MODELING ALTERNATIVE AGRICULTURAL SCENARIOS USING RUSLE AND GIS TO DETERMINE EROSION RISK IN THE CHIPPEWA RIVER WATERSHED, MINNESOTA

by

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ABSTRACT

The Land Stewardship Project (LSP), a Minnesota-based nonprofit organization, is working to quantify water quality, wildlife habitat, economic, and other benefits from working farmlands. Several approaches are being tested in this multi-disciplinary effort to further the growing demand for improved environmental outcomes from agriculture. From these analyses LSP can make recommendations for conservation program implementation and performance-based policies at the state and national level. At the core of this project is modeling research that predicts the benefits that could be produced by farming systems that aim to reduce erosion into nearby streams, which is a significant problem in the United States.

LSP identified the need for a straightforward yet effective model to predict soil loss under varying agricultural scenarios. For this project, an assessment of the Revised Universal Soil Loss Equation (RUSLE) within ArcGIS was conducted as a means to predict erosion risk within Minnesota's Chippewa River Watershed from nearby agricultural lands. Four alternative agricultural scenarios were developed to predict changes in erosion. Results show that increasing agricultural lands under conservation tillage, planting cover crops in cultivated areas, increasing the area under grassland, adding vegetated buffers along streams, and restoring wetlands resulted in the most dramatic decrease in erosion in the Chippewa River study area. A manual detailing data preparation, scenario development, and running the model was developed for LSP. Overall, the use of RUSLE within ArcGIS is an appropriate strategy for LSP's work to identify erosion potential in agricultural areas and to identify and enhance various environmental and economic benefits from agriculture. Beyond modeling soil loss, LSP can use ArcGIS to identify and prioritize areas for monitoring, restoration, and for education and outreach programs.

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TABLE OF CONTENTS

List of Figures

CHAPTER 1: BACKGROUND AND OVERVIEW

In the Midwest, as in many other parts of the United States, agricultural areas make up a significant portion of the landscape. These areas are typically large-scale, industrialized operations that collectively produce a major portion of the world's food and fiber. Currently many U.S. farming operations are largely driven by federal agricultural policies, which subsidize a select set of commodities, including corn, wheat, soybeans, cotton, and rice (Boody et al 2005). Technological and chemical advancements made during World War II allowed for wide-scale agricultural intensification throughout the United States. Today, management practices on U.S. farms reflect these advancements and agricultural producers now rely on irrigation, mechanization, high-yield crops, chemical fertilizers, and pesticides to meet world food demands (Jackson and Jackson 2002).

Despite the enormous production capacity of current farming practices, concern has developed over the long-term sustainability and environmental costs of intensive agricultural systems. Within the last thirty years, a significant amount of research has pointed to local, regional and global consequences of such intensively managed farms. At the local level, croplands are vulnerable to erosion because the soil is continually tilled and left without vegetative cover (Pimentel et al 1995). Local consequences of agricultural intensification also include poor soil fertility due to aeolian and water erosion from exposed topsoil and reduced biodiversity (Tilman et al 2001). Regional consequences include groundwater pollution and eutrophication of surface waters (Matson 1997). On a global scale, one of the most significant problems of agricultural practices includes increases in the greenhouse gases N_2O and NO_x, which can result in atmospheric smog, ozone, and acidification of soil and water in addition to contributing to climatic change (Tilman et al 2001).

Growing concern over the ecological impacts of intensive, mechanized agriculture led to the sustainable agriculture movement (also called the alternative agriculture movement) in the 1980s, which called for significant reforms to modern farming systems (Jackson and Jackson 2002). There is now a wide body of literature that challenges the basic assumptions of conventional farming (Vandermeer and Perfecto 2007) and the sustainable agriculture movement is gaining support and acceptance within mainstream agriculture. This alternative agriculture movement promotes agroecological systems that preserve biodiversity, support overall biological efficiency, and maintain productivity and self-regulation (Altieri 2000). The design of these alternative agriculture systems is based on the application of the following ecological principles (Reinjntjes et al 1992):

1. Recycling biomass, optimizing nutrient availability and balancing nutrient flow.
2. Securing favorable soil conditions for plant growth by managing organic matter and enhancing soil biotic activity.
3. Minimizing losses due to flows of solar radiation, air and water by way of microclimate management, water harvesting and soil management through increased soil cover.
4. Diversification of species and crop genetics within the agroecosystem in both time and space.
5. Enhancing beneficial biological interactions and synergisms among agrobiodiversity components, resulting in the promotion of key ecological processes and services.

These principles can be applied in a number of different ways – each creating unique outcomes for productivity, stability, and resiliency within the overall farm system, depending on resource capital, the market, and factors at the local level (Altieri 2000). The field of agroecology aims to provide both the practical and theoretical knowledge necessary for developing an agricultural system that is not only highly productive, but also environmentally sound, socially equitable, and economically viable – in short, a system that offers *multiple* benefits.

Developing an agricultural system that offers multiple benefits requires a common vision of landscape design and management alternatives. Effective tools are needed to accurately address landscape-level implications of planning and policy regimes. The use of scenario-based alternative futures, made possible by improvements in geographic information systems (GIS) and computer modeling of ecological and economic processes can address these needs (Santelmann et al 2005). Future landscape scenario studies have become more common in recent years both within both the research and natural resource management communities. Alternative landscape futures allow decision makers and stakeholders the opportunity to visualize and evaluate policy and planning choices specifically in time and place or suggest policies to achieve particular goals (Santelmann et al 2005, Nassauer et al 2002). Scenario analysis combined with landscape-level analyses can also be used to characterize uncertainty, test possible impacts and evaluate responses, assist strategic planning efforts, and formulate existing knowledge to determine the range of possible future conditions (Kepner et al 2008).

Computer modeling of ecological and economic processes often requires large data sets, which can be expensive and tedious to collect. These constraints have historically limited computer modeling analyses to those institutions and individuals with ample time and resources. Recent advancements in data collection and increased data availability through online databases have greatly improved the ability of planners, scientists, and natural resource managers to carry out such analyses. An increasing number of state and federal agencies, local governments, and nonprofit organizations now collect and house a plethora of publicly available data. With increasing data availability, the number of user-friendly computer models has also become more widespread.

Alternative futures analysis has recently become a common approach to inform community decisions regarding the potential effects of different options for future land use (Hulse et al 2004). In the last two decades, state and federal agencies, and local governments have placed more focus on community-based environmental planning, or "environmental visioning" which emphasizes decision-making by local stakeholders to address communitywide environmental issues (U.S. EPA 2000). Nonprofit organizations have also begun to incorporate visioning strategies into their work with communities, although it appears to be a more recent phenomenon in this sector. Environmental visioning can be a powerful tool for organizations – particularly for those that have strong ties to their members and communities.

Environmental visioning often relies on GIS technology both to develop and to support different environmental outcomes. By allowing stakeholders to visualize current and alternative scenarios via maps and to more fully understand the future benefits and consequences of each choice, the process aids in developing common understanding, resolving conflicts and cooperative action (Steinitz et al 2003). However, nonprofit organizations may face disadvantages as they often lack the financial resources, technology, and expertise required to implement environmental visioning projects that incorporate alternative futures analysis. Nonprofit organizations are also frequently priced out of the for-profit technology assistance market and lack the staffing power to take on larger technology initiatives (Nonprofit Technology Network 2008).

The goals of this project were threefold. First, it aims to evaluate the implications of alternative agricultural scenarios on erosion within an area of Minnesota's Chippewa River Watershed using GIS. Along these lines, the project seeks to assess the usefulness of using a soil loss model within GIS for LSP. Finally, as a practicum required for completion of my Master's degree at the University of Michigan School of Natural Resources and Environment, this project also aims to provide me the opportunity to further develop skills in GIS and spatial analysis. Project research was implemented during summer 2006 and from 2007 – 2009 through the Land Stewardship Project, a Minnesota-based nonprofit organization.

1.1 CLIENT

The Land Stewardship Project (LSP) is a private, Minnesota-based nonprofit organization that works "to foster an ethic of stewardship for farmland, to promote sustainable agriculture and to develop sustainable communities" (Land Stewardship Project 2001). As a grassroots membership organization made up of farmers, and urban and rural residents, LSP works on local, state, and federal issues related to agriculture and farming. In 1999, LSP began the Multiple Benefits of Agriculture Initiative to promote environmental, social, and economic outcomes from diversified farming systems and pasture-raised livestock (Land stewardship Project 2001). Since the inception of the Multiple Benefits of Agriculture initiative, LSP and its partners have conducted policy analysis, ecological monitoring and observation, and predictive modeling to quantify water quality, wildlife habitat, economic, and other benefits from working farmlands. From these analyses LSP can make recommendations for conservation program implementation and performance-based policies at both the state and national level.

Since the inception of the Multiple Benefits of Agriculture Initiative, LSP has published a number of reports and research articles that detail numerous benefits from adopting alternative agriculture regimes. In one study, a 15-member working group made up of LSP staff, farmers, and scientists used computer modeling to predict the environmental and social benefits that could result from changing agricultural land use practices in Minnesota's Chippewa River and Wells

Creek watersheds (Land Stewardship Project 2001). Through this modeling work, the LSP study addressed both quantitative and qualitative (nonmarket) benefits from various agricultural scenarios. The results of the study found that even minor adjustments in land use practices could improve water quality, reduce soil erosion, enhance soil quality, increase wildlife habitat, create social capital, and reduce toxic chemicals and greenhouse gases (Land Stewardship Project 2001).

The computer modeling studies that LSP and its partners have conducted have been useful for their work in promoting performance-based agriculture policies that support diversified farming systems. However, as for many small nonprofit organizations, LSP has fewer staff and resources to carry out advanced technical work and computer modeling analyses. For that reason, a significant portion of the technical and computer modeling tasks needed for the Multiple Benefits of Agriculture research were carried out by outside collaborators. After completion of this research, LSP identified a desire to integrate computer modeling and GIS technology into their internal operations and research initiatives. Several members of the LSP staff have at least a basic understanding of GIS technology, which provides a foundation for more advanced analyses required for the Multiple Benefits of Agriculture Initiative. The field of geographic information science has grown dramatically in recent years and offers new tools to a range of application areas. LSP's need, coupled with recent efficiencies in GIS and computer modeling technology set the stage for research to provide LSP with a predictive tool for its Multiple Benefits of Agriculture Initiative.

1.2 PROJECT OBJECTIVES

This report describes a hydrologic modeling approach involving a GIS-based application of the revised universal soil loss equation (RUSLE) model and its working intricacies, assumptions, advantages and limitations, and uses the Chippewa River watershed as an example case-study for the approach. The specific objectives of this project are to:

- Use GIS to model current and potential future land cover and management practices as a means to evaluate impacts of alternative agricultural practices on sediment loss in the Chippewa River study area.

- Develop a protocol for efficient and straightforward use of the model by LSP staff and partners.
- Produce a guidebook that details how ArcGIS can be used to prepare data, create land use scenarios, and run the model using a protocol that can be implemented in any watershed where necessary data exist.

In LSP's 2005 study, *Multifunctional Agriculture in the United States*, the ADAPT (agricultural drainage and pesticide transport) model was used to estimate sediment, nitrogen, and phosphorous loading into streams in two Minnesota watersheds. As a field-scale water table management model, ADAPT is useful because of its ability to predict a number of water quality parameters under different land use scenarios. However, ADAPT is also highly technical, costly, and has no visual or spatial components, which make it less suitable for continued use by LSP. A more appropriate model for LSP will strike a balance between ease of use and the ability to make general predictions of soil loss or soil risk. A suitable model must, in addition to tabular results, also produce results spatially so that LSP can more easily represent alternative agricultural scenarios to collaborators and the public. Ideally, all elements of the modeling process will be able to be carried out under a single platform. Finally, appropriate modeling software should be accessible to LSP from a financial standpoint.

In LSP's previous studies on multifunctional agriculture, a number of different parameters were measured against five alternative agricultural scenarios. Projected environmental effects included those on water quality (sediment, nitrogen, and phosphorus loadings), fish populations, greenhouse gases, and carbon sequestration. Projected short-term economic effects included farm production costs and net farm income. Projected cost savings were also evaluated and included savings from reduced sedimentation and flooding. LSP's studies also included an evaluation of potential social benefits of alternative agricultural scenarios.

LSP's research was comprehensive and required ample time and resources to carry out. As an individual researcher, my ability to carry out a study with similar breadth and depth is limited. LSP and I agreed that I would measure one environmental parameter in my study to meet the needs of LSP in finding a more appropriate model and to conduct this project effectively.

Erosion from farm fields was a natural choice given its significance within the agricultural community and because there are a number of soil loss models already in existence. In addition to finding ways to reduce erosion from farm fields, the Land Stewardship Project aims to improve biodiversity within agricultural areas through its Multiple Benefits of Agriculture Initiative. Although the conversion of grasslands and forests to agriculture has contributed to the decline in wildlife habitat, agriculture can, in some circumstances, offer wildlife habitat that is superior to other human-dominated land uses, such as urban areas. Vandermeer et al. (2006) argue that the solution to the dilemma of species conservation is to "focus on the matrix and…the interactions it has with remaining fragments of 'natural' habitats".

Providing habitat for grassland birds where feasible within agricultural areas has become an issue of concern in the Midwest – both for farmers and the public, which places high intrinsic value on birds. Results from the U.S. Geological Survey's Breeding Bird Surveys (BBS) indicate that grassland birds, as a group, have declined more than any other avian group in the United States (Sauer et al 2008). The likely cause of the decline in grassland bird populations is the loss of a significant portion of grassland breeding habitat, much of which was converted to agricultural crops during the twentieth century. In recent years, state and federal agencies have implemented research and management programs aimed at counteracting the decline in grassland birds by balancing high crop production goals with the creation of suitable habitat, such as the Conservation Reserve Program. As part of these programs, several computer-based models have been developed to predict suitable habitat for birds within various land management regimes. Public attention to the plight of bird species has led to a plethora of available data, which provides a strong foundation for using birds in computer modeling research. Although I was unable to assess appropriate models for predicting suitable grassland bird habitat as a part of this project, the scenarios developed here could be used by LSP in conjunction with such a model should they wish to evaluate avian habitat in the future.

For this project to be successful and sustainable, I needed to develop a protocol that produces data in an efficient and straightforward manner. Computer models are often complicated and hard to use without in-depth training, and software platforms often contain an array of functions that are not needed by users with only basic knowledge. I developed a protocol that takes users step-by-step through the process of preparing data, creating land use scenarios, and running the models to eliminate confusion and extraneous functions. The protocol is detailed in an accompanying guidebook (see Appendix) and can be applied to any watershed where necessary data exist.

1.3 STUDY AREA

The Chippewa River Watershed is located in south central Minnesota and drains a 2,080 square mile basin spanning portions of eight counties (Chippewa River Watershed Project 2003). Chippewa Lake forms from the headwaters of the Chippewa River in Douglas County. The river then flows 209 kilometers south to Montevideo where it joins the Minnesota River. Land use within the watershed is primarily agricultural and is dominated by corn and soybean crops (U.S. Department of Agriculture 2002). The Land Stewardship Project chose a 17,994-ha subbasin (Figure 1) of the Chippewa River Watershed for analysis in their Multiple Benefits of Agriculture Initiative. I chose to use the same subbasin (the Chippewa River study area) in my analysis so that LSP can compare the results of my analysis to those of their original study. A large portion of the Chippewa River study area is located in Chippewa County, and a small portion in Swift County. Nearly 90% of the Chippewa study area's 6300 residents live in the city of Montevideo (U.S. Census 2000), which is located at the southern end of the study area. A majority of the study area is planted with corn and soybeans, which have replaced small grain crops over the last few years (Boody et al 2005). The Chippewa River study area has a mean slope of 2%. Soils within the study area range from silt-clay to silt-loam.

The guidelines used to determine the most appropriate models and software for LSP are detailed in Chapter 2, which also includes a description of the RUSLE model. Chapter 3 details the protocol used to prepare data, create alternative agricultural scenarios, and run the model. The soil loss results modeled under the different scenarios are described in chapter 4 which also includes soil risk maps put together for each scenario. The guidebook is included in the Appendix.

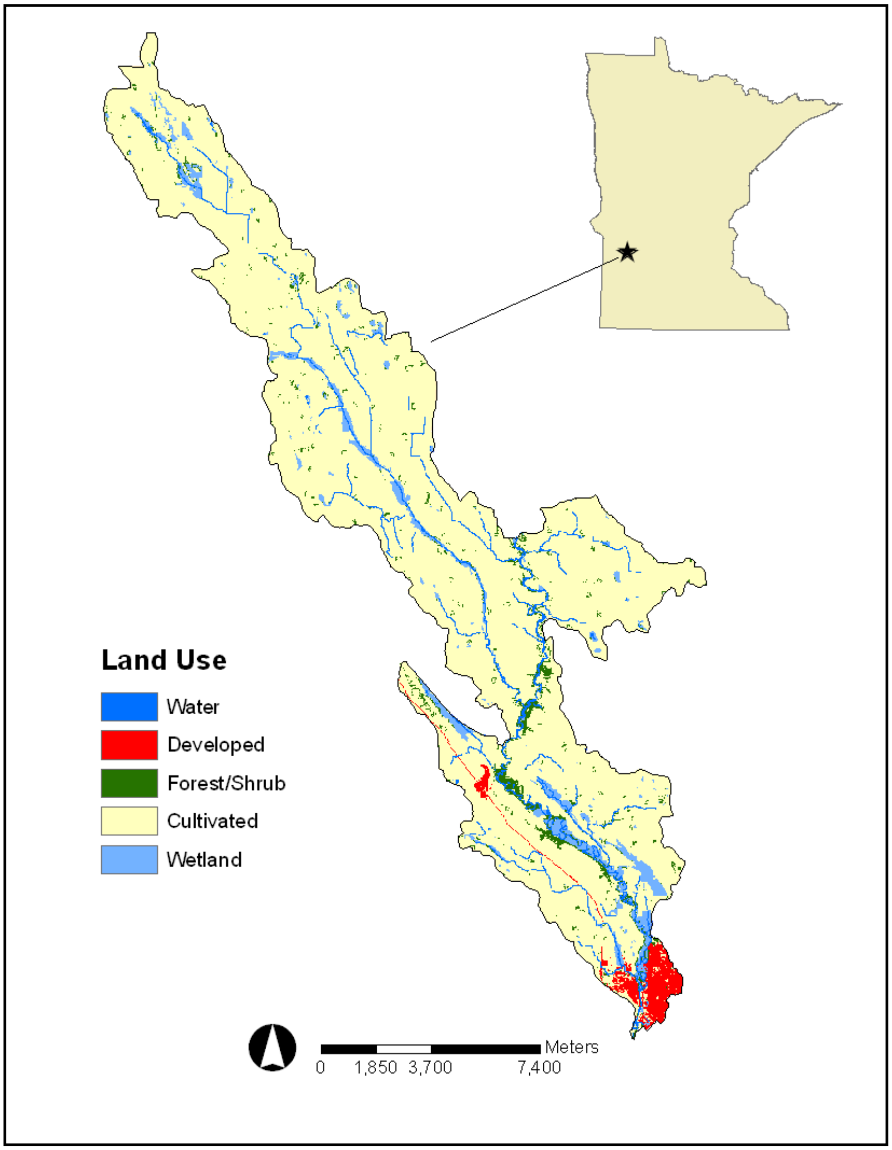


Figure 1. Chippewa River Study Area, located in Swift and Chippewa Counties in southeast Minnesota.

CHAPTER 2: SOFTWARE AND MODEL DESCRIPTION

One of the main goals of this project is to identify an appropriate modeling tool for the Land Stewardship Project's Multiple Benefits of Agriculture Initiative. Such a tool will allow LSP to identify hot spots for potential soil loss under varying land use scenarios. LSP's previous experience with scenario modeling helped to establish some important guidelines for the process of selecting an appropriate tool. Ideally, this modeling tool will be straightforward to users, produce general estimates of erosion risk or sensitivity in both spatial and tabular form, and also be affordable. Because LSP aims to model additional factors beyond soil loss as part of the Multiple Benefits of Agriculture Initiative, a singular software platform that has the capability to model multiple parameters is preferred.

2.1 GUIDELINES FOR MODEL SELECTION

The process of selecting a suitable model was relatively informal and was based on a set of qualitative guidelines established by LSP. Although all of the criteria identified by LSP are important components for the process of selecting a model, two specific criteria stood out as essential: ease of use for staff and the ability to produce maps to indicate where erosion potential may be greatest and which problem areas need to be addressed. The former is important for LSP's internal capabilities, possible continued use within the Multiple Benefits of Agriculture Initiative, and its long-term sustainability. Without the financial resources to hire a staff member with computer modeling experience, current LSP staff must take on the task of learning and using modeling software. The latter is important for LSP's work at both the local and national level. Farm program recommendations and policy initiatives based on the results of modeling research can be used to make informed management and policy decisions. A tool that is straightforward yet also capable of producing robust data outputs will provide LSP with an important foundation for its work.

For the purpose of this project, I will measure soil loss using the chosen modeling tool. While LSP does not wish to sacrifice robustness for ease of use in modeling tools, it aims to find a single platform in which most (if not all) of its modeling work can be carried out. In a recent report, the Nonprofit Technology Network (NTEN 2007) found that "nonprofits are challenged by managing their data effectively on a daily basis" and that "this is hampering their work, making processes redundant and cumbersome and adding precious time and costs to their operations". The Land Stewardship Project has similar challenges and seeks a software platform that will allow for efficient and straightforward data management and processing, rather than using multiple tools for modeling work.

LSP seeks a modeling tool or software platform that will produce results in both tabular and spatial formats. This component is particularly important as LSP seeks to share the results of its modeling research with farmers, policy-makers, and the public. Visual representations presented along with the quantitative results of the effects of changing land use scenarios can be a powerful tool for community planning and policy making. Steinitz (2003) argues that "the most important reason to use a scenario-based approach is the benefit to decision-making processes." For policy-makers, scenarios can be used to test the outcomes of various planning ideas and to examine concerns from the public (Steinitz 2003). For farmers and landowners, the visualization of alternative scenarios can assist them in anticipating the range of potential changes to their lands as a result of planning initiatives (Steinitz 2003). As LSP continues its research for the Multiple Benefits of Agriculture Initiative, it aims to include farmers, landowners, and policy-makers in the process of evaluating a range of scenarios that represent different priorities for future land use. For LSP, the capacity to represent a range of potential management scenarios in both spatial and tabular form will accommodate a diversity of opinions among elected officials, farmers, and members of the public as they seek to make informed decisions about agricultural policy and land use.

For the Land Stewardship Project, cost is an important factor in decision-making around additional operational expenses. The majority of LSP's operating revenue comes from government and foundation grants, membership fees, and contributions. As such, financial resources for costly computer software are limited. For this reason, LSP identified cost as an important criterion for the process of finding a suitable modeling tool. Ideally, the final tool will meet LSP's technical needs, yet also be affordable. Fortunately in recent years the costs associated with computer hardware and mapping software have fallen considerably. The Environmental Systems Research Institute's (ESRI) offers a number of different ArcGIS software license options, the least expensive of which costs only $100 annually. Free extensions for ArcGIS and other software programs and open source mapping and analysis programs have also become widely available in recent years. Although the merits of these options were not evaluated as part of this analysis, information about how they can be used is widely available online should LSP wish to explore their use.

The use of digital technology for spatial analysis and computer modeling has become widespread across a range of sectors. Among LSP staff, experience with digital simulation technology is varied, although most of it is with ESRI's ArcGIS software suite. ArcGIS and its predecessors, ArcView and Arc/Info, make up one of the most popular GIS software suites in existence today (Bolstad 2008). ESRI's Arc software currently surpasses all competing products with respect to user base and annual sales (Bolstad 2008). These facts, coupled with LSP's experience with the ArcGIS suite made a strong case for the use of ArcGIS software for this project and for continued use by LSP. Before making a formal recommendation to LSP, I examined a number of tools that can be used to model soil loss in order to explore whether they could be used in conjunction with the ArcGIS suite.

2.2 SOIL LOSS MODEL SELECTION

Through research from the Multiple Benefits of Agriculture Initiative, the Land Stewardship Project aims to find ways to improve water quality in Minnesota's agricultural regions. Although there are many indicators of water quality, common measures include sediment, nitrogen, and phosphorous loadings. For the purposes of this research, sediment loss from farm fields in the Chippewa River Study area was modeled under alternative agricultural scenarios. Measures of soil loss for this project are not intended as a proxy for water quality but are simply representations of erosion from farms in the study area. Should LSP choose to model nitrogen and phosphorous, there are a number of viable options available at minimal cost. The ArcGIS software suite will serve as a solid foundation for carrying out these analyses, but may require substantial data processing and the use of extensions. Two other options for water quality modeling include Idrisi, a GIS developed by Clark University, and BasinSim, a watershed modeling package developed by the Virginia Institute of Marine Science and the College of William and Mary. Idrisi differs from other GIS software in that it offers image processing in addition to a large suite of spatial data and display functions. Because of Idrisi's development within educational and research institutions, it is straightforward to use and easy to understand for those new to GIS software. BasinSim is a desktop simulation system that can predict sediment and nutrient loads for small to mid-sized watersheds. Users can manipulate land use patterns, visualize characteristics of the watershed, and simulate nutrient and sediment loadings under various scenarios. BasinSim produces results in tabular form only, although these results can be displayed as bar graphs, line graphs, or pie charts. BasinSim is relatively straightforward to use, despite the fact that it requires a large amount of data input, and can be downloaded from the Internet at no cost.

Water quality in many of Minnesota's watersheds is continually monitored in order to assist in decision-making aimed at making improvements to impaired water bodies. However, data collection can be expensive, tedious and time consuming, thereby limiting the work of watershed managers. Predictive modeling has become an alternative approach to some of the limitations involved in traditional water quality monitoring. By combining gathered data, models generalize processes and estimate a net outcome, which can be beneficial for those limited by time and financial resources. Models for sediment yield provide valuable information for predicting future impacts of agricultural activities and for selection of appropriate soil conservation practices.

Although erosion is a natural process, a number of land use practices can result in significantly higher levels of soil loss. Agricultural lands generally experience a greater rate of erosion than that of land under natural vegetation. This is particularly true when tillage is used, as it reduces vegetative cover on the soil surface and disturbs both soil structure and plant roots that would otherwise hold soil in place. A great deal of research has gone into managing erosion – particularly within the agricultural sector. Sediment yield models currently in use include the Water Erosion Prediction Project (WEPP), Agricultural Non- point Source Pollution (AGNPS), Soil and Water Assessment Tool (SWAT) and Topographic Parameterization (TOPAZ). One of the most widely used soil loss models is the Universal Soil Loss Equation (USLE), which was modified in the 1980s and is now called the Revised Universal Soil Loss Equation (RUSLE).

The Universal Soil Loss Equation is the result of a multi-decade data collection and analysis effort initiated in the 1930s by the National Runoff and Soil Loss Data Center and culminating in Agriculture Handbook 537 (Wischmeier and Smith 1978). Developed from erosion plot and rainfall simulator experiments, the USLE is composed of six factors to predict the long-term average annual soil loss (A). The equation includes the rainfall erosivity factor (R), the soil erodibility factor (K), the topographic factors (S and L, slope and slope length, respectively) and the cropping management factors (C and P). The equation takes the product form: A = RKLSCP.

In 1992 a revised version of the USLE was released (the Revised Universal Soil Loss Equation, or RUSLE) to account for temporal changes in soil erodibility and plant factors that were not originally considered (Wischmeier and Smith 1978). As a computerized version of its predecessor, the RUSLE is a mathematical equation designed to make use of the database from which the USLE was derived. The RUSLE model allows users to estimate average annual soil loss for existing conditions and simulate how land use change, climate change, and/or changes in management practices will affect soil loss. Using the RUSLE model, it is possible to estimate soil loss for individual farm fields, river basins, or other appropriate area units. The RUSLE model output also allows users to determine the spatial pattern of soil loss, which enables the identification of critical areas within fields or catchments that are contributing major amounts of soil loss. In addition to its simplicity as an equation, parameter values representing the six USLE factors are widely available, which have added to its success in guiding conservation planning and assessments of sediment yield around the world.

In 2003, an upgrade to the text-based RUSLE was released as a computer model containing both empirical and process-based science in a Windows environment. Like its predecessors, RUSLE2 is used to predict the annual average rate of rill and interrill erosion for several alternative combinations of crop system and management practice. The major visible change in the RUSLE2 is a more modern and easy to use interface that is free for download from the Natural Resource Conservation Service website. The temporal scale used in RUSLE2 is also different from its predecessors in that daily soil loss values are calculated and subsequently added together to determine annual soil loss yields. As a stand-alone soil loss model, the RUSLE2 is a practical option for an organization like LSP working to identify alternative land use scenarios that can reduce erosion from farms. The RUSLE2 model was not appropriate for this research however, given the decision to work within the ArcGIS software platform as a way to incorporate more than one model under a singular platform. Should LSP wish to explore the use of the RUSLE2 for its Multiple Benefits of Agriculture Initiative, it will likely be a smooth transition from the RUSLE, as the input data needed are nearly all the same.

Use of the RUSLE model within GIS is made possible by the spatial format in which the RUSLE factors are presented and offers a spatially distributed approach, as the RUSLE factors are stored as data layers for modeling and spatial analysis. The RUSLE is represented by the simple equation: $A = R * K * LS * C * P$, where each factor represents the following (Institute of Water Resources, Michigan State University 2008):

- A: the predicted average annual soil loss from interrill (sheet) and rill erosion from rainfall and associated overland flow. Units for factor values are usually selected so that A is expressed in tons per acre per year, however for this practicum project A is expressed in tons per hectare per year.
- R: the rainfall-runoff erosivity factor. It is the average annual summation (EI) values in a normal year's rain. The erosion-index is a measure of the erosion force of specific rainfall. When other factors are constant, storm losses from rainfall are directly proportional to the product of the total kinetic energy of the storm (E) times its maximum 30-minute intensity (I). R factors represent the average storm EI values over a 22-year record. R is an indication of the two most important characteristics of a storm determining its erosivity: amount of rainfall and peak intensity sustained over an extended period. For this analysis, the R factor was set to 95 (NRCS Field Office Technical Guide 1996).
- K: the soil erodibility factor. K is a measure of the soil loss rate per erosion index unit for a specific soil as measured on a unit plot, defined as a 72.6 foot length of uniform 9 percent slope managed in continuous clean till fallow. The K factor represents both susceptibility of soil to erosion and the rate of runoff, as measured under the standard unit plot condition. Soils high in clay have low K values (about 0.05 to 0.15), because they are resistant to detachment. Coarse textured soils, such as sandy soils, have low K values (about 0.05 to 0.2), because of low runoff.

- L: the slope length factor, representing the effect of slope length on erosion. It is the ratio of soil loss from the field slope length to that from a 72.6-foot length on the same soil type and gradient. Slope length is the distance from the origin of overland flow along its flow path to the location of either concentrated flow or deposition. Fortunately, computed soil loss values are not especially sensitive to slope length and differences in slope length of + or – 10% are not important on most slopes, especially flat landscapes.
- S: the slope steepness, representing the effect of slope steepness on erosion. Soil loss increases more rapidly with slope steepness than it does with slope length. It is the ratio of soil loss from the field gradient to that from a 9 percent slope under otherwise identical conditions. The relation of soil loss to gradient is influenced by density of vegetative cover and soil particle size. Values of L and S are relative and represent how erodible the particular slope length and steepness is relative to the 72.6 ft long, 9 percent steep unit plot. Values of L and S are usually considered together and range from less than 1 to greater than 1.
- C: the cover-management factor. The C-factor is used to reflect the effect of cropping and management practices on erosion rates. It is the factor used most often to compare the relative impacts of management options on conservation plans. The C-factor indicates how the conservation plan will affect the average annual soil loss and how that soil-loss potential will be distributed in time during construction activities, crop rotations or other management schemes.
- P: the support practice factor. The P-factor reflects the impact of support practices on the average annual erosion rate. It is the ratio of soil loss with contouring and/or stripcropping to that with straight row farming up-and-down slope. Supporting practices include contour farming, cross-slope farming, buffer strips, strip cropping, and terraces.

Although computer models offer many advantages, it is also important to recognize that they are only descriptions of reality and error is inherent in their operation. Errors associated with models can be large depending upon their degree of simplification and quality of information about parameters in the system (Singh and Woolhiser 2002). With increased simplification, uncertainty associated with predicted outcomes is usually higher. Error and uncertainty associated with models also occurs as a result of imprecise measurement and inaccuracy during data collection, modification, and processing (Rae et al 2006). Transforming vector data to raster data during spatial analyses often results in the loss of information and can be identified through a direct comparison between the two data sets. Some of the error that results from data transformation can be diminished by performing spatial analysis at the finest resolution possible (Stokes and Morrison 2003 in Rae et al 2006). Mitigating error can also be accomplished by performing sensitivity analyses. Through this method, the geoprocessing strategy (conducting queries and transforming data are two examples) is varied and the results are compared across the scenarios in order to identify the effects of altering the methodology (Rae et al 2006).

CHAPTER 3: ALTERNATIVE AGRICULTURE SCENARIOS

In previous research conducted by LSP and its partners, four scenarios were developed and run using the ADAPT model as a basis for their environmental analysis in relation to conditions in 1999 (Boody et al 2005). I chose to create similar scenarios for my analysis, using the goals of each scenario as a guide. LSP used baseline landcover data from 1999. I used 2006 National Land Cover Data (NLCD) developed by the Multi-Resolution Land Characteristics Consortium (MRLC) for this analysis as it provided the most current landcover data. The scenarios that LSP developed were based on historical materials created by basin residents and on results from focus groups and interviews. Results from the focus groups provided direction on broad goals for production outcomes under different scenarios, representing a range of possible practices. The scenarios created for my analysis serve as a starting point for future analyses and are not exact replicates of the scenarios originally created by LSP. Should LSP wish to create additional scenarios, they can easily do this using the guidelines laid out in the appendix. The final scenarios were based on a continuation of current trends (Scenario A); best management practices, or BMPs (Scenario B); maximizing diversity and profitability (Scenario C); and increased vegetative cover (Scenario D).

3.1 METHODS

Each RUSLE factor was represented in ArcGIS by a grid (raster) coverage created from spatial and non-spatial data. The following sections detail each factor and how I derived values to apply to the GIS coverages. The reference units of all layers used in the RUSLE model have units in meters (SI).

Rainfall and runoff factor

The rainfall and runoff factor (R) represents the energy available to erode in units of MJ mm ha^{-1} h^{-1} y^{-1}. The Natural Resources Conservation Service (NRCS) Technical Guide (1996) provides a map of RUSLE rainfall factors for all counties in the state of Minnesota. The R factor value represents the average storm erosion index units in an average year's rainfall in (hundreds of foot·tons·inch)/(acre·hour·year). For Chippewa County, the average value 95 and for Swift County, the average value is 90. For this analysis, an R factor of 95 was chosen, since the majority of the study area falls within Chippewa County. A raster file was created in ArcGIS to represent the R factor. To convert from U.S. Customary units to SI units, a conversion factor of 17.02 was used (Renard et al. 1997). Thus, each cell in the final raster file has a value of 1617 (mega joule·millimeter)/(Hectare·hour·year).

Soil erodibility factor

The soil erodibility factor (K) is the soil's resistance to erosion by water in units of (ton·acre·hour)/(hundreds of acre·foot·ton·inch). The K factor values originated from estimates by the Natural Resources Conservation Service (NRCS), United States Department of Agriculture. The NRCS uses national standards to construct soil survey maps which have been digitized and are now available in an online Soil Survey Geographic (SSURGO) database. SSURGO data are available for individual states online at: http://soildatamart.nrcs.usda.gov/. Data for Chippewa and Swift counties were downloaded and modified for use in the RUSLE model. To convert from U.S. customary units to SI units, a conversion factor of 0.1317 was used (Renard et al. 1997). Each K factor value was multiplied by this conversion factor and subsequently multiplied by 10,000 in order to eliminate decimals for the RUSLE model input.

Slope length and slope steepness factor

The slope length factor (L) is a unitless representation of the topography of the study area. In its simplest form, it is the ratio of horizontal slope length to unit-plot slope length (22.13 m raised to a slope-dependent exponent). The slope steepness factor (S) is a unitless representation of slope. The standard slope steepness equation for the RUSLE model is based on data from slopes 0.1-18% (Rendard et al. 1997). For this analysis, the L and S factors were developed using the SSURGO soil data, which were downloaded and modified to develop the K factor. In addition to containing K factor values, the database contains slope length and slope steepness factors for soil survey areas.

Support practice factor

The support practice factor (P) is a unitless representation of agricultural practices. It reflects the effects of practices that will reduce the amount and rate of water runoff and thus reduce the amount of erosion. The P factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. Commonly used supporting cropland practices include cross-slope cultivation, contour farming and strip-cropping. P factor values were not used for this analysis because they can vary significantly across individual farm fields. A P factor value of 1.00 represents no land use influence. Should LSP wish to incorporate P factor values for individual farm fields or generalize them over a larger area, they can easily do so using the tools in ArcGIS.

Cover management factor

The cover management factor (C) is a unitless representation of the cover characteristics. The C factor is used to reflect the effect of cropping and management practices on erosion rates. It is the factor used most often to compare the relative impacts of management options on conservation plans. The C factor indicates how the conservation plan will affect the average annual soil loss and how that soil-loss potential will be distributed in time during construction activities, crop rotations or other management schemes. The C factor is based on the concept of deviation from a standard, in this case an area under clean-tilled continuous-fallow conditions. For example, if a C factor of 0.15 represents the specified cropping management system, it signifies that the erosion will be reduced to 15 percent of the amount that would have occurred under continuous fallow conditions. RUSLE uses a subfactor method to compute soil loss ratios, which are the ratios at any given time in a cover management sequence to soil loss from the unit plot. Soil loss ratios vary with time as canopy, ground cover, roughness, soil biomass and consolidation change. The subfactors used to compute a soil loss ratio values are canopy, surface cover, surface roughness, prior land use and antecedent soil moisture. Because the approach for this analysis was more general, subfactors for soil loss were not calculated. LSP included a small-grains (conventional tillage) land use in their baseline and in scenario A. This class was eliminated for ease of use, since it is not present in the NLCD 2006 baseline data and because LSP reduced acreage in this land cover to 0 in all other scenarios.

C factors used in this analysis came from several sources (Table 1) and where possible, from sources specific to agricultural practices in Minnesota (NRCS RUSLE Technical Guide). Although the C factors used in this analysis were not calculated based on field measurements in the study area, they are intended to serve as a tool to help LSP weight the merits of different crop and cover systems based on predictions of soil erosion under each scenario. As part of the generalized C factors used in this analysis, a number of assumptions were also made. These assumptions were based on information from the literature for each C factor and are listed in Table 1 along with the source. C factors used in this analysis range from 0 (for streams and open water) to 0.6 (for corn under spring mulch with 10% cover). Prior to running the model, each C factor value was multiplied by 10,000 in order to eliminate decimals for the RUSLE model input.

Table 1: C factors used for individual land cover layers in scenario A, B, C, and D

Class	Definition (NLCD or other sources)	C Factor	Source	Assumptions
Open Water	Areas of open water, generally with less than 25% cover of vegetation or soil.	0	Bartsch et al. 2002	No soil is exposed in this class
Streams	Areas of open water, generally with less than 25% cover of vegetation or soil.	0	Bartsch et al. 2002	No soil is exposed in this class
Developed, Open Space	Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover.	0.003	Wischmeir and Smith, 1978	Brush or bushes with average dropfall height of 6 ft; 75% veg. cover; 80% ground cover
Developed, Low Intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of cover.	0	Bartsch et al. 2002	No soil is exposed in this class
Developed, Medium Intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover.	0	Bartsch et al. 2002	No soil is exposed in this class
Developed, High Intensity	Highly developed areas where people reside or work in high numbers. Impervious surfaces account for 80% to 100% of cover.	0	Bartsch et al. 2002	No soil is exposed in this class
Barren Land	Areas of bedrock, desert pavement, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Vegetation accounts for less than 15% of total cover.	0.3	Bartsch et al. 2002; Wischmeir and Smith, 1978	No appreciable canopy; less than 25% cover; between 0-25% ground cover
Deciduous Forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.	0.002	Wischmeir and Smith, 1978	75-100% of area covered by canopy of trees and undergrowth
Corn-soybeans (CN)		0.6	RUSLE Technical Guide, MN NRCS, 1997	Spring mulch tillage; little to no cover
Corn-soybeans (CN)		0.24*	RUSLE Technical Guide, MN NRCS, 1997	Spring mulch tillage; 90% cover
Corn-soybeans (CN)		0.45	RUSLE Technical Guide, MN NRCS, 1997	Spring mulch tillage; 50% cover
Corn-soybeans (CN)		0.6*	RUSLE Technical Guide, MN NRCS, 1997	Spring mulch tillage; 10% cover
Corn-sugar beets (CN)		0.6	RUSLE Technical Guide, MN NRCS, 1997	Spring mulch tillage; little to no cover
Small grains-alfalfa (CT)	Barley, oats, rye, spring wheat, winter wheat.	0.15	RUSLE Technical Guide, MN NRCS, 1997	Spring mulch tillage
Row crops planted with cover crops	Common cover crops in Minnesota include rye and other small grains, buckwheat and hairy vetch.	0.1; 0.2; 0.3**	RUSLE Technical Guide, MN NRCS, 1997	
Pasture/Hay	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops. Pasture/hay vegetation accounts for greater than 20% of total vegetation	0.05	Bartsch et al. 2002; Wischmeir and Smith, 1978	
Grassland/Herbaceous	Areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. Areas are not subject to intensive management such as tilling, but can be utilized for grazing.	0.005	Renard et al., 1997; Wischmeir and Smith, 1978	
Riparian buffer	Native grasses (switchgrass, prairie plants, etc).	0.005	Renard et al., 1997; Wischmeir and Smith, 1978	
CREP Riparian	Native vegetation along stream banks.	0.001	Renard et al., 1997; Wischmeir and Smith, 1978	

Class	Definition (NLCD or other sources)	C Factor	Source	Assumptions
CREP Wetland Reserve	Wetland areas.	0.001	Renard et al., 1997; Wischmeir and Smith, 1978	
Permanent Wetland Reserve	Wetland areas.	0.001	Renard et al., 1997; Wischmeir and Smith, 1978	
Woody wetlands	Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water	0.001	Renard et al., 1997; Wischmeir and Smith, 1978	
Emergent herbaceous wetlands	Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	0.001	Renard et al., 1997; Wischmeir and Smith, 1978	

* For the corn-soybean land use class, a C factor value of 0.4 was used for the four scenarios. Each scenario was also run using C factors of 0.24 and 0.6 for the corn-soybean class to reflect varying amounts of cover under spring mulch tillage.

**Scenario D is the only scenario in which cover crops were added. This class was modified to reflect varying levels of cover. Scenario D was also run using C factors of 0.2 and 0.3 for the cover crop class.

The NLCD 2006 landcover data used for this analysis contained only one agriculture class (cultivated crops). For the scenario development, I added the agricultural classes that LSP used in their study by overlaying the various classes with the NLCD layer. Added classes included corn-soybeans under conservation tillage, corn-soybeans under conventional tillage, corn-sugar beets under conventional tillage, and small grains-alfalfa under conservation tillage, a riparian buffer (Scenarios B, C, and D) and cover crops (Scenario D), which was reflected in a change in C factor value for agricultural areas planted with cover crops rather than the addition of cells in this scenario. I used LSP's rationale as a basis for generating the amount of each class (in hectares), although amounts are not exact replicates of those used in LSP's study (Table 2). There was no overlay disagreement between the cultivated crop class in the NLCD layer and the added classes. Details for how the land cover maps and RUSLE parameters were generated for each scenario are provided in the Appendix.

Finally, lands falling within the Minnesota Conservation Reserve Enhancement Program (CREP) were also added by overlaying with the NLCD layer. These areas are a part of a federal-state natural resource conservation program that works to meet state environmental objectives and to protect environmentally sensitive land throughout the state. Under CREP, program participants voluntarily enroll certain practices in the USDA's Farm Service Agency (FSA) Conservation Reserve Program (CRP) and the Minnesota Re-invest in Minnesota (RIM) program. Under the CREP, participants receive financial incentives for both the CRP and RIM contracts for removing cropland from agricultural production and converting the land to native grasses, trees, and other native vegetation. Coverages for these areas were downloaded from the Board of Soil and Water Resources website and incorporated into the baseline landcover layer, which was used as the foundation for all scenarios.

Table 2. Land use, in hectares, in the Chippewa River study area under the baseline (NLCD 2006) and scenario A (continuation of current practices), scenario B (best management practices), scenario C (high diversity and profitability), and Scenario D (increased vegetative cover).

Land use	**Baseline**	**Scenario A**	**Scenario B**	**Scenario C**	**Scenario D**
Streams	216	216	216	216	216
Marginal Cropland	9	9	9	9	9
CREP Riparian	182	182	182	182	182
CREP Wetland Reserve	452	452	452	452	452
Permanent Wetland Reserve	20	20	20	20	20
Open Water	86	86	86	86	86
Developed, Open Space	806	806	806	806	806
Developed, Low Intensity	229	229	229	229	229
Developed, Medium Intensity	62	62	62	62	62
Developed, High Intensity	24	24	24	24	24
Barren Land	23	23	23	23	23
Deciduous Forest	286	286	286	286	286
Grassland/Herbaceous	470	470	470	470	2470
Pasture/Hay	613	613	613	613	613
Cultivated Crops (Corn-soybeans CT)	10669	5040	8955	3600	1800
Woody wetlands	217	217	217	217	217
Emergent herbaceous wetlands	1383	1383	1383	1609	1609
Corn-soybeans (CN)	NA	4509	0	0	0
Corn-sugar beets (CN)	NA	1120	1000	680	1800
Small grains-alfalfa (CT)	NA	0	426	5876	4000
Riparian buffer	0	0	286	286	842
Cover crops	0	0	0	0	3600*

CT = conservation tillage; CN = conventional tillage

*Hectares planted with cover crops includes corn-soybeans (CT) and corn-sugar beets (CN)

3.2 SCENARIO A: PROJECTION OF CURRENT TRENDS

Scenario A is based on current trends and projects an increase in acreage for corn, soybeans, and sugar beets from the baseline. Scenario A does not include the application of best management practices and includes 5,040 hectares of corn-soybean planted under conservation tillage, 4,509 hectares of corn-soybean planted under conventional tillage. The remaining area under cultivation includes 1,120 hectares of corn-sugar beets planted under conventional tillage.

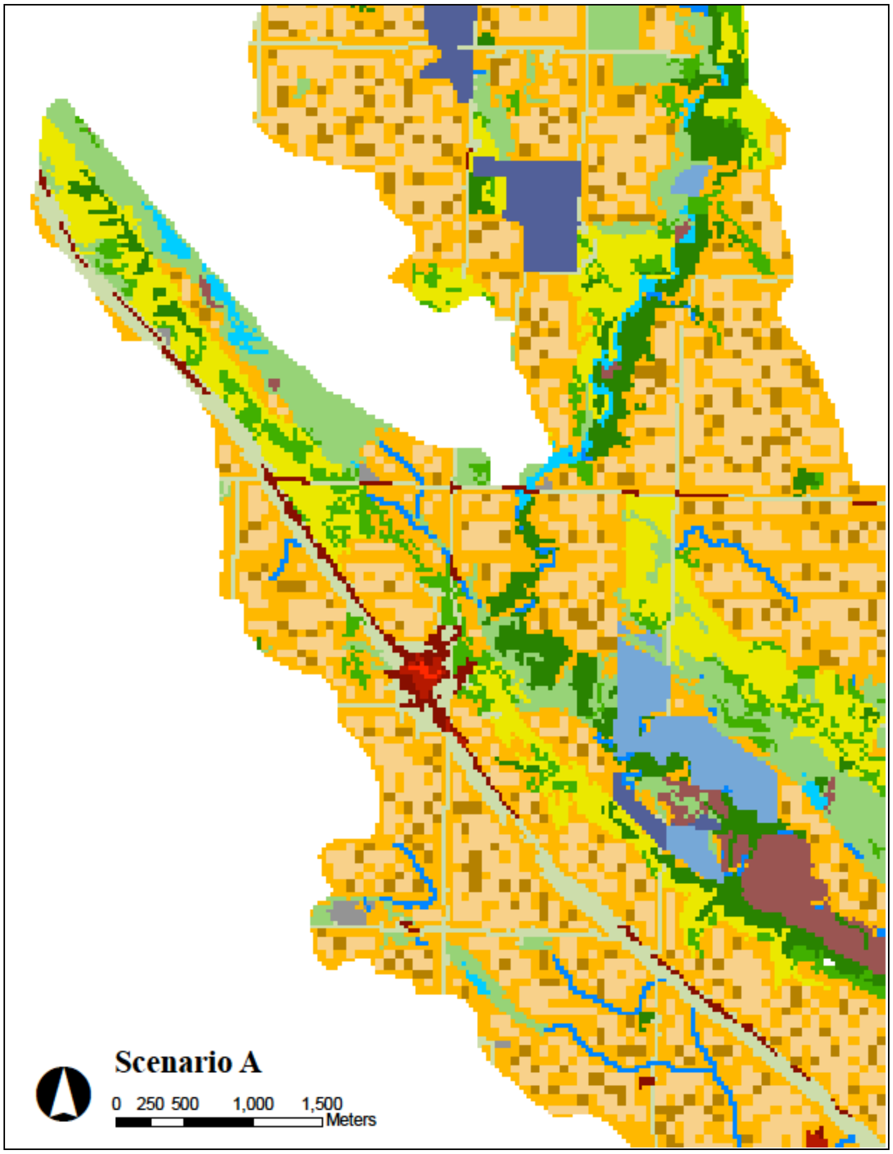


Figure 2: A subset of the Chippewa River study area under Scenario A.

3.3 SCENARIO B: BEST MANAGEMENT PRACTICES

Scenario B is based on best management practices and includes the addition of a 30 meter buffer along streams in agricultural areas, and a reduction of crops under conventional tillage. In this scenario, all corn-soybean rotations are planted under conservation till (8,955 hectares). The area for corn-sugar beets is reduced slightly to 1,000 hectares. Finally, 426 hectares are planted with small grains-alfalfa under conservation till.

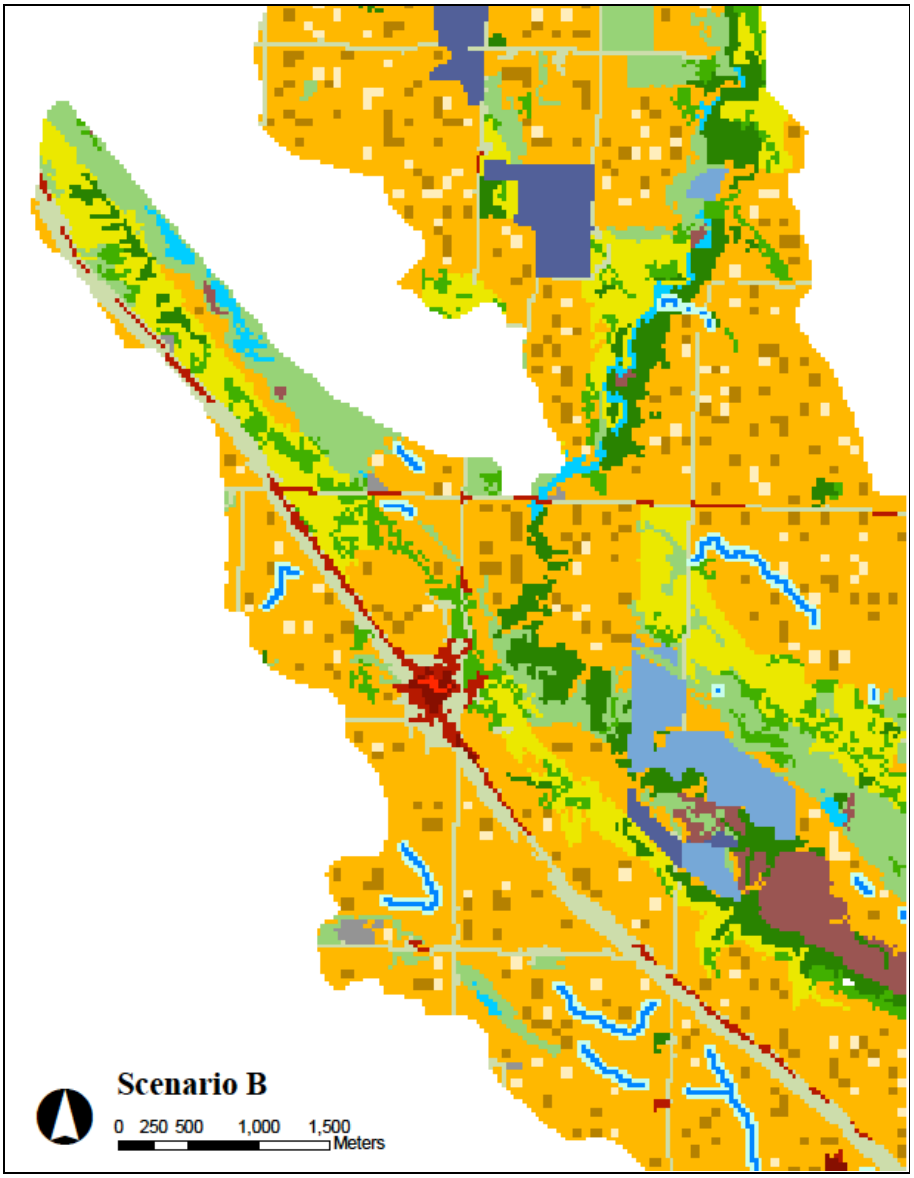


Figure 3: A subset of the Chippewa River study area under Scenario B.

3.4 SCENARIO C: HIGH DIVERSITY AND PROFITABILITY

Scenario C is based on high diversity and profitability with a focus on increased farm profitability to move beyond best management practices. In addition to the changes under Scenario B, Scenario C also included wetland restoration and an increase in small grains and alfalfa with a reduction in area under corn-soybean and corn-sugar beet rotations. In this scenario, the area planted under corn-soybeans (conservation tillage) is reduced to 3,600 hectares and the area planted under corn-sugar beets is reduced to 680 hectares. The area planted under small grains-alfalfa increased in this scenario to 5,876 hectares. LSP's baseline had 154 hectares of wetlands, while the baseline developed for this analysis had 1,600 hectares of wetlands (not including wetlands in the CREP program). For LSP's analysis, 1,200 hectares of wetlands were restored in Scenario C. Because such a large area was already taken up by wetlands in the baseline developed from NLCD data, only 226 hectares of wetlands were restored in Scenario C.

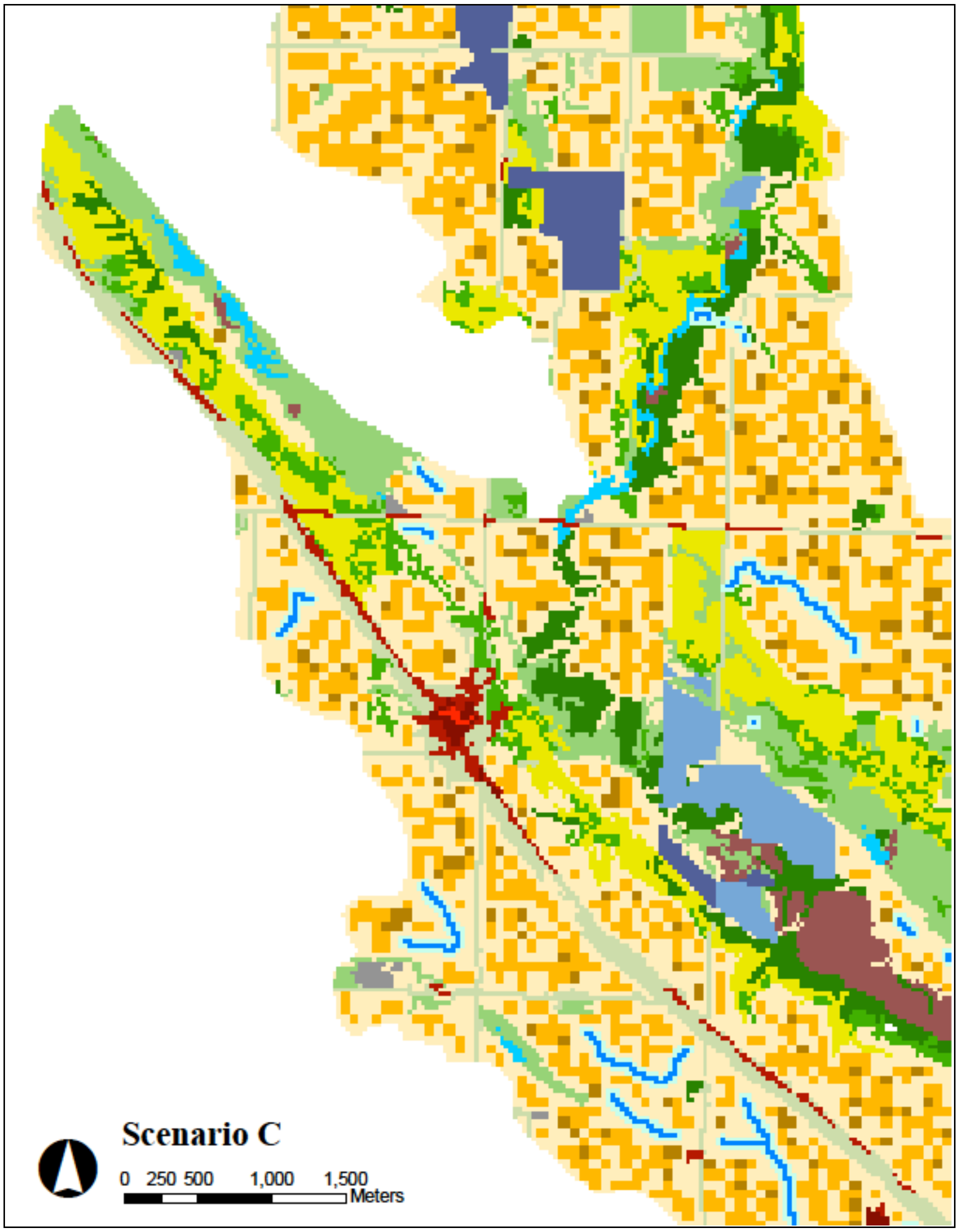


Figure 4: A subset of the Chippewa River study area under Scenario C.

3.5 SCENARIO D: INCREASED VEGEATIVE COVER & BIODIVERSITY

Scenario D is based on increased vegetative cover and wetland restoration for biodiversity conservation. This scenario extends Scenario C by adding perennial cover; grasslands replacing cultivated lands over a large area. Riparian buffers that were also widened to 90 m, and all row crops were planted with cover crops. In this scenario, corn-soybeans (conservation tillage) and corn-sugar beets (conventional tillage) make up 1,800 hectares each, whereas small grains-alfalfa makes up 4,000 hectares of cultivated areas. Grassland areas total 2,470 hectares in this scenario and the riparian buffer makes up 842 hectares.

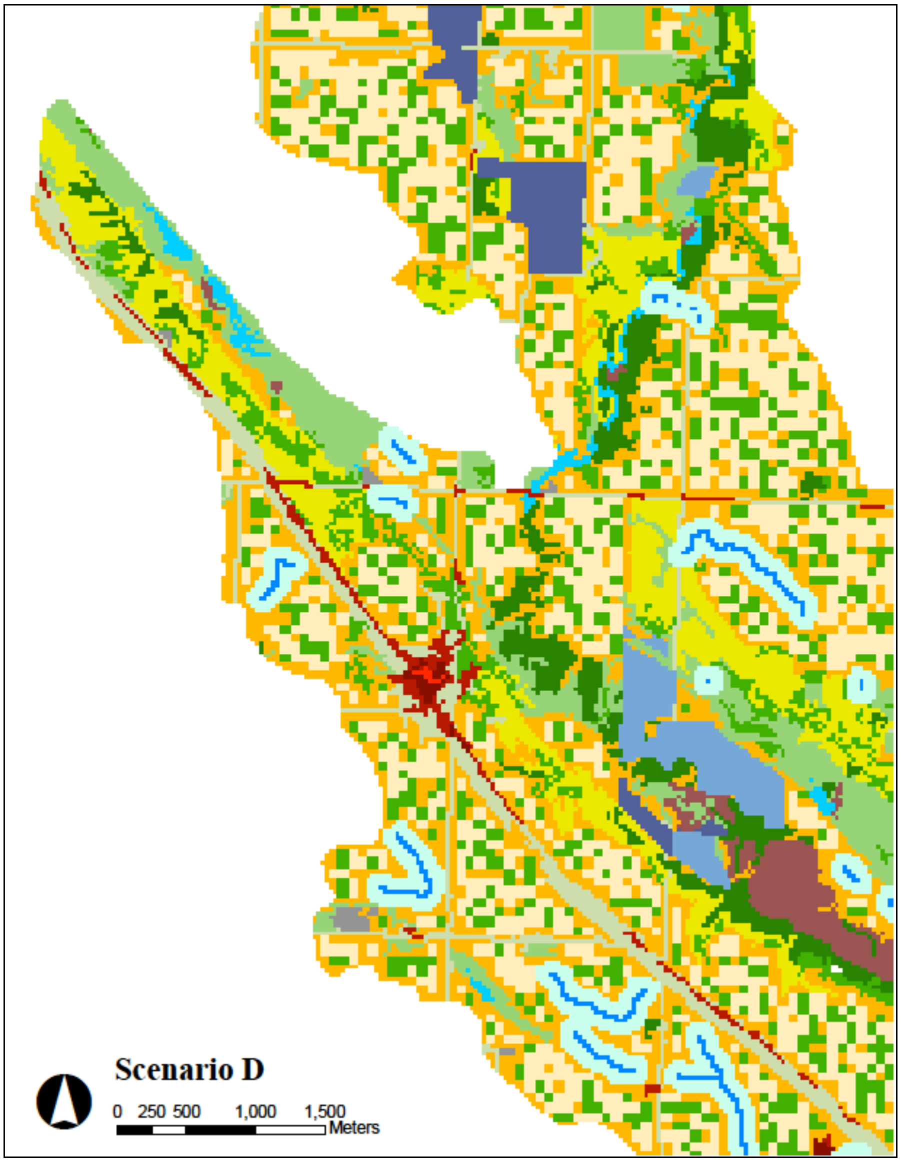


Figure 5: A subset of the Chippewa River study area under Scenario D.

3.6 RUNNING THE RUSLE MODEL

To determine soil erosion output for the Chippewa River study area, a mathematical calculation is performed using the Raster Calculator in ArcGIS, in which each factor layer (R, K, LS, and C) are multiplied. The result is a floating point (decimal) raster grid file, which predicts soil loss on for each cell. Various display and Spatial Analyst (an extension of ArcGIS) tools can be used to extract relevant information from the resulting erosion layer. Because cell values in two of the factor layers created for the model (C and K) were multiplied by 10,000 to eliminate decimal values prior to running the model, all of the resulting erosion values were divided by 100,000,000 to reflect their real values. To convert from tons/hectare/year/cell, each layer was transformed using Raster Calculator. First, each layer was multiplied by 0.09 (the area in hectares of each cell). Layers were then divided by the total number of cells in the study area to eliminate the per cell unit. Finally, the layers were multiplied by 11.11 (10,000 m^2/900 m^2) to scale the data to tons/hectare/year.

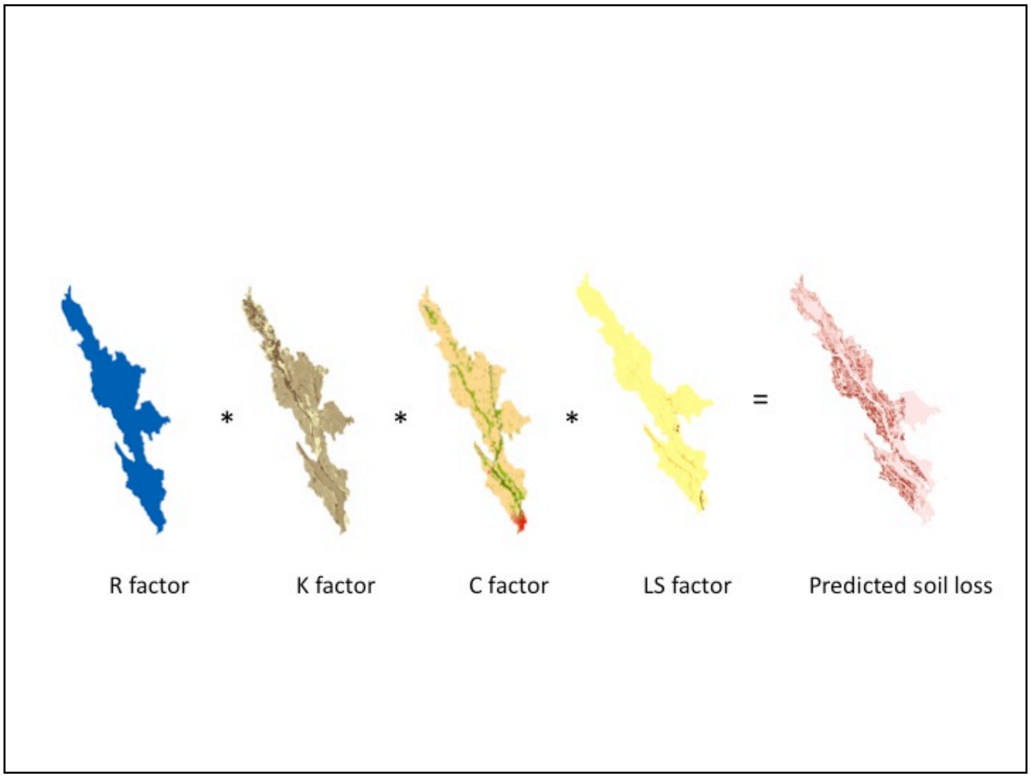


Figure 6: Graphic representation of the RUSLE model.

Ideally all model inputs would be altered systematically to test their sensitivity to variation in each factor and to deal with the inherent uncertainty in using values from the literature rather than from field measurements. Given the large number of land use classes in each scenario and the number of scenarios developed for this project, this is not feasible. As a minimal test of sensitivity, the model was run again for each scenario after varying the C factor value for the corn-soybean (conservation tillage) class to reflect varying amounts of cover (Table 3). This agricultural class was chosen for variation because a significant amount of land is taken up by this class in each scenario. This class also represents a significant area of interest for farmers and LSP and is one land use that can be varied on the ground in order to reduce erosion from farm fields. I expected that with an increase in C factor value, predicted soil erosion would also increase.

Table 3: Variation of C factors for each scenario

C Factor	Cover
0.24	90%
0.45	50%
0.60	10%

The model was also run again for the cover crop class in Scenario D. In this scenario, the corn-soybean (conservation tillage) and corn-sugar beet (conventional tillage) classes are planted with cover crops. The amount and type of cover crop used by farmers varies considerably. Varying the C factor value for this class is an attempt to deal with the uncertainty of using values from the literature rather than determining C factors on the ground. The model was run for Scenario D with a C factor value of 0.1, 0.2, and 0.3 for the cover crop class (which includes corn-soybean (conservation tillage) and corn-sugar beets (conventional tillage)). I then compared the erosion rates calculated under each scenario and each of these varied parameter settings to evaluate the effects of the scenarios on soil loss and the sensitivity of the model to uncertainty.

CHAPTER 4: RESULTS AND DISCUSSION

Results from the RUSLE model indicate that increasing agricultural lands under conservation tillage, planting cover crops in cultivated areas, increasing the area under grassland, adding vegetated buffers along streams, and restoring wetlands resulted in the most dramatic decrease in erosion in the Chippewa River study area (Figure 7). Compared to Scenario A (C = 0.45) predicted soil loss decreased from 6.4 tons/year to 3.15 tons/year in Scenario C, a 51% decrease in soil loss for the study area (Table 4). Further decreases in predicted soil loss were shown in Scenario D, which included the planting of cover crops for the corn-soybean (conservation tillage) and corn-sugar beet (conventional tillage) land use. A C factor of 0.1 for the corn-soybean/corn-sugar beet class resulted in the most dramatic decrease in predicted soil loss (1.21 tons/year) as compared to Scenarios A (6.4 tons/year), B (5.38 tons/year), and C (3.15 tons/year), Figure 7. Maintaining a C factor of 0.3 for the cover crop class in Scenario D also resulted in a decrease in overall predicted soil loss as compared to Scenarios A, B, and C. This may be important for farmers, as a smaller amount of cover could be planted to achieve a similar decrease in soil loss.

As expected, decreasing the C factor for each scenario resulted in a decreasing trend in potential soil erosion across all scenarios. Within scenarios, changing the C factor resulted in quite dramatic decreases in predicted soil loss, particularly in Scenarios A and B (Figure 7). A significant portion of each of these landscapes is made up of cultivated areas, and thus, a change in cover from 10% (C = 0.6) to 90% (C = 0.24) is a clear reflection of such a dramatic shift in cover. In general, total predicted soil loss (tons/year) for the study area decreased after the changes made in Scenario C (Figures 7, 8 and 9). This was likely due to wetland restoration and an increase in small grains-alfalfa under conservation tillage, with significantly reduced the area under corn-soybeans and corn-sugar beets.

Figure 7: Predicted soil loss (tons/yr) under four scenarios in the Chippewa River study area, MN.

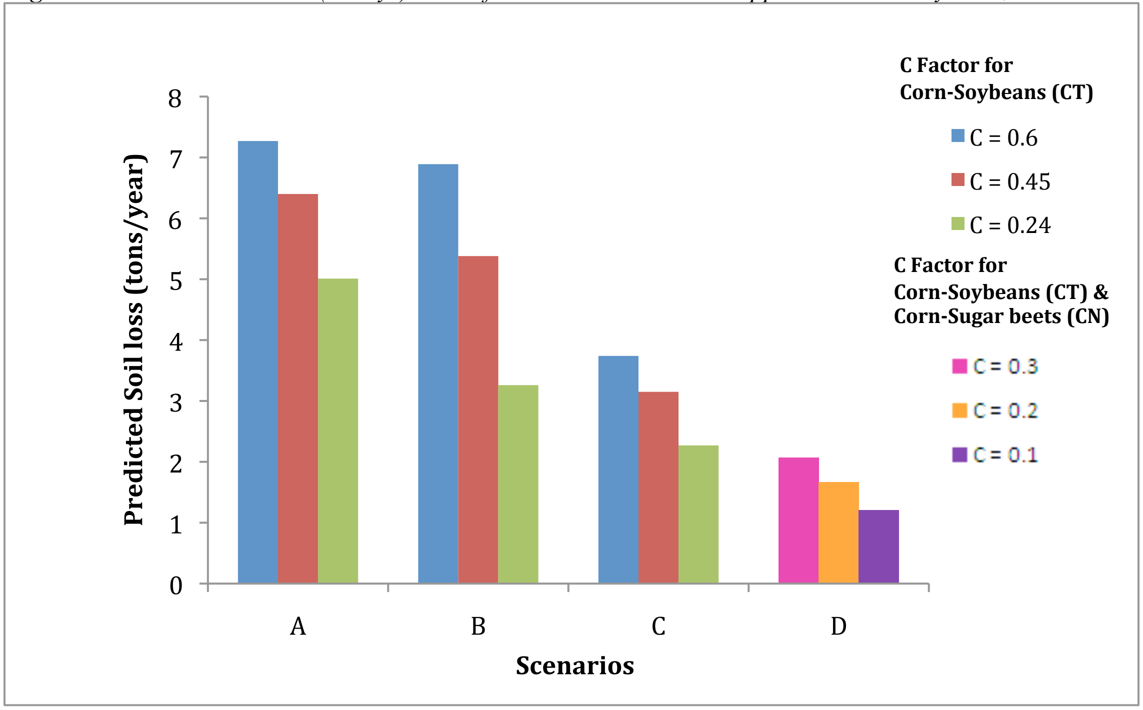
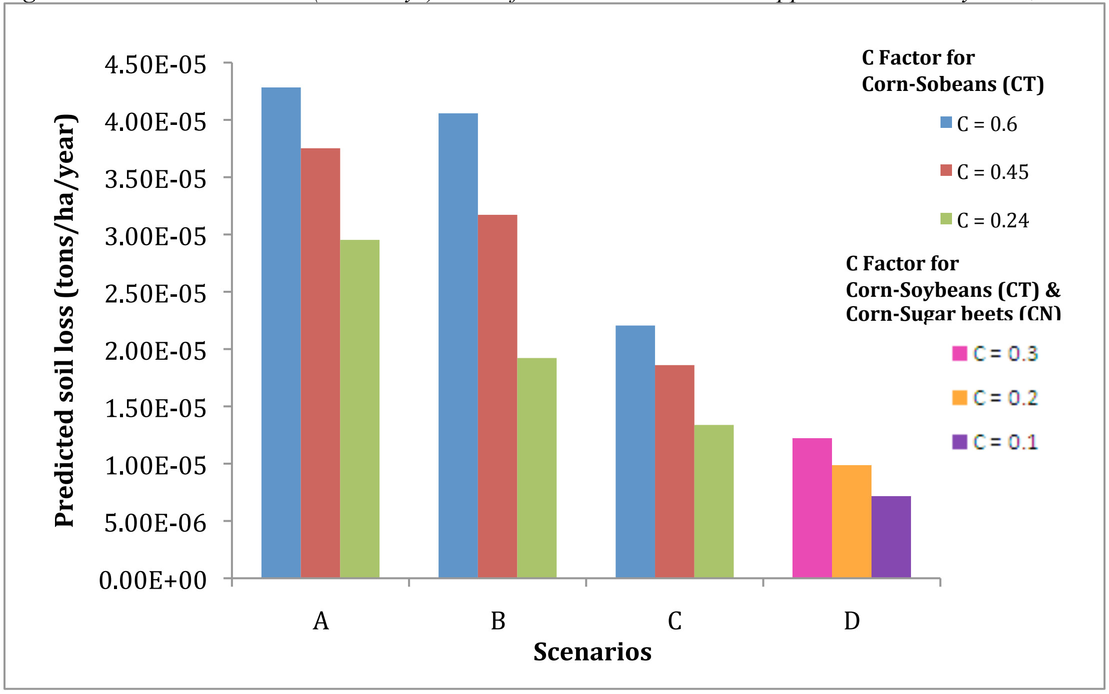


Table 4. Percent change in predicted soil loss in the Chippewa River study area under scenario A (continuation of current practices), scenario B (best management practices), scenario C (high diversity and profitability), and Scenario D (increased vegetative cover).

	Scenario A (Baseline)	**Scenario B**	**Scenario C**	**Scenario D**
Soil Loss (tons/year)	6.4	-16	-51	-81

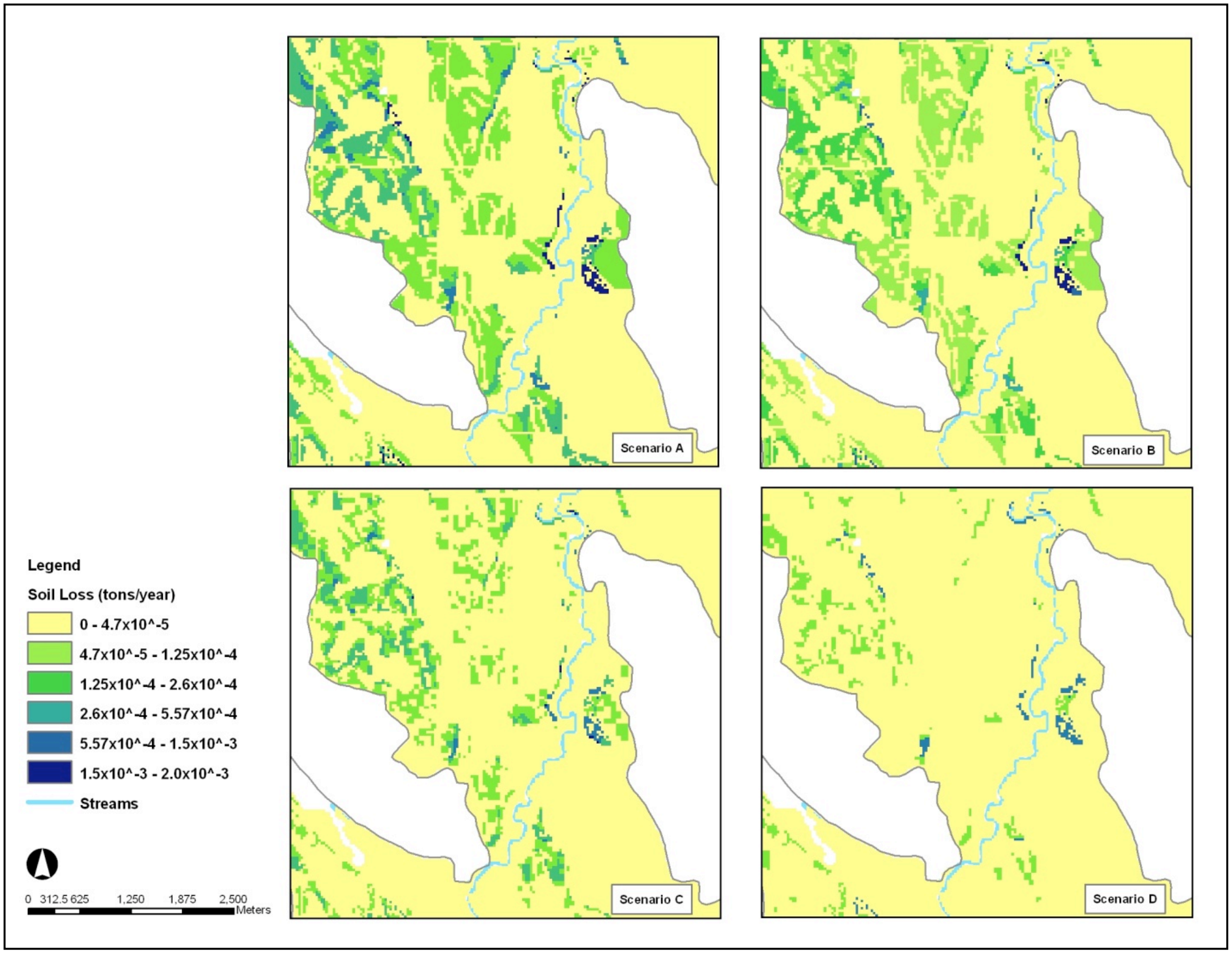
On a per hectare basis, predicted soil loss for the Chippewa River study area followed a similar trend as that for the entire study area. Predicted soil loss decreased from 3.7 x 10^{-5} tons/ha/year in Scenario A to 3.17 x 10^{-5} tons/ha/year in Scenario B, 1.8 x 10^{-4} tons/ha/year in scenario C (C = 0.45) and 9.8 x 10^{-6} tons/ha/year in Scenario D (Figure 8). The reduction in predicted soil loss across scenarios was a result of decreasing C factor values and increasing the area under conservation tillage and crops planted with cover. Predicted soil loss is quite small on a per hectare basis; however given the size of the study area it is easy to see how the cumulative effects of erosion have created a significant number of negative economic and environmental externalities.

Figure 8: Predicted soil loss (tons/ha/yr) under four scenarios in the Chippewa River study area, MN



Results also show that potential soil loss is typically greatest along the steeper sloped banks of streams. In these areas, the LS factor ranges between 2.5 and 9.5. Other “hot spots” of high erosion potential are dispersed throughout the study area and are associated with agricultural land use and areas with silt-clay loam soils, which are generally more susceptible to detachment (Wischmeir and Smith 1978). These areas of high predicted erosion can be seen in Figure 9 (dark blue areas). These maps also show the subsequent reduction in predicted soil loss from Scenario A to Scenario D. Yellow areas depict very low predicted erosion (none in many areas), while light green depicts slightly higher amounts of predicted soil loss in these areas.

Figure 9: Maps depicting a portion of the Chippewa River study area under four scenarios (A, B, C, and D), MN.



4.1 LIMITATIONS OF THE RUSLE MODEL WITHIN ARCGIS

Any analysis performed with a model and at a coarse scale provides a poor substitute for actual measurements. The application of RUSLE within GIS is no exception. However, there are few options other than models when making assessments and predictions of erosion potential, particularly at coarse scales like the Chippewa River study area. The inherent error involved in these types of analyses must be taken into account, especially with the real world applications of results. The main source of error in soil loss for this study is likely from C factor values that were estimated from the literature. Error from C factor values could be reduced by estimating C factor values directly from agricultural fields in the Chippewa River study area, taking into account C value subfactors, which are a function of disturbance, belowground biomass, canopy cover, canopy height, surface cover, and surface roughness. Soil loss estimates are therefore likely overestimates, and decisions made based on the results from this research project should account for that.

An additional limiting factor in the approach presented here is that the front end, or data preparation is time consuming and somewhat tedious. A particular user would not need a significant amount of training in ArcGIS to conduct a similar analysis, but it would likely be time consuming to develop and prepare the data layers. That said, once the data preparation is complete and data layers are ready for the model, it is very easy to run the model and subsequently modify the data layers as needed. Because numeric values are used to represent the cover management factors, adjusting these are quite simple. Editing the area or spatial arrangement of different land use classes can be a more involved process, but with experience, these modifications become much easier. The manual developed as part of this project is intended to guide users through the process of data preparation, scenario development, and running the model, and although quite detailed, provides users with all of the necessary information needed to implement the RUSLE model in ArcGIS.

The RUSLE modeling approach presented here could be improved to better meet LSP's needs with the development of a toolbar in ArcGIS that contains all necessary tools and directions to run the RUSLE model. Such a toolbar was originally intended as part of this project, however it became incredibly cumbersome to develop as it requires detailed knowledge of programming code and it was eventually eliminated from the project.

Should LSP wish to improve the accuracy of model outputs, the organization could implement a field data collection program to gather real-time information about farms, management practices, and crops being grown. This data could then be digitized into raster layers within ArcGIS, and run using the RUSLE model to provide more accurate results of predicted erosion. This option may not be possible for LSP, but could be carried out with the help of a dedicated group of volunteers or interns.

4.2 ADVANTAGES OF THE RUSLE MODEL WITHIN ARCGIS

By simulating management and land use practices on the ground, the RUSLE model within the ArcGIS platform will allow LSP to assess the effects of alternative management practices. LSP, its members, farmers and other researchers can use this tool to make general predictions about the effects of various scenarios and management techniques on soil loss. Although the results from the model are not exact measures of soil loss, they do provide information on areas more susceptible to erosion under different management scenarios. This information will allow LSP and its partners to weigh the costs and benefits of implementing different management actions. This is a key component for LSP as the Multiple Benefits of Agriculture program is largely a collaborative process between LSP members, farmers, and other stakeholders.

Using the RUSLE model within the ArcGIS platform is also particularly useful for LSP's efforts to communicate with its members, the public, and decision-makers about the effects of various management options on soil loss both within the Chippewa River Watershed and in any other area where data are available. Through the use of ArcGIS, LSP can develop erosion risk maps by grouping soil loss estimates into classes (as in Figure 9 above). These classes can be further simplified to levels of soil loss sensitivity. Erosion risk maps can be used by LSP as visual aids online, in publications, and can be developed for specific farms with appropriate data layers and information. LSP could use erosion risk maps to target key areas for various management strategies and as an aid to farmers the organization may be working with. Visual representations of erosion sensitivity under different scenarios may be more easily interpreted by those without a background in modeling or GIS (arguably a significant portion of LSP's members and stakeholders in the Multiple Benefits of Agriculture program).

LSP and its members work to develop strategies and tools for sustainable agricultural practices in Minnesota and throughout the U.S. Limited resources and staff requires that LSP focus its efforts to meet these goals. Modeling alternative agriculture scenarios using RUSLE within ArcGIS provides LSP with the tools to work at multiple scales without the need for increased staff, funding, or field data collection. ArcGIS and the RUSLE model are useful and relevant tools for an organization like LSP. The application of these tools would enhance LSP's work to not only reduce soil loss from farm fields but to identify and enhance various environmental and economic benefits from agriculture.

Overall, the use of RUSLE within ArcGIS is an appropriate strategy for LSP's work to identify erosion potential in agricultural areas. Beyond modeling soil loss, LSP can use ArcGIS to identify and prioritize areas for monitoring, restoration, and for education and outreach programs. Although there are some limitations to using RUSLE and ArcGIS, the benefits outweigh the costs for LSP, particularly given the fact that the cost of a single use license is $100 annually, all other data will likely be free, and once data preparation is complete, the process of modifying the various scenarios is straightforward.

4.3 IMPLEMENTATION OF THE RUSLE MODEL AND ARCGIS

The steps necessary to implement the RUSLE model tool and ArcGIS into an operational mode within LSP would be very simple. If LSP has not already done so, it must purchase and install an ArcGIS 9.3 single use license and Microsoft Office 2007. All data used for the Chippewa River Watershed are stored on an external hard drive and can be transferred to LSP in person or electronically at any time. Guidelines for developing a useful an efficient file management system are included in the manual, as are all directions necessary to prepare data, develop the scenarios, and run the model. The manual can be used again for the Chippewa River Watershed or for any other area where necessary data are available.

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APPENDIX

Modeling with RUSLE and GIS Project Manual

Elena Doucet-Bëer
December 2011

This manual was developed for the Land Stewardship Project and can be used for any area where necessary data are available.

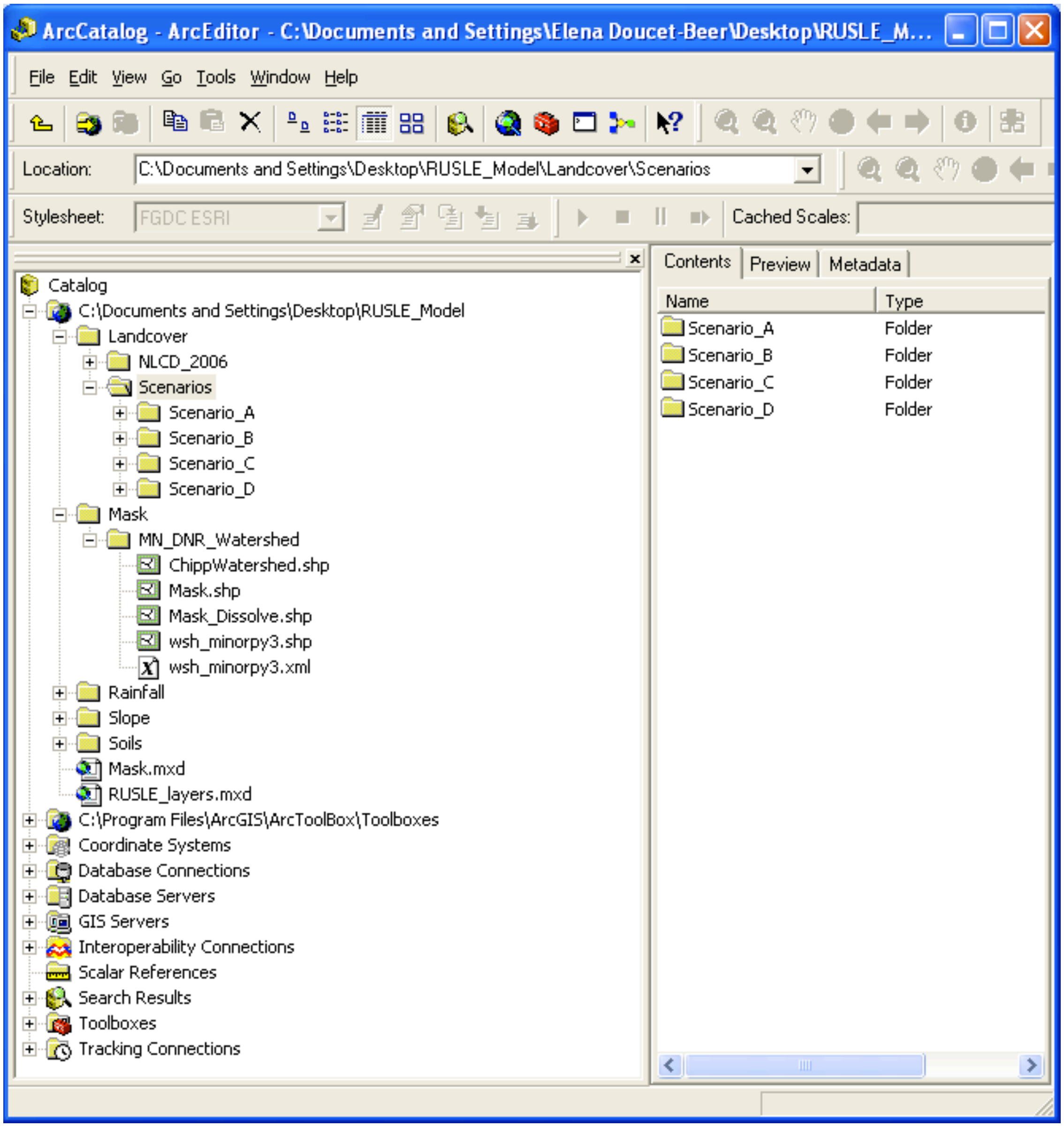
Written for the following software:

- ArcGIS 9.3
- Microsoft Office 2007 (Access)

TABLE OF CONTENTS

File Management

Processing data for the RUSLE model requires a number of different steps. Keeping data files organized is an important component for efficient and effective processing. It is recommended that individual folders be created to hold files for each of the RUSLE factors. The diagram below illustrates the file structure used for this project.



Location: C:\Documents and Settings\Desktop\RUSLE_Model\Landcover\Scenarios

Stylesheet: FGDC ESRI

Cached Scales:

Name	Type
Scenario_A	Folder
Scenario_B	Folder
Scenario_C	Folder
Scenario_D	Folder

1. In the ArcCatalog project directory, create a folder for each of the main components of the RUSLE model: **Landcover**, **Rainfall**, **Slope**, and **Soils**.
2. Within the landcover folder, create a subfolder called **Scenarios**. Within this subfolder, create four subfolders: **Scenario_A**, **Scenario_B**, **Scenario_C**, and **Scenario_D**.
3. In the main directory, create a folder for the mask layer and associated files called **Mask**.

Data Preparation

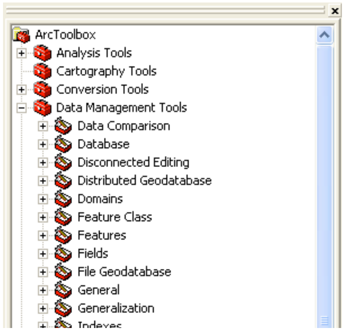
Step 1: Create Mask

The mask layer is created using data from the watershed of interest. It is used to "clip" other data layers used in the model so that all data layers represent the same geographic extent. There are a number of watershed data layer options available from the Minnesota DNR Data Deli website's Hydrography dataset: http://deli.dnr.state.mn.us/index.html. The best choice will depend on the geographic area to be studied. The Data Deli hosts both major (large watershed administrative units) and minor (small watershed administrative unites) datasets. For the purposes of this research project, minor watershed data were used.

1. After choosing the study region/watershed(s), download the data from the MN DNR Data Deli website. Download the data to the **Mask** folder in the RUSLE project directory.

2. If the watershed data's projection is undefined, it's a good idea to correct this prior to creating the mask layer. The projection should be defined as the same projection that the data were provided in. To define a projection for the watershed data layer of interest:

    a. Open a new ArcMap session and add the watershed data layer to the map.
    b. Using ArcToolbox, navigate to **Data Management**, then **Projections and Transformations,** and finally, **Define Projection**.



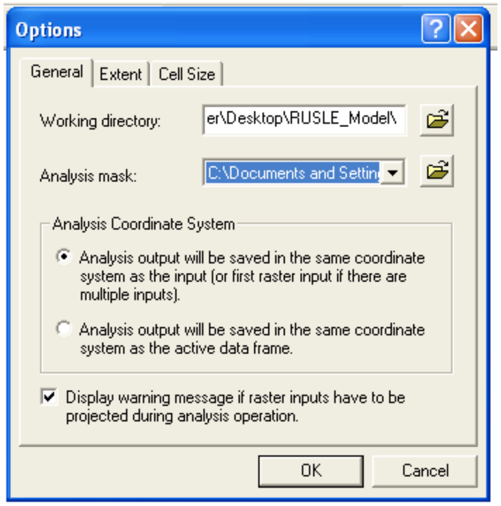
3. To create the mask and "clip" the area of interest from the larger watershed data set:

    a. Highlight the watershed layer in the data layer window and be sure that this is the only layer selected.
    b. Click the **Select Features** button on the ArcMap toolbar in order to select the polygons that will make up the study area. To select more than one polygon, hold the shift key while selecting. Polygons will be highlighted in blue.
    c. Select the **Source** tab at the bottom of the data layer window.
    d. Right click on the watershed layer, and toggle down to **Selection** and under that, **Create Layer from Selected Features**.
    e. Right click on the new layer, toggle down to **Data**, then **Export Data**.
    f. For the output location, select the Mask folder and name the shapefile **Mask**.
    g. If the Mask layer is made up of multiple features, these features must be dissolved to make a single polygon layer. To dissolve features, select each using the **Select Features** button on the ArcMap toolbar.
    h. Within ArcToolbox, navigate to **Data Management Tools**, then **Generalization**, and finally, **Dissolve**. Select Mask within the Input Features window. Rename and save the

file to your Mask folder within the Output Feature Class window. For the purposes of this exercise, this file is renamed “Mask_Dissolve”.

Step 2: Set Mask, Extent and Cell Size

a. Navigate to the **Spatial Analyst** Toolbar and scroll to **Options**.
b. Under the General Tab, select the folder which will serve as the working directory where all analysis results will be stored. For the purposes of this example, the working directory is called **RUSLE_Model.** Individual files can be directed to folders within this working directory by typing in the folder path name or selecting the folder while carrying out processing steps.
c. Under the **Analysis Mask** pull down menu, select Mask_Dissolve.shp. This will be used in all subsequent analyses so output files have the same extent as the Mask_Dissolve layer (the study area)



Working directory: er\Desktop\RUSLE_Model\

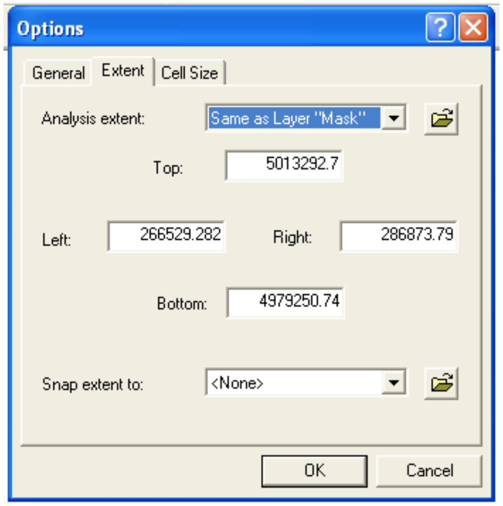
Analysis mask: C:\Documents and Settin

Analysis Coordinate System

● Analysis output will be saved in the same coordinate system as the input (or first raster input if there are multiple inputs).

○ Analysis output will be saved in the same coordinate system as the active data frame.

☑ Display warning message if raster inputs have to be projected during analysis operation.



Analysis extent: Same as Layer "Mask"

Top: 5013292.7

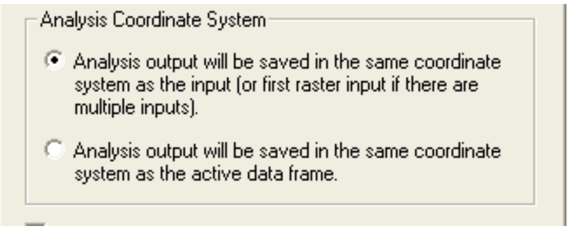
Left: 266529.282

Right: 286873.79

Bottom: 4979250.74

Snap extent to: <None>

d. Under the **Analysis Mask** pull down menu, select Mask_Dissolve.shp. This will be used in all subsequent analyses so output files have the same extent as the Mask_Dissolve layer (the study area)
e. The coordinate system to use for analysis results should be set to:



Analysis Coordinate System

● Analysis output will be saved in the same coordinate system as the input (or first raster input if there are multiple inputs).

○ Analysis output will be saved in the same coordinate system as the active data frame.

f. Select the **Extent** tab. The **Analysis Extent** should be set to Same as Layer “Mask”
g. Select the **Cell Size** tab. The cell size should be set to 30.

Step 3: Create soil erodibility factor (K)

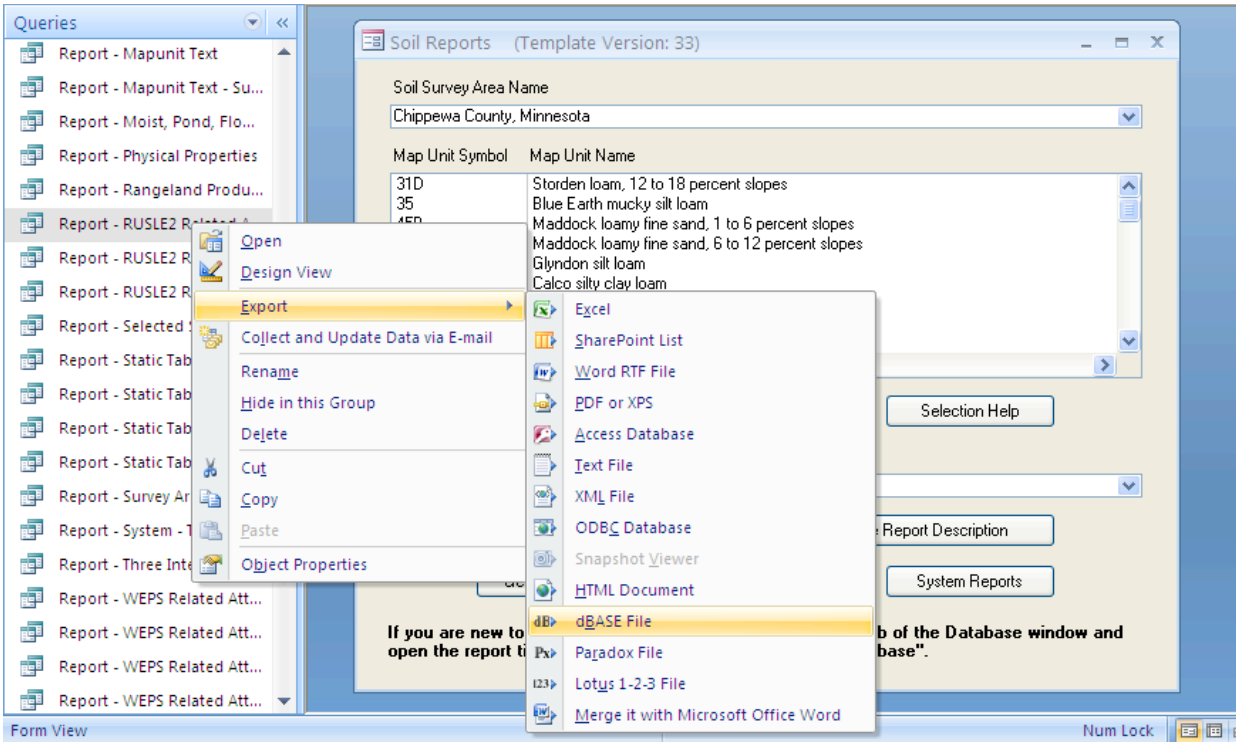
The soil erodibility factor (K) is created using tabular and spatial soils data from the NRCS SSURGO database. County level soils data are available online through the Soil Data Mart at the SSURGO website: http://soils.usda.gov/survey/geography/ssurgo/. Tabular data are provided as a set of ASCII delimited files. Each file corresponds to table in the SSURGO database. The tabular data are not particularly useful until they has been imported into a Microsoft Access SSURGO template database. The tabular soils data can then be joined to the spatial soils data.

1. **Download soils data from the Soil Data Mart**
    a. Create two folders within the Soils folder that is housed in the RUSLE_model folder. ArcCatalog to house the county level soils data. Name these folders Chippewa and Swift.
    b. Download soils data for both Chippewa and Swift counties (files will be sent from the SSURGO website to an email address that is specified at the time the data are ordered). Save each zipped file to its corresponding county folders in the Soils folder.
    c. Navigate to: http://soildatamart.nrcs.usda.gov/Templates.aspx, and select the Template database for Minnesota. Download this template into the Chippewa folder and again into the Swift folder. This will allow the tabular data to be opened and then joined with the spatial soils data in ArcGIS.
    d. The NRCS has a pdf file of Minnesota highly erodible soils by county. This document lists standard soil map unit symbols, map unit names, k values, typical slope percent, typical slope length, and LS values for all counties in the state. Download and save this pdf document.
        i. Within the highly erodible soils document, navigate to the Chippewa County page. Using the select tool within Adobe Reader, copy the Chippewa County page and paste it into a new Excel spreadsheet. Repeat this step for Swift County and paste the page into a separate Excel spreadsheet. Save each file as MUSYM_LS_Chippewa and MUSYM_LS_Swift, respectively.
        ii. In each of the county Excel spreadsheets, delete all columns except the Map Unit Symbol and LS columns. Change the two column headings to **MUSYM** and **LS** and resave each file.

2. **Import tabular soils data into Microsoft Access database**
    a. Launch Microsoft Access and select Open. In the dialog box that opens, navigate to the **RUSLE_Model** folder, then the **Soils** folder, and finally, the **Chippewa** folder. Select the Access database that was saved to this folder.
    b. If an error message appears, close the window and go to the **Options** button in the Security Warning bar, then click **Enable Content**, then ok. In the new window that opens, insert the path to the **tabular** folder within the **Chippewa** folder. All the relevant text files will then be imported into Access as tables.
    c. At the top of the Access navigation pane, select Queries. Scroll to **Report – RUSLE2 Related Attributes**. Double click on this file. It should appear as a

table in the main window. Right click on the file, scroll to **Export**, and then select as **dBASE file**.

d. In the dialog box that opens, browse to the Chippewa soils folder, then the **soil_mn023** folder. This folder is named soil_mn151 for Swift County. The database table will be saved here. Name the table **CHIPPEWA** (or SWIFT).



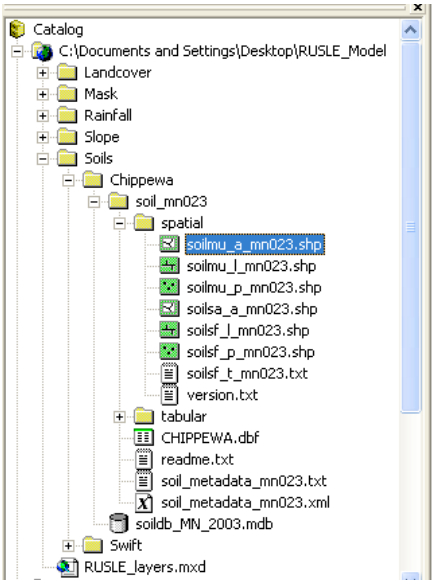
Soil Survey Area Name: Chippewa County, Minnesota

Map Unit Symbol	Map Unit Name
31D	Storden loam, 12 to 18 percent slopes
35	Blue Earth mucky silt loam
	Maddock loamy fine sand, 1 to 6 percent slopes
	Maddock loamy fine sand, 6 to 12 percent slopes
	Glyndon silt loam
	Calco silty clay loam

3. Join attributes from map unit symbol tabular data to spatial soils data

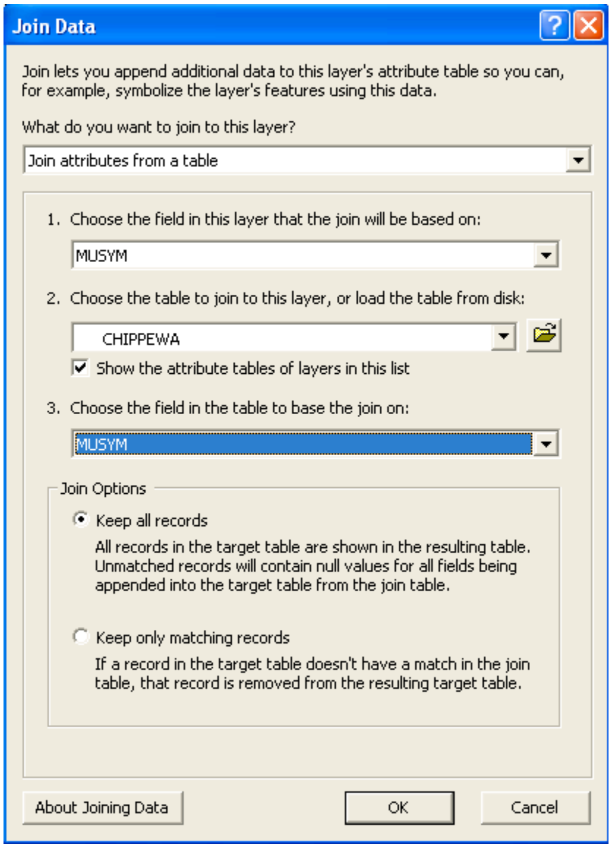
a. Launch ArcCatalog and a new ArcMap session or the existing RUSLE_layers.mxd file.

b. In ArcCatalog navigate to the spatial folder within the Chippewa soils folder. Drag the soilmu_a_mn023.shp file to the open ArcMap session. For Swift County, this file is named soilmu_a_mn151.shp.



- Catalog
  - C:\Documents and Settings\Desktop\RUSLE_Model
    - Landcover
    - Mask
    - Rainfall
    - Slope
    - Soils
      - Chippewa
        - soil_mn023
          - spatial
            - soilmu_a_mn023.shp
            - soilmu_l_mn023.shp
            - soilmu_p_mn023.shp
            - soilsa_a_mn023.shp
            - soilsf_l_mn023.shp
            - soilsf_p_mn023.shp
            - soilsf_t_mn023.txt
            - version.txt
          - tabular
          - CHIPPEWA.dbf
          - readme.txt
          - soil_metadata_mn023.txt
          - soil_metadata_mn023.xml
        - soildb_MN_2003.mdb
      - Swift
    - RUSLE_layers.mxd

c. Right click on the new layer, navigate to **Joins and Relates** and select **Join**. In the dialog box that appears, chose **Join attributes from a table**.



Join Data

Join lets you append additional data to this layer's attribute table so you can, for example, symbolize the layer's features using this data.

What do you want to join to this layer?

Join attributes from a table

1. Choose the field in this layer that the join will be based on:

MUSYM

2. Choose the table to join to this layer, or load the table from disk:

CHIPPEWA

☑ Show the attribute tables of layers in this list

3. Choose the field in the table to base the join on:

MUSYM

Join Options

● Keep all records

All records in the target table are shown in the resulting table. Unmatched records will contain null values for all fields being appended into the target table from the join table.

○ Keep only matching records

If a record in the target table doesn't have a match in the join table, that record is removed from the resulting target table.

   d. **MUSYM** is the field in the soils layer that the join will be based on.
   e. **CHIPPEWA** is the table to base the join on.
   f. **MUSYM** is the field in the table to base the join on. Click ok. The map unit symbol dBASE table will now be joined to the spatial soils data layer.

4. **Generate LS table to join to spatial soils data**
   a. Open a blank database within Microsoft Access.
   b. Under the **External** tab select **Import Excel** spreadsheet.
   c. In the dialog box that opens, browse to the **MUSYM_LS_Chippewa** Excel spreadsheet that was created in step 1. Follow the prompts to import the spreadsheet into Access.
   d. Right click on the new table in the navigation pane and scroll to **Export**, then to **dBASE file**.
   e. Export this file as a dBASE IV table, name it appropriately and save it to the Chippewa soils folder. For this example, the table was saved as **ChippDB**.

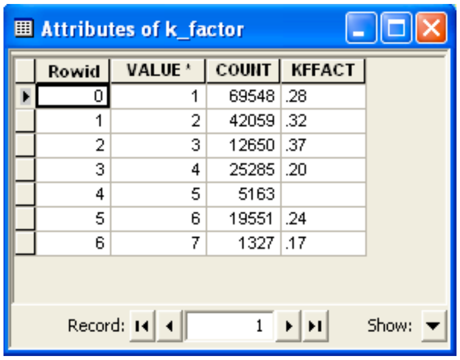
5. **Join attributes from LS tabular data to spatial soils data**
   a. In ArcMap, right click on the Chippewa soils layer, soilmu_a_023 and navigate to **Joins and Relates**, and then **Join**.
   b. Carry out a second join on the soilmu_a_023 layer, following the same steps outlined in c above. In step 2, the join should be made on the **ChippDB table**.
   c. Right click on the soilmu_a_023 layer and scroll to **Data**, then **Export Data**. Save this layer in the Chippewa soils folder and name it appropriately. For this example the file was saved as **ChippJoins**.
6. **Repeat steps 2 – 5 for Swift County**
   a. Follow steps 2 – 5 to generate a usable soils layer for Swift County.

7. **Merge and clip Chippewa and Swift County soils layers**
   a. In ArcToolbox, navigate to **Data Management Tools**, **General**, and **Merge**.
   b. Select the **ChippJoins** and **SwiftJoins** files for the input data layers. Name the new file **ChipSwiMerge.shp** and save it to the Soils folder.
   c. In ArcToolbox, navigate to **Analysis Tools**, **Extract**, and **Clip**. Use the Mask_Dissolve shapefile to clip the ChipSwiMerge shapefile. Save the clipped soils layer to the Soils folder. For this example, the new file was named **Soils_lyr**.
   d. Convert the new soils shapefile to a raster layer using the **convert** tool under the **Spatial Analyst** toolbar. The field should be set to **KFFACT**. Name the file **K_Factor** and save it to the Soils folder.

8. **Convert K factor data**
   a. Reference units of the input images and data layers must have units in either meters or feet. Data from the SSURGO database is represented in U.S. Customary units and should be converted to SI (metric) units as desired erosion output data are metric (tons/hectare/year).

- Note: The C factor and LS factors are unitless and do not need to be converted prior to running the RUSLE model. The R factor layer must be converted (see Step 6).
- To **convert K factor** values from U.S. Customary units to SI units, multiply the U.S. value by **0.1317** (Renard et al. 1997).

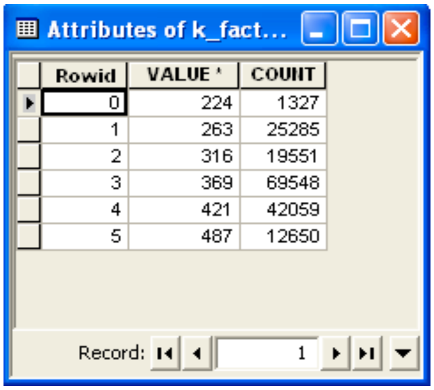
b. When Raster Calculator is used to multiply each factor layer together for an estimate of soil loss, the Value field is used in the multiplication. In the K factor layer attribute table below, the data of interest (K factors) are not in the Value field. The **reclassify** tool must be used to reclassify the Value field so that the K factors are represented in this field.



Rowid	VALUE *	COUNT	KFFACT
0	1	69548	.28
1	2	42059	.32
2	3	12650	.37
3	4	25285	.20
4	5	5163	
5	6	19551	.24
6	7	1327	.17

c. When reclassifying, only integer data can be used – the reclassify tool will round all decimal data to the nearest integer. Multiply each k factor by **10,000** before classifying in order to eliminate decimals.

d. The attribute table for the final K factor layer used in this example is below (not the conversion, elimination of decimal values, and reclassification to the Value field).



Rowid	VALUE *	COUNT
0	224	1327
1	263	25285
2	316	19551
3	369	69548
4	421	42059
5	487	12650

Step 4: Create slope length and slope steepness factor (LS)

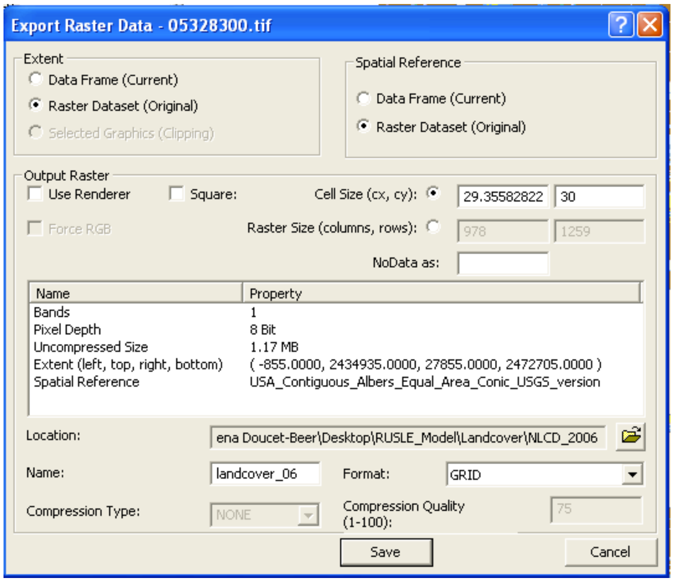
The slope length and slope steepness factor (LS) is created using the same tabular and spatial soils data from the NRCS SSURGO database. The Soils_lyr feature layer that was created in the previous step is simply converted to a raster file, and the field that the conversion is carried out on is set to LS, which is one of the many fields contained within the SSURGO data.

1. Using the **Spatial Analyst** toolbar, convert the **Soils_lyr** feature layer into a raster layer. The field to base the conversion on should be set to **LS**.
2. Name the file **LS_Factor** and save it to the Slope folder within the main RUSLE_Model folder.
3. Right click on the LS_Factor layer and scroll to **Properties**. Select the **Symbology** tab and display the data as unique values.

Step 5: Create cover management factor (C)

The cover management factor (c) is created using land cover data. National Land Cover Data for 2006 (NLCD) was used for this project. This (and other land cover data sets can be downloaded from the Multi-Resolution Land Characteristics Consortium (MRLC): http://www.mrlc.gov/.

1. **Download NLCD 2006 data from the MRLC**
   The file will be in TIF format and should be saved as a raster file.
    a. Right click on the data layer, and scroll to **Data**, then **Export Data**.
    b. In the command window that opens, set the location where the file will be saved. For this example the file is saved in the NLCD_2006 folder, which is a subfolder within the landcover folder.
    c. The format of the file should be set to GRID.
    d. The file should be renamed appropriately. For this example, the file is named Landcover_06.



Export Raster Data - 05328300.tif

Extent
○ Data Frame (Current)
● Raster Dataset (Original)
○ Selected Graphics (Clipping)

Spatial Reference
○ Data Frame (Current)
● Raster Dataset (Original)

Output Raster
☐ Use Renderer
☐ Square:
Cell Size (cx, cy): ● 29.35582822 30
☐ Force RGB
Raster Size (columns, rows): ○ 978 1259
NoData as:

Name	Property
Bands	1
Pixel Depth	8 Bit
Uncompressed Size	1.17 MB
Extent (left, top, right, bottom)	(-855.0000, 2434935.0000, 27855.0000, 2472705.0000)
Spatial Reference	USA_Contiguous_Albers_Equal_Area_Conic_USGS_version

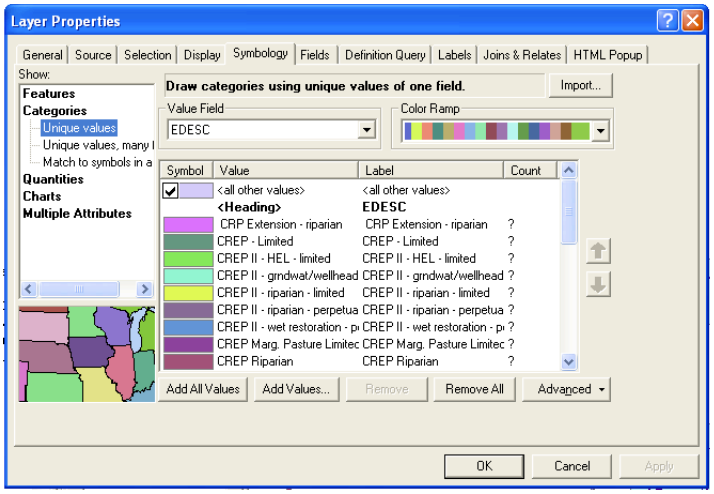
Location: ena Doucet-Beer\Desktop\RUSLE_Model\Landcover\NLCD_2006
Name: landcover_06
Format: GRID
Compression Type: NONE
Compression Quality (1-100): 75

2. **Clip study area using Mask_Dissolve layer**
   In ArcToolbox, navigate to **Data Management Tools**, then **Raster**, **Raster Processing**, and finally, **Clip**.
   a. Be sure to check the box for Input Features for Clipping Geometry, as this will ensure the output file is clipped to the study area extent.
   b. Save the file in the NLCD_2006 folder within the main Landcover folder. For this example, the file is saved as LC_06.

3. **Add additional data layers to landcover layer**
   Other important layers may need to be added to the landcover layer, depending on whether the landcover layer captures all of the relevant cover on the ground. For this example, a Reinvest in Minnesota (RIM) easement layer and a streams layer were added to the landcover layer by using the Burn tool in ArcToolbox.
   a. RIM data can be downloaded from: www.bwsr.state.mn.us/easements/index.html. Streams data can be downloaded from the Minnesota DNR Data Deli: http://deli.dnr.state.mn.us/index.html.
   b. Additional layers to be added will be automatically clipped to the study area during the raster calculator step. In order to preserve all data in each of the additional layers, do not clip the areas before the processing steps below.
   c. The RIM feature layer contains a number of different feature classes, depending on their geographic location and RIM management program. The following feature classes are found within the LSP study area:
      - CREP WR – Conservation Reserve Enhancement Program Wetland Reserve
      - CREP Riparian – Conservation Reserve Enhancement Program Riparian area
      - PWP – Permanent Wetland Preserve
      - Marginal Cropland – Perpetual

   d. These features represent different areas of land that have been taken out of agricultural production. These different features should be added to the landcover layer individually in order that the separate feature classes are preserved.

   e. The BWSR_RIM_easements layer should be displayed by the description feature class (EDESC) in the attribute table so that polygons in each class can be selected, exported, and saved as one layer (so that each class becomes its own layer that can then be combined with the landcover layer).



Draw categories using unique values of one field.

Value Field: EDESC

Color Ramp

Symbol	Value	Label	Count
☑ 🟪	<all other values>	<all other values>	
	<Heading>	**EDESC**	
🟪	CRP Extension - riparian	CRP Extension - riparian	?
🟩	CREP - Limited	CREP - Limited	?
🟩	CREP II - HEL - limited	CREP II - HEL - limited	?
🟦	CREP II - grndwat/wellhead	CREP II - grndwat/wellhead	?
🟨	CREP II - riparian - limited	CREP II - riparian - limited	?
🟪	CREP II - riparian - perpetua	CREP II - riparian - perpetua	?
🟦	CREP II - wet restoration - p	CREP II - wet restoration - p	?
🟪	CREP Marg. Pasture Limitec	CREP Marg. Pasture Limitec	?
🟥	CREP Riparian	CREP Riparian	?

1. Under **Selection** on the main menu, scroll to **Set Selectable Layers**. Check only the BWSR_RIM_easements layer.

2. Holding down the shift key, while using the **Select Features** button on the main menu, select all of the features in one of the RIM classes within the LSP study area. Alternatively, you can open the attribute table for the BWSR_RIM_easements layer, sort the EDSEC column, and select polygons based on their class.

3. For this example there are five different types of RIM easements in the study area, so there will be a total of five different layers created before they will be added individually to the final landcover layer.

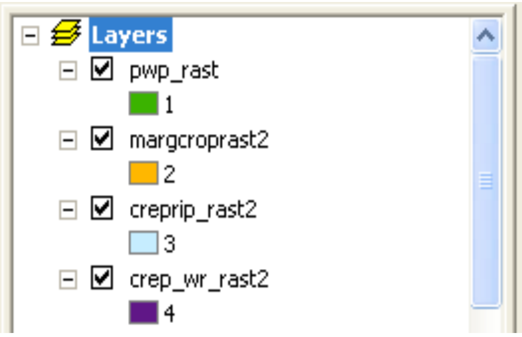
4. Click on the **Selection** tab in the data layers window. The BWSR_RIM_easements layer will be in bold. Right click on this layer, and navigate to **Create Layer from Selected Features**. The new layer will now be displayed in the **Display** tab.

5. Right click on this new layer, and navigate to **Data**, then **Export Data**. Save the new feature layer to the NLCD_06 folder and name it appropriately. These steps must be taken for each RIM class that will be incorporated into the final landcover layer. For this example the four RIM layer are named the following:
   - PWP.shp (permanent wetland preserve)
   - Marginal_crop.shp (marginal cropland)
   - CREP_Riparian.shp (CREP riparian)
   - CREP_WR.shp (CREP wetland reserve)

The newly created RIM feature layers will need to be converted to raster files. In ArcToolbox, navigate to **Conversion Tools**, then **To Raster**, and select **Feature to Raster**.

a. Select the individual RIM layer for the input feature.
b. Using the dropdown menu, select the field to be preserved in the output layer. For this example, the field EDESC was selected in order to preserve information on easement type for each class.
c. Save the output rasters to the NLCD_06 folder within the landcover folder and name them appropriately. The output cell size should be set to 30. For this example, four new raster files were created.

Each of the new RIM raster files should be reclassified so that they do not have the same value (after step iv above they will all have one class with a value of 1). The next step is to mosaic each of them with the landcover layer, but this step will not work if each raster file has the same value. One way to do this is to simply reclassify each of these rasters so that each one has a different value, keeping track of which file has which value. In the example below the values range from 1-4.

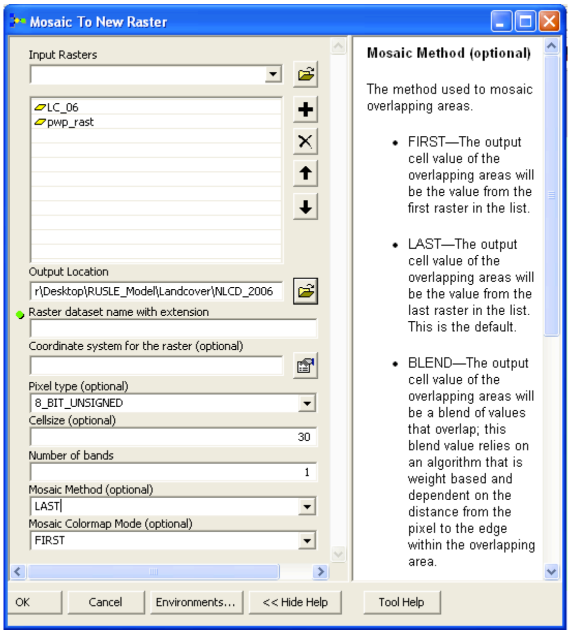


1. To reclassify these raster files, navigate to reclassify under the Spatial Analyst Toolbar. The input raster can be selected from the dropdown menu. The reclass field should be set to Value. Set the new value to 1 for the first file, and save the file to the NLCD_06 folder (subsequent files will have values 2, 3,and 4).

2. The (four) new raster files should be added to the landcover layer using the **Mosaic to New Raster** tool within ArcToolbox. This step will need to be done four times, using the new raster file created from each step for the next raster file, and so on.

3. In ArcToolbox, navigate to **Raster**, then **Raster Dataset**, and select **Mosaic to New Raster**.

4. The input rasters should be the landcover file (LC_06) and one of the RIM raster files. The output location should be set to the NLCD_06 folder. The output file should be named lc_1. Subsequent files can be named lc_2, and so on. Cellsize should be set to 30. Set the Mosaic Method window to LAST and make sure that the RIM file appears last in the input raster list (i.e. it should be below the landcover layer). Click ok.



Input Rasters: LC_06, pwp_rast

Output Location: r\Desktop\RUSLE_Model\Landcover\NLCD_2006

Raster dataset name with extension

Coordinate system for the raster (optional)

Pixel type (optional): 8_BIT_UNSIGNED

Cellsize (optional): 30

Number of bands: 1

Mosaic Method (optional): LAST

Mosaic Colormap Mode (optional): FIRST

Mosaic Method (optional)

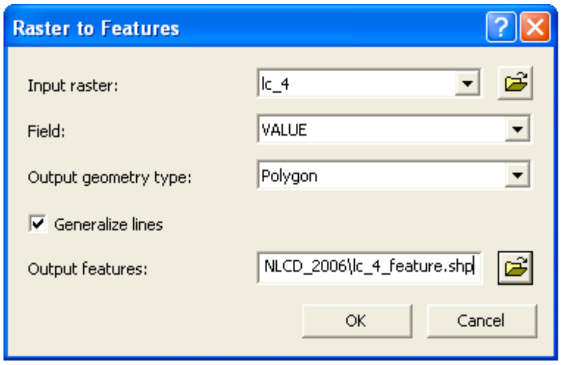
The method used to mosaic overlapping areas.

- FIRST—The output cell value of the overlapping areas will be the value from the first raster in the list.
- LAST—The output cell value of the overlapping areas will be the value from the last raster in the list. This is the default.
- BLEND—The output cell value of the overlapping areas will be a blend of values that overlap; this blend value relies on an algorithm that is weight based and dependent on the distance from the pixel to the edge within the overlapping area.

5. Open **Mosaic to New Raster** again. Add the next RIM raster file to the input raster window. Next, add the newly created landcover layer (for example, lc_1) to the input raster window. Make sure that the RIM raster layer you are merging is last in the list. Follow steps 1-3 until all RIM raster layers have been incorporated and you have a landcover layer that contains all RIM raster layers. The final raster file will be lc_4 and should contain all four RIM layers, each with individual attributes.

4. **Modify the streams layer for use in the model**
   In order to eventually add buffer zones along streams for the various scenarios, areas of the streams layer that are <u>adjacent to agricultural lands</u> need to be extracted so that <u>only</u> these areas are used in creating buffers.

   a. First, convert the lc_4 landcover layer to a feature layer. Navigate to the **Spatial Analysis** toolbar, then to **Convert**, and finally **Raster to Feature**. Select the lc_4 layer for the input, Value in the Field window, and Polygon for the Output geometry type. Name the file appropriately and save it to the NLCD_06 folder.



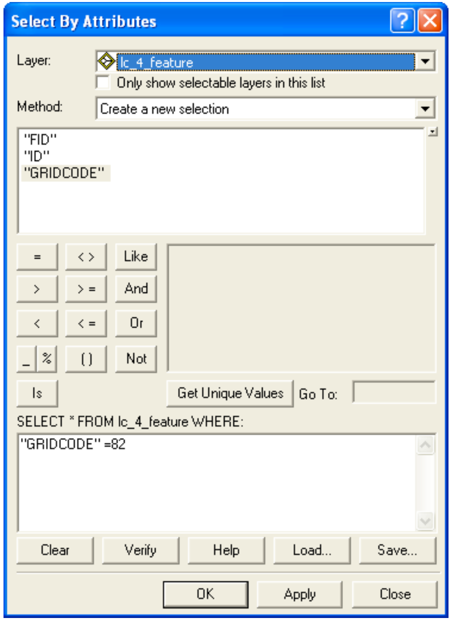
Input raster: lc_4

Field: VALUE

Output geometry type: Polygon

☑ Generalize lines

Output features: NLCD_2006\lc_4_feature.shp



Layer: lc_4_feature

☐ Only show selectable layers in this list

Method: Create a new selection

"FID"
"ID"
"GRIDCODE"

SELECT * FROM lc_4_feature WHERE:

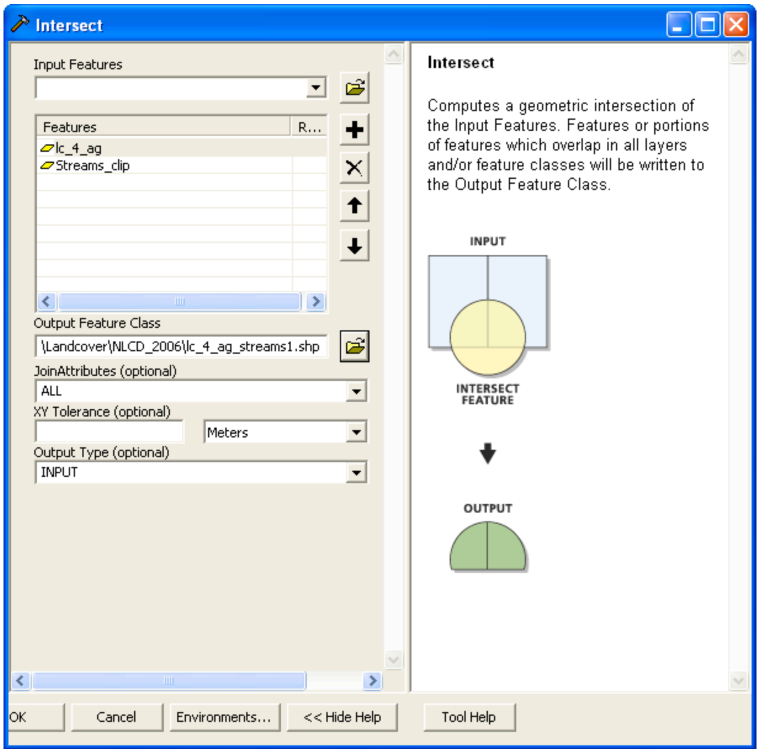
"GRIDCODE" =82

   b. Under the **Selection** toolbar, navigate to **Select by Attributes.**

c. The **Select by Attributes** window will allow for the selection of features of a given class. Here, we are interested in selecting all of the Cultivated Crops features.

d.
   1. Navigate to the lc_4_feature layer in the Layer window.
   2. Navigate to Create a new selection in the Method window.
   3. For the equation window, select "GRIDCODE", then the equals (=) sign, and then 82, which is the gridcode value for Cultivated Crops.
   4. Hit Ok. The new layer will be added to the Layers window.
   5. Right click on the layer and navigate to Data, then Export Data.
   6. Name the layer and save it to the NLCD_06 folder. For this example the new layer is called lc_4_ag.shp.

e. Under ArcToolbox, navigate to **Analysis Tools**, then **Overlay**, and then **Intersect**.



lc_4_ag
Streams_clip

Output Feature Class: \Landcover\NLCD_2006\lc_4_ag_streams1.shp

JoinAttributes (optional): ALL

XY Tolerance (optional): Meters

Output Type (optional): INPUT

Intersect

Computes a geometric intersection of the Input Features. Features or portions of features which overlap in all layers and/or feature classes will be written to the Output Feature Class.

1. Select the two layers that will be intersected – here, the lc_4_ag.shp layer and the streams_clip.shp layers.

2. Name the output feature class and save it in the NLCD_06 folder. The JoinAttributes window should be set to ALL. The Output Type should be set to INPUT. For this example, the new file is named lc_4_ag_streams. This new streams layer will include only sections of streams that intersect with the cultivated crops class.

3. The next step is to reclassify this new streams layer into a raster file. Use the Spatial Analyst Toolbar for this step. For this example, the new file is called lc_4_ag_st_r.

4. The newly created streams raster file must be binary (values of 0 and 1) before it can be added to the landcover layer. To create the binary streams layer, navigate to **Reclassify** under the **Spatial Analyst** toolbar. Add the streams raster file as the input layer, and set the reclass field to Value. All new values should be set to 0, and NoData should be set to 1. The output raster file should be saved to the NLCD_06 folder and named appropriately. For this example the file is named streams_bin. Click Ok.

5. The final landcover layer (here lc_4) already has one class with a value of 1, so this class must be reclassified before adding in the binary streams layer.

6. Reclassify lc_4 using the **Spatial Analyst** toolbar. Leave all classes with the value they have, only reclassify the class with a value of 1. For this example, this class can be reclassified to 10, since there are no other classes with this value. Save the new file as lc_5.

7. To merge the streams layer with the landcover layer (lc_5), navigate to **Raster Calculator** under the **Spatial Analyst** toolbar. Select the first file (streams_bin), then select multiply (*), and then select the lc_5 layer. Select Evaluate.

8. The new file will be called Calculation and will be added to the data layer window. To make this file permanent, right click on the file, navigate to Make Permanent, rename the file, save in the NLCD_06 folder and save. For this example the file is named lc_baseline.

Step 6: Create runoff erosivity factor (R)

The R factor is an index which reflects the amount and rate of runoff associated with rain and the effect of raindrop impact in terms of soil detachment (Renard, etal. 1997). An R factor of 95 was determined from the literature (NRCS Technical Guide 1996). The units for this factor are in U.S. Customary units and must be converted to SI (metric) units before this layer can be used in the RUSLE model. To convert the R factor from U.S. to SI units, multiply the R factor by 17.02 (Renard et al. 1997).

1. To create the R factor layer, reclassify the lc_baseline layer using the **Spatial Analyst** toolbar. The reclass field should be set to Value.
2. All new values should be changed to 1617. Each pixel in the resulting raster will have a value of 1617.
3. Name the new layer **R_Factor** and save it in the Rainfall folder, click ok.
4. The R_factor layer can be added to the map when needed or when running the model.

Step 7: Add extension for use in ArcGIS

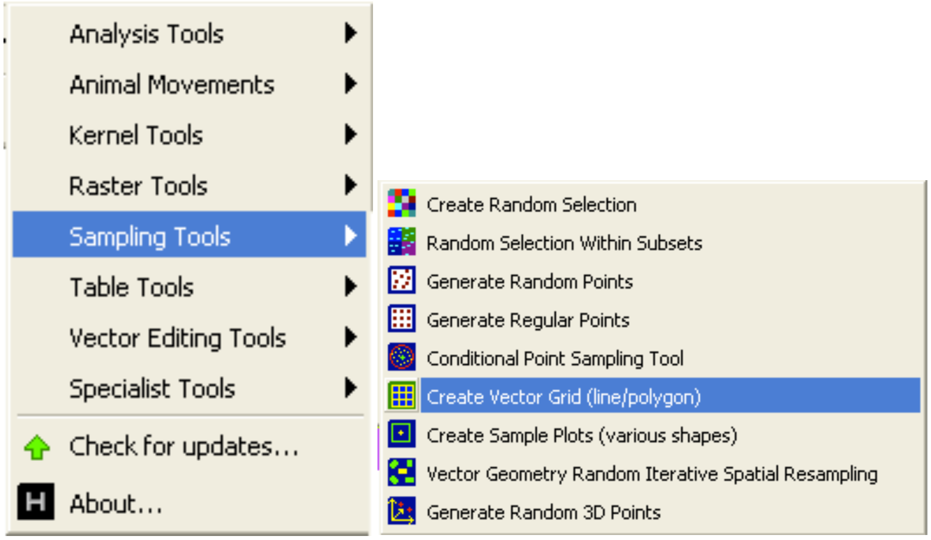
1. The **Hawth's Tools** extension is a very useful tool when added to any version of ArcGIS. This free tool will be helpful for the creation of the various scenarios used as examples in this analysis.
2. The tool can be downloaded from: http://www.spatialecology.com/htools/download.php
3. Download the tool and follow the instructions on how to add it to your ArcGIS toolbar.

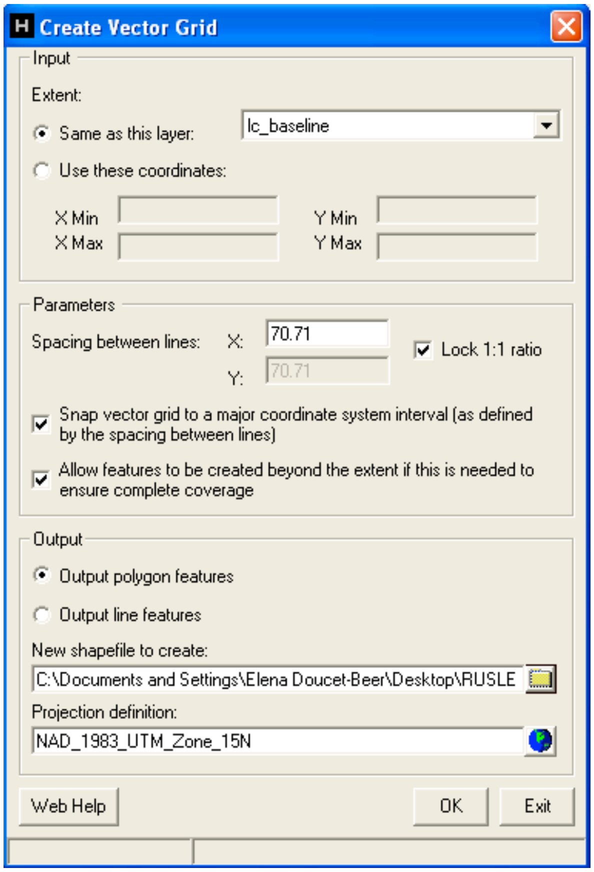
Step 8: Create scenarios

Scenario A is based on current trends and projects an increase in acreage for corn, soybeans, and sugar beets. Each of these classes needs to be incorporated into the lc_baseline layer.

Create Polygon Layer for Agriculture Class Selection

1. Using the **Hawth's Tools** extension, navigate to **Sampling Tools**, then select **Create Vector Grid (line/polygon)**.





Input

Extent:

● Same as this layer: lc_baseline

○ Use these coordinates:

X Min

X Max

Y Min

Y Max

Parameters

Spacing between lines: X: 70.71 Y: 70.71

☑ Lock 1:1 ratio

☑ Snap vector grid to a major coordinate system interval (as defined by the spacing between lines)

☑ Allow features to be created beyond the extent if this is needed to ensure complete coverage

Output

● Output polygon features

○ Output line features

New shapefile to create: C:\Documents and Settings\Elena Doucet-Beer\Desktop\RUSLE

Projection definition: NAD_1983_UTM_Zone_15N

2. Chose the lc_baseline layer for the extent option.

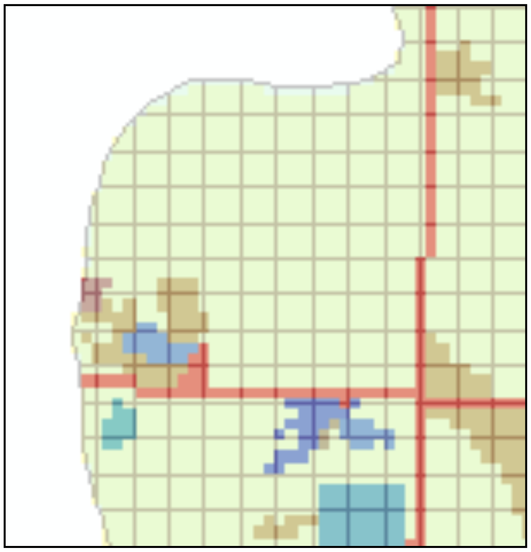
3. For the parameters, set the spacing between lines to 70.71 (this is in meters). Be sure the lock ratio box is checked.

4. Also ensure that the snap vector grid to major coordinate system box is checked. Also check the allow features to be created beyond line extent box.

5. Select output polygon features, name the file Vector_grid_70 and save the new file to the Scenario_A folder.

6. When the Vector_grid_70 layer is added to the layers window, right click on it and select properties.

7. Under the display tab, set the layer to 50% transparent. This will allow you to see which 70.71m^2 (0.5 Ha) squares to select and then output as a new layer, which will represent the additional agricultural layers needed for this scenario (see Table 1).



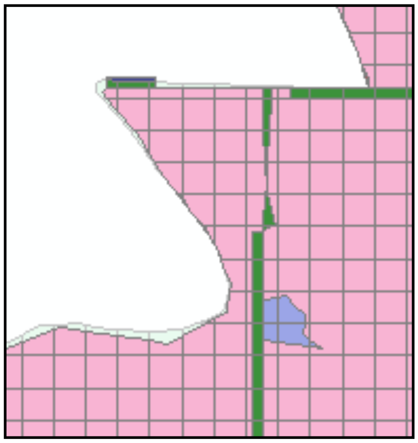
8. The Vector_grid layer can be clipped to the same extent as the lc_baseline layer using the Mask_dissolve layer. Name the new

9. layer Grid_clip_70 and save it to the Scenario_A folder.

10. Convert the lc_baseline raster layer to a feature layer using the **Spatial Analyst** toolbar. Name the feature layer lc_base_feat and save it in the NLCD_2006 folder.

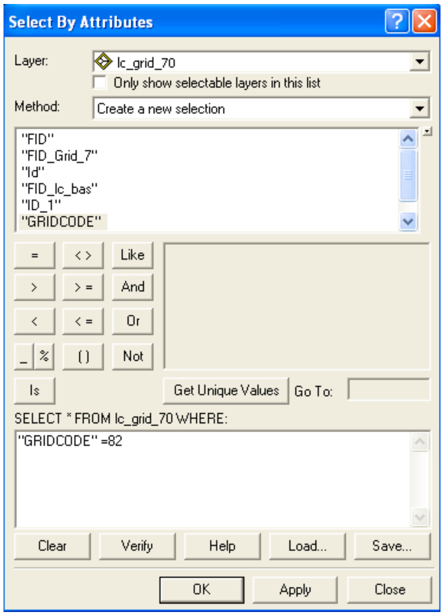
11. In **ArcToolbox**, navigate to **Analysis Tools**, then **Intersect**. In the tool window, select the lc_baseline_feat.shp layer and the Grid_clip_70.shp layer as the inputs.

12. For the output feature class, select the Scenario_A folder and name the file lc_grid_70. Right click on the layer, select properties, and then the **Symbology** tab. In the window, select unique values under categories, then in the value field, select Gridcode. The layer will now be sorted by landcover class. This new layer will resemble the image below:



13. Under the **Hawth's Tools** tab, navigate to **Table Tools**, then select **Add Area Perimeter Fields to Table**. This tool will add a new field or will update existing fields with the area and/or perimeter of each polygon (in coordinate system units). The user can specify a multiplier constant that is applied to each area/perimeter value to change the units (e.g. if the data are in UTM, then applying a multiplier of 0.0001 to the area field will result in the units being hectares instead of m^2).

14. Using the selection tab, navigate to the Select by **Attributes** tool. Chose the lc_grid_70 layer for the input, click on "GRIDCODE", the equals button, and type in 82 (which is the agriculture class). This will select all polygons within the agriculture class.



Select By Attributes

Layer: lc_grid_70

☐ Only show selectable layers in this list

Method: Create a new selection

"FID"
"FID_Grid_7"
"Id"
"FID_lc_bas"
"ID_1"
"GRIDCODE"

SELECT * FROM lc_grid_70 WHERE:

"GRIDCODE" =82

15. Click on the selection tab at the bottom of the table of contents, right click on the bold layer, and navigate to **Create Layer from Selected Features**. Name this new layer ag_grid_70 and save it to the Scenario_A folder.

16. The **Select by Attributes** tool can be used a second time to create a layer that contains only 0.5 Ha squares (polygons) or a range of squares using the > = and < = signs. For this example, all polygons equal to 0.499 hectares were selected and saved as a new layer called ag_70_final. This layer will be used to select squares for the various agricultural classes added or changed for the different scenarios. There are a total of 14624 squares in the ag_70_final layer, which is equal to approximately 7297 hectares.

17. Squares needed for each class can now be selected using the ag_70_final layer. The number of hectares need for each class should be determined before this step. The number of hectares needed for the three different agricultural classes in scenario A is represented in Table 2.

Table 1: Scenario A additional classes

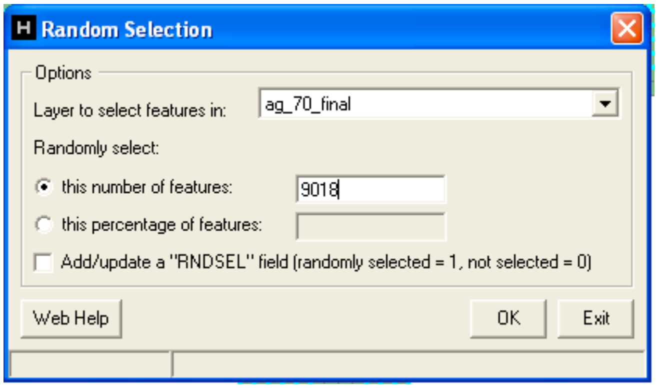
	Percent of Total Landcover	**Hectares**	**Number of features needed in ag_70_final layer**
Corn-soybeans (CT)	32%	5040	NA
Corn-soybeans (CN)	29%	4508.6	9018
Corn-sugar beets (CN)	7%	1120	2240

One option is to select a large subset of squares by hand using the select tools. This is somewhat tedious, however the advantage is that it will allow a user to select specific areas, varying them based on the desired scenario. A more automated approach is to use the **Hawth's Tools** extension to select a number of features (squares) or a percentage of the features in the ag_70_final layer. This approach is described in subsequent steps. Any squares not selected for either the Corn-soybeans (CN) or Corn-sugar beets (CN) class will be "left over" and can be included in the third class, Corn-soybeans (CT).

Hawth's Tools to create selection from feature layer

1. Under the **Hawth's Tools** tab, navigate to **Sampling Tools** and then select **Create Random Selection.**

2. Select the ag_70_final layer as the input layer. In the number of features box, enter 9018, which is the number of features that needs to be selected to sum to 4509 hectares for the corn-soybean (CN) class. Hit ok.



Layer to select features in: ag_70_final

Randomly select:

● this number of features: 9018

○ this percentage of features:

☐ Add/update a "RNDSEL" field (randomly selected = 1, not selected = 0)

3. Create a new layer from the selected features. Name this layer Corn_Soy_CN and save it to the Scenario_A folder.

4. The next step involves a union of the Corn_Soy_CN and the ag_70_final layers so that the features remaining in the ag_70_final layer that were not selected for the Corn-Soybean layer can be used for the Corn-sugar beet class that needs to be created.

5. In **ArcToolbox**, navigate to **Analysis Tools**, then **Overlay**, and click **Union**.

6. Select the Corn_Soy_CN and ag_70_final layers in the input window. In the Output Feature Class window, navigate to the Scenario_A folder, and name the output file 9018_union. Click ok.

7. In the Table of Contents window, right click on the new layer and navigate to **Symbology**. Select Unique values under Category and in the Value Field window select GRIDCODE. The two fields will now be visible. Features with a value of 0 represent the remaining features in the ag_70_final layer that can be selected and saved separately for the Corn-sugar beet layer.

8. Using the **Select by Attributes** tool, select all features in the 9018_union layer that have a value of 0. Save this selection as a new layer. Name this new layer ag_70_2 and save it in the Scenario_A folder.

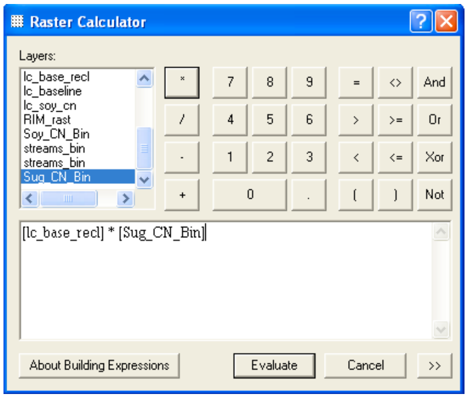
9. Follow the same procedure outlined in steps 1 – 3 above to create the Corn-sugar beet layer. Use ag_70_final_2 as the input layer in **Hawth's Tools** and select 2240 features.

10. Using the **Spatial Analyst** toolbar, convert the Corn_Soy_CN and Corn_Sugar_CN feature layers to raster layers. Name these new files Soy_CN_r and Sug_CN_r, respectively and save them in the Scenario_A folder.

11. Using the **Spatial Analyst** toolbar, reclassify each of these new raster layers to binary rasters. Old data values for the agricultural class should be set to 0 and NoData should be set to 1. Do this for each of the new raster layers, name the files Soy_CN_Bin and Sug_CN_Bin, respectively and save them to the Scenario_A folder.

12. Before these layers can be added to the lc_baseline raster layer, the lc_baseline layer needs to be reclassified because the streams class has a value of 0 (as do the new raster layers created in the previous steps). The new raster layers will be multiplied by the lc_baseline layer to merge the files together (in two separate steps). In order for the multiplication to work, only one file can be binary. When reclassifying the lc_baseline raster layer, keep all class values the same as their original values and only change the streams class value from 0 to another number not already being used. For this example, the streams class was reclassified to 5. The new raster layer is named lc_base_recl and was saved to the Scenario_A folder.

13. To add one of the new agricultural raster layers to the lc_base_recl layer, open **Raster Calculator** under the **Spatial Analyst** toolbar. Chose the lc_base_recl layer, the multiply sign, and then select one of the binary agricultural raster layers. Click Evaluate.



```
[lc_base_recl] * [Sug_CN_Bin]
```

14. The new layer will appear in the Table of Contents window as Calculation. Right click on this layer and navigate to **Data**, then **Export**. Save this new file in the Scenario_A folder as a GRID file and name it appropriately. For this example, the file was named lc_soy_cn.

15. The lc_soy_cn layer needs to be reclassified before it can be merged with the Corn-sugar beet layer (Sug_CN_Bin). Keep all class values the same in this step and only reclassify the value for Corn-soybeans (CN) from 0 to a number not already being used. For this example, the value was reclassified to 6. Save this new layer as lc_soy_cn_r and save it to the Scenario_A folder.

16. Navigate to **Raster Calculator** again, this time selecting the lc_soy_cn_r layer, then the multiply sign, and finally, the other binary agricultural layer (here, Sug_CN_bin). Click Evaluate and follow the same procedure as above to save the Calculation as a new file. For this example the file was named lc_scenario_A.

17. All classes in this layer should have numeric values. For this example, the reclassify tool was used to reclassify the Corn-sugar beet class value from 0 to 7. The new layer was saved as Scenario_a_r.

18. In the NLCD_2006 folder in ArcCatalog, create a copy of the lc_final data layer and rename it lc_baseline. This layer will serve as the starting layer for creating each scenario. Additional classes will be added to this layer to create the various scenarios.

Modify Scenario_A layer for use in model

The C factor values need to be added to the layer that will be used for scenario A, however there are a number of things to be aware of before taking this step.

1. When Raster Calculator is used to multiply each factor layer together for an estimate of soil loss, the Value field is used in the multiplication. The **reclassify** tool must be used to reclassify the Value field in the C factor layer so that the C factors are represented in this field.

2. When reclassifying, only integer data can be used – the reclassify tool will round all decimal data to the nearest integer. Each C factor should be multiplied by **10,000** during the reclassification in order to eliminate decimals.

Table 2: Scenario A Class Definitions and C Factors

Classification	**NLCD 2006 Code or Attribute Value**	**C Factor (x10,000)**
Marginal Cropland	2	4500
CREP Riparian	3	10
CREP Wetland Reserve	4	10
Streams	5	0
Corn-Soybeans (CN)	6	6,000
Corn-Sugar Beets (CN)	7	6,000
Permanent Wetland Reserve	10	10
Open Water	11	0
Developed, Open Space	21	30
Developed, Low Intensity	22	0
Developed, Medium Intensity	23	0
Developed, High Intensity	24	0
Barren Land	31	3,000
Deciduous Forest	41	20
Grassland/Herbaceous	71	50
Pasture/Hay	81	500
Corn-soybeans (CT)	82	4,500
Woody Wetlands	90	10
Emergent herbaceous Wetlands	95	10

Create Scenario B

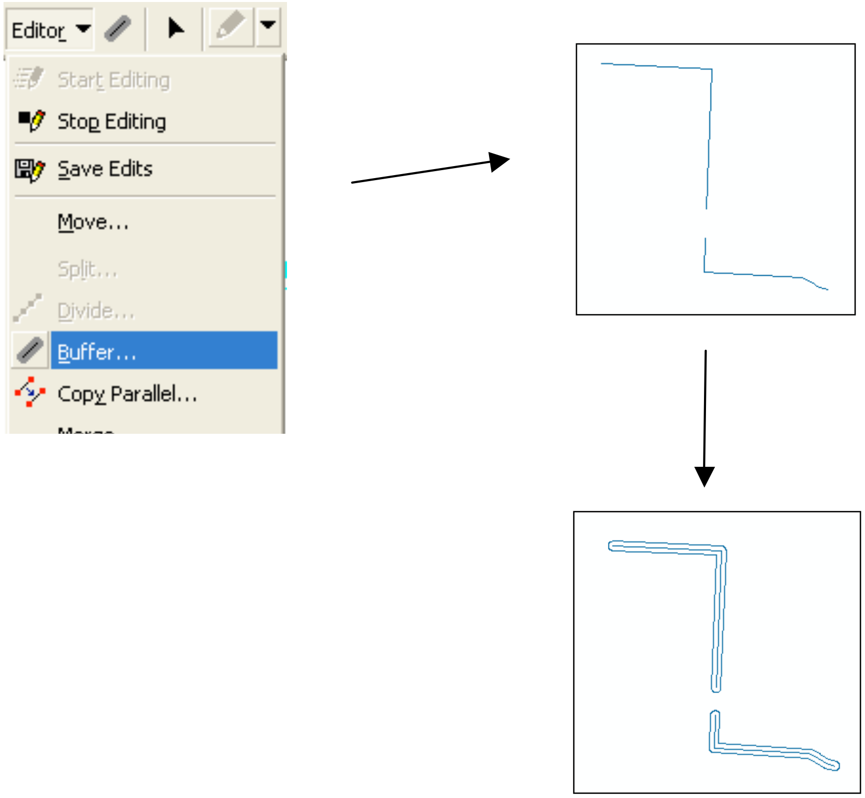
The main changes to the landscape in scenario B include the addition of a 30 meter buffer along streams in agricultural areas, and a reduction of crops under conventional tillage, with an increase in crops under conservation tillage. In order to prevent the addition of a stream buffer from removing cells in permanent classes, the streams layer created for the baseline landcover layer can be edited and then added back in to the landcover layer.

Create Riparian Buffer

1. Add the streams feature layer that was clipped to the study area and then intersected with agricultural areas to the Table of Contents window. For this project, this file was named lc_4_ag_streams.shp. Make a copy of this streams layer and save it to the main NLCD_2006 folder so that it can be used if needed in subsequent steps.

2. Next, an edit session can be started on the **Editor** toolbar to begin removing sections of the stream that lie over areas that should not be taken up by the stream buffer (which will be done in the next step). Make sure the lc_base_recl raster layer can be seen below the newly streams layer. This will allow you to see areas of the stream that should be edited and either removed or adjusted slightly so they only intersect the agricultural classes.

3. Once the streams layer has been edited, the **Buffer** tool can be used to create a 30 meter buffer around all stream sections that remain. Using the **Select Features** tool, select all of the stream features. Using the **Editor** toolbar, navigate to **Buffer**, and enter 30 in the dialog box that opens.



4. Using the **Select by Attributes** tool, select all of the stream sections in the lc_4_ag_streams layer. Do not select any of the buffered areas. Create a new layer from the selected streams layer and save it to the Scenario_B folder.

5. Following the same method in step 4, select the buffered sections from the lc_4_ag_streams layer and create a new layer from the selected class. Save this new layer to the Scenario_B folder.

6. Convert each of the new layers into two raster layers. Next, reclassify each of these raster layers into two binary layers using the reclassify tool under the **Spatial Analyst** toolbar. Save all new layers to the Scenario_B folder.

7. Using the **Raster Calculator** tool under the **Spatial Analyst** toolbar, multiply the lc_5 raster layer by the stream buffer raster layer. Click Evaluate and save the new layer to the Scenario_B folder. Name this file lc_6.

8. Using the **Reclassify** tool under the **Spatial Analyst** toolbar, reclassify the lc_6 layer so that the stream buffer class does not have a value of 0. For this example, the stream buffer value was reclassified to 12 (all other class values should stay the same) and the layer was named lc_7.

9. Using the **Raster Calculator** tool again, multiply the lc_7 raster layer by the stream raster layer. Click Evaluate and save the new layer to the Scenario_B folder. Name this file lc_8.

10. Using the **Reclassify** tool under the **Spatial Analyst** toolbar, reclassify the lc_8 layer so that the stream class does not have a value of 0. For this example, the stream value was reclassified to 5 (all other class values should stay the same) and the layer was named lc_9.

11. Convert the lc_9 raster layer to a feature layer using the **Spatial Analyst** toolbar and save the new layer to the Scenario_B folder.

Intersect Polygon and landcover layers

1. Add the Grid_70_clip feature layer that was created for Scenario A to the Table of Contents window.

2. In ArcToolbox, navigate to **Analysis Tools**, **Overlay**, and finally the **Intersect** tool. Intersect the Grid_70_clip and lc_9 feature layers. Name the new file lc_9_grid and save it to the Scenario_B folder.

3. Using the **Select by Attributes** tool, select all of the polygons in this new layer that are found only in the agriculture class (NLCD code 82). Save this selection as a new layer in the Scenario_B folder. For this example, this layer was named lc_ag_grid.

4. Under the **Hawth's Tools** tab, navigate to **Table Tools**, then select **Add Area Perimeter Fields to Table** to determine the size of each polygon.

5. The **Select by Attributes** tool can be used again to create a layer that contains only 0.5 Ha squares (polygons) or a range of squares using the > = and < = signs. For this example, all polygons equal to 0.499 hectares were selected and saved as a new layer called lc_ag_fin.

Table 3: Scenario B additional classes

	Percent of Total Landcover	Hectares	Number of features needed in final layer
Corn-soybeans (CT)	57%	8955	NA (remainder of cultivated area)
Corn-soybeans (CN)	0%	0	0
Corn-sugar beets (CN)	6%	1000	2000
Small grains-alfalfa (CT)	2.7%	426	852
Riparian buffer	1.8%	286	NA

Hawth's Tools to create selection from feature layer

1. Under the **Hawth's Tools** tab, navigate to **Sampling Tools**, and then select **Create Random Selection.**

2. Select the lc_9_ag_fin layer as the input layer. In the number of features box, enter 2000, which is the number of features that needs to be selected to sum to 1000 hectares for the corn-sugar beet (CN) class. Hit ok.

3. Create a new layer from the selected features. Name this layer Corn_Sug_CN_B and save it to the Scenario_B folder.

4. The next step involves a union of the Corn_Sug_CN_B and the lc_ag_fin layers so that the features remaining in the lc_ag_fin layer that were not selected for the Corn-sugar beet layer can be used for the small grains-alfalfa class that needs to be created next.

5. In ArcToolbox, navigate to **Analysis Tools**, then **Overlay**, and click on **Union**.

6. Select the Corn_Sug_CN_B and lc_9_ag_fin layers in the input window. In the Output Feature Class window, navigate to the Scenario_B folder, and name the output file 2000_union. Click ok.

7. In the Table of Contents window, right click on the new layer and navigate to **Symbology**. Select Unique values under Category and in the Value Field window select GRIDCODE. The two fields will now be visible. Features with a value of 0 represent the remaining features in the lc_9_ag_fin layer that can be selected and saved separately for the Corn-sugar beet layer.

8. Using the **Select by Attributes** tool, select all features in the 2000_union layer that have a value of 0. Save this selection as a new layer. Name this new layer lc_9_ag2 and save it in the Scenario_B folder.

9. Follow the same procedure outlined in steps 1 – 3 above to create the small grains-alfalfa layer. Use lc_9_ag2 as the input layer in **Hawth's Tools** and select 852 features. Name this file smgrain_alf and save it to the Scenario_B folder.

10. Using the **Spatial Analyst** toolbar, convert the Corn_Sug_CN_B and smgrain_alf feature layers to raster layers. Name these new files Sug_CN_B_r and smgrain_r, respectively and save them in the Scenario_B folder.

11. Using the **Spatial Analyst** toolbar, reclassify each of these new raster layers to binary rasters. Old data values for the agricultural class should be set to 0 and NoData should be set to 1. Do this for each of the new raster layers, name the files SugCNBin_B and SmgrainBin_B, respectively and save them to the Scenario_B folder.

12. To add one of the new agricultural raster layers to the lc_9 raster layer, open the raster calculator tool under the **Spatial Analyst** toolbar. Chose the lc_9 layer, the multiply sign, and then select one of the binary agricultural raster layers. Click Evaluate.

13. The new layer will appear in the Table of Contents as Calculation. Right click on this layer and navigate to **Data**, then **Export**. Save this new file in the Scenario_B folder as a GRID file and name it appropriately. For this example, the file was named lc_9_sug_cn.

14. The lc_9_sug_cn layer needs to be reclassified before it can be merged with the small grains-alfalfa layer (SmgrainBin_B). Keep all class values the same in this step and only reclassify the value for Corn-sugar beets (CN) from 0 to a number not already being used. For this example, the value was reclassified to 7. Save this new layer as lc_9__sug_cn_r and save it to the Scenario_B folder.

15. Open the **Raster Calculator** tool again, this time selecting the lc_9_sug_cn_r layer, then the multiply sign, and finally, the other binary agricultural layer (here, SmgrainBin_B). Click Evaluate and follow the same procedure as above to save the Calculation as a new file. For this example the file was named lc_scenario_B.

16. It may be helpful to reclassify this layer as well so that all classes have numeric values (i.e. so that the small grains-alfalfa class doesn't have a value of 0). For this example, the reclassify tool was used to reclassify this class to 8. The new layer was saved as Scenario_B_r.

17. Finally, add in the C Factor values for each class in the Scenario_B_r raster layer. To do this, follow the same procedure used in scenario A so that the C factors are in the Value field.

Table 4: Scenario B Class Definitions and C Factors

Classification	NLCD 2006 Code or Attribute Value	C Factor
Marginal Cropland	2	4500
CREP Riparian	3	10
CREP Wetland Reserve	4	10
Streams	5	0
Corn-Sugar Beets (CN)	7	6,000
Small Grains-Alfalfa (CT)	8	1,500
Permanent Wetland Reserve	10	10
Open Water	11	0
Riparian Buffer	12	50
Developed, Open Space	21	30
Developed, Low Intensity	22	0
Developed, Medium Intensity	23	0
Developed, High Intensity	24	0
Barren Land	31	3,000
Deciduous Forest	41	20
Grassland/Herbaceous	71	50
Pasture/Hay	81	500
Corn-soybeans (CT)	82	4,500
Woody wetlands	90	10
Emergent herbaceous wetlands	95	10

Create Scenario C

The main changes to the landscape in scenario C include a significant increase in small grains-alfalfa under conservation tillage, with a large reduction in area under corn-soybeans and corn-sugar beet rotations. The 30 meter riparian buffer created in scenario B was also incorporated into scenario C. Finally, scenario C also includes wetland restoration (through the creation of wetland buffers), which also decreases the area under cultivation. In order to prevent the addition of wetland buffers from removing cells in permanent classes, wetland buffers should be created first.

Create Wetland Buffers

1. To create the wetland buffers, use the lc_9 raster layer that was created for scenario B. The lc_9 layer contains the 30 meter riparian buffers which will also be a part of the landscape for scenario C.

2. Using the **Spatial Analyst** toolbar, convert the lc_9 raster layer to a feature layer. Name this file lc_9_feat and save it to the Scenario_C folder. Display the classes in this file using the GRIDCODE value so that individual wetlands can be selected and buffered.

3. Start editing this layer using the **Editor** toolbar. Individual wetlands can be selected using the **Selection** tool. For this analysis, approximately 34 wetlands were selected from the Emergent Herbaceous Wetlands class, which were located within the Cultivated Crops class. Wetlands were selected only if they did not share borders with other classes.

4. Once all wetlands to be buffered are selected, select the **Buffer** tool under the **Editor** toolbar. Any buffer size can be input into the **Buffer** dialog box. For this analysis, a buffer size of 60 meters was used in order to add (restore) wetlands to the landscape. A total of 222 hectares of emergent herbaceous wetlands were added for this analysis. The final layer was named lc_9_wet_r.

Intersect Polygon and landcover layers

1. Add the Grid_70_clip feature layer that was created for scenario A to the Table of Contents window.

2. In ArcToolbox, navigate to **Analysis Tools**, **Overlay**, and finally the **Intersect** tool. Intersect the Grid_70_clip and lc_9_wet feature layers. Name the new file lc_9_wet_grid and save it to the Scenario_C folder.

3. Using the **Select by Attributes** tool, select all of the polygons in this new layer that are found only in the agriculture class (NLCD code 82). Save this selection as a new layer in the Scenario_C folder. For this example, this layer was named lc_9_w_ag_gr.

4. Under the **Hawth's Tools** tab, navigate to **Table Tools**, then select **Add Area Perimeter Fields to Table** to determine the size of each polygon.

5. The **Select by Attributes** tool can be used again to create a layer that contains only 0.5 Ha squares (polygons) or a range of squares using the > = and < = signs. For this example, all polygons equal to 0.499 hectares were selected and saved as a new layer called lc_9_w_ag_gr2.

Table 5: Scenario C additional classes

	Percent of Total Landcover	Hectares	Number of features needed in final layer
Corn-soybeans (CT)	23%	3600	7200
Corn-soybeans (CN)	0%	0	0
Corn-sugar beets (CN)	4%	680	1360
Small grains-alfalfa (CT)	38%	5876	NA (remainder of cultivated area)
Riparian buffer	1.8%	286	NA
Emergent herbaceous wetlands	10%	1609	NA

Hawth's Tools to create selection from feature layer

1. Under the **Hawth's Tools** tab, navigate to **Sampling Tools**, and then select **Create Random Selection**.

2. Select the lc_9_w_ag_gr2 layer as the input layer. In the number of features box, enter 7200, which is the number of features that needs to be selected to sum to 3600 hectares for the corn-soybean (CT) class. Hit ok.

3. Create a new layer from the selected features. Name this layer Corn_Soy_CT_C and save it to the Scenario_C folder.

4. The next step involves a union of the Corn_Soy_CT_C and the lc_9_w_ag_gr2 layers so that the features remaining in the lc_9_w_ag_gr2 layer that were not selected for the Corn-soybean layer can be used for the corn-sugar beet class that needs to be created next.

5. In ArcToolbox, navigate to **Analysis Tools**, then **Overlay**, and click on **Union**.

6. Select the Corn_Soy_CT_C and lc_9_w_ag_gr2 layers in the input window. In the Output Feature Class window, navigate to the Scenario_C folder, and name the output file 7200_union. Click ok.

7. In the Table of Contents window, right click on the new layer and navigate to **Symbology**. Select Unique values under Category and in the Value Field window select GRIDCODE. The two fields will now be visible. Features with a value of 0

represent the remaining features in the lc_9_w_ag_gr2 layer that can be selected and saved separately for the Corn-sugar beet layer.

8. Using the **Select by Attributes** tool, select all features in the 7200_union layer that have a value of 0. Save this selection as a new layer. Name this new layer lc_ag_select and save it in the Scenario_C folder.

9. Follow the same procedure outlined in steps 1 – 3 above to create the corn-sugar beet layer. Use lc_ag_select as the input layer in **Hawth's Tools** and select 1360 features. Name this file Corn_Sug_CN_C and save it to the Scenario_C folder.

10. Using the **Spatial Analyst** toolbar, convert the two newly created agriculture feature layers to raster layers. Name these new files Sug_CN_C_r and Soy_CT_C _r, respectively and save them in the Scenario_C folder.

11. Using the **Spatial Analyst** toolbar, reclassify each of these new raster layers to binary rasters. Old data values for the agricultural class should be set to 0 and NoData should be set to 1. Do this for each of the new raster layers, name the files SugCNBin_C and SoyCTBin_C, respectively and save them to the Scenario_C folder.

12. To add one of the new agricultural raster layers to the lc_9_wet_r raster layer, open the **Raster Calculator** tool under the **Spatial Analyst** toolbar. Chose the lc_9_wet_r layer, the multiply sign, and then select one of the binary agricultural raster layers. Click Evaluate.
13. The new layer will appear in the Table of Contents as Calculation. Right click on this layer and navigate to Data, then Export. Save this new file in the Scenario_C folder as a GRID file and name it appropriately. For this example, the file was named lc_wet_soy_C.

14. The lc_wet_soy_C layer needs to be reclassified before it can be merged with the corn-sugar beet layer. Keep all class values the same in this step and only reclassify the value for Corn-soybeans (CT) from 0 to 82 as this is the class value for the previous scenarios. The old values equal to 82 in this layer should also be reclassified to a value of 8, which will represent the small grains-alfalfa class. Save this new layer as lc_w_soy_ct_r and save it to the Scenario_C folder.

15. Open the **Raster Calculator** tool again, this time selecting the lc_w_soy_ct_r layer, then the multiply sign, and finally, the other binary agricultural layer (here, SugCNBin_C). Click Evaluate and follow the same procedure as above to save the Calculation as a new file. For this example the file was named lc_Scenario_C.

16. It may be helpful to reclassify this layer as well so that all classes have numeric values (i.e. so that the corn-soybean class doesn't have a value of 0). For this example, the reclassify tool was used to reclassify this class to 7. The new layer was saved as Scenario_C_r.

17. Finally, add in C Factor values for each class in the Scenario_C_r raster layer. To do this, follow the same procedure used in scenario A so that the C factors are in the Value field.

Table 6: Scenario C Class Definitions and C Factors

Classification	NLCD 2006 Code or Attribute Value	C Factor
Marginal Cropland	2	4500
CREP Riparian	3	10
CREP Wetland Reserve	4	10
Streams	5	0
Corn-Sugar Beets (CN)	7	6,000
Small Grains-Alfalfa (CT)	8	1,500
Permanent Wetland Reserve	10	10
Open Water	11	0
Riparian Buffer	12	50
Developed, Open Space	21	30
Developed, Low Intensity	22	0
Developed, Medium Intensity	23	0
Developed, High Intensity	24	0
Barren Land	31	3,000
Deciduous Forest	41	20
Grassland/Herbaceous	71	50
Pasture/Hay	81	500
Corn-soybeans (CT)	82	4,500
Woody wetlands	90	10
Emergent herbaceous wetlands	95	10

Create Scenario D

Scenario D is based on increased vegetative cover and wetland restoration for biodiversity conservation. Scenario D extends scenario C by replacing cultivated lands with grassland, widening riparian buffers to 90 meters, and planting all row crops with cover crops. Scenario D also includes the addition of 222 hectares of wetlands (as in Scenario C), which similarly decreases the area under cultivation.

Increase riparian buffer width

1. The first step in creating scenario D is to increase the riparian buffer width, which was first created for scenario B. Add the landcover <u>feature layer</u> that was used in scenario C, which contains the edited streams class and the wetland buffers. For this analysis the layer was named lc_9_wet_r_f.

2. Using the **Select by Attributes** tool, select all of the riparian buffer features (GRIDCODE = 12).

3. Start the **Editor tool** and navigate to the **Buffer tool**. In the dialog box that opens, enter 60. A 60 meter buffer will be created along the 30 meter stream buffer in this feature layer (in total, the riparian buffer will equal 90 meters). Save the edits.

4. Convert this feature layer using the **Spatial Analyst toolbar**, and save the new file to the Scenario_D folder.

5. Using the **Spatial Analyst toolbar**, reclassify the new raster layer so that the new riparian buffer has a value of 12, rather than 0. Keep all other class values the same. Save the new file to the Scenario_D folder and name it appropriately. For this analysis, the file was named lc_90.

6. Finally, use **raster calculator** to add the binary streams layer (created and used in previous scenarios) to this landcover layer. Name the final raster layer as strm_90_fin and save it to the Scenario_D folder. The layer will now contain the new 90 meter riparian buffer as well as the restored wetlands (created in scenario C).

7. **Reclassify** this new layer so that the streams class has a value of 5 rather than 0. Save the reclassified file as strm_90_fin2 and save it to the Scenario_D folder.

Intersect Polygon and landcover layers

1. Add the Grid_70_clip feature layer that was created for Scenario A to the Table of Contents window.

2. **Convert** the strm_90_fin raster layer to a feature layer. Name the new file strm_90_feat and save it to the Scenario_D folder.

3. In ArcToolbox, navigate to **Analysis Tools**, **Overlay**, and finally the **Intersect tool**. Intersect the Grid_70_clip and strm_90_fin2 feature layers. Name the new file **lc_90_grid** and save it to the Scenario_D folder.

4. Using the **Select by Attributes tool**, select all of the polygons in this new layer that are found only in the agriculture class (NLCD code 82). Save this selection as a new layer in the Scenario_D folder. For this example, this layer was named **lc_90_ag_gr**.

5. Under the **Hawth's Tools** tab, navigate to Table Tools, then select **Add Area Perimeter Fields** to table to determine the size of each polygon.

6. The **Select by Attributes tool** can be used again to create a layer that contains only 0.5 Ha squares (polygons) or a range of squares using the > = and < = signs. For this example, all polygons equal to 0.499 hectares were selected and saved as a new layer called **lc_90_ag_gr2**.

Hawth's Tools to create selection from feature layer

1. The same procedure used for previous scenarios can be used here to select a random sample of features from the **lc_90_ag_gr2** layer.

2. For this analysis, 8000 features were selected to represent the small grains-alfalfa class and 4000 features were then selected for the grassland class. The new grassland class was eventually merged with the existing NLCD 2006 grassland class (GRIDCODE = 71). The remaining agricultural area is made up of corn-soybeans (CT) and corn-sugar beets (CN) planted with a cover crop. See Table 7 for details on the additional factors.

3. The final scenario D raster layer was named **scenario_d_r**.

4. Finally, add in the classification names and C Factor values for each class in the Scenario_D_r raster layer. To do this, follow the same procedure used in scenario A. Values are listed in Table 8.

Table 7: Scenario D additional classes

	Percent of Total Landcover	Hectares	Number of features needed in final layer
Corn-soybeans (CT) and Corn-sugar beets (CN) – planted with cover crop*	23%	3575	NA (remainder of cultivated area)
Corn-soybeans (CN)	0%	0	0
Small grains-alfalfa (CT)	25%	4000	8000
Riparian buffer	6%	979	NA
Emergent herbaceous wetlands	10%	1609	NA
Grassland**	16%	2000	4000

*Corn-soybean and corn-sugar beat classes were lumped together for this scenario because their C Factor is the same under cover crop planting

**2000 Ha of grassland were added to this scenario to bring the total to 2470 (470 Ha were already on the landscape)

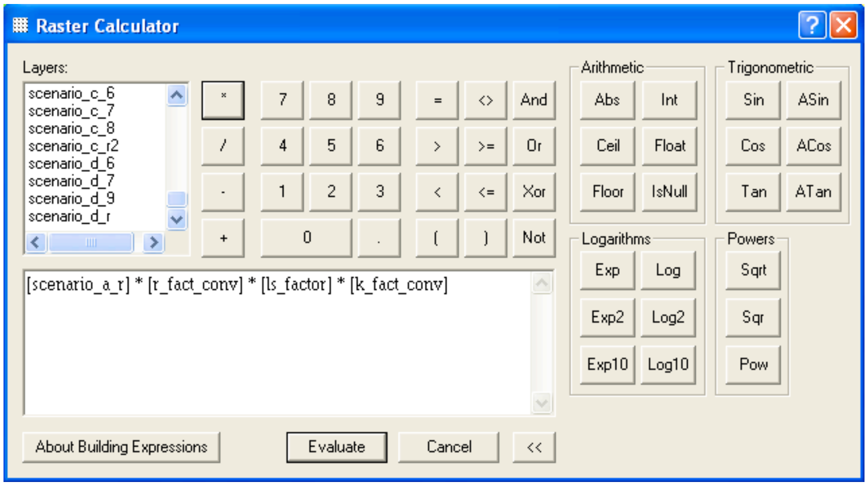
Table 8: Scenario D Class Definitions and C Factors

Classification	NLCD 2006 Code or Attribute Value	C Factor
Marginal Cropland	2	4500
CREP Riparian	3	10
CREP Wetland Reserve	4	10
Streams	5	0
Small Grains-Alfalfa (CT)	8	1,500
Permanent Wetland Reserve	10	10
Open Water	11	0
Riparian Buffer	12	50
Developed, Open Space	21	30
Developed, Low Intensity	22	0
Developed, Medium Intensity	23	0
Developed, High Intensity	24	0
Barren Land	31	3,000
Deciduous Forest	41	20
Grassland/Herbaceous	71	50
Pasture/Hay	81	500
Corn-soybeans (CT)/Corn-sugar beets (CN) with Cover Crop	82	1,000
Woody wetlands	90	10
Emergent herbaceous wetlands	95	10

Step 9: Run the model in ArcGIS

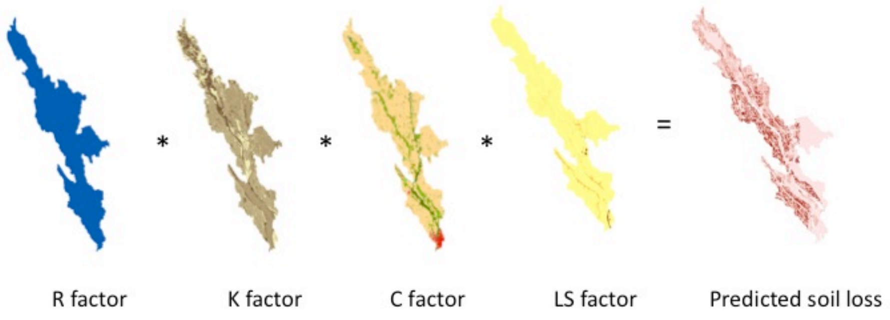
1. To run one of the scenarios created in the previous steps, open the **Raster Calculator** tool under the **Spatial Analyst** toolbar.

2. In the **Raster Calculator Layers** window, build an expression to represent the one below. Each factor layer (R, K, and LS) should appear along with the scenario layer (A, B, C, or D) which represents the C factor to be run in the model. These layers are multiplied together to produce a raster grid layer which will appear in the table of contents in the open ArcMap session as Calculation.



```
[scenario_a_r] * [r_fact_conv] * [ls_factor] * [k_fact_conv]
```

Figure 1: Graphic representation of the RUSLE model.

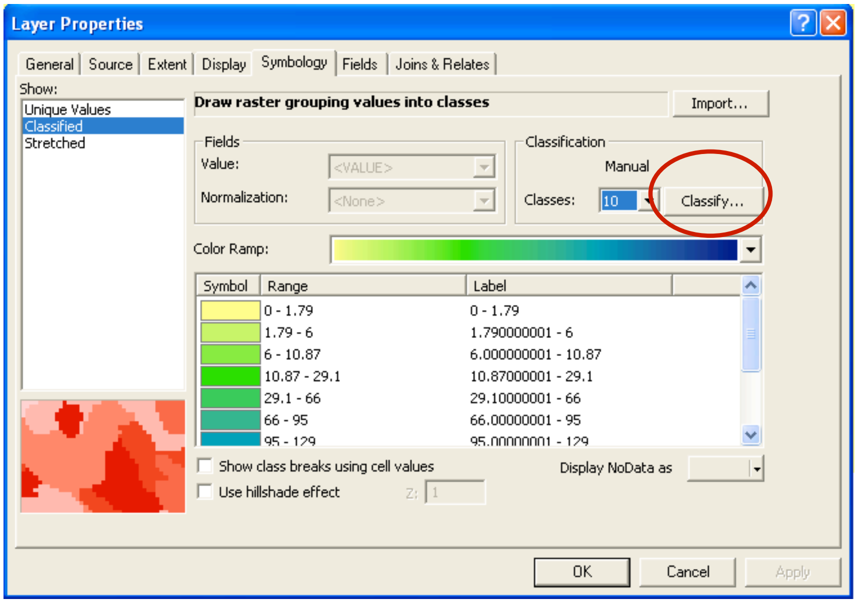


3. Right click on the Calculation output file, scroll to **Data**, then **Export Data**. Name the new file appropriately (for example, A_results_1) and save it to the respective scenario folder.

4. Converting the values in the output raster grid files from tons/hectare/year/cell to the appropriate units (tons/hectare/year) is tedious.
    a. Because the C and K factor layers were multiplied by 10,000, the predicted soil loss layer results will be magnified by a factor of 100,000,000.
    b. The results layers must also be multiplied by .09 (cell/hectare) in order to eliminate the hectare units.
        i. Create an equation in **Raster Calculator** to divide the respective result layer by 9,000,000 (100,000,000 x .09).
        ii. After making this new file permanent, use **Raster Calculator** again to divide the layer by the total number of cells in the study area to eliminate the per cell units.
        iii. After making this new file permanent, use Raster Calculator again to multiply the new layer by 11.11 (10,000 m^2/900 m^2) to scale to tons/hectare/year.

5. To extract relevant information from the resulting soil loss layers, right click on the layer and scroll to **Properties**.

6. Select the Classified option. A window will open asking whether you want to Build Histograms. Click Yes.



Show:
Unique Values
Classified
Stretched

Draw raster grouping values into classes

Fields
Value: <VALUE>
Normalization: <None>

Classification
Manual
Classes: 10

Color Ramp:

Symbol	Range	Label
🟨	0 - 1.79	0 - 1.79
🟩	1.79 - 6	1.790000001 - 6
🟩	6 - 10.87	6.000000001 - 10.87
🟩	10.87 - 29.1	10.87000001 - 29.1
🟩	29.1 - 66	29.10000001 - 66
🟩	66 - 95	66.00000001 - 95
🟦	95 - 129	95.00000001 - 129

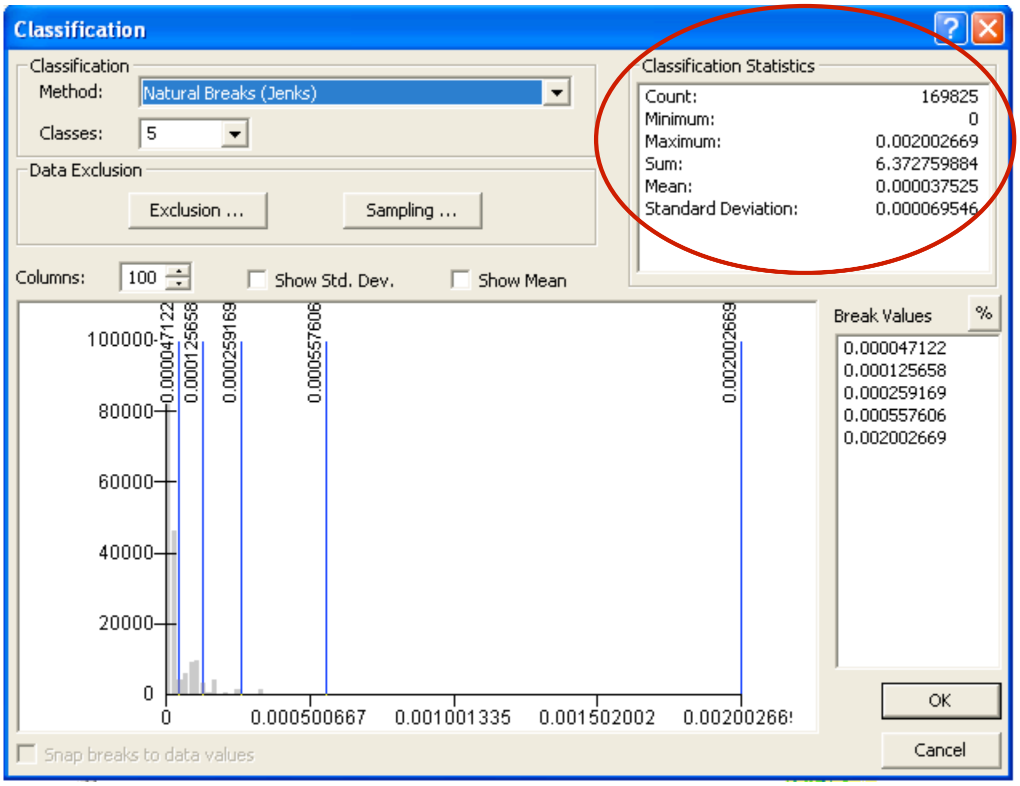
☐ Show class breaks using cell values

Display NoData as

☐ Use hillshade effect Z: 1

7. In the Layer Properties window that is open, click on the **Classify** button. In the window that opens, a number of statistics for this layer will appear in the upper right corner.

8. These statistics represent the count (total cells) maximum, minimum, mean, sum, and standard deviation of predicted soil loss per unit area.



Classification

Classification

Method: Natural Breaks (Jenks)

Classes: 5

Columns: 100

☐ Show Std. Dev.

☐ Show Mean

Classification Statistics

Count:	169825
Minimum:	0
Maximum:	0.002002669
Sum:	6.372759884
Mean:	0.000037525
Standard Deviation:	0.000069546

Break Values

0.000047122
0.000125658
0.000259169
0.000557606
0.002002669

☐ Snap breaks to data values

9. The **Layer Properties** window and the **Classify** tool can be used to display the data in a manner that is most useful for the user. In the Classify window, a number of options exist to classify the data based on different breaks in the data. A common approach is to manually choose the break points or to use the natural breaks option. For LSP’s purposes, it may be most useful to manually classify the data such that areas of high predicted soil loss are highlighted. These areas could then be targeted for specific management actions.