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EFFECTS OF SEDIMENTS ON BMPS FOR HIGHWAY RUNOFF CONTROL

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EFFECTS OF SEDIMENTS ON BMPS FOR HIGHWAY RUNOFF CONTROL

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EFFECTS OF SEDIMENTS ON BMPS FOR HIGHWAY RUNOFF CONTROL

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Numerous studies conducted on highway stormwater runoff and its control with Best Management Practices (BMPs) indicate that sediment is the major pollutant that affects performance and longevity of BMPs. Currently, there are several knowledge gaps related to the effects of sediments on highway BMPs: a) how much sediment will be generated by a construction site by a section of highway with its surrounding watershed under different conditions; b) how sediment is intercepted by different BMPs with or without pretreatment sections; and c) what are the effects of these sediments on BMPs' hydraulic behavior, longevity, and pollutants removal or release. The objectives of this study are to: 1) develop models to predict both surface runoff and sediment yield from highway systems under different conditions; and 2) evaluate how to incorporate models into design and management of BMPs for highway runoff control.

RUSLE2 was used to estimate sediment yield for different settings (e.g., construction sites, different highway sections) under different environmental (e.g., soils, vegetation, slopes) and weather conditions (e.g., different rain events). Several highway sites across the state were selected to model runoff and sediment delivery under various construction scenarios. Several BMP designs were modeled at each of the highway sites to assess how the sediments would affect longevity of the BMP. Results indicate that BMPs reduce pollutants within channels. The data also points to BMPs on stabilized sites having higher efficiencies and longer lifespans. The

developed models will assist in the planning, design and management of structural BMPs for highway runoff control.

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Chapter 1 Introduction

1.1 Background

Erosion is a natural phenomenon that occurs when soils and sediments are moved by wind, glacial motion, water flow, and raindrop impact. Rain on the ground surface causes two types of erosion, interrill and rill. "Inter-rill erosion is the movement of soil by rain splash and its transport by this surface flow. Rill erosion is erosion by concentrated flow in small rivulets" (Penn State 2015).

The sediment eroded may carry additional pollutant load from the hillside abutting the highway. Pollutants could be nitrogen, phosphorus, carbon, or other roadway pollutants that wash off of the hillside. It is important to treat the soil and pollutant load prior to entering a water body. This treatment process prevents pollutants from getting into water bodies and adversely affecting plants and wildlife. For stormwater runoff, treatment is generally accomplished through implementation of best management practices, BMPs.

The Clean Water Act (CWA) was established to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters," through processes that reduce the pollutant loads within the water bodies (U.S. EPA 1972). The Clean Water Act mandates the application of BMPs on construction sites larger than one acre and requires a National Pollutant Discharge Elimination System (NPDES) permit. Under Section 404, highway sites fall into infrastructure development, and must be in compliance with the CWA (U.S. EPA 2014_c).

1.2 Objectives

The goals of this project were to estimate the amount of erosion from roadway construction sites and to evaluate the impacts of sediments on BMPs treating runoff from those sites. RUSLE2 (USDA 2008) was used to estimate the annual erosion and sediment yield from the construction sites considering various erosion control management methods that might be used in Nebraska. Once the sediment yield was found, a model was designed to estimate the sediment capture efficiency of different BMPs and to evaluate the lifespan of each BMP before it is filled with sediment.

The two major objectives of this project were:

- Develop a model to predict sediment yield from highway construction sites under different erosion management conditions.
- Develop a model to estimate the lifespan of sediment control BMPs treating runoff from highway construction sites.

The first objective of developing a model was done by evaluating existing erosion modelling software, and identifying a model that can be easily used by highway designers to estimate surface runoff and sediment yield. The second objective was completed by developing a model that considers the sediment load to the BMP and the sediment trapping efficiency of the BMP to estimate the time before the BMP would fill with sediment.

The BMPs selected for evaluation were: detention ponds, infiltration trenches, grass lined swales, grass lined swales with rock check dams, and bioretention areas. Each respective BMP requires different measures of efficiency to accurately assess its effectiveness and lifespan.

Chapter 2 Literature Review

2.1 Soil Erosion and Impacts

Starting from as long ago as 4,000 years, the ancient Incas of Peru were utilizing very sophisticated farming practices to reduce erosion. This was done with terracing very steep slopes by building walls down the hillside and hauling tons of topsoil up to 700 miles to the fields. These terraces were constructed so well that even now they are producing crops (Kell 1938).

"In the mid 1940's, W.D. Ellison defined erosion as, "…a process of detachment and transport of soil particles." Detachment is the separation of soil particles from the soil mass and is expressed in units of mass/area. Soil particles separated from the soil mass are referred to as sediment. Sediment movement downslope is sediment transport, described as sediment load, expressed in units of mass/width of slope" (USDA 2008).

There are many problems with erosion on and off site. On site, these are loss of topsoil, loss of fertilizers, and decrease in crop yields due to decreasing soil productivity. Off-site the problems are pollution of water bodies, surface water with suspended solids creating muddy water bodies, and often requiring dredging operations to remove sediments and the pollutant loads settling in the water bodies (Verstraeten et al. 2002).

"Highway departments spend thousands of dollars every year cleaning away the debris and soil washed onto the roads from adjoining fields. The washing of fertile soil from fields onto the highways is a direct loss of the producing power and capital of the farmer, and its removal is a public expense that should be avoided. From a field of 15 acres in western Pennsylvania it was estimated by one of the highway foremen that approximately 60 tons of soil, were removed by one rain. Most of this soil came from a cultivated field in corn where the rows were not on the contour. Had this field been protected by alternate close-growing strips and cultivated on the contour the loss to the farmer would have been prevented, and the State would have been saved the expense of removing the soil from the highway" (Kell 1938).

Farmers were encouraged to utilize grassed swales or biofiltration systems as early as 1938, by planting grass or leaving prairie in the natural drainage channels instead of plowing and planting there. It was also recommended at that time to use buffer strips through a field and to use strip cropping along the contours of the field (Kell 1938).

2.2 Best Management Practices

"On September 1, 1978, EPA proposed regulations (43 FR 39282) addressing the use of procedures and practices to control discharges from activities associated with or ancillary to industrial manufacturing or treatment processes. The proposed rule indicated how BMPs (Best Management Practices) would be imposed in NPDES permits to prevent the release of toxic and hazardous pollutants to surface waters. The regulations (40 CFR Part 125, Subpart K, Criteria and Standards for Best management Practices Authorized under Section 304(e) of the CWA) were proposed in August 21, 1978, in the NPDES regulations (43 FR 37078)" (U.S. EPA 1994).

The EPA defines best management practices as: "a permit condition used in place of or in conjunction with effluent limitations to prevent or control the discharge of pollutants. BMPs may include a schedule of activities, prohibition of practices, maintenance procedure, or other management practice." (U.S. EPA 2013_b).

The type of pollution found on construction and highway sites is non-point source pollution. Non-point source pollution is defined as: pollution from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrologic modification (EPA 2014). While the pollutants in the non-point source pollution may vary between general sites and highway sites, the pollutants are addressed the same. The EPA requires that all construction sites have BMPs in place during construction and after construction on newly disturbed sites of one acre or more.

2.3 BMP Types

BMPs are generally classified as either non-structural or structural in nature. Non-structural BMPs are a function of how an operation is done, such as sweeping streets to remove sediments before they can be transported to a waterway. Non-structural BMPs tend to be low impact and may be practices such as: low or no-till operations, limits on amount of impervious areas and prescribed burns in forested areas (Ice 2004). Additional examples of non-structural BMPs are: public education, public participation and implementation, monitoring of illicit discharge, and generally accepted good housekeeping of sites. Some BMPs are structural, such as a detention pond used to settle and remove sediment from stormwater runoff. These structural BMPs may be construction or post-construction BMPs.

Structural BMPs are physical devices that mitigate pollution. They are designed to catch and allow pollutants to settle out or filter the pollutants in runoff and slow the flow velocity. There are multiple structural BMPs, such as: silt fence, check dams, basins and ponds, and rock lined swales (MDOT 2015).

According to the EPA, there are many construction BMPs available (**Table 2. 1**) to manage stormwater runoff during construction activities (U.S. EPA 2014).

Table 2. 1 Recommended Stormwater BMPs (U.S. EPA 2014)

Erosion Control	Chemical Stabilization
	Compost Blankets
	Dust Control
	Geotextiles
	Gradient Terraces
	Mulching
	Riprap
	Seeding
	Sodding
	Soil retention
	Soil roughening
	Temporary slope drain
	Temporary stream crossings
	Wind fences and sand fences
Runoff Control	Check dams
	Grass lined channels
	Permanent slope diversions
	Temporary diversion dikes
Sediment control	Brush barrier
	Compost filter berm
	Compost filter sacks
	Construction entrances
	Fiber rolls
	Filter berms
	Sediment basins and rock dams
	Sediment filters and sediment chambers
	Sediment traps
	Silt fences
	Storm drain inlet protection
	Straw or hay bales
	Vegetated buffer

Additionally, there are many post-construction BMPs (**Table 2. 2**) to manage stormwater (U.S. EPA 2014_c):

Table 2. 2 Recommended Post-Construction BMPs (U.S. EPA 2014_c)

Innovative BMPs for Site Plans	Alternative Turnarounds
	Conservation Easements
	Development Districts
	Eliminating Curbs and Gutters
	Green Parking
	Green Roofs
	Infrastructure Planning
	Low Impact Development (LID) and Other Green Design Strategies
	Narrower Residential Streets
	Open Space Design
	Protection of Natural Features
	Redevelopment
	Riparian/Forested Buffer
	Street Design and Patterns
	Urban Forestry
Infiltration	Grassed Swales
	Infiltration Basin
	Infiltration Trench
	Permeable Interlocking Concrete Pavement
	Pervious Concrete Pavement
	Porous Asphalt Pavement
Filtration	Bioretention (Rain Gardens)
	Catch Basin Inserts
	Sand and Organic Filters
	Vegetated Filter Strip
Retention/Detention	Dry Detention Ponds
	In-Line Storage
	On-Lot Treatment
	Stormwater Wetland
	Wet Ponds
Other	Alum Injection
	Manufactured Products for Stormwater Inlets

There are many factors that can affect the selection of best management practices. Some of these factors include: cost, land availability, topography, target pollutant, watershed size, land cover, and soil type (Hunt and White 2001). All of these should be considered prior to initiating design and construction of runoff management systems.

2.4 BMP Pollutant Removal

BMPs are typically measured by their pollutant removal ability. The pollutants that the EPA found in the Nationwide Urban Runoff Program (NURP) study, a comprehensive study of runoff that occurred between 1978 and 1983, are listed below (U.S. EPA 1983):

- Total Suspended Solids (TSS)
- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Total Phosphorus (TP)
- Soluble Phosphorus (SP)
- Total Kjeldahl Nitrogen (TKN)
- Nitrate + Nitrite (N)
- Total Copper (Cu)
- Total Lead (Pb)
- Total Zinc (Zn)

According to the U.S. EPA, the common contaminants found in stormwater runoff are (U.S. EPA 1999_a):

- Sediments and Floatables
- Pesticides and Herbicides
- Organic materials
- Metals
- Oil and Grease/ Hydrocarbons
- Bacteria and Viruses
- Nitrogen and Phosphorus

Different BMPs have different target pollutants. Vegetated filter strips are effective at reducing: runoff volume, peak flow, and sediments through filtration and sorption and biological processes. Bioretention areas, or rain gardens, target: runoff volume reduction, sediments, and peak flow reduction through filtration and sorption, biological processes, and plant uptake. A gravel trench, or rock lined swale, effectively reduces: runoff volume, peak flow and sediments through filtration and sorption and biological processes. Infiltration basins target: runoff volume reduction, peak flow reduction, and sediments through filtration and sorption and biological processes. Dry water quality swales, or grassed swales, effectively reduce: volume, peak flow, sedimentation, filtration and sorption, and biological processes (Geosyntec 2013). Stormwater detention ponds target sedimentation, metals, nutrients, hydrocarbons, oxygen demanding material, bacteria, and dissolved nutrients (MNPCA 2000).

2.4.1 Detention Pond

Detention ponds are designed to reduce peak flows from a rain event (Nguyen 2010). This is done by storing excess runoff volume and slowing the discharging of that water, allowing hydraulic conditions downstream to remain steady (FHWA 2014). The first flush of runoff contains the majority of pollutants, so having a long enough detention time in the basin to capture the first flush is critical to allowing the pollutant load, including: nutrients, heavy metals, and sediments, to settle (FHWA 2014).

A negative aspect of detention ponds is they require large footprints. Additionally, no part of a detention pond may be below the groundwater table (Nguyen 2010). Public safety is important with basins because there is a risk of individuals falling in (FHWA 2014). At times water in ponds will heat up, and as it is discharged may alter the temperature of a main waterway, potentially affecting cold water fisheries. Regular maintenance, including inspection and mowing of buffer areas, will improve the operation of the pond (U.S. EPA 1999_d).

A design recommendation is to have an upstream pre-treatment system in place (UDFCD 2010). The depth should not exceed 20 feet at any point within the pond, to allow all stored water to discharge within the desired time (U.S. EPA 1999_d).

Retention time within the basin should be 72 hours. The first flush is always targeted to be detained within the pond for as long as possible, but if a small storm is encountered, the first flush may not effectively be treated. If not designed properly, the first flush may enter the system, and shortly thereafter begin to discharge, allowing the most polluted runoff to discharge into a natural channel (Barrett 2008). Trash racks should be considered to prevent debris from discharging from the basin (Beaupre et al. 2010).

2.4.2 Infiltration Trench

In many applications, infiltration of runoff is the preferred method of flow control (Nguyen 2010). Infiltration trenches address most of the contaminants found in stormwater (FHWA 2014). Those contaminants include: sediments, metals, nutrients, bacteria, biochemical and chemical oxygen demanding substances (MNPCA 2000). However, a site must be suitable for infiltration by having an infiltration rate of greater than 0.5 inches per hour (Nguyen 2010).

Two types of infiltration trenches are subsurface and surface infiltration trenches. The subsurface infiltration trench is relatively expensive, due to the construction of an underground pit filled with some media, such as gravel; whereas, the surface infiltration trench is more cost effective and well suited for highway sites (FHWA 2014). In climates with harsh winters, water that enters the infiltration trench may freeze, rendering the trench ineffective, so it is recommended that the trench be below the freeze line (FHWA).

With certain geographic conditions, such as if the water table or bedrock is within three feet of the bottom of the trench, infiltration trenches may not be suitable to treat or trap pollutants before reaching the water table or bedrock (MNPCA 2000). Infiltration trenches may not be suitable during construction activities, because they will rapidly fill with sediments, rendering them ineffective quickly after construction. Once a site is entirely stabilized, implementation of this system is encouraged (Burack et al. 2008). These device are not suitable on steep slopes or in fill material (Beaupre et al. 2010).

It is recommended to have less than a 5 acre watershed contributing to infiltration trenches (CSQA 2003). Additionally, infiltration trenches should be at least 150 feet from potable water wells to prevent groundwater pollution (MNPCA 2000). A pretreatment system is highly recommended for infiltration trenches to be effective as well (U.S. EPA 2014_c). Infiltration trenches should be at least 10 feet downgrade, or 100 feet upgrade of any foundations to prevent any structural issues arising for that foundation (Beaupre et al. 2010).

2.4.3 Grass Lined Swale

Grass lined swales are primarily designed to remove suspended solids, with secondary processes including: ion exchange, biotransformation, and biological uptake (WSDOT 2010). These systems may include infiltration components, such as check dams, sand beds, and drain tile (FHWA 2014) to increase the effectiveness of the BMP. Swales are effective at removing multiple pollutants including: metals, nitrate, phosphorus, and sediments (FHWA 2014). Swales may be utilized to divert water around a potential pollutant source (MNPCA 2000). According to a study done by Yu et al. (1994), it is recommended that swales have a maximum slope of 5%, with a length of 30-60 meters (100-200 feet) and a minimum 0.6 meter (2 foot) bottom width. It was found that check dams enhance the performance of swales (Yu et al. 2001).

Swales do not perform well with a total maximum daily load (TMDL) for phosphorus (WSDOT 2010). If a swale remains wet for an extended period of time, a nuisance bug habitat may have inadvertently been created (FHWA 2014). There is a potential that some metals and nutrients may leach from the vegetation into the stormwater (U.S. EPA 1999_c). Significant efficiency reductions can be made if there is a long period of dry weather (more than 35% of the summer). This reduces the amount of vegetation available in the swale to filter stormwater runoff (Weiss et al. 2010).

Design considerations for swales include length and slope, affecting the detention time, which is an efficiency driver (Yu et al. 2001). Based on a study in Austin, TX, a pretreatment length of 8 meters from the edge of the highway to the center of the swale is recommended (Barrett et al. 1998). Desired residence time should be greater than 9 minutes within the swale (Ferguson 1998).

Swales are common BMPs along highways due to their shape and size (Stagge & Davis 2006). This is because the swale footprint often can fit inside the existing highway right of way.

2.4.4: Grass Lined Swale with Rock Check Dam

Rock check dams can be implemented as part of a swale type of best management system. These control devices are generally utilized at sites with steeper slopes (Balousek et al 2007; NDOR 2008). Although check dams are used with steeper slopes, it is not recommended to implement check dams as a pollution control practice above a grade of 6% (MNPCA 2000).

Check dams reduce the velocity of stormwater runoff by ponding behind rock dams temporarily, allowing pollutants to settle out of the water (Balousek et al. 2007). They are simple to design, and do not have a high cost associated with them (MDEQ 2010). Additionally, check dams are easy to construct and do not have a large footprint (NDOR 2008; MDEQ 2010). Check dams are effective on sites between 2 and 10 acres, in small channels (U.S. EPA 2014_a).

When designing a check dam, the rocks should extend up the sideslope of the swale to the top on both edges, while the center of the dam should be 6 inches lower than the top (NDOR 2008; ITD 2014). When designing check dams near roadways, ensure the high flow point is below the road surface elevation, to avoid flooding (ITD, 2014; NDOR 2008). A general rule for designing checks is to have the toe of the upstream check at the same elevation as the top of the downstream check dam (MNPCA 2000; NDOR 2008). The Minnesota Pollution Control Agency (2000) created a guide (**Table 2. 3**) to aid in the layout of checks.

Table 2. 3 Check Dam Spacing Recommendations (MNPCA, 2000)

Ditch Grade (%)	Spacing (feet)
1	200
2	100
4	50
6	33
Grades above 6% are not recommended	
8	25
10	20

A disadvantage of rock check dams is they require cleaning, which entails removing all the rocks, cleaning the sediment out of the percolation and backwater areas, and replacing all rocks (Balousek 2007). It is not recommended to utilize check dams on sites larger than 10 acres. Over the course of time these systems can clog with debris, reducing the efficiency of the BMP (MDEQ 2010). Check dams are generally not very effective for removal of fine sediment because most fine sediments are able to pass through the pores, or over the dam (Rozumalski et al. 2001).

2.4.5: Bioretention Area

Bioretention areas, also known as rain gardens, first developed in Prince George’s County, Maryland, with the intent of improving water quality and aesthetics (Hunt and White 2001). They are designed to be flower beds or landscaped areas, with the purpose of collecting, storing, infiltrating, and treating runoff (Davis 2005).

The vegetation in the bioretention area may include a wide variety of plantings. Flowers and natural grasses may be seen in some areas, while trees and shrubs may be seen in larger areas. It has also been found that vegetables may be used in lieu of other vegetation to make a more productive space. If vegetables are used, it may reduce the consumption of potable water, as the vegetation will be watered from stormwater and groundwater (Richards et al. 2015)

"Bioretention generally consists of a porous media, supporting a vegetative layer, with a surface layer of hardwood mulch. A ponding area serves as reserve space for runoff storage and provides additional time for water to infiltrate into the media during and after rainfall events" (Hsieh and Davis 2005). Stormwater runoff is reduced through percolation and evapotranspiration within rain gardens (Roy-Poirier et al. 2010).

It is not entirely known what the removal ability of sediments and other pollutants is due to the recent creation of rain gardens as BMPs (Hunt and White 2001). Stormwater runoff containing suspended solids and other similar pollutants, such as nutrients, tend to have less pollutant load going out of the bioretention basin than entering (Tornes 2005). As the hydraulic conductivity of the garden lessens, detention time increases, which allows more pollutant removal (Li et al. 2009).

When designing a rain garden, it is imperative that all vegetation be water tolerant (Hunt and White, 2001). Gardens can be set to infiltrate, or to discharge, depending on soil conditions and engineer design (Hunt and White 2001; Tornes 2005).   Surface area to watershed area ratio recommendations vary from 1:45 to 1:5 (Davis et al. 2009; PDEP 2006). Ponding depth is recommended to be no greater than 6 inches to allow for water to be ponded for less than 72 hours (PDEP 2006). There are some situations that rain gardens are not recommended. One is when the groundwater table is within 6 feet of the ground surface. Also, rain gardens are not generally recommended in areas where slopes are greater than 20%, or where mature trees have to be removed to construct rain gardens (U.S. EPA 1999_b).

2.5 BMP Efficiencies

Table 2. 4 shows a table of efficiencies found in previous studies of the target BMPs. It is based upon these values that the efficiencies are calculated for this project.

Table 2. 4 BMP Efficiencies from Past Research

BMP Type	Author	Efficiency
Grassed Swale	Schueler et al (1992)	70%
	Kahn et al. (1992)	83%
	Barrett et al (1998)	85%
	Backstrom (2003)	79-98%
	Stagge (2006)	73-84%
	Dorman et al (1989)	98%
	Harper and Herr (1993)	81-87%
	Burack et al. (2008)	65%
	Kercher et al (1983)	99%
	Wang et al (1981)	80%
Detention Pond	Schueler (1992)	50-90%
	Hartigan (1989)	80-90%
	US EPA (1999d)	30-65%
	Yuon & Pandit (2012)	50-94%
	Burack et al. (2008)	70-90%
	Harrell & Ranjithan (2003)	85-91%
Infiltration Trench	Schueler (1992)	90%
	Burack et al. (2008)	90%
	Veenhuis et al. (1988)	60-80%
	Fletcher (2005)	85%
Rain Garden	Hunt et al (2008)	60%
	Hsieh and Davis (2005)	29-96%
	Li and Davis (2009)	96-99%
	PGDER (1993)	90%
	Water Environment Research Foundat	71-88%
	Ackerman and Stein (2008)	>60
Check Dam	Boix-Fayos et al (2008)	77-98%
	Schueler T. (1987)	20-40%
	Yu et al (1993)	21-95%
	Kaighn and Shaw (1996)	49%
	MDEQ (2010)	>80%

2.6 Applicability to Roadsides

2.6.1 What BMPs are normally used near roads

The majority of BMPs utilized for general sites are also implemented along roads. There is a spatial consideration that is associated with roadway construction, as easements are generally narrow. A recent study done for the National Cooperative Highway Research Program Transportation Research Board National Research Council evaluated all BMPs and Low Impact Development for highway stormwater runoff events. **Table 2. 5** is a list compiled by the Transportation Research Board showing the recommended practices to implement along highways (Reilly et al. 2006):

Table 2. 5 Recommended Highway BMPs (Reilly et al. 2006)

Highway LID Techniques	Permeable Pavement
	Roadside Infiltration/Exfiltration Trenches
	Roadside Swales and Bioswales
	Curb Cuts or Perforated Curbs
	Filter Strips and Bioslopes
	Narrow Pavement Designs
	Near Roadway LID Opportunities
Pre-Treatment Devices	Inlet Devices
	In-Line Devices
	Floatables Traps
Primary Treatment BMPs	Tanks and Vaults
	Oil Water Separators
	Hydrodynamic Devices
	Sedimentation Ponds and Forebays
	Surface Filters (Filter Fabrics)
	Vegetated Swales and Filter Strips
Secondary Treatment BMPs	Bioretention
	Media Filters
	Infiltration/Exfiltration Trenches/Basins
	Detention and Retention Ponds
Tertiary Treatment BMPs	Advanced Biological Systems
	Flocculent / Precipitant Injection Systems
	Aeration and Volatilization Devices
	Disinfection Systems
Hydrologic/Hydraulic Controls	Flow Splitters
	Energy Dissipaters
	Dams
	Berms
	Weirs
	Orifices
Other BMPs	Multistage Outlet Designs
	Infiltration/Exfiltration Trenches/Basins
	Evaporation Enhancement Systems

Chapter 3 Methods

Chapter 3 discusses the methodology of estimating the sediment transport off a site. This sediment then enters a BMP, with the efficiency varying as the properties of the site and the BMP vary.

3.1 Runoff and Sediment Yield Model Selection

3.1.1 Model Requirements

In the project proposal it was stated that one of the goals of this research was to "…develop models to predict both surface runoff and sediment yield from highway systems under different conditions", therefore, it was necessary to use a model that accurately calculated sediment yield from highway systems.

In addition, it was critical to have a user-friendly system that did not require background knowledge in other programs, large amounts of time, or significant data collection prior to utilizing the program. This model also needed to fit the above criteria of being easy to use, have accessible data, and be fast to run.

3.1.2 Evaluation of Candidate Models

Several models that evaluate runoff and sediment yield were evaluated for use in this project. These include: Agricultural Non-Point Source Pollution software (AGNPS) (NRCS 1989), the Soil and Water Assessment Tool (SWAT)(NRCS 2012), the Spreadsheet Tool for Estimating Pollutant Load (STEPL) (EPA 2013$_a$), the Generalized Watershed Loading Function (GWLF) (Haith et al. 1992), and the Revised Universal Soil Loss Equation2 (RUSLE2) (USDA 2008). The considerations used to evaluate the models were: the time required to run the model, data needed for the model, and ease of use.

The AGNPS model required more data than users would be able to easily attain for highway construction sites. In addition, the time and effort required to run the model was too high to justify using. The SWAT model had similar restrictions regarding significant time and effort to get the results output by the SWAT software. SWAT was also challenging to use for someone who may be using the software on an infrequent basis.

The STEPL model was not easy to understand for a user who was not exposed to it, making it challenging to use as a quick tool to estimate sediment transport. The GWFL model is very thorough, to the point that it requires too much data to be known prior to running to be efficiently used for this application.

The RUSLE2 model was relatively quick to run, easy to use, and did not have too many data input requirements. Much of the data, such as storm patterns, local soils, management practices, and local climate are embedded in the model. The RUSLE2 software was then selected to be the sediment yield and transport modelling program used.

3.2 RUSLE2 Model

3.2.1 Site Layout for RUSLE2 Model

RUSLE2 calculates the soil eroded and transported along a flow path starting at the top of the hill and ending at a flow channel at the bottom of the hill. Sediment yield delivered to the flow channel at the bottom of the hill is calculated from the sediment detachment minus sediment deposition along the flow path.

The RUSLE2 flow path (**Figure 3. 1**) is defined as the "path taken by overland flow on a smooth soil surface from its point of origin to the concentrated flow area that ends the overland flow path; runoff is perpendicular to hillslope contours" (USDA 2008). The total watershed area is defined as the area in which a drop of water will flow to the same point. The sub-watershed boundary is the area in which a drop of water will flow into any first order channel, or tributary, which then feeds into the second-order channel. The overland flow path is the path water takes to reach the downhill side of the sub-watershed and enter into a concentrated flow channel. The software models from the top of the hill down to a channel, it does not model any part of the channel.

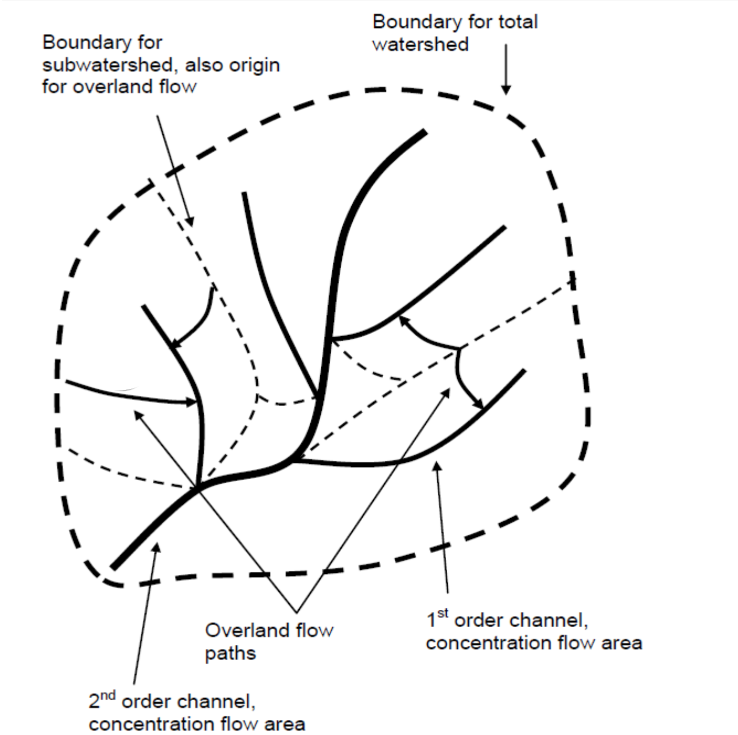


Figure 3. 1 Watershed diagram showing overland flow paths (USDA 2008)

RUSLE2 displays four output values: soil loss from the eroding portion of the slope, detachment for the entire overland flow path, conservation planning soil loss, and sediment delivery (yield). Soil loss is the net loss of sediment from the eroding portion of the overland-flow path. This value is used in conservation planning to select cover-management and support practices to control soil loss to a value less than soil loss tolerance or some other conservation planning criteria. Detachment is the total sediment production for the overland flow path length represented in a RUSLE2 computation. Sediment delivery (yield) is the amount of sediment leaving the flow path (sediment delivered at the bottom, outlet, of the flow path) represented in a RUSLE2 computation. Total deposition for the overland-flow path is the differences between total detachment (sediment production) and sediment yield. Conservation planning soil loss gives partial credit to remote deposition depending on where the deposition occurs along the overland-flow path. RUSLE2 gives very little credit as "soil saved" for deposition that occurs near the end of the overland-flow path. Conservation planning soil loss is generally less than total detachment (sediment production) and greater than sediment yield" (USDA 2008).

Sediment delivery is the important result from RUSLE2 to evaluate BMP performance. This value is the amount of soil transported to the bottom of the hillside and into a channel, which is then assumed to go into a BMP. Sediment delivery is given in units of tons of sediment per acre per year.

"RUSLE2 is land-use independent, which means that it can be applied to any land use where mineral soil is exposed to raindrop impact and Hortonian overland flow" (USDA 2008). Hortonian overland flow is how water generally flows horizontally across land surfaces after the rainfall has surpassed the infiltration capacity of the soil and depression (pond) storage capacity. "RUSLE2 can be applied to crop, pasture, hay, range, disturbed forest, mined, reclaimed, construction, landfill, waste disposal, military training, park, wild, and other lands. RUSLE2 does not apply to undisturbed forestlands and lands where no mineral soil is exposed, and surface runoff is produced by a mechanism other than rainfall intensity exceeding infiltration rate" (USDA 2008). RUSLE2 is also able to be applied to transitional land uses, such as transitioning from pasture to cropland or cropland to pasture.

Detachment "starts at the upper end of the overland flow path and steps down-slope, segment by segment, routing the water and sediment down-slope" (USDA 2008). Detachment for each segment is accounted for by calculating how much sediment leaves and enters each segment.

RUSLE2 uses the NRCS Method (USDA 1999) to find the excess rainfall rate, which is used to calculate the runoff depth. "Runoff is calculated by using discharge (flow) values for runoff to compute sediment transport capacity, contouring effectiveness, and critical slope length for contouring" (USDA 2008). To increase accuracy within RUSLE2 the sub segment length may be decreased, creating more, smaller steps down the slope.

Sediment transport capacity is found at the top and bottom of each segment. The transport capacity uses the Manning's roughness coefficient, η, (Chaudhry 1993) to calculate the shear stress acting on the soil particles affecting transport.

There are four possible scenarios for routing the sediment: 1) detachment over the entire segment, 2) deposition over the entire segment, 3) deposition ends within the segment, and 4) deposition begins within the segment. "Detachment occurs over the entire segment when the transport capacity at the upper end of the segment is greater than the incoming sediment load, and the transport capacity at the lower end of the segment is greater than the maximum possible sediment load at the lower end of the segment" (USDA 2008). This case is applicable for convex, uniform, and the upper portion of concave slopes, seen in **Figure 3. 2**.

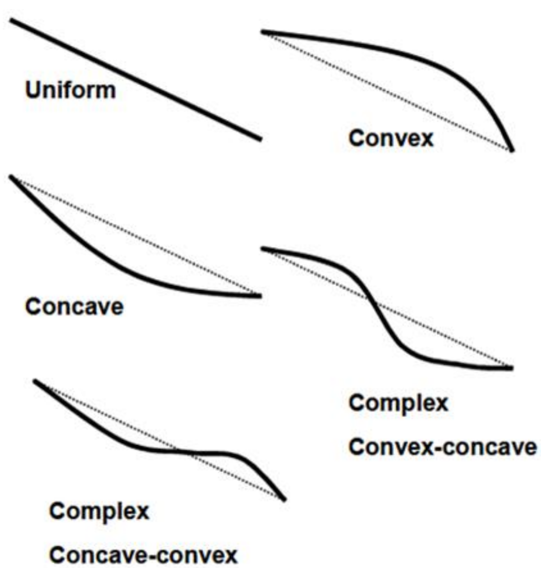


Figure 3. 2 Possible flow path profiles (USDA 2008)

Deposition over the entire segment occurs when transport capacity is less than sediment load at the top and bottom of the segment. This may happen in a setting such as deposition occurring in a grass strip or in a concave slope. Deposition ends within a segment when the transport capacity increases within the segment, thus causing deposition to occur only in the top portion of the segment. Deposition within the segment ends when transport capacity increase to become equal to sediment load, this could occur in a convex, complex concave, or convex slope. “RUSLE2 assumes that interrill erosion occurs simultaneously with deposition,” which is a valid assumption on hillsides, although it is questionable for flat surfaces and the bottom of concave hillsides (USDA 2008).

Deposition begins within a segment when transport capacity decreases over the segment length as the sediment load increases. The soil deposition starts where the transport capacity and the sediment load are equal (USDA 2008). This may occur in a concave or complex convex-concave slope.

RULSE2 calculates average annual erosion and sediment yield due to rainfall for a single hillside strip as the weight of soil per acre per year, T/Ac-yr, per unit width of strip. This quantity of soil eroded in one strip is multiplied by the area that is represented by that strip. Then the yields from all the areas are summed to determine the total amount of soil transported to the bottom of a slope on a site. A representative strip is a single hillside profile that reflects an area that has the same slopes, lengths, cover, and soil. If there is any variation in site or slope conditions, there must be representative strips to reflect each area. **Figure 3. 3** shows a hillside divided into representative strips and the areas represented by each strip. With each black line being a representative strip, and the corresponding gray polygon being the representative area.

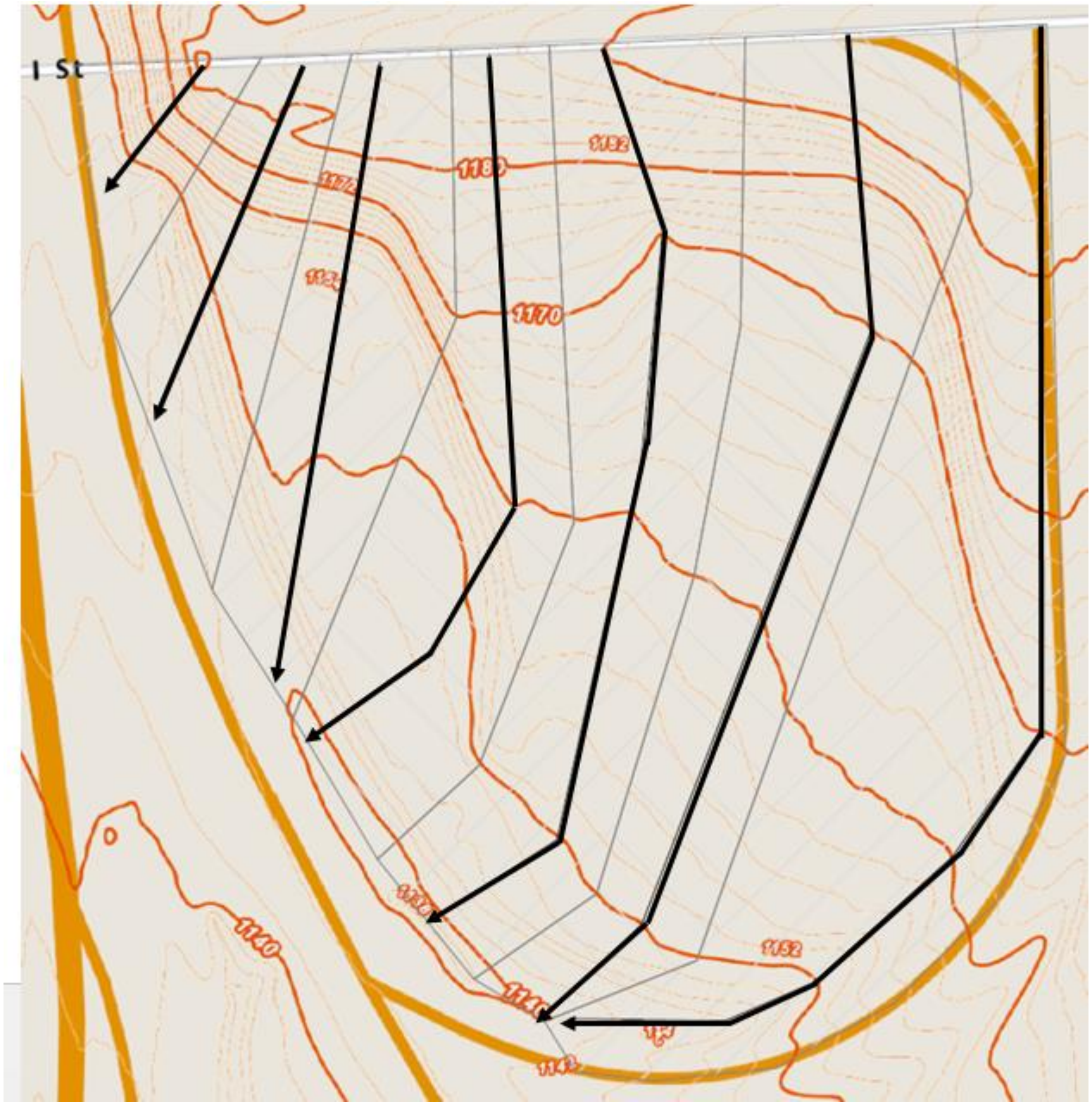


Figure 3. 3 Representative strips (black lines) and areas (gray polygons) represented by each strip

3.2.2 RUSLE2 Governing Equation

The governing equation for RUSLE2 is:

$$a_i = r_i k_i l_i S c_i p_i \quad (3.1)$$

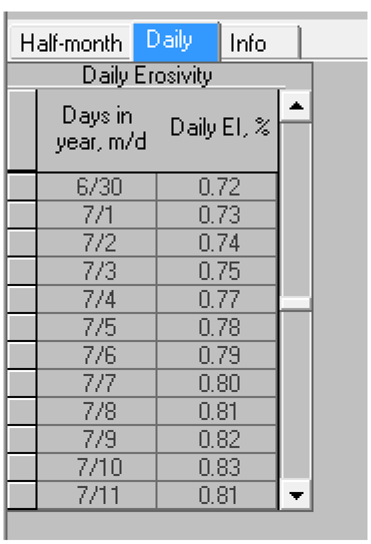
where a_i is the average soil loss for the i^{th} day of the year. This is generally a long-term quantity, which means it estimates average erosion over multiple months or years, and is then disaggregated into a daily value. r_i is the erosivity factor. The erodibility factor is k_i. The soil length factor is l_i. S is the slope steepness factor. c_i represents the cover management factor. The supporting practices factor is represented by the term p_i.

The erosivity factor (r_i) is a function of the precipitation and establishes how erosive precipitation is on a daily basis. "Erosivity is the product of a storm's energy and the maximum 30-minute intensity for an individual storm" (USDA 2008). This excludes any storm data that has less than 0.5 inch of precipitation and extreme storm events that are greater than a 50 year return period. The average annual erosivity values were obtained from 15-minute precipitation gages that measure the intensity of the storm. The erosivity factor is a disaggregated daily value from the monthly erosivity factor (R_m), which is equal to the average monthly erosivity density times the average monthly precipitation.

$$\mathrm{R_m} = \alpha_\mathrm{m} \mathrm{P_m} \tag{3.2}$$

$$\alpha_\mathrm{m} = \hat{\mathrm{e}} \bar{\mathrm{I}}_{30} \tag{3.3}$$

Equation 3.3 shows the average monthly erosivity density (α_m) equals the effective unit energy for the month (ê) times the representative maximum 30-minute storm intensity for the month ($\bar{\mathrm{I}}_{30}$). An example of the daily erosivity density for Douglas County, NE is found in **Figure 3. 4**

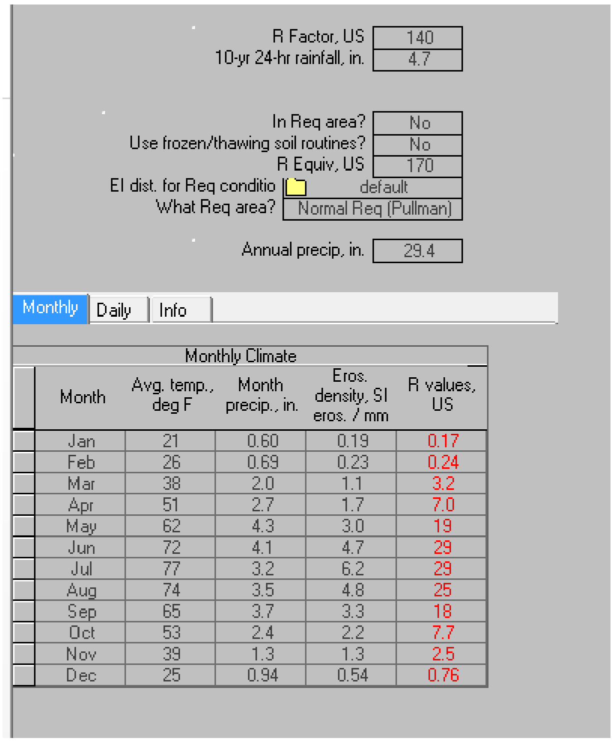


Days in year, m/d	Daily EI, %
6/30	0.72
7/1	0.73
7/2	0.74
7/3	0.75
7/4	0.77
7/5	0.78
7/6	0.79
7/7	0.80
7/8	0.81
7/9	0.82
7/10	0.83
7/11	0.81

Figure 3. 4 Example of Douglas County erosivity data June 30-July 11

Example of Douglas County erosivity data June 30-July 11.

Figure 3. 5 shows the Douglas County, Nebraska climate data by month, including monthly erosivity which is then disaggregated into the erosivity factor for the i^{th} day.


R Factor, US: 140
10-yr 24-hr rainfall, in.: 4.7
In Req area?: No
Use frozen/thawing soil routines?: No
R Equiv, US: 170
EI dist. for Req conditio: default
What Req area?: Normal Req (Pullman)
Annual precip, in.: 29.4

Monthly | Daily | Info

Monthly Climate

Month	Avg. temp., deg F	Month precip., in.	Eros. density, SI eros. / mm	R values, US
Jan	21	0.60	0.19	0.17
Feb	26	0.69	0.23	0.24
Mar	38	2.0	1.1	3.2
Apr	51	2.7	1.7	7.0
May	62	4.3	3.0	19
Jun	72	4.1	4.7	29
Jul	77	3.2	6.2	29
Aug	74	3.5	4.8	25
Sep	65	3.7	3.3	18
Oct	53	2.4	2.2	7.7
Nov	39	1.3	1.3	2.5
Dec	25	0.94	0.54	0.76

Figure 3. 5 Douglas County, Nebraska climate data including: average temperature, average monthly precipitation, erosivity density month

The soil erodibility factor (k_i) is a function of four sub-factors, which are: texture sub-factor (k_t), organic matter sub-factor (k_o), soil structure sub-factor (k_s), and the soil profile permeability sub-factor (k_p). Equation 3.4 shows the soil erodibility equation.

$$\mathrm{k_i} = \frac{\mathrm{k_t k_o + k_s + k_p}}{100} \tag{3.4}$$

"Soil texture is a term commonly used to designate the proportionate distribution of the different sizes of mineral particles in a soil" (Brown 1990). The soil texture can be broken into 4 classes: sand, silt, clay, and loam. "RUSLE2 uses values for sand, silt, and clay fractions to compute soil erodibility, the distribution of the sediment particle classes at the point of detachment, and the diameter of the small and large aggregate particle class" (USDA 2008). RUSLE2 considers the top 4 inches of soil to be the layer that is susceptible to erosion, so when acquiring soil data, the top layer is most important.

"Soil organic matter reduces the k factor value because it produces compounds that bind soil particles and reduce their susceptibility to detachment by raindrop impact and surface runoff. Also, organic matter increases soil aggregation, which increases infiltration and reduces runoff and erosion" (USDA 2008). RUSLE2 uses a nomograph to establish the percentage of organic matter (O_m) within the soil. This value is then plugged into equation 3.5 to calculate the sub-factor.

$$\mathrm{k_o} = 12 - \mathrm{O_m} \tag{3.5}$$

"Soil structure refers to the arrangement of soil particles, including primary particles and aggregates, in the soil. The soil erodibility nomograph soil structure sub-factor refers to how the arrangements of soil primary particles in aggregates and the arrangement of aggregates in the soil affect erosion under unit plot conditions. The unit plot is the base condition to establish all the coefficients, with base conditions being: "72.6 foot long, 9% slope, maintained in continuous fallow, tilled up and down hill to a seedbed condition periodically to control weeds and break crusts that form on the soil surface" (USDA 2008). Four structural classes are used in the nomograph. These classes are 1) very fine granular, 2) fine granular, 3) medium or coarse granular, and 4) blocky, platy, or massive. These classes are defined in the USDA-NRCS soil survey manual (NRCS 2015). The classes used to derive the soil erodibility nomograph were those in use in the mid-1960s when the experiments were conducted. The definitions for those classes should be used to assign RUSLE2 values for soil structure. Equation 3.6 is for the soil erodibility nomograph soil structure sub-factor:

$$k_s = \begin{cases} \text{fields: } \begin{cases} 3.25(S_s - 2) \text{ if } k_t + k_o + k_s \geq 7 \\ k_t + k_o + k_s \text{ if } k_t + k_o + k_s < 7 \end{cases} \\ \text{construction:} \qquad 3.25(2 - S_s) \end{cases} \tag{3.6}$$

where: S_s = the soil structure class. Soil mineralogy has a significant effect on k for some soils, including subsoils, soils located in the upper Midwest of the US, and volcanic soils in the Tropics. Soil structure affects k because it affects detachment and infiltration" (USDA 2008).

"Permeability of the soil profile affects k because permeability affects runoff. The soil permeability sub-factor is a measure of the potential of the soil profile in unit-plot conditions for generating runoff. Six permeability classes that range from 1) rapid (very low runoff potential) to 6) very slow (very high runoff potential) are used to rate the soil profile for infiltrating precipitation and reducing runoff. The USDA-NRCS soil survey definitions (NRCS 2015) for soil profile permeability should be used to assign a soil permeability class in applying the soil erodibility nomograph. The assigned permeability class must not be based simply on a permeability measurement of the surface soil layer. The permeability rating should take into account the presence of restricting layers and the landscape position. For example, the permeability rating for a sandy soil underlain by a restricting layer might be moderate for the soil at the top of a hillslope but be very slow if the soil is at the bottom of the hillslope. The RUSLE2 temporal soil erodibility equation described in Section 4.5 (of the RUSLE2 Science Documentation) takes into account how the permeability rating varies as climate varies among locations" (USDA 2008). The equation for the permeability sub-factor is given by:

$$k_p = 2.5(P_r - 3) \tag{3.7}$$

where P_r is the soil profile permeability class.

The soil length factor (l_i) is a representation of the length of the hillside. Equation 3.8 shows the soil length factor calculation.

$$l_i = \frac{(x_i{}^{m+1} - x_{i-1}{}^{m+1})}{\lambda_u{}^m (x_i - x_{i-1})} \tag{3.8}$$

where x_i is the distance to the lower end of the segment; x_{i-1} is the distance to the upper end of the segment; λ_u is the length of the unit plot; m is the slope length exponent found from equation 3.9.

$$m = {}^{\beta}\!/_{1+\beta} \tag{3.9}$$

where β is the ratio of rill to interill erosion for the i^{th} segment. Equation 3.10 is a function of rill and interill erodibility ($\frac{k_r}{k_i}$), subsurface conditions ($\frac{c_{pr}}{c_{pi}}$), cover conditions ($\frac{e^{-0.05fg}}{e^{-0.025fg}}$), slope effects($\frac{s/_{0.0896}}{3s^{0.8}+0.56}$), slope angle ($s$), and percent of ground covered (f_g).

$$\beta = (\frac{k_r}{ki})(\frac{c_{pr}}{c_{pi}})(\frac{e^{-0.05f_g}}{e^{-0.025f_g}})(\frac{s/_{0.0896}}{3s^{0.8}+0.56}) \tag{3.10}$$

The slope steepness factor measures the topography of the land. Equation 3.11 shows the slope relationship to the steepness factor (S).

$$S = \begin{cases} 10.8s + 0.03 \text{ if } m < 9\% \\ 16.8s - 0.5 \text{ if } m \geq 9\% \end{cases} \tag{3.11}$$

where s is the steepness percentage of the hill.

"Cover-management refers to how vegetation, soil condition, and material on and in the soil affect erosion" (USDA 2008). The cover-management factor (c) in the RUSLE2 equation (1) describes erosivity and erodibility of the soil. Erosivity is related to rainfall amount and intensity, and is an index of the rainfall. Erodibility is a factor based on soil properties and on cover-management. "The soil erodibility factor (k_i) represents the combined effect of susceptibility of soil to detachment, transportability of the sediment, and the amount and rate of runoff per unit rainfall erosivity for unit plot conditions" (USDA 2008). The cover management factor equation is seen in:

$$c = c_c g_c s_r r_h s_b s_c p_p a_m \quad (3.12)$$

where c is the cover management factor, c_c is the canopy sub-factor; g_c is the ground cover sub-factor; s_r is the soil surface roughness sub-factor; r_h is the ridge height sub-factor; s_b is the soil biomass sub-factor; s_c is the soil consolidation sub-factor; p_p is the ponding effect sub-factor; and a_m is the antecedent moisture sub-factor.

Canopy cover is calculated by:

$$c_c = 1 - f_c e^{(-0.1 h_f)} \quad (3.13)$$

where f_c is the fraction of canopy cover; and h_f is the effective fall height from the canopy in feet.

The canopy cover is vegetative material both alive and dead that covers the runoff surface (ground) but does not come in contact with the surface. The canopy intercepts some of the raindrops, which reduces raindrop energy. The erosivity has a direct relationship with impact energy of the drops, so if the energy is lowered, erosivity lessens as well. However, some of these raindrops impact the plant and reform as drops which then fall from the canopy to impact the surface.

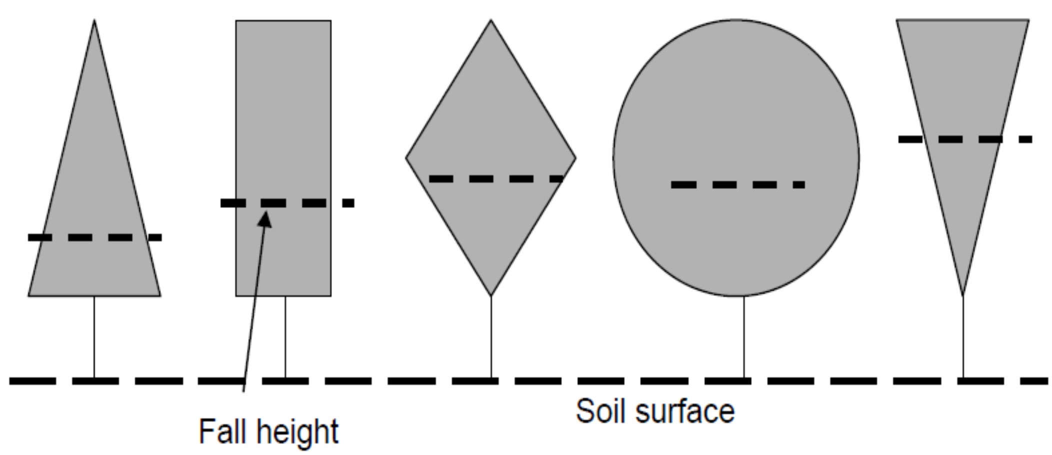


Figure 3. 6 Effective fall height for differing plant shapes (USDA 2008)

While looking down from above, the canopy cover is the total area minus the space where a raindrop can fall unobstructed to the soil surface. The effective fall height may fluctuate plant by plant, but there is only one effective fall height for the cover. That value is found by finding the single average fall height that gives the total impact energy from the variety of heights. As plants mature, they grow taller, and may become thicker, both of which change the effective fall height. The shape of the plant affects the effective fall height as well, as seen in **Figure 3. 6**. There are also scenarios where there are multiple canopy layers that may be affecting the impact energy, in which case the user calculates a new single fall height totaling the impact energy from all plants using equation 3.14, below, and inputs that value into RUSLE2. RUSLE2 does not include canopy that is immediately above the ground surface.

$$\mathrm{f_{ce}} = \mathrm{f_c} * (1 - \mathrm{f_g}) \tag{3.14}$$

where f_{ce} is the effective canopy cover; f_c is the canopy cover sub-factor; and f_g is the portion of soil surface covered by ground cover.

Ground cover is material that is in contact with the soil surface. This material can be live and dead plant matter, rocks, mulch, erosion control materials, crop residue, manure, plant litter, and mosses. "Ground cover is probably the single most important variable in RUSLE2 because it has more effect on erosion than almost any other variable, and applying ground cover is the simplest, easiest, and most universal way of controlling erosion" (USDA 2008).

"Ground cover reduces erosion by protecting the soil surface from direct raindrop impact, which reduces interrill erosion. Ground cover also slows surface runoff and reduces its detachment and transport capacity, which reduces rill erosion" (USDA 2008). It can be seen from **Figure 3. 7**, that rill erosion is reduced more by ground cover than interrill erosion is.

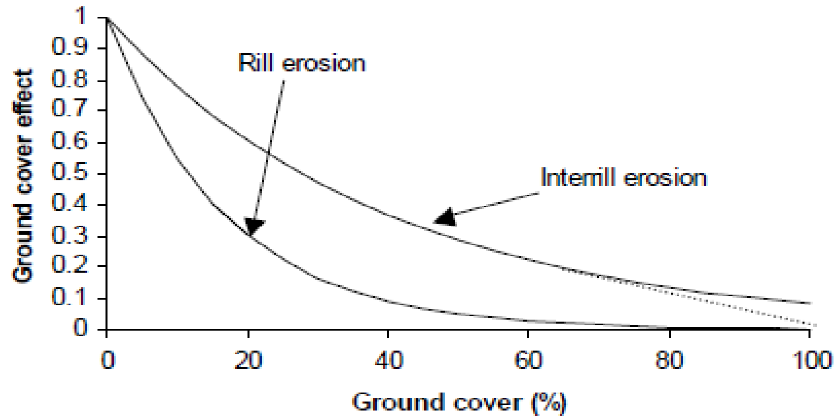


Figure 3. 7 Ground cover effects on rill and interrill erosion (USDA 2008)

The ground cover sub-factor (g_c) is calculated using:

$$g_c = e^{bf_g} \quad (3.15)$$

where b is the coefficient describing relative effectiveness of ground cover, found in equation 3.16, and f_g is ground cover percent.

$$b = -\ln\left[\frac{a_t}{(a_i + a_r)}\right]/f_g \quad (3.16)$$

with a_t being the total relative erosion with ground cover , found in equation 3.17 and a_i is the relative interrill erosion on a bare soil with all other conditions the same as when cover is present, and a_r is the relative rill erosion on a bare soil with all other conditions the same as when cover is present.

$$a_t = a_r e^{(-0.06f_g)} + a_i e^{(-0.025f_g)} \quad (3.17)$$

The soil roughness is a measure of the random peaks and valleys left in the soil following a soil disturbing operation. Over time the soil will settle and have a smooth surface, which RUSLE2 accounts for. The valleys left in the soil act like small depression storage systems, with the runoff slowing as it flows through the depression and sediment drops out the water flow. The rougher the soil, the more water is able to infiltrate.

Two different types of soil roughness are: short term and long term, where short term is caused by tillage and construction equipment. "Long term roughness evolves over time after the last mechanical soil disturbance on pasture, range, landfills, and reclaimed land. Long term roughness is related to vegetation type (bunch versus sod-forming), plant roots near the soil surface, local erosion and deposition by water and wind, and animal traffic" (USDA 2008). Long term soil roughness is a function of time to consolidation of the soil. Time to consolidation is an important factor on construction sites. This is a measure of how long it takes for the soil particles to become more compacted so they aren't as erodible. "RUSLE2 assumes seven years for the time to consolidation" (USDA 2008). Soil roughness is calculated using equation 3.18.

$$s_r = e^{[-0.66(R_a-0.24)]} \tag{3.18}$$

where R_a is the adjusted roughness value, calculated by:

$$R_a = 0.24 + (R_{it} - 0.24) * \left[0.8\left\{1 - e^{(-0.0015B_{ta})}\right\} + .02\right] \tag{3.19}$$

where R_{it} is initial roughness adjusted for soil texture and can be found in **Table 3. 1**, and B_{ta} is the total mass of buried residue and dead roots averaged over the soil disturbance depth after the operation.

Ridges affect erosion through sediment production and flow direction. How the ridges and furrows are ploughed along the hillside affects where the water is routed. The best option for tilling is along the contours, meaning perpendicular to the natural flow direction. If the sideslope of the ridge is steep, the erosion rate increases.

Table 3. 1 Soil texture adjustment factor (USDA 2008)

Soil texture class	Adjustment factor
clay	1.39
clay loam	1.22
loam	1.05
loamy sand	0.78
sand	0.69
sandy clay	1.25
sandy clay loam	1.13
sandy loam	0.90
silt	0.81
silt loam	1.02
silty clay	1.33
silty clay loam	1.23

The ridge height sub-factor varies with the ridge height itself, as seen in **Figure 3. 8**. "Ridge height is used to represent ridge sideslope steepness because ridge height values can be easily visualized and measured for ridge forming operations" (USDA 2008). While using a planter, small ridges are left in the soil that may not be accounted for within RUSLE2. "The effect of ridges on sediment production diminishes in RUSLE2 as land slope steepness increases above 6 percent because the local steepness of the ridges becomes almost equal to the land slope at steepness above 30 percent" (USDA 2008).

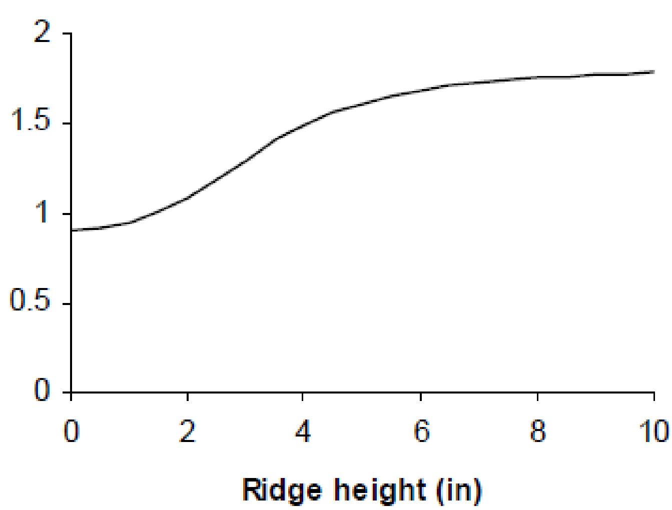


Figure 3. 8 Ridge height effectiveness (USDA 2008)

As the steepness of the overland flow path changes, the ridge height sub-factor also varies. Equation 3.20 calculates the daily ridge height sub-factor when the overland flow path steepness is less than six percent (r_{h6}).

$$r_{h6} = \begin{cases} 0.9(1 + .0582H^{1.84})\ for\ H \leq 3\ inches \\ 2.136\left[1 - e^{(-0.484H)}\right] - 0.336\ for\ H > 3\ inches \end{cases} \tag{3.20}$$

where H is the daily ridge height, calculated using:

$$\mathrm{H} = \mathrm{H_s} + \mathrm{H_e} \tag{3.21}$$

where H_s is the daily ridge height component associated with settlement, and H_e is the daily ridge height component associated with interrill erosion.

If the overland flow path steepness is greater than six percent, equation 3.22 is used.

$$\mathrm{r_h} = 1 + (\mathrm{r_{h6}} - 1)\mathrm{e}^{[-\mathrm{a_h}(s - 0.509989)]} \tag{3.22}$$

where s is the overland flow path steepness, and a_h is found using:

$$\mathrm{a_h} = \begin{cases} 16.02 - 0.927\mathrm{H\ if\ H} \leq 10\ \mathrm{inches} \\ 6.75\ \mathrm{if\ H} > 10\ \mathrm{inches} \end{cases} \tag{3.23}$$

"Soil biomass in RUSLE2 includes live and dead roots, buried plant litter and crop residue from vegetation "grown" on-site, and added materials (external residue) that were buried or directly placed in the soil. These materials, including rock, added as an "external residue," are assumed to be organic materials that decompose and reduce soil erodibility. Live roots affect soil loss by mechanically holding the soil in place, resisting erosive forces if the roots are exposed, and producing exudates that reduce soil erodibility. Also, live roots are a measure of plant transpiration that reduces soil moisture, which in turn increases infiltration and reduces runoff and soil loss" (USDA 2008). RUSLE2 also models plant death, where the live roots become dead roots and start the decomposition process. Soil tends to cling to dead roots when the roots are exposed or when the soil is disturbed. When the dead roots decompose, they turn into organic matter, which helps increase infiltration, reduce soil erodibility, and reduce runoff. Buried residue is all assumed to be organic matter, that acts the same as dead roots, but because it is buried it is less effective at reducing runoff because they do not have the mechanical soil binding abilities as roots.

The soil biomass equation is:

$$s_b = c_b e^{(-0.0026B_{rt} - 0.00066B_{rs})/s_c{}^{0.5}} \tag{3.24}$$

where $c_b = 0.951$ unless there is very low soil mass, then $c_b = 1.0$; B_{rt} is the sum of live and dead root biomass averaged over a 10 inch depth; B_{rs} is the amount of buried residue averaged over the depth linearly, ranging from three inches if the soil is not consolidated, to one inch if the soil is fully consolidated; and s_c is the soil consolidation sub-factor.

When a mechanical disturbance breaks up the soil, the erodibility and erosion increase. After a soil is mechanically disturbed, through a wetting and drying process, the soil particles becomes adhered to one another, and a crust is formed at the soil surface. This process is soil consolidation. "Soil consolidation in RUSLE2 refers to the decrease in soil erodibility following a mechanical soil disturbance rather than an increase in bulk density" (USDA 2008). The assumptions for soil consolidation are:

$$s_c = \begin{cases} 0.45 \text{ at full consolidation} \\ 1.0 \text{ immediatley following disturbance} \end{cases} \tag{3.25}$$

As stated above, the assumed normal time to full consolidation is seven years in climates with more than 10 inches of rain annually. Time to consolidation in climates with 10 inches or less is 20 years. If a soil has more binding power, like clay and organics, the soil consolidation effect is greater (USDA 2008).

The ponding effect sub-factor is a function of the $10\ year - 24 hour$ precipitation amount and the land steepness. Water ponds on flat areas after intense storms, reducing erosivity. This factor is most significant in the Southeast United States. As the $10\ year - 24\ hour$ precipitation amount increases, the ponding effect decreases. As the land steepness increases, the ponding effect increases in the flat areas.

Antecedent soil moisture is only applicable in the Northwest Wheat and Range Region (NWRR). None of Nebraska is within the NWRR, so antecedent moisture will not be considered in this document.

RUSLE2 utilizes a Crop Management Zone Map (CMZ Map) to help users select the appropriate crops for the zone they are located in. **Figure 3. 9** shows the CMZ map of Nebraska.

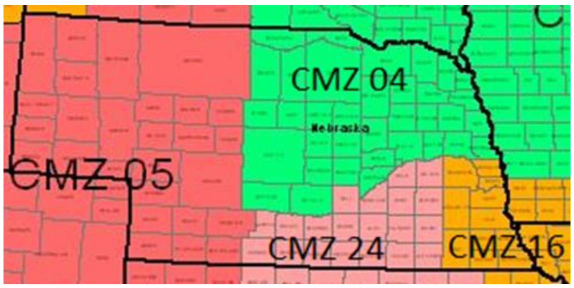


Figure 3. 9 Nebraska CMZ map (USDA 2008)

"Support practices include: contouring (ridges around the hillslope); filter and buffer strips (strips of dense vegetation on the contour); rotational strip cropping (a system of equal width cropping strips that are annually rotated with position along the overland flow path); terraces and diversions (ridges and channels that divide the overland flow path, collect runoff, and redirect it around the hillslope); and small impoundments (impoundment terraces and sediment traps)" (USDA 2008). These practices are in addition to best cover management operations, found in **Table 3. 2**. "Most support practices affect rill and interrill erosion and sediment delivery by reducing runoff's erosivity and transport capacity by redirecting the runoff around the hillslope; dividing the overland flow path that reduces the accumulation of runoff; slowing the runoff with strips of rough soil surface, heavy surface residue, or dense vegetation; and capturing and ponding runoff" (USDA 2008).

"Contouring is the creation of ridges and furrows by tillage equipment, earth moving machines, and other soil disturbing operations to redirect runoff from a path directly downslope to a path around the hillslope. Grade along the furrows is zero when contouring is "perfectly on the contour," which results in runoff spilling uniformly over the ridges along their length. If furrow grade is not level, runoff flows along the furrows until it reaches low ridge heights or local low areas on the hillslope. The runoff breaks over ridges in these locations" (USDA 2008).

Table 3. 2 Examples of Cover Management Operations from RUSLE2

Operation	Effects	Comment
Moldboard plow	Kills vegetation, disturbs soil, buries residues, redistributions biomass in soil	Primary tillage, first step in growing a crop
Planting	Disturbs a strip of soil, seeds a crop	Includes a **begin growth** process. The name for the appropriate vegetation description is entered to represent the crop being grown
Broadcast seeding	Seeds a particular vegetation. This seeding operation does not disturb the soil.	Includes a **begin growth** process. The name for the appropriate vegetation description is entered to represent the vegetation that is seeded.
Volunteer weeds	Starts growth of volunteer weeds	Includes a **begin growth** process. The name for the appropriate vegetation description is entered to represent the volunteer weeds
Harvest	Kills vegetation and flattens some of the standing residue	Typical operation for crops like corn, soybeans, and wheat
Baling straw	Removes residue, flattens standing residue	Removes residue and flattens remaining standing residue
Silage harvest	Removes live biomass, kills vegetation	Leaves a portion of the live biomass in the field to represent harvest losses
Mowing	Removes live biomass, add cut material back as external residue, regrow vegetation	Cuts the live biomass but leaves it in the field. Does not kill vegetation. **Begin growth** process calls vegetation description that regrows vegetation after mowing
Baling hay	Remove live biomass, regrows hay	**Begin growth** process calls vegetation description for vegetation that regrows after the hay harvest
Frost kills vegetation	Uses a **kill vegetation** process	RUSLE2 does not model plant growth. Must tell RUSLE2 when vegetation is killed, even if it occurs naturally
Fire	Remove residue/cover	RUSLE2 can not remove dead roots from the soil
Apply mulch	Add other residue/cover	Use to apply mulch to represent construction sites
Apply plastic mulch in a vegetable field, water in a rice field, or deep snow at a construction site in mountains	Apply non-erodible cover	Shuts off erosion for period that non-erodible cover is present. Use a **remove non-erodible cover** process to remove cover and to restart erosion.

The factors that influence the effectiveness of contouring practices are: steepness, ridge height, storm severity and runoff, row grade, contouring failure, and temporal changes. Steepness affects the contouring because, if a slope is steep, there will not be significant ponding to slow and direct the flow. Ridge height is important because if there is not much height, the flow will overtop the ridges very quickly, and will cease to follow the contoured flow path. If a storm is severe, there is likely a high runoff rate, which, unless the contours are more like terraces, the runoff will rapidly flow over or through the contour. Row grade is how the rows are oriented compared to the contour. If the row grade is perfectly up and down hill, it is parallel to the overland flow path, encouraging more runoff to flow directly to the bottom of the hillside; whereas, if it is perfectly on the contour, the runoff will follow each row along the contour line. At some point when the runoff rate and steepness become too large, the contouring fails. Finally, as time elapses sediment fills the ridges established along the contour, and at the same time, the ridge height is being reduced. At some point with both of these activities occurring, there will no longer be a functional contour.

Filter and buffer strips are known as porous barriers. Filter strips are generally dense vegetation strips that are at the bottom of an overland flow path. Buffer strips are multiple narrow strips of dense permanent vegetation that are spaced along the flow path. Both of these support practices slow the flow of runoff as it goes through the barrier. By the end of the barrier, water is spread thinly across the slope, instead of in a channel. If the strips retard the water enough, sediment is able to fall out of the water, and at the same time there will be a backwater area uphill of the barrier that slows the flow more. After a length of time, the strips will become clogged with sediment and be mostly ineffective. At that point, the strips will need to be removed and reconstructed.

Rotational strip cropping is a practice where a crop is planted in a section, with a different crop right next to the first crop. These crops are rotated annually to utilize the nutrients left by the other plant type, and to reduce erosion. To be strip cropping there must be at least two different plant types, but more can be utilized. Generally in Nebraska, corn and soy beans will be rotated, but alfalfa and wheat could also be included in the rotational strip cropping. Within strip cropping there are two main types that are applied: contour strip cropping and field strip cropping. With contour strip cropping the rows are directly following the hillside contours, "in long, relatively narrow strips of variable width on which dense erosion-control crops alternate with clean-tilled or erosion-permitting crops placed" in strips (Kell 1938). Field strip cropping is essentially the same as contour strip cropping, except the strips do not follow the contours. **Figure 3. 10** shows field strip cropping.

Figure 3. 10 Rotational strip cropping- corn and soy beans (NRCS n.d.)

"Diversions and terraces are constructed specifically to intercept overland flow and redirect the runoff around the hillslope in a low gradient channel. Terraces are constructed on a sufficiently low grade to cause deposition and even on a level grade with a closed outlet to conserve soil moisture in dry climates. Diversions are constructed on a sufficiently steep grade so that deposition does not occur but on a sufficiently flat grade so that erosion does not occur.

Constructed terraces and diversions typically involve ridges and accompanying channels that convey the runoff to a protected open channel or an underground pipe that conveys the runoff downslope to a safe outlet. Disposal channels must be lined with vegetation, stone, or other material to prevent erosion because flow erosivity can be quite high in these channels" (USDA 2008). There are two types of terraces in the agricultural arena: gradient and parallel tile outlet (PTO). Gradient terraces follow the contours of the hillside, with a minor grade going toward a lined channel flowing downhill, seen in **Figure 3. 11**.

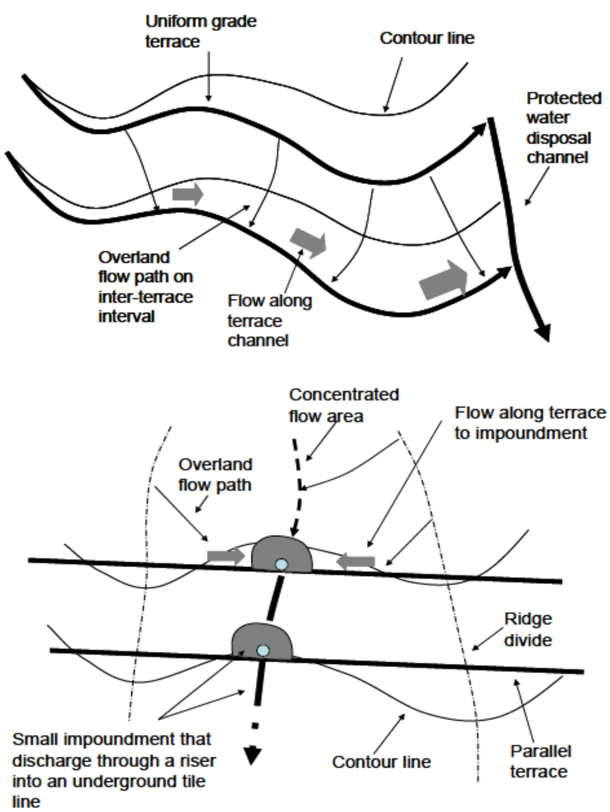


Figure 3. 11 Gradient terrace and PTO terrace diagram (USDA 2008)

Gradient terraces tend not to be evenly spaced along the hillside. The PTO terraces are in the same general direction as the contours, but run in straight lines. Small impoundments that collect overland flow and sediment are formed at the concentrated flow path through the terrace. A vertical riser is located within the impoundment, so the water enters the riser, and connects to a pipe, also known as a tile line. Ridges divide the hillside into multiple sections with shorter overland flow distances to the impoundment.

Small impoundments are depressions in the soil that catch stormwater runoff and allow sediment to settle to the bottom. There is usually an outlet device, like a riser, in the impoundment to allow the water to flow out once the basin is full of water. Impoundments are generally paired with another support practice, such as with terraces seen in **Figure 3. 11**, where the water is slowed and directed to the impoundment.

3.2.3 Using RUSLE2

3.2.3.1 Install Model

RULSE2 is a free model produced by the United States Department of Agriculture (USDA), Agricultural Research Service (ARS), and can be found on the ARS website (USDA 2008). The installation and operating instructions are found in Appendix A. The Natural Resources Conservation Services (NRCS) has also composed a "RULSE2 – Instruction and User Guide" which is accessible at: http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm.

3.2.3.2 Data Collection

The data necessary to run RUSLE2 are: geographic location, soil type, topographical information, soil cover management system, soil management support practices, and sediment barrier systems. Geographic location is needed to set the climate data. Since the climate data are incorporated within the model software, the user needs to input the county and state where the project is located. Soil type can be found based on location using soils maps, by selecting a generic soil within RUSLE2, or the user can specify soil type based on known fill material. Topographical information can be found through GIS maps, engineer topographic designs, or survey data. For most projects, engineer design will likely be used. The management (soil cover) chosen for the site may vary over time from when it is an open construction site, to post construction when the site is completely stabilized with permanent vegetative cover. Support practices are primarily based on topographic design and can include systems like: contour planning (designing topography to reduce erosion), terraces, diversions, and small check dams. Because of steep slopes at highway construction sites, contouring on the construction site may not be very significant, compared to an agricultural field, where the way the field is planted has a significant effect on the amount of soil eroded. Therefore contouring is often assumed to be up-and-down hill. Barrier systems are engineer-designed management systems, which should be found in the design drawings. These barrier systems include: wattles, berms, silt fences, sediment barriers, and straw bales.

3.2.3.3 Model Process

RUSLE2 inputs and outputs are shown in Appendices B through D, for user guidance and reference. The general process includes:

1. Open a new plan
2. Enter project name and geographic location
3. Create worksheet
4. Create hillslope
5. Choose location
6. Select soil on site
7. Enter topographical data for strip (e.g., length and slope)
8. Choose management practice that fits site
9. Select support practices
10. Set sediment barrier types

11. Repeat steps 4-10 until all strips have been input

3.3 Sediment Impacts on BMPs

3.3.1 BMP Model Rationale

It is assumed that all of the soil eroded from the site is transported into a BMP prior to flowing into a waterbody. The intent of the BMP modelling software is to determine the life-span of the BMP based on its sediment-trapping efficiency, which depends on variable site conditions and BMP design. The conditions that dictate efficiency differ by BMP and should all be easily accessible for an engineer to attain. The model should give users the quantity of soil deposited in the BMP on an annual basis and the estimated lifespan of the BMP in question. This program should be used as a tool to adjust BMP designs to meet their required performance and lifespan. Users should also be able to compare construction site management options and different types of BMPs using this program to assist them in determining what fits the site best.

The BMP model was created to use the RUSLE2 results as input. Users will first input the sediment delivery from RUSLE2 as tons/acre/year from the construction site, which will be converted into tons/year to the BMP. The user will input soil type, watershed area, BMP volume, and how full the BMP will be before cleanout or reconstruction is required. Not all of the input variables are applicable to every BMP.

3.3.2 BMP Selection

BMPs are often required to treat stormwater runoff from highway construction sites. The BMPs that are used for this application are used primarily to capture sediment, and they must be suitable to roadside applications (e.g., relatively small footprints). The BMPs selected to be modeled and evaluated were detention ponds, infiltration trenches, grass-lined swales, grass-lined swales with check dams, and bioretention areas.

3.3.2.1 Detention Pond

Detention ponds (**Figure 3. 12**) are very common BMPs in municipal stormwater management systems. Detention ponds work by temporarily storing stormwater runoff within the basin. The water should be detained for up to 72 hours (U.S. EPA 1999_d), allowing time for sediment particles to settle to the bottom of the basin. There is an outlet works system to allow water to slowly be released into natural channels, which helps reduce peak flow. The trapping efficiency range is between 50 and 90%, based on past studies conducted on detention ponds (**Table 2. 4**). Detention ponds are especially effective when the construction site is open and lacks slope stabilization since it can handle large volumes of runoff, and it can remove large amounts of sediment; however, detention ponds are still very effective after the site has been stabilized with permanent cover. The detention pond is also relatively easy to manage and clean out as needed throughout the construction project. Ponds are generally utilized for larger sites, because they can treat significant amounts of runoff.

Figure 3. 12 Detention pond (Stormwater Management)

3.3.2.2 Infiltration Trench

Infiltration trenches (**Figure 3. 13**) work similarly to detention ponds, as they also detain water within the system. The porous media within the infiltration trench is used to help filter the sediment out of stormwater runoff. There is no outlet system within infiltration trenches, because the intent of this BMP is to allow runoff to infiltrate into the groundwater table. The trapping efficiency range of infiltration trenches is 60-90% based on past studies of infiltration trenches (**Table 2. 4**). They are not as useful on large sites, or sites with bare soil. The total volume of the BMP is already 60% filled with gravel (leaving 40% of the total volume as empty pore spaces within the gravel bed) before any stormwater enters the system. This means that the capacity of infiltration trenches is a lot lower than that of a detention pond with the same footprint. Once a site has been stabilized, infiltration trenches could be a viable option, because they allow the stomwater to naturally infiltrate into the ground, with all the sediment and pollutant load remaining in the trench.

Figure 3. 13 Infiltration Trench (DCCC 2009)

3.3.2.3 Grass Lined Swale

Grass lined swales (**Figure 3. 14**) target pollutants by reducing the flow velocity of stormwater runoff using filter media, in this case vegetation. As the flow velocity of runoff is reduced, the time runoff is in the system increases, allowing pollutant loads more time to settle to the bottom of the swale. The removal efficiency range of grassed swales is 65-99% based on recent studies of grassed swales (**Table 2. 4**). These post construction BMPs do not take up much space. As with infiltration trenches, swales will fill up with sediments if they are downstream of a construction site with bare soil. Therefore, they may be better applied as a post-construction BMP.

Figure 3. 14 Grass lined swale (Bioinfiltration Swales)

3.3.2.4 Grass Lined Swale with Rock Check Dam

Grass lined swales with check dams (**Figure 3. 15**) are similar to grassed swales, with the stormwater runoff being slowed as it passes through the vegetation. With the check dams in place, there will be some ponding within the system as well, which slows the runoff further, allowing even more time for the sediment to settle out of the flow. The removal efficiency range of grassed swales with rock check dams is 20-98% based on past studies on these systems (**Table 2. 4**). Previous research also states that grassed swales are more efficient with check dams present (Yu et al. 1993). Grassed swales with check dams are post construction BMPs that are ideal for small footprints. Since the goal of swales with check dams is to slow the flow of runoff, they do not have a large capacity, making them less effective for construction sites with bare soil.

Figure 3. 15 Grass lined swale with rock check dam (DDOT 2014)

3.3.2.5 Bioretention Area

Biretention areas, or rain gardens, (**Figure 3. 16**) treat stormwater runoff by temporarily storing runoff within the depression created for rain gardens. The stormwater should be able to infiltrate, and will also be directed to an outlet works into a channel. As the water is temporarily detained, the peak flow should be reduced in streams and creeks prior to the treated stormwater entering receiving streams. According to previous studies on bioretention gardens, the trapping efficiency range is 29-99% (**Table 2. 4**). Rain gardens are great BMPs for high visibility areas that still require a stormwater BMP. These rain gardens are highly recommended to be used as post construction management systems, due to the amount of landscape design and cost that is input to construct an effective and pleasing garden. These areas treat small to medium sized runoff areas, with a recommendation of treating under 10 acres of runoff area. **Figure 3. 16** shows a rain garden at the University of Nebraska-Omaha visitor center.

Figure 3. 16 Bioretention Garden (UNL 2015)

3.3.3 BMP Model Process

The process for the BMP model may vary slightly depending on the BMP selected to use. Generally the steps are:

1. Input sediment delivery (t/Ac/yr) data for each representative strip for a given construction site into erosion data table
2. Input areas (Ac.) associated with each representative strip for a given site into erosion data table
3. Input the TOTAL sediment delivery for a given watershed into the *Sediment Delivery Data* cell
4. Select the soil type that reflects the given construction (or post-construction) watershed
5. Select the BMP to implement
6. Enter BMP-specific data (eg., volume, percent filled before cleanout, total watershed area, media fill type, length, slope, width, density of grass, sideslope length, and grass height)
7. Evaluate efficiency and estimated lifespan
8. Redesign as needed

Each BMP has different efficiency variables, which are discussed in the specific BMP sections. A detailed tutorial explaining how to use the BMP model is provided in **Appendix E BMP Design Tutorial.**

3.3.3.1 BMP Model Data Requirements

The BMP model was created to estimate the impacts (e.g. amount of sediment deposited in a BMP and its lifespan) on a BMP based on site-specific data along with the RUSLE2 sediment yield output. The site data needed for each BMP type are shown in **Table 3. 3**.

Table 3. 3 BMP Data Requirements for BMP Model

	BMP				
Data Required	Detention Pond	Infiltration Trench	Grass lined Swale	Grass lined Swale with Rock Check Dams	Bioretention Area
Sediment Delivery	X	X	X	X	X
Soil Type in Watershed	X	X	X	X	X
BMP Volume	X	X			
Total Watershed Area	X	X		X	X
BMP Media Type		X			
Percent Filled before cleanout	X				
Slope of Swale			X	X	
Width of Swale			X	X	
Density of Filter Media			X	X	
Horizontal Side slope of swale			X	X	
Height of Vegetation in swale			X	X	
Length of swale			X	X	
Depth of Bioretention Cell					X
Height of Check Dam				X	
Spacing of Check Dam				X	
Number of Check Dam				X	
Area of Bioretention Cell					X

The sediment yield computed in RUSLE2 (T/Ac./yr.), is input to the BMP model which calculates total sediment yield from the entire construction site (T/yr.), based on the representative areas of each strip. The BMP model uses the total sediment yield and the BMP efficiency to calculate the time for the BMP to fill with sediment.

The soil type in the watershed (construction site) should be the same as that used within RUSLE2. Soil type is necessary for all BMPs to estimate the density of the soil, which allows the BMP model to calculate the volume of sediment transported into the BMP annually. That annual sediment transport quantity is then multiplied by the efficiency of the BMP to determine the volume of sediment deposited within the BMP annually, which, in turn is used to estimate the lifespan of the BMP.

3.3.3.2 Detention Pond

User inputs required for detention ponds are BMP volume, total watershed area, and percent filled before cleanout. The total BMP volume is in units of Acre-feet, which is a surface area in acres, and an average depth in feet. Total area of the watershed (construction site) is the contributing area for the BMP, with units of acres. Percent filled before cleanout is how full the pond will be, before it needs maintenance or cleanout.

A BMP volume to contributing watershed area ratio is calculated (Volume: Area ratio), see equation 3.26. Soil particle diameter is also determined, based on user input soil type, and **Table 3. 4**.

$$V\!:A\ Ratio = \frac{Detention\ Pond\ Volume}{Watershed\ Area} \tag{3.26}$$

Table 3. 4 Soil Particle Diameter Based on Soil Size Class

Soil Type	D50 (inches)
Clay	0.000106
Clay Loam	0.000354
Loam	0.001693
Loamy Sand	0.014173
Sand	0.011417
Sandy Clay	0.007874
Sandy Clay Loam	0.007874
Sandy Loam	0.010236
Silt	0.000079
Silt Loam	0.000827
Silty Clay	0.000094
Silty Clay Loam	0.000315

For detention ponds, the sediment trapping efficiency is a function of the volume-to-area ratio (volume of detention pond to area of watershed) and the particle size of the sediment. Equation 3.27 shows how the efficiency (ε) of detention ponds is calculated.

$$\varepsilon = (0.2 * e_{VA}) + (0.8 * e_{D50}) \quad (3.27)$$

where e_{VA} is the efficiency factor of the volume to area ratio based on **Figure 3. 17**. The V:A ratio affects the efficiency of a detention pond because as the pond volume increases the detention time increases providing more time for the sediment to settle out of suspension. If the detention pond volume is zero, obviously the removal efficiency would be zero. As the volume increases, the efficiency increases; however, it would never reach 100% because very fine sediments will not settle regardless of the pond's volume (detention time). A logarithmic relationship between the V:A ratio and the efficiency factor is proposed ranging from 0.0 for a V:A ratio of 0.0001 to 0.9 for a V:A ratio of 1.0 (**Figure 3. 17**) based on efficiency ranges found in previous studies (**Table 2. 4**).

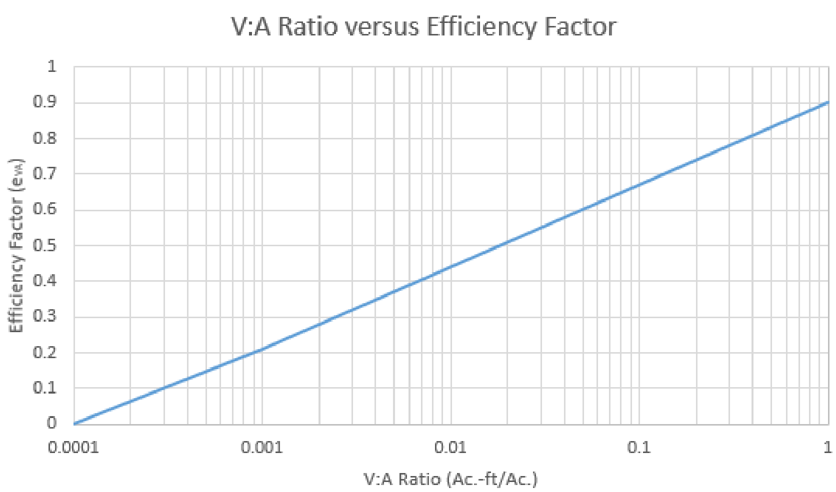


Figure 3. 17 Detention pond volume-to-area ratio vs. efficiency factor

The variable e_{D50} is the efficiency factor based on the sediment diameter (**Table 3. 5**). Settling velocity of the sediment drives the amount of sediment that is deposited within the detention pond. **Figure 3. 18** is used to determine the settling velocity, based on soil particle diameter. Large particles have a faster settling velocity. Smaller sediment diameters will have a longer settling time, meaning the smaller the sediments (eg. clays) will likely remain suspended. **Figure 3. 18** shows the soil particle diameter efficiency factor curve (e_{D50}). The curve reflects a settling velocity curve, with minimal settling occurring for small particles, and rapid settling for large particles.

Table 3. 5 Particle Diameter with Corresponding Settling Velocities

Soil Type	D50 (inches)	Settling Velocity (ft/sec)
Clay	0.000106	6.36E-05
Clay Loam	0.000354	5.18E-04
Loam	0.001693	6.59E-03
Loamy Sand	0.014173	5.20E-01
Sand	0.011417	1.13E-01
Sandy Clay	0.007874	8.10E-02
Sandy Clay Loam	0.007874	8.10E-02
Sandy Loam	0.010236	1.02E-01
Silt	0.000079	1.31 E.05
Silt Loam	0.000827	1.54E-03
Silty Clay	0.000094	4.20E-05
Silty Clay Loam	0.000315	4.46E-04

The 0.2 and 0.8 multipliers associated with the factors are to weight the relative importance of the two variables. Since large particles (e.g. sand) will settle even in very small detention ponds and very small particles (e.g. clay) will likely not settle even in very large ponds, particle size is considered the more important determinant of efficiency. Therefore, sediment diameter has the 0.8 multiplier and the V:A ratio is given the 0.2 multiplier.

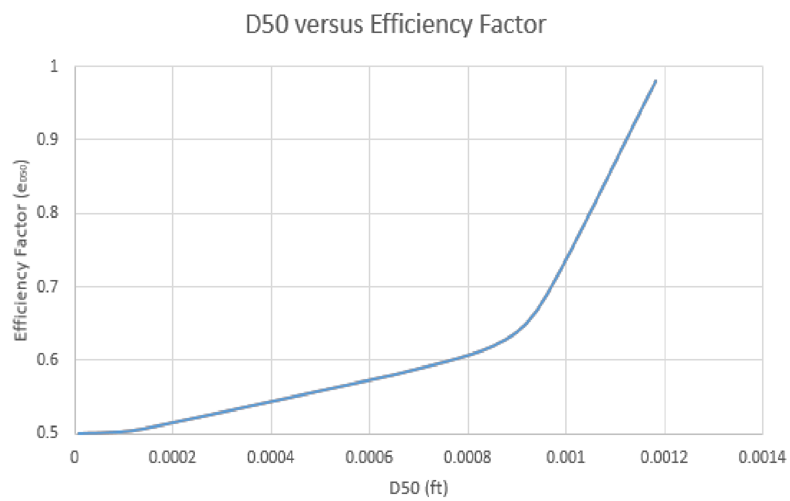


Figure 3. 18 Detention pond sediment diameter vs. efficiency factor

The volume of sediment that is deposited in the BMP is calculated by multiplying the efficiency by the volume of sediment transported into the BMP. Estimated BMP lifespan is then determined using the volume of the BMP, the percent filled, and the volume of sediment deposited in the BMP (3.28).

$$Detention\ Pond\ Lifespan = \frac{(BMP\ Volume)(Percent\ Filled\ Before\ Cleanout)}{Volume\ of\ Soil\ Deposited\ in\ BMP\ /\ year} \quad (3.28)$$

If the lifespan is greater than 50 years, the model displays the estimated lifespan is > 50 years. This may indicate that the BMP is oversized.

3.3.3.3 Infiltration Trench

The user inputs for infiltration trenches are the infiltration trench fill type, infiltration trench volume, and contributing watershed area. The total BMP volume is in units of Acre-feet. For infiltration trenches, this is the gross volume of the trench, not the volume accounting for the media fill porosity. Total area of the watershed is the contributing area for the BMP, with units of acres. BMP Media Fill type is based on the material placed in the trench. Typically, gravel is used as the media fill of choice within infiltration trenches, with an average porosity (η) of 40% (USDA 1999).

The volume and area are again used to calculate the Volume: Area ratio, which influences the efficiency. The media, though, affects the BMP volume, depending on porosity. The Volume: Area calculation is:

$$Volume\!:Area = \frac{(Gross\ BMP\ Volume)(Fill\ Media\ Porosity)}{(Watershed\ Area)} \qquad (3.29)$$

Infiltration trench efficiency is based on the volume-to-area ratio (volume of infiltration trench: area of the watershed) up to a maximum of 90% efficiency. This is based upon efficiency studies of infiltration trenches (Burack et al. 2008). As particles suspended in stormwater enter the infiltration trench, the sediments fall into the porous cavities of the trench and settle out. The small particles will likely remain suspended, which is why the maximum efficiency is 90%. As volume of the infiltration trench approaches zero, there is less settling of the suspended sediments, causing a low efficiency (50%). The lower limit of 50% is based on past studies of infiltration trenches, where the lowest efficiency was found to be 50%. Inversely, if the trench has a large volume, the stormwater will all enter the BMP, creating a high efficiency (90%). This relationship is based on past studies (**Table 2. 4**) and are assumed to be linear from low volume to high volume, capping at 90% efficient. Equation 3.30 shows the efficiency of infiltration trenches with respect to the volume-to-area ratio.

$$\varepsilon = \begin{cases} 0.4106\mathrm{V\!:A} + 0.4962 \text{ if } \mathrm{V\!:A} \leq 1.0 \\ 0.9 \text{ if } \mathrm{V\!:A} > 1.0 \end{cases} \qquad (3.30)$$

where $V\!:A$ is the ratio of the volume of the porous spaces in the trench to area of a watershed. If the V:A is greater than 1.0, the efficiency is a maximum at 90%. **Figure 3. 19** shows the efficiency curve based on the volume-to-area ratio.

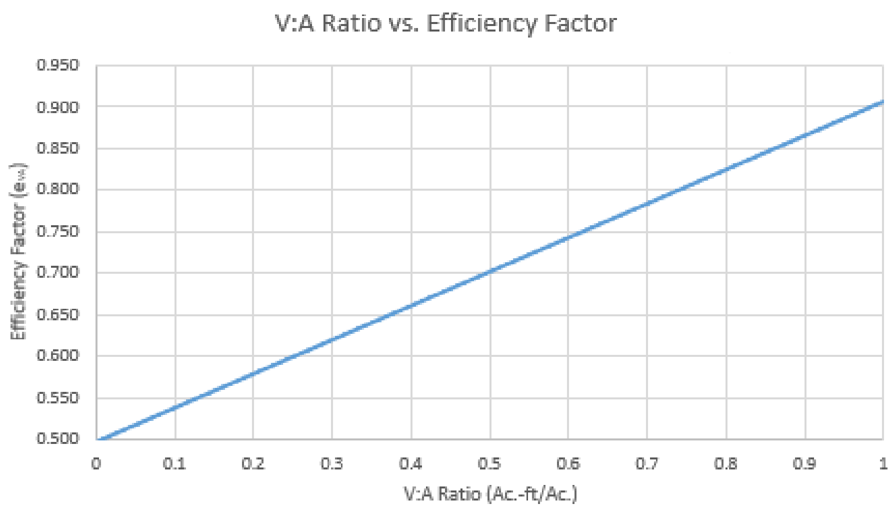


Figure 3. 19 Infiltration trench volume to area ratio efficiency factor

The volume deposited in the BMP is calculated by multiplying the efficiency by the volume of sediment transported into the BMP.

Estimated infiltration trench lifespan is then determined using the volume of the BMP, factoring in porosity, and the volume of sediment deposited in the BMP (3.31).

$$Infiltration\ Trench\ Lifespan = \frac{(Gross\ BMP\ Volume)(Fill\ Media\ Porosity)}{Volume\ of\ Soil\ Deposited\ in\ BMP/_{year}} \quad (3.31)$$

If the lifespan is greater than 50 years the model displays the estimated lifespan is >50 years. This may indicate that the BMP is oversized.

3.3.3.4 Grass Lined Swale

User inputs for grass lined swales are the swale length, slope of the swale, bottom width of the swale, horizontal side slope of the swale, grass cover density, and the grass height. The swale length is in units of feet, and this length should be the total horizontal length from upstream end to downstream end. The slope of the swale is in units of percent. As only one swale slope is asked for, use the average slope over the swale. Swale bottom width (b) is in units of feet (**Figure 3. 20**). Grass cover density is the approximate cover of grass within the swale, which is defined as one minus the amount of open spaces in the grass when looking straight down on it. The cover density ranges from 0.0 to 1.0 with the density determining the Manning roughness coefficient. Horizontal side slope (z) of the swale is seen in **Figure 3. 20**, with units of feet. Grass height is the average grass height in units of feet.

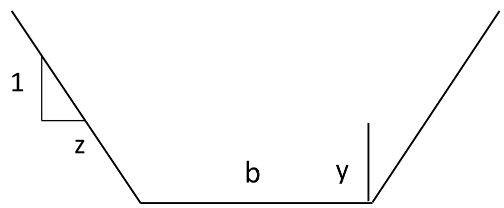


Figure 3. 20 Swale Width (b), Horizontal Sideslope (z), and Grass Height (y)

The Manning roughness coefficient is estimated based in the grass density input. The roughness of the surface varies with the density of the grass. See **Table 3. 6** for the variance in roughness associated with grass cover density.

Settling duration is a function of the water treatment depth and the settling velocity of the soil being transported, as shown below:

$$\text{Settling Duration} = \frac{\text{Treatment Depth}}{\text{Settling Velocity}} \tag{3.32}$$

Treatment depth is considered to be the height of that grass (y) lining the swale (**Figure 3. 20**) because sediment removal is only considered to occur in that depth, with all water depth above the grass height being untreated.

The settling velocity is the rate at which a specified type of eroded soil settles to the bottom of the BMP, see **Table 3. 5**.

Travel time is a function of the swale length and the flow velocity of the runoff, as shown in equation 3.33.

$$\text{Travel Time} = \frac{\text{Swale Length}}{\text{Flow Velocity}} \tag{3.33}$$

where the swale length is the horizontal distance from the beginning of the swale to the end. The flow velocity is calculated using the Manning Equation:

$$V = \frac{k_n}{n} R^{2/3} S^{1/2} \tag{3.34}$$

where V is the flow velocity, k_n is a constant (1.486 for English units); n is the Manning roughness coefficient (**Table 3. 6**); R is the hydraulic radius; and S is the slope of the swale.

Table 3. 6 Density of grass to Manning's Roughness Coefficient Relationship (Chow 1959)

Density	n
100%	0.5
90%	0.453
80%	0.403
70%	0.352
60%	0.302
50%	0.252
40%	0.201
30%	0.151
20%	0.101
10%	0.050
0%	0.03

The hydraulic radius of a trapezoidal channel is found by:

$$R = \frac{(b+2y)y}{b+2y\sqrt{1+z^2}} \tag{3.35}$$

BMP volume is also calculated, which accounts for the length of the swale, width of the swale, and height of the grass (3.36).

$$BMP\ Volume = (Swale\ Length)(Swale\ Width)(Grass\ Height) \tag{3.36}$$

Efficiency of grass lined swales is a function of settling duration and travel time, according to the Alabama Drainage Conservation Design Practices (Nara and Pitt 2005). The efficiency of the grass lined swale is found using equation 3.37. Based on the literature (Water Environment Research Foundation et al. 2014) an approximate maximum efficiency for grass lined swales was 77%. Therefore, the maximum efficiency is set at 77%.

$$\text{Efficiency} = \begin{cases} \frac{\text{Traveling Time}}{\text{Settling Duration}} \text{ if } \leq 77\% \\ 77\% \text{ if } \frac{\text{Traveling Time}}{\text{Settling Duration}} > 77\% \end{cases} \quad (3.37)$$

3.3.3.5 Grass Lined Swale with Rock Check Dams

Grass lined swales with rock check dams have two sediment capture processes. Where ponding occurs behind a check dam, the sediment removal is the same is in a detention pond. Where ponding is not present, removal is the same as in a grass lined swale. User inputs for grass lined swales with rock check dams are the total swale length, slope of the swale, bottom width of the swale, horizontal side slope of the swale, grass cover density, the grass height, the height of the check dams, the number of check dams, spacing of check dams, and the watershed area. The swale length is in units of feet, and this length should be the total horizontal length from upstream end to downstream end. The slope of the swale is in units of percent. Swale bottom width (b) is in units of feet (**Figure 3. 20**). Horizontal side slope of the swale (z) is seen in **Figure 3. 20**, with units of feet. Grass cover density is the approximate cover of grass within the swale. The cover density ranges from 0.0 to 1.0 with the density determining the Manning roughness coefficient. Grass height is the average grass height in units of feet. Height of the check dams is in units of feet, and is the height of each individual dam. Number of dams in the swale is unit-less, and is simply how many check dams will be within the length of the swale. Check dam spacing is recommended to be based on swale slope, **Table 3. 7** shows recommended spacing based on slope. Spacing is in units of feet. Total area of the watershed (construction site) is the contributing area for the BMP, with units of acres.

Table 3. 7 Check dam spacing recommendations (MPCA 2000)

Ditch Grade (%)	Spacing (feet)
1	200
2	100
4	50
6	33
Grades above 6% are not recommended	
8	25
10	20

Sediment removal in the ponded portions of the BMP is a function of the ratio of the ponding volume and the area of the watershed (construction site). Check dam ponding volume is calculated using:

$$Check\ Dam\ Ponding\ Volume =$$

$$\frac{(\frac{1}{2})(Dam\ Spacing)(Dam\ Height)(Number\ of\ Dams)(Swale\ Width)}{43560\,\frac{sq.\ ft.}{Ac.}} \qquad (3.38)$$

Volume-to-Area ratio is then calculated using the check dam ponding volume and the total watershed (construction site) area.

Sediment removal in the non-ponded portion of the BMP is a function of the particle settling velocity and the travel time in the swale. The Manning roughness coefficient is estimated based in the grass density input. The roughness of the surface varies with the density of the grass. See **Table 3. 6** for the roughness associated with grass cover density.

Settling duration is a function of the water flow depth and the settling velocity of the soil being transported, as shown below:

$$\text{Settling Duration} = \frac{\text{Treatment Depth}}{\text{Settling Velocity}} \tag{3.39}$$

Treatment depth is considered to be the height of that grass (y) lining the swale (**Figure 3. 20**) because sediment removal is only considered to occur in that depth, with all water depth above the grass height being untreated. The settling velocity is the rate at which a specified type of eroded soil settles to the bottom of the BMP, see **Table 3. 5**.

Travel time is a function of the swale length and the flow velocity of the runoff, as shown in equation 3.40.

$$\text{Travel Time} = \frac{\text{Swale Length}}{\text{Flow Velocity}} \tag{3.40}$$

where the swale length is the horizontal distance from the beginning of the swale to the end. The flow velocity is calculated using the Manning Equation:

$$\mathrm{V} = \frac{\mathrm{k_n}}{\mathrm{n}} \mathrm{R}^{2/3} \mathrm{S}^{1/2} \tag{3.41}$$

where V is the flow velocity, k_n is a constant (1.486 for English units); n is the Manning roughness coefficient (**Table 3. 6**); R is the hydraulic radius; and S is the slope of the swale. The hydraulic radius of a trapezoidal channel is found by:

$$\mathrm{R} = \frac{(\mathrm{b}+2\mathrm{y})\mathrm{y}}{\mathrm{b}+2\mathrm{y}\sqrt{1+\mathrm{z}^2}} \tag{3.42}$$

BMP volume is also calculated, which accounts for the length of the swale, width of the swale, and height of the grass (3.43).

$$BMP\ Volume = (Swale\ Length)(Swale\ Width)(Grass\ Height) \tag{3.43}$$

The efficiency of grass lined swales with rock check dams is a combination of swale and ponding efficiencies. The way total efficiency of the system is determined is by finding a swale segment length to total BMP length ratio, and a check dam segment length to total BMP length ratio, as seen in **Figure 3. 21**, and multiplying these factors by the efficiency factors. Equation 3.44 shows how the total efficiency of the system is calculated.

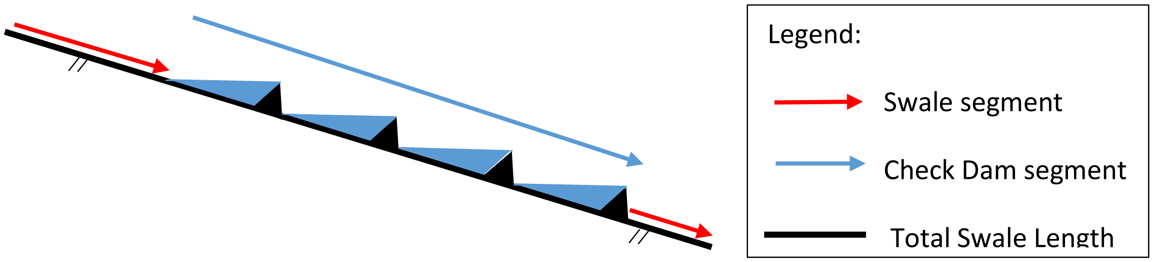


Figure 3. 21 Grassed swale with rock check dams length ratios

$$\text{Efficiency} = \left(\frac{\text{Total Swale Segment Length}}{\text{Total Swale Length}}\right) * \text{Swale Efficiency} + \left(\frac{\text{Total Check Dam Segment Length}}{\text{Total Swale Length}}\right) * \text{Check Dam Efficiency} \qquad (3.44)$$

The efficiency of the swale segment of the system is determined the same way it is calculated for a swale without check dams. See **Section 3.3.2.3** Grass Lined Swale for efficiency functions of grassed swales.

The efficiency of the check dam segment is treated similarly to a pond. It is a function of the ratio of the volume of the water behind all check dams to the area of the watershed and the particle size of the sediment eroded. Equation 3.45 shows the efficiency of the check dam.

$$\varepsilon = (0.2 * e_{VA}) + (0.8 * e_{D50}) \qquad (3.45)$$

where e_{VA} is the efficiency factor of the volume to area ratio based on **Figure 3. 22**. e_{D50} is the efficiency based on the eroded sediment particle diameter, found in **Figure 3. 23**.

The volume to area ratio affects the efficiency of a check dam because as the storage volume increases, the detention time also increases, which allows more retention time for the sediment to settle out. The range of efficiencies was determined from literature, found in **Table 2. 4**. When the check dams are the same height as the height of the grass, the volume behind the checks to area is near zero, giving the minimum efficiency of a lined swale. As the volume of the pond increases, so does the efficiency of the check dams. The maximum efficiency of the check dams is 98% based on literature.

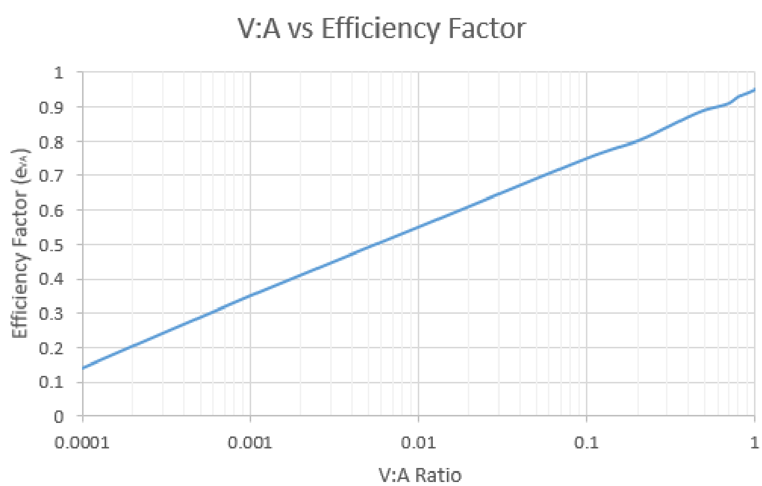


Figure 3. 22 Check Dam Volume: Area Efficiency

The D50 of the sediment eroded is the average diameter of the soil particles. The diameter determines the settling velocity of the soil particles. Based on this value, the efficiency is established from **Figure 3. 23**.

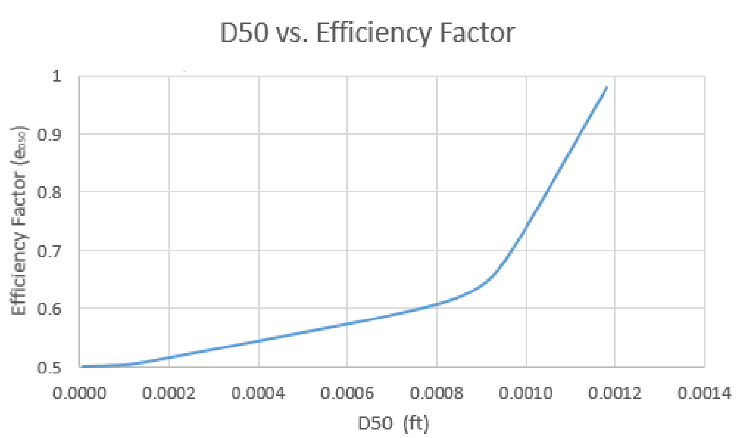


Figure 3. 23 Check Dam D50 Efficiency

The 0.2 and 0.8 multipliers in equation 3.45 are weighting factors for V:A and D50 indicating the relative importance of each value in the check dam efficiency calculation. Since the settling velocity varies so greatly between soil types and diameters, it affects the efficiency more than the volume: area ratio. **Table 3. 5** shows the settling velocities of the varying soil sizes.

3.3.3.6 Bioretention Area (Rain Garden)

The inputs required for bioretention areas are rain garden area, rain garden depth, the total watershed area, and depth of infiltration cell below the rain garden. The total BMP area is in units of square feet, which is a surface area. The recommended surface area of bioretention cells is 1/5 of the watershed area (Davis et al. 2009; PDEP 2006). The BMP depth is also input in feet, and is the depth of the depression (basin) that captures and temporarily stores the runoff. Total area of the watershed (construction site) is the contributing area for the BMP, with units of acres. Depth of infiltration cell below rain garden is in units of feet. It is assumed that if there is an infiltration cell beneath, the fill media is gravel, with a porosity of 40%.

Many bioretention areas have infiltration cells under the rain garden, which also accounts for some of the BMP volume. The total BMP volume is calculated using equation 3.46.

$$Total\ BMP\ Volume = \left(\frac{(BMP\ Surface\ Area)(BMP\ Basin\ Depth)}{43560\ \frac{sq.ft.}{Ac.}}\right) + \left(\frac{(Depth\ of\ infiltration\ cell)(BMP\ Surface\ Area)(Media\ Porosity)}{43560\frac{sq.ft.}{Ac.}}\right) \qquad (3.46)$$

A BMP volume to contributing watershed area ratio is calculated (Volume: Area ratio), see equation 3.47.

$$Volume: Area = \frac{(Total\ BMP\ Volume)}{(Watershed\ Area)} \qquad (3.47)$$

There is a minimum recommended treatment of the first 0.5 inch of stormwater runoff over the entire site (Schueler and Holland, 2000).

Bioretention garden efficiency is based on the Volume: Area ratio of the garden and site watershed (construction site) area. The range of efficiencies for rain gardens was based on past studies that had efficiency calculated and noted in the literature (**Table 2. 4**). **Figure 3. 24** shows the efficiency curve of bioretention gardens based on the volume: area ratio. As the volume: area approaches 0, the efficiency severely drops, because rain gardens perform by allowing runoff to slow and pool for a period of time before either infiltrating, evaporating, or discharging through an outlet works system. If the runoff does not sufficiently slow and pool, the efficiency of this system decreases. Once the V:A reaches approximately 0.1, the efficiency increases at a much more gradual rate, because there is enough capacity to partially treat the stormwater runoff.

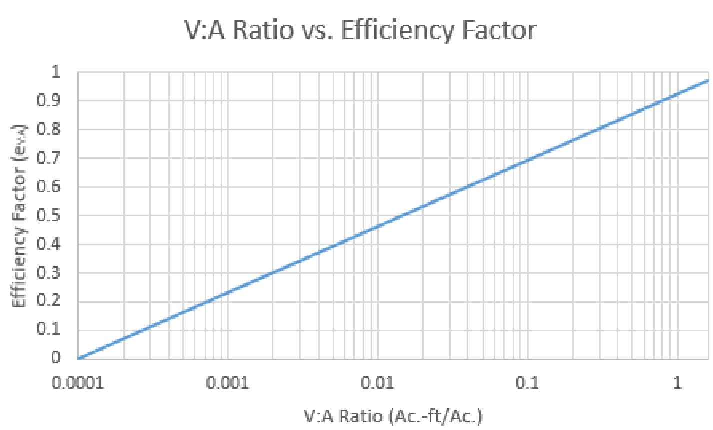


Figure 3. 24 Bioretention Area V:A Efficiency

The volume of sediment deposited in the BMP is calculated by multiplying the efficiency by the volume of sediment transported into the BMP. The lifespan determined by the efficiency takes into consideration that once the garden becomes $\frac{1}{10}$ filled, it will need to be cleaned out. This is because after there is noticeable sedimentation within the area, the infiltration rate will decrease. This may cause water to pool longer than 72 hours, which may create a potential mosquito breeding ground.

3.4 Model Calibration

3.4.1 RUSLE2 Model Calibration

The Universal Soil Loss Equation (USLE) was originally published in 1965. It has been in use since that time, with many modifications to the software (e.g. modified to the Revised Universal Soil Loss Equation 2, RUSLE2 model). Throughout the last 50 years, the USDA has done significant calibration tests to get the data as accurate as possible. Since there has been so much time invested into the USDA calibration, this project considered the RUSLE2 model to be pre-calibrated for the given modelling conditions (e.g. soils, climate).

3.4.2 BMP Model Calibration

The BMP model was not tested with a field model. All efficiency estimates are based on literature. A potential future study could test the accuracy of the BMP model in the field. The data within the BMP Model could be validated as part of a future study.

3.5 Model User's Guide Development

The flow chart found in **Figure 3. 25** shows the process of erosion from RUSLE2 input requirements and RUSLE2 output, to the BMP model inputs, including the final outputs of the efficiency and lifespan of the BMP.

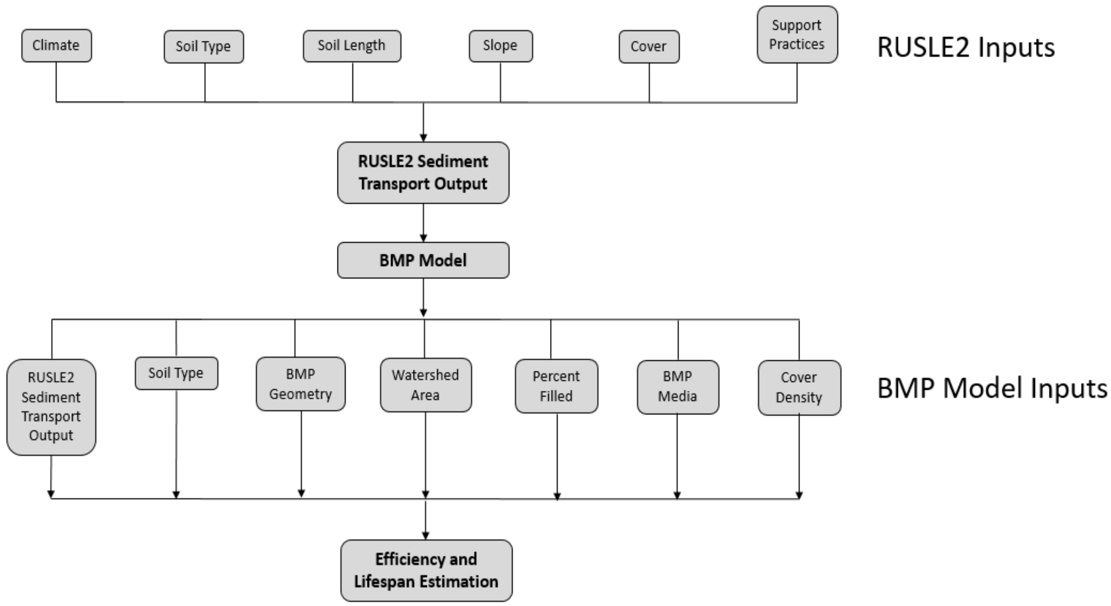


Figure 3. 25 RUSLE2 and BMP Model Input and Output Flow Chart

The model user's guide for RUSLE2 can be found in Appendix A, with RUSLE2 site examples for I-80 at Center Street Omaha, I-80 at I street Omaha, and I-80 in Sidney, Nebraska, located in Appendixes B, C, and D, respectively. The BMP model user's guide is located in Appendix E.

Chapter 4: Results

4.1 RUSLE2 Results for Case Study Sites

As a construction project develops, the site typically changes from pre-existing vegetation to bare ground, which can be followed by a variety of cover management practices and finally post-construction vegetative cover.

Three hypothetical roadside construction sites (I-80 at Center Street, I-80 at I Street, and the I-80 Sidney Off-ramp) were evaluated for erosion and sediment transport under various cover practices. A compilation of total sediment delivery from three example sites, based on different management practices is found in **Table 4. 1, Table 4. 2** and **Table 4. 3** for I-80 at Center Street, I-80 at I Street, and I-80 at Sidney, respectively.

For all the sites evaluated, the pre-construction vegetative cover (tall fescue grass) produced the least amount of sediment. The practice that produced the most sediment was the bare cut site with no cover. The post construction permanent cover vegetation produced the second least amount of sediment across all sites. For the temporary cover, for all three of these sites, the roll material was found to allow the least amount of erosion, followed by the straw mulch at 2000 lb/ac, and finally the straw mulch at 1000 lb/ac. The long-term cover of permanent seeding covered with straw mulch at 4000 lb/ac was less effective than the mixed grass.

4.1.1 Interstate- 80 Center Street On-Ramp, Omaha, NE

A hypothetical construction site on the Interstate-80 Northbound on-ramp at Center Street in Omaha, NE was modelled using RUSLE2 to estimate the quantity of sediment eroded and transported from the site under various management conditions. The site covers 1.12 Ac. with silt-loam soils. Modelling details can be found in Appendix B Center Street RUSLE2 Example.

Table 4. 1 Center Street RUSLE2 Results: Varying Cover Management

Center Street RUSLE2 Data: Varying Management		
Construction Period	**Management Practice** [a]	**Total Sediment Delivery (t/yr)**
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.0115
Open Site	Highly Disturbed; Bare Cut; Rough	41.3
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	10.835
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	18.33
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	2.968
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	0.745
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	12.26
Permanent Cover	CMZ Zone [b] 16 Construction Site Templates: Cool Seasonal Grass; Not Harvested; Good Stand	0.111

a: All cover management practice titles are RULSE2 file hierarchy

b: CMZ refers to Crop Managemnt Zone (3.2.2 RUSLE2 Governing Equation)

4.1.2 Interstate-80 I Street On-Ramp, Omaha, NE

A hypothetical construction site on the Interstate-80 Northbound on-ramp at I Street in Omaha, NE was modelled using RUSLE2 to estimate the quantity of sediment eroded and transported from the site under various management conditions. The site covers 11.4 Ac. with silt-loam soils. Modelling details can be found in Appendix C I Street RUSLE2 Example.

Table 4. 2 I Street RUSLE2 Results: Varying Cover Management

I Street RUSLE2 Data: Varying Management		
Construction Period	**Management Practice a**	**Total Sediment Delivery (t/yr)**
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.111
Open Site	Highly Disturbed; Bare Cut; Rough	1069.8
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	255.55
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	447.48
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	46.39
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	8.075
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed-Spring	295.7
Permanent Cover	CMZ Zone b 16 Construction Site Templates: Cool Seasonal Grass; Not Harvested; Good Stand	1.065

a: All cover management practice titles are RULSE2 file hierarchy

b: CMZ refers to Crop Managemnt Zone (3.2.2 RUSLE2 Governing Equation)

4.1.3 Interstate-80 Sidney Off-Ramp, Sidney, NE

A hypothetical construction site on the Interstate-80 Westbound off-ramp at Sidney, NE was modelled using RUSLE2 to estimate the quantity of sediment eroded and transported from the site under various management conditions. The site covers 3.29 Ac. with loam soils. Modelling details can be found in Appendix D Sidney RUSLE2 Example.

Table 4. 3 Sidney off-ramp RUSLE2 Results: Varying Cover Management

Sidney Off Ramp RUSLE2 Data: Varying Management		
Construction Period	**Management Practice** [a]	**Total Sediment Delivery (t/yr)**
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.0152
Open Site	Highly Disturbed; Bare Cut; Rough	212.62
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	52.14
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	90.73
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	16.77
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	2.94
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	86.75
Permanent Cover	Strips Barriers Management; Cool Seasonal Grass; Not Harvested, Moderate Stand	0.125

a: All cover management practice titles are RULSE2 file hierarchy

4.2 BMP Model Results for Case Study Sites

The five BMPs were evaluated on all the theoretical construction sites. Three sizes of each BMP type (0.01 acre-feet, 0.1 acre-feet, and 1 acre-foot) were evaluated. All BMP efficiencies listed in the tables are calculated in the BMP model.

4.2.1 Interstate-80 Center Street On-Ramp, Omaha, NE

Within the theoretical Center Street on ramp in Omaha, NE, there are many management practices that may occur over the course of construction. **Table 4. 4** through **Table 4. 8** show the potential management practices from before construction, to final permanent cover on the site, with sediment delivery and lifespan estimation of each BMP sized at 0.01 acre-feet, 0.1 acre-feet, and 1 acre-foot.

Table 4. 4 Center Street with various RUSLE2 Cover Management Practices and 3 Detention Pond design sizes

(Site Area: 1.12 Ac.; 65% Filled Before Cleanout; Soil: Silt-Loam) *					
Construction Period	**Management Practice**	**Total Sediment Delivery (t/yr) ****	**Estimated Lifespan (BMP Volume: 0.01 Ac.-ft) (years)**	**Estimated Lifespan (BMP Volume: 0.1 Ac.-ft) (years)**	**Estimated Lifespan (BMP Volume: 1.0 Ac.-ft) (years) *****
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.0115	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	41.3	0.7	6	>50
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	10.835	3	24	>50
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	18.33	2	14	>50
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	2.968	9	33	>50
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	0.745	38	>50 ****	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	12.26	2	21	>50
Permanent Cover	CMZ Zone 16 Construction Site Templates: Cool Seasonal Grass; Not Harvested; Good Stand	0.111	>50 ****	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

Table 4. 5 Center Street with various RUSLE2 Cover Management Practices and 3 Infiltration Trench design sizes

(Site Area: 1.12 Ac.; Media Fill: Gravel; Soil: Silt-Loam)*					
Construction Period	**Management Practice**	**Total Sediment Delivery (t/yr) ****	**Estimated Lifespan (BMP Volume: 0.01 Ac.-ft) (years)**	**Estimated Lifespan (BMP Volume: 0.1 Ac.-ft) (years)**	**Estimated Lifespan (BMP Volume: 1.0 Ac.-ft) (years) *****
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.0115	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	41.3	0.8	5	45
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	10.835	3	18	>50
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	18.33	2	11	>50
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	2.968	11	>50	>50
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	0.745	43	>50	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	12.26	3	16	>50
Permanent Cover	CMZ Zone 16 Construction Site Templates: Cool Seasonal Grass; Not Harvested; Good Stand	0.111	>50 ****	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

Table 4. 6 Center Street with various RUSLE2 Cover Management Practices and 3 Grass Lined Swale design sizes

(Site Area: 1.12 Ac.; Media Fill: Gravel; Soil: Silt-Loam)*					
Construction Period	Management Practice	Total Sediment Delivery (t/yr) **	Estimated Lifespan (BMP Dimensions: 40'x20') (years)	Estimated Lifespan (BMP Dimensions: 200'x45') (years)	Estimated Lifespan (BMP Dimensions: 1000'x90') (years) ***
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.0115	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	41.3	0.6	7	>50
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	10.835	2	26	>50
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	18.33	1	15	>50
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	2.968	9	>50	>50
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	0.745	34	>50	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	12.26	2	23	>50
Permanent Cover	CMZ Zone 16 Construction Site Templates: Cool Seasonal Grass; Not Harvested; Good Stand	0.111	>50 ****	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

Table 4. 7 Center Street with various RUSLE2 Cover Management Practices and 3 Grass Lined Swale with Rock Check Dam design sizes

(Site Area: 1.12 Ac.; Media Fill: Gravel; Soil: Silt-Loam)*					
Construction Period	Management Practice	Total Sediment Delivery (t/yr) **	Estimated Lifespan (BMP Dimensions: 60'x10')(1 dam @ 2' height w/ 50' spacing) (years)	Estimated Lifespan (BMP Dimensions: 240'x20')(4 dams @ 2' height w/ 50' spacing) (years)	Estimated Lifespan (BMP Dimensions: 725'x60')(14 dams @ 2' hieght w/ 50' spacing) (years) ***
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.0115	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	41.3	1.5	11	>50
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	10.835	6	42	>50
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	18.33	3	25	>50
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	2.968	21	>50	>50
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	0.745	>50	>50	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	12.26	5	37	>50
Permanent Cover	CMZ Zone 16 Construction Site Templates: Cool Seasonal Grass; Not Harvested; Good Stand	0.111	>50 ****	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

Table 4. 8 Center Street with various RUSLE2 Cover Management Practices and 3 Bioretention Pond design sizes

(Site Area: 1.12 Ac.; Media Fill: Gravel; Soil: Silt-Loam)*					
Construction Period	**Management Practice**	**Total Sediment Delivery (t/yr) ****	**Estimated Lifespan (BMP Dimensions: 45'x45'x0.25') (years)**	**Estimated Lifespan (BMP Dimensions: 95'x95'x0.5') (years)**	**Estimated Lifespan (BMP Dimensions: 300'x300'x0.5') (years) *****
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.0115	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	41.3	0.2	1.2	9
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	10.835	0.9	4.4	34
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	18.33	0.5	2.6	20
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	2.968	3.3	16	>50
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	0.745	13.3	>50	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	12.26	0.8	3.9	30
Permanent Cover	CMZ Zone 16 Construction Site Templates Cool Seasonal Grass; Not Harvested; Good Stand	0.111	>50 ****	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

4.2.2 Interstate-80 I Street On-Ramp, Omaha, NE

Within the theoretical I Street on ramp in Omaha, NE, there are many management practices that may occur over the course of construction. **Table 4. 9** through **Table 4. 13** show the potential management practices from before construction, to final permanent cover on the site, with sediment delivery and lifespan estimation of each BMP sized at 0.01 acre-feet, 0.1 acre-feet, and 1 acre-foot.

Table 4. 9 I Street with various RUSLE2 Cover Management Practices and 3 Detention Pond design sizes

(Site Area: 11.4 Ac.; 65% Filled Before Cleanout; Soil: Silt-Loam)*					
Construction Period	**Management Practice**	**Total Sediment Delivery (t/yr) ****	**Estimated Lifespan (BMP Volume: 0.01 Ac.-ft) (years)**	**Estimated Lifespan (BMP Volume: 0.1 Ac.-ft) (years)**	**Estimated Lifespan (BMP Volume: 1.0 Ac.-ft) (years) *****
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.111	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	1069.8	0.0	0.3	2.4
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	255.55	0.1	1	>50
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	447.48	0.1	0.6	5.7
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	46.39	0.7	6	>50
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	8.075	4	35	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	295.7	0.1	1	8.7
Permanent Cover	CMZ Zone 16 Construction Site Templates Cool Seasonal Grass; Not Harvested; Good Stand	1.065	29	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

Table 4. 10 I Street with various RUSLE2 Cover Management Practices and 3 Infiltration Trench design sizes

(Site Area: 11.4 Ac.; 65% Filled Before Cleanout; Soil: Silt-Loam)*					
Construction Period	Management Practice	Total Sediment Delivery (t/yr) **	Estimated Lifespan (BMP Volume: 0.01 Ac.-ft) (years)	Estimated Lifespan (BMP Volume: 0.1 Ac.-ft) (years)	Estimated Lifespan (BMP Volume: 1.0 Ac.-ft) (years) ***
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.111	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	1069.8	0.0	0.3	2
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	255.55	0.1	1	8
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	447.48	0.1	0.7	4
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	46.39	0.7	7	43
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	8.075	4	39	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	295.7	0.1	1.1	7
Permanent Cover	CMZ Zone 16 Construction Site Templates Cool Seasonal Grass; Not Harvested; Good Stand	1.065	32	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

Table 4. 11 I Street with various RUSLE2 Cover Management Practices and 3 Grass Lined Swale design sizes

(Site Area: 11.4 Ac.; 65% Filled Before Cleanout; Soil: Silt-Loam)*					
Construction Period	Management Practice	Total Sediment Delivery (t/yr) **	Estimated Lifespan (BMP Dimensions: 40'x20') (years)	Estimated Lifespan (BMP Dimensions: 200'x45') (years)	Estimated Lifespan (BMP Dimensions: 1000'x90') (years) ***
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.111	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	1069.8	0.0	0.3	3
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	255.55	0.1	1	11
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	447.48	0.1	0.6	6
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	46.39	0.5	6	>50
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	8.075	3	35	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	295.7	0.1	1	10
Permanent Cover	CMZ Zone 16 Construction Site Templates Cool Seasonal Grass; Not Harvested; Good Stand	1.065	24	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

Table 4. 12 I Street with various RUSLE2 Cover Management Practices and 3 Grass Lined Swale with Rock Check Dam design sizes

(Site Area: 11.4 Ac.; 65% Filled Before Cleanout; Soil: Silt-Loam)*					
Construction Period	**Management Practice**	**Total Sediment Delivery (t/yr) ****	**Estimated Lifespan (BMP Dimensions: 210'x5')(1 dam @ 1.0' height w/ 200' spacing) (years)**	**Estimated Lifespan (BMP Dimensions: 650'x5')(3 dams @ 2.5' height w/ 200' spacing) (years)**	**Estimated Lifespan (BMP Dimensions: 950'x40')(4 dams @ 2.5' hieght w/ 200' spacing) (years) *****
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.111	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	1069.8	0.1	0.35	3
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	255.55	0.2	1.5	14
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	447.48	0.1	0.84	8
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	46.39	1.2	8.1	>50
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	8.075	6.9	47	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	295.7	0.2	1.3	12
Permanent Cover	CMZ Zone 16 Construction Site Templates Cool Seasonal Grass; Not Harvested; Good Stand	1.065	>50 ****	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

Table 4. 13 I Street with various RUSLE2 Cover Management Practices and 3 Bioretention Pond design sizes

(Site Area: 11.4 Ac.; 65% Filled Before Cleanout; Soil: Silt-Loam)*					
Construction Period	**Management Practice**	**Total Sediment Delivery (t/yr) ****	**Estimated Lifespan (BMP Dimensions: 45'x45'x0.25') (years)**	**Estimated Lifespan (BMP Dimensions: 95'x95'x0.5') (years)**	**Estimated Lifespan (BMP Dimensions: 300'x300'x0.5') (years) *****
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.111	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	1069.8	0.02	0.1	0.4
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	255.55	0.1	0.3	1.9
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	447.48	0.04	0.2	1.1
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	46.39	0.4	1.5	10
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	8.075	2.2	9	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	295.7	0.06	0.2	2
Permanent Cover	CMZ Zone 16 Construction Site Templates Cool Seasonal Grass; Not Harvested; Good Stand	1.065	16	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

4.2.3 Interstate 80 Off-Ramp, Sidney Off-Ramp

Within the theoretical Sidney off ramp in Sidney, NE, there are many management practices that may occur over the course of construction. **Table 4. 14** through **Table 4. 18** show the potential management practices from before construction, to final permanent cover on the site, with sediment delivery and lifespan estimation of each BMP sized at 0.01 acre-feet, 0.1 acre-feet, and 1 acre-foot.

Table 4. 14 Sidney Off-Ramp with various RUSLE2 Cover Management Practices and 3 Detention Pond design sizes

(Site Area: 3.29 Ac.; 65% Filled Before Cleanout; Soil: Loam) *					
Construction Period	**Management Practice**	**Total Sediment Delivery (t/yr) ****	**Estimated Lifespan (BMP Volume: 0.01 Ac.-ft) (years)**	**Estimated Lifespan (BMP Volume: 0.1 Ac.-ft) (years)**	**Estimated Lifespan (BMP Volume: 1.0 Ac.-ft) (years) *****
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.0152	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	212.62	0.2	1	12.6
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	52.14	1	6	>50
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	90.73	0.4	3	29.5
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	16.77	2	17	>50
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	2.94	11	>50	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	86.75	0.4	3	30.9
Permanent Cover	Strips Barriers Management; Cool Seasonal Grass; Not Harvested, Moderate Stand	0.125	>50 ****	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

Table 4. 15 Sidney Off-Ramp with various RUSLE2 Cover Management Practices and 3 Infiltration Trench design sizes

(Site Area: 3.29 Ac.; 65% Filled Before Cleanout; Soil: Loam) *					
Construction Period	**Management Practice**	**Total Sediment Delivery (t/yr) ****	**Estimated Lifespan (BMP Volume: 0.01 Ac.-ft) (years)**	**Estimated Lifespan (BMP Volume: 0.1 Ac.-ft) (years)**	**Estimated Lifespan (BMP Volume: 1.0 Ac.-ft) (years) *****
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.0152	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	212.62	0.2	1	10
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	52.14	0.7	6	39
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	90.73	0.4	3	23
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	16.77	2	18	>50
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	2.94	12	>50	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	86.75	0.4	3	24
Permanent Cover	Strips Barriers Management; Cool Seasonal Grass; Not Harvested, Moderate Stand	0.125	>50 ****	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

Table 4. 16 Sidney Off-Ramp with various RUSLE2 Cover Management Practices and 3 Grass Lined Swale design sizes

(Site Area: 3.29 Ac.; 65% Filled Before Cleanout; Soil: Loam) *					
Construction Period	Management Practice	Total Sediment Delivery (t/yr) **	Estimated Lifespan (BMP Dimensions: 40'x20') (years)	Estimated Lifespan (BMP Dimensions: 200'x45') (years)	Estimated Lifespan (BMP Dimensions: 1000'x90') (years) ***
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.0152	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	212.62	0.1	2	15
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	52.14	0.5	6	>50
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	90.73	0.3	3	34
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	16.77	2	19	>50
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	2.94	9	>50	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	86.75	0.3	4	36
Permanent Cover	Strips Barriers Management; Cool Seasonal Grass; Not Harvested, Moderate Stand	0.125	>50 ****	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

Table 4. 17 Sidney Off-Ramp with various RUSLE2 Cover Management Practices and 3 Grass Lined Swale with Rock Check Dam design sizes

(Site Area: 3.29 Ac.; 65% Filled Before Cleanout; Soil: Loam) *					
Construction Period	Management Practice	Total Sediment Delivery (t/yr) **	Estimated Lifespan (BMP Dimensions: 100'x5')(3 dams @ 2.0' height w/ 33' spacing) (years)	Estimated Lifespan (BMP Dimensions: 250'x20')(7 dams @ 2.0' height w/ 33' spacing) (years)	Estimated Lifespan (BMP Dimensions: 950'x50')(25 dams @ 2.0' hieght w/ 33' spacing) (years) ***
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.0152	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	212.62	0.3	2	18
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	52.14	1.0	10	>50
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	90.73	0.6	6	43
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	16.77	3	30	>50
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	2.94	18	>50	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	86.75	0.6	6	45
Permanent Cover	Strips Barriers Management; Cool Seasonal Grass; Not Harvested, Moderate Stand	0.125	>50 ****	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

Table 4. 18 Sidney Off-Ramp with various RUSLE2 Cover Management Practices and 3 Bioretention Pond design sizes

(Site Area: 3.29 Ac.; 65% Filled Before Cleanout; Soil: Loam) *					
Construction Period	**Management Practice**	**Total Sediment Delivery (t/yr) ****	**Estimated Lifespan (BMP Dimensions: 45'x45'x0.25') (years)**	**Estimated Lifespan (BMP Dimensions: 95'x95'x0.5') (years)**	**Estimated Lifespan (BMP Dimensions: 300'x300'x0.5') (years) *****
Pre Construction	Highly Disturbed; Pre-Construction Vegetative Cover; Tall Fescue Grass	0.0152	>50 ****	>50 ****	>50 ****
Open Site	Highly Disturbed; Bare Cut; Rough	212.62	0.09	0.4	2.5
Temporary Cover	Highly Disturbed; Construction with Temporary Practice; Temporary Mulch or Annual Cover; Straw Mulch 2000 lb/ac.	52.14	0.4	1.5	10.1
	Highly Disturbed; Blade and Mulch; Blanket; Blade Fill, Straw Mulch 1000	90.73	0.21	0.9	5.8
	Highly Disturbed Land; Blade and Mulch; Blanket; Blade Fill, Roll Material	16.77	1.1	4.6	31
Long Term Cover	Highly Disturbed; Long term Vegetation; Continuous N Mixed Grass	2.94	6.5	26	>50
	Highly Disturbed; Construction With Permanent Practices; Permanent Seeding; Straw Mulch 4000 lb/ac., with seed- Spring	86.75	0.22	0.9	6
Permanent Cover	CMZ Zone 16 Construction Site Templates: Cool Seasonal Grass; Not Harvested; Good Stand	0.125	>50 ****	>50 ****	>50 ****

* All values assume no sediment coming from banks, resulting in longer lifespan estimation.
** From RUSLE2
*** A 1.0 ac.-ft BMP on this size site is likely unreasonably large
**** Permanent cover produces nearly no erosion or sediment production, resulting in very long lifespan

4.3 Discussion

Through the course of this study, it has been found that erosion is a largely variable event. If a site is well constructed or established with good ground cover and a stable soil there will be minimal annual erosion. When a site is on poor soil, with minimal ground cover and is poorly designed, the opportunity for soil erosion increases significantly. Sediment Control BMPs are installed to treat the soil erosion, whether large or small quantities of soil are moved.

The function and longevity of sediment control BMPs depend upon many site-specific conditions and can vary significantly from location to location. Engineers should use good site design and management practices to reduce erosion and extend the life of the BMP on site.

The BMP model developed in this study does not account for temporal variability in efficiency. As a BMP becomes filled with sediment, the efficiency is reduced. Modelling the temporal change in efficiency is a complex process, which was not evaluated in this project, but could be investigated in future work.

RUSLE2 depends upon a hypothetical storm sequence that is based historical data. While the hypothetical storm sequence reflects average rain data collected over many years, it is an estimation. With the climatic changes that have occurred in recent years, there may be some variance with this storm sequence.

Within RUSLE2 and the BMP model, the cover and soil are assumed to be uniform and constant across the entire site. Due to this simplification, the soils and cover may not perfectly match an entire site.

The BMP model uses generic soil types, not specific soils that can be found in soils surveys and maps. This is another simplification that may create some discrepancy between the lifespan estimation and the actual lifespan of the BMP.

BMPs themselves have erosion occurring within them from the sidewalls of basins and from vegetative cover dying, decomposing and turning into soil. No internal erosion or soil production from vegetation was accounted for within the BMP model because the amounts of soil produced from these avenues is not very well known.

The efficiency of the BMPs was found using past studies of BMPs, and may not be valid for site-specific conditions. These efficiency functions would benefit from further study.

Chapter 5 Conclusions

A notable finding from this study is that sites produce the least amount of erosion in their fully vegetated, pre-construction state. The next least sediment producing site is a fully stabilized site after construction is completed. Putting these two findings together, it is ideal for a site to be under construction within the shortest amount of time possible. If it is not going to be a short term project, the best option is to construct the project in stages, where the least amount of soil is disturbed at a time.

Designing the BMP to the size and layout of the site is critical to not over-design the system. There were several estimated lifespans well above 50 years. When a site is designed, it is not very likely that 50 years will pass without being re-designed within that time. Therefore, it is not reasonable to design and build a BMP that will outlast the design life of the rest of the project. A cost of construction to cost of maintenance comparison may be necessary to evaluate what the optimal performance of the BMP may be.

Based on other project performances, the results that were found for bare cut sites up to long-term stabilization on sites seems reasonable. The most erosion occurs when a site does not have permanent ground cover, which is where BMPs are most needed. The BMP that is selected for the construction portion of a project must be chosen knowing that there will be significant quantities of sediment moving in that period. The BMP utilized while a site is under construction may not be the same BMP that should be utilized for post-construction management. It may not be reasonable for any number of factors including: the size of the site, other support practices in place that reduce erosion, and easement restrictions, for a large pond to be in place once a site has mostly permanent cover.

The cover management system implemented on a site significantly impacts the amounts of erosion and sediment yield on a site. Large amounts of sediment are eroded while a site has bare soil. As a site is seeded with permanent cover, the soil erosion and yield on the site may be almost non-existent. At times, the bare-soil erosion and sediment yield may be 10,000 times higher than that for a permanent cover, as seen at I Street.

BMP longevity varies greatly depending on the sediment load entering the BMP, which is based on the cover management practice, among other things. For a bare-soil construction site, it is possible to have an appropriately sized BMP fill with sediment within a year. With the same BMP and site after the soil has been stabilized with permanent grass cover, the BMP may perform for decades, or even the design life of the site. It is very important to stabilize a site as soon as possible to reduce the erosion of the site, and increase the longevity of the BMP.

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Appendix A RUSLE2 Tutorial

1. Install RUSLE2

   a. Go to the web site: http://www.ars.usda.gov/Research/docs.htm?docid=6038, and scroll to the bottom of the screen. Select the *RUSLE2 2014 Download*.

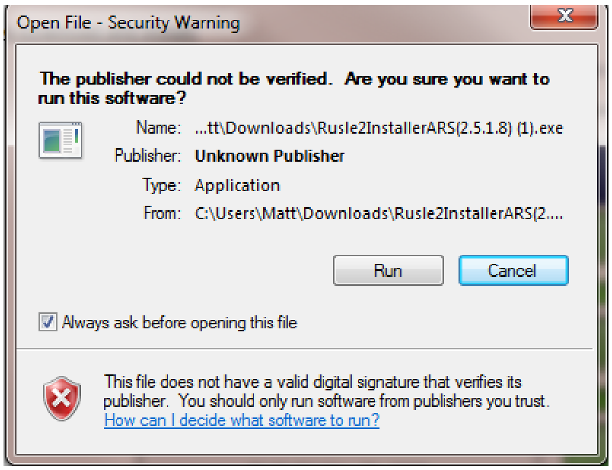


Figure A 1

   b. You will get the pop-up shown in **Figure A 1**. Select *Run*.

   c. There will then be a RUSLE2 Setup Wizard window that pops-up. Select *Next.*

   d. There will then be a License agreement, **Figure A 2**. Select *I accept the agreement,* and then *Next.*

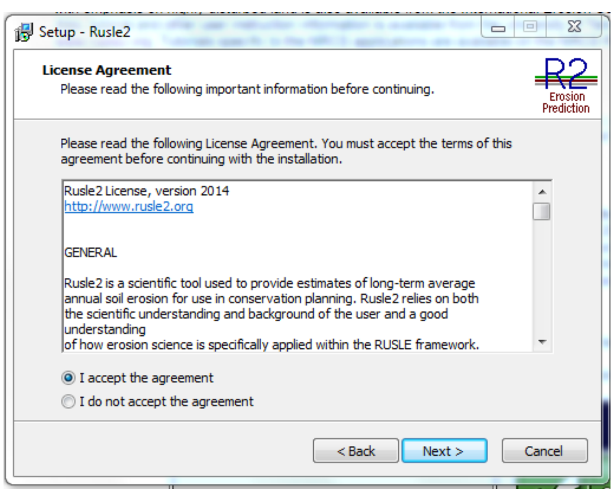


Figure A 2

e. Finally, there will be a window that says "ready to install," Select *Install.*

f. After the installation is complete, there will be a window that looks like **Figure A 3**. Check both of the boxes, then select *Finish.*

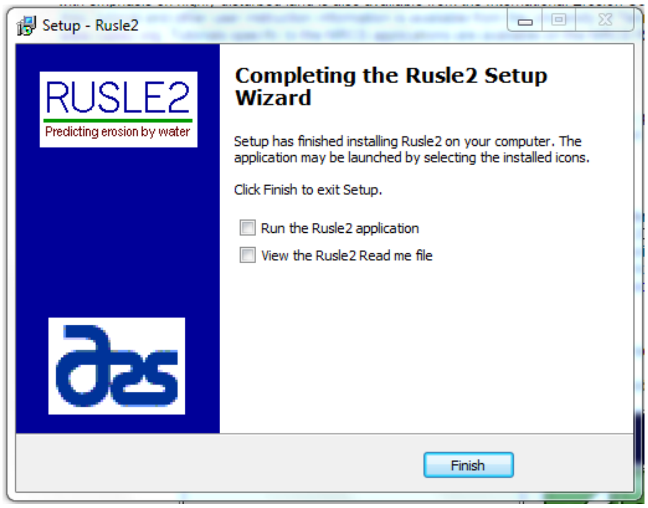


Figure A 3

g. Once the installation is complete, RUSLE2 will open. Minimize RUSLE2 and continue the installation process.

h. Open Windows Explorer and browse to the C: Drive, select *Program Files (x86)*, then *USDA,* then *RUSLE2,* and *ARS.* Within that file, create a new folder called *Archive*, as seen in **Figure A 4**.

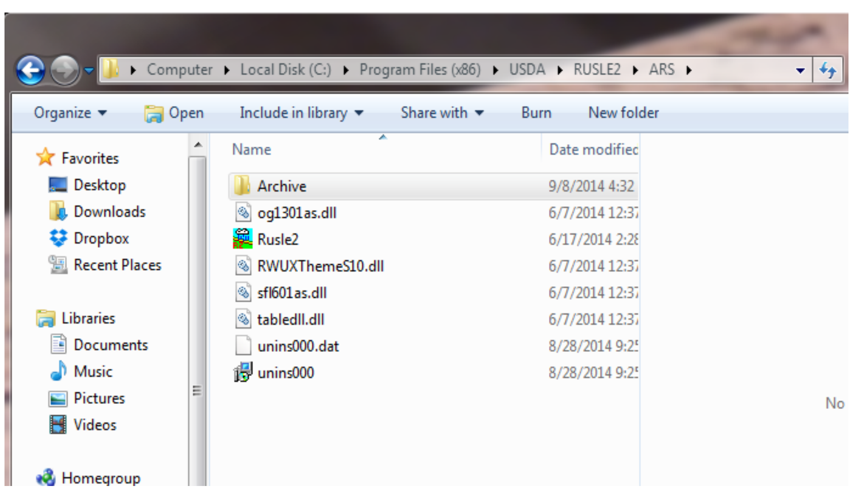


Figure A 4

2. Install data from the NRCS RUSLE2 site.

    a. Go to the NRCS RUSLE2 site:

       http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm.

    b. Along the side of the webpage are tabs shown in **Figure A 5**.

        i. Select *Data Files* under Climate Data and select *NEclim and save or copy and paste it to the previously created Archive* folder.

Figure A 5

        ii. Select *Crop Management Zone Maps* within Crop Management Templates. Using the CMZ map, select the *Data files* associated with the project state. For Nebraska, select *CMZ 04, CMZ 05, CMZ 16, CMZ 24*. Save these to the *Archive* folder.

        iii. Select *Data Files* within Soils Data. For Nebraska, select *NE zip file.*

        iv. Finally select *RUSLE2 Technology* and *RUSLE2 Program* under Training Materials.

    c. Within the *Archive* folder, unzip the files within this folder.

3. Open RUSLE2

a. When you first open the program there will be an introduction window that opens, as seen in **Figure A 6**. Select *Plan* and *Construction Site Basic Complex Slope.* Then click *OK*.

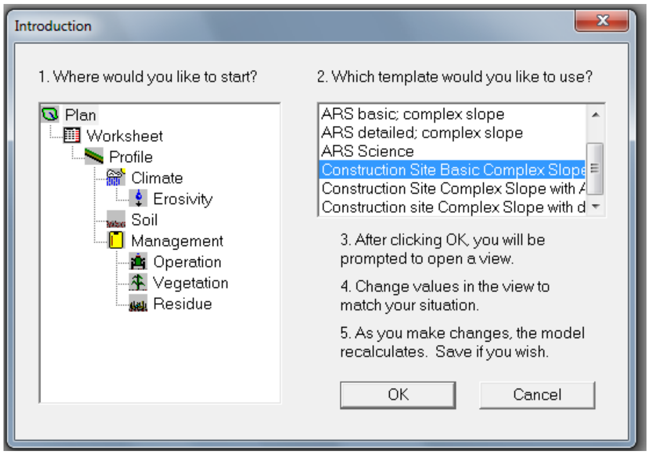


Figure A 6 RUSLE2 Introduction window

b. Open the *default* file.

c. A plan window should open, if not, open a plan window by going to *File\open\plan\default.*

4. Import RUSLE2 Data

   a. At the top of the RUSLE2 program window, open *Database, Import RUSLE2 database.*

   b. Another window will open up, **Figure A 7**. Go to the *Local Disk, Program Files (x86), USDA, RUSLE2, ARS, Archive.*

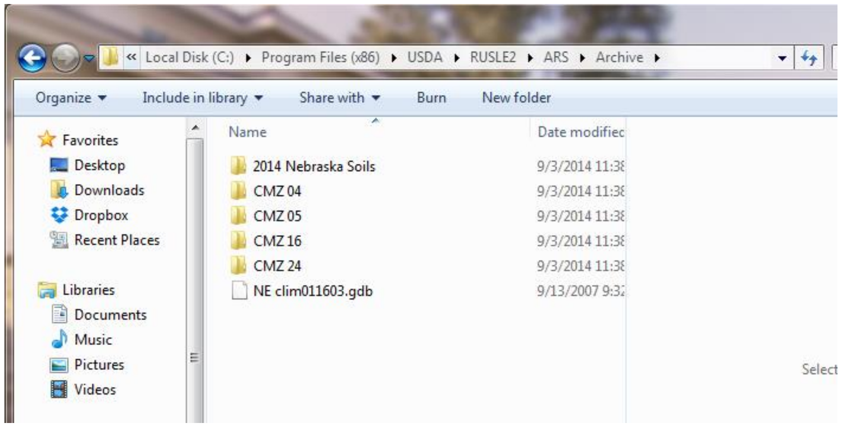


Figure A 7

c. Within the *Archive* folder, all of the downloaded data files should already be decompressed within this folder.

   i. Select the *CMZ 04* file, and click *Open.*

   ii. There will be an additional Window that opens (**Figure A 8**). Within that window check the box corresponding to *managements,* and *All.* Then click *Import.*

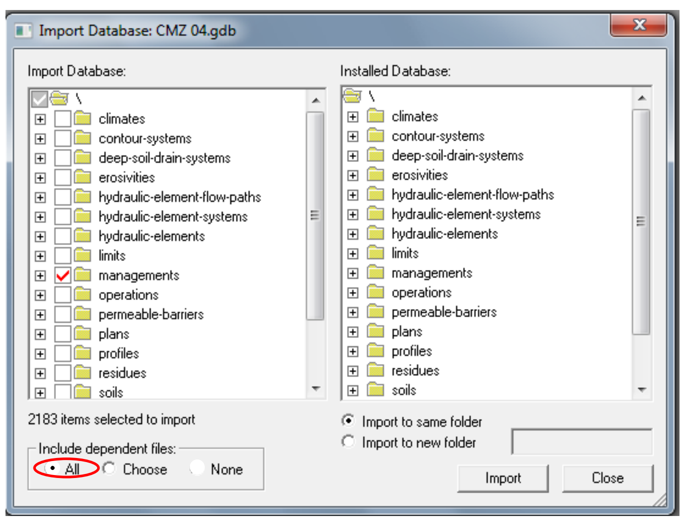


Figure A 8

iii. There may be an error message that looks like the message below (**Figure A 9**). Click *OK.* This message is only stating that it cannot import

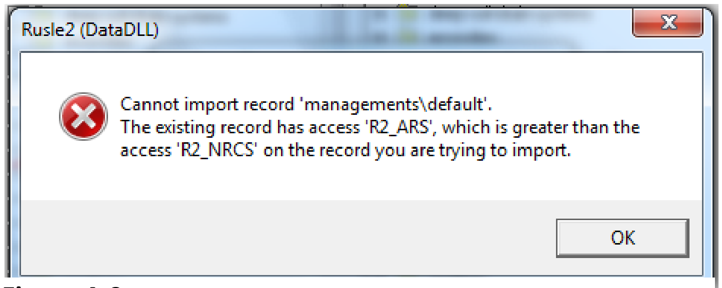


Figure A 9

the default files because ARS already has them.

iv. Using the above process, import the remaining CMZ (crop management zone) files to accurately represent the area your project is in. If you do not know what CMZ the project is located in, see **Figure 3. 9**. You may also use generic cover managements, but the CMZ covers are specified for what will likely be encountered within your project site.

v. Also import the *NE clim* file (**Figure A 10**).

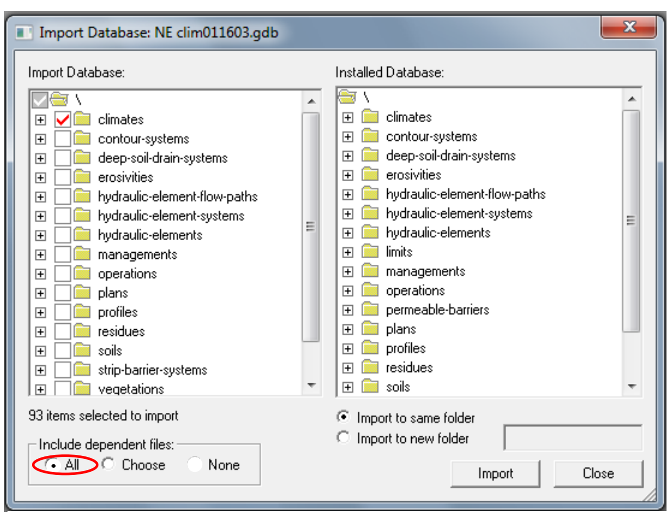


Figure A 10

1. When importing, check next to *climates* and *All*.

2. There may be a warning message that comes up like the one in **Figure A 11**. Click *OK.*

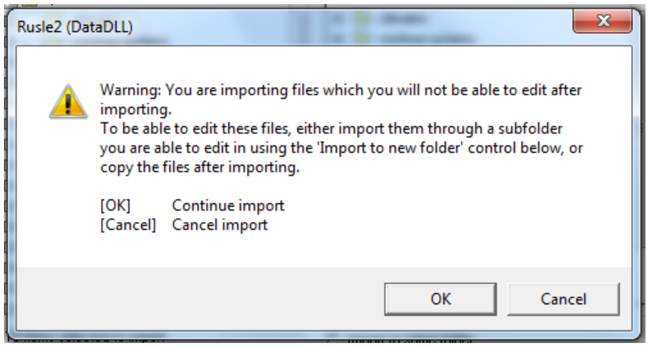


Figure A 11

vi. Finally, import the soils data that you will be using. It is not recommended to import all available soils data, just what is needed for your specific site.

1. When importing the soils data for the counties that you need, check *Soils* and *All.*

5. Fill out the *Plan* window, **Figure A 12**.

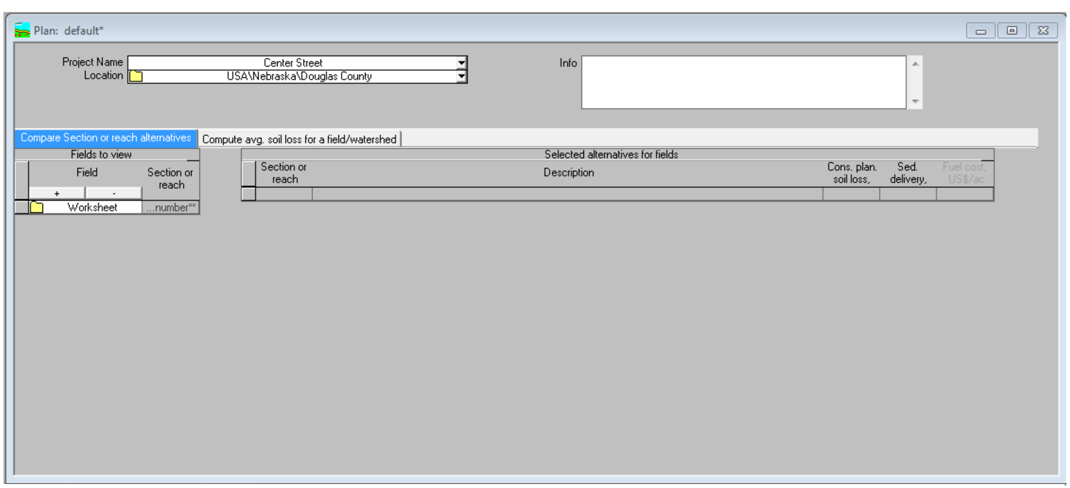


Figure A 12

a. Return to the *Plan* sheet and fill in the *Project Name.*

b. Click the drop down arrow next to *Location,* and scroll to the *USA* folder, then find the *Nebraska* folder and find the county in which your project is located.

c. Click on the tab that says: *Compare Section or reach alternatives.*

6. Fill out the *Worksheet* window.

a. Click on the folder icon next to the *Worksheet* tab. The Worksheet window, **Figure A 13**, should come up.

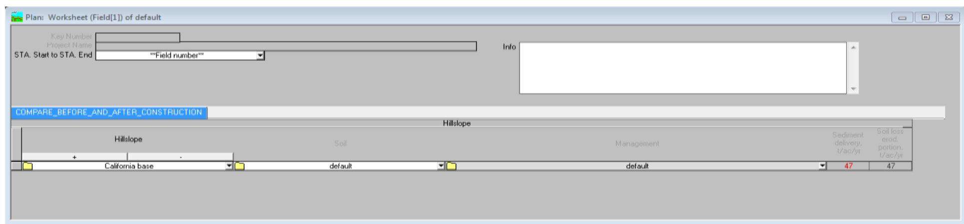


Figure A 13

b. Select the folder icon on the far left of the window, under *Hillslope*. The Profile window, **Figure A 14**, will appear.

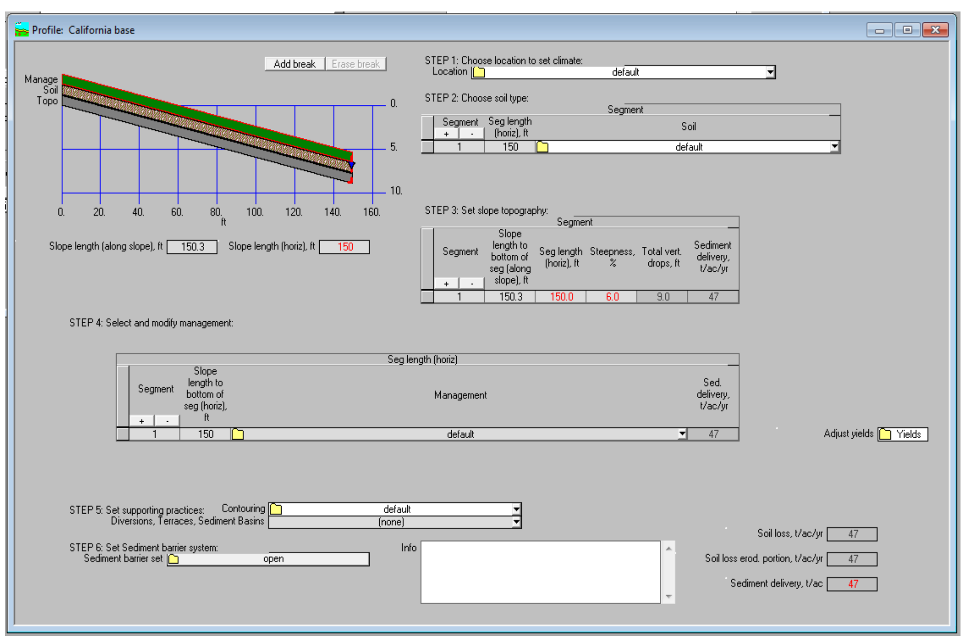


Figure A 14

c. At the top of this window, next to *Step 1:* click on the drop down arrow and select the location of the project. (This should be the same as the location you selected earlier, see step 5b.)

d. Under *Step 2:* Change the soil using the drop down arrow to select the most fitting type of soil for this site by either using this site: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx , or using the - *Generic Soils.*

   i. Once the soil map is opened, zoom to the project site location.

   ii. Click the button at the top of the screen says AOI, this stands for Area Of Interest (**Figure A 15**).

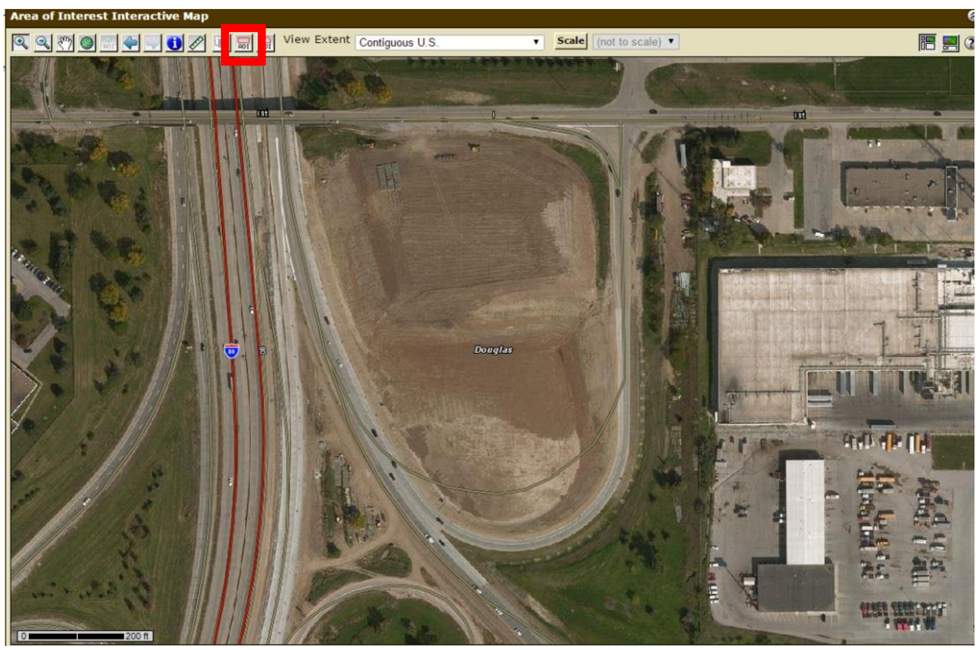


Figure A 15 Soil Survey AOI (Area of Interest)

   iii. Draw a box around the area you are interested in. A box with diagonal hatching should appear over the area drawn (**Figure A 16**).

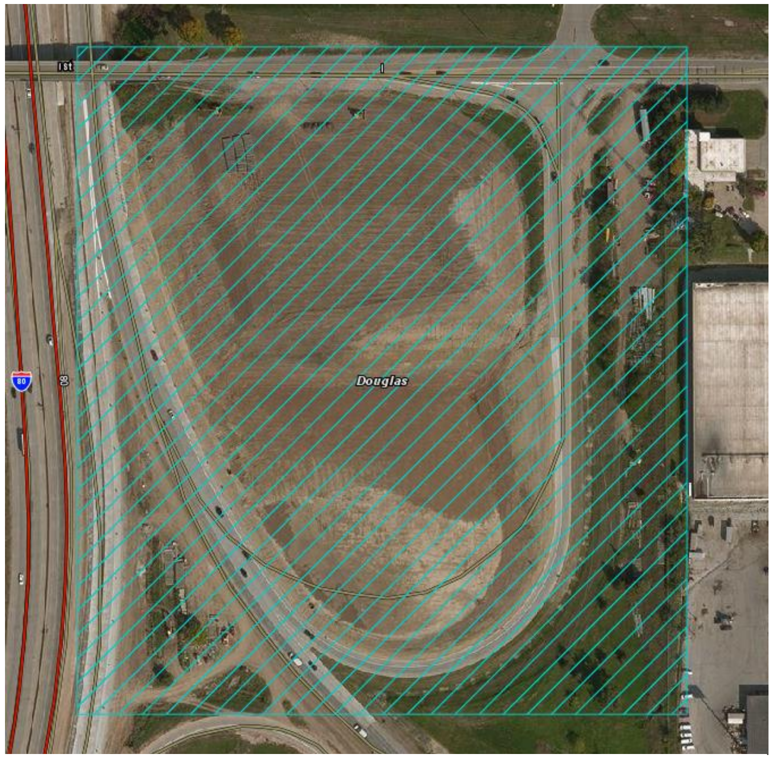


Figure A 16

iv. At the very top of the screen, click on *Soil Map* to view the soils in the designated area of interest (**Figure A 17**).

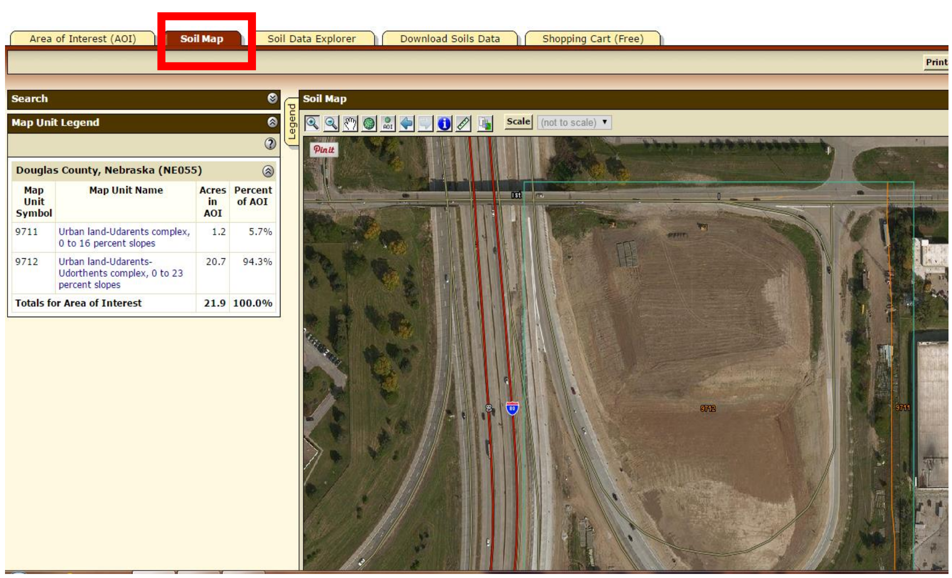
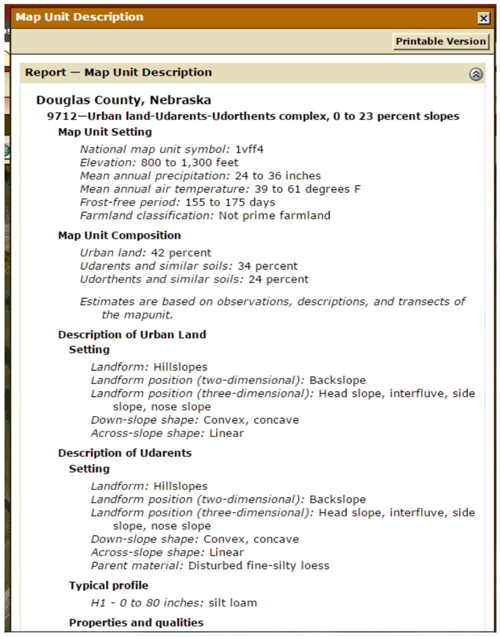


Figure A 17

v. Click on the *Map Unit Name* for the soil that is within the project site, and a new window will open displaying a detailed description of the soil properties (**Figure A 18**).


Map Unit Description
Printable Version
Report — Map Unit Description

Douglas County, Nebraska

9712—Urban land-Udarents-Udorthents complex, 0 to 23 percent slopes

Map Unit Setting

National map unit symbol: 1vff4
Elevation: 800 to 1,300 feet
Mean annual precipitation: 24 to 36 inches
Mean annual air temperature: 39 to 61 degrees F
Frost-free period: 155 to 175 days
Farmland classification: Not prime farmland

Map Unit Composition

Urban land: 42 percent
Udarents and similar soils: 34 percent
Udorthents and similar soils: 24 percent

Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Urban Land

Setting

Landform: Hillslopes
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Head slope, interfluve, side slope, nose slope
Down-slope shape: Convex, concave
Across-slope shape: Linear

Description of Udarents

Setting

Landform: Hillslopes
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Head slope, interfluve, side slope, nose slope
Down-slope shape: Convex, concave
Across-slope shape: Linear
Parent material: Disturbed fine-silty loess

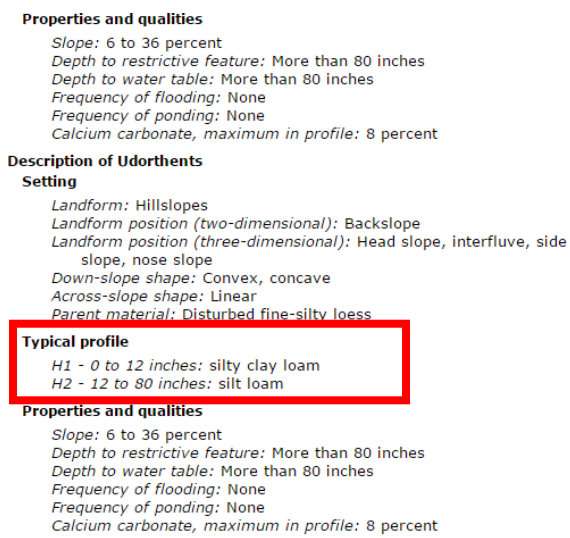
Typical profile

H1 - 0 to 80 inches: silt loam

Properties and qualities

Figure A 18

vi. At the bottom of the window, there is a *Typical Profile* section that describes the layers of soil within a typical profile (**Figure A 19**).


Properties and qualities

Slope: 6 to 36 percent
Depth to restrictive feature: More than 80 inches
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum in profile: 8 percent

Description of Udorthents

Setting

Landform: Hillslopes
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Head slope, interfluve, side slope, nose slope
Down-slope shape: Convex, concave
Across-slope shape: Linear
Parent material: Disturbed fine-silty loess

Typical profile

H1 - 0 to 12 inches: silty clay loam
H2 - 12 to 80 inches: silt loam

Properties and qualities

Slope: 6 to 36 percent
Depth to restrictive feature: More than 80 inches
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum in profile: 8 percent

Figure A 19

e. Change the length of the hillside to the left of *Step 3* in the box titled *Slope Length (horiz), ft.*

f. Under *Step* 3: If the hill does not have a constant slope, add segments, change *Segment Lengths*, and *Steepness* to be reflective of your site.

g. After changes have been made to the topography, look at the *Profile View* to make sure the profile looks correct.

h. Under *Step 4:* Click the drop down arrow to change the *Management* to be reflective of your site. If you select *Highly Disturbed Land,* there will be many construction site options.

i. Change the support practices next to *Step 5:* within the *Contouring,* assume that the contouring is *up-and-down slope,* unless you know it is something different.

j. If there are any *Diversions, Terraces, or Sediment Basins* on the strip profile select the support practice that is most reflective of your site.

k. Next to *Step 6:* click on the folder icon. A new window will open up that looks like **Figure A 20**.

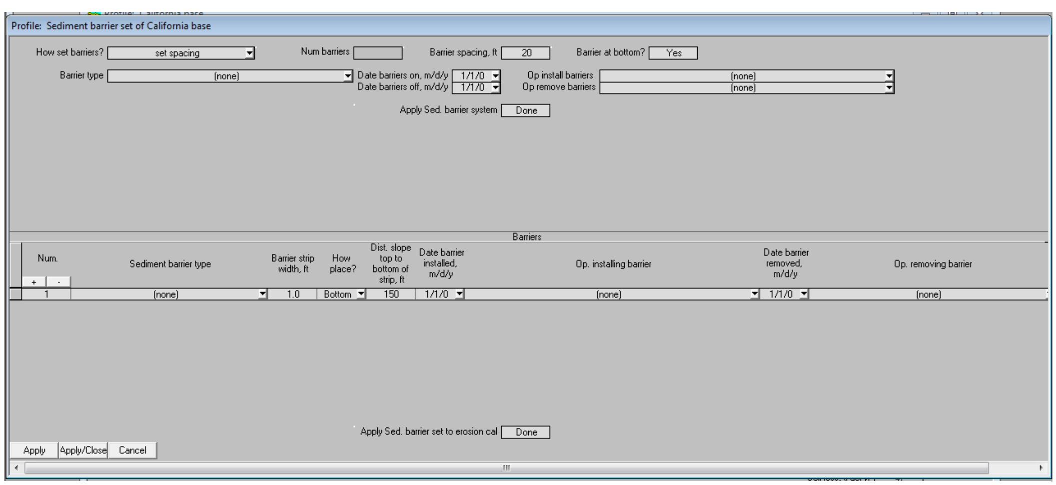


Figure A 20

l. Set the barriers to reflect what sediment barriers will be in place on the strip profile. When finished, click *Apply/Close*.

m. Go to *File, Save As*, and save this profile. There will be another pop-up as seen in **Figure A 21**. Select: *Replace all references to the old file with references to this new one.* Click *OK.*

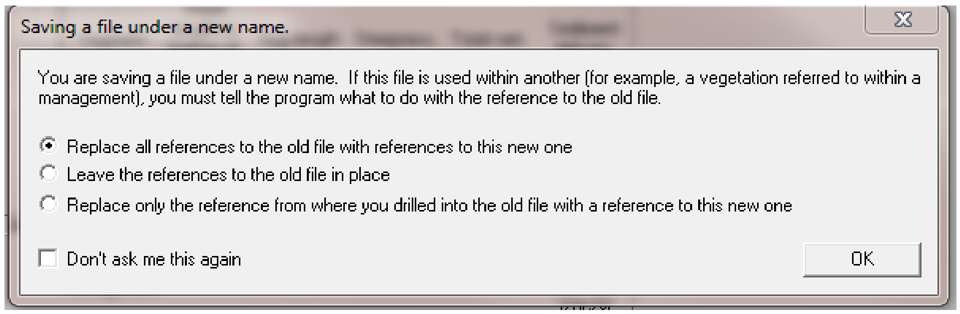


Figure A 21

n. Close the Profile. RULSE2 will ask if you want to save the changes to the slope. Select the appropriate answer. I will select *Yes.*

o. The *Worksheet* window will then look similar to **Figure A 22**.

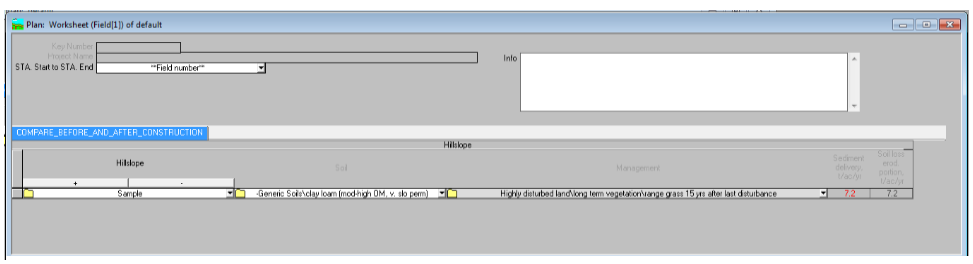


Figure A 22

p. If there is more than one representative strip for the site, click the *+* button below *Hillslope*. This will duplicate the first profile. Select the folder next to the Profile#2 hillslope to edit this profile. Be sure to save this profile as a different name.

q. Create as many profiles as needed to represent your site.

7. Sediment Delivery

a. To the far right of each hillslope, a *Sediment Delivery* is displayed in units of tons per acre per year per unit width of strip (T/Ac/yr).

b. Record the sediment delivery in the BMP model spreadsheet, seen in **Table A 1**. This will be used to compute the total delivery on the site by multiplying the sediment delivery of a strip by the representative area for that strip. This value will be summed with all other representative strip sediment deliveries to calculate a total sediment delivery on a site.

Table A 1 *Site Profiles, Representative Areas, Sediment Delivery, & Total Sediment Delivery*

Site Conditions																		Results	
Strip #	Total Length (ft)	L1 (ft)	Starting Elevation (ft)	Ending Elevation (ft)	ΔH1 (ft)	Slope1 %	L2 (ft)	Starting Elevation (ft)	Ending Elevation (ft)	ΔH2 (ft)	Slope2 %	L3 (ft)	Starting Elevation (ft)	Ending Elevation (ft)	ΔH3 (ft)	Slope3 %	Representative Area (Ac.)	Sediment Delivery (t/ac/yr)	Sediment Delivery (t/yr)
1	130	81	4267	4255	12	14.8	49	4255	4251	4	8.2						0.3107	0.26	0.080782
2	134	71	4275	4255	20	28.2	63	4255	4252	3	4.8						0.3106	0.16	0.049696
3	138	63	4275	4262	13	20.6	75	4262	4251	11	14.7						0.307	0.49	0.15043
4	124	57	4275	4263	12	21.1	67	4263	4252	11	16.4						0.3082	0.54	0.166428
5	110	55	4275	4265	10	18.2	55	4265	4260	5	9.1						0.2866	0.27	0.077382
6	92	53	4275	4266	9	17.0	39	4266	4263	3	7.7						0.208	0.23	0.04784
7	75	75	4273	4267	6	8.0											0.109	0.21	0.02289
8	63	63	4272	4270	2	3.2											0.103	0.1	0.0103
9	37	37	4272	4272	0	0.0											0.0876	0.001	0.0000876
SITE																	2.0307		0.6058356

Appendix B Center Street RUSLE2 Example

The northbound Interstate 680 on-ramp from Center Street, shown in **Figure B 1**, is located in Omaha, Nebraska, in the central part of Douglas County (41.235020, -96.083994).

Figure B 1 Center Street on-ramp from Douglas County GIS Map

Fill out the Plan window with the *Project Name* as Center Street, and the *Location* as USA\Nebraska\Douglas County as in **Figure B 2**.

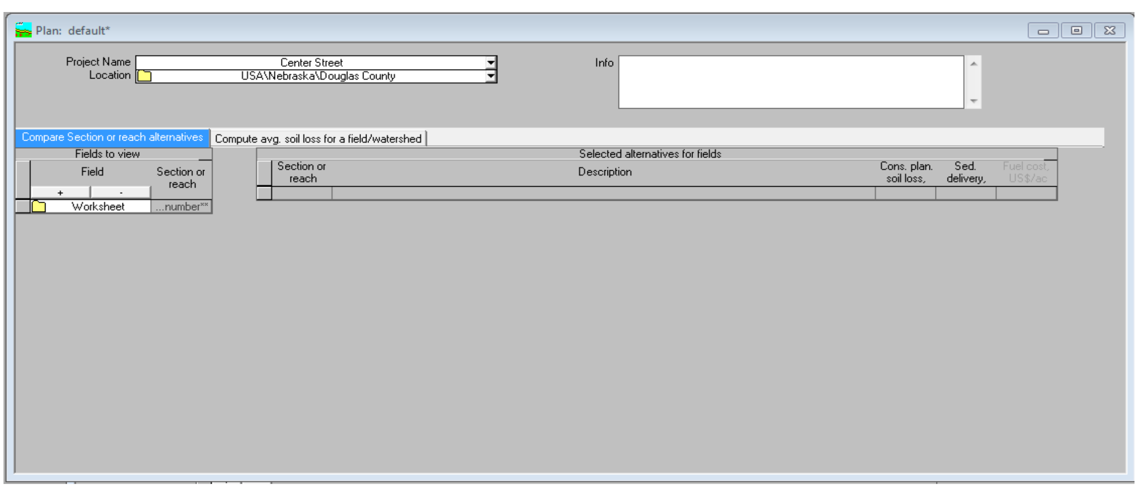


Figure B 2 Center Street RUSLE2 Plan View

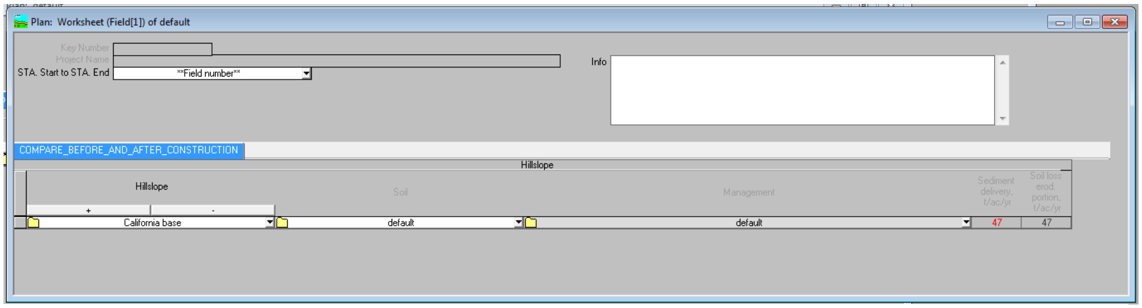


Figure B 3

Select the folder to the right of *Worksheet*. A new window will open (**Figure B 3**).

Select the folder to the left of *California Base*, the RUSLE2 profile window will open.

When in RUSLE2 in the Profile window within STEP 1, select *USA, Nebraska, Douglas County* as shown in **Figure B 4**.

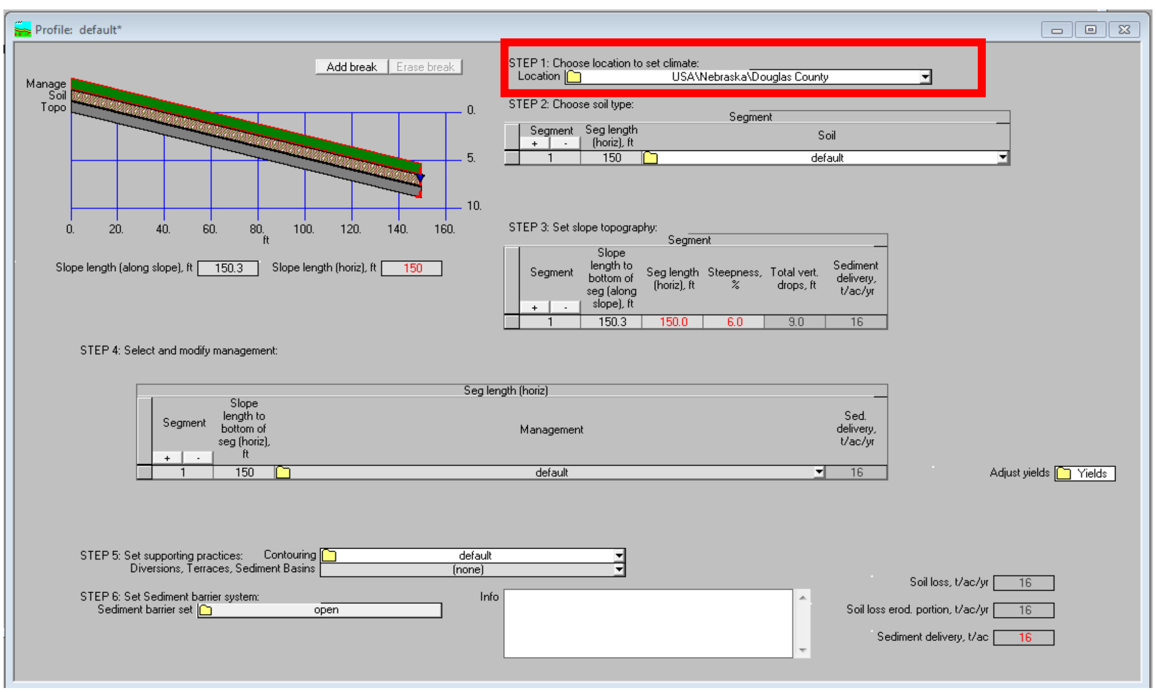


Figure B 4 Center Street RUSLE2 Location

Based on the USDA Web Soil Survey the soil is classified as a Douglas County 9712- Urban Land-Udarents-Udorthents complex, shown in **Figure B 5**. This a Silty-Loamy soil. In RUSLE2 under

STEP 2 select *Generic Soils, silt loam (l-m OM)*, shown in **Figure B 6**. This reflects the soil for the site, as it is a Silt Loam, with low to moderate Organic Matter. If there is a fill material, indicate

Map Unit Legend

Douglas County, Nebraska (NE055)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
9712	Urban land-Udarents-Udorthents complex, 0 to 23 percent slopes	13.6	97.4%
9719	Urban land-Udorthents-Marshall complex, 0 to 9 percent slopes	0.3	2.2%
9720	Urban land-Udorthents-Pohocco complex, 0 to 16 percent slopes	0.1	0.4%
Totals for Area of Interest		**13.9**	**100.0%**

Figure B 5 Douglas County Soils Map

that soil type within RUSLE2.

The strips (black dashed lines) used to calculate sediment delivery to the slope bottom (red line) are superimposed on the Douglas County GIS map (2014) **Figure B 7**. The numbers next to the black dashed strips in **Figure B 7** correlate to the strip numbers in **Table B 1**. The hatched areas correspond to the representative areas associated with each representative strip.

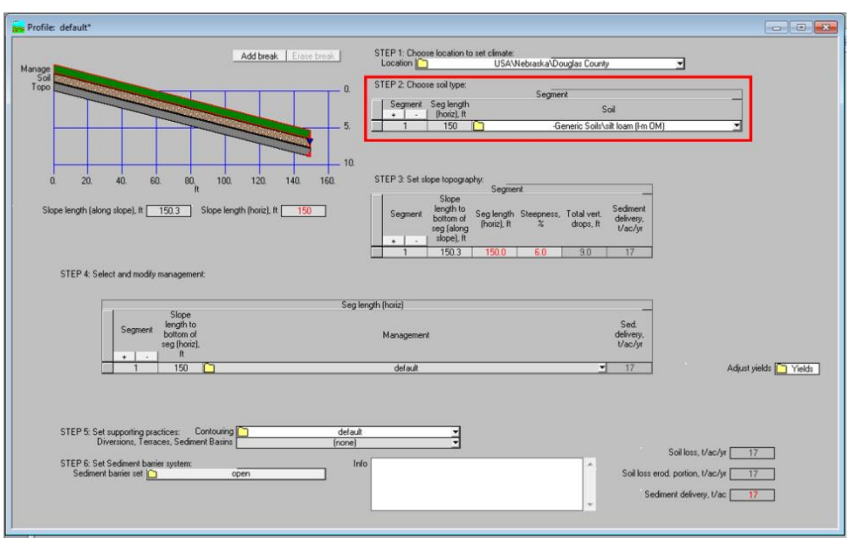


Figure B 6 RUSLE2 Soils Input

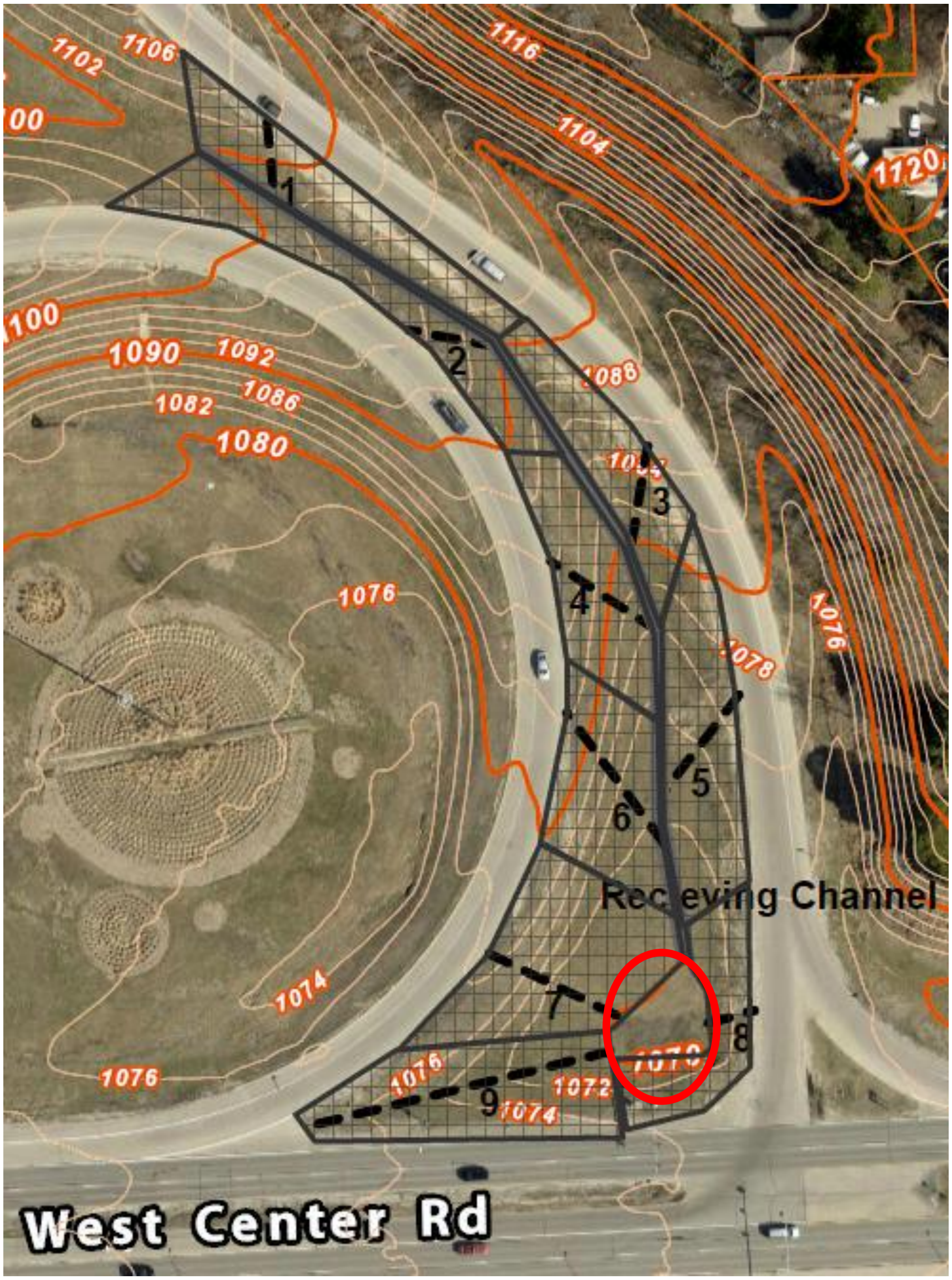


Figure B 7 Center Street RUSLE2 Representative Strips (black) and potential BMP location (red)

The elevations, hillslope lengths and the potential BMP location are found in **Figure B 7** from the Douglas County GIS site and are input into ***Table B 1***.

Table B 1

Site Conditions				
Strip #	**Length (ft)**	**Starting Elevation (ft)**	**Ending Elevation (ft)**	**Slope (%)**
1	20	1094	1093	5.0
2	28	1092	1090	7.1
3	35	1082	1080	5.7
4	46	1084	1076	17.4
5	42	1076	1073	7.1
6	68	1080	1071	13.2
7	78	1078	1070	10.3
8	21	1072	1070	9.5
9	165	1077	1070	4.2
SITE				

Using the data from ***Table B 1***, the slope is calculated from the change in elevation divided by the horizontal distance. For strip 1 change the slope length (horiz) is 20 feet as seen in **Figure B 9**. Ensure that the horizontal distance is 20 feet, and not the length along the slope.

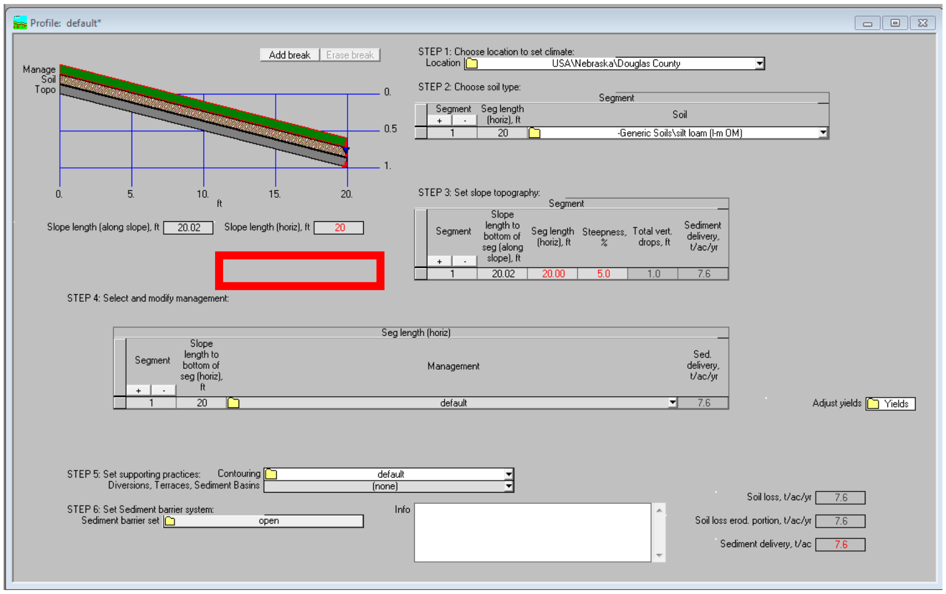


Figure B 9 Center Street RUSLE2 Slope Length

In STEP 3, also change the Steepness % to 5 , shown in **Figure B 8**.

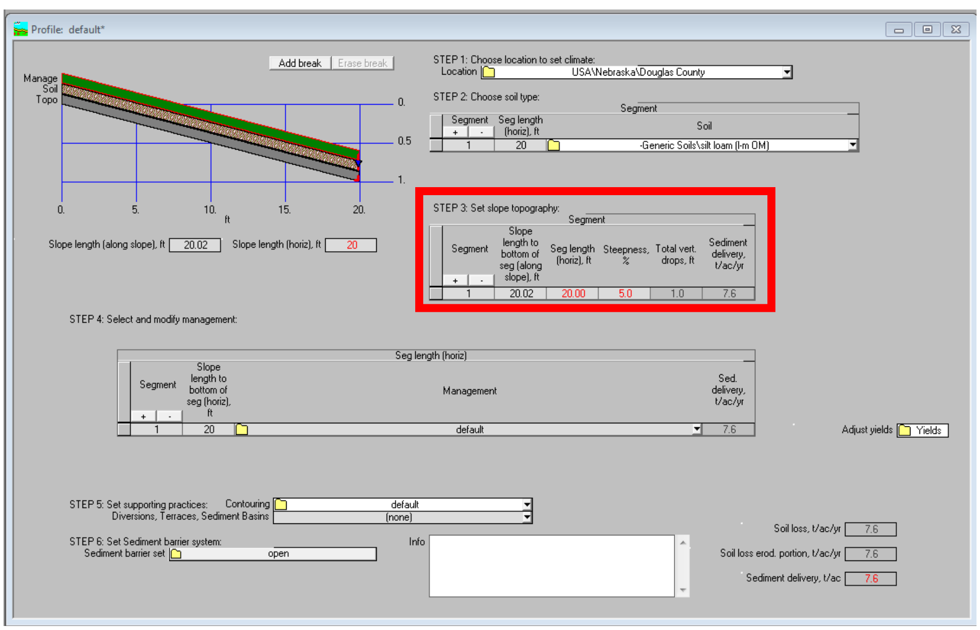


Figure B 8 Center Street RUSLE2 Topography

In STEP 4 the management that is best associated with this site is *CMZ 16, Construction Site Template, Cool season grass, good stand*, shown in **Figure B 11**.

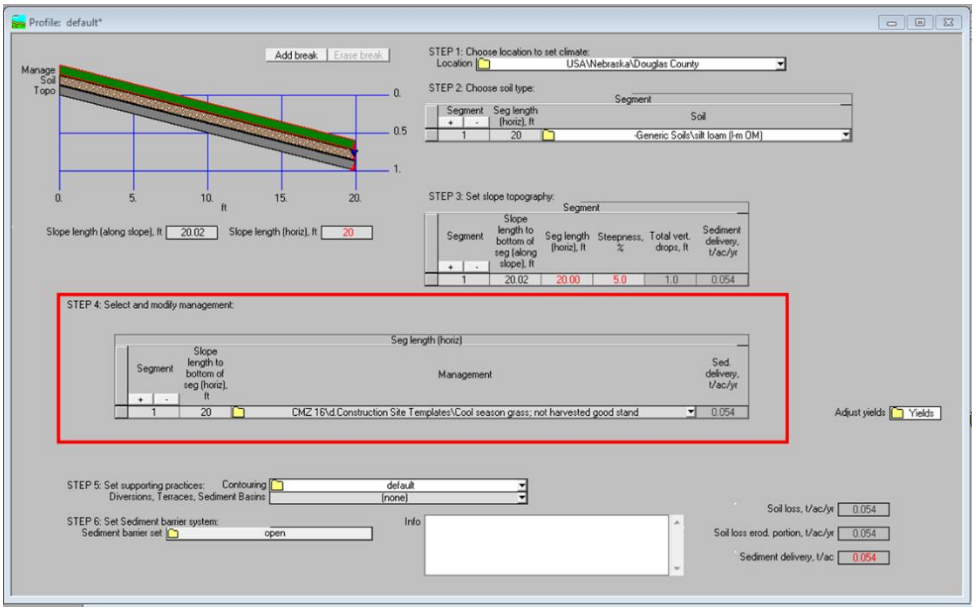


Figure B 11 Center Street RUSLE2 Management

For contouring on this site, the worst case scenario was assumed, i.e., contouring directly up and down the hill, because that will allow the most runoff. There are no diversions, terraces or basins along this strip, so none were selected. **Figure B 10** shows STEP 5.

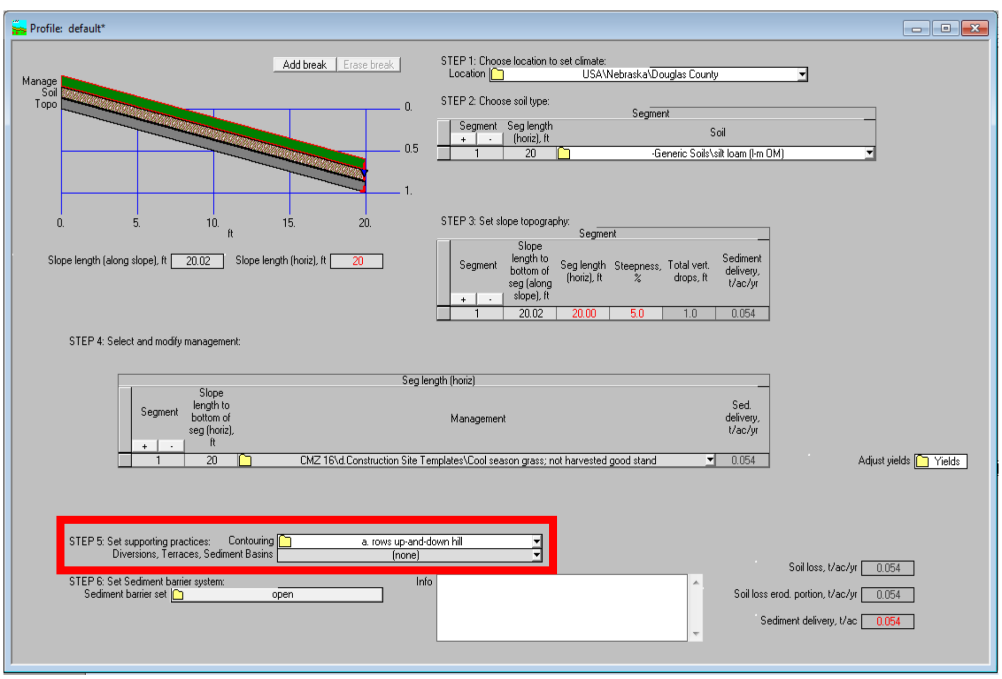


Figure B 10 Center Street RUSLE2 Support Practices

When STEP 6 is selected, a new window opens that looks like **Figure B 12**. For the Center Street site, there are no sediment barriers to establish, so click Apply/Close.

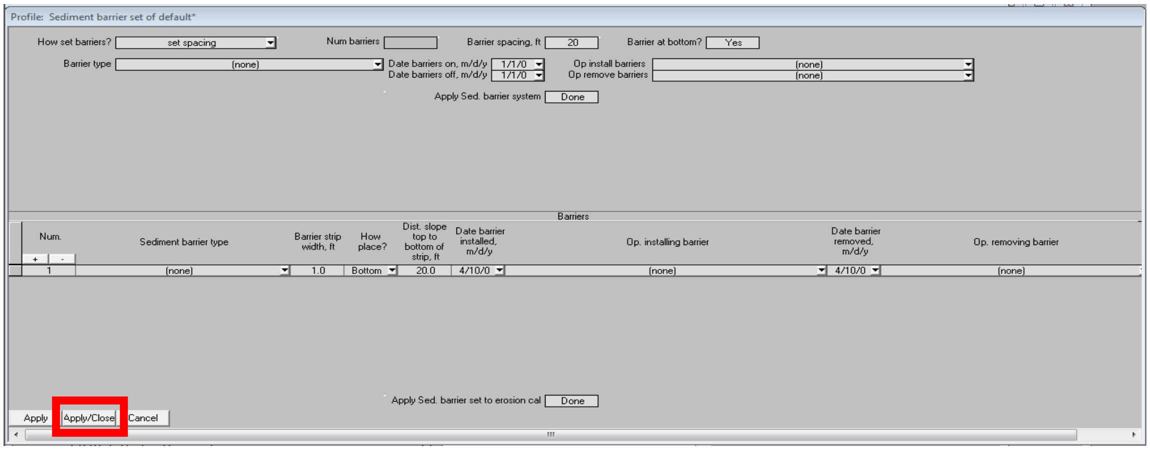


Figure B 12 Center Street RUSLE2 Sediment Barriers

The final Profile for Strip 1 on the Center Street site should resemble **Figure B 13**. Note that for strip 1, the slope is constant. The slope may be complex for other strips. The total annual Sediment Delivery to the bottom of strip 1 is 0.054 tons/acre. This volume will be multiplied by the area represented by Strip 1 to calculate the total sediment yield delivered to the receiving channel from that area.

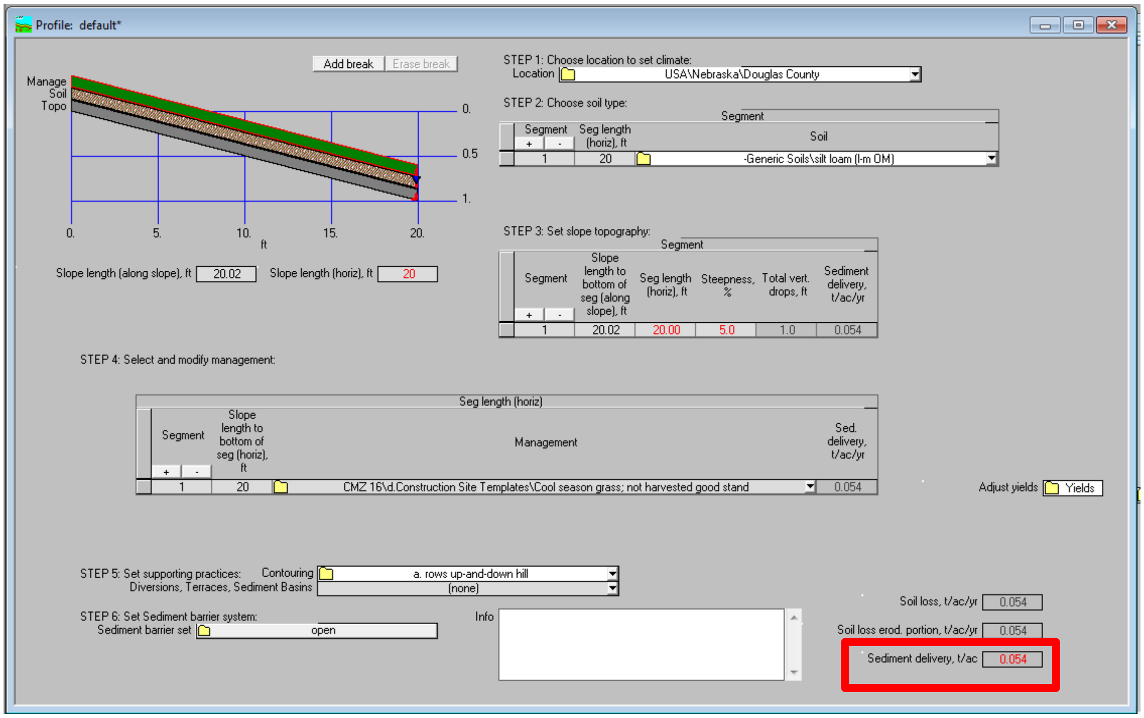
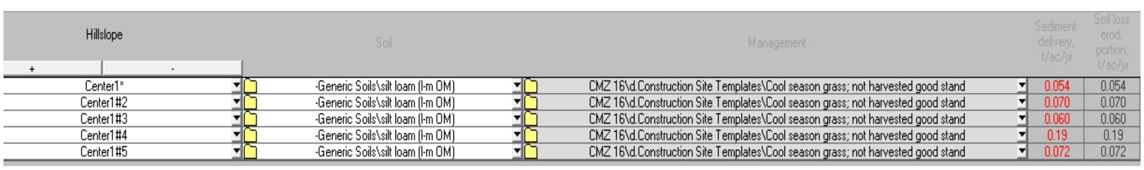


Figure B 13 Center Street RUSLE2 Sediment Delivery

Save the profile, and add a new profile using the + button under *Hillslope* to represent the second strip. Do this for all the remaining strips.

After all the profiles are input into RUSLE2, the worksheet should look like **Figure B 14**.



Hillslope	Soil	Management	Sediment delivery, t/ac/yr	Soil loss erod. portion, t/ac/yr
Center1*	-Generic Soils\silt loam (l-m OM)	CMZ 16\d.Construction Site Templates\Cool season grass; not harvested good stand	0.054	0.054
Center1#2	-Generic Soils\silt loam (l-m OM)	CMZ 16\d.Construction Site Templates\Cool season grass; not harvested good stand	0.070	0.070
Center1#3	-Generic Soils\silt loam (l-m OM)	CMZ 16\d.Construction Site Templates\Cool season grass; not harvested good stand	0.060	0.060
Center1#4	-Generic Soils\silt loam (l-m OM)	CMZ 16\d.Construction Site Templates\Cool season grass; not harvested good stand	0.19	0.19
Center1#5	-Generic Soils\silt loam (l-m OM)	CMZ 16\d.Construction Site Templates\Cool season grass; not harvested good stand	0.072	0.072

Figure B 14 Center Street RUSLE2 Completed Worksheet

For each strip there will be an area of the site represented by that strip. The area should have the same characteristics as the strips, that is, the length and topography must be the same for RUSLE2 to accurately calculate sediment delivery. Shown in **Figure B 15** are the areas, in acres, designated with each strip. Input this data into the table found in the BMP model.

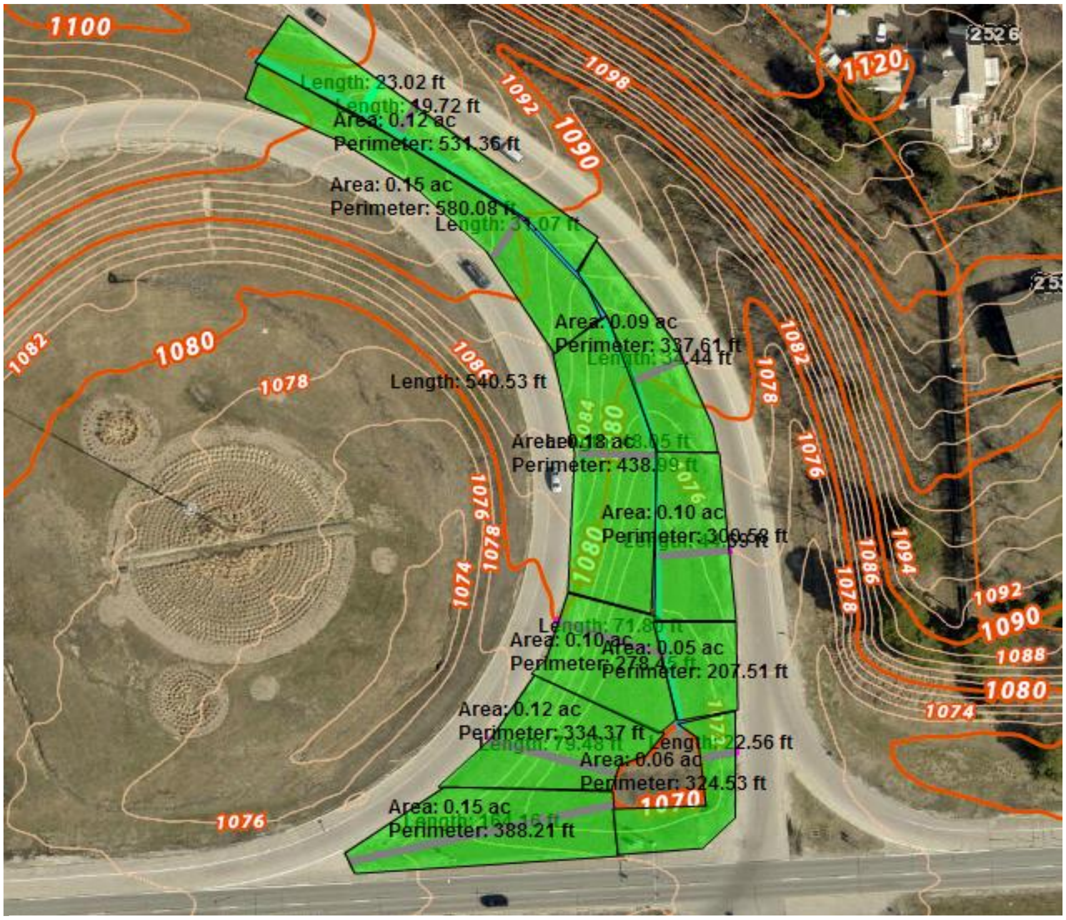


Figure B 15 Center Street Representative Areas

These areas are then multiplied by the Sediment Delivery to get tons of sediment transported for the given area, and then summed to get sediment transported for the entire site.

Table B 2 shows all of the calculations.

Table B 2

Site Conditions						Results	
Strip #	**Length (ft)**	**Starting Elevation (ft)**	**Ending Elevation (ft)**	**Slope (%)**	**Slope Area (Ac.)**	**Sediment Delivery (t/ac/yr)** *	**Sediment Delivery (t/yr)****
1	20	1094	1093	5.0	0.12	0.054	0.00648
2	28	1092	1090	7.1	0.15	0.07	0.0105
3	35	1082	1080	5.7	0.09	0.06	0.0054
4	46	1084	1076	17.4	0.18	0.19	0.0342
5	42	1076	1073	7.1	0.1	0.072	0.0072
6	68	1080	1071	13.2	0.15	0.14	0.021
7	78	1078	1070	10.3	0.12	0.11	0.0132
8	21	1072	1070	9.5	0.06	0.088	0.00528
9	165	1077	1070	4.2	0.15	0.054	0.0081
SITE						0.838	0.11136

* From RUSLE2 software calculations.
** Column 6 x Column 7

Appendix C I Street RUSLE2 Example

The *Northbound* Interstate 80 on-ramp from I Street, shown in **Figure C 1**, is located in Omaha,

Figure C 1

Nebraska, in the central part of Douglas County (41.215294, -96.088817).

Fill out the Plan window with the *Project Name* as I Street, and the *Location* as

USA\Nebraska\Douglas County as in **Figure C 2**.

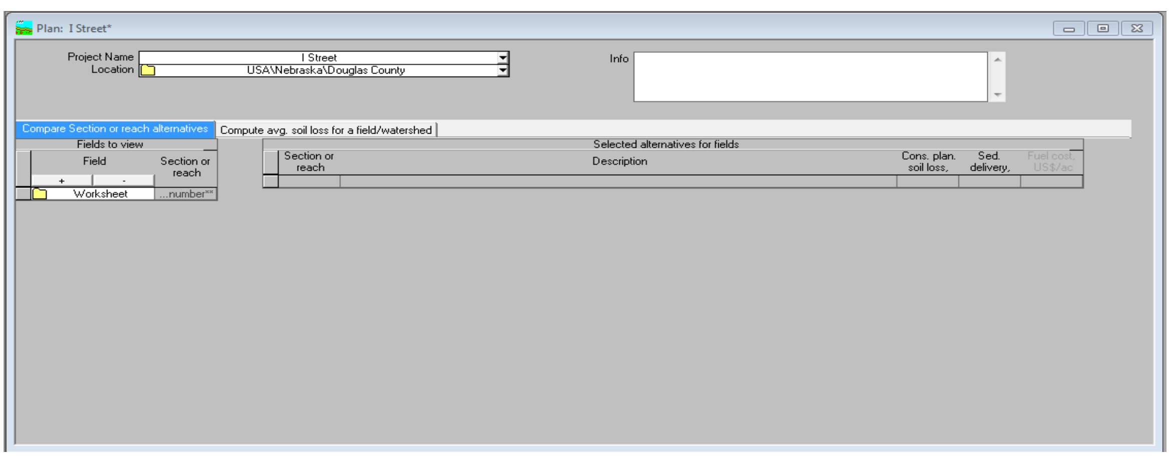


Figure C 2

Select the folder to the right of *Worksheet.* A new window will open (**Figure C 3**).

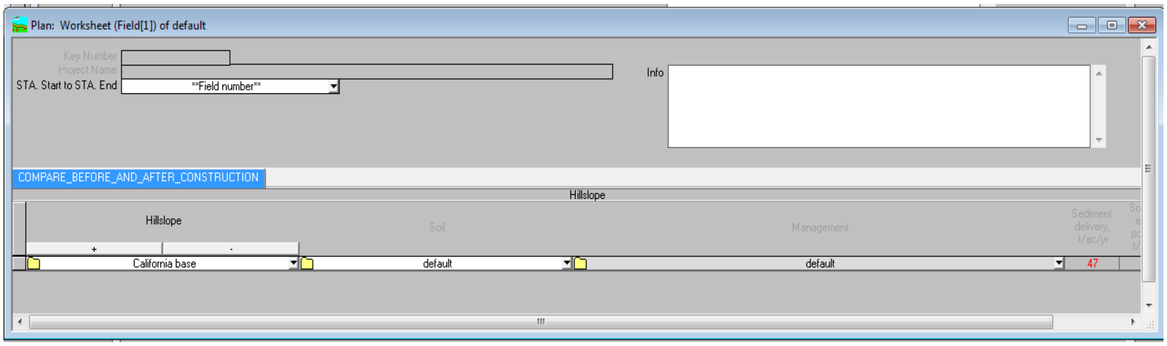


Figure C 3

Select the folder on the far left of the screen, the RUSLE2 profile window will open.

When in RUSLE2 in the profile window within STEP 1, select *USA, Nebraska, Douglas County* as shown in **Figure C 4**.

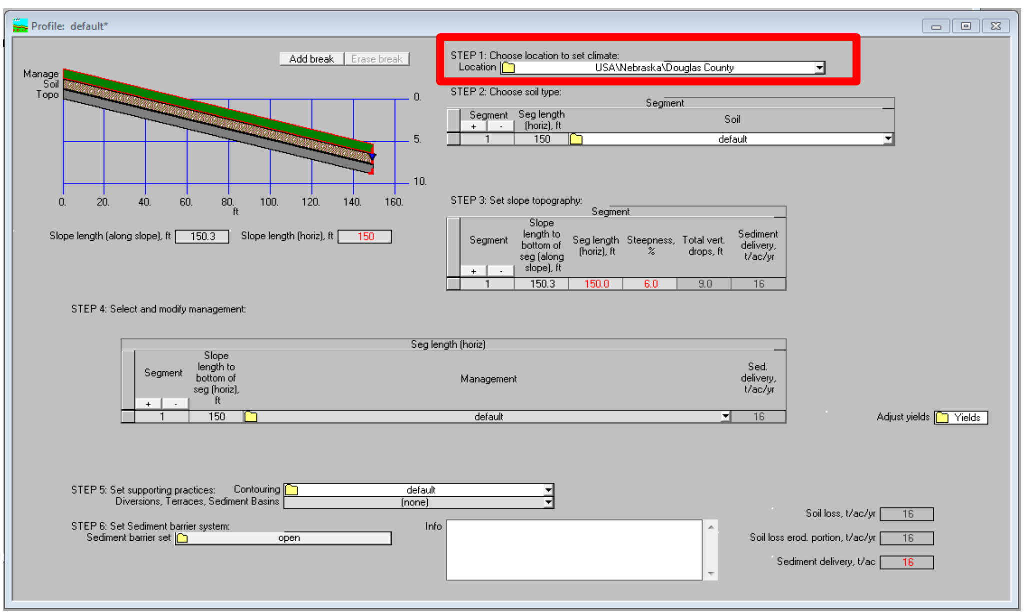


Figure C 4 I Street RUSLE2 Location

Based on the USDA Web Soil Survey the soil is classified as a Douglas County 9712- Urban Land-Udarents-Udorthents complex, shown in **Figure C 6**. This a Silty-Loamy soil.

Douglas County, Nebraska (NE055)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
9711	Urban land-Udarents complex, 0 to 16 percent slopes	0.1	0.4%
9712	Urban land-Udarents-Udorthents complex, 0 to 23 percent slopes	20.6	99.6%
Totals for Area of Interest		**20.7**	**100.0%**

Figure C 6 I Street Soils from Douglas County Soils Map

In RUSLE2 under STEP 2 select *Generic Soils, silt loam (mod-high OM)*, shown in **Figure C 5***.* This reflects the soil for the site, as it is a Silt Loam, with low to moderate Organic Matter. If there is a fill material, indicate that soil type within RUSLE2.

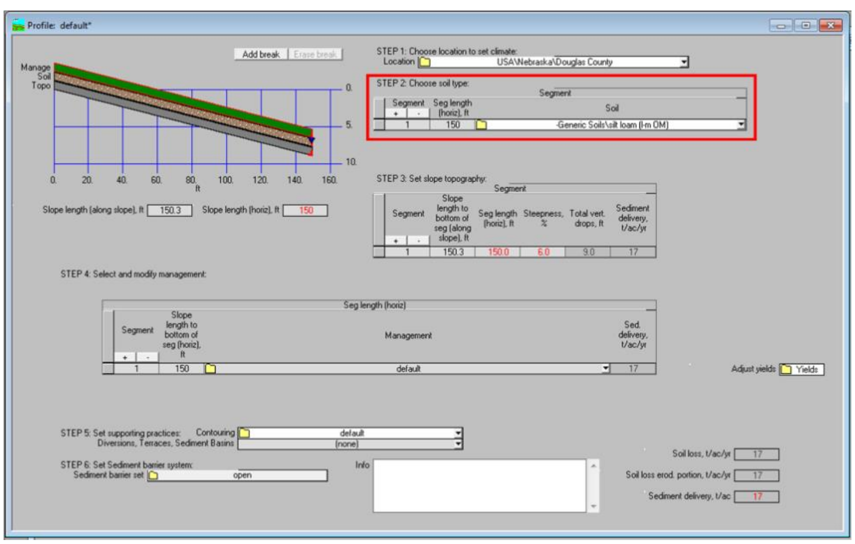


Figure C 5 I Street Soils in RUSLE2

Based on the Douglas County GIS map (2014), seen in **Figure C 7**, the strips (lines) used to calculate sediment delivery are shown.

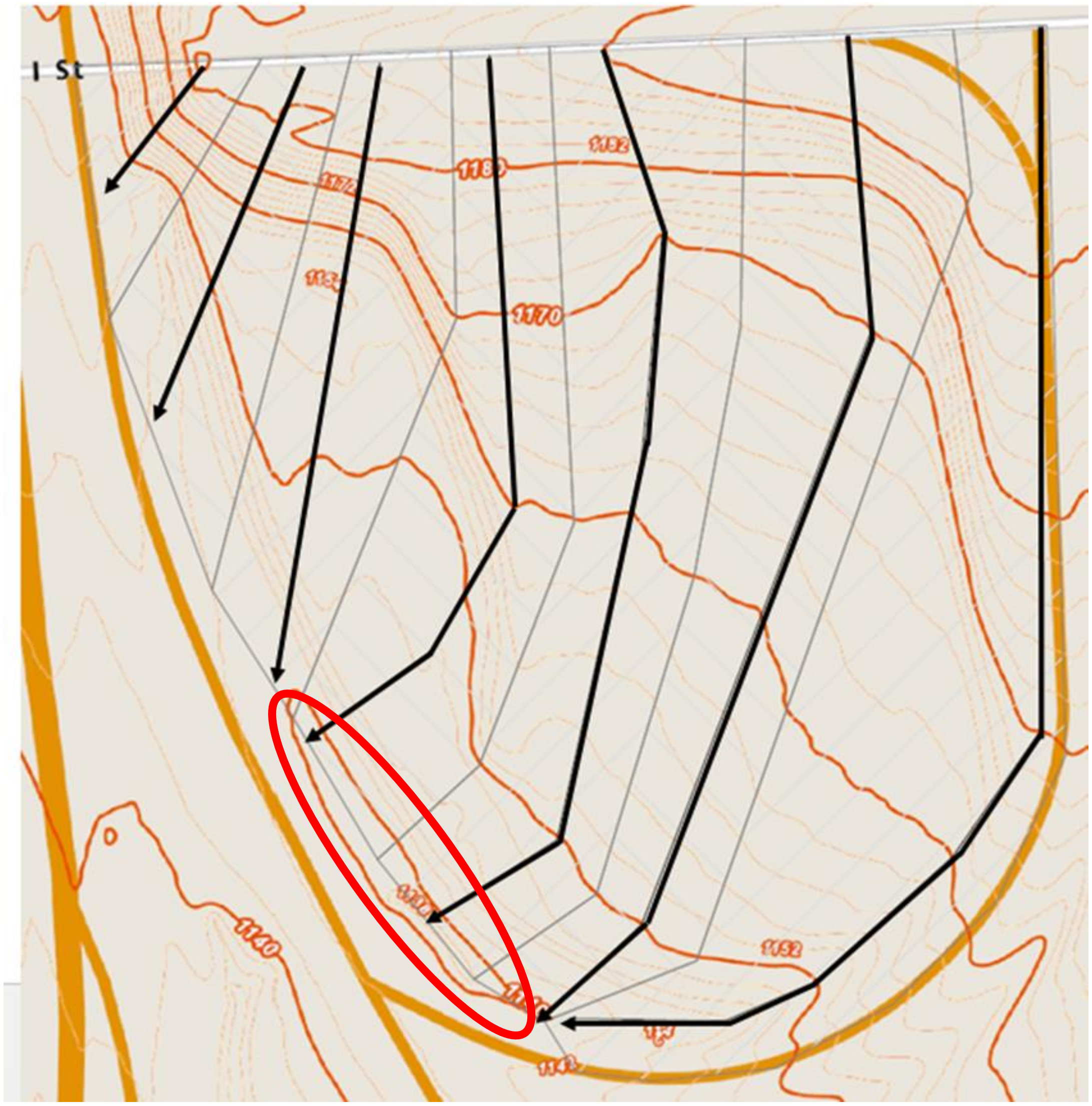


Figure C 7 I Street Topography and RUSLE2 Representative Strips (black arrows) and Representative Areas (grey hatching) and Potential BMP Location (red oval)

The elevations and hillslope lengths are found in that figure from the Douglas County GIS site and are also input into **Table C 1**.

Table C 1

	Total Length (ft)	Area (Ac.)	L1 (ft)	Starting El. (ft)	Ending El. (ft)	ΔH1 (ft)	Slope 1 %	L2 (ft)	Starting El. (ft)	Ending El. (ft)	ΔH2 (ft)	Slope 2 %	L3 (ft)	Starting El. (ft)	Ending El. (ft)	ΔH3 (ft)	Slope 3 %
1	502	0.48	502	1149	1140	9	1.8										
2	493	0.54	96	1180	1146	34	35.4	397	1146	1140	6	1.5					
3	479	0.97	65	1183	1180	3	4.6	79	1180	1156	24	30.4	335	1156	1140	16	4.8
4	574	0.57	81	1185	1180	5	6.2	153	1180	1152	28	18.3	340	1152	1140	12	3.5
5	593	1.02	304	1187	1160	27	8.9	73	1160	1150	10	13.7	216	1150	1140	10	4.6
6	675	2.17	145	1190	1170	20	13.8	423	1170	1154	16	3.8	107	1154	1140	14	13.1
7	830	2.03	75	1195	1190	5	6.7	152	1190	1170	20	13.2	603	1170	1140	30	5.0
8	907	1.58	121	1196	1190	6	5.0	336	1190	1164	26	7.7	450	1164	1140	24	5.3
9	1017	1.74	1017	1197	1140	57	5.6										
10	38	0.29	38	1142	1140	2	5.3										

Using the data from **Table C 1**, the slope is calculated from the change in elevation divided by the horizontal distance. For strip 1 change the slope length (horiz) to 502 feet as seen in **Figure C 8**. Ensure that the horizontal distance is 502 feet, and not the length along the slope.

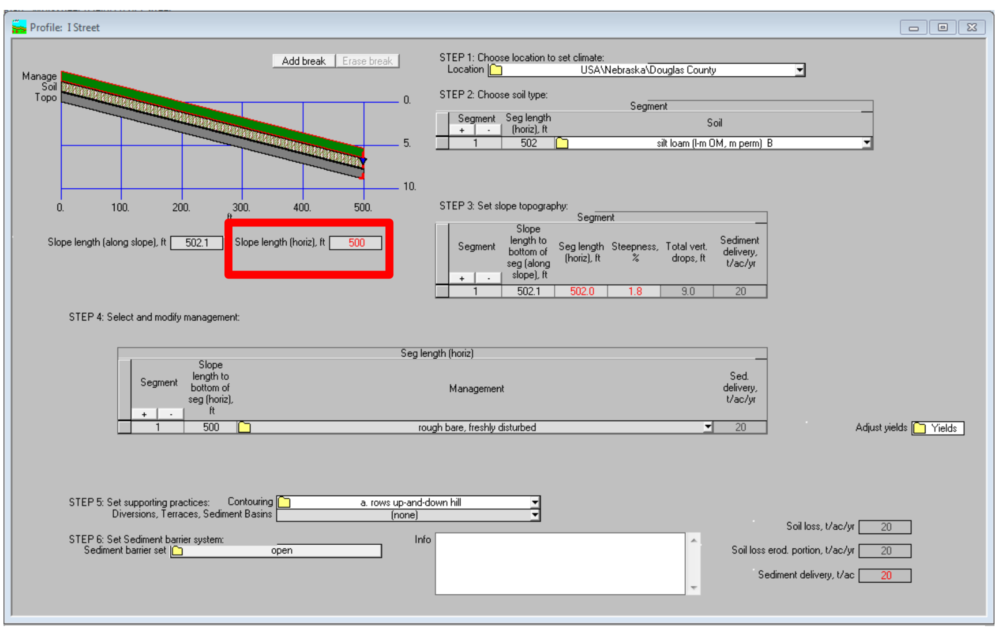


Figure C 8 I Street RUSLE2 Slope Length

In STEP 3, also change the Steepness % to 1.8, shown in **Figure C 9**.

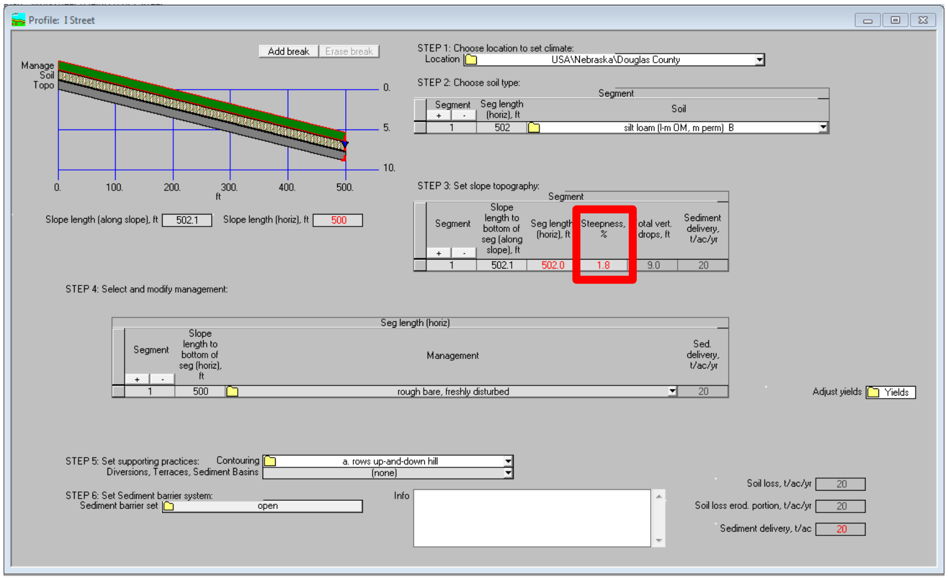


Figure C 9 I Street RUSLE2 Slope Steepness

In STEP 4 the management that is best associated with this site is *Highly disturbed land; bare; bare, rough*, shown in **Figure C 10**.

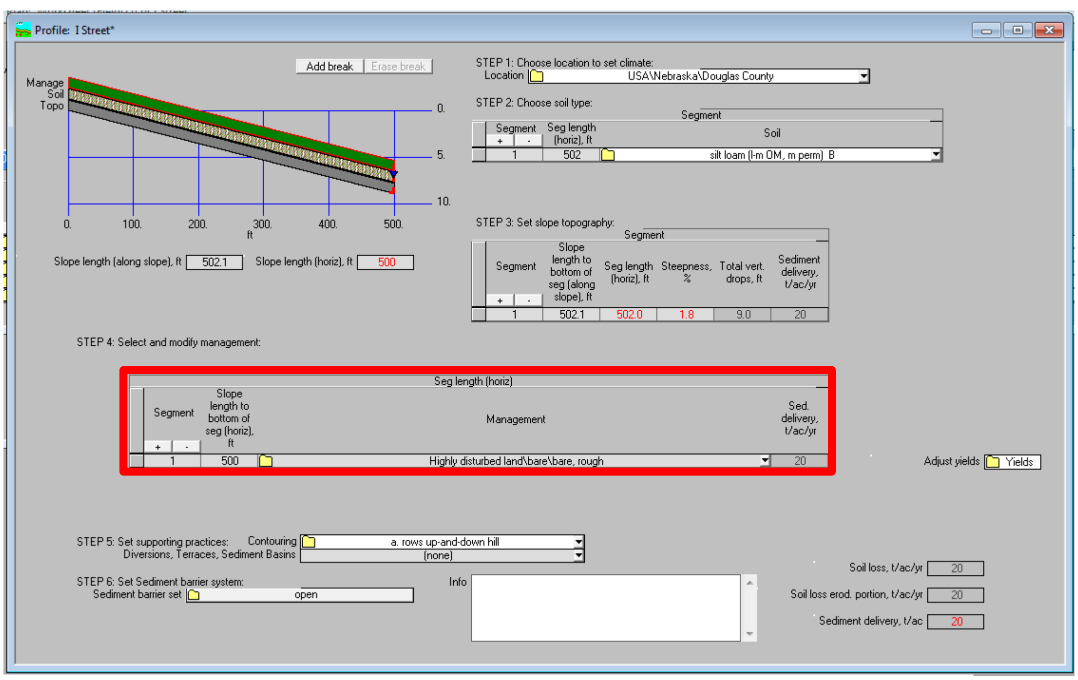


Figure C 10 I Street RUSLE2 Management

For contouring on this site, the worst case scenario was assumed, i.e., contouring directly up and down the hill, because that will allow the most runoff. There are no diversions, terraces or basins at the bottom of this strip, so none were selected. **Figure C 11** shows STEP 5.

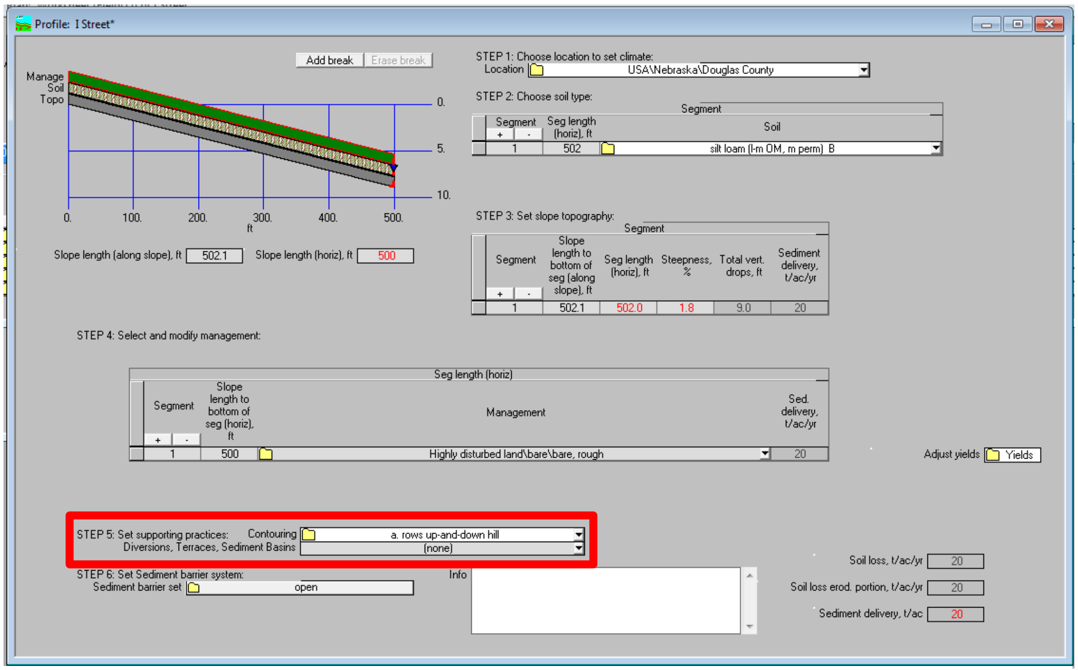


Figure C 11 I Street Support Practices

When STEP 6 is selected, a new window opens that looks like **Figure C 12**. For the I Street site, there are no sediment barriers to establish, so click Apply/Close.

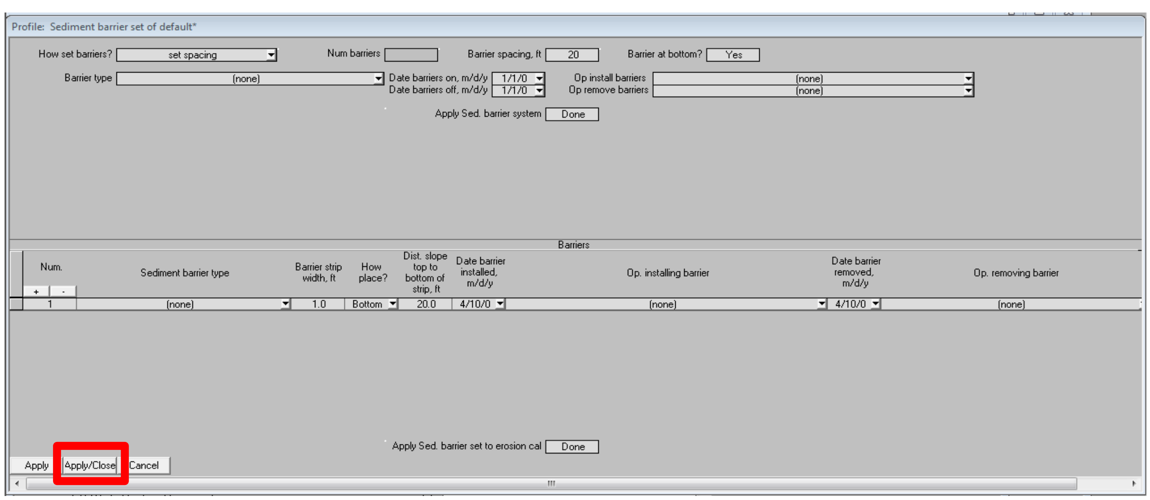


Figure C 12 I Street RUSLE2 Sediment barrier System

The final Profile for Strip 1 on the I Street site should resemble **Figure C 13**. The total annual Sediment Delivery to the bottom of strip 1 is 20 tons/acre.

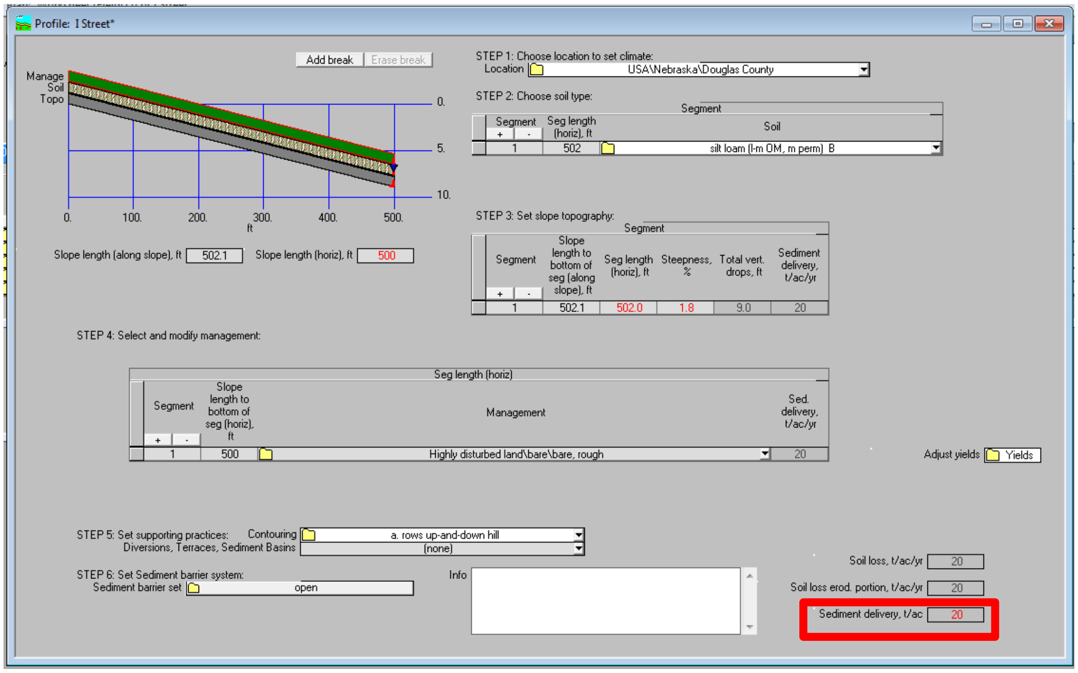


Figure C 13 I Street RUSLE2 Sediment Delivery

This value will be multiplied by the area represented by strip 1 to calculate the total sediment yield delivered to the receiving area from that area.

Save the profile and add a new profile using the + button under the *Hillslope* to represent the second strip. Do this for all the remaining strips. After all the profiles are input into RUSLE2, the worksheet should look like **Figure C 14**.

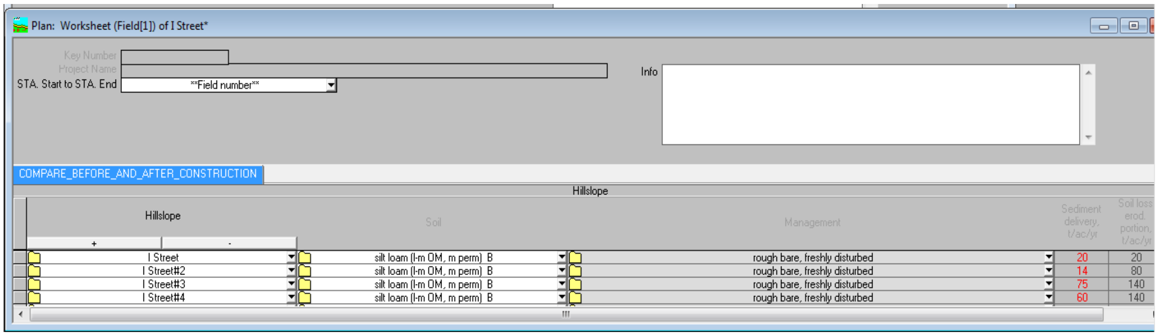


Figure C 14 I Street RUSLE2 Completed Worksheet

For each strip there will be an area of the site associated with that strip. The representative area should have identical qualities as the representative strip, that is, the length and topography must be the same throughout the representative area for RUSLE2 to accurately calculate sediment delivery. Input this data into the table found in the BMP model. These representative areas are then multiplied by the Sediment Delivery to get tons of sediment transported for the given area, and then summed up to give sediment transported for the site. **Table C 2** shows all of the calculations.

Table C 2

Rough Bare, Freshly Disturbed																			
	Total Length (ft)	Area (Ac.)	L1 (ft)	Starting El. (ft)	Ending El. (ft)	ΔH1 (ft)	Slope 1 %	L2 (ft)	Starting El. (ft)	Ending El. (ft)	ΔH2 (ft)	Slope2 %	L3 (ft)	Starting El. (ft)	Ending El. (ft)	ΔH3 (ft)	Slope 3 %	Sediment Delivery (t/ac/yr)	Sediment Delivery (t/yr)
1	502	0.48	502	1149	1140	9	1.8											20.000	9.6
2	493	0.54	96	1180	1146	34	35.4	397	1146	1140	6	1.5						14.000	7.56
3	479	0.97	65	1183	1180	3	4.6	79	1180	1156	24	30.4	335.0	1156	1140	16	4.8	75.000	72.75
4	574	0.57	80.5	1185	1180	5	6.2	153	1180	1152	28	18.3	340.5	1152	1140	12	3.5	60.000	34.2
5	593	1.02	304	1187	1160	27	8.9	73	1160	1150	10	13.7	216.0	1150	1140	10	4.6	83.000	84.66
6	675	2.17	145	1190	1170	20	13.8	423	1170	1154	16	3.8	107.0	1154	1140	14	13.1	130.000	282.1
7	830	2.03	75.0	1195	1190	5	6.7	152	1190	1170	20	13.2	603.0	1170	1140	30	5.0	94.000	190.82
8	907	1.58	121	1196	1190	6	5.0	336	1190	1164	26	7.7	450.0	1164	1140	24	5.3	110.000	173.8
9	1017	1.74	1017	1197	1140	57	5.6											120.000	208.8
10	38	0.29	38.0	1142	1140	2	5.3											19.000	5.51
																			1069.8

* From RUSLE2 software calculations.
** Column 6 x Column 7

Appendix D Sidney RUSLE2 Example

The westbound Sidney, Nebraska off-ramp from Interstate 80, shown in **Figure D 1**, is located

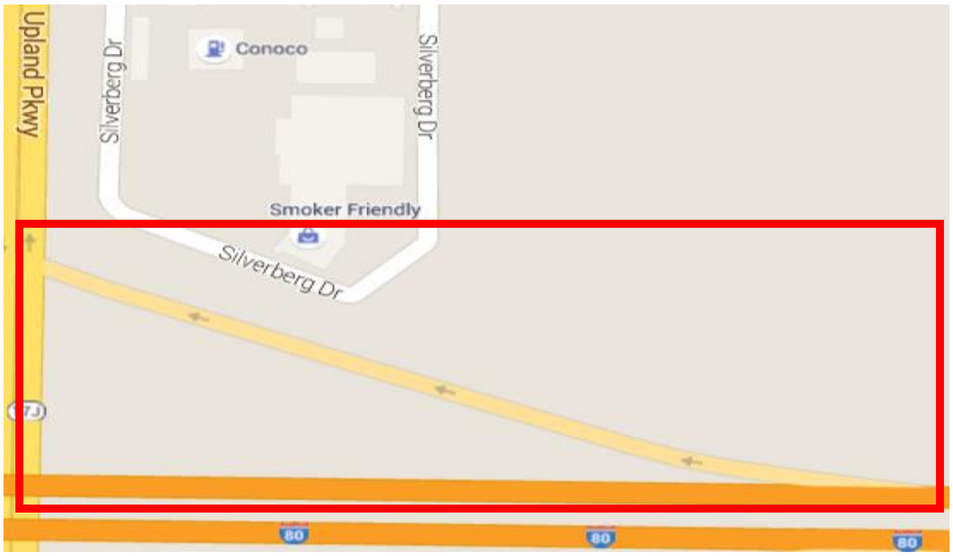


Figure D 1 Sidney project site area (red box)

near Sidney, Nebraska, in Cheyenne County (41.113525, -102.947657).

Fill out the Plan window with the *Project Name* as Center Street, and the *Location* as USA\ Nebraska\ Cheyenne County as shown in **Figure D 2**.

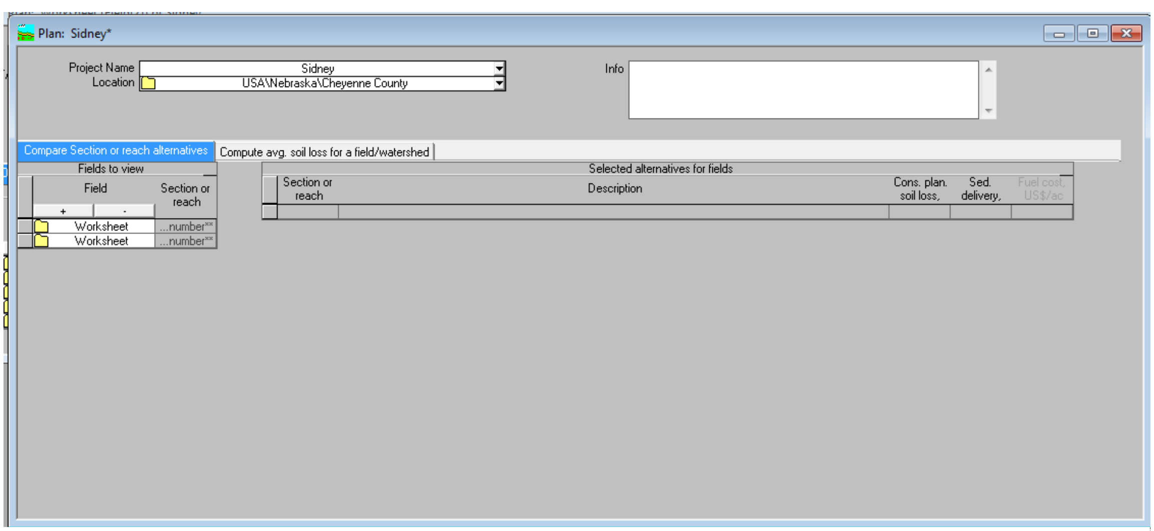


Figure D 2

Select the folder to the right of *Worksheet*. A new window will open (**Figure D 3**)

Select the folder icon on the far left side of the page, the RUSLE2 Profile window will open.

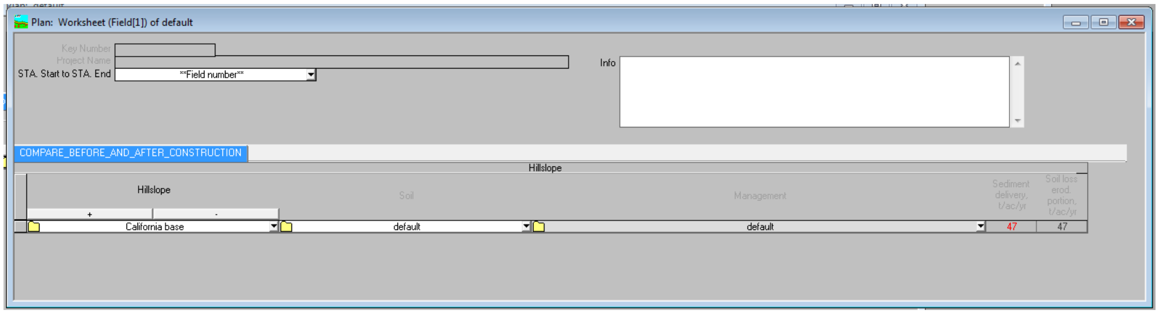


Figure D 3

When in the RUSLE2 profile within STEP 1, select *USA, Nebraska, Cheyenne County* as shown in

Figure D 4.

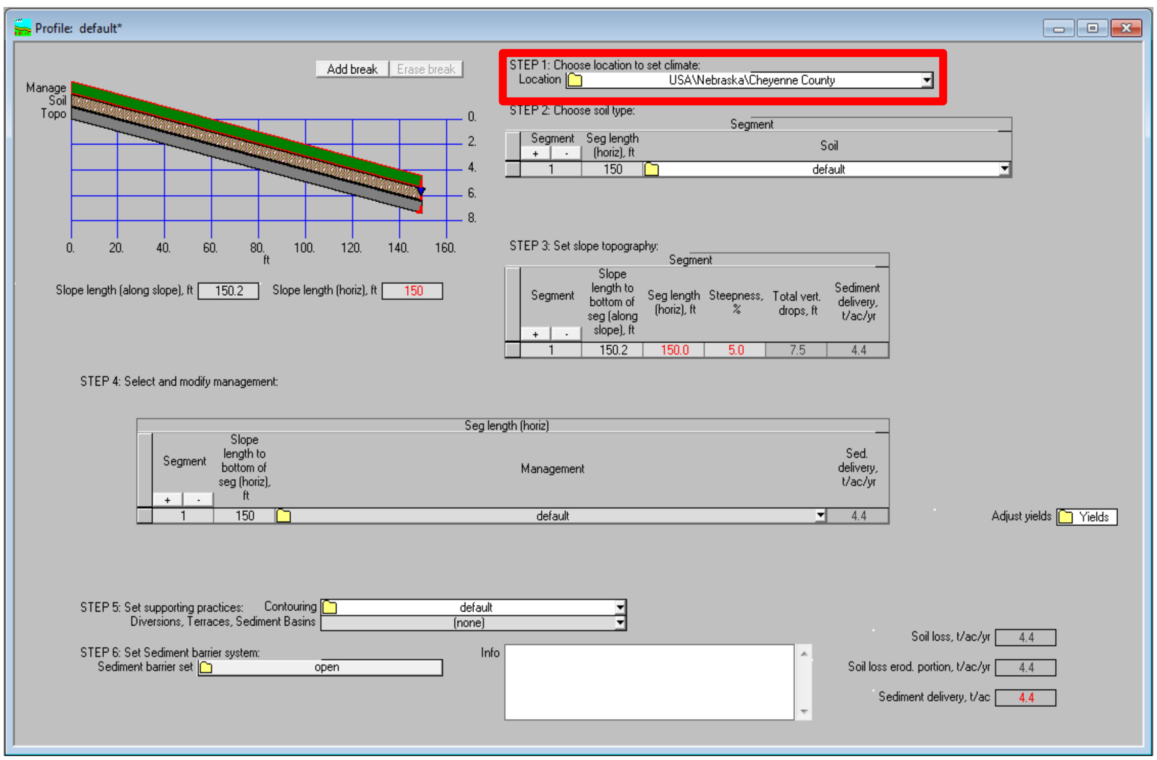


Figure D 4 Sidney Off-Ramp RUSLE2 Location

Based on the USDA Web Soil Survey the soil is classified as a Rosebud-Canyon Complex 1736, shown in **Figure D 5**. This a Loamy soil.

Cheyenne, Nebraska (NE033)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
1736	Rosebud-Canyon complex, 3 to 9 percent slopes	9.0	44.8%
5101	Alliance loam, 1 to 3 percent slopes	10.6	52.4%
5150	Canyon fine sandy loam, 6 to 30 percent slopes	0.6	2.8%
Totals for Area of Interest		**20.2**	**100.0%**

Figure D 5 Cheyenne County Soil Survey

In RUSLE2 under STEP 2 select *Generic Soils, loam (low-mod OM)*, shown in **Figure D 6**. This reflects the soil for the site, as it is a Loam, with low to moderate Organic Matter.

The strips (yellow lines) used to calculate sediment delivery are superimposed on the United States Geological Survey GIS map (USGS TNM 2.0 Viewer), seen in **Figure D 7**. The elevations and hillslope lengths found in **Figure D 7** are input into **Table D 1**.

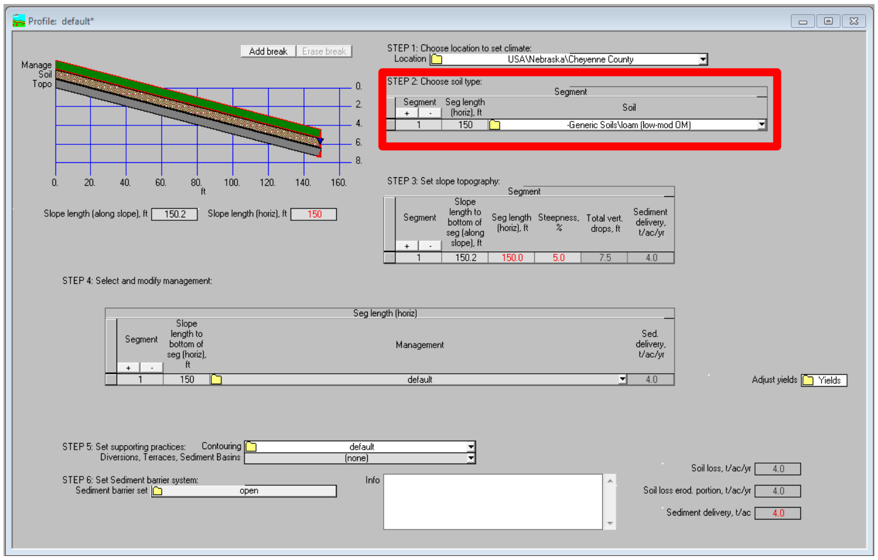


Figure D 6 RUSLE2 Sidney Off-Ramp Soils

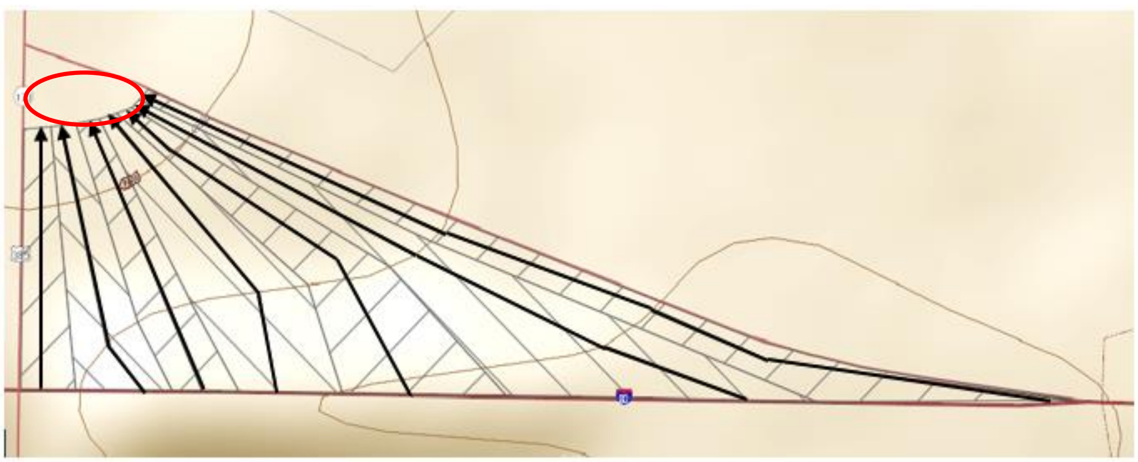


Figure D 7 Sidney Off-Ramp RUSLE2 Representative Strips (black lines) and Representative Areas (grey hatching) and Proposed BMP Location (red oval)

Table D 1

Strip #	Total Length (ft)	L1 (ft)	Starting Elevation (ft)	Ending Elevation (ft)	ΔH1 (ft)	Slope 1 %	L2 (ft)	Starting Elevation (ft)	Ending Elevation (ft)	ΔH 2 (ft)	Slope 2 %	L3 (ft)	Starting Elevation (ft)	Ending Elevation (ft)	ΔH3 (ft)	Slope 3 %	Slope Area (Ac.)
1	291	291	4256	4247	9	3.1											0.199
2	320	46	4275	4257	18	39.1	93	4257	4251	6	6.5	180	4251	4247	4	2.2	0.429
3	332	77	4275	4263	12	15.6	173	4263	4250	13	7.5	82	4250	4247	3	3.7	0.466
5	363	97	4275	4255	20	20.6	266	4255	4247	8	3.0						0.738
7	498	88	4275	4263	12	13.6	410	4263	4247	16	3.9						1.462
6	772	42	4273	4267	6	14.3	305	4267	4258	9	3.0	425	4258	4247	11	2.6	0.93
4	1065.5	321	4273	4270	3	0.9	745	4270	4247	23	3.1						0.712
SITE																	3.294

Using the data from **Table D 1**, the slope is calculated by from the change in elevation divided by the horizontal distance. For strip 2 the slope length (horiz) is 320 feet as seen in **Figure D 8**. Ensure that the horizontal distance is 320 feet, and not the length along the slope.

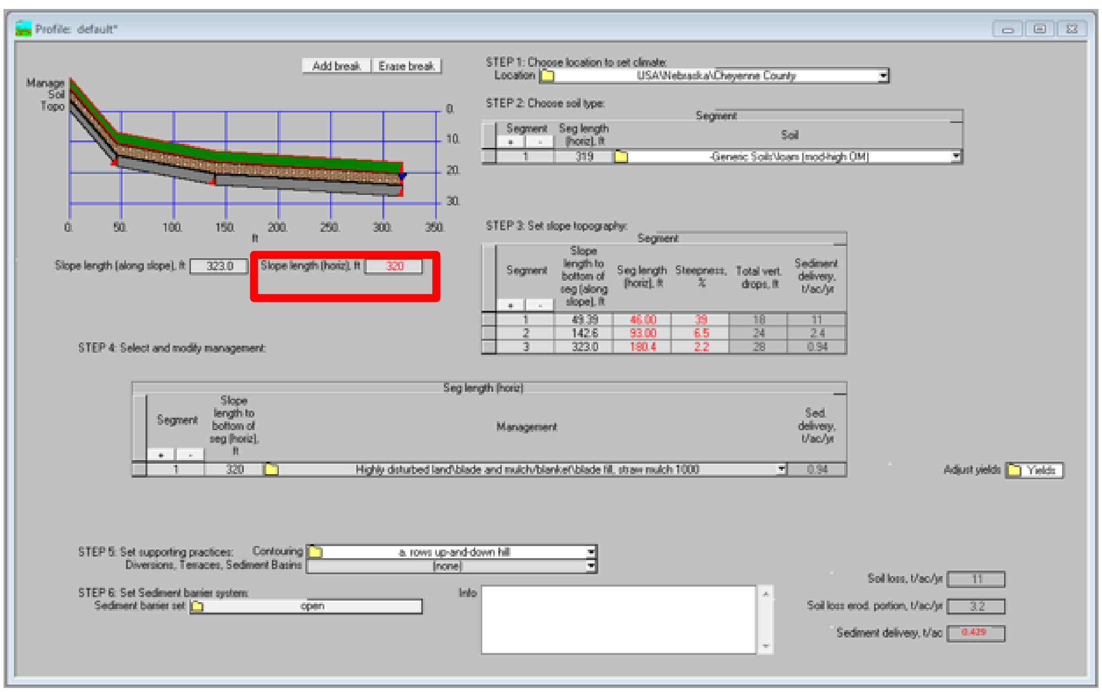


Figure D 8 Sidney Off-Ramp Slope Length

In STEP 3, also add two new segments. One at 46 feet with a 39% slope, second at 93 feet with a slope of 6.5%, and finally at 180 feet with a 2.2% slope. Shown in **Figure D 9**.

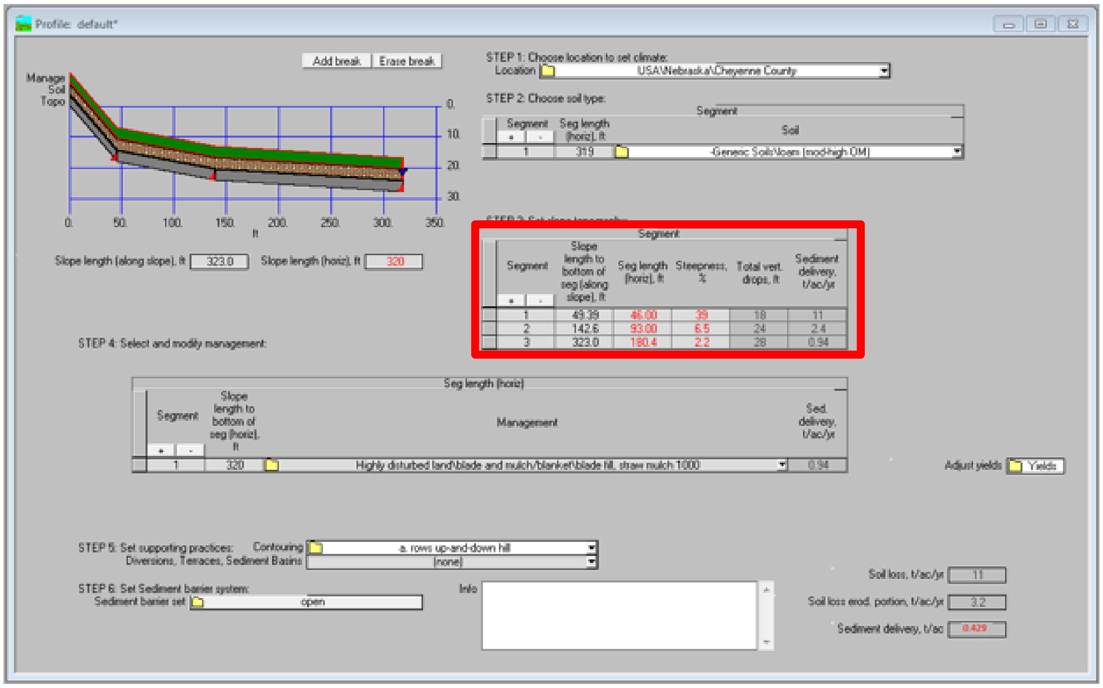


Figure D 9 Sidney Off-Ramp RUSLE2 Slope Steepness

In STEP 4 the management that is best associated with this site is *Highly disturbed land; blade and mulch/ blanket; blade fill, straw mulch 1000*, shown in **Figure D 10**.

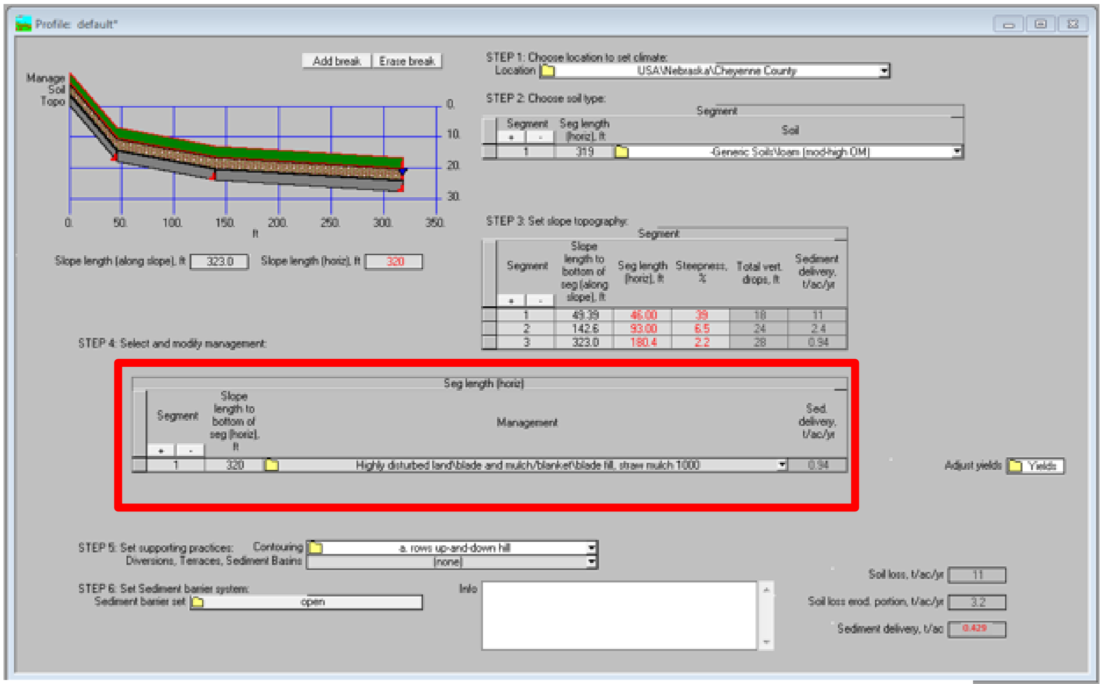


Figure D 10 Sidney Off-Ramp RUSLE2 Management

For contouring on this site, the worst case scenario was assumed, i.e., contouring directly up and down the hill, because that will allow the most runoff. There are no diversions, terraces or basins at the bottom of this strip, so none were selected. **Figure D 11** shows STEP 5.

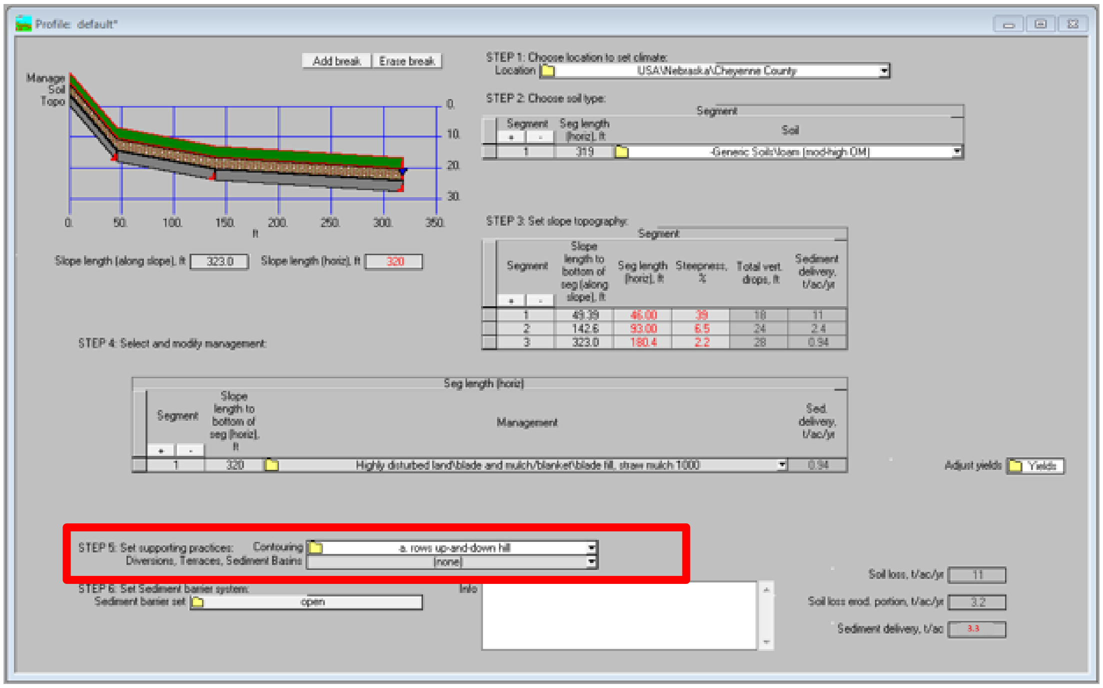


Figure D 11 Sidney Off-Ramp RUSLE2 Support Practices

When STEP 6 is selected, a new window open that looks like **Figure D 12**. For the Sidney off-ramp, there are no sediment barriers to establish, so click Apply/Close.

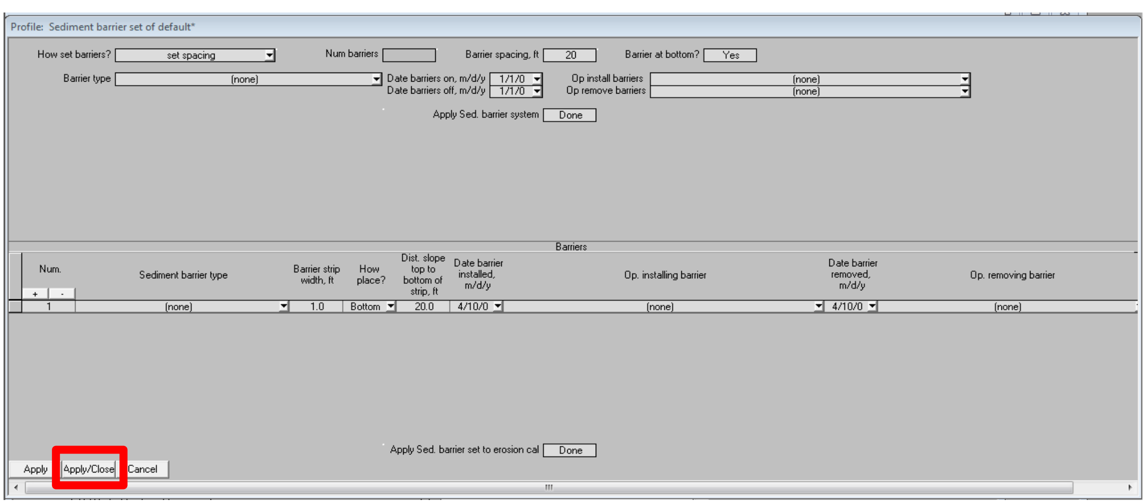


Figure D 12 Sidney Off-Ramp RUSLE2 Sediment Barriers

The final Profile for Strip 1 on the Sidney off-ramp site should resemble **Figure D 13**. The total annual Sediment Delivery to the bottom of strip 2 is 3.3 tons/acre.

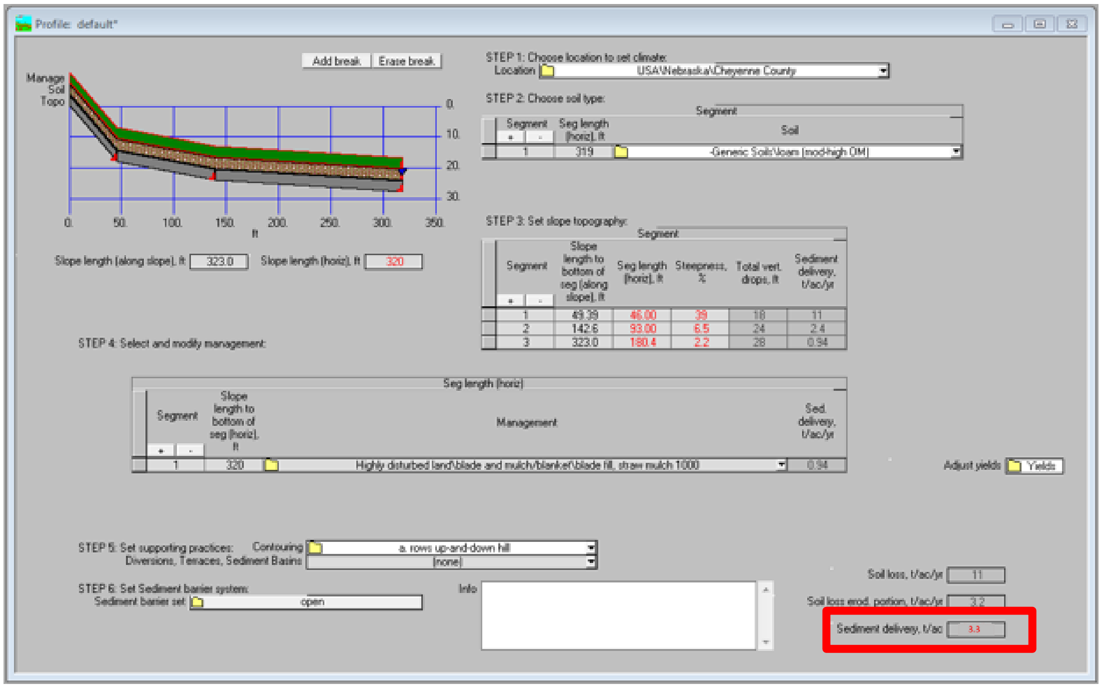


Figure D 13 Sidney Off-Ramp RUSLE2 Sediment Delivery

This value will be multiplied by the area represented by strip 1 to calculate the total sediment yield delivered to the receiving channel from that area.

Save the profile, and add a new profile using the + button under *Hillslope* to represent the second strip. Do this for all the remaining strips.

After all the profiles are input into RUSLE2, the worksheet should look like **Figure D 14**.

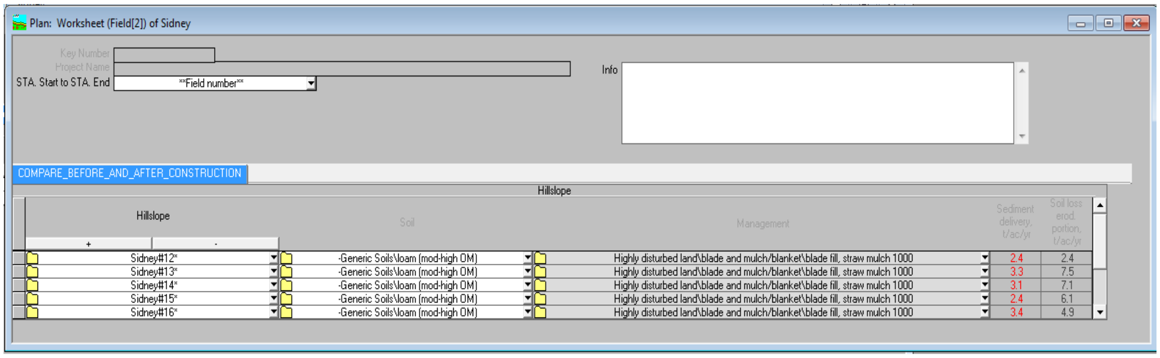


Figure D 14 Sidney Off-Ramp RUSLE2 Completed Worksheet

For each strip there will be an area of the site associated with that strip. The representative area should have identical qualities as the representative strip, that is, the length and topography must be the same throughout the representative area for RUSLE2 to accurately calculate sediment delivery. Input this data into the table found in the BMP model. These areas are then multiplied by the Sediment Delivery to get tons of sediment transported for the given area, and then summed up to give sediment transported for the site. **Table D 2** shows all of the calculations.

Table D 2

Strip #	Total Length (ft)	L1 (ft)	Starting Elevation (ft)	Ending Elevation (ft)	ΔH1 (ft)	Slope 1 %	L2 (ft)	Starting Elevation (ft)	Ending Elevation (ft)	ΔH2 (ft)	Slope 2 %	L3 (ft)	Starting Elevation (ft)	Ending Elevation (ft)	ΔH3 (ft)	Slope 3 %	Slope Area (Ac.)	Sediment Delivery (t/ac/yr)	Sediment Delivery (t/yr)
1	291	291	4256	4247	9	3.1											0.199	2.4	0.476584
2	320	46	4275	4257	18	39.1	93	4257	4251	6	6.5	180	4251	4247	4	2.2	0.429	3.3	1.4166667
3	332	77	4275	4263	12	15.6	173	4263	4250	13	7.5	82	4250	4247	3	3.7	0.466	3.1	1.4439624
5	363	97	4275	4255	20	20.6	266	4255	4247	8	3.0						0.738	3.4	2.5097245
7	498	88	4275	4263	12	13.6	410	4263	4247	16	3.9						1.462	3.4	4.9719927
6	772	42	4273	4267	6	14.3	305	4267	4258	9	3.0	425	4258	4247	11	2.6	0.93	2.5	2.325241
4	1065.5	321	4273	4270	3	0.9	745	4270	4247	23	3.1						0.712	3.4	2.4196511
SITE																	3.294		10.81893

* From RUSLE2 software calculations.
** Column 6 x Column 7

Appendix E BMP Design Tutorial

Once the sediment data is calculated within RUSLE2, the sediment will flow into a theoretical BMP, where the efficiency, sedimentation, and lifespan are estimated.

1. The RUSLE2 output data is compiled in **Table E 1**, which is found on the first page (BMP Selection Tab) of the BMP Design Software.

Table E 1 Sidney Off-Ramp site total Sediment Delivery

Strip #	Total Length (ft)	L1 (ft)	Starting Elevation (ft)	Ending Elevation (ft)	ΔH1 (ft)	Slope 1 %	L2 (ft)	Starting Elevation (ft)	Ending Elevation (ft)	ΔH2 (ft)	Slope 2 %	L3 (ft)	Starting Elevation (ft)	Ending Elevation (ft)	ΔH3 (ft)	Slope 3 %	Slope Area (Ac.)	Sediment Delivery (t/ac/yr)	Sediment Delivery (t/yr)
1	291	291	4256	4247	9	3.1											0.199	0.0028	0.000556
2	320	46	4275	4257	18	39.1	93	4257	4251	6	6.5	180	4251	4247	4	2.2	0.429	0.0054	0.0023182
3	332	77	4275	4263	12	15.6	173	4263	4250	13	7.5	82	4250	4247	3	3.7	0.466	0.0053	0.0024687
5	363	97	4275	4255	20	20.6	266	4255	4247	8	3.0						0.738	0.0052	0.0038384
7	498	88	4275	4263	12	13.6	410	4263	4247	16	3.9						1.462	0.0041	0.0059956
6	772	42	4273	4267	6	14.3	305	4267	4258	9	3.0	425	4258	4247	11	2.6	0.93	0.003	0.0027903
4	1065	321	4273	4270	3	0.9	745	4270	4247	23	3.1						0.712	0.0032	0.0022773
SITE																	3.294		0.0151769

2. Enter the Total Sediment Delivery (t/yr) in the *Input Sediment Delivery Data (T/YR)* cell, **Figure E 1**.
3. Select the generic soil type (**Figure E 1**) that fits the project site. This could be the generic soil that was input in RUSLE2, or if a specified soil was input, choose the soil that most accurately describes the soil on site.

Input Sediment Delivery Data (T/YR):	0.0152
Select Generic Soil Type:	Loam
Select BMP:	Detention Pond

Figure E 1 BMP Model Selection Page Input

4. Choose the BMP that you wish to investigate (**Figure E 1**).

5. A message will appear that directs you to the tab corresponding to the BMP selected (**Figure E 2**).

See Detention Pond Sheet

Figure E 2 BMP Model Selection Page Output

Detention Pond

6. If a Detention Pond is selected, you will be directed to the Detention Pond tab. Once it is opened, the screen will display **Figure E 3**.

Input BMP Volume (Ac-ft)	0.1000
Select Percent Filled Before Cleanout:	65.00%
Input TOTAL Watershed Area (Ac)	2.037
BMP Volume: Watershed Area Ratio	0.0490918
Generic Soil Type on Site	Loam
Soil Density (lb/ft^3)	103.0
Soil Particle Diameter (ft)	1.41E-04
Volume of Soil Transported Into BMP Annually (ft^3/yr)	210.10
Efficiency of BMP	0.52
Volume of Soil Deposited in BMP (ft^3/yr)	110.21
Estimated Lifespan of BMP (years)	25.7

Figure E 3 BMP Model Detention Pond Page with user inputs (blue cells) and model outputs (white cells)

a. The top three cells are user input data pieces.

   i. The first cell is the detention pond volume, in ac-ft. That is the surface area of the pond in acres, multiplied by the depth of the pond in feet. The volume of the BMP is defined by engineer design.

   ii. The second cell is the percent filled before cleanout. There is a drop down menu to the right of the cell that allows you to select the amount the BMP will be filled before it needs to be cleaned out. This percentage is multiplied by the total volume of the BMP, so the spreadsheet calculates the life of the BMP based on that percent filled.

   iii. The third cell is the total watershed area producing runoff and sediment that flows into the BMP. This value should not be reflective of any water that does not flow into the BMP.

b. The remainder of the cells are used to calculate the efficiency of the BMP. See **Section 3.3.3 BMP Model Process** for explanation on how the efficiency was calculated.

   i. The Volume: Area ratio is calculated by taking the gross volume of the BMP times the percent filled, divided by the drainage area. The ratio partially determines the efficiency of the BMP.

   ii. Generic Soil Type is taken from the BMP Selection sheet and is used to determine the density of the sediment and diameter of the sediment particles.

   iii. Soil Density is an assigned value based on the generic soil selected. This value dictates the volume of the sediment as it fills the BMP.

iv. Soil Particle Diameter determines soil settling velocity, and it affects sediment capture efficiency of the BMP. The particle diameter is based on the generic soil type selected in the BMP Selection sheet.

v. Volume of Soil Transported Annually is the total sediment delivery from the BMP Selection sheet multiplied by the soil density.

vi. As stated, the efficiency of BMP is based on the volume: area ratio and the soil particle diameter.

vii. Volume of Soil Deposited in BMP is calculated by multiplying the volume of soil transported into the BMP by the efficiency of the BMP.

viii. Estimated Lifespan of BMP is calculated from the sediment capture capacity of the BMP, divided by the volume of soil deposited in the BMP annually.

Infiltration Trench

c. If an Infiltration Trench is selected, you will be directed to the Infiltration Trench tab. Once it is opened, the screen will display **Figure E 4**.

d. The top three cells are user input data pieces.

i. The first cell is the media fill type. That is the type of material (eg. gravel) that is filling the trench. There is a porosity associated with the media selected, which dictates the volume of empty space.

ii. The second cell is the gross BMP volume, in ac-ft. That is the surface area of the trench in acres, multiplied by the depth of the trench in feet. The volume of the BMP is defined by engineer design.

Select BMP Media Fill Type:	Gravel (η=40%)
Input BMP Volume (Ac-ft)	1.0000
Input TOTAL Watershed Area (Ac)	2.037
Volume:Area Ratio *	4.713
Generic Soil Type on Site	Loam
Soil Density (lb/ft^3)	106.1
Volume of Soil Transported Annually into BMP (ft^3/yr)	203.92
Efficiency of BMP	0.90
Volume of Soil Deposited into BMP (ft^3/yr)	183.53
Estimated Lifespan of BMP (years)	>50

Figure E 4 BMP Model Infiltration Trench Page with user inputs (blue cells) and model outputs (white cells)

iii. The third cell is the total watershed area producing runoff and sediment that flows into the BMP. This value should not be reflective of any water that does not flow into the BMP.

e. The remainder of the cells are used to calculate the efficiency of the BMP. See **Section 3.3.3 BMP Model Process** for explanation on how the efficiency was calculated.

i. The Volume: Area ratio is calculated by taking the volume of porous spaces, divided by the drainage area. The ratio determines the efficiency of the BMP.

ii. Generic Soil Type is taken from the BMP Selection sheet and is used to determine the density of the sediment and diameter of the sediment particles.

iii. Soil Density is an assigned value based on the generic soil selected. This value dictates the volume of the sediment as it fills the BMP.

iv. Volume of Soil Transported Annually is the total sediment delivery from the BMP Selection sheet multiplied by the soil density.

v. As stated, the efficiency of BMP is based on the volume: area ratio.

vi. Volume of Soil Deposited in BMP is calculated by multiplying the volume of soil transported into the BMP by the efficiency of the BMP.

vii. Estimated Lifespan of BMP is the volume of the BMP's porous space, divided by the volume of soil deposited in the BMP annually.

Grass Lined Swale

7. If a Swale is selected, you will be directed to the Swale tab. Once it is opened, the screen will display **Figure E 6**.

   a. The top six cells are user input data pieces.

      i. The first cell is the length of the swale, in feet. This is the horizontal distance down the swale.

      ii. The second cell is the slope of the BMP. That is the difference in elevation divided by the length of the swale.

      iii. The third cell is the width of the BMP, in feet. That is the horizontal distance across the bottom of the swale.

      iv. The fourth cell is the density of the grass cover. This is a percentage that reflects the Manning roughness coefficient. This is based on how much open space there is when looking down at the grass cover.

Input Length of Swale (ft):	125
Input Slope of Swale (%):	4.00%
Input Width of Swale (ft):	10
Select how Dense the Grass Cover is:	0.7
Select horizontal side slope of the swale (z) (See diagram to right)	2
Input the Height of Grass (ft)	0.6
Settling Duration (sec)	131.1
Travel Time (sec)	228.9
Volume of BMP (ft^3)	750
Generic Soil Type on Site	Loam
Soil Density (lb/ft^3)	106.1
Volume of Soil Transported Annually into BMP (ft^3/yr)	203.92
BMP Efficiency:	77%
Volume Deposited in BMP Annually (ft^3/yr)	157.02
Estimated Lifespan of BMP (years)	4.8

Figure E 6 BMP Model Grass Lined Swale Page with user inputs (blue cells) and model outputs (white cells)

v. The fifth cell is the horizontal side slope of the swale (z). **Figure E 5** shows how the horizontal side slope (z) is defined.

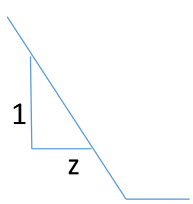


Figure E 5 Swale Sideslope (z)

vi. The last user input cell is the grass height in the swale, in feet.

vii. All the variables that the engineer inputs, except the density of grass cover are defined by engineer design.

b. The remainder of the cells are used to calculate the efficiency of the BMP. See **Section 3.3.3 BMP Model Process** for explanation on how the efficiency was calculated.

    i. The settling duration is calculated using the geometry of the BMP and the settling velocity of the soil based on soil type. This value is in seconds.
    ii. Travel time, in seconds, is calculated by dividing the swale length by the flow velocity, calculated using the Manning equation.
    iii. The volume of the swale is based on the geometric design, and is the gross volume.
    iv. Generic Soil Type is taken from the BMP Selection sheet and is used to determine the density of the sediments.
    v. Soil Density is an assigned value based on the generic soil selected. This value dictates the volume of the sediment as it fills the BMP.
    vi. Volume of Soil Transported Annually is the total sediment delivery from the BMP Selection sheet multiplied by the soil density.
    vii. As stated, the efficiency of BMP is based on the settling duration and the travel time.
    viii. Volume of Soil Deposited in BMP is calculated by multiplying the volume of soil transported into the BMP by the efficiency of the BMP.
    ix. Estimated Lifespan of BMP is the volume of the BMP's porous space, divided by the volume of soil deposited in the BMP annually.

<u>Grass Lined Swale with Rock Check Dam</u>

8. If a Grassed Swale with Rock Check Dam is selected, you will be directed to the Grassed Swale Rock Check Dam tab. Once it is opened, the screen will display **Figure E 7**.

Input TOTAL Length of Swale (ft):	950
Input Slope of Swale (%):	6.00%
Input Width of Swale (ft):	50
Select how Dense the Grass Cover is:	0.4
Select horizontal side slope of the swale (z) (See diagram to right):	2
Input the Height of Grass (ft):	0.4
Input the Height of Dam(s) (ft):	2.0
Input Number of Dams in Swale:	25.0
Input Spacing between each Dam (ft):	33.0
Input Total Watershed Area (Ac.):	3.3
Check Dam Volume (Ac-ft)	0.95
Volume: Area Ratio	0.29
Settling Duration (sec)	147.9
Travel Time (sec)	139.4
Volume of BMP (ft^3)	43750
Generic Soil Type on Site	Loam
Soil Density (lb/ft^3)	106.1
Soil Particle Diameter (ft)	0.000141
Volume of Soil Transported Annually into BMP (ft^3/yr)	203.92
BMP Efficiency:	60%
Volume Deposited in BMP Annually (ft^3/yr)	121.97
Estimated Lifespan of BMP (years)	>50

Figure E 7 BMP Model Grass Lined Swale with Rock Check Dam Page with user inputs (blue cells) and model outputs (white cells)

a. The top ten cells are user input data pieces.

i. The first cell is the length of the swale, in feet. This is the horizontal distance down the swale.

ii. The second cell is the slope of the bottom of the BMP. That is the difference in elevation divided by the length of the swale.

iii. The third cell is the width of the BMP, in feet. That is the horizontal distance across the bottom of the swale.

iv. The fourth cell is the density of the grass cover. This is a percentage that reflects the Manning roughness coefficient. This is based on how much open space there is when looking down at the grass cover.

v. The fifth cell is the horizontal side slope of the swale (z). **Figure E 8** shows what the horizontal side slope refers to.

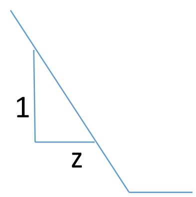


Figure E 8 Swale Sideslope (z)

vi. The sixth cell is the grass height in the swale, in feet.

vii. The seventh cell is the check dam(s) height, in feet. This will be the height of all check dams.

viii. The eight cell is the number of check dam(s) within the swale.

ix. The ninth cell is the spacing between each check dam, in feet.

x. The tenth cell is the total watershed area producing runoff and sediment that flows into the BMP. This value should not be reflective of any water that does not flow into the BMP.

xi. All the variables that the engineer inputs, except the density of grass cover are defined by engineer design.

b. The remainder of the cells are used to calculate the efficiency of the BMP. See **Section 3.3.3 BMP Model Process** for explanation on how the efficiency was calculated.

i. The check dam volume is a calculated value using the user input height, spacing, width, and the number of dams. By finding the volume behind one check dam, and multiplying that volume by the number of dams in the BMP.

ii. The volume-to-area ratio is calculated using the sum of the gross volume behind all of the check dams, divided by the total watershed area.

iii. The settling duration is calculated using the geometry of the BMP and the settling velocity of the soil based on soil type. This value is in seconds.

iv. Travel time, in seconds, is calculated by dividing the swale length by the flow velocity, calculated using the Manning equation.

v. The volume of the swale with check dams is a geometric factor, and is the gross volume. This is the sum of the total check dam volume and the swale volume.

vi. Generic Soil Type is taken from the BMP Selection sheet and is used to determine the density of the sediment and diameter of the sediment particles.

vii. Soil Density is an assigned value based on the generic soil selected. This value dictates the volume of the sediment as it fills the BMP.

viii. Soil Particle Diameter determines soil settling velocity, and it affects sediment capture efficiency of the BMP. The particle diameter is based on the generic soil type selected in the BMP Selection sheet.

ix. Volume of Soil Transported Annually is the total sediment delivery from the BMP Selection sheet multiplied by the soil density.

x. As stated, the efficiency of BMP is based on the volume: area ratio, the soil particle diameter, settling duration, and travel time.

xi. Volume of Soil Deposited in BMP is calculated by multiplying the volume of soil transported into the BMP by the efficiency of the BMP.

xii. Estimated Lifespan of BMP is calculated from the sediment capture capacity of the BMP, divided by the volume of soil deposited in the BMP annually.

Bioretention Area

9. If a Bioretention area is selected, you will be directed to the Bioretention (Rain Garden) tab. Once it is opened, the screen will display **Figure E 9**.

Input BMP Area (ft^2) *	3000.0
Input BMP Depth (ft)	1.50
Input TOTAL Watershed Area (Ac)	11.39
Input Depth of Infiltration Cell Below Rain Garden (ft)	0.75
Total BMP Volume (Ac-ft)	0.124
Volume:Area Ratio	0.011
Generic Soil Type on Site	Silt Loam
Soil Density (lb/ft^3)	96.7
Volume of Soil Transported Annually into BMP (ft^3/yr)	983.91
Efficiency of BMP	47%
Volume of Soil Deposited into BMP (ft^3/yr)	460.42
Estimated Lifespan of BMP (years)	1.17

Figure E 9 BMP Model Bioretention Area Page with user inputs (blue cells) and model outputs (white cells)

a. The top four cells are user input data pieces.

   i. The first cell is the surface area of the garden, in square feet.

   ii. The second cell that needs to be populated is the depth of the BMP, in feet.

   iii. The third cell is the total watershed area producing runoff and sediment that flows into the BMP. This value should not be reflective of any water that does not flow into the BMP.

   iv. The fourth cell is the total depth of the infiltration cell below the rain garden, in feet. This is if there is a designed infiltration area under the garden, if there is no infiltration area, this value equals 0.

   v. All the variables that the engineer inputs are defined by engineer design. The design of the BMP may change as the engineer sees fit.

b. The remainder of the cells are used to calculate the efficiency of the BMP. See **Section 3.3.3 BMP Model Process** for explanation on how the efficiency was calculated.

   i. The volume of the bioretention area is a geometric factor. It is the sum of the surface area of the cell multiplied by the ponding depth within the cell, and the surface area of the cell multiplied by the depth of the infiltration cell.

   ii. The volume-to-area ratio is calculated using the sum of the gross volume of the bioretention area, plus the porous volume of the infiltration cell, divided by the total site area.

iii. Generic Soil Type is taken from the BMP Selection sheet and is used to determine the density of the sediment and diameter of the sediment particles.

iv. Soil Density is an assigned value based on the generic soil selected. This value dictates the volume of the sediment as it fills the BMP.

v. Soil Particle Diameter determines soil settling velocity, and it affects sediment capture efficiency of the BMP. The particle diameter is based on the generic soil type selected in the BMP Selection sheet.

vi. Volume of Soil Transported Annually is the total sediment delivery from the BMP Selection sheet multiplied by the soil density.

vii. As stated, the efficiency of BMP is based on the volume: area ratio.

viii. Volume of Soil Deposited in BMP is calculated by multiplying the volume of soil transported into the BMP by the efficiency of the BMP.

ix. Estimated Lifespan of BMP is calculated from the sediment capture capacity of the BMP, divided by the volume of soil deposited in the BMP annually.