

E AAL

Erosion Vulnerability Assessment for Agricultural Lands

Tutorial

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DISCLAIMER

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This tutorial assumes that the user has a moderate to intermediate knowledge of ArcGIS software, GIS processing, and GIS datasets.

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ACRONYMS

- BMP: Best Management Practice
- CDL: Cropland Data Layer
- CLU: Common Land Unit
- DEM: Digital Elevation Model
- EVAAL: Erosion Vulnerability Assessment for Agricultural Lands
- GIS: Geographic Information System
- gSSURGO: gridded Soil Survey Geographic Database
- HUC: Hydrologic Unit Code
- LiDAR: Light Detection And Ranging
- NASS: National Agricultural Statistics Service
- NRCS: Natural Resource Conservation Service
- SPI: Stream Power Index
- TMDL: Total Maximum Daily Load
- USDA: United States Department of Agriculture
- USLE: Universal Soil Loss Equation
- WDNR: Wisconsin Department of Natural Resources

1.0 OVERVIEW

The Wisconsin Department of Natural Resources (WDNR) Bureau of Water Quality has developed EVAAL, the Erosion Vulnerability Assessment for Agricultural Lands, to assist watershed managers in prioritizing areas within a watershed which may be vulnerable to water erosion (and associated nutrient export) and which may contribute to downstream water quality problems. It evaluates locations of relative vulnerability to sheet, rill, and gully erosion using information about topography, soils, rainfall, and land cover. This tool is intended for relatively small watersheds (less than ~75 km²) that have already been identified as watersheds that contribute higher nonpoint source pollutant loads, such as subbasins identified in a Total Maximum Daily Load (TMDL) study as relatively high-loading. This tool enables watershed managers to prioritize and focus their field-scale data collection efforts, thus saving time and money while increasing the probability of locating fields with high sediment and nutrient export for implementation of BMPs.

This tutorial demonstrates the application of EVAAL on a subbasin of the Plum Creek watershed in eastern Wisconsin. It is approximately 5.5 km² in area with land use dominated by agricultural activity. Tutorial data is available for download from the WDNR ftp site (ftp://dnrftp01.wi.gov/geodata/EVAAL_V1_0) as two Esri file geodatabases, one that provides the input data needed to successfully run EVAAL, and another containing EVAAL outputs for the watershed. Only the data in the input geodatabase is needed to run EVAAL; the data in output geodatabase is provided for comparison to the user's own output. Note that individual tool runs may not provide the exact same results, as difference in areas included and parameters chosen will likely influence the result.

Detailed information regarding the methods applied in this tutorial can be found in the companion document, EVAAL Methods Documentation. That report contains an introduction to the tool development, descriptions of the model inputs, the methodologies applied, and the model outputs, as well as a comparison to another commonly used soil loss model, example applications of the model, references, and appendices.

2.0 HOW DOES EVAAL WORK?

The EVAAL toolset was designed to quickly identify areas vulnerable to erosion using readily available data and a user-friendly interface. This tool estimates vulnerability by separately assessing the risk for sheet and rill erosion (using the Universal Soil Loss Equation, USLE), and gully erosion (using the Stream Power index, SPI), while deprioritizing those areas that are not often hydrologically connected to surface waters (also known as internally drained, or non-contributing areas). These three pieces are combined to produce the following outputs:

- erosion vulnerability index for the area of interest (raster and tabular);
- areas vulnerable to sheet and rill erosion;
- areas of potential gully erosion;
- areas hydrologically disconnected from surface waters.

It is important to note that erosion “vulnerability” refers to an area’s susceptibility to sediment and nutrient runoff given certain, assumed management practices. The erosion vulnerability index output is a *relative*, non-dimensional index, which means that output from separate model runs should not be compared directly. Direct comparison is only advisable for areas that have been included in the same model run. The erosion vulnerability output is a non-dimensional index, meaning it is only intended to *prioritize or rank*, not estimate the real value of sediment or nutrient runoff.

EVAAL is an ArcGIS Toolbox divided into several different tools, to facilitate greater control over inputs. The workflow can be divided into several stages: creating a hydrologically conditioned DEM, identifying and removing from analysis those areas on the landscape that do not drain to surface waters, estimation of potential gully erosion, estimation of relative soil loss potential from sheet and rill erosion, and the calculation of an erosion vulnerability index.

For more information on the methods underlying the tools and processes, users are encouraged to read the Methods Documentation for EVAAL.

3.0 SYSTEM REQUIREMENTS

To successfully install and operate EVAAL, the following requirements are needed:

- Minimum 1.50 GB of RAM
- ESRI ArcGIS 10.1 or 10.2 Desktop
- ESRI ArcGIS 10.1 to 10.2 Spatial Analyst Extension

The tool makes use of several functions in ArcGIS’s Spatial Analyst Extension and so it is necessary to have access to this license. To verify it is available select the ArcMap Toolbar, move down to Customize, select Extensions, and check the “Spatial Analyst” box. If you do not have access to the Spatial Analyst extension, contact your system administrator for information on how to gain access.

4.0 EVAAL INPUTS

EVAAL has several input data files that are required in order to run. It is recommended that these files be formatted within an ESRI file geodatabase, but is not required. Refer to [Appendix B](#) for instructions on how to obtain the required datasets for areas outside the tutorial dataset domain. **All input data must be in the Wisconsin Transverse Mercator geographic projection (EPSG: 3071) (ftp://dnrftp01.wi.gov/geodata/projection_file/).**

- LiDAR DEM
High quality, fine scale elevation data (less than 3-meter X/Y resolution) is central to this tool and to the accurate modeling of landscape scale hydrology. LiDAR data is available for numerous Wisconsin counties, some of which are freely available on the WisconsinView website (<http://wisconsinview.org/>)

- **Area of Interest/Watershed Boundary**
This is used to define the area in which erosion vulnerability is to be assessed. It is strongly recommended to be a watershed boundary less than 75 square kilometers. The tool may or may not run to completion on areas larger than recommended. Certain functions of EVAAL require a buffered version of the area of interest; instructions for creating a buffered version of the area of interest can be found in [Appendix C](#).
- **gSSURGO Data**
EVAAL requires information about the erodibility of local soils. The tool was written specifically to access this data from the statewide Gridded Soil Survey Geographic Database, or gSSURGO database. The gSSURGO database is freely available from the [USDA-NRCS Geospatial Datagateway](#). Note that this is a statewide dataset and so is very large and can take several hours to download.
- **Culvert Polylines**
The LiDAR DEMs are of such high resolution that features such as road berms are clearly discernable and create what are known as “digital dams”. When hydrologic terrain attributes are calculated, these digital dams make it seem as though the flow of water is being impeded as it runs over the landscape. In order to accurately determine if rain water is likely to run off into surface waters or if it will pond and infiltrate before reaching surface waters, it is necessary to “break” these dams. This requires a vector layer of culverts to be created for the area of interest. See [Appendix A](#) for instructions on how to create the culverts layer; **note that this must be done prior to running the tools.**

EVAAL also uses the following data, but the user is not required to download or provide it prior to running the tool, provided an internet connection is available; the capability to automatically download and process this data is built into the tool.

- **Frequency-Duration Precipitation Data**
Precipitation amounts for a given frequency and duration of storm event is available from the National Weather Service. This information is used to assess if an area on the landscape is hydrologically connected to surface waters, given a specified size storm event.
- **National Cropland Data Layer (CDL)**
Data about specific crops grown in an area are produced from the National Agricultural Statistics Service (NASS). These data layers are used to infer a generalized agricultural management scheme from a crop rotation sequence. For example, 2 years of corn, 1 year of soybeans, and 2 years of alfalfa would be considered a dairy rotation. It is recommended to use at least 5 years of data to determine the generalized rotations. For more information on how a generalized crop rotation is created, users should consult the EVAAL methods documentation.

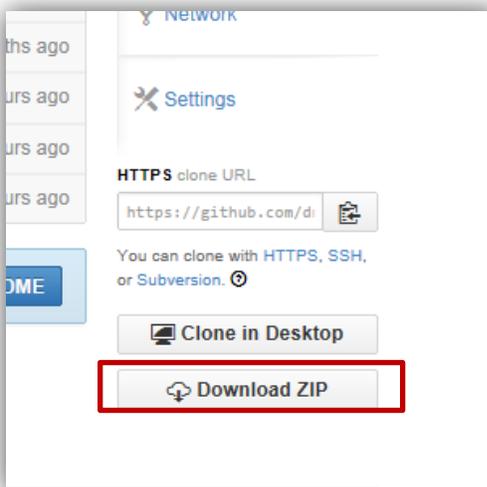
Within the tool are the options to use additional datasets to customize the output.

- **Zone boundaries**
These are vector files that delineate specific zones within the area of interest and are used to aggregate the erosion vulnerability index or other output values. For example, these boundaries could be for tracts, agricultural fields, or tax parcels. The default of EVAAL is to calculate erosion vulnerability for every grid cell on the landscape. In order to assess which agricultural fields or tracts have the most potential for erosion, the zone boundary input layer can be used to average the erosion vulnerability index for each field or tract.
- **Best Management Practices (BMPs)**
A raster layer of digitized BMP locations can be used to deprioritize areas that already have BMPs currently installed. Examples of these features are grassed waterways, strip cropping, cover crops, and riparian buffers, see [Appendix C](#) for assistance in creating this file.

5.0 EVAAL SETUP

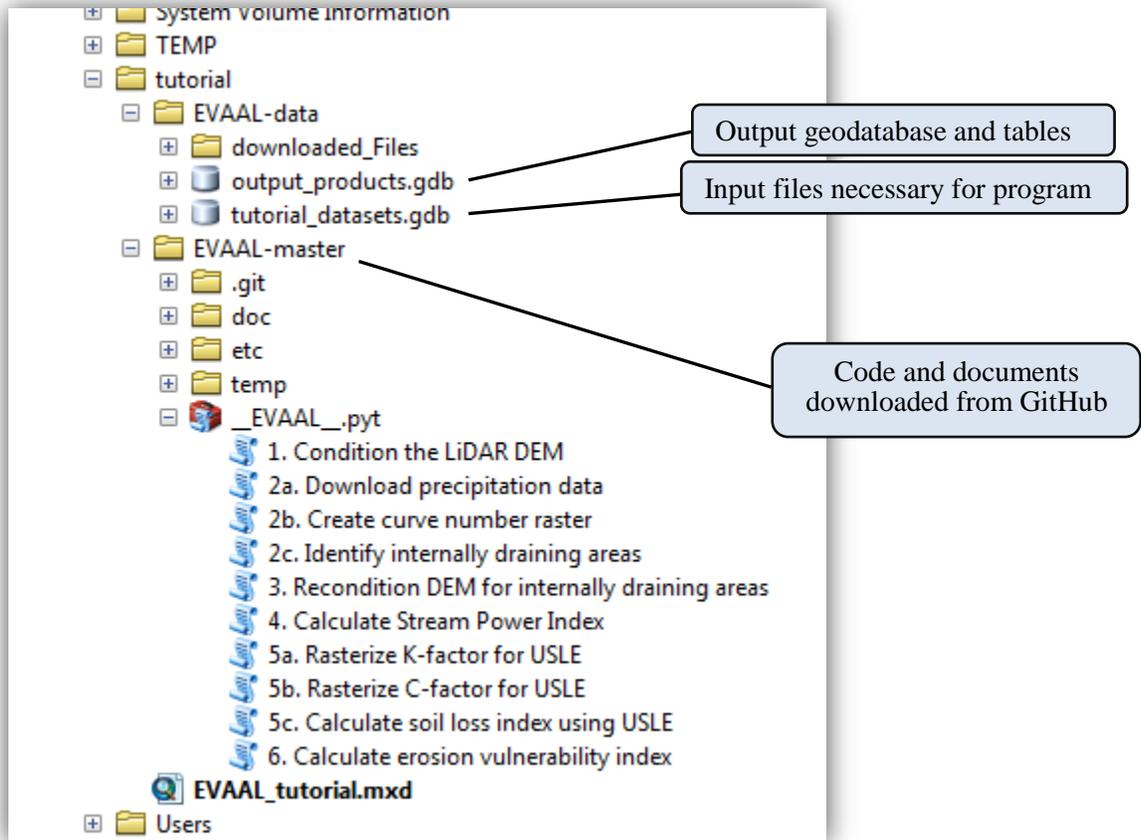
5.1 Accessing and setting up EVAAL files

The most recent version of EVAAL can be downloaded from the DNR Water Quality Modeling team’s GitHub repository, under the project name of “EVAAL” (<https://github.com/dnrwaterqualitymodeling/EVAAL>). Once at this page select the button on the right-hand side of the page labeled “Download ZIP”.



The tools and associated files are downloaded as one zip file. The file should be unzipped to a directory to which all users must have permission to write. In addition, there may not

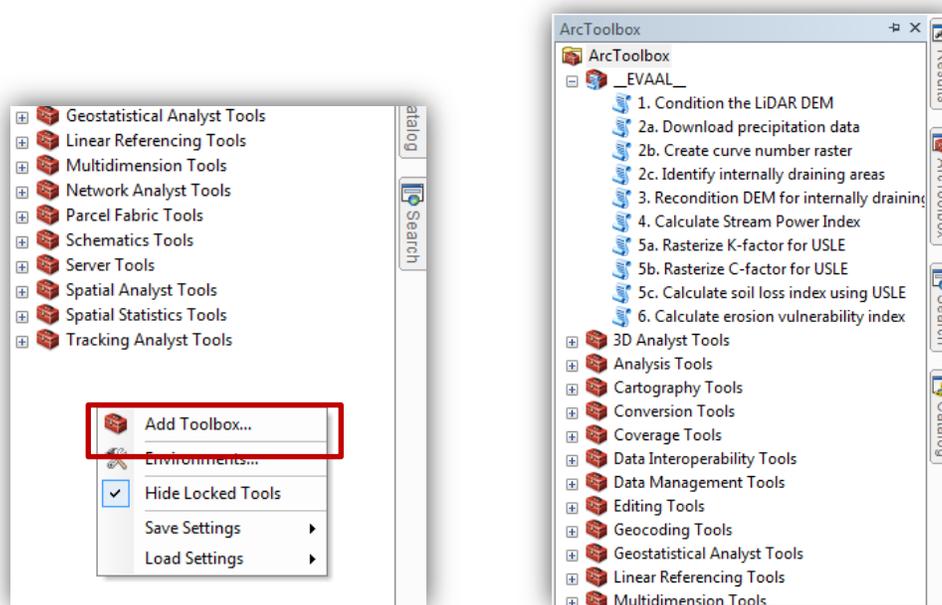
be spaces or “reserved”¹ characters within the folder pathname. For this tutorial, the model files were unzipped to a folder called “tutorial.” The input datasets are available for download from ftp://dnrftp01.wi.gov/geodata/EVAAL_V1_0. The geodatabase containing the tutorial inputs is titled “tutorial_datasets.gdb.” It is recommended that the user create a geodatabase to hold the outputs of EVAAL, this has been done for the tutorial and is called “output_products.gdb” in this example. Instructions on how to create a geodatabase are located in [Appendix C](#).



5.2 Loading EVAAL

EVAAL was designed to be used with ArcGIS 10.1 or 10.2. It can be run from ArcMap or from ArcCatalog. Running from the latter will limit any issues with schema locks, though this tutorial demonstrates running the tools from ArcMap in order to show images of the output files as they are created. EVAAL runs as a series of scripts in a Python Toolbox, this allows for an easy interface from within ArcGIS. To access and run the scripts from ArcMap, open the ArcToolbox window, right-click within this window and select “Add Toolbox...”, then navigate to where the file from GitHub was unzipped, open the “EVAAL-master” folder, and select the “__EVAAL__.pyt” toolbox.

¹ “Reserved” characters include: ?, %, *, :, “, |, <, >, and “.”.



This toolbox should now show up in the ArcToolbox window. Upon opening this toolbox, ten functions should be visible. To ensure the tool is visible every time the user opens ArcMap or ArcCatalog, right-click the ArcToolbox again, then “Save Settings”, then click “To Default.”

A note on terminology: this program is implemented as an ArcGIS Toolbox, and so each individual step is, in ArcGIS terminology, a tool. For our purposes, these ten steps will be referred to as steps or functions, to avoid confusion between the EVAAL toolset, ArcToolboxes, and tools.

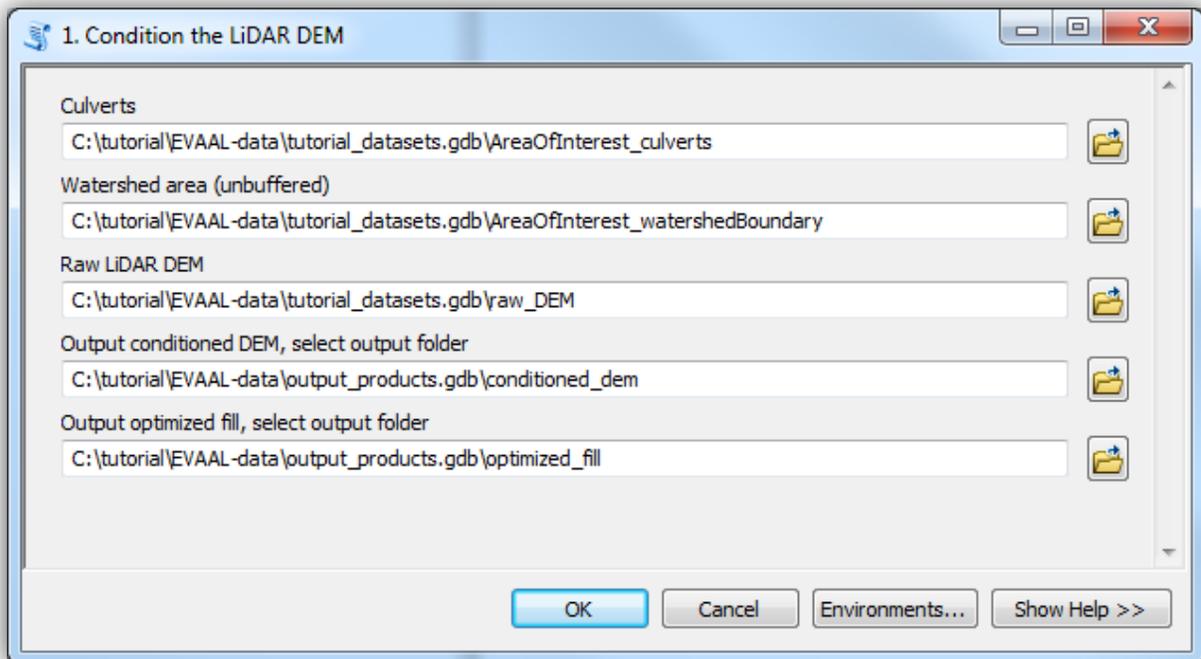
6.0 RUNNING EVAAL

To conceptualize the workflow for EVAAL, it is helpful to group the functions within the EVAAL toolset, therefore these functions have been given numbers and letters to group them according to their purpose. Note that if the user is running the functions from ArcMap 10.1 the output files WILL NOT be automatically added to your map document (this is an unfortunate ArcGIS bug). As a result, if the user would like to view the files created from any step, the user needs to “Add Data...” and open the output files in their ArcMap document. Additionally, users should remember to always specify the output folder for the output files, to avoid confusion and misplaced files. Runtimes given are for the tutorial dataset, a watershed approximately 5.5 square kilometers (2.5 square miles) in area, on a computer with a 64-bit Intel Xeon processor and 6 GB of RAM; running the analyses on larger watersheds or “slower” computers will result in longer runtimes. For the tutorial area of interest, output files are included in the “output_products.gdb” and images of these files are found in [Appendix D](#). If errors are encountered, users are encouraged to consult the [Troubleshooting](#) section of this tutorial.

6.1 Step 1: Condition the LiDAR DEM

Runtime with tutorial dataset: ~8 minutes

This step utilizes the culverts layer that has already been created. Note that for large areas of interest this step will have a long runtime (e.g., for areas nearing 50 square kilometers, expect several hours).



Inputs:

- Culverts – feature class to break digital dams (Polyline feature class)
- Watershed boundary – or boundary for area of interest (Polygon feature class)
- Raw LiDAR DEM – DEM (needs to be larger than area of interest) from which the watershed of interest is being cut (Raster)

Outputs:

- Conditioned DEM – the DEM modified for more accurate drainage assessment (Raster)
- Optimized fill – a DEM which has been modified so all the water drains off the landscape (Raster)

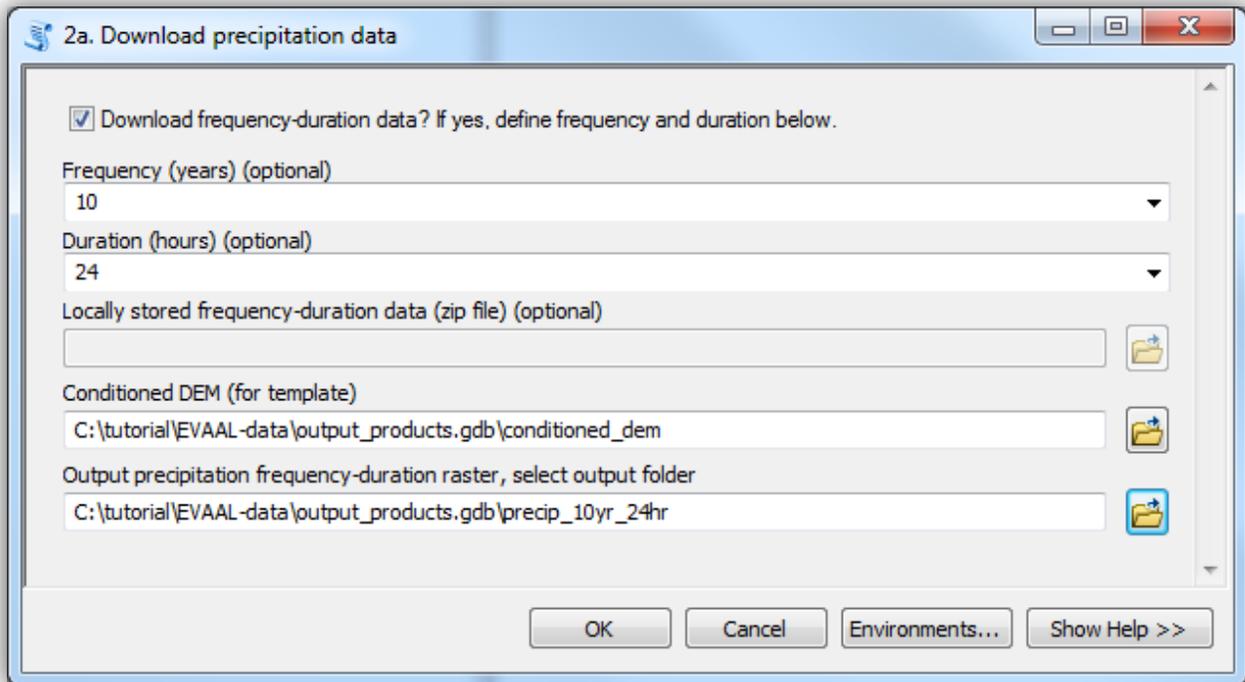
6.2 Identify Internally Drained Areas

These steps assess if an area on the landscape will store water or if the water will run off into a stream or lake. Areas which do not drain to surface waters (i.e., drain internally) are deprioritized in this analysis as they are considered to be hydrologically disconnected from surface waters and therefore do not directly contribute to surface water quality issues.

6.2.1 Step 2a: Download Precipitation Data

Runtime with tutorial dataset: ~ 30 seconds

The frequency-duration precipitation data is used to assess which areas will drain to surface waters and which areas will not, given a user-defined rainfall event. The larger the storm (the less frequent and the longer duration) selected, the fewer areas that will be considered as disconnected to surface waters and not contributing to runoff.



Inputs:

- Desired frequency and duration to use in analysis (a 10-yr, 24-hr storm is recommended, but the user can change as desired)

OR

- Zip file of locally stored precipitation data (use check box at top to toggle this option). For instructions on how to acquire this data, see [Appendix B](#).
- Conditioned DEM from **Step 1** for use as a template

Outputs:

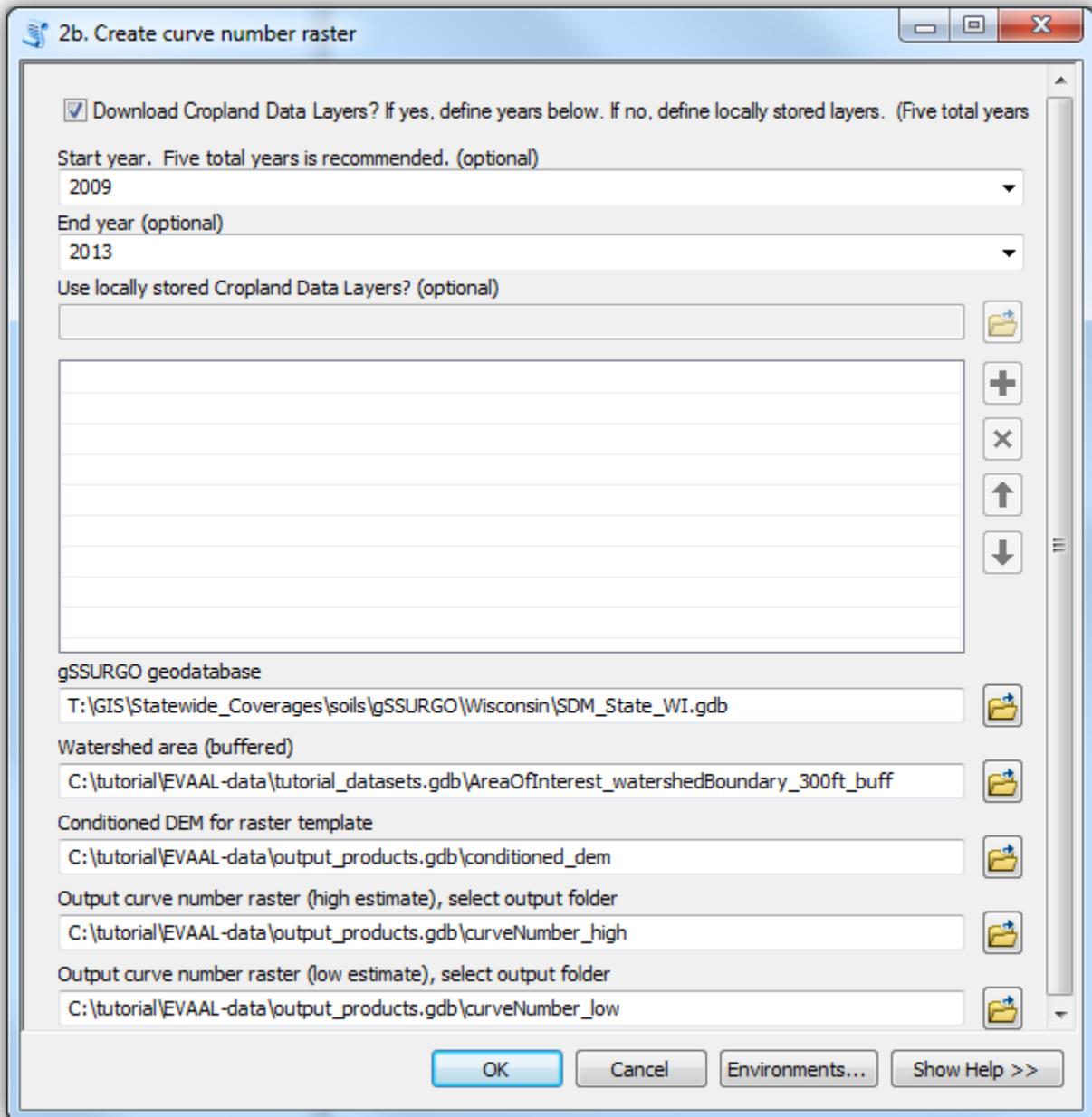
- The frequency-duration precipitation layer (Raster)

6.2.2 Step 2b: Create Curve Number Raster

Runtime with tutorial dataset: ~ 3 minutes

The curve number method is a way of estimating the amount of runoff. This estimate considers land use, land cover and the hydrologic soil group, which is based on infiltration rate. It also depends on factors such as type and amount of tillage, and amount of year-round residue/crop cover. Such factors are difficult to assess without direct observation, and so the function outputs both a high estimate of the runoff potential (high curve number) and a low estimate of runoff potential (low curve number). It is left to the user to decide whether to assume that management in their area of interest is generally

facilitating infiltration (low curve number) or if management is hindering infiltration (high curve number).



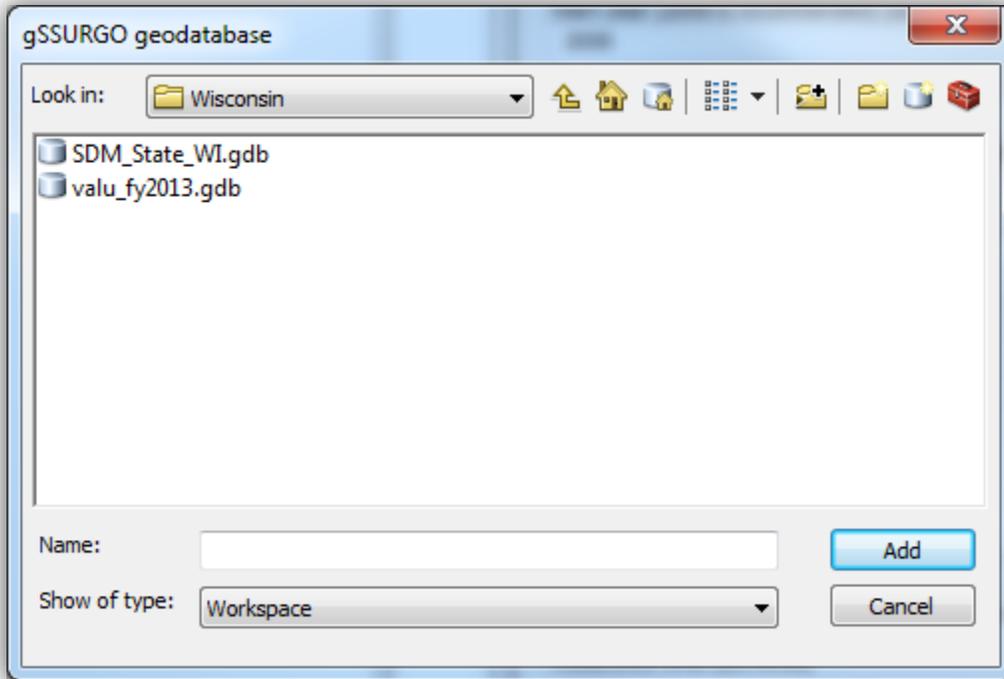
Inputs:

- Starting and ending years for cropland layers to download (recommended to use at least five years)
- OR**
- Location of local cropland layers (use check box at top to toggle this option)
- Location of gSSURGO database, select just the geodatabase file, not specific tables or files within. For instructions on how to acquire this data, see [Appendix B](#).
- Buffered watershed boundary (Polygon Feature Class)

- Conditioned DEM from **Step 1** for use as a template

Outputs:

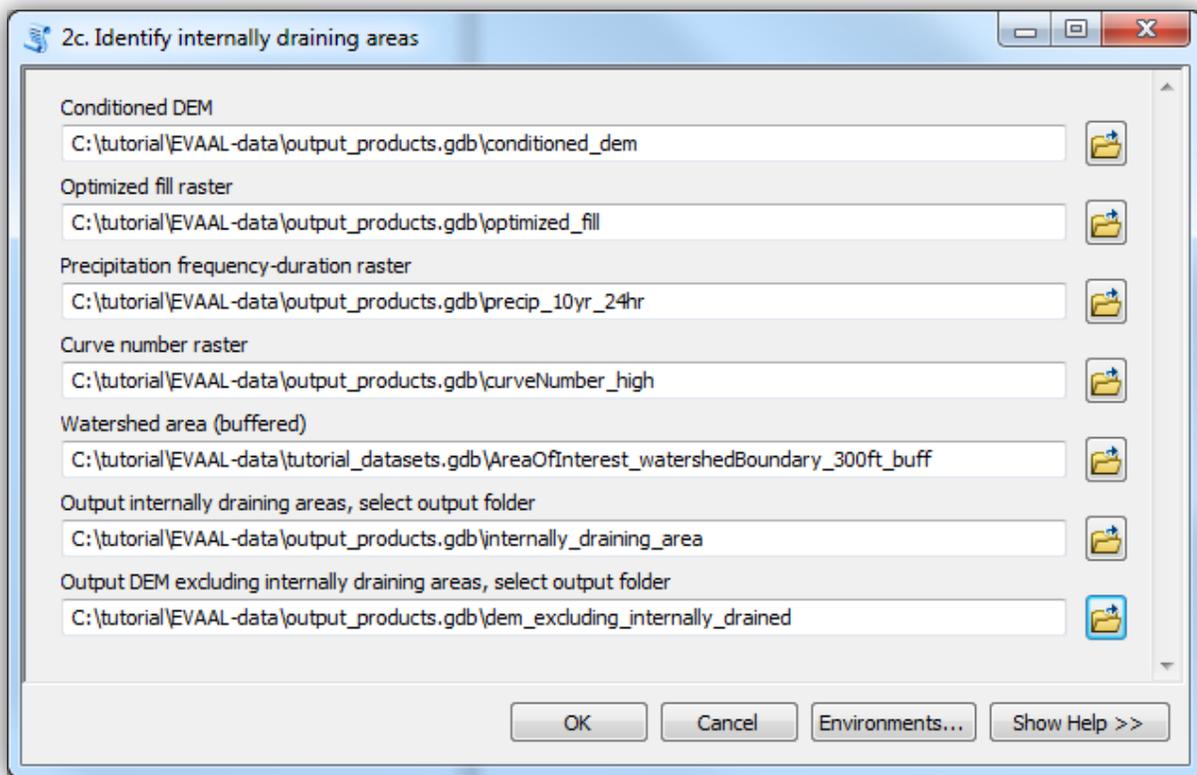
- Output curve number raster, high estimate (Raster)
 - Assuming management practices that increase runoff
- Output curve number raster, low estimate (Raster)
 - Assuming management practices that reduce runoff



6.2.3 Step 2c. Identify internally draining areas

Runtime using tutorial dataset: ~3 minutes

This function utilizes the output from the previous steps to identify those areas that are disconnected to surface waters and do not contribute to runoff, given a certain storm event. Note that this tool must be run twice if the user wants to use both curve number estimates in later steps. If no internally draining areas are found in the area of interest, this function will return a message saying so. It will produce a file for the internally draining areas and a DEM excluding internally draining areas, but the former will be null and blank and the latter will be identical to the conditioned DEM. Because the following step expects these output files, input them in Step 3, as if there were internally drained areas.



Inputs:

- Conditioned DEM, from **Step 1**
- Optimized fill raster, from **Step 1**
- Precipitation frequency-duration, from **Step 2a**
- Curve number raster (either high or low; in this example practices that increase runoff are assumed and the high curve number is used), from **Step 2b**
- Buffered watershed boundary (Polygon Feature Class)

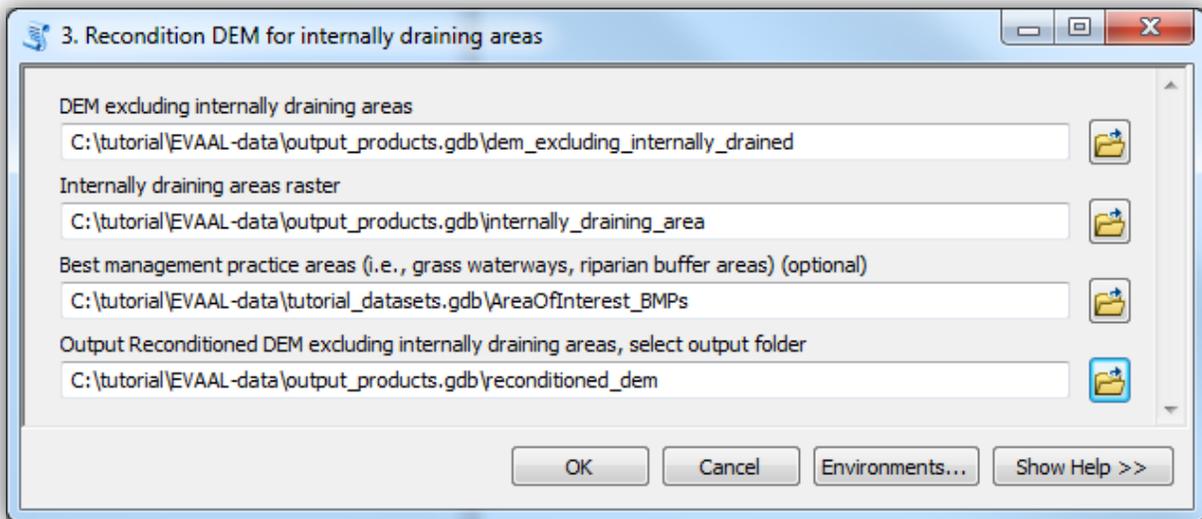
Outputs:

- Internally draining areas, shows those areas of the landscape found not to be connected to surface waters (Raster)
- DEM excluding internally draining areas, a modified DEM with non-contributing areas removed (Raster)

6.3 Step 3: Recondition DEM for internally draining areas

Runtime with tutorial dataset: ~30 seconds

This step produces a reconditioned DEM that accounts for areas that do not contribute to runoff. This is similar to what was produced in Step 1, but it now has the non-contributing areas removed from the DEM.



Inputs:

- DEM excluding internally draining areas, from **Step 2c**
- Internally draining areas raster, from **Step 2c**
- BMPs if available or desired (Raster). In this example, three areas of known BMPs, representing grassed waterways, are used. For instructions on how to create this dataset, please refer to [Appendix C](#)

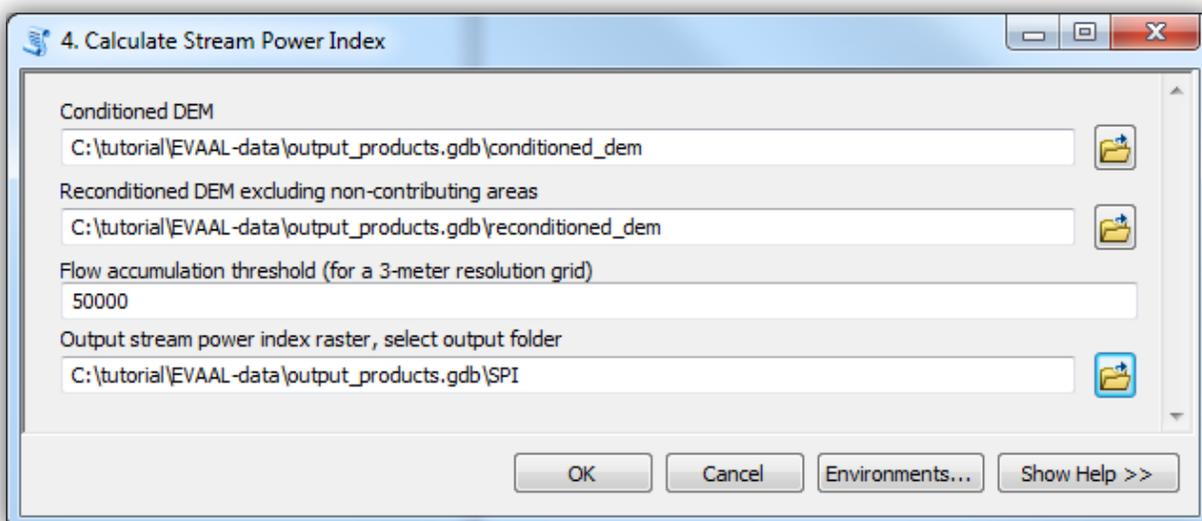
Outputs:

- Reconditioned DEM, excluding those areas that are internally drained (Raster)

6.4 Step 4: Calculate Stream Power Index

Runtime with tutorial dataset: ~20 seconds

The stream power index is used to estimate areas that are susceptible to gully erosion.



Inputs:

- Conditioned DEM, from **Step 1**
- Reconditioned DEM, excluding non-contributing areas, from **Step 3**
- Flow Accumulation Threshold, the default value of 50000 is recommended, though the capability is provided for advanced users interested in altering the flow accumulation threshold. Raising this value will include longer flow paths, potentially modeling streamflow as opposed to overland flow. Alternatively, lowering this value will shorten flow paths.

Outputs:

- Stream power index (Raster)

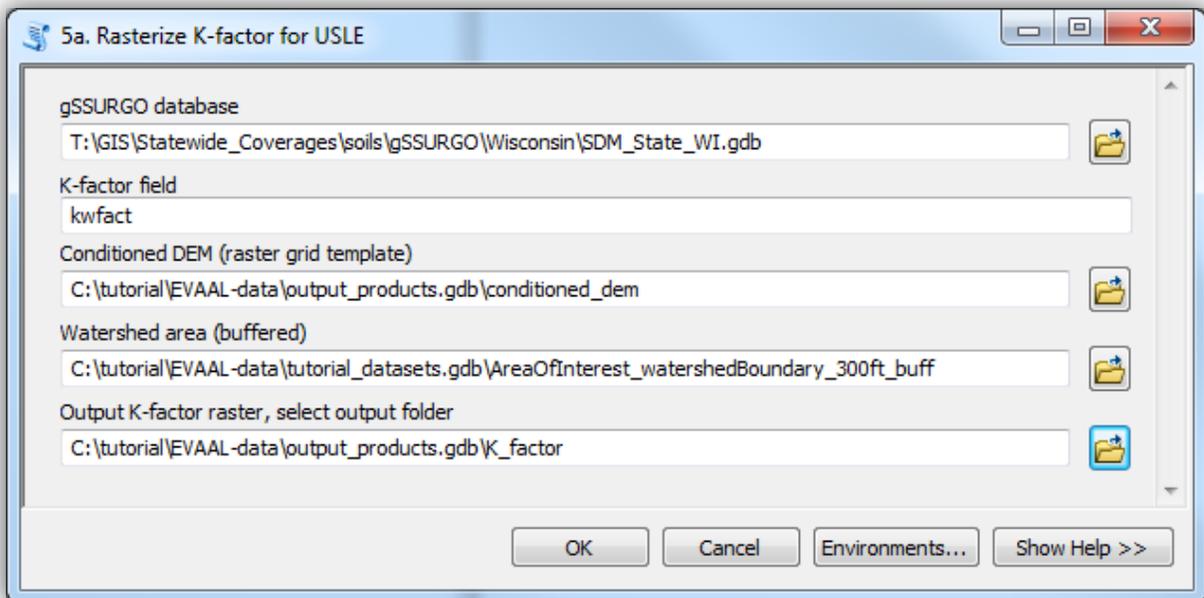
6.5 Step 5: Estimating Sheet and Rill Erosion

The Universal Soil Loss Equation (USLE) is used to estimate soil loss potential from sheet and rill erosion. The version of the USLE in this tool calculates an index of soil loss using rainfall erosivity, soil erodibility, slope/slope-length, and a land cover factor (see Methodology document for additional details). The results of the USLE analysis should be used relatively instead of quantitatively.

6.5.1 Step 5a: Rasterize K-factor for USLE

Runtime with tutorial dataset: ~2 minutes

The K factor is easily estimated for the area of interest by referencing the gSSURGO database.



Inputs:

- Location of gSSURGO database, as in **Step 2b**, select just the geodatabase file, not specific tables or files within
- K factor field, leave this as 'kwfact', unless you know that the title of this field in the gSSURGO table has been modified

- Conditioned DEM, from **Step 1**
- Buffered watershed boundary (Polygon Feature Class)

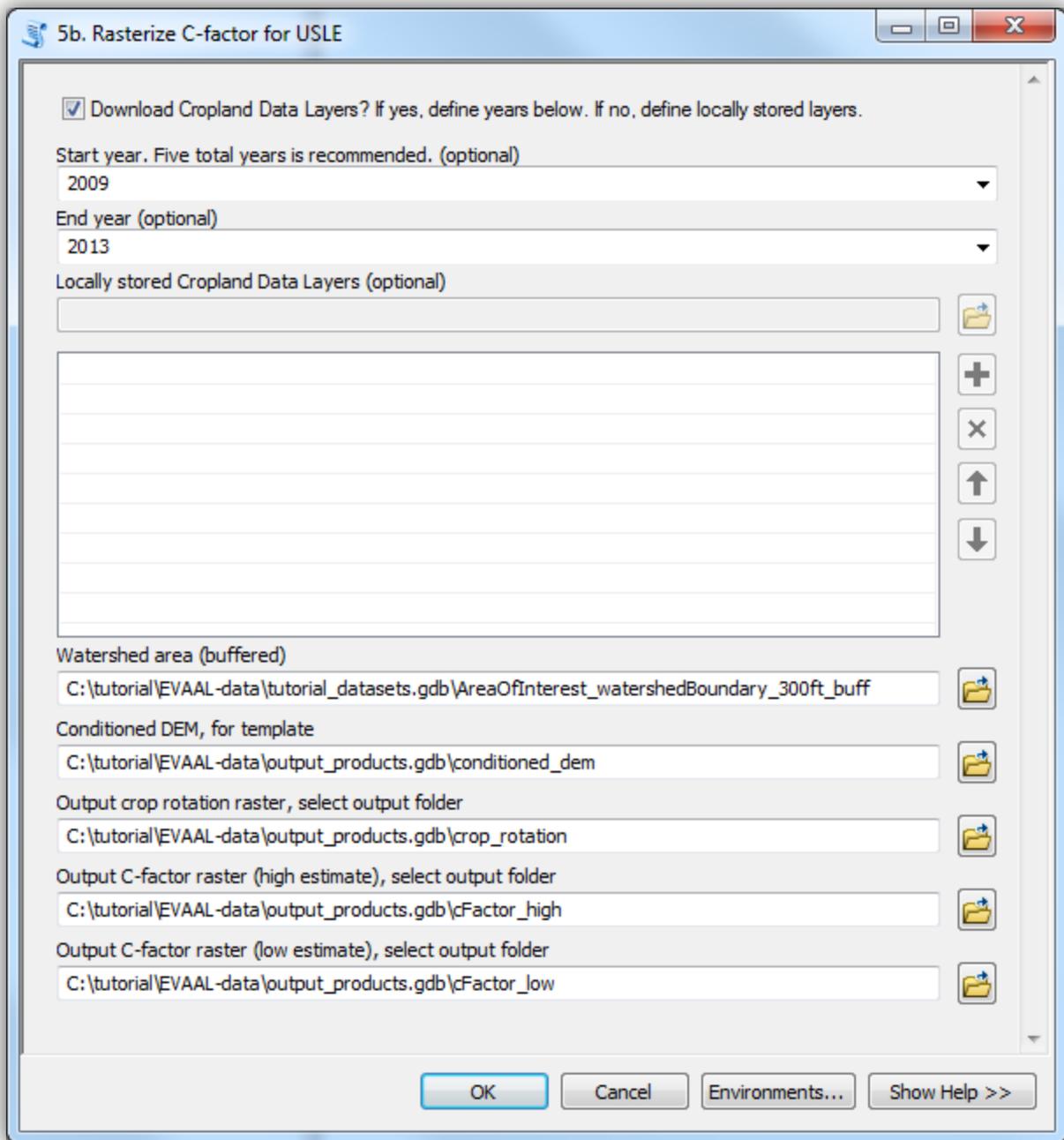
Outputs:

- K factor showing the erodibility of the soils in the area of interest (Raster). Note that there are a few locations in Wisconsin where soils were not surveyed—the toolbox does not attempt to evaluate erosion vulnerability in these areas.

6.5.2 Step 5b. Rasterize C-factor for USLE

Runtime with tutorial dataset: ~1 minute

The Cropland Data Layer (CDL) is used to estimate the C factor by calculating a probable crop rotation scenario. As there are potentially many variations in tillage and cropping, the specifics of management cannot be estimated without direct observation. As with the curve number, high and low C factors are calculated assuming management practices that might enhance runoff and management practices that might reduce runoff, respectively.



Inputs:

- Years for cropland layers to download (recommended to use five years)
- OR**
- Location of local cropland layers (Rasters), in this example, using local CDL files that have been previously downloaded are used (these are found in the “tutorial_datasets.gdb” file geodatabase in the EVAAL-data folder)
- Buffered watershed boundary (Polygon Feature Class)
- Conditioned DEM, from **Step 1**

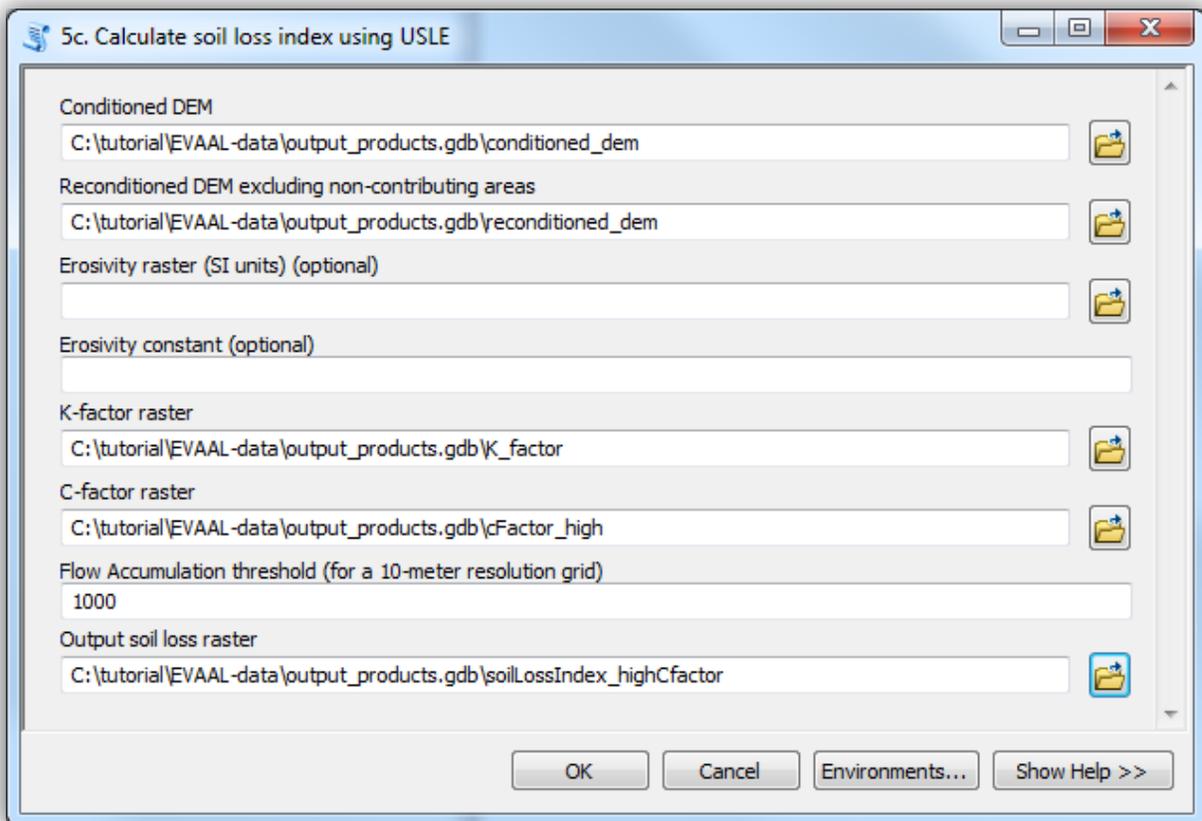
Outputs:

- Crop rotation (Raster) map showing the estimated crop rotation, created from cropland data layers (rotation descriptions are included in attribute table; to symbolize this layer see [Appendix C](#))
- C factor, high estimate, assuming practices contributing to erosion (Raster)
- C factor, low estimate, assuming conservation practices (Raster)

6.5.3 Step 5c. Calculate soil loss using USLE

Runtime with tutorial dataset: ~20 sec

When running the USLE, it is possible to define the rainfall erosivity factor. Erosivity is generally understood to vary at coarse spatial scales, and so by default is assumed not to vary in the study area. However, if it is known to vary within the watershed, the option is available to input an erosivity raster or a user-specified constant. Note that to calculate the soil loss with both the high C and low C factor estimates, it is necessary to run this tool twice.



Inputs:

- Conditioned DEM, from **Step 1**
- Reconditioned DEM, from **Step 3**
- Optional erosivity values
 - A raster map of rainfall erosivity
 - OR**
 - An erosivity constant

- K-factor, from **Step 5a**
- C-factor, from **Step 5b**, either high or low. In this example management is assumed to be contributing to or at least not mitigating erosion, and so a high C factor is used.
- Flow Accumulation Threshold, the default value of 1000 is recommended, though the capability is provided for advanced users interested in altering the flow accumulation threshold. As in **Step 6.4**, raising this value will include longer flow paths, potentially modeling gully or even stream erosion as opposed to overland sheet and rill erosion. Alternatively, lowering this value will shorten flow paths.

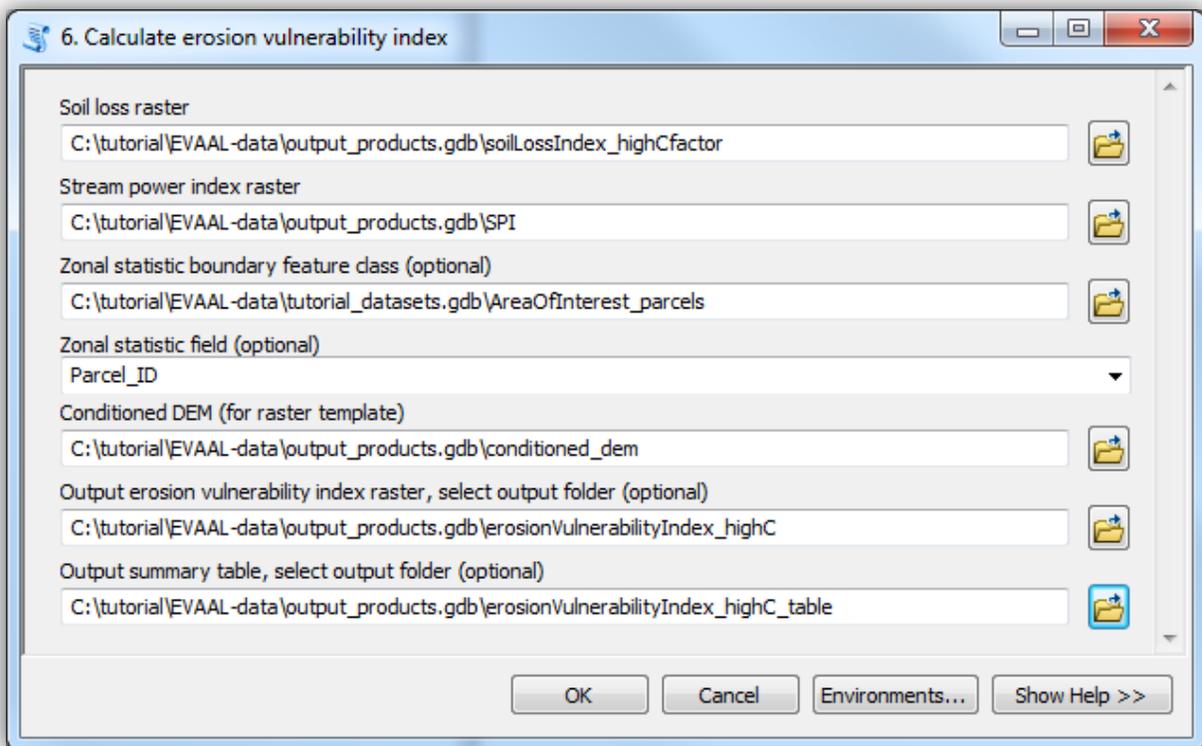
Outputs:

- Soil loss index map (Raster)

6.6 Step 6. Calculate Erosion Vulnerability Index

Runtime with tutorial dataset: ~20 seconds

The final step is to combine the susceptibility to gully erosion with the susceptibility to sheet and rill erosion to produce the erosion index.



Inputs:

- Soil loss index raster, from **Step 5c**
- Stream power index, from **Step 4**
- Optional zonal boundary layer (Polygon Feature Class), such as CLU, tract, field or tax parcel layers. This boundary layer is used to create a summary table of the erosion index, with each record being a feature within the boundary layer. This

example uses a parcel boundary layer for the area, which contains fake data on the tax parcels of the properties.

- Optional zonal statistic field which is the column name, by which the erosion index should be summarized, defaults to each individual polygon in the layer. This example summarizes the erosion index for each parcel within the area of interest therefore “Parcel_ID” (the name of the column within the layer) is entered.
- Conditioned DEM, from **Step 1**

Outputs:

- The erosion index map (Raster), this map shows the locations that are most susceptible to sheet, rill, and gully erosion. Note that this is an optional output. If the user is interested only in producing a tabular output do not enter a name here and no file will be produced.
- Table showing summary statistics of the erosion vulnerability index, grouped by the input boundaries. This allows for identifying those fields or landowners that are potentially the most susceptible to erosion. (See [Appendix C](#) for displaying this in a map.)

OBJECTID*	PARCEL_ID	ZONE_CODE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	1	1	33414	300726	-1.79847	13.24726	15.04572	0.517054	2.179365	17276.84
2	10	2	50540	454860	-1.79847	11.59767	13.39614	0.243714	1.602026	12317.31
3	2	3	70489	634401	-1.79847	13.48691	15.28538	-0.192884	1.761061	-13596.17
4	3	4	76955	692595	-1.79847	12.39436	14.19283	0.201797	1.792314	15529.3
5	4	5	36875	331875	-1.79847	10.1166	11.91507	0.256754	1.678992	9467.787
6	5	6	5461	49149	-1.669627	6.681793	8.35142	0.22225	1.358734	1213.705
7	6	7	44978	404802	-1.79847	8.605974	10.40444	-0.566001	1.378529	-25457.59
8	7	8	141354	127218	-1.79847	11.20028	12.99875	0.297285	1.63438	42022.44
9	8	9	135316	121784	-1.79847	11.42358	13.22206	-0.255574	1.447784	-34583.3
10	9	10	20225	182025	-1.79847	8.569066	10.36754	-0.65133	1.157667	-13173.14

7.0 OUTPUT OPTIONS

EVAAL allows for different purposes and scenarios to be produced and explored.

7.1 Modifying the Frequency-Duration of Precipitation Input

The frequency-duration precipitation data is used to assess locations that drain to surface waters and locations that do not have outflows and drain water internally. By increasing the frequency and duration of the storm input, for example from the default 10-year 24-hour storm to 100- or 500-year storm, the amount of area that drains internally decreases as the simulated runoff overflows more of the depressions. A stronger storm creates fewer internally drained areas, increasing the area included in calculating the erosion index.

7.2 Creating Different Management Scenarios

The curve number is an estimate of the runoff potential for a certain soil given a certain land cover. It is based on the hydrologic soil group as well as management factors such as cover type and tillage. Similarly, the C factor in the USLE is derived from the amount of canopy, surface cover, surface roughness, and prior land use. Both the C factor and curve number need field-specific information to know how management factors impact their values. For each of these, best- and-worst case scenarios are assumed, creating high and low curve number and C factor output raster layers. It is left to the user whether the soil erosion vulnerability index should be a worst- or best-case scenario. Or the user can run the index twice, once for best-case and once for worst-case, then look at the difference between the two outcomes; those areas with the greatest difference show areas where there would be the greatest erosion reduction if going from poor to good management practices.

8.0 TROUBLESHOOTING

EVAAL has been run, checked, and tested to catch and fix any potential errors in the underlying code. There are still errors that can happen and below is a list of common and potential problems and solutions.

Possible Issue 1: File open in another program

Message	“WindowError: [Error 32] The process cannot access the file because it is being used by another process: <filename>”
Problem	The script cannot delete a file in the scratch geodatabase. This could be because the scratch database is open or because of another issue with ArcMap or ArcCatalog.
Possible Solution	Close ArcMap and/or ArcCatalog and try running the program again.

Possible Issue 2: Too many characters in name

Message	“Could not save raster dataset to <filepath> with output format GRID” or “Name of single band grid cannot have more than 13 characters”
Problem	ArcGIS cannot save the file as a GRID format to a normal folder if the file has too many characters in the name.
Possible Solution	Save the file to a file geodatabase or if you would like to output the file to a location outside a geodatabase, reduce the number of characters or save the file as a TIFF (with a .tif extension).

Possible Issue 3: ArcCatalog won't open at all or won't open the EVAAL Toolset folder and crashes

Message	A window will open with the heading “ArcGIS Desktop has encountered a serious application error and is unable to continue”
Problem	There is a bug with the Python toolbox on which EVAAL runs.
Possible Solution	The best solution seems to be to delete a results file that ArcGIS automatically creates. Navigate to C:\Users\<user>\AppData\Roaming\ESRI\Desktop10.x\ArcToolbox (where you replace the <user> with your local username) and then delete the “ArcToolbox.dat” file. Note that the AppData folder is a hidden folder, and to find it is necessary to make all hidden folders visible or to type the above path directly into Windows Explorer.

Possible Issue 4: Compact cannot execute

Message	“ExecuteError: Failed to execute. Parameters are not valid. Error 000188: Only supported by personal geodatabases Failed to execute (Compact)”
Problem	Issue with deleting or cleaning the scratch geodatabase.
Possible Solution	Go into the EVAAL folder, and then into the ‘Scratch’ folder and delete scratch.gdb

Possible Issue 5: There are lines of NoData on the Erosion Vulnerability Index output

Message	No error message because the tool runs to completion
Problem	There are some areas of the zonal statistics boundary layer that do not have data and so the NoData values get transferred to the output.
Possible Solution	Rerun the tool without any zonal statistics layer.

Possible Issue 6: Where is the output?

Message	No error message because the tool runs to completion
Problem	The output maps are not automatically added to the map document or the output file is not in the expected folder.
Possible Solution	1. Add the the output manually to the map document 2. If you cannot find the output, check to make sure that you specified the file path to your output geodatabase. Its possible the file is in your scratch geodatabase within the scratch folder of the EVAAL folder or maybe your default geodatabase.

Possible Issue 7: Error in reading/writing data

Message	“ExecuteError: ERROR 999999: Error executing function. Workspace or data source is read only.”
Problem	Some functions run multiple procedures and cannot access local files.
Possible Solution	1. Delete the scratch geodatabase in the “Scratch” folder within the EVAAL code folder and restart the session. 2. Use ArcCatalog to avoid schema lock issues. 3. If error persists, see Issue 3, and delete the ArcToolbox.dat file.

9.0 TECHNICAL SUPPORT

Technical issues can be sent to dnrwaterqualitymodeling@wisconsin.gov and will be responded to by one of the Wisconsin Department of Natural Resources Modeling Technical Team staff.

Updated versions of EVAAL, user’s manual, and documentation can be retrieved from the DNR Water Quality Modeling Team’s [GitHub](#).

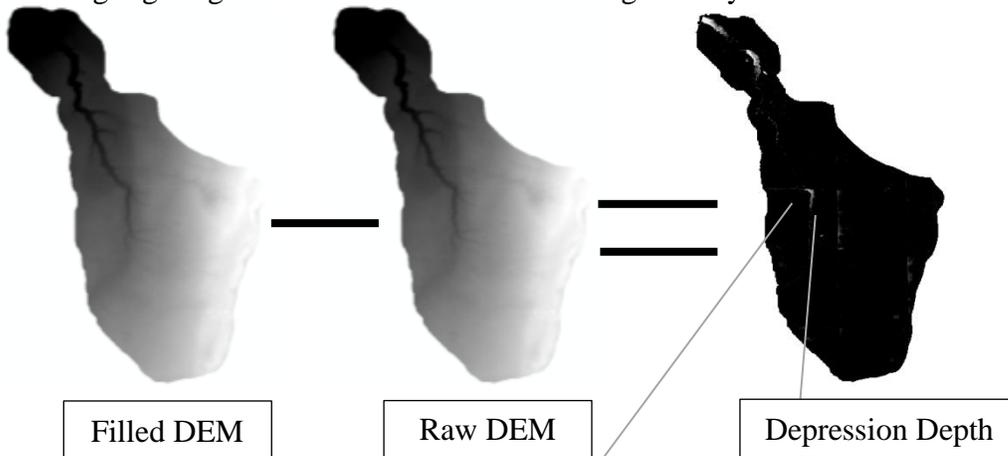
Links to the model files, documentation, and tutorial data can be found on the WDNRs website: <http://dnr.wi.gov/topic/Nonpoint/EVAAL.html>.

10.0 APPENDICES

Appendix A Creating Culverts Layer

The high resolution of the LiDAR DEM shows roads and highways in high relief. When modeling water flow over the landscape, this creates “digital dams” that artificially impound the water. In reality there are usually culverts or bridges that are allowing water to flow through road berms and other barriers. To rectify this, it is necessary to create a layer of ‘culverts’ so that water can flow unimpeded. To create this layer, follow these steps:

1. Create a “filled” DEM using the Fill tool in ArcGIS Spatial Analyst “Hydrology” toolbox. This creates a map where all internally draining areas have been ‘filled up’ (elevation increased) so that all the water flows off of the map. Then subtract the original DEM from the filled raster using the Spatial Analyst ‘Map Algebra’ “Raster Calculator” (Fill – Dem). This results in a raster of the depression depths, highlighting those areas that are not draining directly to streams.

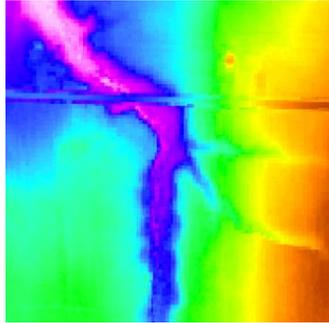


2. Deep depressions near road berms are places where a culvert is probably located. Locate one of these depressions using the depression depth raster, just created, and zoom to it.

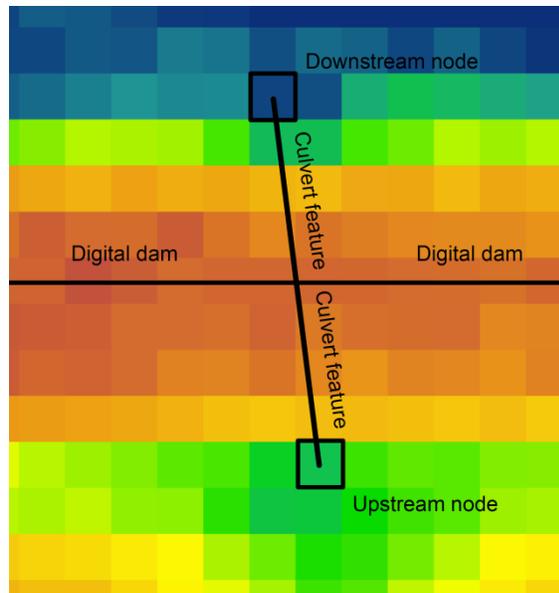


3. To visualize digital dams, open the “Symbology” tab in the original DEM’s “Property” tab (found by right-clicking the layer in the table of contents). Choose the

“Stretched” option using “From Current Display Extent” with the Statistics box, and choose a color gradient that spans multiple hues (e.g., a rainbow color scheme).



4. Create an empty line feature class. To do this, open the ArcCatalog window, and right-click a geodatabase in which you would like the culverts layer. Select ‘New’ and select ‘Feature Class.’ Type the name of the culverts layer, and make sure to select the “**Line**” type of feature. You may be prompted to select the coordinate reference system for this layer, you can navigate to the “NAD_1983_HARN_Transverse_Mercator” projection or you can copy and paste this into the search bar and select this projection under the “Layers” tab. Select the defaults for the remainder of the pages.
5. Start an editing session with this new feature. Right-click the new feature, and select “Edit Features” and select “Start Editing.” The “Create Features” panel should open on the side of ArcMap. If it does not, move to the editor tool bar and select the pencil over the pad icon. Select the name of the layer that you have just created, and make sure that the ‘Line’ function is highlighted in the “Construction Tools” window.
6. Each culvert should have only two nodes. **The nodes must be drawn in order from upstream to downstream, across the digital dam.** Use the depression depth raster created in Step 1 to navigate to impounded areas. Then switch to the original DEM to identify the side of higher elevation and lay down the first node of the culvert. Then click to lay down the downstream end of the culvert. After these two clicks, right click and select “Finish Sketch” or just push F2 on your keyboard. It can be difficult to be certain which locations are actually higher in elevation than those in the downstream area, so it can be very helpful to use the “Identify” tool on the toolbar () to extract pixel elevations. While editing, save often by selecting the “Editor” on the Editor Toolbar and select “Save Edits.”



7. Repeat this process until all digital dams have culverts spanning them. Then select the “Editor” on the Editor Toolbar and select “Save Edits” and then “Stop Editing.” The culverts layer has been completed.

Appendix B Data Acquisition

Refer to the following steps if you require any of the input data.

B1 LiDAR DEMs

To find LiDAR DEMs go the [WisconsinView](#) website. Here, LiDAR DEMs are available in county wide downloads for certain counties. They are large files and so may take some time to download. It is not necessary to clip the LiDAR DEM to the area of interest; the script will do this automatically.

B2 gSSURGO Database

The gridded Soil Survey Geographic Database can be found on the [USDA - NRCS Geospatial Data Gateway](#) website. On the menu on the right-hand side, select “Order by State” and then select Wisconsin. Scroll down to the “Soils” section and check the box next to “Gridded Soil Survey Geographic (gSSURGO) by State” box. Then select the green “Continue” button at the bottom of the screen. Select continue again, and then enter your contact information and the email you wish the download notification to be sent. After this page, verify the info is correct and select “Place Order”. Within several minutes you will receive an email message with a link to an FTP download. Click this and the gSSURGO dataset will begin downloading (this is a large file and so may take some time). Once it is done, unzip it to a folder of your choice – you may want to put it in the same folder as your other input datasets. You need only navigate here to find the geodatabase that the EVAAL function requires to complete its analysis.

B3 Cropland Data Layers

The CDL can be automatically downloaded by EVAAL. If you would like to see these files for a larger area, you can find them at the [USDA - NRCS Geospatial Data Gateway](#) website (where the gSSURGO database was found). At the homepage, you will need to select the area in which you are interested (state, county, or a custom bounding box) and then navigate to the “Land Use Land Cover” section and select the “Cropland Data Layer.” All other steps are the same as for the gSSURGO Database.

B4 Precipitation

As with the CDL, the precipitation data of storm frequency-duration can be downloaded by EVAAL. If you are interested in downloading this data manually, they are available from the Nation Weather Service website. The specific page to obtain the files can be found at this website <ftp://hdsc.nws.noaa.gov/pub/hdsc/data/mw/>. This page is not the most user-friendly and care should be taken to download the correct files. It is recommended to search the page to find the proper file. Press ‘ctrl + f’ to bring up the search/find box and search for ‘mw’ + the desired frequency + ‘yr’ + desired duration + ‘ha.zip’ (i.e., for 100-year, 6-hour, search ‘mw100yr06ha.zip’) and you’ll find the correct file to download. Once this has downloaded, unzip it to a folder of your choice and navigate to this file when prompted in Step 2a.

B5 Watershed boundaries

As stated earlier, it is recommended to run EVAAL using a watershed boundary as the area of interest. Furthermore, it is recommended to use a watershed that is smaller than 75 sq. km., a larger area than this could take an excessive amount of time. For this reason, a HUC 12 (75 sq. km. or 30 sq. mi.) watershed boundary or smaller is recommended. Official HUC watersheds are available for download from the [USDA - NRCS Geospatial Data Gateway](#) website, just as the gSSURGO and CDL, and are found in the “Hydrologic Units” section, after the area of interest has been specified. To create a custom watershed boundary, the watershed tool within ArcGIS can be used (see the online help pages <http://resources.arcgis.com/en/help/main/10.1/index.html#/Watershed/009z00000059000000/>).

Appendix C ArcGIS Tasks

Several GIS tasks are referenced in this document that are not fully explained. This section is meant to help as a reference to perform these ancillary tasks but is not meant to be a full guide.

C1 Creating a geodatabase

EVAAL has been designed and tested to use files that are formatted in an ESRI file geodatabase. It is also recommended to output files to a file geodatabase. To create a geodatabase, use ArcCatalog (either stand alone, or within ArcMap) and navigate to the folder in which you want to place the file geodatabase. Right-click on the folder and select “New” and scroll down to “File Geodatabase” and then name the file as you choose.

C2 *Buffering a polygon*

Several steps in the EVAAL toolset ask for the watershed boundary file in a buffered form. This is because certain processes may be changed by edge effects. To create a buffered watershed file, select the “Geoprocessing” tab at the top of ArcMap and scroll down to “Buffer.” Input your watershed (or other area of interest boundary) and select the output location and name of the output file (preferably a file geodatabase). You are then asked to enter the distance of the buffer, it is recommended that this be 300 feet, to correspond with some of the functions in EVAAL, the default values for the other options are sufficient. Select “OK” and a feature class of your area of interest, enlarged 300 feet (or what was specified) is created.

C3 *Creating a BMP raster layer*

Step 3 has an optional input for a best management practices raster layer. The purpose of this layer is to deprioritize from the final erosion index those areas where best management practices are in place. Examples of these areas include grassed waterways and riparian buffers. To create this layer, it will be necessary to have satellite imagery, such as that from the National Agriculture Imagery Program, so that the BMPs can be traced and digitized.

In ArcCatalog, either stand-alone or from within ArcMap, right-click on the file geodatabase in which you would like the BMP layer added, select ‘New’, then select ‘Feature Class...’ In this menu that pops up, select “Polygon Features” as the feature type, and name the file appropriately. You may be prompted to select the coordinate reference system for this layer, you can navigate to the “NAD_1983_HARN_Transverse_Mercator” or you can copy and paste this into the search bar and select this projection under the “Layers” tab. Select the defaults for the remainder of the pages.

Your new file should be added to ArcMap, if not, add it. You will not see anything as there is currently nothing in it. Right-click on the file name in the table of contents and select “Edit Features” and “Start Editing.” If the “Create Features” menu does not open automatically, add the “Editor” toolbar, and select the “Create Features” menu from this toolbar. Click on the name of the BMP layer and then down in the “Construction Tools” menu, select “Freehand.” With this tool, trace over the BMP features in the area of interest. Click once to begin tracing, and then move the mouse over the outline of the grassed waterways and click again when finished, this will complete the polygon. If the outcome is not satisfactory, select the undo button (or push ‘ctrl’ + ‘z’) to remove it, or just delete the polygon, and then start again. Repeat this procedure for all the desired BMPs in the area of interest. Once finished, select “Editor” and from the dropdown menu, select “Save Edits” and then “Stop Editing.”

Next, open the ArcToolbox title “Conversion Tools”, select “To Raster” and open up “Polygon to Raster.” Select the just created BMP polygon feature for the input, and use the default for “Value Field” and input the directory and filename of the output. Assuming the map document in which this work is being done is in Universal Transverse Mercator projection, in “Cellsize” and input 3, or whatever the cellsize of your LiDAR

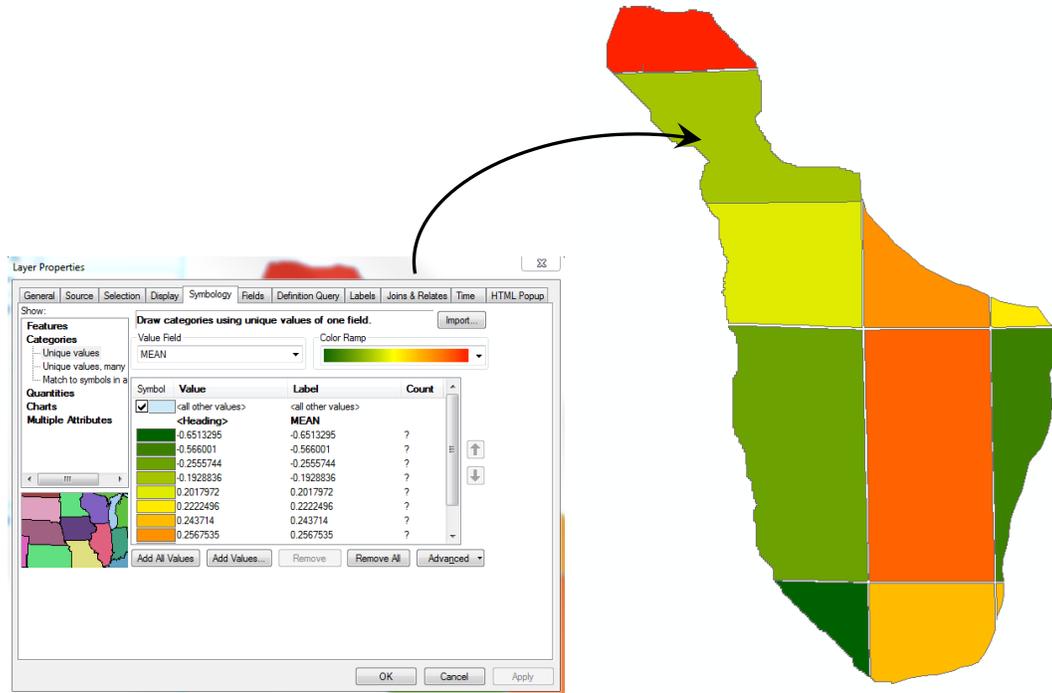
DEM. (If it is not in this projection, it is recommended that the user changes the projection to this.) Select “OK” and create a raster file of BMPs which can now be used in Step 3.

C4 *Symbolizing the crop rotation layer*

A crop rotation layer is produced in Step 5b. This was produced using certain assumptions and several years of the Cropland Data Layers. In order to interpret and verify this layer’s accuracy, it is necessary to symbolize the layer and add a label to each crop rotation code. The best way to do this is to use the symbology from the raster layer distributed with the EVAAL package. Add the crop rotation file to the map document, right-click the file name in the table of contents, and select ‘Properties.’ Select the “Symbology” tab, and make sure that “Unique Values” is selected on the left-hand side. In the upper right-hand corner select the folder icon, and again select the folder icon to browse to the EVAAL file that was downloaded from GitHub, and open it, open the “etc” folder, and select the “rotationSymbology.lyr.” This will add the rotation label to the code, and symbolize the layer a certain way.

C5 *Joining an erosion vulnerability index table to a polygon layer*

The option of using a zonal statistics boundary layer is provided in Step 6. This allows for the erosion index to be aggregated or summarized by certain boundary units, such as fields, tracts or parcels. The output is a table, where each feature within the boundary layer has summary statistics of the erosion index calculated. In this way, it is possible to find the tract with the highest mean erosion index, or the highest maximum erosion index by examining the table. Using this table, you can create a map of the erosion index summarized by each boundary unit. This will provide cartographical display of fields or landowners that are potentially more susceptible to erosion, rather than finding which specific locations are more susceptible. To create this map, add the boundary file that you used in Step 6 (for this tutorial that is the made-up zone boundary file for the tutorial area) to your map document, and right-click on it in the table of contents. Select “Join and Relates” and in the first box select the column by which you summarized the vulnerability index, for this tutorial it would be “Parcel_ID” and make sure the proper erosion vulnerability index table output is selected in the middle box and then select “PARCEL_ID” in the bottom box and hit “OK.” You have now joined the information that has been summarized for each feature class to the feature class itself. By going into that layer’s symbology and selecting ‘Categories’ or ‘Quantities’ you can then select the summary statistic of your choice (e.g., mean or maximum) in order symbolize each boundary by its erosion index. Here we’ve symbolized by the mean erosion index for each parcel.



These images show the parcels, symbolized by which have the greatest mean erosion index (red being the highest, green being the lowest).

C6 *Manually aggregating by zonal boundary layer*

EVAAL allows for the automatic aggregation of the erosion vulnerability index by a zonal boundary layer, from which easy to read maps can be created. Aggregating the stream power index or the USLE soil loss index raster by the same zonal boundary layer must be done manually.

From ArcMap or ArcCatalog, navigate to the “Spatial Analyst” toolbox, open and select the “Zonal” toolbox open up the “Zonal Statistics as Table” tool. In the menu, in the “Input raster or feature zone data” place enter the zonal boundary layer that is being used to aggregate. For “Zone field” select the criteria that is being used for aggregation. For the “Input value raster” select either the SPI or the USLE soil loss index and then input the title of the table in “Output table”. This will then produce a table that can be joined to the zonal boundary layer, which can then be symbolized as in Appendix C5.

Appendix D **Output Files**

The tutorial files are listed here as a reference so that the user may verify the appearance of their own output as well understand where and how the files are being used in the program.



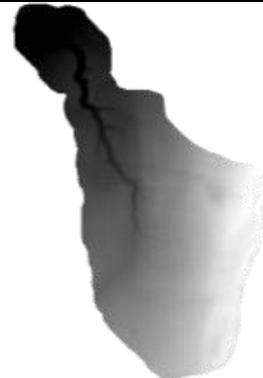
Watershed boundary – polygon feature class, used as input in Steps 1, and as buffered boundary in 2b, 2c, 5a and 5b



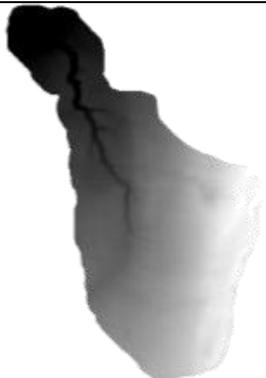
Culverts (shown with watershed boundary for viewing) – lines feature class, used as inputs in Step 1



Raw LiDAR – raster, used as input in Step 1



Conditioned DEM – raster, produced in Step 1, used as input in Steps 2a, 2b, 2c, 4, 5a, 5b, 5c, and 6



Optimized Fill – raster, produced in Step 1, used as input in Steps 2c, 5a,



Frequency-Duration Precipitation – raster, produced in Step 2a, used as input in Step 2c



Curve Number – raster, produced in Step 2b, used as input in Step 2c.



Internally Drained Areas – raster, produced in Step 2c, used as input in Step 3



DEM Excluding Internally Drained Areas – raster, produced in Step 2b, used as input in Step 3



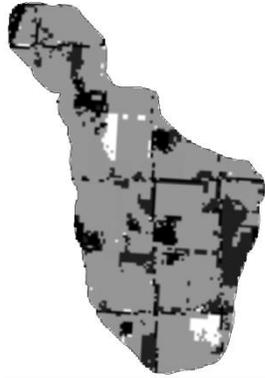
Reconditioned DEM Excluding Internally Drained Areas – raster, produced in Step 3, used as input in Steps 4 and 5c



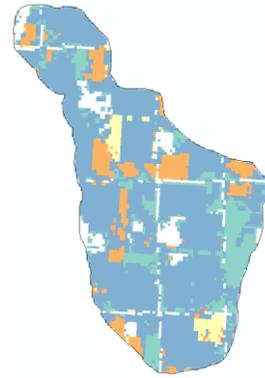
Stream Power Index – raster, produced in Step 4, used as input in Step 6



K-Factor – raster, produced in Step 5a, used in Step 5c



C-Factor – raster, high and low produced in Step 5b, only high or low used as input in Step 5c



Crop Rotation – raster, produced in Step 5b (see Appendix C for symbolizing with above colors)



Soil Loss – raster, produced in Step 5c, used as input in Step 6



Erosion Vulnerability Index – raster, produced in Step 6
