceeding the ranges below may in fact be an outlier. Use best professional judgment.

# Outliers – InterQuartile Method

| | Phosphorus (lbs.yr) | Sediment (Tons/yr) | Soil Loss (Tons/yr) | $BOD_5$ (lbs/yr) | Nitrogen (lbs/yr) |
|---|---|---|---|---|---|
| Alternative Tile Intake – gravel | >1.5 | >1.7 | >2 | - | - |
| Bioretention Basin | >4.4 | >1.5 | NA | - | - |
| Cover Crop | >13.2 | - | - | - | - |
| Critical Area Planting | >168 | >201 | >145 | - | - |
| Filter Strip | >130 | >50.8 | >76.7 | - | - |
| Grade Stabilization Structure | >118.2 | >132.4 | >122.3 | - | - |
| Grassed Waterway and Swales | >140 | >142.4 | >163 | - | - |
| Septic System Improvement | >17 | - | - | <81 or >665 | >43.8 |
| Streambank and Shoreline Protection | >88.5 | >89.9 | >112.0 | - | - |
| Terrace | >68.7 | >58.9 | >79.7 | - | - |
| WASCOB | >81.9 | >80.1 | >88.3 | - | - |

The InterQuartile Method

Values are declared outlier if:

Value < 1st quartile – 1.5 x InterQuartile Range

Value > 3rd quartile + 1.5 x Interquartile Range

## Appendix D

## Unit Area Load Calculations

The Unit Area Load approach is used to estimate phosphorus and total suspended sediment export to receiving water bodies.

Load (lb/yr) = area (acres) x UAL (lb/acre-year)

| Land Use | Total Phosphorus UAL (lb/acre-year) | TSS UAL (T/acre-year) |
|---|---|---|
| **Cropland** | 0.4 | 1.7-2.6 |
| **Forest/Grassland** | 0.08 | 0.1 |
| **Urban – high density** | 0.11 | 0.21 |
| **Urban – low density** | 0.80 | 0.1 |

Example: The Lake Wobegon Watershed District converted 147 acres of cropland to native grasses. Estimate the sediment and phosphorus reductions for this project.

Total Phosporus = 147 x 0.4 = 58.8 lb/yr, grassland = 147 x 0.08 = 11.8 lb/yr
Reduction = 58.8 – 11.8 = 47 lbs/yr

Total Suspended Sediment = 147 x 2 = 294 T/yr, grassland = 147 x 0.1 = 14.7 T/yr
Reduction = 294 – 15 = 279 T/yr

# Modeling Soil Erosion with $^{137}$Cs

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## Executive Summary

In order to develop landscape-scale estimates of soil erosion in Minnesota's agricultural landscapes, we conducted a broad survey study of $^{137}$Cs in cultivated fields and uncultivated grassland reference sites located across the southern third of Minnesota. Because the only source of $^{137}$Cs is nuclear fission and it binds tightly to soils, landscapes were "labeled" with $^{137}$Cs during aboveground testing of nuclear weapons in the 1950s and 1960s. As a result of this, $^{137}$Cs inventories can serve as an effective tracer for soil movement on decadal timescales. A $^{137}$Cs conversion model was used to determine soil erosion rates for 107 locations in cultivated sites. Measured soil erosion rates ranged from 49 t ha$^{-1}$ yr$^{-1}$ (erosion) to -74 t ha$^{-1}$ yr$^{-1}$ (deposition). Based on these measured rates, regression models were developed with the goal of broadly predicting soil erosion rates based on topographic characteristics. Digital terrain attributes were calculated from LiDAR-derived (Light Detection And Ranging) digital elevation models and then used as predictor terms in regression model development. Resulting models showed that: (1) profile curvature, (2) planform curvature, and (3) slope steepness were significant model terms in predicting erosion rates for different Minnesota Major Land Resource Areas (MLRAs). The resulting regression models were able to explain 38% of the variability observed in measured soil erosion rates. When applied to cultivated landscapes, the regression models create maps of predicted long-term rates of soil erosion or deposition. These maps will be helpful to BWSR personnel, soil conservationists, and other local government unit personnel to help identify which portions of the landscape would benefit the most from perennial vegetation conservation practices. In a complementary manner, these maps may also be used to quantify the soil and water quality benefits of farmland enrollment into a conservation program (or, conversely, the environmental impact of converting perennially vegetated land for cultivation).

## Introduction

Recent increases in corn and soybean prices have resulted, in the upper Midwest, in a shift toward increasing land managed for row crop production at the expense of perennial grasslands, including loss of CRP lands [*Wright and Wimberly*, 2013]. Under greater crop commodity prices, even marginally productive portions of the landscape can become profitable for farmers. The increase in cultivation on certain portions of the landscape can have detrimental impacts on soil and water quality through increased erosion. More specifically, landscape segments that are characterized by steep slopes and high curvature are especially prone to soil erosion [*Ritchie and McHenry*, 1990; *Wischmeier and Smith*, 1965; 1978]. While these ideas are well-established, resources to expand and apply them to broad portions of the landscape have been limited. In particular, wide availability of Digital Elevation Models (DEMs) has, until recently, been limited to products with a 30 m pixel resolution (or greater). While helpful in characterizing landscape-scale trends, this resolution was too coarse to produce a data product that could be meaningfully applied to many farm fields because important topographic features can often be smaller than 30 m. Subsequently, studies that showed the utility of including digital terrain attributes such as slope and curvature [*Hurst et al.*, 2012; *Moore et al.*, 1993; *Yoo et al.*, 2005] required site-specific surveys that contained sufficient detail but were limited in spatial scope.

More recently, Light Detection and Ranging (LiDAR) technology has advanced and become more affordable such that detailed DEMs are now becoming widely available for large areas. The State of Minnesota has been involved in coordinating and collecting statewide coverage of LiDAR data from 2010 through 2012 and those data products are now freely available. The MN LiDAR data have been used to produce digital elevation models with pixel resolutions of 1 and 3 meters and vertical accuracy of about 10 cm (root mean square error, county-specific values available at http://www.mngeo.state.mn.us/chouse/elevation/CVA_map_mn_lidar.pdf ). The availability of these high-resolution DEMs provides the opportunity for a new assessment of soil erosion potential around Minnesota's farmland under row crop vs. grassland cover.

Detailed DEMs, however, only provide a portion of the information needed to assess land use impacts on soil erosion in the landscape. A separate measure of soil movement is also necessary to complement the DEMs and develop relationships suitable for quantifying topographic and land management effects on soil erosion. One method suitable for tracking soil erosion over time is measurement of $^{137}$Cs activity in a variety of landscape positions, which can reflect different erosion (or deposition) history. $^{137}$Cs is a radioactive isotope produced only as a result of high-yield thermonuclear reactions. In the 1950s and early 1960s, aboveground testing of thermonuclear bombs resulted in wide global distribution of $^{137}$Cs (and other isotopes). Fallout of $^{137}$Cs via dry and (mostly) wet deposition is locally homogenous (although larger regional and global patterns do exist due to differences in precipitation, [*Longmore*, 1982] and $^{137}$Cs binds strongly to soil minerals [*Ritchie and McHenry*, 1990]. Because atmospheric testing of nuclear weapons ceased when the limited nuclear test ban treaty went into effect (October, 1963), the presence of $^{137}$Cs in the soil profile can be used to interpret the movement of soil over an approximately 50-yr time span and help calculate long-term average erosion rates in agricultural soils when used in conjunction with $^{137}$Cs data from nearby reference sites (perennial grasslands).

The goals of this study were to: (1) measure long-term average soil erosion rates for a variety of landscape positions across the predominantly-agricultural landscapes in the southern third of Minnesota, and (2), develop empirical models based on digital terrain attributes in order to expand soil erosion estimates to nearby similar croplands. It is the intent of this work that maps of long-term soil erosion rates can be used by local government units (LGUs) and Soil and Water Conservation District (SWCD) personnel to help identify landscape positions that are most prone to erosion as well as to quantify long-term (50-yr) average erosion rates. This information can help SWCD and LGU personnel identify priority locations for establishment (or maintenance) of CRP lands (or similar perennial cover) in order to protect Minnesota's soil and water resources while also helping to ensure more effective use of limited conservation funds.

### Important Considerations

Results from this work are intended to be helpful for estimating long-term average erosion rates under cropland and grassland scenarios based on digital terrain attributes. More specifically, cropland scenarios reflect corn and soybean row crop agriculture, which dominates Minnesota's agricultural landscape. *Empirical models developed here do not attempt to account for differences in soil erosion that may result from agricultural management practices such as no-till, conservation tillage, or contour tillage (or other practices).* It is assumed that these practices varied and were not constant over the 50-yr time period that $^{137}$Cs measurements encompass. *Because of differences in management practices, results presented here may differ from actual erosion/deposition rates on an individual farm*. Rather, these results are intended to estimate the average amount of soil erosion that would be prevented for a given landscape element if it were enrolled in a conservation program such as CRP (or otherwise managed in perennial vegetation).

## Methods

### Study Areas

Sites for this study were selected to include the Major Land Resource Areas [*USDA*, 2006] of Minnesota that are dominant in the agricultural lands comprising roughly the southern third of the state. Agricultural lands in the north western portion of the state (Red River Valley) were not included because of a history of land surface re-shaping to accommodate water drainage [*McCullough,* 2002] which precludes meaningful analysis of $^{137}$Cs data.

**Northern Mississippi Valley Loess Hills (MLRA 105) -** Landscapes in MLRA 105 are bedrock-controlled. The bedrock consists of gently sloping strata of sandstones, dolomites, and limestones, with an occasional thin layer of shale. Streams are deeply incised in this karstic landscape. Although most or all of this area was glaciated at one time, intense erosion associated with periglacial conditions, has stripped away most of the glacial sediments. Thick (2.5 to 10 m) Peorian age loess now mantles the existing high relief landscape, often directly overlying bedrock. This landscape has a well-developed surficial drainage network, high relief, and virtually no closed depressions. Sediments that reach streams are transported out of the landscape. Presettlement vegetation was mainly hardwood forest on the slopes and either hardwood forest or prairie on the broader uplands.

**Eastern Iowa and Minnesota Till Prairies (MLRA 104) -** Landscapes in MLRA 104 (the northern extension of the Iowan Erosion Surface [*Ruhe et al.*, 1968]) are also relatively old and have well-developed surficial drainage. These landscapes are outside the boundary of the Wisconsinan glacial advance but were previously covered with a thick deposit of heavy Pre-Illinoisan clay-loam till. They have moderate relief and have developed a well-connected drainage network. Thin (0.5 to 0.75 m) Peorian age loess mantles these landscapes. The loess is somewhat sandier than that found in MLRA 105 to the east, but appears to be derived from the same western source [*Mason et al.,* 1994]. Presettlement vegetation in the region was mainly tall-grass prairie.

**Central Iowa and Minnesota Till Prairies (MLRA 103) -** Landscapes in MLRA 103 have developed mainly on glacial sediments associated with the Late Wisconsinan Des Moines Lobe advance. These sediments are generally loamy in texture. Because of the moderate relief and young age of these sediments, there has been little development of stream networks or other surficial drainage. Most of the landscape consists of closed depressions and a deranged drainage network. Presettlement vegetation in the area was dominated by prairie grasses with wetland vegetation present in the low-lying areas.

Consequently, sediments that are eroded from the uplands by tillage or water erosion are still retained within the landscape.

**Rolling Till Prairie (MLRA 102A) -** Landscapes in MLRA 102A have developed mainly on glacial moraines, outwash plains, terraces, and floodplain deposits. Much of the drainage in this MLRA is poorly organized and small depressions known as prairie pothole ponds and lakes are common. Most of the sediments eroded from upland areas are retained within the landscapes. Most of the landscape consists of closed depressions and a deranged drainage network. Similar to the Central Iowa and Minnesota Till Prairies, presettlement vegetation in the area was dominated by prairie grasses with wetland vegetation present in the low-lying areas.

A summary of sample location distribution is shown in Figure 1. Agricultural sites included UMN research and outreach center farms (Waseca, Lambteron, Morris) as well as private landowners identified via contacts with the MN Department of Agriculture and local Soil and Water Conservation Districts. In additional to agricultural sites, nearby grassland locations were selected to serve as reference points for $^{137}$Cs data. The key criteria for these sites was that they have been under perennial grassland cover for at least the past 50 years as verified by a combination of approaches including historic air photos (going back to 1938), landowner knowledge, and DNR records (for Scientific and Natural Areas, SNAs). In total, 215 points were sampled across southern Minnesota, 107 cropland sites and 108 grassland sites.

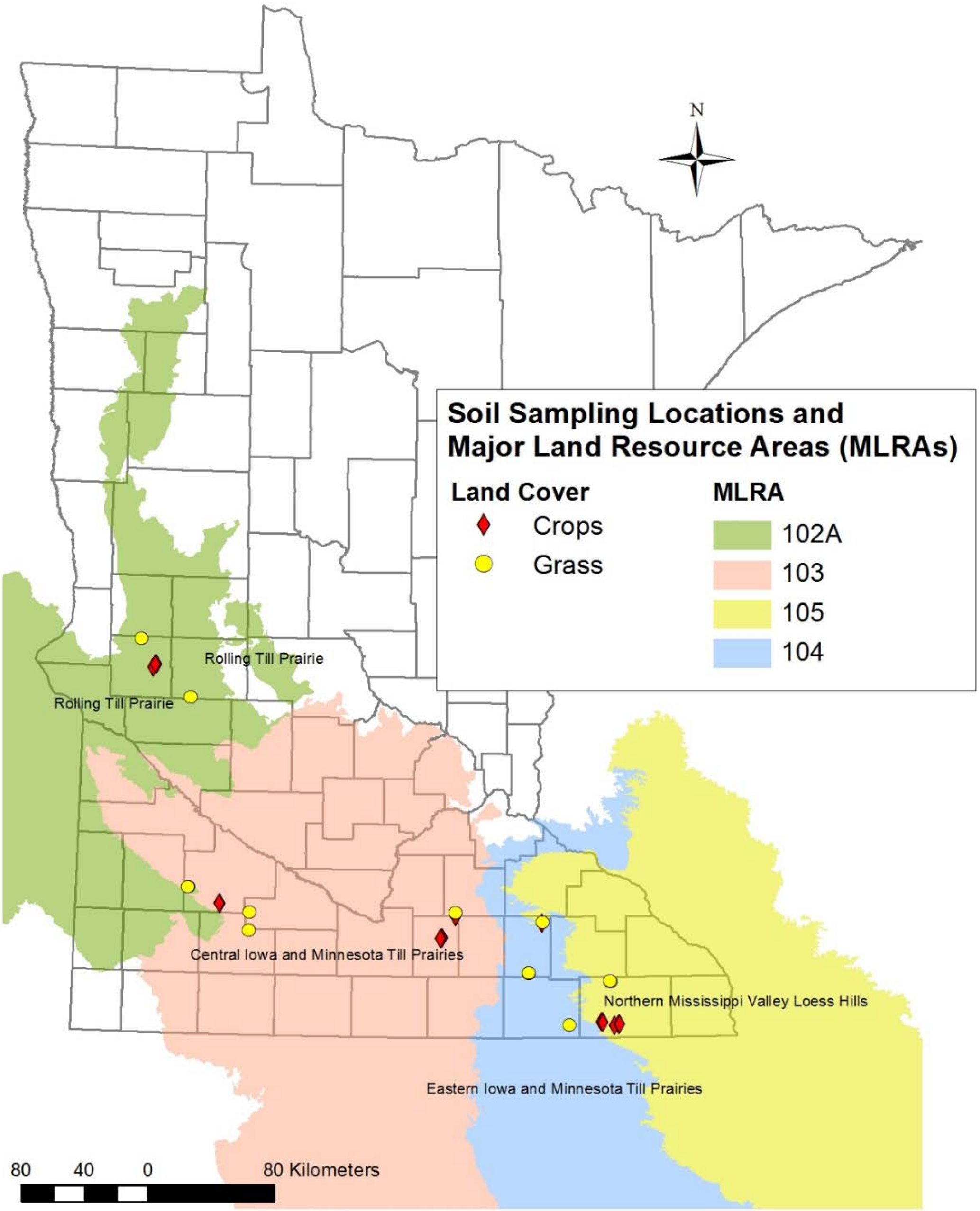

Figure 1. Minnesota Map showing the location of soil sampling locations with respect to Major Land Resource Areas across southern Minnesota. MLRA Numbers correspond with USDA designations and text above.

## Soil Sample Collection

Field-sampling points were selected by inspecting the terrain attribute maps and identifying points that represented the range of attribute values present at a given site. In this manner, our sampling approach was targeted at representing the range of available terrain attribute values. Care was taken to select sampling points where terrain attribute values did not change abruptly from one pixel to the next in order to avoid sites that may be particularly sensitive to small differences in sample location. In the field, sampling points were located with a handheld GPS unit (accuracy was typically better than 3m, comparable to the pixel size of the 3m DEM used for model development). Soil samples were collected to 150 cm in the following depth increments: 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-40, 40-50, 50-75, 75-100, 100-125, and 125-150 cm. Samples in the upper 50 cm were collected by excavating a shallow pit (Figure 2) and then carefully collecting about 500 g of soil from each depth increment which was placed in a labeled plastic bag. At the same time a bulk density sample was collected from the same depth increment using a brass cylinder of known volume, which was pushed into the soil and then excavated.

A slide-hammer cylindrical corer (5 cm diameter, 30 cm long) with internal plastic sleeves (AMS, American Falls, Idaho, USA) was used to collect soil samples below 50 cm depth. Between sample increments, the hole was widened with a 7.0 cm diameter closed basket auger and then cleaned with a 7.0 cm diameter planer auger to prevent soil from above from contaminating the next sample. Sleeves were removed from the corer after sampling, capped on each end, labeled with the date, sample number, location, and depth, and placed in a labeled plastic zipper bag. Samples were stored with ice in coolers while in the field. Following transport to the laboratory, they were stored in a cold room until processed.

Figure 2. Photo showing sample collection increments for a typical soil pit. Pit face sampling was performed for the upper 50 cm. A multi-stage core sampler was used to collect samples to a depth of 150 cm.

## Soil Sample Processing

### Bulk Density

Sample bulk density was determined for each depth increment in the upper 50 cm (pit face sampling) by inserting a metal ring of known volume into soil and then carefully collecting the soil volume contained within the ring. Upon returning to the lab, soils were dried overnight at 105°C. Following drying, the soil was weighed, then sieved (2 mm) to remove root and rock fragments before calculating bulk density. Bulk density determined via the metal ring method for the 40-50 cm depth increment was assumed to be representative of bulk density for deeper soil depths (in order to avoid potential compaction effects on bulk density data that may have been introduced from the hand-driven hammer corer.

### $^{137}$Cs and Soil Organic Carbon (SOC)

Soil samples for elemental and $^{137}$Cs analyses were dried at 35°C overnight. Samples in plastic core sleeves were expelled prior to drying. Following drying, samples were hand-ground with a mortar and pestle and sieved (2 mm) to remove root and rock fragments before storage in either polycarbonate bottles or polyethylene Bags. For $^{137}$Cs samples, a subsample of approximately 200-250 g was loosely packed to a depth of 1 cm center thickness in a Marinelli beaker, sealed with tape to prevent exchange of gasses with the atmosphere, and stored until analyzed. Prior to elemental analysis, carbonates were removed via HCl fumigation after methods described by [*Harris et al.*, 2001]. Briefly, samples were placed into plastic weigh-boats (following visual inspection to ensure no identifiable plant material was present) and wetted with milli-Q water (18MΩ or greater). Soils were then fumigated overnight in a dessicator with HCl vapor. The dessicator lid was opened and excess HCl vapor was allowed to dissipate for 2-3 hours in a fume hood before samples were moved to an oven and dried overnight at 40°C. Then, a known mass of sample was weighed for elemental analysis (organic C) via high-temperature combustion on a VarioMAX elemental analyzer (Elementar Americas Inc.) calibrated to glutamic acid standards. Elemental analyzer runs were interspersed with blanks and check-standards (glutamic acid). Mean deviation on duplicate samples was 0.05 %.

### $^{137}$Cs activity measurement via gamma spectroscopy

Samples were measured for their $^{137}$Cs content via gamma spectroscopy on a high purity germanium crystal detector (GX4018 coaxial, Canberra Industries, Inc.). Analysis time varied with sample depth and typically ranged from 8h (surface samples) to 24h (deep samples). Gamma spectra were energy- and efficiency calibrated based on an internally-prepared standard mixture of BL-5 uranium ore

($^{238}$U series in secular equilibrium) combined with $^{137}$Cs. The standard was mixed with deep loess parent material (no $^{137}$Cs detectable) to achieve an activity of 5.122 to 5.430 Bq g$^{-1}$ (depending on compound). Data were processed with the Genie2000 software and resulting sample activities are reported as Bq kg$^{-1}$. Minimum detectable activity (MDA) varied with acquisition time and sample activity and was determined for each sample individually. For data reported here, the mean MDA/signal ratio for samples collected from the soil surface was typically around 10%. Duplicate analyses of select samples showed mean difference of 0.06 Bq kg$^{-1}$ with an average coefficient of variation of 3.7%.

## Digital Terrain Attributes

Digital terrain attributes were calculated from LiDAR-derived digital elevation models (DEMs) available from the Minnesota Elevation Mapping Project:

http://www.mngeo.state.mn.us/committee/elevation/mn_elev_mapping.html

The final elevation product is available with cell sizes of both one and three meters. For this work, we opted to use the three-meter DEM as the base from which to determine digital terrain attributes. This decision was based on 1) the accuracy of the handheld GPS unit used for field work; 2) the observation that the one meter product tends to include more temporary features in crop lands such as tillage tracks from farm implements; and 3) preliminary results that show similar overall results between models based on both one- and three-meter DEMS. Three meter DEMs were used to calculate digital terrain attributes with the ArcGIS software package (v 10.2). Primary attributes (percent slope, profile curvature, and planform curvature) were calculated directly with available spatial analyst tools. Because of deranged drainage patterns and numerous internally drained areas common in MLRAs 102A and 103, we also explored DEM pits as an explanatory topographic feature.

Early efforts with digital terrain attribute modeling also included secondary attributes such as the Compound Topographic Index (CTI) and Stream Power Index (SPI). Preliminary results showed that these secondary terrain attributes did not substantially improve the predictive power of multiple regression models [*Dalzell et al*, 2011]. Further, the DEM software processing tool we employed (TauDEM; http://hydrology.usu.edu/taudem/taudem5/index.html) contained idiosnycracies that precluded its application for generating our final predictive models. These problems appeared to become worse when applied to larger DEMs such as the county-scale data used for this project. Because it was important that products from this work be applicable to broad portions of Minnesota's agricultural landscape, (as well as preliminary results that suggested their limited utility to improve predictive models) we ultimately opted to exclude secondary terrain attributes (SPI and CTI) from our analysis.

## Estimation of Soil Erosion Rates (Proportional Model)

For each sampling pit, soil erosion/deposition rates were determined by comparing the $^{137}$Cs inventory (whole profile) against the inventory of grassland sites. Differences in the $^{137}$Cs inventory were converted to rates of soil movement based on a simple proportional model (PM) [*Walling et al.*, 2002]. The basic PM for estimating soil erosion based on $^{137}$Cs inventories takes the form:

$$Y = 10\frac{BdX}{100T}$$

where:

*Y* = soil erosion rate (t $ha^{-1}$ $yr^{-1}$; negative erosion indicated soil deposition)

*B* = bulk density of the soil (kg $m^{-3}$)

*d* = the depth of cultivation (m)

*X* = percentage reduction in the $^{137}$Cs inventory relative to a reference site: $(A_{ref}-A)/A_{ref}*100$

$A_{ref}$ = $^{137}$Cs reference inventory for undisturbed site (Bq $m^{-2}$)

A = $^{137}$Cs inventory for each sampling point (Bq $m^{-2}$)

*T* = time elapsed since onset of $^{137}$Cs accumulation (y)

For this study, the value of "d" was determined by inspecting $^{137}$Cs distribution profiles of cultivated sites. Most sites showed soil mixing to a depth of 0.20 or 0.25 m. The value of "d' was set to 0.225m. The bulk density (B) was determined based on the average measured value of samples in the upper 25 cm. $A_{ref}$ was determined from $^{137}$Cs profiles of samples collected at reference sites across the study area. While reference sites were selected based on criteria of no cultivation history and perennial vegetation cover over the past approximately 50 years, some $^{137}$Cs profiles showed signs of disturbance and soil redistribution (in particular, several samples from a private hay field located in Dodge county). These sites were excluded from consideration as reference sites. The remaining sites were used to compute a mean total $^{137}$Cs inventory value, which was 1989.7 Bq $m^{-2}$. The time since onset of $^{137}$Cs accumulation (T) was set to reflect the difference between the timing of sample collection (2011) and the ratification of the nuclear test ban treaty of 1963 (48 y).

This model has the advantage of being mathematically straightforward and relatively easy to use. This model does not attempt to differentiate between erosion caused by water vs. tillage. Such models exist [*Li et al.*, 2010; *Walling et al.*, 2002], but rely on additional parameterization and a suite of assumptions that are beyond the scope of this work. Further, such models are not applied to study areas as large as employed in this study. However, given our application of these results to broader statewide trends (as opposed to a detailed study of one hillslope), we opted to use a simple model that could be easily applied without requiring estimates of additional parameters.

## Statistical Analysis

Simple multiple linear regression analysis was applied to develop empirical relationships between terrain attributes and soil erosion rates determined based on $^{137}$Cs inventories. Soil erosion rates were the model response variable while MLRAs (fixed effect) and digital terrain attributes were input as potential predictor variables. Interactions were also allowed between MLRAs and digital terrain attributes. Following initial model creation, non-significant terms were removed and the process was repeated. The end result was a set of four equations (one for each MLRA) to predict soil erosion rates based on digital terrain attributes. Statistical significance was determined at the $\alpha = 0.05$ level. In cases where p values are not provided in the text, statistical significance is neither assigned nor implied.

Before model creation, 25% of the samples were randomly selected (Microsoft Excel random number generator). Those samples were excluded from the model development exercise and used to validate the prediction expression.

## Results

$^{137}$Cs profiles from undisturbed grassland sites showed generally the same distribution across all sample sites. After excluding profiles that showed evidence of soil disturbance, an average $^{137}$Cs inventory was determined based on data from 30 pits (Figure 3). The average $^{137}$Cs inventory of these sites was 1989.7 Bq m$^{-2}$; this was used as the value of $A_{ref}$ to parameterize the Proportional Model.

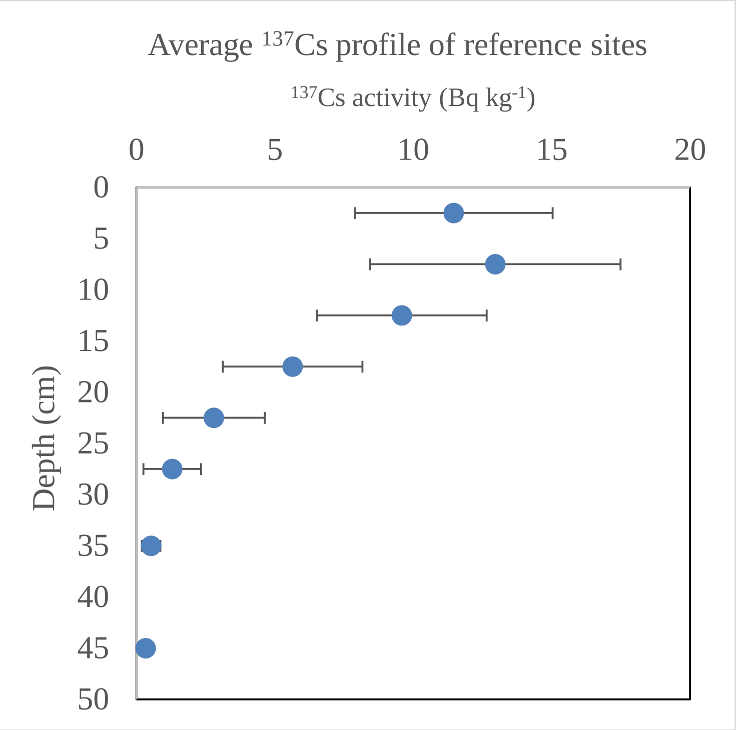

Figure 3. Average $^{137}$Cs activity profile of grassland reference sites. The mean value of reference sites was used to parameterize the Proportional Model in order to estimate soil erosion rates based on $^{137}$Cs inventories at cultivated sites.

Observed data showed that cropland soils had $^{137}$Cs inventories that ranged from 467.3 (eroding sites) to 4079.8 Bq m$^{-2}$ (depositional sites). In nearly all crop sites, the $^{137}$Cs profile in the upper 20-25 cm was uniform, reflecting efficient mixing accomplished by agricultural tillage (Figure 4). Eroding sites exhibited overall depleted $^{137}$Cs activities as deeper soils (unlabeled by $^{137}$Cs) are incorporated into the tillage layer following erosion of previous topsoil. Depositional sites, by contrast, showed deep $^{137}$Cs profiles, reflecting the previous positon of the soil surface and accumulation of soil eroded from upland sites.

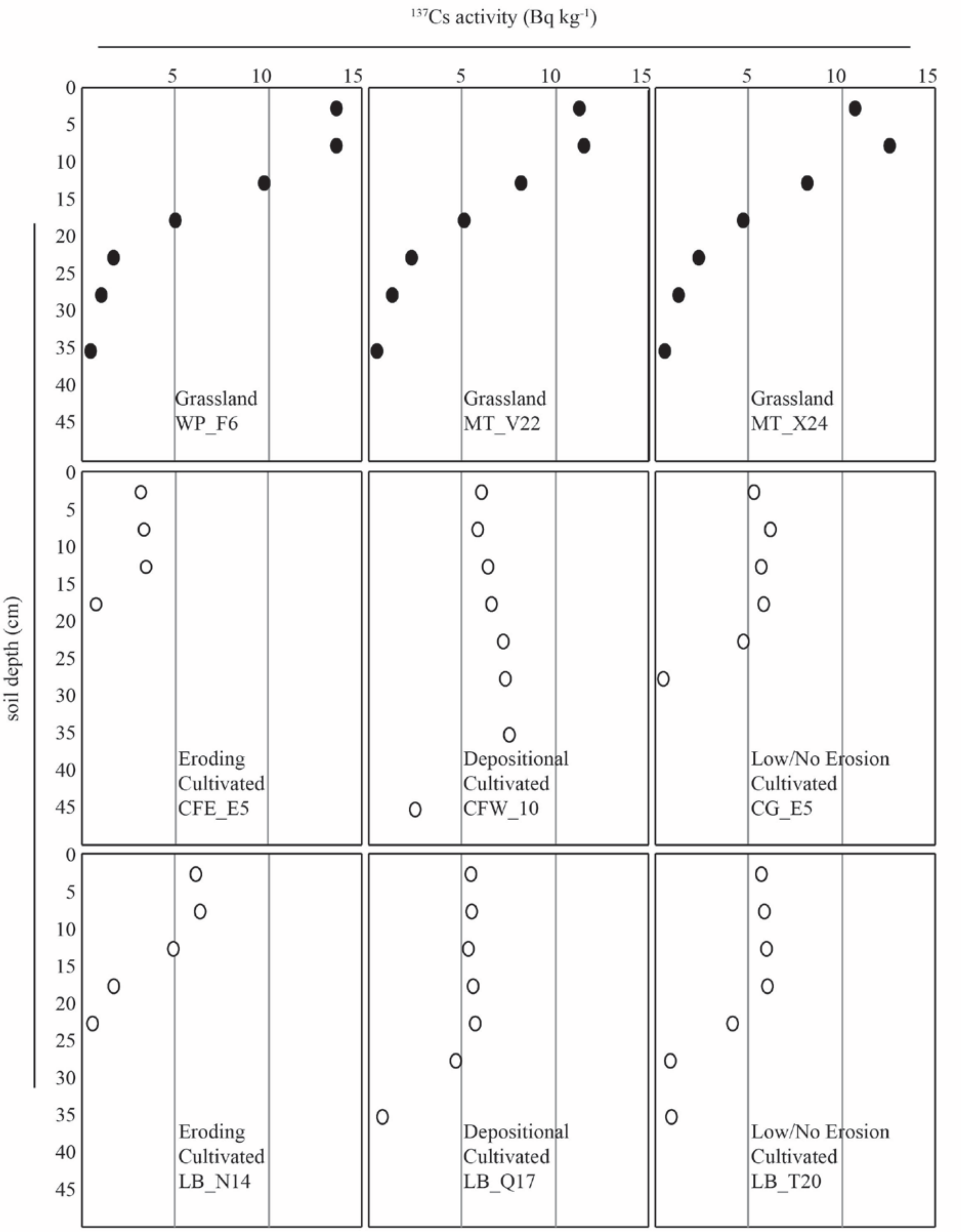

Figure 4. Representative $^{137}$Cs profiles from grassland reference sites as well as cultivated sites reflecting different erosion/deposition histories.

The equations that resulted from multiple linear regression analysis showed significant terms for slope steepness, profile curvature, and plan curvature as well as differences in the prediction expression for each MLRA (below). Terms that differ between MLRAs are highlighted in bold.

## Permanent Cover Reduction Models

### MLRA 102A Rolling Till Prairie

$$Y = -31.39703+\mathbf{10.14056}+(5.86678*\text{Slope})+(-14.00313*\text{ProCurve})+((\text{Slope}-5.38106)*\mathbf{-6.30051})+((\text{PlanCurv}-(-0.08753))*\ \mathbf{-35.43550})+(28.55380*\text{PlanCurv})$$

### MLRA 103 Central Iowa and Minnesota Till Prairies

$$Y = -31.39703+\mathbf{6.83722}+(5.86678*\text{Slope})+(-14.00313*\text{ProCurve})+((\text{Slope}-5.38106)*\mathbf{-5.82018})+((\text{PlanCurv}-(-0.08753))*\ \mathbf{-21.90729})+(28.55380*\text{PlanCurv})$$

### MLRA 104 Eastern Iowa and Minnesota Till Prairies

$$Y = -31.39703+\mathbf{-25.94160}+(5.86678*\text{Slope})+(-14.00313*\text{ProCurve})+((\text{Slope}-5.38106)*\ \mathbf{13.83139})+((\text{PlanCurv}-(-0.08753))*\mathbf{78.54040})+(28.55380*\text{PlanCurv})$$

### MLRA 105 Northern Mississippi Valley Loess Hills

$$Y = -31.39703+\mathbf{8.96382}+(5.86678*\text{Slope})+(-14.00313*\text{ProCurve})+((\text{Slope}-5.38106)*\mathbf{-1.71070})+((\text{PlanCurv}-(-0.08753))*\mathbf{-21.19761})+(28.55380*\text{PlanCurv})$$

The prediction expression was able to explain 33% of the variability in the observed data ($r^2 = 0.33$). The 25% of samples reserved for the validation data set showed a similar agreement between observed and predicted values of soil erosion or deposition (Figure 5) with an $r^2$ value of 0.54. That comparison included two influential data points, however. When excluded, the regression between observed and predicted data was similar but the $r^2$ value decreased to 0.24. When applied to the all data points across the study area, $r^2$ agreement between observed and model-predicted soil erosion and deposition rates was 0.38 (Figure 5).

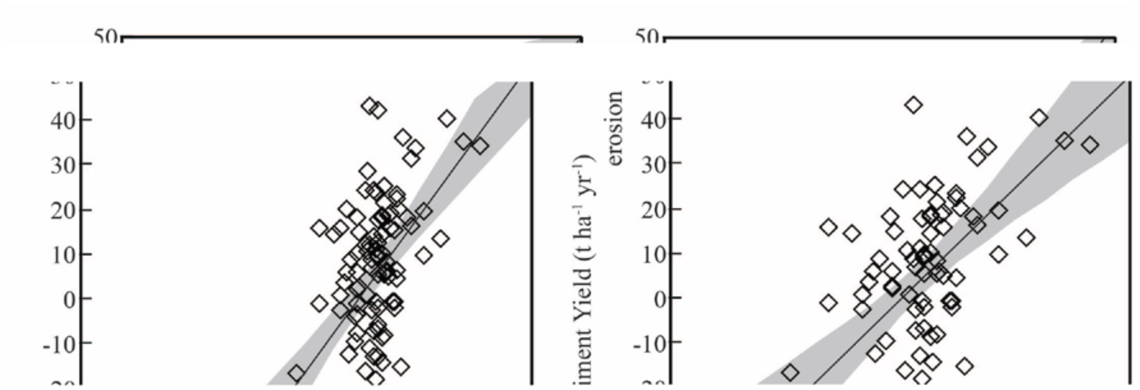

Figure 5. Results from a simple multiple linear regression model established to predict soil erosion rates from digital terrain attributes. The left panel shows the model applied only to the data points that were used to develop the model. The right panel shows all data points.

## Discussion

The regression models developed for this study were able to predict 38% of the variability in observed soil erosion rates across the study area ($p < 0.0001$). Additional variability in the observed data that is not accounted for by the model is likely the result of several factors ranging from uncertainty in parameterization of the Proportional Model to differences in management practices across all study sites and MLRAs which would have produced different erosion rates over the past half-century (as well as random error introduced during sample and data collection). The models developed here are able to predict and quantify broad trends in soil erosion or deposition rates across a large portion of Minnesota's agricultural landscape.

Regression models were applied to each MLRA to generate maps that predict the long-term average soil erosion rates for the landscape under cultivated land use. A brief examination of a selected field in MLRA 105 is helpful for highlighting some of the uses and potential pitfalls of these data products (Figure 6). While there are some locally high areas of potential soil erosion within the field, most are near zero and the field-wide average soil erosion rate is 6.7 t ha$^{-1}$ yr$^{-1}$. A widely applied estimate of tolerable soil loss is about 11 t ha$^{-1}$ yr$^{-1}$ [*Hudson*, 1995]. The depositional site located along the southern edge of the field (Figure 6) also highlights the importance of including additional information when considering locations for soil conservation practices. If that depositional site is situated along a ditch, it is likely that deposited sediment may be periodically re-mobilized and transported to receiving waterways during large storm events (something that is not considered by this model).

Based on the assumption that soil erosion (over decadal time-scales) is close to zero on perennially-vegetated landscapes, the soil erosion map can be used as a tool by BWSR staff, soil conservationists, or other interested parties as a method for estimating the amount of soil erosion that may be prevented for specific landscape segments when enrolled in conservation programs. Conversely, this map may also be used to predict the amount of erosion that may occur if conservation land is converted to cultivation. It is important to note that we did not perform this analysis for any forested landscapes and results of this analysis should not be applied to forest vs. cropland comparison without further development and testing.

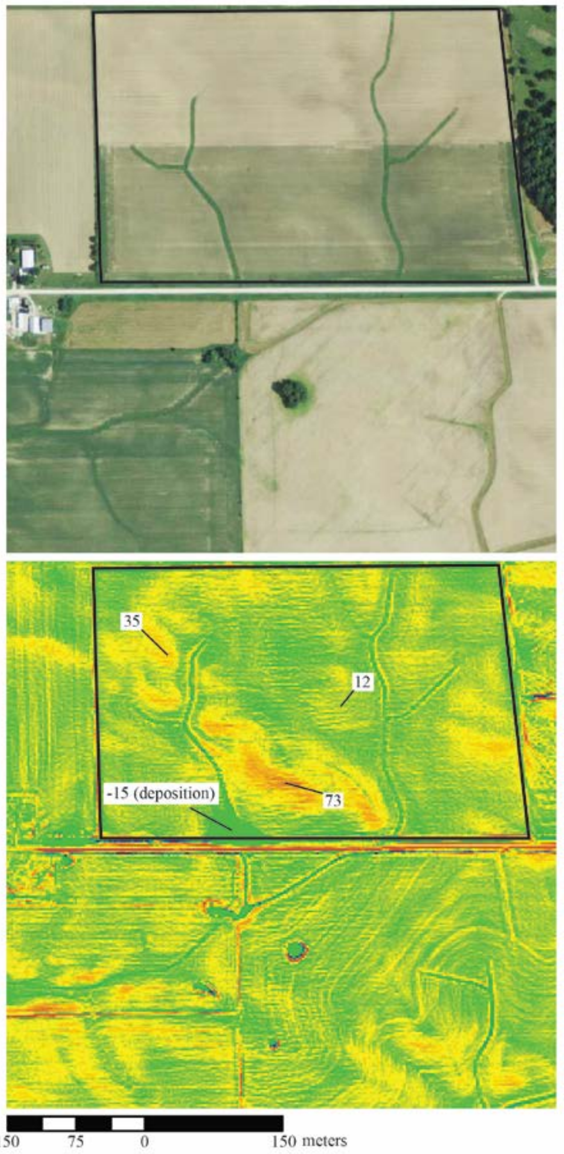

Figure 6. Example output of the multiple regression model for a selected farm field in MLRA 105. Based on digital terrain attributes, the model result shows localized areas of potentially high soil erosion rates while the overall field average erosion rate is 6.7 t $ha^{-1}$ $yr^{-1}$.

## Suggestions for Future Work

*Model Refinement* - A portion of the uncertainty unaccounted for by the regression model is likely to arise from differences in management practices across the agricultural sites used for this study. One potential way to quantify that uncertainty is to conduct more focused research on smaller sites with more uniform management practices. The UMN Research and Outreach centers are good candidates for this kind of inquiry and additional sampling is already underway as part of separate project. Ongoing analysis of additional future samples (in addition to those collected for this study) are likely to yield predictive regression models which are able to further constrain topographic effects on soil erosion under more specific sets of management practices. As further refinements are developed and become available, we will remain in communication with BWSR personnel to discuss the potential for improving existing conservation estimator projects. Additional refinement may be possible through application of more sophisticated conversion models to estimate soil erosion rates based on $^{137}$Cs inventories. This effort would require more detailed information (or robust sets of assumptions) in order to parameterize the additional variables that are considered by these models.

*Accounting for stream networks* – The models developed from this study are based solely on predicting long-term soil erosion rates from digital terrain attributes. They do not account for the potential of downslope deposited sediment to be further re-mobilized into streams or rivers during large runoff events. Potential methods to account for this may include intersecting results from this soil erosion model with flow direction and flow accumulation information to highlight areas where high soil erosion occurs in close proximity to receiving waterways.

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## **Appendix A –** Method for Determining Field-Average Erosion/Deposition Rates

This brief tutorial is intended to provide someone with basic GIS experience (and access to ArcMAP software with Spatial Analyst) the ability to compute field-average erosion/deposition rates based on the raster maps produced from this study.

Inputs:

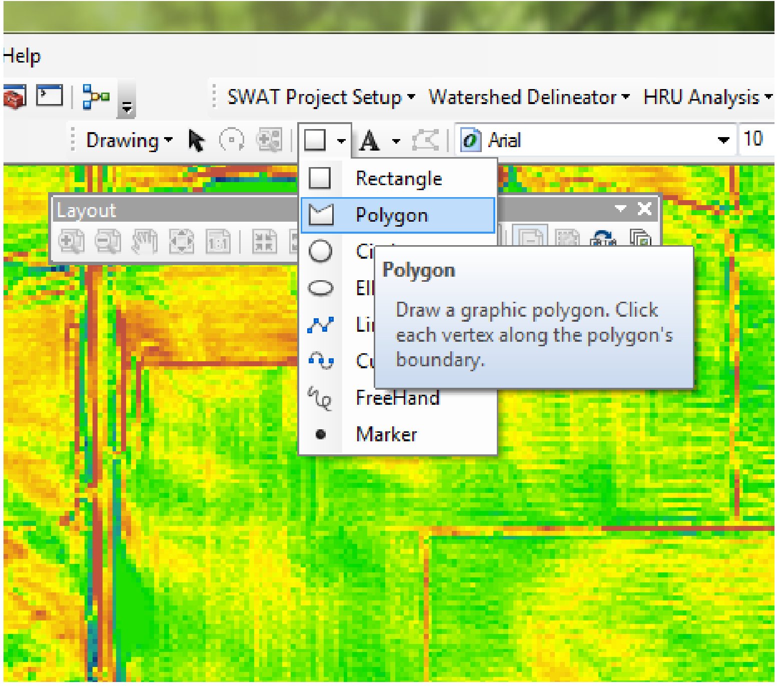
1. Soil erosion/deposition raster for your county of interest (required)
2. Air Photo layer to help identify area of interest (optional but very helpful)

Outputs:

1. Shapefile of your area of interest
2. Raster showing the average predicted erosion/deposition rate for your area of interest.

### **Step 1. Manually delineate your field or area of interest.**

- After identifying your field/area of interest, use the ArcMAP drawing tool to draw a polygon around your area. (Fig A-1)
- Using the ArcMAP "Draw" toolbar, select the draw polygon tool and create an appropriate polygon around your area. (Fig A-2)
- From the "Drawing" drop-down menu, select "Convert Graphics to Features" and add the exported data to the map as a layer. (Fig A-3)



Draw a graphic polygon. Click each vertex along the polygon's boundary.

**Figure A-1**

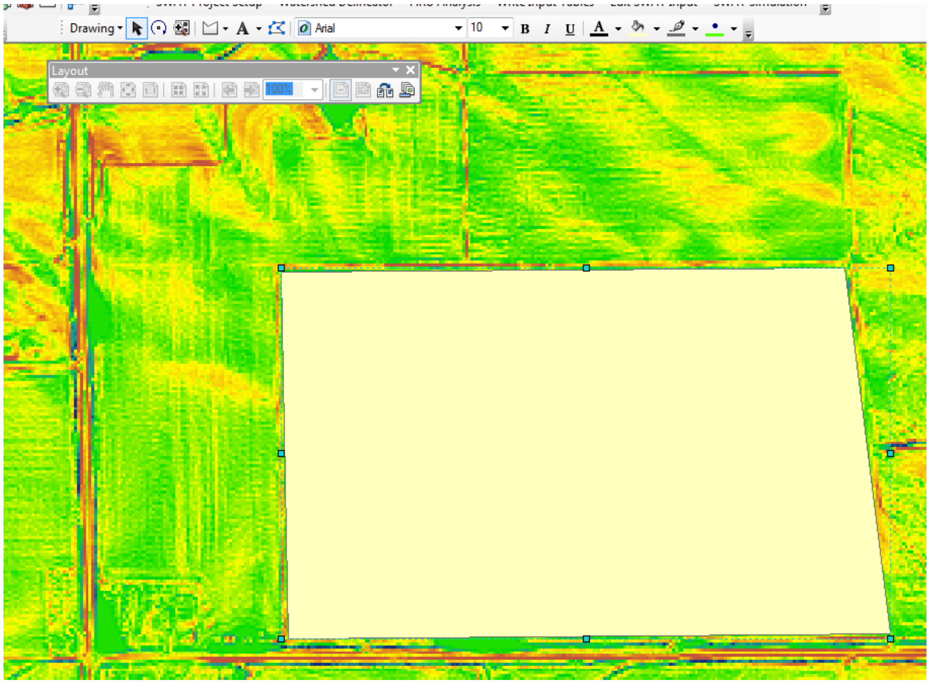
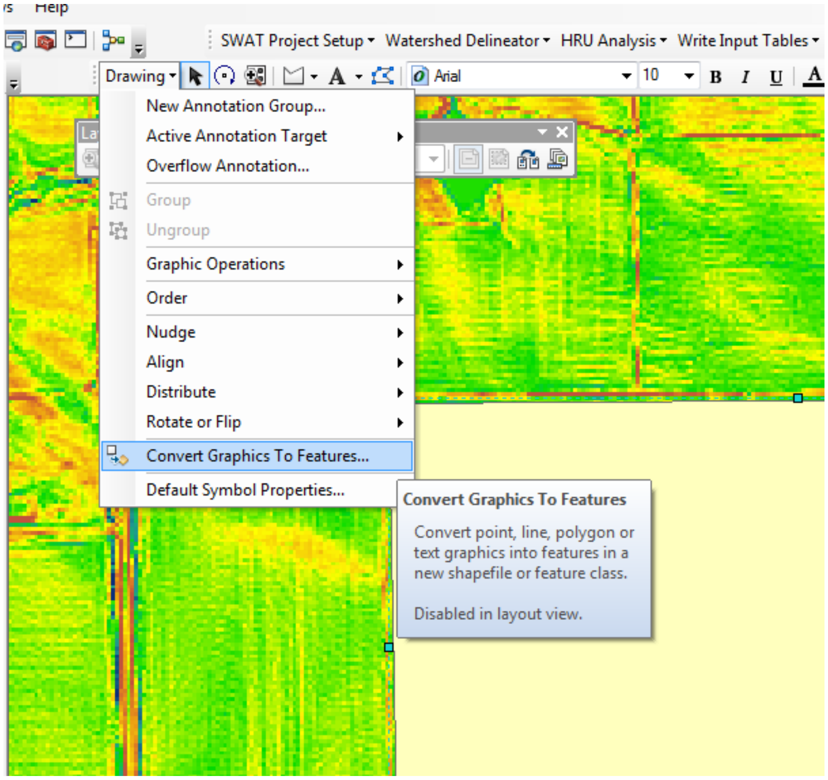


Figure A-2



**Convert Graphics To Features**

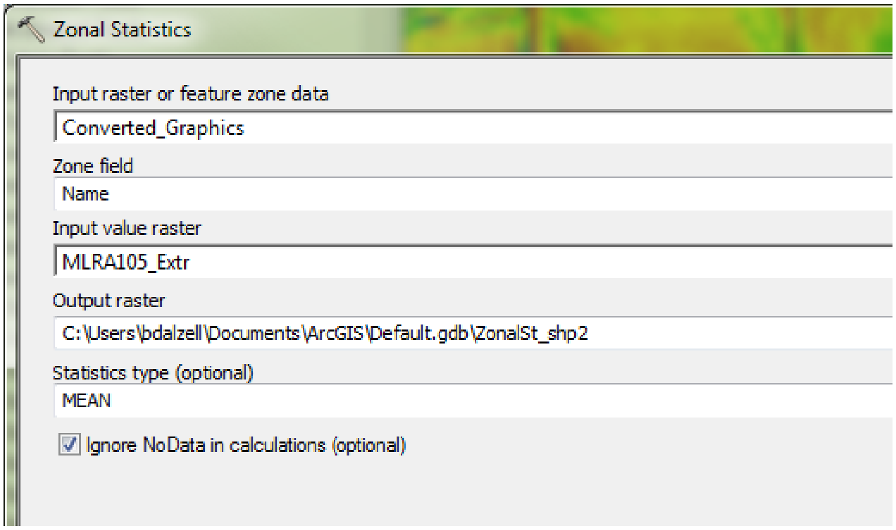
Convert point, line, polygon or text graphics into features in a new shapefile or feature class.

Disabled in layout view.

Figure A-3

**Step 2. Perform zonal statistics.**

- Launch the “zonal statistics” tool (Spatial Analyst -> Zonal -> Zonal Statistics). (Fig A-4)
- Input raster or feature zone data = the converted graphics (created in step 1 above)
- Zone field = name
- Input value raster = the soil erosion/deposition rate raster for your area.
- Output raster = select an appropriate location and file name.
- Statistics type = MEAN



Input raster or feature zone data
Converted_Graphics
Zone field
Name
Input value raster
MLRA105_Extr
Output raster
C:\Users\bdalzell\Documents\ArcGIS\Default.gdb\ZonalSt_shp2
Statistics type (optional)
MEAN
☑ Ignore NoData in calculations (optional)

**Figure A-4**

The resulting raster should occupy the same extent as your field/area of interest. The raster will have only one value, which is the mean erosion/deposition rate for your area. (Positive values indicate erosion, negative values indicate deposition)