Agricultural Conservation Planning Framework
ArcGIS® Toolbox User's Manual
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ABSTRACT: Agricultural Conservation Planning Framework (ACPF) comprises an approach for applying concepts of precision conservation to watershed planning in agricultural landscapes. To enable application of this approach, USDA/ARS has developed a set of Geographic Information System (GIS) based software tools to identify candidate locations for different types of conservation practices that can be placed within and below fields in order to reduce, trap and treat hydrologic flows, and thereby improve water quality in agricultural watersheds. This manual describes how to apply the ACPF planning tools, with instructions on input data, data maintenance and file management, digital-terrain-model processing, stream delineations, runoff risk assessment, and execution of Python programming scripts that are used to propose conservation-practice placements. Possible locations for surface-intake filters, drainage water management, grassed waterways, contour buffer strips, nutrient removal wetlands, water/sediment control basins, and denitrifying bioreactors are identified and mapped by the ACPF tools. Routines that help the user assess a watershed's riparian corridors and identify appropriate designs and placements of riparian buffers and saturated buffers are also included as part of the ACPF toolbox. This third version features a new landscape discretization routine to delineate riparian catchments and enables the user to include water bodies and wide rivers in the riparian assessment. Results from applying these tools provide an inventory of opportunities for conservation practice placement at the Hydrologic Unit Code (HUC) 12 watershed scale, which is meant to help facilitate the watershed planning process. USDA/ARS has developed ACPF input data bases for land use and soils for >8,000 HUC12 watersheds in the Midwest. High resolution terrain data, typically obtained through LiDAR surveys, are required. This manual accompanies these ACPF software tools as a training and referencing resource for use with the third version of these tools, written for use in ArcGIS version 10.2.2 through 10.6. Also included in the Version 3 download is a separate toolbox tested for compatibility with ArcGIS Pro Versions 2.1 and 2.2. The authors strongly recommend these tools be used as part of a collaborative planning effort that includes local landowners, and be applied by planning staff with knowledge of, and access to, the subject watershed.

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Agricultural Conservation Planning Framework – ArcGIS® Toolbox Software User's Agreement

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Suggested citation formats:

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General concepts behind the ACPF:

Tomer, M.D., S.A. Porter, D.E. James, K.M.B. Boomer, J.A. Kostel, and E. McLellan. 2013. Combining precision conservation technologies into a flexible framework to facilitate agricultural watershed planning. Journal of Soil and Water Conservation 68:113A-120A. http://www.jswconline.org/content/68/5/113A.full.pdf+html

Development of specific practice siting tools:

Tomer, M.D., S.A. Porter, K.M.B. Boomer, D.E. James, J.A. Kostel, M.J. Helmers, T.M. Isenhart, and E. McLellan. 2015. Agricultural Conservation Planning Framework: 1. Developing multi-practice watershed planning scenarios and assessing nutrient reduction potential. J. Environ. Qual. 44(3):754-767. https://dl.sciencesocieties.org/publications/jeq/articles/44/3/754

Development of the riparian classification scheme:

Tomer, M.D., K.M.B. Boomer, S.A. Porter, B.K. Gelder, D.E. James, and E. McLellan. 2015. Agricultural Conservation Planning Framework: 2. Classification of riparian buffer design-types with application to assess and map stream corridors. J. Environ. Qual. 44(3):768-779. https://dl.sciencesocieties.org/publications/jeq/articles/44/3/768

Preface and Input Data

a Background

The ACPF toolbox is specifically designed to work with the data and data structure provided by the Agricultural Conservation Planning Framework (ACPF) (Figure 1) that has been developed at the USDA/ARS National Laboratory for Agriculture and the Environment (NLAE) in Ames, IA. The results from applying this toolbox to data for a particular watershed provide an inventory of opportunities for placement of conservation practices, which is intended to assist towards improving the management of agricultural water quality. Results should be tested in a way that uses local knowledge through stakeholder/landowner participation, and is supported by field verification, to arrive at an actual watershed plan. Results can be used flexibly to enable the watershed plan to focus on nutrients (N and/or P), sediment, or both. Results do not provide engineering design for practices, but should identify locations where particular types of conservation practices could be installed with good accuracy. However, no guarantee is made concerning any practice or any suggested practice location in any watershed. Local knowledge and local planning expertise will be required to apply results in a way that benefits the watershed planning process and resulting watershed outcomes. Further information on the intended benefits and application of the ACPF are given in Tomer et al. (2013; 2015a; 2015b). It is assumed herein that ACPF users are experienced with the ArcGIS environment and its file/data handling protocols.

b Structure

An updated ACPF database was released concurrently with the release of the ACPF V3 toolbox. Changes to the database structure include a more detailed land use assignment and expansion of the Soil Profile table (to include an additional NCPPI field). The remaining data structure is consistent, and the ACPF V3 toolbox is compatible with either the new or old data structure. However, ACPF V3 will not work with the ACPF V1 database structure. If using an older ACPF fgdb (will lack a SoilProfile table), the user should utilize the "get ACPF Soils Data" utilities tool to update to a data structure that is compatible with recent toolbox releases. The user can also refer to the "ACPF_Moving from Version 1" word doc included in the ACPF download. The ACPF toolbox and required base data (at the HUC12 watershed scale, Figure 2) can be downloaded from the following website: http://northcentralwater.org/acpf

All data in the ACPF database are stored in an ArcGIS file geodatabase (fgdb) structure, with a separate fgdb for each HUC12 watershed in the study area (Figure 2). ***Users must retain this fgdb structure, and all output files should be written back to the original fgdb.*** The name of each file geodatabase, when initially downloaded, will be "acpf" + HUCID, where HUCID is the 12-digit HUCID number of that watershed (i.e. acpf070802010901.gdb). Changes can be made to the name of the fgdb, but the name should ***ALWAYS*** end in the 12-digit HUCID number. For example, "new_acpf070802010901" OR "acpf_new_070802010901", but NOT "acpf070802010901_new".

Within each fgdb, numerous base layers have been developed. Descriptions of these base layers are contained in Table 1. ***Prior to using the ACPF toolbox, it is highly recommended*** that the user both verify that the base layers exist in the fgdb and become familiarized with their structure and content.

If you are working in an area in which the ACPF land use and soils input data have not been made available for download, the ACPF provides utilities by which to manually generate the required input data layers in the required ACPF structure. See utilities section for further guidance on this process.

Descriptions of output files to be created while running the ACPF toolbox are contained in Table 2. Output files should be saved back to the same fgdb that is currently being worked on. While output filenames are not fixed, suggestions are provided for each output layer. ***Again, at a minimum, it is suggested that the 12-digit HUCID number for the watershed end the name of every file***. For example: "Wetlands071000081505", where "071000081505" is the 12-digit HUC ID number for the watershed.

A high-resolution digital elevation model (DEM) is **NOT** included as a base layer for each HUC12, but is a key data requirement for many of the tools. High-resolution DEMs are becoming commonly available in many areas, typically derived from light detection and ranging (LiDAR) sensor surveys. It is the responsibility of the user to obtain an appropriate DEM for each HUC12 watershed to be processed and add this layer to the fgdb. ***The horizontal map unit of the DEM MUST be meters,*** although any horizontal or vertical resolution is accepted*.* In addition, **the ACPF toolkit requires that all input layers be in the same projection.** The ACPF database is maintained in a Universal Transverse Mercator (UTM) projection, with UTM zones being determined by the centroid location of the watershed boundary of each HUC12. The DEM should also extend beyond the watershed boundary enough to ensure coverage of all fields that may lie only partly within the watershed. The base layer "buf" + inHUC, which is included in the fgdb, provides a convenient extent (watershed and field boundary feature classes buffered by 1000 meters) by which to clip the DEM.

The remainder of this manual steps through each tool in the ACPF toolbox in order, defining first the required inputs to each tool and the outputs to be created, followed by a description of the function each tool performs. The first section is focused on hydro-modification of the input DEM.

c Software Requirements:

The ACPF toolbox requires that the user have the following software installed:

1) ArcGIS Advanced version 10.3 or higher, with Spatial Analyst Extension

2) TauDEM 5.3 Complete Windows installer (Terrain Analysis Using Digital Elevation Models, Copyright © 2004 David Tarboton, Utah State University). Available for download at no cost from:
http://hydrology.usu.edu/taudem/taudem5/downloads.html

d ArcMap Settings:

In Geoprocessing ---> Geoprocessing Options: Make sure "overwrite the outputs of geoprocessing operations" is checked and that Background Processing is "Enabled".

- Since the release of ArcGIS 10.4, background processing is not supported for tools that call to third party software, such as TauDEM. Therefore, the following ACPF tools must be run in the foreground when using ArcGIS 10.4 or higher. To ensure foreground processing, right click on the tool itself (from within ArcGIS toolbox) --> Properties --> General --> Click on "always run in foreground".
    - 2.a Flow Network Definition – Peuker Douglas

- 2.c Stream Reach & Catchments
- 3.c D8 Distance To Stream
- 4.d Moore Terrain Derivatives
- Utilities. Update Edited Field Boundaries

- The ACPF toolbox should be stored in a permanent file location on your computer ***(not the desktop), in the same data structure that the ACPF toolbox was obtained***. This data structure includes a parent directory "ACPF_V3", which contains an "ACPF_V3.tbx" file, a "scripts" folder, which contains the python programs that the toolbox needs to access, a "docs" folder, containing any documentation, a "metadata" folder, and a land use lookup table titled "ACPF_CDLlkup.dbf". ***In addition, the pathname to the "ACPF_V3 directory should not contain any spaces!*** For example:

    - Incorrect pathname: C:\DATA\ACPF Testing\ACPF_V3
    - Correct pathname: C:\DATA\ACPF_Testing\ACPF_V3

e Tips and Tricks:

- It is very important that both the current and scratch workspace (set in Geoprocessing --> Environments --> Workspace) are set to LOCAL file locations. Setting workspace directories to a network location will significantly slow processing speeds and reduce overall performance.

- The ACPF toolbox is designed to run using the ArcGIS 64-bit background geoprocesssor, although foreground, 32-bit processing is also supported. When taking advantage of background geoprocessing, the toolbox is not fully responsive to the current ArcMap session. Errors may occur if input layers are open in the current ArcMap or ArcCatalog session **AND** involved in a join. ***Joins should be removed from any input layers prior to running a tool.*** The ArcGIS 64-bit background geoprocessing environment requires an additional software installation package available from Esri.

- Output layers of the ACPF toolbox are often used as inputs to other ACPF tools. Many times, this requires that the attribute table of both input and output layers remain in a predictable structure. ***If the user plans to add/delete/alter fields of any of the ACPF datasets, it is recommended that changes be made to a copy of the original layer.***

- ***Pay attention to the z-factor!*** The z-factor is required as an input to many of the tools. Be sure you know both the horizontal and vertical units of your digital elevation model; if they are not the same units then a correction must be applied, i.e., the z-factor. The z-factor is a conversion factor that provides equivalence between the units of measure for the vertical (or elevation) units when they are different from the horizontal coordinate (x,y) units of the input surface. It is the number of vertical (z) units in each ground (x,y) units. ***If the vertical units are not corrected to the horizontal units, the results of surface tools will not be correct*** (Esri, 2014).

- Any vertical resolution (integer or float, feet, cm or m) DEM may be used with the ACPF toolbox. However, the ***horizontal resolution MUST be in whole meters***. Experience has shown improved processing speeds and reduced disk space requirements when z-units are converted to integer cm units.

- When running any ACPF tool, progress can be monitored from within ArcMap by viewing the Results window, found under the Geoprocessing tab. This window will also contain any error messages generated by the ACPF toolbox.

- Version 3 of the ACPF allows for the incorporation of water body features (wide rivers and lakes) into the stream network, allowing these features to be modeled appropriately by many of the subsequent ACPF tools. Water body features are provided as polygons and can be obtained from a variety of sources, such as the National Hydrography Dataset (NHD), state and/or local resources, or manual digitization. The user should be aware of any potential impacts or unintended side effects when providing or creating these features, and should read through section 2.d if they plan to take advantage of this ACPF process.

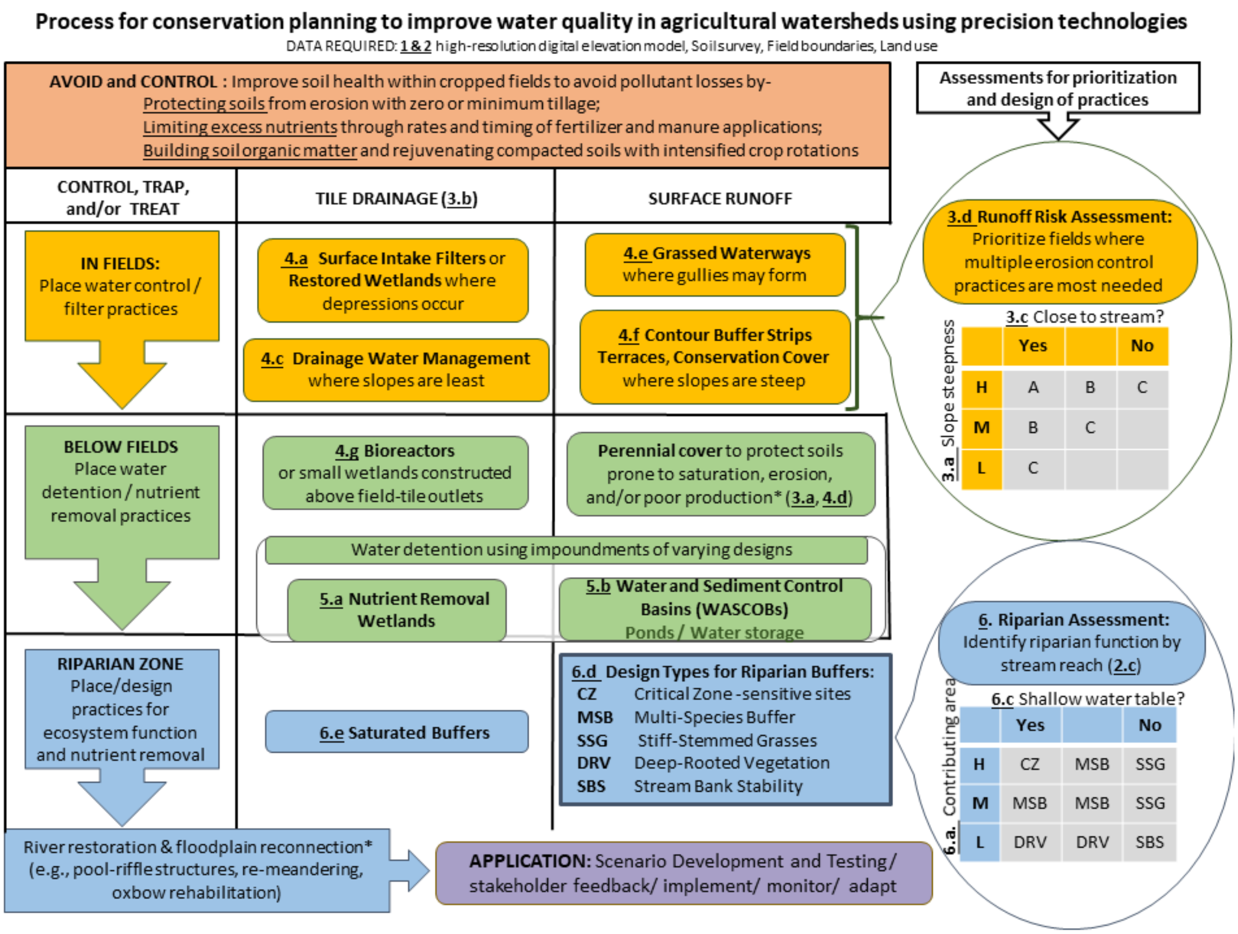


Figure 1. Conceptual diagram for the Agricultural Conservation Planning Framework (Tomer et al., 2013), with section numbers in this manual identified where appropriate. * indicates planning options where use of additional data sources, modeling tools, and/or novel site-specific designs are suggested.

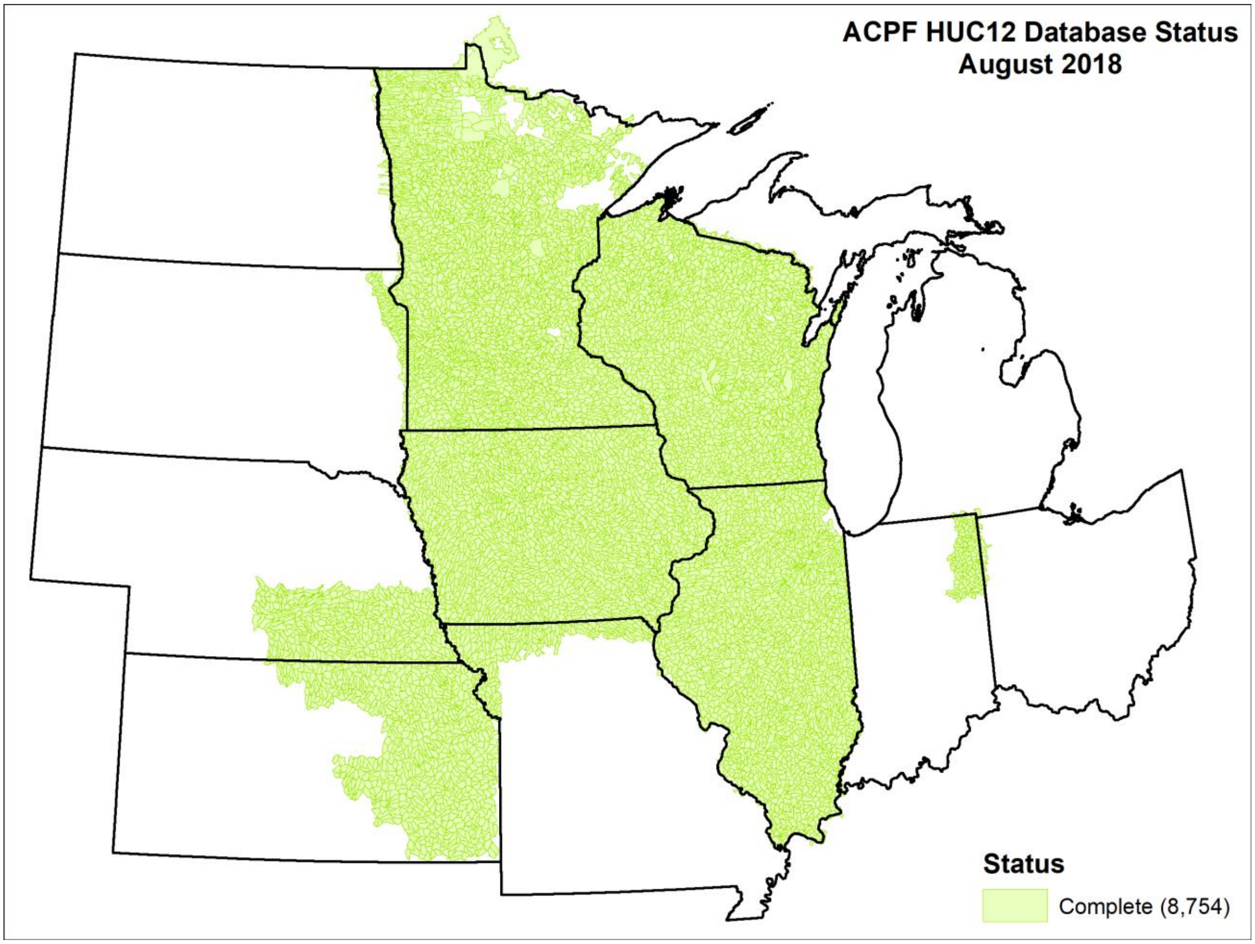


Figure 2. Current extent of study area included in the Agricultural Conservation Planning Database (as of August 2018).

f Base Layers

Table 1. Base layers included in file geodatabase		
Name	**Type**	**Description**
bnd + inHUC	Polygon	Watershed boundary (USGS WBD derived from NHD)
buf + inHUC	Polygon	Watershed boundary merged with field boundaries and buffered out by 1000 meters – base data is clipped to buffered extent to ensure coverage for all fields that may lie partly within watershed
FB + inHUC	Polygon	Agricultural field boundaries that have been manually updated from 2005 USDA/FSA data. The field boundary feature class contains an "isAG" field in the attribute table to provide a general classification for agricultural land. Possible "isAG" values include: • 0 = Non-agricultural (Forest, Water/Wetland, Urban, LT 15ac, and Unassigned) • 1 = Agricultural • 2 = Pasture/grass/alfalfa Note: The "isAG" field can be used for simple land use queries rather than performing a join with the land use table.
Soils DATA: gSSURGO SurfHrz + inHUC SurfTex + inHUC SoilProfile + inHUC	 Thematic Raster Table Table Table	 USDA/NRCS 10-meter soils raster that can be joined to soil tables through mapunit or cokey field Surface horizon table Surface texture table Soil Profile table, contains attribute information below the surface horizon
LU6_ + inHUC	Table	Land use table derived from the most recent 6 years of the NASS CDL; can be joined to field boundary layer by a unique FBndID. Contains information on majority crop found among the pixels (from original remote sensing data) in each field within the classified NASS data, % majority crop (indicates confidence in the crop cover assigned by year), 6–yr land cover strings (Tomer et al., 2015a), a generalized land use classification, and an agricultural land use classification for each field.
CH_ + inHUC	Table	Crop history table derived from all available years of the NASS CDL; can be joined to field boundary layer by a unique FBndID. Contains information on majority crop and % majority crop for each year in the dataset.
wsCDL2012 wsCDL2013 wsCDL2014 wsCDL2015 wsCDL2016 wsCDL2017	Thematic Raster	USDA NASS Cropland Data Layers for the most recent 6 years. The filename ends with the 4-digit year that it represents.
DEM + inHUC	Continuous Raster	A LIDAR-derived DEM of meter horizontal resolution ***must be generated by the user and added to the fgdb***. This should be an unfilled DEM, meaning that sinks still exist.

g Data Formats and File Naming Conventions

Table 2. Output Files (will usually be created in this order)

Name	Type	Description
D8FlowDir + inHUC	Thematic Raster	Raster of flow direction from each cell to its steepest downslope neighbor, using ArcGIS D8 flow direction values.
D8FlowAcc + inHUC	Continuous Raster	Raster of accumulated flow. Cell values equal the number of upstream cells flowing into each target cell in the output raster.
DEMFill + inHUC	Continuous Raster	DEM that has been processed so that all sinks have been filled.
Hshd + inHUC	Continuous Raster	Shaded relief. Derived from unfilled DEM.
AreaFlowNet + inHUC	Polyline	Flow network polyline derived from the Flow Network Definition – Area Threshold tool.
PDFlowNet + inHUC	Polyline	Flow network polyline derived from the Flow Network Definition - Peuker Douglas tool.
DepthGrid + inHUC	Continuous Raster	Depth grid, in which each cell represents the elevation difference between the filled and unfilled DEM.
Flowpaths + threshold + inHUC	Polyline	Flow network polyline derived from the Visualize Flowpaths tool.
NewDEM + inHUC	Continuous Raster	Unfilled DEM containing altered elevation values along user-provided cut and/or dam lines.
StreamReach + inHUC	Polyline	Polyline feature class representing each reach in a stream network.
Catchments + inHUC	Thematic Raster	Polygon feature class representing each sub watershed. The "gridcode" value of each polygon will equal the "LINKNO" of its corresponding reach in the StreamReach feature class.
StreamReachWB + inHUC	Polyline	Polyline feature class representing each reach, shore line, and wide river edge in a hydrologic network.
WaterBodies + inHUC	Polygon	Polygon feature class containing wide river and lake features.
Slope + inHUC	Continuous Raster	Slope raster derived from LIDAR DEM (in percent rise).
SlopeTable + inHUC	Table	Table that contains slope information on a field by field basis. Can be linked to the field boundary feature class through the FBndID.
DrainageTable + inHUC	Table	Table that, based on a user selected query of by-field slope and soils information, classifies agricultural fields (including pasture) as tile-drained or non tile-drained. Can be linked to the field boundary feature class through the FBndID.
DistToStrm + inHUC	Continuous Raster	The distance to stream raster calculates the horizontal distance (in meters) to the channel for each grid cell, moving downslope according to D8 flow model until a stream grid cell is encountered.
RunoffRisk + inHUC	Table	Table that contains runoff risk information on a field by field basis. Can be linked to the field boundary feature class through the FBndID. The ***runoff risk table contains information on agricultural fields only (including pasture)***, as identified by the 6-year generalized land use classification. As a result, the # of rows

		in the attribute table of the runoff risk table will usually be less than that of the input field boundary feature class.
Depressions + inHUC	Polygon	Polygon layer created as an output of the Depression Identification tool. Will contain a unique "Depress_ID".
Depress_Wsheds + inHUC	Polygon	Polygon layer created as an output of the Depression Watersheds tool. Will contain a unique "Depress_ID".
DrainageMgmt + inHUC	Polgyon	Polygon layer created as an output of the Drainage Water Management tool. Polygons will represent discrete areas (larger than a user-specified % of field or acreage) where all elevation values are within a user-specified contour interval that can be chosen between .3 and 1.5 meters (default is 1.0 m).
SCA + inHUC	Continuous Raster	A grid of specific catchment area, which is the contributing area per unit contour length using the multiple flow direction D-infinity approach. The contributing area of each grid cell is taken as its own contribution plus the contribution from upslope neighbors that have some fraction draining to it according to the D-infinity model
SPI + inHUC	Continuous Raster	A grid of SPI (Stream Power Index) values. The stream power index is a measure of the erosive power of flowing water. Predicts net erosion in areas of profile convexity and net deposition in areas of profile concavity (decreasing flow velocity)
TWI + inHUC	Continuous Raster	A grid of TWI (Topographic Wetness Index) values. Predicts zones of saturation where SCA is typically large and β is small.
GrassWaterway + inHUC	Polyline	Polyline layer created as an output of the Grassed Waterway tool.
CBS + inHUC	Polygon	Polygon layer created as an output of the Contour Buffer Strip tool.
Bioreactor + inHUC	Polygon	Polygon layer created as an output of the Bioreactors tool.
NRW + inHUC	Polygon	Output Nutrient Removal Wetland feature class (polygon). Each suitable site will contain 2 rows in the output attribute table - one for each wetland polygon (pooled area - permanent storage) and one for the buffer polygon (vegetated area - variable storage) polygon. Attributes will be the same for each of the 2 rows. Each polygon will have a unique "SiteID".
NRWDrainageAreas + inHUC	Polygon	Output Nutrient Removal Wetland Drainage Area feature class (polygon). Each polygon will have a unique "SiteID".
WASCOBs + inHUC	Polyline	Output WASCOB polyline feature class. Each polyline will represent a transect line of 100 m length, and will contain site-specific information as attributes.
WASCOBbasin + inHUC	Polygon	Polygon layer representing the basin, or area which would pond water upstream of each WASCOB, for all input WASCOBS.
HAC + inHUC	Thematic Raster	Thematic raster representing a classification of an estimated depth to water table, used to identify riparian zone management opportunities.
RiparianCatchments + inHUC	Polygon	Polygon feature class representing riparian catchments along the stream reach corridor that drain to a user-specified length.
RAP + inHUC	Polygon	Polygon feature representing 15 meter riparian attribute polygons along the stream reach corridor. These correspond to the riparian catchments and can be joined together via the unique identifier, "riparianid".

RiparianRelation	Relationship Class	Relationship class which provides a connection between input riparian catchments and outputs RAPs.
RiparianFunction + inHUC	Table	Output riparian function table, containing site specific information for each RAP, particularly suggested buffer widths based on upslope runoff characteristics and denitrification potential. Can be linked to either the riparian catchment or RAP feature classes through a unique "riparianid".
SaturatedBuffer + inHUC	Table	Output saturated buffer table, containing site specific information on suitability for saturated buffers, particularly soils, topography, land use, and bank height characteristics. May be joined to either the riparian catchment or RAP feature class through a unique "riparianid".

1. DEM preparation

1.a DEM: Pit Fill / Hole Punch

Required Inputs	Outputs
INPUT LAYER: Unfilled DEM (DEM + inHUC)	Conditioned DEM raster (Input DEM + '_p' + inHUC)
USER DECISION: Maximum Fill Depth (Z-units)	

The ACPF Toolbox requires a high-resolution digital elevation model (DEM) suitable for terrain analysis and hydrologic modeling. The first set of tools in the ACPF toolbox, titled "DEM Preparation", are designed to prepare the DEM to accurately represent hydrologic flow routing. Accurate flow routing enables greater confidence in application of the ACPF conservation-practice siting tools. The DEM should extend about 1,000 meters beyond the watershed boundary. This buffered extent ensures that the elevation data can be used to delineate a new watershed boundary, which is necessary because discrepancies will exist between a LiDAR-derived watershed boundary and the boundary provided by the USGS National Hydrography Dataset. In addition, this wider extent ensures coverage of fields that only partly lie within the watershed.

The process to produce DEMs derived from active sensors datasets (i.e. LiDAR) can be challenging. These products are subject to high variability and the result is likely to include many pits and small depressions that should be considered artifacts of the collection process. In order to remove slight irregularities, the Pit Fill / Hole Punch tool can be used to create an enhanced DEM that smooths the surface while maintaining 'true' depressions that can be important features, particularly in glacial and karst landscapes.

Pit-filling is the process by which all 'one cell sinks' are removed from a DEM. One cell sinks are those cells which are lower than all surrounding cells and cannot have one of the eight flow direction values assigned to it. The cells are removed by the process of setting all sinks (from the Sink tool) in the DEM to null. The DEM is then filled and a difference raster (filled - unfilled) is calculated. All cells that have positive fill are 'one cell sinks'. The elevations of these cells are changed to the filled elevation and all other cell elevations remain unaltered.

Hole-punching is a process where only 'true' depressions greater than a supplied depth parameter are retained in the output DEM. This process was developed to overcome the inconsistent filling of sinks in ESRI's Fill tool. The hole-punching tool begins this process by filling existing depressions in the initial DEM using the Fill command. The difference, or depth of fill, between the initial and filled DEM is then calculated and all areas with positive fill are turned into unique 'fill regions' using Region Group. Depth and area statistics are calculated for each region and those meeting or exceeding the depth criteria (i.e. are deeper than the supplied depth parameter) are retained by setting the region's sink cells to Null in the initial DEM. The DEM is then filled again; the water 'flows' out the bottom of the previously identified depressions through the 'Null' sinks; and then new 'fill regions' that remain can be defined and evaluated. This process continues iteratively until no fill regions greater than the criteria remain. The final step is to return the original elevation values to all of the 'Null' sinks created during this process, creating a fully populated DEM.

- The input DEM can be a file-geodatabase raster or an independent file system raster that is supported by ArcGIS.
- The output raster will be returned in the same format as the input raster, unless the user chooses a different output format.
- The Maximum Fill Depth represents the deepest fill depth allowed in the output raster. No depressions deeper than this value will be filled.
- The Maximum Fill Depth value should be input using the same Z-units as the input raster. Typically 0.0-1.0 for Z-units in meters and 0-100 for Z-units in centimeters.
- We suggest a maximum fill depth that is consistent with the vertical accuracy of the input data, often 0.1-0.3 m (10-30 cm). The National Standard for Spatial Data Accuracy (NSSDA) defines the vertical accuracy of a data set by the root mean square error (RMSE) of the elevation data in terms of feet or meters at ground scale. This information is usually derived following a quality assurance process, which tests the vertical accuracy of the elevation data over various ground covers. Keep in mind, therefore, that vertical accuracy may vary between land cover types. Information on vertical accuracy for your LiDAR dataset should be contained in the metadata provided by the publisher of your dataset. Using the vertical accuracy of your dataset as the Maximum fill depth in the Pit Fill/Hole Punch tool will reduce the noise (i.e. smooth) the DEM only within the bounds of the error range of the data itself, while maintaining what is considered “true and accurate” data.

1.b D8 Terrain Processing

Required Input Layers	Output Layers
INPUT LAYER: Unfilled DEM (DEM + inHUC)	D8 Flow Direction raster (D8FlowDir + inHUC)
	Filled DEM raster (DEMFill + inHUC)
	D8 Flow Accumulation raster (D8FlowAcc + inHUC)
	Hillshade raster (Hshd + inHUC)

The D8 terrain processing tool acts on the input DEM to generate four terrain processing derivatives. The tool first performs a fill operation. The fill process involves raising the elevation values within all depressions to that of the pour point out of the depression, so that flow pathways from the depression become part of a continuous flow network that routes all flows to the watershed outlet. The fill process does not distinguish between types of depressions, and fills all sinks in the DEM, including real depressions. Having run the pit fill - hole punch tool beforehand ensures the difference between the filled and the unfilled DEM identifies depressions that are either actual depression or targets for editing, rather than discrepancies resulting from survey and interpolation errors.

The nest step in the D8 terrain processing tool applies the ArcGIS D8 flow routing algorithm (Esri, 2011), which assumes that overland flow from each grid cell is directed to a single neighboring cell that is determined by the steepest downward slope gradient, to the filled DEM to generate a flow direction raster. This flow direction raster is then used to generate a flow accumulation raster, in which the value at each grid cell represents the number of upstream grid cells draining to that point. A hillshade raster is also generated using the unfilled DEM for visualization purposes.

1.c Identify Impeded Flow (Depression Depth)

Required Inputs	**Outputs**
INPUT LAYER: Unfilled DEM (DEM + inHUC)	Depth Raster (DepthGrid + inHUC)

When using an unfilled DEM, depressions present in the landscape will prevent continuous flow throughout the watershed. As a result, flowpaths that enter a depression will simply stop, as there are no surrounding lower elevations for that flow to travel towards. This is desirable for some analyses, where depressions are a natural feature of the landscape. However, false impoundments will also occur, particularly on the upslope sides of bridges, and roadways where road-side ditches drain through culverts. These false impoundments must be corrected, and the following sections describe both cutter and dam-builder DEM editing tools to help correct for false impoundments. However, the number and locations of such corrections that are necessary to prepare the DEM for a given watershed is a judgment call. This current tool (Depression Depth) is included to help users identify false impoundments and locate the end points of each cut line more accurately. When approaching this DEM editing process, bear in mind that too many or poorly placed edits will have unwelcome consequences for your analysis, as will too few edits

The tool identifies where surface depressions exist in the input DEM. This tool differs from the depression identification tool (see Section 3.a) in that it is designed to aid the user in identifying where to place "cut lines" as part of the hydro-conditioning process.

The tool acts by calculating elevation differences between the unfilled and filled DEM developed in the previous terrain processing tool. The output depth grid is a continuous raster, in which each grid cell represents the elevation difference at that location, in the same z-units as the DEM. These elevation differences represent depressions, or sinks, in the landscape. While these sinks may represent real depressions, oftentimes false depressions are created behind road crossings or other obstructions to flow.

When used as a visual aid for the hydro-conditioning process, which is often an iterative process, the output DEM from the Manual Cutter / Dam Builder tool (Section 1.e) will be used as the input DEM to this tool. Used in this way, the user can determine where depressions still exist after running the manual cutter/dam builder tool.

1.d Visualize Flowpaths

Required Input Layers	Output Layer
INPUT LAYER: D8 Flow Accumulation raster (D8FlowAcc + inHUC)	Flowpath + threshold in acres + inHUC
INPUT LAYER: D8 Flow Direction raster (D8FlowDir + inHUC)	
USER DECISION: Area Threshold (acres)	

The “correction” or hydro-modification of a DEM is conducted by the user to ensure flowpaths throughout the watershed are accurately represented. It is most important to make these corrections along major flow paths; for instance, it is more important to correct for flow beneath every highway bridge identified as a false impoundment than it is to correct for flow beneath every roadside driveway that has (or may not have) a culvert. This step provides a polyline output that represents a set of flow paths, with a minimum area threshold selected by the user, which is subsequently used to allow the DEM editing process to be performed consistently. The extent of the flow path network is reviewed in combination with the depth raster to identify candidate locations for DEM editing in the next tool (Manual cutter and dam builder). A value between 1 and 10 acres of contributing area is suggested for the area threshold. The smaller the area threshold selected, the more extensive will be the set of candidate locations for editing. This acreage threshold (rounded down to the nearest integer) is embedded in the name of the output, (i.e. a 2.5 acreage threshold will be recorded as "2ac" in the name of the output file.

1.e Manual Cutter / Dam Builder (Repair Flow Paths)

Required Inputs	**Outputs**
INPUT LAYER: Cut Lines (manually created by user) (optional)	New unfilled DEM to reflect cut and/or dam lines (NewDEM + inHUC)
INPUT LAYER: Dam Lines (manually created by user) (optional)	Filled DEM raster (DEMFill + inHUC) (generated from NewDEM)
INPUT LAYER: Unfilled DEM	Flow Direction raster (D8FlowDir + inHUC) (generated from NewDEM)
	Flow Accumulation raster (D8FlowAcc + inHUC) (generated from NewDEM)
	Hillshade raster (Hshd + inHUC) (generated from NewDEM)

Following the creation of a flow network, it is ***absolutely necessary*** that the user take the time to analyze the flow network polyline to identify errors, which often occur from the initial automated flow routing. These errors may include locations where the flow line becomes obstructed and "jumps out" of the channel or is not routed under roads in locations of culverts.

The user can correct these errors using the "Manual Cutter/Dam Builder" tool, which involves a revision of the input DEM by altering elevation values along user-provided polyline features. Input line layers may include cut lines, dam lines, or both (separate feature class required for each), and may include multiple lines to be processed at once.

Cut lines may be desirable when an obstruction to flow is present in the DEM that should be "burned through", such as a culvert which routes flow beneath a road. When the culvert is not represented in the DEM, the flow routing process will encounter an obstruction (in this case a road) forcing the flow to "back up" rather than pass through it. Grid cells in the DEM that are located along each cut line will be replaced with the ***minimum*** elevation value found along the cut line.

Dam lines may be desirable when an obstruction to flow is desired yet absent in the DEM. An example may include low relief landscapes in which the direction of flow is not apparent, causing the watershed boundary to be ambiguous. By providing a dam line along the border of the watershed, flow direction can be guided towards the downstream drainage network. Grid cells in the DEM that are located along each dam line will be replaced with the ***maximum*** elevation value found along the dam line.

When the tool is run, a new DEM (containing altered elevation values along lines) will be created. The D8 Terrain Processing tool will automatically be rerun using the new DEM as the input, to ensure that all terrain derivatives (Filled DEM, Flow Direction, Flow Accumulation, and Hillshade), are created using the most current DEM surface raster. The user should then rerun both the identify impeded flow and visualize flowpaths tools using this NewDEM to ensure errors have been corrected, and to identify any further issues that need to be addressed. By performing these 'corrective' steps early in the process, the user will ultimately save time compared with finding errors in the flow network later when applying subsequent practice siting tools. If no errors in the flow network are found ***(a result one should only expect after several iterations of steps 1.c-1.e)***, the user can move on to Section 2.

The user will be required to create a feature class containing the cut and dam lines to be added. If both cuts and dams are to be used, a separate feature class must be created for cut lines and dam lines. Feature class file(s) can be stored in any location, as the user will be prompted to select the input line file(s) when running the tool. It is often easiest to store the file in the same fgdb that you are currently working with.

To create a feature class containing the cut or dam lines to be added:

1. Navigate (using ArcCatalog or ArcMap) to the location where the feature class will be located. Right click in the file location and select new ---> feature class. Any name can be given to the feature class, but you will want to ensure that it is unique. "CutLines" + inHUC or "DamLines" + inHUC is a good choice. ***Make sure to specify that it is a line feature type.*** Hit next and provide the correct projection (the ACPF requires that all input layers be in the same projection). Continue to hit next through the next several pages, accepting the default settings. Hit finish.

2. Add the newly created feature class to an ArcMap document and begin an editing session. Editor toolbar --->Start Editing. Open the editing window "Create Features" and select the newly created feature class as the layer to edit.

TIP: It is recommended to right click on the feature class you are editing (such as the cut or dam lines), and make this layer the "only selectable layer". This prevents the inadvertent deletion or modification of any other features while in an editing session.

3. Using auxiliary data (aerial photography, hillshade, etc.) zoom into locations where incorrect flow pathways exist. Using the flowpaths from the "Visualize Flowpaths" tool and depressions from the "Identify Impeded Flow" tool, in conjunction with the hillshade, LiDAR DEM, and aerial imagery, will greatly aid in locating incorrect flow paths. ***The hillshade, aerial photography, and LIDAR DEM may all be required to determine where errors occur and where flow should be routed.*** To add a line, ensure the feature is selected in the "Create Features" window, and draw a line either through the obstruction to flow (cut line), or where you want to add an obstruction (dam line).

TIP: On-screen display techniques, such as contrast stretching, can improve one's ability to locate where lines should be placed when viewing the DEM. To adjust histogram stretching, right-click the DEM and select Properties ---> Symbology. Under Type – select either Standard Deviations (set n to either 1 or 2) or Histogram Equalization. Scroll down. From Statistics, select "From Current Display Extent". These setting will help to visualize what is happening with discrete pixel elevation values as one zooms in or pans to different locations.

4. Once all desired lines have been created, save edits and stop editing. Editor toolbar > Save Edits. Editor toolbar --> Stop Editing.

NOTE: A conservative approach should be taken when drawing cut or dam lines, as it is preferred to modify the original DEM as little as possible. Obstructions to flow may not always exist at the exact location that the stream diverts from the correct flow path. An example is a stream road crossing that has not been cut to represent the existence of a culvert. This obstruction will create a ponded area above the road, causing the flow to be diverted at the upstream end of the ponded area. To correct this, a small cut line should be drawn across the road where the culvert exists, and not through the entirety of the ponded area. In other cases, the location of the obstruction will not always be obvious. In such cases, drawing a line from the point where the stream diverts to a point where the flow pathway should follow is suggested. Examples of where to draw cut lines are shown in Figure 3.

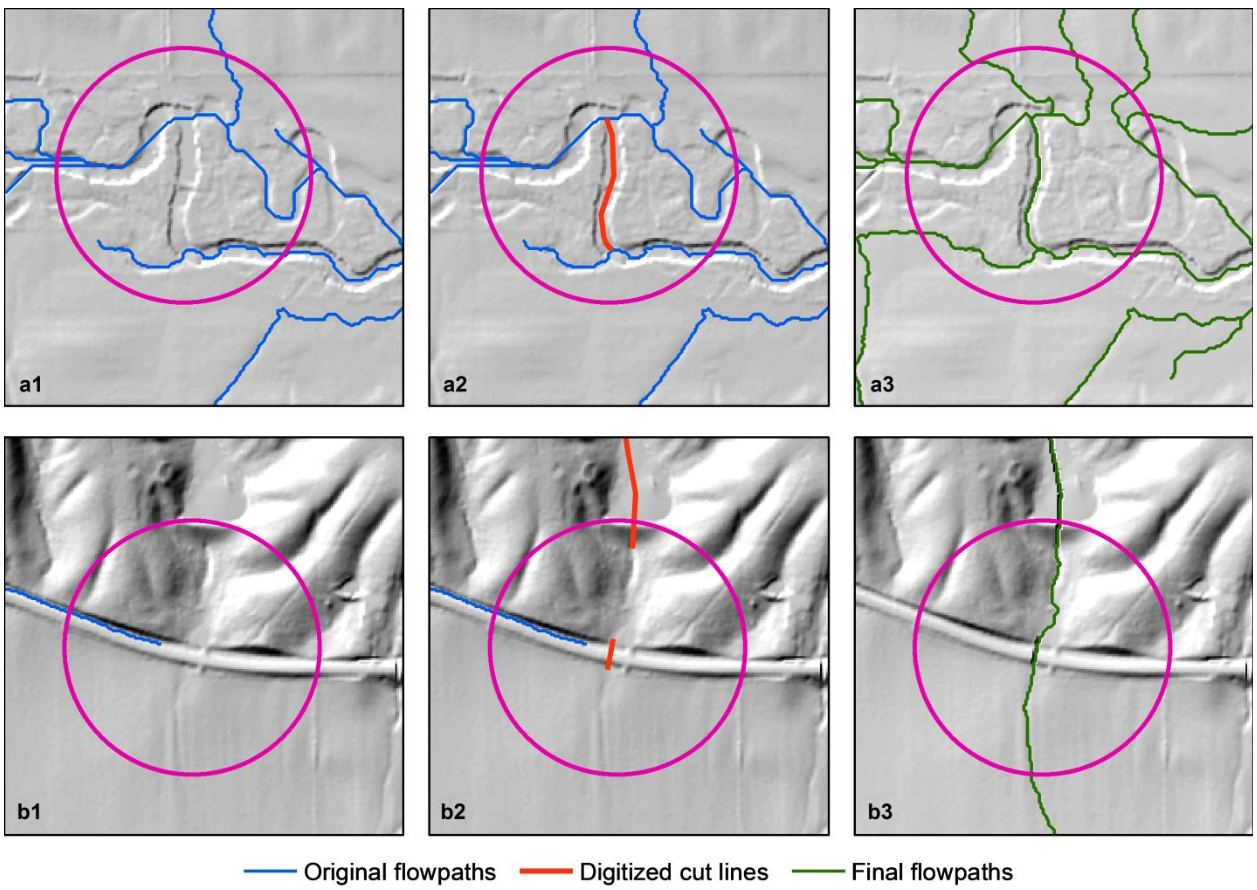


Figure 3. Manually digitized cut lines and their impact on derived flow pathways

NOTE: This is an iterative process. One round of cut and/or dam lines may not solve all issues, and often a second and then further rounds of edits may be needed. During this process, ongoing edits should be made to the line feature class that was created, such as adding additional cut lines or removing those that did not achieve the desired result. ***Each time the manual cutter/dam builder tool is run, the original DEM (not the output NewDEM from a***

previous run) should be used as the input raster. The "Visualize Flowpaths" and "Identify Impeded Flow" tools should also be rerun to gauge flow network accuracy.

NOTE: Once satisfied, ***the most recently created New DEM should be used as the input DEM in all remaining tools***. This new DEM will be unfilled, meaning that sinks will still exist. As D8 terrain processing is automatically rerun when the Manual Cutter/Dam Builder tool is run, all terrain processing derivatives (filled DEM, flow direction, flow accumulation, and hillshade) will be derived from this most recent DEM.

2. Develop Stream Network and Catchments

The primary objective of Section 1 was to edit the DEM using cut lines, and if needed, dam lines, to provide final versions of unfilled and filled DEMs, and to derive flow accumulation and flow direction rasters that are as accurate as possible. In this section, we begin to characterize the watershed by delineating the stream network and subdividing the watershed into sub-watersheds, which are called catchments in the ACPF. In the first two sub-sections, two options for defining your watershed's flow network are provided; the output from either one can be used to define the watershed's perennial stream network in subsection 2.c.

NOTE: DO NOT use National Hydrography Datasets (e.g., NHD+) to forcibly assign stream locations. This is strongly discouraged for several reasons; the age (circa 1950s) and coarser scales from which those datasets originate will negatively impact the accuracy of flow routing, which will consequently impact results of the ACPF, particularly the riparian assessment (Section 6). In addition, the NHD stream locations will not correspond to the terrain derivatives that were derived from your DEM, causing many of the ACPF tools to either fail or run incorrectly.

2.a Flow Network Definition - Area Threshold

Required Inputs	**Outputs**
INPUT LAYER: D8 Flow Accumulation raster (D8FlowAcc + inHUC)	Flow Network (AreaFlowNet + inHUC) (polyline)
INPUT LAYER: D8 Flow Direction raster (D8FlowDir + inHUC)	
USER DECISION: Area threshold (acres)	
INPUT LAYER: Watershed boundary (bnd + inHUC) (optional)	

The Flow Network Definition – Area Threshold tool applies an area threshold (area of upstream drainage, in acres) to a flow accumulation grid to create an output flow network polyline. The area-threshold method is recommended for watersheds formed in more recent (Wisconsinan age) glacial landscapes, where classic stream formation and geomorphic land dissection processes have had little influence in the development of the landscape. That is, watersheds with dense networks of drainage ditches may be better suited to the area-threshold approach to begin the process of identifying streams.

The flow accumulation grid is assigned a "NODATA" value for those grid cells that are below the threshold, and a "1" value for those grid cells above the threshold. The reclassified grid is then used, along with the D8 flow direction grid, in ESRI's "Stream to Feature" tool to generate the output flow network polyline. The stream order (Strahler, 1969) is also calculated and assigned to each segment of the output flow network. ***The "StreamType" attribute of this polyline coverage must be edited by the user (as described in section 2.c) to enable the remaining ACPF tools to operate on perennial streams.*** It is better to err towards too small an area accumulation threshold than too large a one, to avoid errors of omission when identifying the perennial channel network (Section 1.e).

Important: The output flow network should always extend upstream beyond perennial and into intermittent and ephemeral drainageways. This will help to consistently identify perennial streams (see Section 2.c) and facilitate accurate conservation planning results, including, but not limited to, locations of riparian practices. This is why the "StreamType" field of the output flow network polyline ***MUST be manually populated*** by the user in Section 2.c; to accurately distinguish the perennial stream network. This classification must be integer values and can be simple (1 to indicate perennial streams, 0 to indicate ephemeral or intermittent drainageways), or complex (e.g., 0 - ephemeral or intermittent, 1 - perennial, 2 - floodplain or braided, 3 - wide river centerline). Stream reach and catchments (Section 2.c) can be generated for only those stream segments with a "StreamType" value >= 1.

2.b Flow Network Definition - Peuker-Douglas

Required Inputs	Outputs
INPUT LAYER: Filled DEM (DEMFill + inHUC)	Peuker Douglas Flow Network (PDFlowNet + inHUC)
INPUT LAYER: D8 Flow Direction raster (D8FlowDir + inHUC)	Pour Points (optional; not created if pour point(s) are provided by user)
INPUT LAYER: Watershed boundary (bnd + inHUC)	
INPUT LAYER: Pour Points (optional)	

The Peuker Douglas channel network tool combines the functionality of the "Peuker Douglas", "D8 Contributing Area" and "Stream Drop Analysis" tools available in TauDEM software to generate a flow network polyline for the watershed. This method is founded in classical geomorphology and historical studies that evaluated relationships between watershed size and channel-reach slopes and lengths (between confluences) in different regions.

Description taken from TauDEM (Tarboton, 2004):

> "With this method, the DEM is first smoothed by a kernel with weights at the center, sides, and diagonals. The Peuker and Douglas (1975) method (also explained in Band, 1986), is then used to identify upwardly curving grid cells. This technique flags the entire grid, then examines in a single pass each quadrant of 4 grid cells, and unflags the highest. The remaining flagged cells are deemed 'upwardly curved', and when viewed, resemble a channel network. This proto-channel network sometimes lacks connectivity, and/or requires thinning, issues that were discussed in detail by Band (1986). The thinning and connecting of these grid cells is achieved here by computing the D8 contributing area using only these upwardly curving cells. An accumulation threshold on the number of these cells is then determined via drop analysis."

Drop Analysis

A stream's drop is the difference in elevation from the beginning to the end of a stream segment, which is identified as the sequence of linked channel cells with the same stream order. Drop Analysis automatically determines a flow accumulation threshold value by searching for possible threshold values within a search range (between 500 and 100,000 grid cells) that meet the constant drop property. The approach divides the search range into 50 possible threshold values (using logarithmic spacing), and attempts to select the right threshold automatically by evaluating a stream network for a range of thresholds and examining the constant drop property of the resulting Strahler streams. Basically, it asks the question: Is the mean stream drop for first order streams statistically different from the mean stream drop for higher order streams, using a T-Test. If the T test shows a significant difference, then the stream network does not obey this "law" so a larger threshold needs to be chosen. The smallest threshold for which the T test does not show a significant difference (i.e. the t-statistic is <2) gives the highest resolution stream network that obeys the constant stream drop "law" from geomorphology (Broscoe, 1959), and is the threshold chosen for the "objective" or automatic mapping of streams from the DEM. In practice, results of the drop analysis (or the area threshold) only provide estimates of where stream initiation points and channel locations occur throughout the watershed. These locations must be confirmed (or edited) to ensure that the stream network represents the actual distribution of perennial channels to the extent possible (see next Section).

Pour Points

The drop analysis procedure requires watershed pour point(s). The user has the option to either 1) Provide their own set of pour point(s), or 2) Allow pour point(s) to be automatically generated. The automated process selects the highest flow accumulation grid cells (> 4 standard deviations from the mean flow accumulation value) that fall along the border of the USGS-derived watershed boundary. These locations are then converted to points and used as input to the tool. The user can optionally save the automatically generated pour point(s) by specifying an output file name and location. It is ***strongly suggested*** that the automatically generated pour point file be saved, then manually reviewed and edited by the user to ensure the appropriate location of the pour point(s). The tool should then be rerun, with the manually edited pour point(s) provided as an input.

The flow accumulation grid is assigned a "NODATA" value for those grid cells that are below the threshold (as determined via drop analysis), and a "1" value for those grid cells above the threshold. The reclassified grid is then used, along with the D8 flow direction grid, in ESRI's "Stream to Feature" tool to generate the output flow network polyline. The Strahler stream order is also calculated and assigned to each segment of the output flow network. The "StreamType" ***attribute of this polyline coverage must be edited by the user (as described in section 2.c) to enable subsequent ACPF tools to operate on perennial streams.***

Important: The output flow network should always extend upstream beyond perennial and into intermittent and ephemeral drainageways. This will help to consistently identify perennial streams (see Section 2.c) and facilitate accurate conservation planning results, including, but not limited to, locations of riparian practices. This is why the "StreamType" field of the output flow network polyline ***MUST be manually populated*** by the user in Section 2.c; to accurately distinguish the perennial stream network. This classification must be integer values and can be simple (1 to indicate perennial streams, 0 to indicate ephemeral or intermittent drainageways), or complex (e.g., 0 - ephemeral or intermittent, 1 - perennial, 2 - floodplain or braided, 3 - wide river centerline). Stream reach and catchments (Section 2.c) can be generated for only those stream segments with a "StreamType" value >= 1.

2.c Stream Reach and Catchments

Populating the "StreamType" field

Required Inputs	Outputs
INPUT LAYER: Flow Network (AreaFlowNet + inHUC) or (PDFlowNet + inHUC)	No separate coverage - Reclassification of stream polylines

Following the correction of errors in the DEM (Section 1) and creation of a flow network (in section 2.a or 2.b), the user ***is expected to*** populate the "StreamType" field in the attribute table of the flow network file. The goal of this step is to identify perennial stream segments with continuous (i.e. year-round) flow along the stream bed (excepting years of drought).

While the flow network will delineate concentrated flow pathways in the watershed, these pathways should extend above perennial streams to include preferably all the watershed's intermittent and many of its ephemeral drainageways. For purposes of conservation planning, this distinction between flow network elements and relative constancy of flow is an important one. While riparian management opportunities occur along perennial streams, attributes of concentrated flow paths above streams are also important for conservation planning and erosion modeling along ephemeral drainageways. The approach used here preserves the capacity to use the ACPF input data for both types of applications. But at this step, we focus on delineating perennial streams, which define the locations of riparian areas and are important because:

> "Riparian areas are transition zones between terrestrial and aquatic ecosystems that are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands, and include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems." (National Research Council, 2002).

While ephemeral drainageways may interact with a riparian area during high flows, these locations present different management opportunities than those that exhibit perennial flow with riparian attributes throughout most years. The "StreamType" field allows for classification of flow network segments into distinct conservation management areas, and at a minimum should designate perennial stream segments that have adjoining riparian zones appropriate for conservation management. In addition, runoff risk assessment of agricultural fields (see Runoff Risk Assessment Tool – Field Characterization), is based on proximity to perennial streams, rather than ephemeral channels. The accuracy of your delineations of perennial channels will influence how your results will be viewed by local stakeholders, so this is a critical step in developing your input data.

The process requires that the user view the flow network, a vector polyline layer, on-screen and interactively select those segments that fit the above description of a perennial stream segment. Using the field calculator in ArcMap, the segments selected should be calculated to a unique "StreamType" value (suggested value of "1" for perennial streams). It is useful during this process to utilize the hillshade ***AND*** aerial photography to determine where a channel and/or water are present. Additionally, the stream order of each flow network segment is included in the "StrahlOrd" field of the attribute table and may help speed the process. Color infrared (CIR) photography flown in the spring is particularly useful, as most streams will have water in them during this time and open water has an obvious dark appearance in CIR imagery. It is also easier to see streams when the leaves are off hardwood trees. By default, all flow network segments are originally given a “StreamType” value of 0.

While the user may come up with their own classification scheme, ***“StreamType” field values must be integers***. The classification scheme can be simple (1 to indicate perennial streams, 0 to indicate ephemeral or intermittent drainageways), or complex (0 – ephemeral or intermittent, 1 - perennial, 2 – floodplain or braided, 3 – wide river centerline). Many of the remaining ACPF tools generate more accurate results if they act upon a carefully selected subset of “StreamType > 0” classification values. For example, the stream network and catchments will be generated for only those flow network segments with a "StreamType" value >= 1, indicating perennial streams.

To calculate segments to a “StreamType” value of 1 (Figure 4):

1. Interactively select segment(s) where the “StreamType” field should be = 1. (To select multiple segments at once, hold the shift key down while selecting elements. It is helpful to make the flow network the “Only Selectable Layer” by right-clicking on the flow network feature class in the TOC and choosing the Selection tab.

TIP: If only part of a segment should be categorized as “StreamType” = 1, the segment may be split, which involves entering an editing session. Editor toolbar --->Start Editing ---> select the flow network as the layer to edit. Select the segment that should be split (only one segment can be selected at a time), and using the split symbol, split the line. The editing session must be ended before moving on to the next tool (Figure 5).

2. Once the segment(s) is selected, open the attribute table and right click on the “StreamType” field, then select “Field Calculator”.
3. Enter the value 1 in the box (figure 4), and hit OK. The segments selected should now have a “StreamType” = 1.
4. If a mistake is made during the field calculator process, simply select the segment where the mistake was made and calculate the “StreamType” field to the correct value.

NOTE: Segments classified to a “StreamType” value of 1 should constitute a continuous, perennial flow network. Care should be taken that small segments between stream confluences are not overlooked. There may be rare exceptions to this, where a disconnected perennial stream network may be representative of the surface hydrology, such as in cases of disappearing streams in karst landscapes, or in landscapes with braided stream systems where surface flow is not constrained within a continuous channel. It is ultimately a judgment call by the user to determine which stream segments constitute a perennial flow network. Firsthand knowledge of the watershed will often be helpful to make the judgments involved with defining the stream network.

NOTE: Only perennial flow segments (“StreamType” = 1) should be used to generate the stream reach and catchments in the next step of the toolbox.

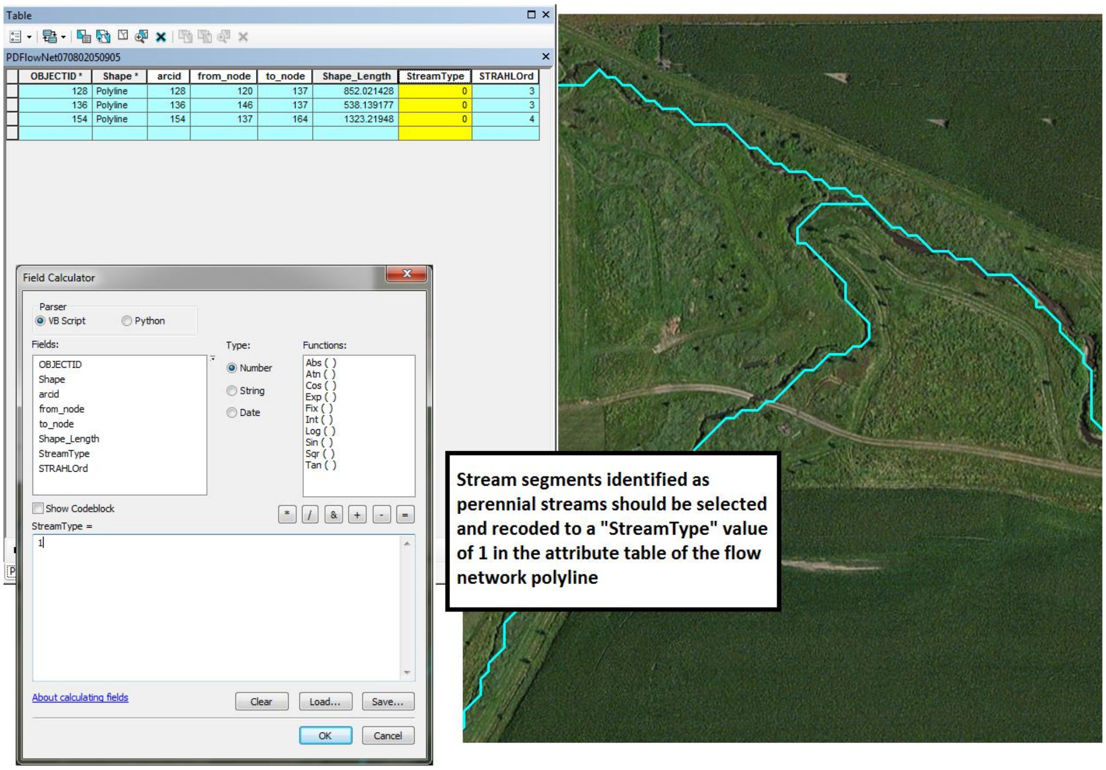


Figure 4. Field Calculation of “StreamType” field of the flow network

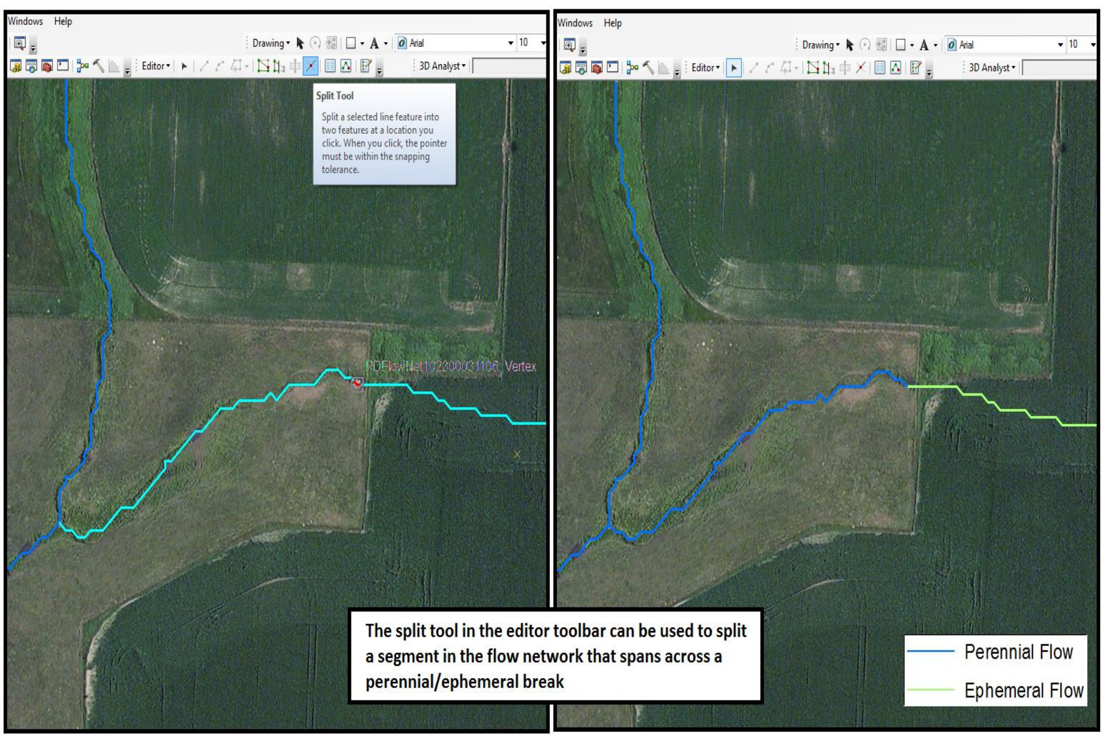


Figure 5. Splitting a stream segment using the editor toolbar

Generate Stream Reach Outputs

Required Inputs	Outputs
INPUT LAYER: Flow Network (AreaFlowNet + inHUC) or (PDFlowNet + inHUC)	Stream Reach polyline layer (StreamReach + inHUC)
INPUT LAYER: D8 Flow Direction raster (D8FlowDir + inHUC)	Catchments polygon layer (Catchments + inHUC)
INPUT LAYER: Filled DEM raster (DEMFill + inHUC)	
USER DECISION: Field name (StreamType) to create stream reach and catchment	
USER DECISION: Classification value (StreamType value)	
INPUT LAYER: Pour Points (optional)	

Once the “StreamType” field in the flow network file has been populated, a stream network (in the form of a stream reach polyline feature class) and a catchments file (in the form of a polygon feature class) are created. ***It is strongly advised to limit catchment and stream reach delineation to perennial flow segments, or those identified as having a “StreamType” value equal to 1*** (See step 2.C – Populating the “StreamType” field).

Both the stream reach and catchments layer are generated using the TauDEM software program. The stream reach will contain numerous fields in the attribute table (Table 3), several of which are required for use in later tools in the ACPF toolbox. Each reach (junction to junction) in the output stream reach will have a corresponding catchment, or drainage area, to that section of stream. The “LINKNO” field in the attribute table of the output stream reach will equal the “gridcode” field in the attribute table of its associated catchment.

NOTE: Unless the option to merge the stream reach with water bodies (Section 2.d) is chosen and implemented, this stream reach layer will represent the stream network in all future tools, including Runoff Risk Assessment, Riparian Function Assessment, and others.

NOTE: A new watershed boundary can be generated by manually dissolving those catchments that drain to the outlet of the watershed you are currently processing. This will move existing watershed boundaries to provide a new boundary based on the finer resolution of current DEM data sources. Note the original HUC boundaries were mapped at least several decades ago, through manual interpretation of relatively coarser resolution data and imagery. In cases of non-headwater watersheds, the use of pour points will provide a separation between catchments belonging to neighboring watersheds. This new boundary can then be used in all follow-on ACPF tools that ask for a watershed boundary. Please note that alteration of the watershed boundary may have jurisdictional implications for your watershed project. It will often be helpful to identify and clarify differences in watershed boundaries that occur according to new data sources. Watershed boundaries often cross near level areas and even fine resolution LiDAR-based DEMs data can present challenges for discerning boundaries with consistent accuracy. Local information such as drainage district maps can help identify actual flow directions in some situations.

Table 3. Stream Reach polyline attributes	
Attributes	**Description**
LINKNO	Link Number. A unique number associated with each link (segment of channel between junctions). This is an arbitrary number that varies depending on the number of processes used.
DSLINKNO	Link Number of the downstream link. -1 indicates that this does not exist.
USLINKNO1	Link Number of first upstream link. -1 indicates no links upstream.
USLINKNO2	Link Number of second upstream link. -1 indicates no links upstream.
DSNODEID	Node identifier for node at downstream end of stream reach.
Order	Strahler Stream Order
Length	Length of the link
Magnitude	Shreve Magnitude of the link. This is the total number upstream stream junctions.
DS_Cont_Ar	Drainage area at the downstream end of the link. This is one grid cell upstream of the downstream end because the drainage area at the furthest downstream grid cell includes the area of the tributary stream being joined.
Drop	Drop in elevation from the start to the end of the link
Slope	Average slope of the link (computed as drop/length)
Straight_L	Straight line distance from the start to the end of the link
US_Cont_Ar	Drainage area at the upstream end of the link
WSNO	Watershed number. Will be equal to both “LINKNO” and the “GRIDCODE” field of the output catchments feature class
DOUT_END	Distance, along flow paths, to the outlet from the downstream end of the link
DOUT_START	Distance, along flow paths, to the outlet from the upstream end of the link
DOUT_MID	Distance, along flow paths, to the outlet from the midpoint of the link

2.d Merge Stream Reach with Water Bodies (optional)

Required Inputs	**Outputs**
INPUT LAYER: Stream Reach polyline layer (from Section 2.c) (StreamReach + inHUC)	Stream reach and water bodies polyline (StreamReachWB + inHUC)
INPUT LAYER: D8 Flow Accumulation raster (D8FlowAcc + inHUC)	Water bodies polygon (optional)
INPUT LAYER: Lakes polygon coverage (optional)	
INPUT LAYER: Wide river polygon coverage (clipped to boundary (bnd)) (optional)	

SUMMARY

Open surface water bodies such as lakes, reservoirs, and wide rivers are an important feature of many watersheds. This step allows these features to be merged with the stream reach just created in Section 2.c. A coverage (or coverages) of water bodies, representing lakes and/or wide rivers, must be provided by the user. After this step, you will have two stream reach coverages, one with water bodies merged and one without, and may use either layer in future tools. In the Input/Output table for each succeeding tool that requires a stream reach coverage, the best choice of which coverage to use will be indicated.

IMPORTANT: Be aware that incongruencies can occur between water body polygons and lidar-derived flowpaths, especially where the terrain along the shoreline is flat. Flowpaths may weave in and out of water body polygons, or may not enter/exit lakes at the correct location. Similarly, lidar-derived stream centerlines may not coincide with (stay within) wide river polygons. A major effort should be taken to minimize these differences. These issues can be addressed either through further digitizing of the water body polygons, or editing of cut and dam lines to alter the lidar-derived flowpaths, as shown in Figure 6. If major incongruencies are not edited and removed, follow-on tools (such are riparian catchments, height above channel, and all riparian assessments) will give poor and inaccurate results.

PROCESS

Water bodies must be provided as closed polygons. The provided stream reach will be erased from the interior of water body polygons. Water bodies are then converted to polylines and merged with the stream reach polyline. The result is that the outline of lake polygons (lake shorelines), and the edge of wide river polygons will be represented as reaches in the output.

IMPORTANT: This tool does **NOT** alter flow direction values. Instead, the tool performs simple vector processing to merge the input water body polygons with the existing stream reach polyline. As a result, the resultant stream reach with water bodies merged does not “agree” with the terrain derivatives derived from the DEM. Due to this lack of agreement, TauDEM is unable to generate the same attributes as those generated for the stream reach with water bodies merged. All attributes are lost from the output stream reach with merged water bodies as a consequence. A spatial join is performed to recover the “LINKNO” value from the original stream reach ONLY where these reaches have not been modified. In locations where a wide river or shoreline has been merged, a unique LINKNO is given to each new reach (junction to junction). A water body type classification of “stream”, “shoreline”, or “wide river” is also assigned. Reaches in the output layer will be split at every junction with another (stream or shoreline) polyline.

Ensuring congruency between the stream reach and water body polygons, specifically that the existing stream centerline enters / exits water bodies in the correct location, as well as ensuring that the stream centerline does not weave in and out of water body polygons, will greatly improve the quality of the output layer. In some cases, disagreement between water body polygons and flow direction values may cause inaccurate delineation of drainage areas to the stream reach with water bodies merged. These differences will be seen in later ACPF tools, primarily the riparian catchment delineation. (Sec. 6a)

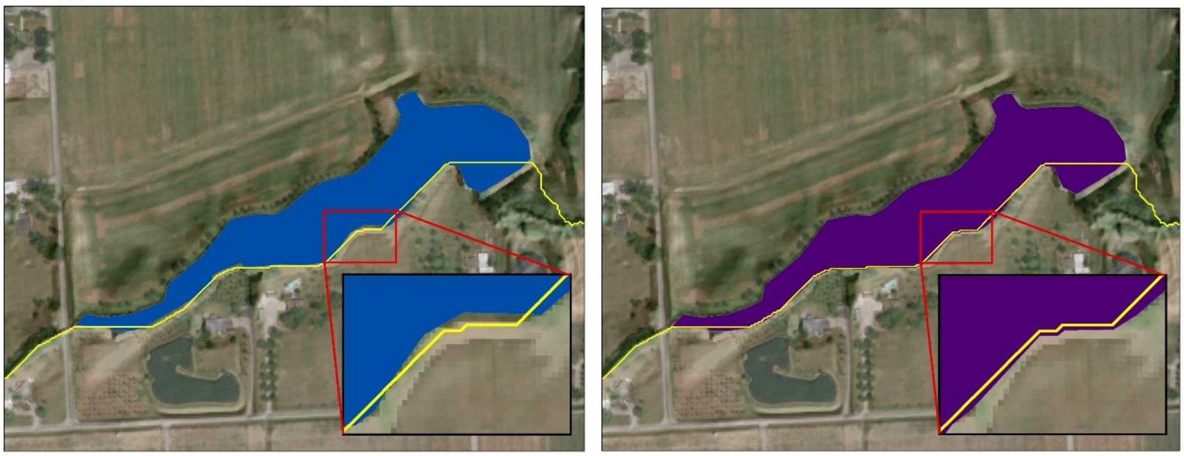


Figure 6. Left: Incongruence between stream centerline and lake polygon. Right: Congruence between stream centerline and lake polygon, following a manual edit of the lake polygon to ensure that the stream line is contained within the polygon.

While care should be taken to ensure this congruency between water body polygons and the input stream reach (through further digitizing or water body polygons or editing of cut and dam lines), differences will often remain. This tool performs a “behind the scenes” editing in an effort to ensure a clean output layer. Incongruent stream segments are identified following the merge of water-body and stream-reach polylines. Stream reaches with more than 1 intersection with a water body (i.e., that exit and re-enter a water body, which is not actually possible) are deleted from the output. Again, this processing DOES NOT alter any flow direction values or terrain derivatives.

Guidance on Inputs

Stream Reach

Input Stream Reach. This is created as a result of the "Create Stream Reach and Catchments" tool.

Lakes (optional)

Input lake polygon(s). Must be a polygon feature class and may contain multiple lakes to be processed at once. **NOTE:** It is recommended that lakes have a perimeter of at least 500 m to represent realistic riparian corridor management. We have found inconsistent results in subsequent tools in cases where small ponds are included in the merge process.

Wide Rivers (optional)
Input Wide River polygon(s). This must be a closed polygon feature class. It is recommended that wide river polygons be provided when the width of the river exceeds a threshold, such as > 3 times the resolution of the DEM. In most cases, streams in headwater watersheds will never reach a width that would require the creation of a wide river polygon.

Advantages of incorporating water bodies

The Output stream reach (polyline) with water bodies merged may be used as in input in all follow-on tools **that indicate acceptance of this dataset (tool input will specify 'stream reach with or without merged water bodies).** Important benefits from a merged stream polyline on succeeding ACPF tools include:

- Distance To Stream: Distance to stream will be calculated as the distance from each grid cell in the input raster to the stream reach merged with water bodies, rather than to a stream centerline that flows throughout the middle of a lake or wide river. This will improve the results of the runoff risk assessment, which uses distance to stream as a classifying variable.

- Height Above Channel: Height above channel values are calculated as the difference in elevation between each grid cell in the input raster to the channel grid cell into which it will flow. Channel cells will be represented by the stream reach merged with the water bodies.

- Riparian Catchments: Riparian catchments will be delineated along each stream reach in the input layer, which will include edges of wide rivers and lakeshores. This allows for conservation planning and riparian analysis to occur for lakeshores and in areas dominated by lakes and wide rivers.

3. Field Characterization

3.a By-Field Slope Statistics

Required Inputs	Outputs
INPUT LAYER: Field Boundary feature class (FB + inHUC)	By-Field Slope Table (SlopeTable + inHUC)
INPUT LAYER: Unfilled DEM (NewDEM + inHUC)	Slope Raster (Slope + inHUC)
USER DECISION: Z-factor	

The by-field slope statistics tool generates 2 outputs: 1) a slope raster (in percent rise), and 2) a slope table, containing slope related statistics on a field-by-field basis. The slope raster is created using the input DEM and the Slope tool in ArcGIS.

The slope table can be linked to the field boundary feature class through a unique "FBndID" field, and contains the following information for each field as attributes:

Table 4. By-Field Slope Table attributes	
Attributes	**Description**
FBndID	Field boundary ID: join field
MeanSlope	Mean slope (% rise) of each field
Slope75Pct	3^{rd} quartile (75^{th} percentile) slope value (% rise) of each field
Pct_lt1:	percentage of field less than 1% slope
Pct1_2:	percentage of field 1 – 2% slope
Pct2_5:	percentage of field 2 – 5% slope
Pct5_10:	percentage of field 5 – 10% slope
Pct10_15:	percentage of field 10 – 15% slope
Pct_gt15:	percentage of field > 15% slope

Slope statistics contained in this table will provide information to identify the extent of tile drained fields in the watershed, the relative risk of runoff among fields, and identify fields suitable for runoff control practices such as grassed waterways and contour buffer strips.

3.b Tile Drainage Classification

Required Inputs	Outputs
INPUT LAYER: Field Boundary feature class (FB + inHUC)	Drainage Table (DrainageTable + inHUC)
INPUT LAYER: Soils Raster (gSSURGO)	
INPUT TABLE: Slope Table (SlopeTable + inHUC)	
USER DECISION: AND/OR	
USER DECISION: Condition 2: SOILS	

The Tile Drainage Determination tool estimates which fields, among those with an "isAG" value of 1 or 2, are likely to be tile drained based on a combination of by-field slope and soils information. The output of the tool is a drainage table (drainagetable + inHUC), containing by-field slope and soils information and a drainage classification (YES, NO, or NonAg). Pastureland is included as agricultural land in the classification. "Null" values in the drainage classification indicates a field that drains entirely out of the watershed.

Two conditions are examined within each field; a slope condition and a soils condition, as defined below.

<u>Condition 1 (Slope):</u>
>= 90% of field is less than 5% slope

Condition 2 (Soils) (User must select one):

a. The field has a mean hydric soils percentage >= 10%. The percentage of hydric soil in a field is estimated as the area-weighted mean (% hydric) of all soil map units in the field. As of the 2015 version of the NCSS database, soil survey information estimates the typical extent (percent of area) of hydric soils (defined below) that would be expected within soil map unit polygons. A weighted average for the proportion of soil map units found in each field is calculated.
b. >= 40% of field consists of a dual drainage hydrologic group (A/D, B/D, or C/D) or D class soil.

The user must then select an AND/OR factor. If "AND" is chosen, both conditions (Slope and Soils) must be met in order for a field to be classified as tile-drained. Requiring both conditions to be met is more restrictive, and is suggested in landscapes where tile-drainage is not widespread. If "OR" is chosen, a field is considered tile-drained if either condition is met. An "OR" factor is more inclusive, and is suggested in landscapes where tile-drainage is widespread.

Soil attributes can be further defined as:

<u>Hydric Soils</u>

The National Technical Committee for Hydric Soils (NTCHS) defines a hydric soil as a soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part (Federal Register, 1994).

Hydrologic Group (Dual Drainage Classes)

Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

Dual drainage class soils are certain wet soils that are placed in hydrologic group D (i.e. water movement through the soil is restricted or very restricted) based solely on the presence of a water table within 60 centimeters of the surface, even though the saturated hydraulic conductivity may be favorable for water transmission. If these soils have been adequately drained, then they are assigned to dual hydrologic soil groups (A/D, B/D, and C/D) based on their saturated hydraulic conductivity and the water table depth when drained. The first letter applies to the drained condition and the second to the undrained condition. (NRCS, 2009).

It is ***strongly suggested*** that the user become familiarized with the NRCS gSSURGO data layer prior to selecting conditions from which to delineate tile-drained from non tile-drained fields. As soil surveys are traditionally based on county boundaries, oftentimes SSURGO data exhibit discrete county breaks, where attributes differ on each side of a county line. While appearance of political boundaries in soil surveys are being reduced through annual revisions to soil survey databases, and these updates are being included in the ACPF soils database, county boundaries may still appear in the soil data. To avoid using the less consistent soils input data in this and other queries using soils data, it is useful to view the different soil attributes prior to running the Tile Drainage Determination tool (Figure 7). To view the different gSSURGO attributes:

1. Add the gSSURGO layer for the current HUC12 watershed to an ArcMap document. In the attribute table of the gSSURGO raster, the two fields, “HYDROGRP” and “HYDRIC”, contain information on the mean hydric percent and hydrologic group designation for each mapunit.

2. Right click on the gSSURGO layer ---> Properties.

3. Under Symbology ---> Unique Values, select either the “HYDROGRP” or the “HYDRIC” field, then ---> Add All Values.

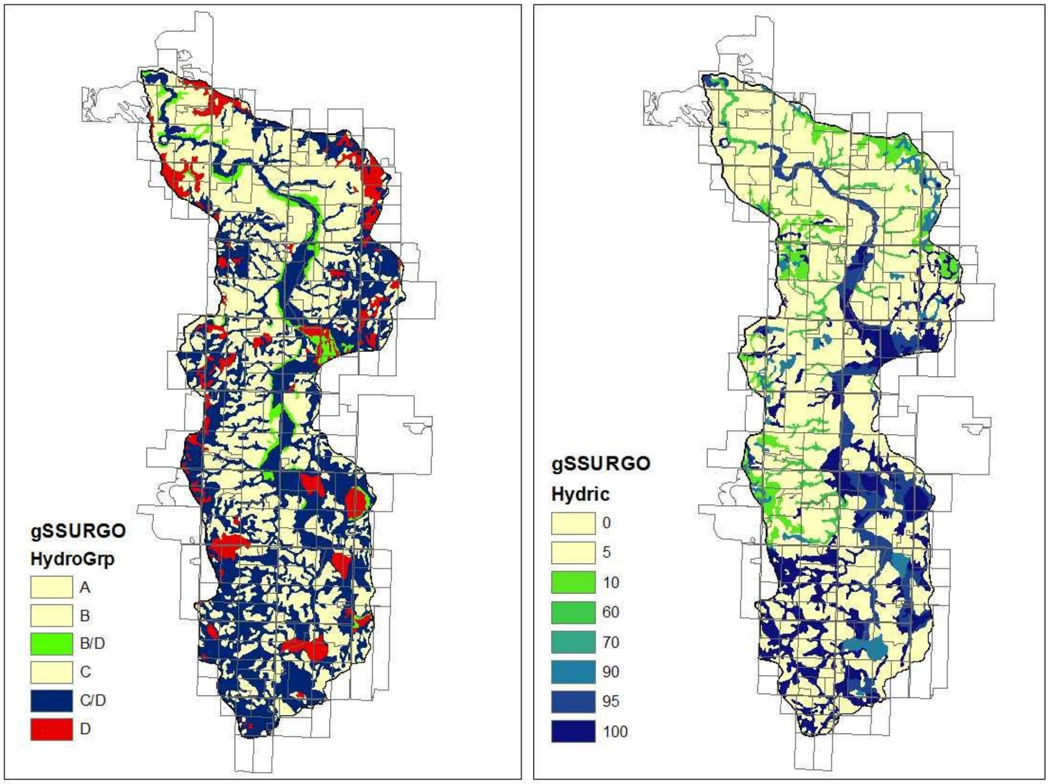


Figure 7. gSSURGO soil attributes included in Tile Drainage Determination tool

IMPORTANT: THESE ARE CONSIDERED DEFAULT CONDITIONS AND THE USER SHOULD INTERROGATE RESULTS FOR CONSISTENCY WITH LOCAL KNOWLEDGE AND KNOWN DISTRIBUTIONS OF TILE-DRAINAGE NETWORKS. The user may manually alter the drainage classification of a given field (i.e. altering a "NO" classification to a "YES" in the output drainage table) where additional local knowledge on drainage patterns exist, or if the user would like to alter the criteria used to estimate the existence of tile drainage. The user is free to re-designate fields as tile drained based on hydric, dual drainage, and slope criteria s/he may choose. Joins to land use (LU6_ + inHUC) and/or by-field slope statistics tables can provide the user wide discretion on specifying the tile drainage designations.

The drainage table can be linked to the field boundary feature class through the "FBndID" field, and contains the following information for each field as attributes:

Table 5. By-Field Drainage Table attributes

Attributes	**Description**
FBndID	Field boundary ID: join field
PctHyd:	Mean % hydric soil – area-weighted mean % hydric of all soil mapunits in field
PctDualDrg:	percentage of field that is a "dual drainage– (A/D, B/D, or C/D) or D class soil
PctSlp_lt5:	percentage of field that is less than 5% slope
Drained:	Drainage classification: YES (tile-drained), NO (non tile-drained) or NonAg

3.c Distance To Stream (D8)

Required Inputs	Outputs
INPUT LAYER: Stream Reach (StreamReach + inHUC or StreamReachWB + inHUC)	Distance To Stream raster (DistanceToStream + inHUC)
INPUT LAYER: D8 Flow Direction raster (D8FlowDir + inHUC)	
INPUT LAYER: Water Bodies polygon (optional, include if StreamReachWB + inHUC was input)	

The "Distance to Stream (D8)" tool uses an input Stream Reach (polyline) and a D8 Flow Direction grid to calculate the horizontal distance (in meters) to the channel from each grid cell, moving downslope according to the D8 flow model until a stream grid cell is encountered. The stream reach should represent only perennial flow, a distinction that is achieved by populating the "StreamType" field of the flow network prior to running the "Stream Reach & Catchments" tool.

The stream reach polyline is converted to a raster and serves as the input stream raster grid in the "D8 Distance to Stream" tool available in TauDEM software. The output is a Distance to Stream raster, a continuous grid where each cell value is the horizontal distance (in meters) from that cell to the stream reach, following the flow path defined by the D8 Flow Direction grid. Results of this tool are used to rank fields according to relative risk of sediment delivery (see 3.d Runoff Risk Assessment Tool).

3.d Runoff Risk Assessment

Required Inputs	**Outputs**
INPUT LAYER: Field Boundary feature class (FB + inHUC)	Runoff Risk Table (RunoffRiskTable + inHUC)
INPUT LAYER: Slope Table (SlopeTable + inHUC)	
INPUT LAYER: D8 Distance To Stream raster (DistanceToStream + inHUC)	

The 3 x 3 "runoff risk assessment" matrix is completed for ***agricultural fields only*** (identified by an "isAG" value of "1" or "2" in the attribute table of the field boundary feature class), and is used to classify a given field according to its risk of direct runoff contribution to stream channels in the watershed. Risk classification includes A (very high risk), B (high), C (moderate), and D (low) designations.

Runoff Risk Assessment:
Prioritize fields where multiple erosion control practices are most needed

Close to stream?

Slope steepness	Yes		No
H	A	B	C
M	B	C	D
L	C	D	D

Figure 8. Runoff Risk Matrix (Tomer et al., 2015b)

The two sides of the matrix create a cross-classification of two variables: 1) slope steepness, and 2) proximity to stream. A sediment delivery ratio (SDR) is used as proxy for stream proximity. A slope steepness and SDR value is found for each agricultural field and converted to a rank (high, med, or low) for each field. These two variables are then used in a cross classification to characterize runoff risk on a by-field basis.

Input Variables

1. By-field Sediment Delivery Ratio

The sediment delivery ratio is calculated using an equation developed by Ouyang and Bartholic (1997), which is used in the Minnesota Phosphorus Index (Lewandowski et al., 2006) and is described by:

$$SDR = x^{-0.2069}$$

Where; x is the distance, in feet, from the ***edge of each field*** to the nearest stream.

A distance to stream raster, generated as an output of the "D8 Distance to Stream" tool, is used to calculate stream proximity. Each cell value in the input grid is equal to the horizontal distance (in meters) to the stream, moving downslope according to the D8 flow model, until a stream grid cell is encountered. Distance to the stream ***from the field edge*** is estimated using the ***minimum distance to stream value*** found within each field. This minimum distance value is translated to a sediment delivery ratio for each field using the equation above. Fields within 10 feet of the stream are considered to border the stream, and the distance value is converted ('adjDTS') to 1 foot, resulting in an SDR value of 1. Fields within 10 feet of the stream are assigned an SDR value of 1, while fields 5,000 ft or further from the stream receive a value of 0.17, the lowest SDR value suggested using this P Index equation (Lewandowski et al., 2006).

2. By-field Slope Steepness

The slope steepness of each field is identified as the 3rd quartile, or 75th percentile, slope value (in % rise) within each field. That is, 25% of the field consists of slopes greater than this value. Use of the 75th percentile slope estimate is appropriate based on the following statement from the MN P Index:

> "Sediment and phosphorus are not lost evenly from all parts of a field, but come from a few critical source areas called the 'most limiting areas of significant extent', which are generally the areas with the steepest slope (Lewandowski et al., 2006). 'Of significant extent' means that the 'most limiting area' selected should represent the characteristics of at least 20% of the field."

Ranking of fields

Prior to performing a cross classification, each agricultural field must be classified into a high, medium, or low rank for each of the two input variables. The user is given two options for each of the input variables: 1) To provide thresholds for classification of slope and/or SDR values into a high, medium, or low classification, or 2) Allow thresholds to be automatically generated using a 20%-40%-40% split. These two options are described below.

User-Provided Thresholds

The user may provide thresholds to classify fields into a high, medium, or low rank for each of the two input variables.

1. Sediment Delivery Ratio

If specified by the user, the High SDR will represent the value (decimal between 0 and 1) ***above which*** a field will be classified as "high", and the Medium SDR will represent the value ***above which*** a field will be classified as “medium”. Values below Medium SDR will be classified as “low”. The lowest SDR value is 0.17, which corresponds to those field >= 5000 ft from the stream. We suggest considering stream buffer distances when selecting the SDR value that distinguishes High from Medium classes of sediment delivery. Fields bordered by a riparian buffer having widths of 20, 30, and 50 ft would have SDR values of 0.54, 0.49, and 0.45, respectively. A threshold of 0.4 (equates to ~80 feet from edge of field to channel) would highlight all fields near the stream that do not have relatively wide riparian buffers as having a ‘high’ SDR, while a threshold of 0.6 (equates to ~10 ft from edge of field to channel) would only select fields that have virtually no buffer between the field and the stream as having a ‘high’ SDR. The second threshold the users selects demarks the ‘medium’ from ‘low’ SDR classes. This value cannot be less than 0.17. Choosing a value between 0.30 and 0.17 is suggested to designate fields within >350 to >5000 ft of the stream as having ‘Low’ SDR. See table 6 and Figure 9 below for a conversion chart between SDR and distance.

Table 6. Conversion between SDR and distance from edge of field to stream. From the MN Phosphorus Index

Distance From Edge of Field to Stream	SDR (Sediment Delivery Ratio
1 foot	1
10 feet	.62
20 feet	.54
30 feet	.49
50 feet	.45
75 feet	.41
100 feet	.39
150 feet	.35
200 feet	.33
500 feet	.28
1000 feet	.24
1500 feet	.22
2000 feet	.21
2650 feet (1/2 mile)	.20
5000 or greater	.17

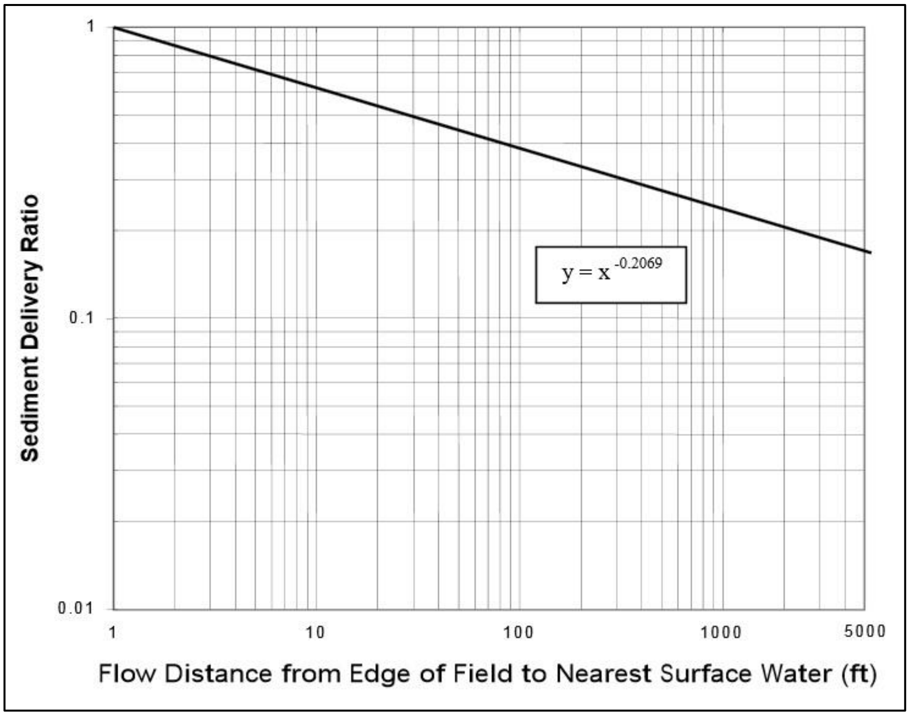


Figure 9. Sediment Delivery Ratio (SDR) plotted against Flow Distance from Edge of Field to Nearest Surface Water.

2. Slope Steepness
The by-field slope value represents the steepest 25% of the field. This option allows the user to specify two slope thresholds against which the 75th percentile slope will be classified to identify which fields will be classified as "High", "Medium" and “Low” steepness. The larger value will separate “High” from “Medium” steepness fields, while the smaller value will distinguish between “Medium and “Low” steepness fields. The user will need to consider the landscape in defining these breakpoints. In flat, heavily tile-drained watersheds, High > 5% and Low < 2% (with 5% < Medium < 2%) might adequately segregate the relative steepness of fields, whereas in more dissected terrain, values in 10 - 15% and 5 – 8% ranges might best segregate fields by relative steepness.

<u>No thresholds provided (default)</u>
If user-provided threshold values are not provided for SDR or slope, thresholds will be automatically generated according to a 20-40-40 breakdown of fields. That is, the top 20% of fields (steepest 20%, nearest 20% to stream) will be given a “high” classification, while the next 40% of fields will receive a “medium” classification, and the lowest 40% of fields will receive a “low” classification.

NOTE: The 20-40-40 breakdown may not always be consistent with the actual distribution of SDR estimates. For example, if more than 20% of the fields border the stream, and therefore receive a SDR value of 1, more than 20% of fields will be classified into the “high” category. This issue does not arise with the slope steepness classification.

NOTE: Threshold values may be provided for one of the input variables (slope steepness or SDR) while allowing the other variable to be classified according to the automatically generated 20-40-40 breakdown.

Runoff Risk Classification

Once the cross classification is applied, each agricultural field will receive a runoff risk classification, ranging from A (very high), to B (high), C (moderate), and D (low). A "low" classification does not mean that a runoff-control conservation practice would not benefit a given field, but rather indicates that other fields have a greater potential to deliver sediment and phosphorus to the stream via surface runoff.

The output runoff risk table contains detailed information for each agricultural field found during the runoff risk assessment. The table can be linked to the field boundary feature class through the "FBndID", and contains the following information for each agricultural field as attributes:

Table 7. Runoff Risk Table attributes

Attributes	**Description**
FBndID	Field boundary ID: join field
DTS_ft	Minimum distance to stream, in feet, for each agricultural field.
AdjDTS	Adjusted minimum distance to stream, in feet, for each agricultural field. If DTS_ft < 10, the distance is converted to 1.
SDR	Sediment delivery ratio for each agricultural field according to MN Phosphorus Index, using the AdjDTS
Slope75Pct	3^{rd} quartile, or 75^{th} percentile, slope value in % rise within each field
SDRRank	SDR rank (High, Medium, or Low)
SlopeRank	Slope steepness rank (High, Medium, or Low)
RunoffRisk	Runoff risk classification: A Very high, B High, C Moderate, D Low

4. Precision Conservation Practice Siting

4.a Depression Identification

Required Inputs	**Outputs**
INPUT LAYER: Unfilled DEM (DEM + inHUC)	Depressions polygons (Depressions + inHUC)
INPUT LAYER: gSSURGO soils raster (gSSURGO)	Depression Depth raster (optional)
USER DECISION: Z-factor	
INPUT LAYER: Field Boundary feature class (FB + inHUC) (optional)	
INPUT LAYER: Stream Reach (StreamReach + inHUC) (optional) Use non-merged stream reach	
INPUT LAYER: Water Bodies (optional)	

Depressions are common in the glacial landscapes of the Midwest and present challenges for managing water quality and wetness of fields. Poorly drained and hydric soils are common in these depressions, and to enable cropping of areas subject to surface ponding, drainage has often been improved by installing surface drains (or intakes) as part of in-field tile drainage systems. Conservation practices that may be appropriate in depressions can include filter practices to treat water entering the tile intakes, with impacts on drainage rate that are acceptable. There are several types of intake filter practices including blind (sand-bed) intakes and grass buffers. Wetland restorations may also be feasible where soil wetness in depressions is frequently problematic for crop production. The potential benefits of these practices include reduced sediment and phosphorus loads, and water storage. See Smith and Livingston (2013), and Kessler and Gupta (2015) for further discussion of specific practice options to manage water in topographic depressions.

Locations of depressions in agricultural fields may be suited for several types of conservation practices, including **NRCS practice codes: 620 - Underground Outlet, 657 – Wetland Restoration**

The Depression identification tool identifies surface depressions in the input DEM. This is performed by performing a "fill" process on the input DEM, then subtracting the input DEM from the filled DEM. Depression regions are then converted to polygons, and polygons are overlaid with the input DEM to extract the range of elevation values within each depression. This range of values represents the maximum depths of ponding that may occur in each depression. Polygons are also overlaid with gSSURGO to determine the mean percent of hydric soils within each depression.

The user has the option to limit the extent of depressions based on user specifications. This can include none, all, or a combination of the following criteria:

1) The mean percent hydric soils within each depression must be greater than a user-specified value.

2) Depressions must be centered on agricultural fields (including pasture), as identified by an "isAG" value of “1” or “2” in the attribute table of the field boundary feature class.
3) Depressions cannot intersect the stream reach.
4) Depressions cannot be centered within water bodies.
5) Depressions must have a minimum depth of (x) cm.
6) Depressions must have a minimum surface area of (y) acres.

NOTE: Even using a hydrologically conditioned DEM or after running the “Manual Cutter” tool, ***there will likely still be some artificial depressions*** associated with roads or artifacts of the terrain processing (Figure 10).

NOTE: After running the depression identification tool, it is ***strongly suggested*** that the output layer be reviewed, and any false depressions be manually deleted. Once edited, the layer can be used as an input to the "Depression Watersheds" tool to identify the drainage area to each depression. Alternatively, the user may interactively select true depressions on-screen rather than delete false depressions. When used as an input to the Depression Watersheds tool, the selection will be honored and watersheds will be found for only those depressions selected.

NOTE: If the “Output Depression Depth Raster?” is checked, a depth raster will be output to the file location provided. Each grid cell indicates the depth of the depression in that location, in the same vertical units as the input DEM.

The output depression feature class (Depressions + inHUC) contains the following information for each depression as attributes.

Table 8. Depression polygon attributes	
Attributes	**Description**
Depress_ID	Unique ID for each depression
PctHydric	Mean % hydric soil of each depression
MaxDepthCM	Maximum depth (in cm) of each depression

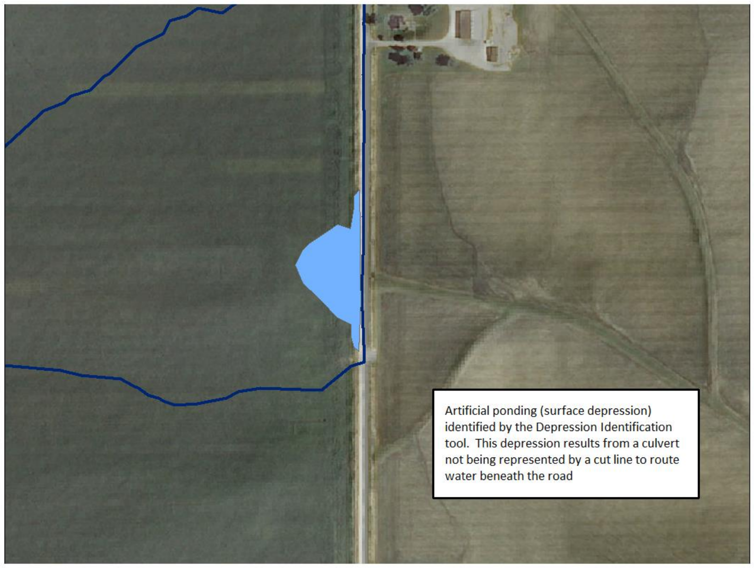


Figure 10. False depression identified at location of a culvert/road intersection.

4.b Depression Drainage Area

Required Inputs	Outputs
INPUT LAYER: Depressions polygon feature class (Depressions + inHUC)	Depression Drainage Area polygons (Depress_Wsheds + inHUC)
INPUT LAYER: Input DEM (NewDEM + inHUC)	

The "Depression Drainage Area" tool delineates watershed contributing areas to each unique depression in the input Depressions feature class.

NOTE: In contrast to most other tools in the ACPF toolbox, D8 Flow Direction values for the Depression Drainage Area tool are derived from an ***unfilled DEM***. This is to prevent upstream depressions from being included in the drainage area of a lower depression.

NOTE: This tool should only be run following a manual review of the "Depression" feature class, during which false or inaccurate depressions are manually deleted. Alternatively, the user may interactively select true depressions on-screen rather than delete false depressions. When used as an input to the Depression Watersheds tool, the selection will be honored and watersheds will be found for only those depressions selected.

The output is a Depression Drainage Areas feature class (Depress_Wsheds + inHUC), which can be linked to the depression feature class through a "Depress_ID" field, and contains the following information for each drainage area as attributes.

Table 9. Depression Drainage Area polygon attributes	
Attributes	**Description**
Depress_ID	Unique ID for each depression; can be used as join field with Potholes layer
DrainageHA	Drainage area (in hectares) to each unique depression

4.c Drainage Water Management

Required Inputs	Outputs
INPUT LAYER: Unfilled DEM (NewDEM + inHUC)	Drainage Management polygons (DrainageMgmt + inHUC)
INPUT LAYER: Field Boundary feature class (FB + inHUC)	
INPUT Table: Drainage Table (DrainageTable + inHUC)	
USER DECISION: Z-factor	
USER DECISION: CONTOUR INTERVAL (default is 1 meter, may range from 0.3-1.5 meters)	
USER DECISION: EITHER Minimum Percent of Field (30-100%) OR Minimum Acreage (default is 20 ac) within field that user-defined contour must occupy	

A controlled drainage system reduces nitrogen loads by raising the in-field water table during part of the year, thereby reducing overall tile drainage volume. Other processes such as denitrification may be enhanced but this has not yet been confirmed by research. Several published studies have evaluated tile discharge and nutrient loads under drainage water management systems (e.g., Williams et al., 2015). The water table is controlled through the use of gate structures that are adjusted at different times during the year. When field access is needed for planting, harvest or other operations, the gate can be opened fully to allow unrestricted drainage. When the gate is used to raise water table levels in the midst of the growing season, this may allow more plant water uptake during dry periods, which can increase crop yields. Crop grain yield increases have been documented with controlled drainage and this has primarily been attributed to the increased availability of soil water (Delbecq et al., 2012).

NRCS practice codes: 554 – Drainage Water Management

Controlled drainage may be used on fields with flat topography (typically one percent or less slope), such as in flood plains and on flat fields typical of the large areas of the glaciated Midwest. The practice can be expensive to design and install in areas with slopes steeper than about one percent because of the number of control structures required in a typical field.

A single control gate (depending on its design) can influence the water table in an area of a field that has about a 0.5 meter change in elevation. To identify fields potentially suited to this practice, the Drainage Water Management tool identifies all areas within tile-drained, agricultural fields where a contour interval between 0.3 and 1.5 m (chosen by the user), comprises more than a minimum acreage or a minimum user-defined percentage of the field (must be at least 30% of the field).

Process

Only tile-drained fields are tested for controlled drainage suitability, which are identified using the "drainage" classification output of the Tile Drainage Classification tool (Section 3.b). Using the contour interval specified by the user, the tool works by finding the number of contour intervals ***(rounded to the nearest integer)*** that can exist within a given field, based on the total range of elevation values. For example, a field with an elevation range of 432 cm contains approximately four 1-meter contours, while a field with an elevation range of 476 cm contains approximately five 1-meter contours.

432/100 = 4.32 -----> 4 (Round down)
476/100 = 4.76 -----> 5 (Round up)

The field is then sliced into that number of equal-interval elevation zones, and each zone is analyzed for drainage management suitability based on areal extent. If any zone occupies more than the minimum acreage or the minimum user-defined percentage of the field, that field is flagged as a candidate for controlled drainage and the contour zone is added to the output drainage management opportunity feature class.

NOTE: There may be more than one contour-interval zone for a given field that meets the selection criteria, if more than one zone comprises more than the user-selected percentage of the field (applies if that percentage is <50%).

NOTE: Actual implementation of controlled drainage will typically require more detailed survey information on field topography and drainage patterns than ACPF products provide, because existing tile drainage patterns and possible impacts on neighboring fields must be determined. Alteration or replacement of tile may often be required.

NOTE: The user is expected to identify the contour interval (minimum is 0.3 m; maximum is 1.5 m; default is 1.0 m) and a minimum percentage of the field that the area found within the zone must occupy to be flagged as a candidate site, with a minimum of 30% of the field or a minimum acreage that the area found must occupy. The contour interval may be varied to allow for different designs and landscape settings in which water table control gates may be used as a part of drainage management systems. A contour interval that exceeds 0.5 m will increase the likelihood that multiple gate structures will be needed to control water table elevations. That is, more complicated engineering designs may be necessary if a large contour interval is selected. Choosing a smaller contour interval will reduce the number of fields that meet the criteria, but this may be appropriate in very low relief (e.g., lacustrine) landscapes.

The output is a Drainage Management polygon feature class (DrainageMgmt + inHUC), which contains all contour zone(s) within each field that meet the above criteria.

Table 10. Drainage Management polygon attributes	
Attributes	**Description**
FBndID	Field boundary ID: join field
cont_acres	Size (in acres) of area within the contour interval
fld_acres	Size (in acres) of the field
pct_field	Percentage of the field that lies within the contour interval
cont_int	Contour interval chosen.

4.d Moore Terrain Derivatives

Required Inputs	Outputs
INPUT LAYER: Filled or Unfilled DEM (DEMFill + inHUC or NewDEM + inHUC)	Specific Catchment Area raster (SCA + inHUC)
INPUT LAYER: Slope raster (Slope + inHUC)	Stream Power Index raster (SPI + inHUC)
	Topographic Wetness Index raster (TWI + inHUC)

Secondary topographic attributes combine two or more primary attributes (slope, aspect, plan and profile curvature, flow-path length, and upslope contributing area), and can be used to characterize the spatial variability of specific hydrological, geomorphological, and ecological processes occurring in landscapes (Wilson and Gallant, 2000). The Moore Terrain Derivatives tool generates two of these secondary topographic attributes from an input digital elevation model, and can be used to infer surface characteristics about the susceptibility of landscapes to erosion (Stream Power index - SPI) and the landscape distribution of soil water movement and accumulation (Topographic Wetness index - TWI).

The D-infinity approach to flow routing is employed to allow for flow divergence to be represented and to more robustly model the movement of water across a surface. The D-infinity approach was developed by Tarboton (1997), and allows flows from a single grid cell to be proportionally distributed to two downstream cells, rather than a single cell as with the D8 flow model. (Figure 11) The procedure is based on representing flow direction as a single angle taken as the steepest downward slope on the eight triangular facets centered at each grid point. Upslope area is then calculated by proportioning flow between two downslope pixels according to how close this flow direction is to the direct angle to the downslope pixel (Tarboton, 1997)

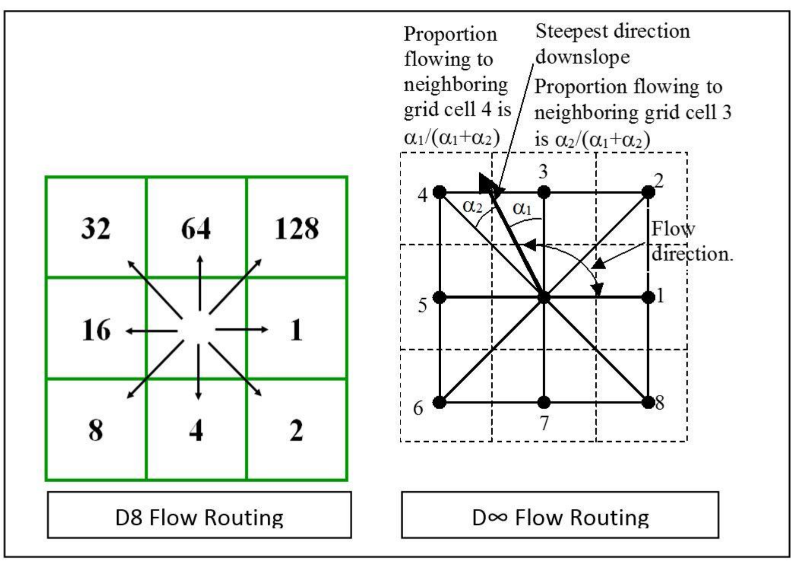


Figure 11. Comparison of D8 and D∞ flow routing algorithms (Tarboton, 1997).

In the tool interface, the user will provide an input DEM. This DEM may be filled or unfilled, depending on user preference. The choice to use a filled vs. unfilled DEM requires thoughtful evaluation of the quality of your DEM as well as landscape characteristics. Subsequent tools, primarily grassed waterway siting, utilize Moore's Stream Power Index (SPI) raster, where high SPI values indicate potential locations for grassed waterways. Values for SPI can differ significantly depending on the input DEM, as SPI values represent a normalized multiplication of 2 primary terrain derivatives; slope and flow accumulation. Use of an unfilled DEM will tend to have a lower overall range of flow accumulation values due to flowpaths being interrupted by sinks or pits, while use of a filled DEM, with fully connected flowpaths, will see increased flow accumulation values due to increased flowpath length. The increased flow accumulation associated with the filled DEM will result in a higher range of SPI values.

In medium to highly dissected landscapes, characterized by steeper ground and fewer depressions/potholes, a filled DEM is the preferred input. In these landscapes, a fully connected hydrologic network is desired, while concurrently reducing erroneous sinks in the DEM considered to be LiDAR artifacts.

In poorly dissected landscapes, characterized by low slopes and often poorly drained land with frequent depressions/potholes, an unfilled DEM will often be the preferred input. A fully connected hydrologic network is atypical in these landscapes, as many flowpaths terminate in depressions rather than flowing to the watershed outlet. Use of an unfilled DEM will result in lower SPI values in depressions and low-sloping areas, reducing the likelihood that these areas are suggested for grassed waterways. Erroneous or 'artifact' sinks in LiDAR-derived DEMs, however, often occur along flow paths (including small gullies), and should be filled to prevent flowpath lengths from being inappropriately shortened. Otherwise, low SPI values will occur in areas where a grassed waterway may be appropriate or even a high priority. We strongly advise running the pit-fill hole-punch tool in the utility section of the ACPF to fix many of the issues associated with artifact sinks in the DEM. This tool is designed to fill small pits in the original DEM, enabling better connectivity of flow paths. But, if these artifacts persist, use of a filled DEM may be appropriate even in poorly dissected landscapes. In these cases, it is suggested that the user provide the depressions feature class to the grassed waterway tool (following a manual review/edit session to remove false depressions) to prevent grassed waterways from being sited through depressions.

The DEM is first processed through a D-infinity flow routing algorithm to generate a specific-catchment-area (SCA) grid, in which SCA is the contributing area per unit contour length (that is, SCA = contributing area divided by grid-cell size). The contributing area of each grid cell is taken as its own contribution plus the contribution from upslope neighbors that have some fraction draining to it according to the D-infinity flow model.

The output specific catchment area grid is then used, along with a user-provided slope raster, to generate the following secondary topographic attributes:

- Stream Power Index (SPI) The stream power index is a measure of the erosive power of flowing water based on the assumption that discharge (q) is proportional to specific catchment area. The index predicts net erosion in areas of profile convexity and net deposition in areas of profile concavity (decreasing flow velocity). High SPI values indicate a greater erosive power. The equation for SPI is defined as:

SPI = ln(SCA * tan β), *where SCA is specific catchment area and β is slope in degrees.*

- Topographic Wetness Index (TWI). The topographic wetness index assumes steady state conditions and uniform soil properties to predict zones of saturation where specific catchment area is typically large and slope is small. High TWI values indicate a greater likelihood of saturation. The equation for TWI is defined as:

TWI = ln(SCA / tan β), *where SCA is specific catchment area and β is slope in degrees.*

NOTE: Values of .001 are added to both the SCA and β grids to prevent errors associated with division by 0.

4.e Grassed Waterways (SPI Threshold)

Required Inputs	Outputs
INPUT LAYER: Stream Power Index raster (SPI + inHUC)	Grassed Waterway polylines (GrassWaterways + inHUC)
INPUT LAYER: Field Boundary feature class (FB + inHUC)	
USER DECISION: EITHER Standard Deviation Threshold or SPI Value Threshold	
INPUT LAYER: Stream Reach polyline non-merged (StreamReach + inHUC)	
INPUT LAYER: Water Body polygon (optional)	
INPUT LAYER: Depression polygon (optional) (Depressions + inHUC)	

Grassed waterways are installed to reduce the risk of concentrated flow (gully) erosion. This practice may be effective in preventing gully erosion for three reasons. First, the growing grasses can reduce mean velocity of runoff, which discourages soil detachment. Second, grass vegetation subjected to high water velocity may be pushed to lie flat on the surface, and the flattened grass may then provide a physical barrier to prevent gully formation. Third, the fibrous root systems of grasses lead to increased soil strength, which can limit detachment of soil particles that otherwise may be prone to occur with seepage from the soil surface under saturated conditions. Although grassed waterways are among the most common of conservation practices, they remain under-utilized in many of the country's steeper farmed landscapes, and their capacity to reduce erosion under saturation excess runoff (seepage) conditions may be under-appreciated. Grassed waterways have not been the most frequently evaluated practice in recent conservation-effectiveness research, but several papers by Fiener and Auerswald (2003; 2006) provide a good starting point to learn more. We emphasize that grassed waterways are designed to convey runoff, and are not meant to trap sediment.

The grassed waterways – SPI threshold tool applies a user-defined threshold to an input stream power index (SPI) raster. SPI is a measure of the erosive power of flowing water, and is based on the assumption that discharge (q) is proportional to specific catchment area. SPI predicts net erosion in areas of profile convexity and net deposition in areas of profile concavity (decreasing flow velocity). The tool interface requires that the user define either a standard deviation threshold (between 2 and 5 standard deviations above the mean SPI value), or a specific SPI value. SPI values that are greater than the value specified will be selected as locations suitable for grassed waterways. SPI values above the selected threshold are first recoded to a value of 1, then smoothed using a majority filter. Values of 1 are expanded by 1 cell to increase overall connectivity between cells, then thinned to a maximum width of 1 cell. Regions are then converted to an output polyline layer. The input stream reach polyline is converted to a raster and serves to remove grid cells corresponding to the stream network. The output is clipped to agricultural field (excluding pasture) as identified by an "isAG" value of "1". Finally, grassed waterways less than 50 meters in length are excluded from the output.

NOTE: The choice to use an unfilled or filled DEM to generate the Stream Power Index raster can have a major impact on results. See further discussion on this topic in section 3.d Moore Terrain Derivatives.

NOTE: it is suggested that the user provide the depressions feature class to the grassed waterway tool (following a manual review/edit session to remove false depressions) to prevent grassed waterways from being sited through glacial depressions that are found in many Midwestern landscapes. In addition, if lakes and or wide river polygons are available, these should also be provided to prevent siting waterways through water bodies.

4.f Contour buffer strips

Required Inputs	**Outputs**
INPUT LAYER: Field Boundary feature class (FB + inHUC)	Contour Buffer Strip polygons (CBS + inHUC)
INPUT LAYER: Slope raster (Slope + inHUC)	
INPUT LAYER: Slope table (SlopeTable + inHUC)	
INPUT LAYER: Unfilled DEM (NewDEM + inHUC)	
INPUT LAYER: D8 Flow Accumulation raster (D8FlowAcc + inHUC)	
USER DECISION: Z-factor	
USER DECISION: Buffer Strip Width (feet, default is 15 feet)	

Contour buffer (or filter) strips are strips of perennial vegetation planted along topographic contours, which may be alternated with wider cultivated strips that are farmed on the contour. Contour buffer strips are in-field runoff control practices that use permanent vegetation to decrease the length of slopes along which runoff accumulates, and thereby reduce sheet and rill erosion. They are similar yet complementary to grassed waterways because both use grass vegetation, but contour buffer strips are oriented differently by being placed along topographic contours to intercept flows. This practice can be used in combination with grassed waterways, but the types of grass may differ with stiffer stems being preferred in buffer strips. The Contour Buffer Strip tool identifies locations for buffer strips in agricultural fields that, when located along the contour and in areas of high slope, will intercept the largest amount of runoff in a given field. This typically occurs at lower slope (i.e., footslope) positions. This approach is, in essence, based on recent research in Iowa that has documented benefits of reduced runoff volume and improved water quality derived from installation of contour buffer strips, particularly when placed at footslope positions (Zhou et al., 2014; Hernandez-Santana et al., 2013).

NRCS practice codes: 332 – Contour Buffer Strips

NOTE: The Contour Buffer Strips tool acts on ***agricultural fields only*** (i.e. an “isAG” value of “1”). Fields identified as pasture (i.e. an “isAG” value of “2”), will be omitted from the analysis.

<u>**Process**</u>

A mask of 4 - 15% slope is generated ***for agricultural fields only (excluding pasture).*** The mask is smoothed by majority filter and interior holes smaller than 1/2 acre are filled in.

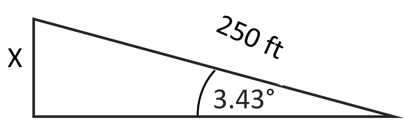
Table 11 shows the maximum allowable terrace spacing (as defined by the NRCS) for given slope ranges. (NRCS, 2014).

Table 11. NRCS Maximum Terrace Spacing based on erosion prediction tools	
Field Grade in %	**Maximum Spacing (in feet) with Soil Loss to "T"**
3.6 - 5.5	300
5.6 - 8.5	250
8.6 - 12.5	200
12.6 - 18	150

Terrace spacing values from Table 11 are adapted for use in the ACPF as described in Table 12. Contours are generated ***within the slope mask*** on a by-field basis. ***Contour intervals are chosen so that resulting contours are spaced approximately equal to the NRCS-recommended spacing, using the 3rd quartile slope value of each field***. Three contour interval values are possible, and are determined using the mean value (representative slope) of each slope range. The process is described in detail in the below examples.

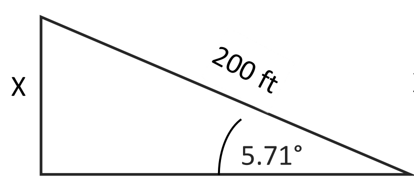
Table 12. Adapted ACPF spacing based on 3rd quartile slope and NRCS recommendations			
3rd quartile slope (%) value of field	**Suggested spacing (feet)**	**Representative slope used to determine contour interval**	**Contour Interval (to achieve suggested spacing (ft in elevation)**
4 – 8	250	6	14.75
8 – 12	200	10	19.8
12 - 15	150	13.5	20.1

Example 1:
3rd quartile slope range: 4–8%
Representative slope: 6%
6% slope = 3.43°
Recommended spacing: 250 ft



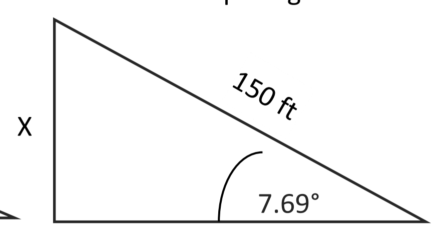
Contour interval = X
Sin(3.43°) = X / 250 ft
X = 14.75 ft

Example 2:
3rd quartile slope range: 8-12%
Representative slope: 10%
10% slope = 5.71°
Recommended spacing: 200 ft



Contour interval = X
Sin(5.71°) = X / 200 ft
X = 19.8 ft

Example 3:
3rd quartile slope range: 12–15%
Representative slope: 13.5%
13.5% slope = 7.69°
Recommended spacing: 150 ft



Contour interval = X
Sin(7.69°) = X / 150 ft
X = 20.1 ft

Contours ***that have a length of at least 100 meters*** are selected and buffered to a user-specified width (buffer strip width).

Concentrated flow pathways greater than 2 acres in upstream drainage are buffered by 10 meters on each side and removed from the contour buffer strip output. As a result, contour buffer strips are not sited through concentrated flow pathways, but are instead generated on the side slopes flanking these drainageways.

Output buffers strips are smoothed using a PAEK algorithm (Polynomial Approximation with Exponential Kernel) to smooth sharp angles and provide results that should better accommodate farming operations. Note output contour location will usually need to be further modified or smoothed to maintain trafficability for farm implements (that is, results should not be viewed as an actual suggested design/layout for the practice in any given field). A field boundary ID (FBndID) and mean slope is attributed to each contour buffer strip included in the output layer.

Table 13. Contour Buffer Strip polygon attributes

Attributes	**Description**
FBndID	Field boundary ID
Mean Slope	Mean slope (in % rise) of each buffer strip

4.g Edge of field Bioreactors

Required Inputs	Outputs
INPUT LAYER: Field Boundary feature class (FB + inHUC)	Bioreactor feature class (Bioreactors + inHUC)
INPUT LAYER: Drainage table (DrainageTable + inHUC	
INPUT LAYER: Unfilled DEM (NewDEM + inHUC)	
INPUT LAYER: D8 Flow Accumulation raster (D8FlowAcc + inHUC)	
INPUT LAYER: D8 Flow Direction raster (D8FlowDir + inHUC)	
INPUT LAYER: gSSURGO raster	
USER DECISION: Z-factor	

Denitrifying bioreactors typically comprise a buried bed of woodchips that receive a portion of tile drainage flows from an adjoining field. The woodchips provide a carbon source, which combined with the reducing (oxygen limiting) conditions in the saturated subsurface environment, encourage naturally occurring bacteria to reduce nitrate to di-nitrogen gas in a stepwise process (denitrification). A number of recently published studies on this practice are available; Schipper et al. (2010) provided a good overview. Field performance studies (e.g., Christianson 2012) have shown a range of efficiencies. In general, hydraulic retention times between 8 and 18 hrs are needed to reduce nitrate concentrations by half. Assuming a 12 hour hydraulic retention time, Moorman et al. (2015) found that nitrate loads in tile drainage can be reduced by 20-30% by bioreactors of 1 m (3.3 ft) depth and occupying <0.3% of the drainage area. We locate bioreactors sized at 0.5% of the field drainage area to account for construction disturbance and the possibility to allow retention times >12 hrs in the actual design, which may be needed where increased drainage volumes occur under cold conditions that slow microbial processes. Hydraulic retention time requirements in bioreactors are a subject of ongoing research (Moorman et al., 2015).

NRCS practice codes: 605 – Denitrifying Bioreactor

<u>Process</u>

The area of upstream drainage recommended for bioreactor treatment is 20 to 100 acres. In each tile-drained, agricultural field, the point of highest flow accumulation within this 20 – 100 acre range is identified along the border of each field. Points are excluded if their location corresponds to the upstream edge of a field, as bioreactors should be placed in areas where a tile outlet may be accessible (i.e. where a flowpath exits a field). To determine whether a point falls along the upstream or downstream edge of a field, the maximum flow accumulation value (within 20 – 100 acres) within the entirety of each field is compared to the maximum flow accumulation value (within 20 – 100 acres) along the border of each field. If the values differ, the point is omitted from analysis. The upstream drainage area to each remaining point is then delineated, and points are removed if a minimum of 10 acres of upstream drainage does not fall within the field in which the bioreactor would be installed.

Following the initial filtering of potential sites, remaining points are tested to determine if the elevation values surrounding the selected points of drainage accumulation are conducive for bioreactor installation. Site-specific topography should include a gently-sloping area surrounding the point of installation, this criterion helps avoid sites where larger excavation volumes would be required for practice installation. A 100 meter buffer is generated around each potential site and clipped to the field in which the bioreactor would be installed. The elevation difference between the land surface and the elevation at the installation point is found within this 100 meter buffer, and elevation differences within 1 meter are selected and converted to contiguous polygons. To qualify as a potential bioreactor site, the polygon must meet two criteria; first, the surface area of the polygon must be equal to or greater than the area required to treat the amount of upstream drainage at that location (the area available for bioreactor installation must be ≥ 0.5% of the upstream drainage). Second, the mean percent hydric soil within the polygon should be less than 90%, to help avoid placement of bioreactors in very poorly drained or wetland soils. If both conditions are met, a square approximately equal to 0.5% of the size of the drainage area of the bioreactor is generated and centered upon the centroid of each polygon and added to the output Bioreactor feature class.

The output Bioreactor feature class (Bioreactors + inHUC) contains the following information for each site as attributes.

Table 14. Bioreactor polygon attributes

Attributes	**Description**
pointid	Unique identifier for each bioreactor site
FBndID	Field boundary ID
bnd_acc	Flow accumulation (in acres) at the point of bioreactor installation
min_acres	Minimum surface area of potential bioreactor; 0.5% of upstream flow accumulation at the point of installation
elev	Elevation (in same units as DEM) at the point of bioreactor installation
pcthydric	Mean percent hydric soil of the area within 1 meter elevation of the point of installation

5. Impoundment Siting

5.a Nutrient Removal Wetlands

Required Inputs	Outputs
INPUT LAYER: Input unfilled DEM (NewDEM + inHUC)	Nutrient Removal Wetland polygons (NRW + inHUC)
INPUT LAYER: D8 Flow Direction raster (D8FlowDir + inHUC)	Nutrient Removal Wetland Drainage Area polygons (NRWDrainageAreas + inHUC)
INPUT LAYER: D8 Flow Accumulation raster (D8FlowAcc + inHUC)	
INPUT LAYER: Watershed boundary (bnd + inHUC)	
INPUT LAYER: Stream Reach non-merged (StreamReach + inHUC) (optional)	
INPUT LAYER: Water Body polygon (optional)	
INPUT LAYER: Roads (optional)	
USER DECISION: Z-factor	
USER DECISION: Spacing (meters)	
USER DECISION: Wetland Impoundment Height (meters, default is 0.9 meters, range of 0.6-1.2 meters)	
USER DECISION: Wetland Buffer Height (meters, default is 1.5 meters, range of 1-1.6 meters)	

Iowa's Conservation Reserve Enhancement Project (CREP) program developed general criteria for siting wetlands to strategically locate them below tile drained fields and provide an off-site strategy for reducing nitrate from tile drainage water. Nutrient removal wetlands have the potential to remove 40-90% of the nitrate in tile drainage, depending on the nitrate load intercepted by the wetland (which varies with watershed size, land use, and precipitation) and the area of the wetland. The Nutrient Removal Wetland siting tool allows the user to sample locations along collective flow pathways for suitability of nutrient removal wetlands. Candidate sites can be ranked based on watershed and wetland areas, and topographic buffers. Further details on wetland siting criteria and discussion of factors impacting prioritization of candidate sites can be found in Tomer et al. (2013b).

NRCS practice codes: 656 – Constructed Wetland, 658 – Wetland Creation

Siting process

Potential impoundment locations (points) are generated along all collective flow paths within the drainage range established for nutrient removal wetlands (> 60 HA (~ 150 acres) --> maximum watershed drainage). A threshold is applied to the input D8 flow accumulation grid to delineate flow paths, which is converted to a polyline. Points are then generated continuously along this polyline at a user-specified distance interval (spacing). Locations are sorted by contributing area and most downstream sites are tested first.

At each location, an impoundment is simulated in the DEM, creating both a pooled area (of user-specified height – measured from the top of the bank) and a vegetated buffer (of user-specified height – measured from the top of the wetland pool). The drainage area to each impoundment is delineated, and descriptive statistics are generated, including the size of the pooled area, the size of the buffer, and the ratio of pooled area to the amount of drainage that it receives. If a site is found to be suitable according to suitability criteria, the site is "kept" and added to the output feature class. If not suitable, the site is omitted, and the next upstream site is tested.

Default settings for nutrient removal wetlands are listed in Table 15. The user can modify default settings within a predetermined range, including the impoundment height, buffer height, and spacing distance. Drainage range and suitability criteria are not modifiable.

Table 15. Default and optional parameters for nutrient removal wetlands

Parameter	**Description**
Drainage range	> 60 HA – maximum watershed drainage
Suggested Spacing Distance (* Modifiable)	default: 250 meters optional: 100, 150, 200, 250 meters
Impoundment Height (* Modifiable)	default: 0.9 meters optional range: 0.9 - 1.2 meters
Buffer Height (* Modifiable)	default: 1.5 meters optional range: 1.0 – 1.6 meters
Suitability Criteria	Pooled area/Drainage Area ratio: 0.5 – 2.0% Buffer area/Pooled area ratio: < 4.0

NOTE: Processing time will increase with a decrease in spacing distance (i.e., increase in sampling density).

At each sample point, focal statistics of the input DEM are used to assign the following variables:

- **Bank height:** range of elevation values within a 20 meter buffer around each point
- **Top of bank elevation:** maximum elevation value within a 20 meter buffer around each point
- **Channel elevation:** minimum elevation value within a 20 meter buffer around each point

Points are omitted from analysis if the bank height exceeds 4 meters **OR** if the drainage area at the point does not fall within the drainage range specified for nutrient removal wetlands (minimum of 60 HA and maximum of total watershed drainage). The bank height restriction avoids identifying possible wetlands in locations with well-incised streams where high impoundments would be necessary and instability of riparian zone sediments would be a possible concern.

To mimic installation of a nutrient removal wetland, an impoundment is simulated at each sample point, creating a pooled area upstream of the sample point. The ***impoundment elevation*** is defined by adding the user-selected impoundment height (in meters) to the top of bank elevation at the sample point. The ***buffer elevation*** is defined by adding the user-selected buffer height (in meters) to the impoundment elevation at each sample point. This vegetated buffer is required to account for times of high flow, to estimate where drainage impedance may occur, and can be considered an opportunity for permanent vegetation/habitat enhancement. Each impoundment is then tested for suitability following the default suitability criteria as detailed in Table 15.

NOTE: It is optional, particularly in watersheds with wide rivers, that the user may choose to avoid identifying wetlands along the main channel. By providing the Stream Reach polyline feature class in the tool interface (using the unmerged stream reach coverage), on-screen selections applied to the Stream Reach polyline (i.e. segments with stream order greater than x) will be obeyed. If provided, any sample points that intersect the stream reach (or stream reach selection) will be omitted from analysis, leaving only those points with a contributing area exceeding 60 HA and that lie upstream of the stream reach (or stream reach selection) that will be tested for wetland suitability. In areas of wide river, an alternative solution is to provide wide river (or water body) polygons in place of, or in addition to, the stream reach. If provided, sampling points that fall within water body polygons will be excluded from analysis.

NOTE: It is optional, but recommended, that the user choose to avoid roads by providing a roads polyline feature class in the tool interface. A roads layer is not provided as a base layer in the ACPF database, but will usually be easily accessed from a GIS state database. A site will be considered unsuitable if either the pooled area **OR** the buffer area intersects the road layer.

Two output layers will be created as an output to the tool:
1) A polygon layer delineating the pooled area and buffer, and site-specific information for each suitable site.
2) A polygon layer delineating the drainage area to each suitable site. These rows will have a unique “SiteID” join field.

NOTE: In the attribute table of the polygon layer delineating the pooled area and buffer (output 1 above), there ***will be two rows allocated to each suitable impoundment site***; one for the pooled area polygon and one for the buffer polygon. These rows will have the same unique “SiteID”.

The NRW feature class contains the following site-specific information as attributes:

Table 16. Nutrient Removal Wetland polygon attributes	
Attributes	**Description**
SiteID:	ID field
CoverType	Identifies polygon as wetland pool or buffer
ContAreaHA:	Contributing area in HA upstream of the wetland
PoolAreaHA:	Surface area of wetland pool in HA
BuffAreaHA:	Surface area of buffer in HA
StrmElev:	Estimated channel elevation (in same units as DEM) at the location that a wetland impoundment is simulated
BankHeight:	Estimated bank height (in same units as DEM) at the location that a wetland impoundment is simulated
BankElev:	Estimated top of bank elevation (in same units as DEM) at the location that a wetland impoundment is simulated
PoolStorAF:	Volume (in acre feet) of permanent storage provided by the pooled area
VarStorAF:	Volume (in acre feet) of variable storage provided by the vegetated buffer

5.c WASCOBS (Water and Sediment Control Basins)

Required Inputs	Outputs
INPUT LAYER: Input Unfilled DEM (NewDEM + inHUC)	WASCOB polylines (WASCOBs + inHUC)
INPUT LAYER: D8 Flow Accumulation raster (D8FlowAcc + inHUC)	
INPUT LAYER: D8 Flow Direction raster (D8FlowDir + inHUC)	
INPUT LAYER: Field boundary feature class (FB + inHUC)	
INPUT LAYER: Stream Reach non-merged (StreamReach + inHUC)	
INPUT LAYER: Watershed Boundary (bnd + inHUC)	
USER DECISION: Embankment Height (meters, default is 1.5 meters, range of 1-4.5 meters)	
USER DECISION: Z-factor	

WASCOBS, or water and sediment control basins, are small embankments built across (perpendicular) a drainageway in an agricultural field. This practice can reduce sediment and total phosphorus loads, attenuate peak runoff discharge, and reduce risk of gully formation down gradient. The WASCOB tool identifies potential locations for these structures on watersheds from 2 to 50 acres in size. A user-provided embankment height defines the height of the WASCOB (as measured from the bottom center of the drainageway). The WASCOB is a commonly installed practice in much of the Midwest, and information on design and sediment retention can be found in basic texts on engineering of hydrologic structures. However, there is little information in the peer reviewed literature on this practice; Mielke (1985) is one of the rare examples we found. Gassman et al. (2010) evaluated conservation performance in an Iowa watershed following conservation improvements that included WASCOBs.

NRCS practice codes: 638 – Water and Sediment Control Basin

<u>Process</u>

Potential WASCOB locations (points) are generated approximately every 200 feet along flow paths within the drainage range established for WASCOBS (2 – 50 acres). A threshold is applied to the input D8 flow accumulation grid to delineate this drainage range, which is converted to a polyline.

Points are limited to ***agricultural land use fields only, including pasture***. Points are first removed if the elevation change between itself and the next upstream point is not enough to install a WASCOB at the user-specified height without flooding out the upstream location. At each remaining point, a 100 m wide transect is drawn perpendicular to the mean direction of flow of that drainageway. The elevation profile of the transect line is then analyzed to estimate the shape of the drainageway and determine the suitability of the location for WASCOB installation.

Two requirements must be met for the embankment to be qualified and tabulated in the attribute table. First, the height of each side of the drainageway must be at least the height of the embankment to be qualified and tabulated in the attribute table. In other words, the drainageway must possess enough curvature (or slope convergence) to allow installation of a WASCOB at that location. Second, the height of each side of the drainageway must not be more than twice the height of the embankment. In other words, the drainageway is not too incised to preclude installation of a WASCOB at that location.

Transect lines that meet these two criteria are appended to the output WASCOB feature class. Additionally, WASCOBS that fall within 50 meters of the main stream reach (representing perennial flow) will be omitted from analysis. Lastly, WASCOBS that cross a field's boundary will also be deleted to associate each suggested WASCOB with a specific agricultural field. This simply helps with mapping logistics; WASCOBs can be placed along field boundaries in practice.

NOTE: After running the WASCOB tool, it is strongly suggested that the output layer be reviewed, and any erroneous WASCOBs be manually deleted. For example, WASCOBS that intersect objects like homesteads or roads. The layer can then be used as an input to the WASCOB basins tool to identify the basin, or upstream area that would pond water during times of high flow, were the WASCOB to be installed. Alternatively, the user may interactively select WASCOBs on-screen rather than delete WASCOBs. When used as an input to the WASCOB basins tool (next section), the selection will be honored and basins will be found for only those WASCOBs selected. The output polyline feature class will have the following site-specific information as attributes:

Table 17. **WASCOB polyline attributes**

Attributes	**Description**
WASCOBID	Unique Identifier
ContAreaAC:	Contributing Area (in acres) upstream of each WASCOB (derived from filled DEM)
Elevation:	Elevation at bottom center of drainageway (location of sample point) (in vertical map units)
EmbankHgt:	WASCOB embankment height as specified by the user (in vertical map units)
lbank_hgt	Height (range of elevation values, in vertical map units) for the left bank of the drainageway
rbank_hgt:	Height (range of elevation values, in vertical map units) for the right bank of the drainageway

5.d WASCOBS Basins

Required Inputs	Outputs
INPUT LAYER: WASCOBs (WASCOBs + inHUC)	WASCOB basin polygons (WASCOBbasin + inHUC)
INPUT LAYER: Filled DEM (DEMFill + inHUC)	WASCOB basin depth raster (optional)
INPUT LAYER: D8 Flow Direction (D8FlowDir + inHUC)	
USER DECISION: Z-factor	

The WASCOB Basin tool delineates the area which would pond water up-gradient of each WASCOB during times of high flow. The process involves "burning" each WASCOB into a filled DEM (using the user-defined embankment height for each WASCOB), then determining the sink regions that are created upstream of each WASCOB as a result.

NOTE: This tool should be run following a manual review of the "WASCOBs" feature class, during which erroneous WASCOBS are manually deleted. This includes WASCOBS that intersect objects like homesteads or roads, or where installation is unfeasible due to other reasons. Alternatively, the user may interactively select WASCOBS on-screen. When used as an input to the WASCOB basins tool, the selection will be honored and basins will be found for only those WASCOBs selected.

Process

The WASCOB polyline feature class is specified by the user as an input to this tool. The embankment height of the input WASCOBs (in the same vertical units of the DEM) is obtained from the "EmbankHgt" field of the input feature class. The input WASCOB layer is converted to a raster, and the minimum elevation value (from a filled DEM) is found along each WASCOB. This elevation value represents the elevation at the bottom center of the drainageway. This elevation value is then added to the height of the embankment (for example, 150 cm) along the entirety of the WASCOB line. The new elevation values are used to replace the elevation values along the WASCOB in the filled DEM. The result is a raster of the original filled DEM except where a WASCOB is present, in which case each grid cell is given the elevation value of the WASCOB. By using a filled DEM, no depressions should initially be present. Once WASCOBs have been burned onto the filled DEM, the filled DEM is then put through a "fill" process to identify the depressions created as a result of adding the WASCOBs.

NOTE: If the "Output WASCOB basin depth raster?" is checked, a depth raster will be output to the file location provided. Each grid cell indicates the depth of the ponded area in that location, in the same vertical units as the input DEM. These data are summed to provide an estimated volume of water storage capacity above each WASCOB.

The output is a WASCOB basin polygon layer (WASCOBbasin + inHUC), which represents the ponded area behind each WASCOB during times of high flow, and contains the following information for each WASCOB basin as attributes.

Table 18. WASCOB Basin polygon attributes	
Attributes	**Description**
WASCOBID	Unique Identifier
StorageAF	Potential storage volume (in acre feet) of each WASCOB basin
SurfAreaHA:	Surface area (in HA) of each WASCOB basin

6. Riparian Assessment

Conceptually, the riparian assessment component of the ACPF evaluates riparian settings in a watershed by discretizing its perennial stream corridors into user-specified lengths, then delineating the land area contributing to each length of stream, separately for each side of the channel. These sub-watershed areas are called “riparian catchments.” In the ACPF riparian assessment, each riparian catchment is classified based on catchment size and the topography near the stream. These attributes are then used to identify opportunities to match riparian buffer design to functional opportunities each landscape setting provides to intercept runoff, influence shallow groundwater, and stabilize streambanks with riparian vegetation. Numerous tools have been developed within the ACPF to analyze site-specific conditions that affect riparian function and conservation management opportunities, including soil characteristics, topography, and upstream drainage area and land use to help determine suitability of each riparian site for novel riparian practices, such as saturated buffers or carbon-enhancement of saturated buffers using woodchip bioreactor walls or trenches (Schipper et al., 2010). Riparian catchments enable multiple linkages between the riparian corridor and its upstream draining area, and between conservation opportunities found in riparian and upland settings. This section begins by delineating the riparian catchments. Note these are only developed along perennial stream segments that were designated in Section 2.c, with the option to also delineate riparian catchments above lake and/or wide rivers, from Section 2.d.

6.a Create Riparian Catchments

This tool creates riparian catchments along the stream reach corridor at a user-specified length. Each output catchment will be given a unique “riparianID". The riparianID is structured to follow:

"x"_ "y"_"z"

where
x = the linkno defined by the input stream reach to the tool
y = a number ranging from 1 to n for the number of riparian segments discretized along that reach
z = 1 if the riparian catchment lies to the right of the stream, or 2 if the riparian catchment lies to the left of the stream

Required Inputs	Outputs
INPUT LAYER: Stream Reach with or without merged water bodies (StreamReach + inHUC or StreamReachWB + inHUC)	Riparian catchments (RiparianCatchments + inHUC)
INPUT LAYER: Water Bodies (polygon) (optional) (may alternatively input independent lakes or wide river polygon feature class, if only one waterbody type exists)	
USER DECISION: Riparian Segment Length (default 250 meters, range from 100-500 meters)	
INPUT LAYER: D8 Flow Direction raster (D8FlowDir + inHUC)	
INPUT LAYER: D8 Flow Accumulation raster (D8FlowAcc + inHUC)	
INPUT LAYER: Field Boundary polygon (FB + inHUC)	
NPUT TABLE: Drainage Table (DrainageTable + inHUC)	

NOTES ON INPUTS

The Input Stream Reach feature class (polyline layer, with or without merged water bodies) is an output of either the "Create Stream Reach And Catchments" or the "Merge Stream Reach with Water Bodies" tool. It is suggested you use a merged coverage if one is available, so that riparian catchments are placed along shorelines of water bodies. That is, if a merged coverage was generated in Section 2.d that will be utilized in watershed planning, be sure to use that merged input feature class here.

The Input Water Bodies polygon feature class should include any wide river polygons and/or lakes, merged into a single feature class. If only one type of water body exists, you may provide the standalone feature class of either lakes or wide rivers. If provided, output catchments will be omitted from the interior of the input water body polygons.

Riparian Segment Length

Approximate length along each input stream reach for which a unique riparian catchment will be generated. A 250-meter length is the default value, but the user can choose any value from 100 to 500 meters. A smaller interval might be helpful in watersheds with complex terrain and/or small fields, while a larger interval may be appropriate in watersheds with broad topographic features/large fields. The length chosen will determine the relative number of riparian catchments delineated. Stream reaches less than this length will have only one riparian catchment on each side of the reach.

Note this is an approximate length that will be adjusted as required to divide each stream reach into an equal number of segments without leaving any gaps. An adjustment is also performed to account for sinuosity along the stream reach (Figure 12), in an effort to minimize the variability in the straight line distance among all riparian corridor elements along a given reach. More sinuous segments are shortened and less sinuous segments are lengthened proportionally, based on the contribution of each segments' straight line length to the total straight line length of that reach. Once the segments have been delineated and their lengths adjusted, they are used as an input to the watershed command to delineate the watershed to each unique length of stream. The stream reach itself is then used to split the watershed in two, so that the drainage area to each side of the stream can be discriminated.

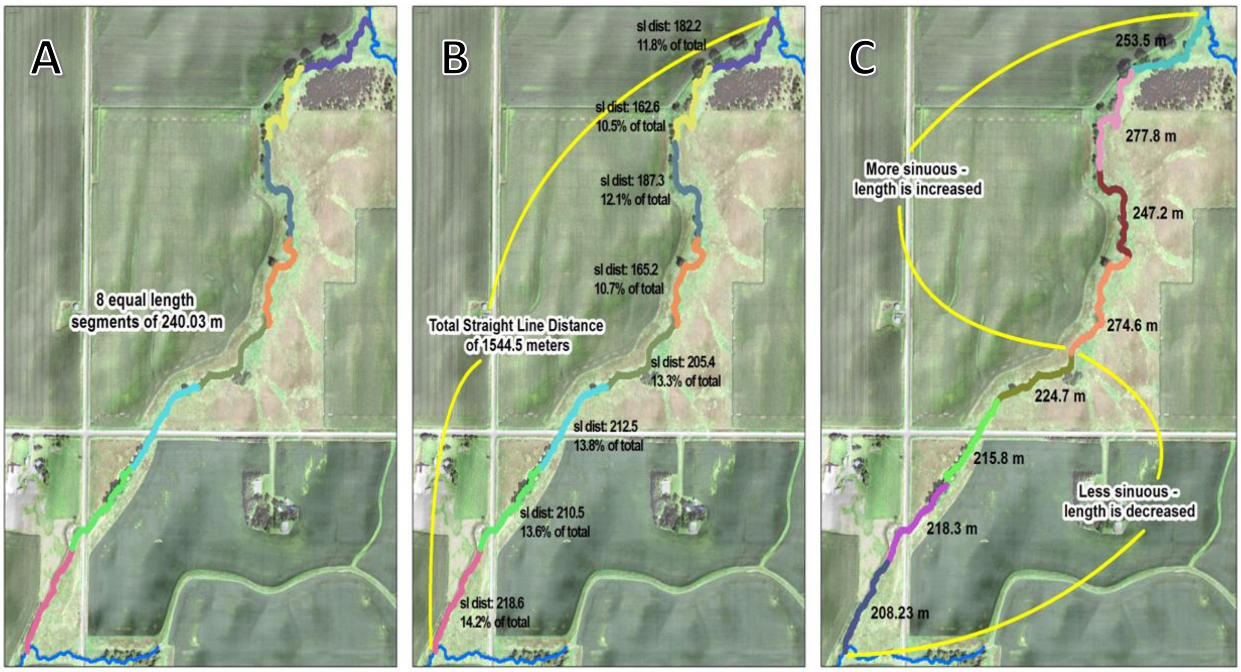


Figure 12. Example of adjusting segment length based on sinuosity. The above stream reach is 1,920 m total in length, and the riparian segment length chosen was 250 m. That's approximately (A) eight 240.03 m segments, (B) that have a total straight line distance of 1,544.5 m, which are then (C) adjusted by length according to differences in sinuosity (100/8 segments = 12.5%).

IMPORTANT: ***It is very important to maintain congruence among input layers throughout the riparian suite of tools.*** If a stream reach with water bodies has been provided as the input, you must also provide water body polygons as an input. The attributes calculated for each riparian catchment are described below.

Output Riparian Catchments

The attribute table of the output feature class will contain the following fields:

ATTRIBUTES	DESCRIPTION
riparianID	Unique identifier for each riparian catchment, with x_y_z designating stream reach (x), riparian segment counter along the reach (y), and side of stream (z)
len_met	Actual length of the stream (in meters) along each unique riparian section of the stream reach.
sl_len	Straight line distance (in meters) along each unique riparian section of the stream reach.
acres	Size (in acres) of each riparian catchment. Represents the drainage area to its corresponding section of the stream.
catchment	Catchment that each riparian catchment is contained within (equals “LINKNO” value in input stream reach layer, and “gridcode” value in Catchments + inHUC layer). Riparian catchments are nested within subcatchments, which are nested within catchments.
subcatch	Subcatchment that each riparian catchment is contained within. Subcatchments represent a left, a right, and a headwaters catchment for each stream reach.
CropAcres	Acreage of cropland (isAg value of 1) in each riparian catchment
PastAcres	Acreage of pasture (isAg value of 2) in each riparian catchment
TiledAcres	Acreage of tile-drained land (“Drained” classification of “YES” in drainage table) in each riparian catchment

NOTE: When water bodies are merged into a stream reach, new “LINKNO” values are assigned to those features that represent lake or wide river shorelines. Therefore, these stream reaches will no longer be related to the “LINKNO” and “gridcode” fields of the stream reach and catchments layer that were generated prior to the incorporation of water bodies.

NOTE: Riparian catchments are nested within subcatchments, which are nested within catchments. If wide rivers have been merged into the stream reach, slight spatial discrepancies may exists between these nested layers. This is expected, as you are now delineating drainage areas to shorelines rather than to a single stream centerline.

6.b Create Riparian Attribute Polygons (RAPs)

Required Inputs	Outputs
INPUT LAYER: Stream Reach feature class (Use same input as in 6.a, either StreamReach + inHUC or StreamReachWB + inHUC)	Riparian Attribute Polygons (RAP + inHUC)
INPUT LAYER: Riparian Catchments (RiparianCatchments + inHUC, created in section 6.a)	Riparian Relation (Relationship Class)

SUMMARY

This tool creates a 15-m wide riparian attribute polygon (or RAP) for each riparian catchment in the input Riparian Catchments feature class. These polygons are for ***VISUALIZATION*** purposes only. Each RAP will be used as the geographical unit ***by which to visualize*** stream side conditions within each riparian catchment or the riparian zone of the catchment, such as slope, land use, soils, and analytical output results such as riparian buffer design types. ***NOTE: Past versions of the ACPF employed rectangular "Riparian Assessment Polygons", which have now been abandoned.***

IMPORTANT:

A relationship class will be created between the riparian catchments and their associated RAPs when applying this tool. This allows the features to be visually connected via the "identify" tool in any follow-on ArcMap session. If both layers are added to the table of contents, using the identify tool on either feature will allow the user to simultaneously visualize both the geography and attributes of its connected feature. Riparian Catchments and RAPs are connected via a unique "riparianID".

While each RAP will be connected to a single riparian catchment, output buffers are not "clipped" by riparian catchment. Some riparian catchments are very narrow areas adjacent to the stream, and do not extend out to the length of the 15-meter RAP. In these instances, clipping by the riparian catchment would create atypically shaped RAPs. Therefore, slight incongruities between RAPs and their associated riparian catchments will occur. Keep in mind the RAPs are for display and not used for analysis.

Notes on Input Layers

Input Stream Reach feature class

Input Stream Reach feature class (polyline layer, with or without merged water bodies). This is an output of either the "Create Stream Reach And Catchments" (section 2.c) or the "Merge Stream Reach with Water Bodies" tool (Section 2.d). **IMPORTANT**: If a merged coverage was generated in Section 2.d that will be utilized in watershed planning, be sure to use that merged input feature class. The same stream reach layer that was used as an input to the "Create Riparian Catchments" tool **MUST** be provided here.

Input Riparian Catchments

Input Riparian Catchments. This is an output of the "Create Riparian Catchments" tool. Each catchment should have a unique "riparianID".

Output Riparian Buffers
Output riparian buffers. Each buffer will be connected to a single Riparian Catchment via the "riparianID" field.

Output Relationship Class
Output riparian relationship class which will provide the connection between input riparian catchments and output RAPs. This allows the features to be visually connected via the "identify" tool in any follow-on ArcMap session. If both layers are added to the table of contents, using the identify tool on either feature will allow the user to simultaneously visualize both the geography and any attributes of its connected feature. This relationship class must be stored in the same file geodatabase as the riparian watersheds and riparian buffers.

Output RAPs
The attribute table of the output feature class will contain the following fields:

ATTRIBUTES	DESCRIPTION
riparianID	Unique identifier, x_y_z designating stream reach (x), riparian segment counter along the reach (y), and side of stream (z)
len_met	Actual length of the stream (in meters) along each unique riparian section of the stream reach.
sl_len	Straight line distance (in meters) along each unique riparian section of the stream reach.

6.c Height Above Channel

Required Inputs	Outputs
INPUT LAYER: Unfilled DEM (NewDEM + inHUC)	Height Above Channel raster (HAC + inHUC)
INPUT LAYER: Stream Reach feature class (Use same input as in 6.a, either StreamReach + inHUC or StreamReachWB + inHUC)	Relative Elevation raster (RelElev + inHUC) (optional)
INPUT LAYER: D8 Flow Direction raster (D8FlowDir + inHUC)	
INPUT LAYER: Water Body (polygon) (optional) (may alternatively input independent lakes or wide river polygon feature class, if only one waterbody type exists)	
USER DECISION: Z-factor	

The Height Above Channel tool uses an input unfilled DEM, D8 Flow Direction grid, and Stream Reach feature class (polyline) to find the elevation difference between each grid cell in the input DEM and the stream-channel grid cell that will receive overland flow from that cell. These elevation differences are reclassified into height above channel categories and used to estimate the extent of low-lying areas along the riparian corridor. That is, elevation differences are found between the grid cells of the unfilled DEM and the elevation found along the stream reach polyline where flow from that cell enters the channel or water body, following D8 Flow Direction flowpaths. The result is the Relative Elevation raster, a continuous raster of elevation difference ***relative to receiving channel and water body elevations***.

The Relative Elevation grid is reclassified into the following depth categories and output as a thematic "Height Above Channel" ("HAC") grid:

- Channel: < 0
- Very low (< 1.5 meters)
- Low (1.5 – 3 meters)
- Medium (3 – 5 meters)
- High (>5 meters)

6.d Riparian Function Assessment

Required Inputs	Outputs
INPUT LAYER: Stream Reach feature class (Use same input as in 6.a, either StreamReach + inHUC or StreamReachWB + inHUC)	Riparian Function Assessment Table (RiparianFunction + inHUC)
INPUT LAYER: Riparian Catchments (RiparianCatchments + inHUC)	
INPUT LAYER: Input Height Above Channel raster (HAC + inHUC)	

The second supplemental matrix in the conservation planning framework, "Riparian Assessment" (Fig. 12), can be used to determine site-specific designs for riparian buffers. The process analyses two variables within each riparian catchment; 1) The potential for the riparian zone within each catchment to provide denitrification of shallow groundwater, which is based on the width of the low-lying land (< 1.5 meter height) within 90 meters of the stream, and 2) the amount of drainage area passing through the riparian zone of each catchment (equal to the size of the riparian catchment). The riparian zone within each catchment is defined as a 90 meter buffer out from the stream reach associated with each riparian catchment. Each variable is ranked into a high, medium, or low category, and a cross classification is then applied to map the relative correspondence of potential runoff contributions with the extent of low-lying areas (where water tables are likely to be shallow and subject to influence of plant roots) throughout the riparian corridors in the watershed. The results of the cross classification can be used to identify opportunities to improve riparian management by installing permanent vegetation in ways specifically designed to intercept surface runoff, influence shallow groundwater in low-lying areas, and stabilize stream banks, in places where consequent water quality benefits can be best realized.

The resultant function classification can best be displayed using the RAP visualization polygons. Details are provided by Tomer et al. (2015b); a review of riparian practices by Schultz et al. (2009), and a meta-analysis of nitrate removal in buffers by Mayer et al. (2009) were instrumental in developing the criteria used in the ACPF riparian classification scheme. The user is also referred to Dosskey et al. (2010) for a review of riparian vegetation and its potential functioning in water quality improvement.

Results from the watershed-wide riparian buffer planning identifies where opportunities exist to intercept surface runoff (SSG-type buffers), shallow groundwater (DRV-type buffers), or both runoff and groundwater (CZ and MSB type buffers). Where neither opportunity exists, riparian plantings can be designed to reduce bank erosion (SBS-type buffers).

NRCS Practice Standards: Riparian Forest Buffer (391); Streambank Protection (580)

Riparian Assessment:
Identify riparian function by stream reach

Shallow water table width

Ruonff Delivery	H	M	L
H	CZ	MSB	SSG
M	MSB	MSB	SSG
L	DRV	DRV	SBS

Design types for Riparian Buffers:

CZ	Critical zone/sensitive sites
MSB	Multi-species buffer for water uptake, nutrient & sediment trapping
SSG	Trap runoff & sediment with stiff-stemmed grasses
DRV	Use deep rooted vegetation tolerant of saturated soils
SBS	Emphasize stream bank stability

Figure 13. Riparian assessment matrix and riparian buffer design types. (Tomer et al., 2015b). The two axes of the riparian assessment matrix shown above create a cross-classification of two variables: 1) width of low lying land, and 2) runoff delivery (the amount of local surface runoff) to each riparian segment.

Process:
The stream reach is first segmented by its associated riparian catchment, then each unique segment is buffered, on its appropriate side, by 90 meters to create "riparian zones" within which to analyze riparian conditions. ***(Note: use of "riparian zone" herein generally refers to distance-from-stream geographic buffers).*** The assessment categorizes each riparian zone into one of 5 major ecological functions, as well as recommends riparian buffer widths. Each riparian zone is first ranked into a high, medium, or low classification for each of two input variables: 1) Runoff contributing area, defined as the size of the riparian catchment, and 2) average width of low-lying land, calculated based on the number (area) of grid cells within the 90-m wide analytical buffer that are within 1.5 m elevation of the stream elevation, divided by the straight line riparian segment length. In most watersheds, wider zones of low-lying land will provide greater opportunities to promote denitrification utilizing deep rooted vegetation that can enhance carbon availability at depth.

Input notes:
The input Stream Reach feature class is a polyline layer, with or without merged water bodies. This is an output of either the "Create Stream Reach And Catchments" or the "Merge Stream Reach with Water Bodies" tool. ***The same stream reach layer that was used as an input to the "Create Riparian Catchments" tool MUST be provided here.***

Cross Classification
Prior to performing a cross classification, each riparian catchment is classified into a high, medium, or low rank for each of the two input variables. The ranking of each variable within each riparian catchment will be contained in the "DenPotRank" and "RunoffRank" field of the output riparian function assessment table.

Denitrification Potential Rank

The classification of riparian zones based on width of low-lying land characterizes the natural capacity for a riparian zone to provide water quality benefits through denitrification. Riparian zones with a wide zone of low-lying land present opportunities to consistently influence groundwater with a widened buffer that includes deep rooted vegetation, leading to this classification of riparian site. These widths were determined based on a review of nitrogen removal in riparian buffers (Mayer et al., 2007).

- High – Low-lying land (<1.5 m height above channel) extends on average to distances >50 m from the stream.
- Medium – Low-lying land extends on average to distances between 25 and 50 m from the stream.
- Low –Low-lying land extends on average to distances less than 25 m from the stream.

Runoff Delivery Rank

The classification of Riparian zones based on local runoff delivery identifies where a significant potential for runoff contribution exists, to show where buffer vegetation should be widened to at least 10 m and include stiff-stemmed grasses to effectively intercept runoff, leading to this classification of riparian sites:

- High - those riparian zones that have the greatest potential to receive overland flow, and that would convey half the surface runoff from the watershed that contribute to the stream, if all areas were to generate runoff equally. Riparian management in these sites should often be extended to include conservation treatments on ephemeral waterways that are up-gradient.
- Medium – Riparian zones where a buffer occupying exactly 2% of the total contributing area to the RAP would be wider than 10 meters. A 2% 'buffer-area ratio' will typically be needed to meet NRCS technical guidance (Dosskey et al., 2011). That is, if $X_{rz}/CA<0.02$, where CA is the size of the riparian catchment, expressed in m^2, and X_{rz} is the area of a 10-m wide riparian buffer adjacent to the stream within that riparian catchment, then the runoff class is 'Medium'.
- Low – a 10 meter wide (or narrower) buffer provides the minimum recommended buffer- area ratio of 0.02. That is, the runoff class is 'Low' if $X_{rz}/CA>0.02$. In this class, the buffer widths required for bank stabilization and for runoff interception are similar (see Tomer et al., 2015b).

Once the cross classification is applied, buffer widths are recommended for each riparian design (Figure 14) as follows:

- A minimum of a 6 meter wide buffer (for riparian zones with low runoff and a narrow low-lying land zone - SBS-type sites)
- A wider buffer (10 – 90 meters) to meet the NRCS recommended 0.02 buffer-contributing area ratio (in areas where surface runoff dominates - SSG and some MSB)
- A wider buffer (25 – 50 meters) if a wide area of low-lying land would allow denitrification opportunities (in areas dominated by wide zones of low-lying land– CZ, DRV, and some MSB).

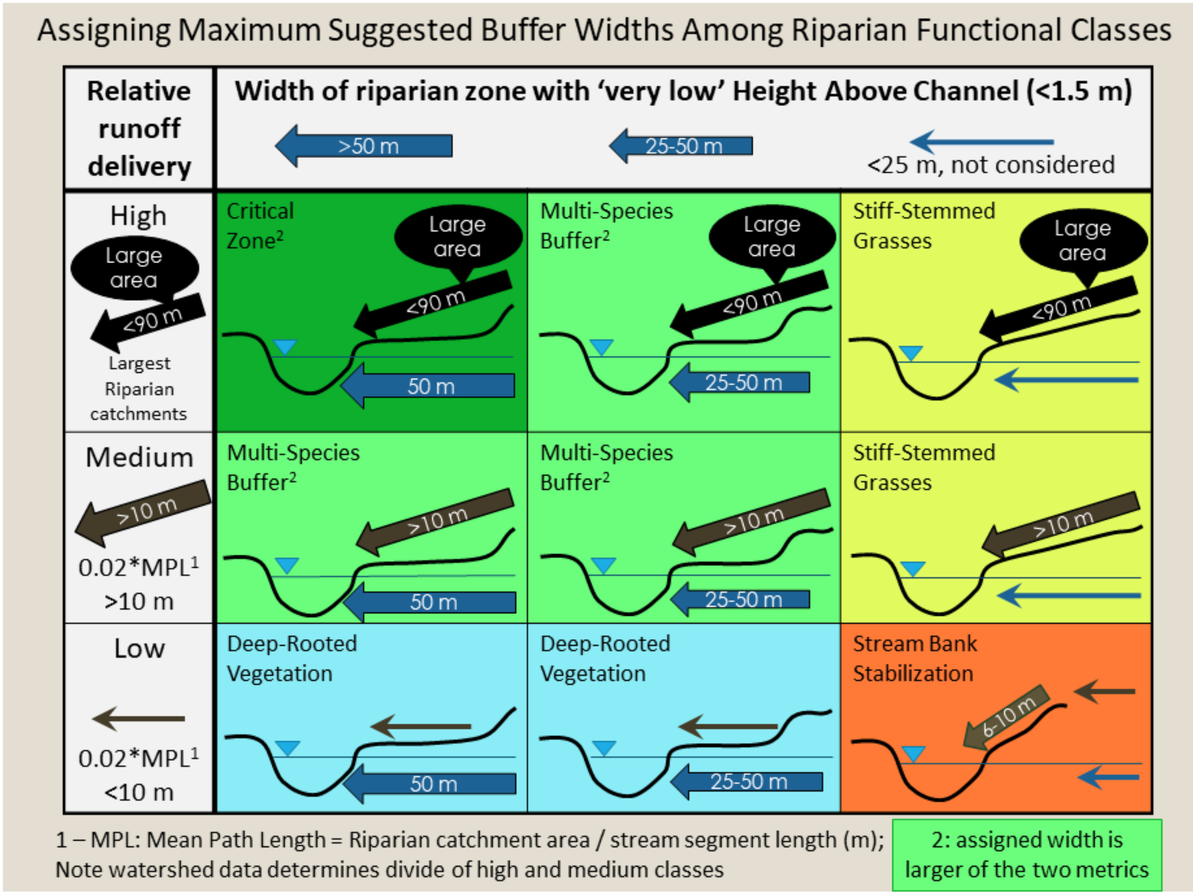


Figure 14. Graphical depiction of the above explanation on determining buffer widths.

The output riparian function table (Riparian Function + inHUC) contains the following attribute information for each riparian catchment. This information is best visualized via the RAP visualization polygons. The "riparianid" field can be used to join the table to the RAP feature class:

Table 20. Riparian Function Table attributes	
Attributes	**Description**
Riparianid	Unique identifier, x_y_z designating stream reach (x), riparian segment counter along the reach (y), and side of stream (z)
Wdthlt1_5	Average width of low "height above channel elevations (< 1.5 meters) within the riparian zone of each riparian catchment
len_met	Actual length of the stream (in meters) along each unique riparian section of the stream reach.
sl_len	Straight line distance (in meters) along each unique riparian section of the stream reach.
Ratio_10m	Ratio of the area of a 10 meter buffer (2500 m^2) divided by local runoff. NRCS guidelines suggest an area/runoff ratio of at least 0.02, and wider buffers are suggested for ratios < 0.02
RunoffRank	Runoff Delivery Rank: High, Med, or Low
DenPotRank	Denitrification Potential Rank (based on width of low-lying land): High, Med, or Low
Function	Riparian Buffer Design Type
NRCSWidth	Suggested buffer width according to the NRCS (in meters)
BuffWidth	Suggested buffer width using ACPF guidelines (in meters). See below.

The suggested buffer width for each RAP is populated using the following table, based on Function, Wdthlt1_5, and NRCS width (width needed for runoff interception).

Riparian Function	**Suggested Buffer Width (BuffWidth)**
'Multi Species Buffer' and NRCSwidth > 90	90 meters
'Multi Species Buffer' and NRCSwidth < 25	25 meters
'Multi Species Buffer' and NRCSwidth >= 25 and NRCSwidth <= 90	NRCSwidth
'Critical Zone' and NRCSwidth > 90	90 meters
'Critical Zone' and NRCSwidth < 25	25 meters
'Critical Zone' and NRCSwidth >= 25 and NRCSwidth <= 90	NRCSwidth
'Stiff Stemmed Grasses' and NRCSwidth > 90	90 meters
'Stiff Stemmed Grasses' and NRCSwidth <= 90	NRCSwidth
'Deep Rooted Vegetation' and Widthlt1_5 > 50	50 meters
'Deep Rooted Vegetation' and Widthlt1_5 <= 50	SWT Width
'Stream Bank Stabilization' and NRCSwidth < 6	6 meters
'Stream Bank Stabilization' and NRCSwidth >= 6	NRCSwidth

6.e Riparian Denitrifying Practices

Required Inputs	Outputs
INPUT LAYER: Stream Reach feature class (Use same input as in 6.a, either StreamReach + inHUC or StreamReachWB + inHUC)	Saturated Buffer Table (SaturatedBuffer + inHUC)
INPUT LAYER: Riparian catchments (RiparianCatchments + inHUC)	
INPUT LAYER: Unfilled DEM (NewDEM + inHUC)	
USER DECISION: Z-factor	
INPUT LAYER: Slope Raster (Slope + inHUC)	
INPUT LAYER: gSSURGO (gSSURGO)	
INPUT TABLE: Soil Profile Table (SoilProfile + inHUC)	
INPUT LAYER: CDL Land Use Raster (wsCDL"…")	
USER DECISION: Minimum Organic Matter % (default is 1.7%, range of 1.5-5.1%)	
USER DECISION: Maximum % Coarse Soils (default is 65%, range of 50-75%)	
USER DECISION: Minimum % of near stream soils (within 20 meters of stream) in which ALL soil conditions must be met (default is 35%, range of 25-75%)	
USER DECISION: Minimum % of riparian zone (within 90 meters of stream) that must consist of slopes between 2 and 8% (default is 35%, range of 25-75%)	
USER DECISION: Maximum bank height (in feet) (default is 12 feet, range of 8-14 feet)	

The riparian denitrifying practices tool utilizes site-specific information within each riparian zone to map the feasibility of saturated buffers, and riparian locations where the saturated buffer practice may need to be supplemented with use of introduced carbon (typically woodchips) to enhance riparian denitrification.

Saturated buffers employ a lateral distribution line within a riparian buffer and a diversion gate that intercepts a tile above its outlet to a stream. The diversion gate comprises a control structure that diverts outflow portion of the tile flow to the distribution line and raises the water table within the buffer, which enhances the buffer's ability to naturally remove nutrients conveyed by tile drainage. This is a new practice that is the subject of ongoing research, however, early research results are promising (Jaynes and Isenhart, 2014), and the practices is relatively inexpensive to install especially where riparian buffer vegetation is already present. We have utilized the recently approved NRCS practice standard in devising this tool to assess riparian zones for suitability as saturated buffer sites. However, we have also identified where the opportunity for carbon enhancement of the saturated buffer practice is indicated, i.e., locations where all siting criteria for saturated buffers are met *except* the soil organic matter concentrations; this single limitation may be overcome by adding carbon in the form of a woodchip-filled trench, installed parallel to the distribution line, to achieve increased denitrification. This enhancement would be considered experimental, but denitrification walls have proven effective under a range of design options discussed by Shipper et al., (2010).

NRCS practice codes: 604 – Saturated Buffer

Process

The tool evaluates riparian-zone settings for each riparian catchment, according to three sets of criteria, described below. Similar to the riparian function assessment (sec. 6.d), the riparian zone within each catchment is defined as a 90 meter buffer out from the stream reach associated with each riparian catchment. To qualify as a candidate site for a saturated buffer, the riparian zone must meet ALL three criteria. In general, these criteria help ensure that: 1) subsurface discharge of drainage water is likely to raise the water table into the root zone where soil organic carbon is available to support denitrification processes; 2) stream bank heights are <12 ft (as a default value), so that risks of bank failure/ collapse resulting from raising the water table are minimized; and 3) slopes within the riparian zone are 'dominantly' (defined at the user's discretion) in the range of 2-8%; this is meant to minimize risks of inundating adjacent field crops, but avoid areas steep enough that risks of erosion and surface seepage flows can be avoided. Note the latter two criteria are meant to help avoid unintended consequences that might accompany this practice.

Sites found to meet all conditions for saturated buffers EXCEPT for the presence of high organic matter soils (> 1% soil organic carbon at a 0 – 100 cm depth) are flagged as possible sites for carbon-enhancement, particularly riparian bioreactor walls (or trenches) placed below saturated-buffer distribution lines. A variety of design options can be considered on a site-specific basis (see Schipper et al., 2010).

IMPORTANT: Saturated buffers are a practice deployed within the riparian zone, which the ACPF defines as a 90 meter buffer out from the stream associated with each riparian catchment. The saturated buffer tool uses this 90 meter zone to analyze slopes and land use adjacent to the stream. However, bank height and soil properties are also important considerations for the saturated buffer practice. Specific soil properties must only exist between the stream and where the lateral distribution lines are placed (minimum of 10 m). Likewise, bank heights are more accurately represented by looking only a short distance away from the stream, rather than a full 90 m. Due to these considerations, a 20 meter buffer (rather than the 90 m associated with our defined riparian zone) is used to calculate these attributes (soil properties and bank height) within each riparian catchment.

1. SOILS CRITERIA.

The practice standard for saturated buffers specifies a minimum buffer width of 10 meters, which is the minimum distance required between the lateral tile lines where the practice is installed and the stream channel. It is necessary that certain site-specific conditions exist only within this 10-m riparian zone. However, the saturated buffer tool analyzes soils data within a 20-m riparian zone (representing twice the minimum required riparian width) from the stream. Note that the spatial resolution of the input soils data (gSSURGO) is 10 meters. When analyzing soils data within a 20 meter riparian zone, therefore, we are examining on average a 2 pixel width from the adjacent stream polyline. Stream polylines have no width. In headwater streams, this is appropriate. In areas of wide rivers, however, the 20 meter zone may not extend beyond the wide river, and the underlying attributes may reflect water rather than the adjacent land soil properties. In these situations, we suggest that the user merge wide river polygons into the stream reach (sec. 2.d), so that wide river shorelines can be properly analyzed for saturated buffer suitability.

To qualify as a candidate, a default 35% of the area within the 20 meter buffer within each riparian catchment must meet all required soils attributes, as described below. The user may vary this area requirement between 25 and 75%.

a) Average soil organic matter from 0 - 100 cm depth must exceed 1.7% to promote denitrification potential. The user may vary the minimum organic matter required between 1.7 and 5.1%. The percent of soil organic matter is defined by an area-weighted average of organic matter % across all soil map units from 0 – 100 cm depth. The 1.7-5.1% SOM range equates to a minimum mass concentration of soil organic carbon between 1 and 3%. We note that anecdotal evidence from experimental sites suggests that well-established buffer vegetation may be as (or more) important than soil organic carbon for enhancing denitrification potential.
b) Maximum coarse material content (comprising percent sand content plus percent coarse fragments) must be < 65% among all horizons between 50 and 150 cm depths. This promotes residence time and decreases risk of vertical flows and leaching of discharged tile-water nitrate to below soil profile depths. Coarse material is defined as the sum of sand contents (0.05 -2 mm in size) and larger fragments (>2 mm).
c) Drainage Class must be "very poorly drained, poorly drained, somewhat poorly drained, or moderately well drained"; to ensure capacity of buffer to maintain discharged water near the surface.

2. TOPOGRAPHY

Saturated buffers present two major concerns relative to topography.

a) First, elevation differences between the saturated buffer and adjacent cropland are needed to minimize inundation risk for cropland adjacent to the buffer. Yet, although the adjacent cropland should be at a higher elevation than the buffer, elevation differences that are too great may indicate steep slopes in the riparian zone, which may introduce risks of from overloading, seepage, bank instability, and sloughing resulting from saturated buffer installation. *Therefore, intermediate slopes are preferred for this practice.* ***Slopes between two and eight percent must occupy a default minimum of 35% of each 90-m riparian zone.*** The user may vary this minimum requirement between 25 and 75%.

b) Second, steep banks greater than about 12 feet in height may present a risk in terms of bank sloughing, particularly when increasing the relative saturation of the subsoil. The tool calculates elevation differences between each grid cell in a 20-meter riparian zone and the nearest grid cell coinciding with the stream polyline, using a Euclidean distance measure. To estimate stream bank height, we calculate the 75th percentile of these elevation differences. This ***estimated bank height must be less than or equal to 12 feet by default to qualify as a candidate site for saturated buffers.*** This bank height parameter is modifiable between 8 and 14 feet, to allow flexibility as our knowledge about the risk associated with the practice increases.

3. LAND USE
   a) Agricultural land (either cropland or pasture) must exist within the 90-m riparian zone. The criterion is meant to avoid forested riparian zones.

Input notes:
The input Stream Reach feature class (polyline layer, with or without merged water bodies) is an output of either the "Create Stream Reach And Catchments" or the "Merge Stream Reach with Water Bodies" tool. The same stream reach layer used as an input to the "Create Riparian Catchments" tool must be provided here.

The output Saturated Buffer table (SaturatedBuffer + inHUC) contains the following attribute information for each riparian catchment. This information is best visualized via the RAP visualization polygons. The “riparianid” field can be used to join the table to the RAP feature class:

Table 21. Riparian Practice Table attributes	
Attributes	**Description**
riparianid	Unique identifier, x_y_z designating stream reach (x), riparian segment counter along the reach (y), and side of stream (z)
PctNrSoil	Percent of area (within 20 meters of the stream length associated with each riparian catchment) meeting ALL soil conditions
DomMeanOM	Mean organic matter % of dominant mapunit within 20 meters of stream (0-100 cm depth)
DomMaxCrse	Max coarse material % of dominant mapunit within 20 meters of stream (50–150 cm depth)
DomDrCls	Drainage classification of dominant mapunit within 20 meters of stream
PctCrop	Percent cropland within 90-m riparian zone
PctPasture	Percent pasture within 90-m riparian zone
PctForest	Percent forest within 90-m riparian zone
PctNonAg	Percent non-ag land within 90-m riparian zone
PctSlp2_8	Percent of 90-m riparian zone occupied by slopes 2 – 8%
BankHgtCM	Estimated bank height (in cm)
SatBuff	YES/YES with carbon enhancement/NO classification for saturated buffer suitability

Reason	Reason for disqualification, if receiving a NO classification for saturated buffers. Includes the following categories, and may be a combination of:
	• Steep Banks: (bank height is greater than user-specified threshold –between 6 and 10 ft)
	• Soils: Do not meet all three required soil attributes (within 20 meters of stream):
	  ○ organic matter >= 1.7% (0 – 100 cm depth)
	  ○ coarse material <= 50% (50 – 150 cm depth)
	  ○ Drainage classification of very poorly drained, poorly drained, somewhat poorly drained, or moderately well drained”
	• Topography: 2 – 8 % slopes do not occupy a default minimum 35% of 90-m riparian zone
	• Land Use: cropland or pasture does not exist within riparian zone

UTILITIES

Included in the ACPF Toolbox are a suite of programs designed to assist the user in developing and maintaining the data that is used during conservation planning activities. The goal of including these tools is to allow the user to become independent of the authors in their use of the ACPF in the future.

The utilities described below offer the opportunity to create a new ACPF file-geodatbase anywhere in the conterminous United States. In order to use the ACPF conservation planning tools, it is strongly recommended that user who create their own ACPF database adhere to the naming conventions described above in **Preface and Input Data** section. If you choose to pursue the creation of an ACPF database independent of those provided online, there are a few datasets required to insure success;

- High-resolution elevation data – the ACPF tools depend heavily on a well-formed, hydrologically corrected, high-resolution digital elevation model (DEM). While there are ACPF tools available to hydrologically correct elevation data, the original DEM is expected to be contributed by the User. We have found that a 2-meter resolution DEM is a good fit between too coarse (>= 5m) and too fine (<2m). We strongly suggest converting the Z-values from floating-point meter values to integer centimeter values, in order to reduce disk space requirements and enhance the processing speed of the tools.

- Agricultural field boundaries - the ACPF has been designed to support field-level agricultural conservation planning. The original data used to create this database were the pre-2008 Farm Bill FSA Common Land Unit (CLU) datasets. These data has been extensively edited to reflect crop-specific land use consistent with land cover as derived from NASS Crop Data Layer datasets and aerial photography, and no longer reflects discrete ownership patterns. A field boundary feature class is a necessary element on the ACPF data structure. This dataset can be one of your own choosing – CLUs, local assessor office polygons, or polygons that you have digitized. The process described below offers the User to contribute and edit polygon feature classes that seek to create land use-specific field boundaries to be used in the conservation planning process.

Basic Steps to Creating an ACPF file-geodatabase

These steps, when followed, will result in a single HUC12 watershed that conforms to the describe ACPF database structure and naming conventions and will be compatible with the ACPF Toolbox.

1. Create an ACPF file-geodatabase (e.g. acpf070802020103) using an appropriate method in ArcMap or ArcGIS Pro.
   - In ArcCatalog; right-click, New, File Geodatabase.
   - Use the Create File GDB (Data Management) tool.
   - Use the arcpy.CreateFileGDB_management scripting tool.
2. Create the watershed boundary feature class
   - Use the ACPF naming convention for a HUC12 watershed, e.g. bnd070802020103.
   - In ArcMap, add the source watershed feature class, select the watershed of choice, export to the ACPF fgdb, add to the ArcMap session.
3. Create the initial filed boundary feature class
   - In ArcMap, add the source field boundary feature class.

- Select those filed that Intersect the watershed boundary feature class.
- Export to the ACPF fgdb as 'FB070802020103_edit', add to the ArcMap session.
- The field boundaries will be used in follow steps to create the final filed boundary feature class and the land use tables.

4. Create the buffered watershed boundary
   - The buffered watershed boundary is established at a distance from the original watershed boundary and the field boundaries to insure that the land use, soils, and elevation fully capture the watershed's extent. Invariably, the watershed boundary that will be derived from the high-resolution DEM will differ from the original.
   - Use the Union tool to combine the watershed boundary and field boundaries feature classes. Allow the output to end up in the default workspace.
   - Using the Buffer tool, buffer the Union output by 1,000 meters to create the buffered watershed boundary. Use the Dissolve All option.
   - The output should be set to the watershed's ACPF fgdb using the ACPF naming convention, e.g. buf070802020103.
5. Download the ACPF Soils data
   - Use the **Utilities>u1. Get ACPF Soils Data** tool to download the soils data.
   - The input to the tool is the buffered watershed boundary feature class, e.g. buf070802020103.
   - The tool will extract the gSSURGO raster and create the soils attribute tables; soil profile, surface horizon, and surface texture. These data will not be added directly to the ArcMap session, check for them in ArcCatalog or the Catalog window.
6. Download the ACPF Land Use data
   - Use the **Utilities> u2. Get NASS CDL by Year(s)** tool to download multiple years of land use data.
   - The inputs to the tool are the buffered watershed boundary feature class (e.g. buf070802020103), and the ACPF_CDLlkup.dbf table. The ACPF_CDLlkup.dbf can be found in the folder where the ACPF Toolbox is installed.
   - Check the appropriate boxes for the years of land use data to download. There needs to be at least 6 years of data for the land use tools to run. The current online database carries data from 2010-2017.
   - The tool will extract the land use rasters for each year selected and populate the attribute tables. These data will not be added directly to the ArcMap session, check for them in ArcCatalog or the Catalog window.
7. Create the final ACPF land use data
   - Depending on the condition of the field boundary feature class, creating the final land use data may be an iterative process.
   - Use the **Utilities>u3. Update Edited Field Boundaries** tool using the field boundary polygon feature class (e.g. FB070802020103_edit) and the ACPF_CDLLkup.dbf table as inputs.
   - The outputs will include the field boundary feature class (e.g. FB070802020103), a land use summary table (e.g. LU6_070802020103) and the crop history table (e.g. CH_070802020103).
   - To check the land use assignment, join the FB polygons with the crop history table using the FBndID field as the join field, then symbolize on the 'pct17' field. This attribute carries the percent of the field assigned to the dominant land use for each field.

- Examine those polygons whose ‘pct17’ is less than 75%. Use the NASS CDL data in your workspace and aerial photography to determine if the field boundaries should be edited.
- Once editing is complete, re-run the **Utilities>u3. Update Edited Field Boundaries** tool using the updated field boundary feature class. Once satisfied, delete all the intermediate FB, LU6, and CH datasets.

The final database should appear as…

Contents Preview Description

Name	Type
bnd070802020103	File Geodatabase Feature Class
buf070802020103	File Geodatabase Feature Class
CH_070802020103	File Geodatabase Table
FB070802020103	File Geodatabase Feature Class
gSSURGO	File Geodatabase Raster Dataset
LU6_070802020103	File Geodatabase Table
SoilProfile070802020103	File Geodatabase Table
SurfHrz070802020103	File Geodatabase Table
SurfTex070802020103	File Geodatabase Table
wsCDL2010	File Geodatabase Raster Dataset
wsCDL2011	File Geodatabase Raster Dataset
wsCDL2012	File Geodatabase Raster Dataset
wsCDL2013	File Geodatabase Raster Dataset
wsCDL2014	File Geodatabase Raster Dataset
wsCDL2015	File Geodatabase Raster Dataset
wsCDL2016	File Geodatabase Raster Dataset
wsCDL2017	File Geodatabase Raster Dataset

u.1. Get ACPF Soils Data

Required Inputs	Outputs
INPUT LAYER: Buffered Boundary feature class (buf + inHUC)	gSSURGO raster (gSSURGO)
	Soil Profile table (SoilProfile + inHUC)
	Surface Horizon table (SurfHrz + inHUC)
	Surface Texture table (SrfTex + inHUC)

Soils data for the ACPF has been expanded to support agricultural conservation planning in the conterminous United States. The **Get ACPF Soils Data** tool allows ACPF users to update or create new soils data found in the traditional ACPF database structure. The tool will extract the NRCS gSSURGO soils raster (10m resolution) and modify it to work within the ACPF processing framework for the selected watershed. Additionally, the three associated ACPF soils tables will be extracted for the map units found in the output soils raster.

- The soils data will be extracted to the boundaries of the Input Buffered Boundary feature class. Traditionally, this is the ACPF 'buf' feature class (i.e. buf070802010302), which was established as a 1,000 meter buffer around the watershed's field boundary feature class. The ACPF 'buf' feature class was used to extract the original soils data in the ACPF watershed file-geodatabases
- The output soils raster will use the ACPF naming convention for soils data;
    - gSSURGO – the soils raster
    - SoilProfile + inHUC – soils profile table
    - SurfHrz + inHUC – surface horizon table
    - surfTex + inHUC – surface texture table
- The output soils raster will have the same projection as the Input Buffered Boundary feature class argument.

u.2. Get NASS CDL by Year

Required Inputs	Outputs
INPUT LAYER: Buffered Boundary feature class (buf + inHUC)	ACPF Land Use raster (wsCDL + Year)
USER DECISION: Select Desired Year(s) of NASS CDL data	
INPUT TABLE: ACPF LandUse Lookup table (ACPF_CDLlkup)	

The NASS Cropland Data Layer for the ACPF has been assembled to support agricultural conservation planning in the conterminous United States. The **get NASS CDL by Year(s)** tool allows ACPF users to augment the current six years of land use data found in the traditional ACPF database structure or create new land use data for an empty ACPF database. The tool will extract the NASS CDL data for the input year(s) and modify it to work within the ACPF processing framework for the selected watershed. It is important to note that not all states have the same period of record when it comes to the NASS CDL. Some states, Illinois and North Dakota, have data back to 1999, while others have fewer years of data. The conterminous 48 states have a complete record starting in 2008. If you input a year that is incongruent with the states period of record, the tool will ignore the selection. See the NASS metadata page to determine if your area of interest has data for the year in question. The metadata that pertains to the original NASS Cropland Data Layer can be found on the home web site at http://www.nass.usda.gov/research/Cropland/metadata/meta.htm.

- The NASS CDL data will be extracted to the boundaries of the Input Buffered Boundary feature class. Traditionally, this is the ACPF 'buf' feature class (i.e. buf070802010302), which was established as a 1,000 meter buffer around the watershed's field boundary feature class. The ACPF 'buf' feature class was used to extract the existing land use data in the ACPF watershed file-geodatabase.
- The output land use raster will use the ACPF naming convention for land use data (i.e. wsCDL2009).
- The output land use raster will have the same projection as the Input Buffered Boundary feature class argument.
- The ACPF Land Use Lookup table is used to populate required fields in the ACPF land use rasters. A copy of the 2015 table h been included in the ACPF install directory.
- Valid years are from 2000 to 2020.

We are planning for the future. In subsequent years, a new year can be added to the Parameters value list by editing the Parameters property sheet for the 'Select the desired Year(s)' list.

- Right-click on the tool and select 'Properties'
- Click on the 'Parameters' tab
- Click on the 'Select the desired Year(s)' entry
- Click on the ellipses (…) on the Filter>Value List
- Add the new year to the bottom of the list (e.g. '2018')

u.3. Update Edited Field Boundaries

Required Inputs	Outputs
INPUT LAYER: Edited Field Boundary feature class (e.g. FB_edit + inHUC)	Updated Field Boundary feature class (FB + inHUC)
USER DECISION: 'Less Than' feature size (Acres)	
INPUT TABLE: ACPF Land Use lookup table (ACPF_CDLlkup)	

The ACPF field boundaries dataset has been assembled to support field-level agricultural conservation planning. The original data used to create this database are the pre-2008 Farm Bill FSA Common Land Unit (CLU) datasets. Please note that all USDA programmatic and ownership information that was associated with the original data have been removed. Beyond that, these data has been extensively edited to reflect crop-specific land use consistent with land cover as derived from NASS Crop Data Layer datasets and aerial photography, and no longer reflects discrete ownership patterns.

As the original field boundary data were constructed using NAIP imagery, users of the ACPF Toolbox may find it necessary to update these data to reflect current conditions. The relationship between the field boundary feature class and the land-use lookup tables (e.g. FB070801050403; LU6_070801050403 and CH_070801050403) requires a one-to-one relationship based upon the FBndID field. If the field boundary feature class is edited, this relationship will be corrupted. The Update Edited Field Boundaries tool will rebuild the land-use lookup tables based on the contents of an edited field boundary feature class, using the NASS CDL rasters present in the watershed's file geodatabase.

Process

- The user inputs an edited version of the original field boundary feature class (e.g. FB070801050403_edit). The User must make a copy of the original field boundary feature class for editing purposes...the original feature class is an invalid input to this tool. Alternatively, the user could use a completely different field boundary feature class that is not a copy of the original. If so, this feature class must be named using the same structure as noted above.
- When running this tool for the first time, the original field boundary feature class will be renamed to append '_orig' to the feature class name.
- Only existing watershed land use rasters will be used to update the new land use lookup table. The land use rasters must be named as 'wsCDL' + Year (e.g. wsCDL2012) or they will not be included in the processing.
- The 'ROTVAL' field must exist and be populated in each land use raster. The appropriate values for 'ROTVAL' can be found in the ACPF Land use Lookup Table. This table should exist in the base directory of the "ACPF" download folder.
- A minimum of six (6) years of land use data (rasters) must exist locally in the watershed file-geodatabase for the tool to run.
- The user may exclude small fields from processing by assigning a numeric value to the 'Less Than' feature size argument. The default is 15 acres and the minimum value is 5 acres. Any field

that has an area less than or equal to the input value will be assigned a GenLU value of 'Less Than 15 acres' or whatever the input value entered.

- The ACPF Land use Lookup Table enables the necessary assignment of a generalized, single-letter crop to each cover type in the land-use rasters. A copy of this table, ACPF_CDLlkup.dbf, is included in the main ACPF Toolbox directory.

u.4. Project ACPF FGDB to New Spatial Reference

Required Inputs	**Outputs**
INPUT GEODATABSE: Existing ACPF FileGeodatabase (e.g. acpf + inHUC)	Output Directory of newly projected fgdb
USER DECISION: Output Spatial Reference	

This tool projects an ACPF workspace to a new spatial reference.

ACPF data are maintained in an ArcGIS file-geodatabase structure. By design, all feature classes and rasters for ACPF data are in the same coordinate system. There may be some instances where the ACPF database needs to be converted to a different spatial reference. This tool will copy an existing ACPF file-geodatabase to a new ACPF file-geodatabase with the selected output spatial reference. Any tables that may exist in the input file-geodatabase will be copied to the output file-geodatabase.

- The ACPF file-geodatabase must not exist in the output directory.
- The ACPF toolbox expects a coordinate system with X-Y units in meters.

For storage purposes, the ACPF database is maintained in the USA_Contiguous_Albers_Equal_Area_Conic_USGS projection (WKID: 102039 Authority: ESRI). This spatial reference uses the NAD83 datum. At this time, this tool does not support transformations from NAD83 to other datums or spheroids. Thus, the output spatial reference should employ the NAD83 datum...to do otherwise invites poor results. If a datum other than NAD83 is desired, it is recommended that the User undertake projecting the ACPF data on an individual dataset basis.

u.5. Find Terraces

Required Inputs	Outputs
INPUT LAYER: Elevation Raster	Terrace polyline feature class (Terrace + inHUC)
USER DECISION: Curvature threshold	
USER DECISION: minimum Terrace Length	
USER DECISION: Endpoint Snap Distance	
USER DECISION: Feature Extend Distance	
USER DECISION: Z-Factor	
INPUT LAYER: Field Boundary Feature Class (FB + inHUC) (optional)	
INPUT LAYER: Stream Feature Class (optional)	
USER DECISION: Stream buffer distance	

The Find Terraces tool attempts to extract sharply curved features from a high-resolution DEM. Features that exhibit a relatively high degree of convex curvature are identified, extracted and converted to polyline features. Typically, these sharply curved features are agricultural terraces, although water and sediment control basins (WASCOBs), and impoundments may also be extracted. Most of these features are an earthen embankment, or a combination ridge and channel, constructed across the field slope intended to reduce soil loss due to surface erosion.

The Find Terraces tool constructs a profile curvature raster from the input DEM and uses a threshold to identify cells that are sharply convex. The threshold is the minimum convex profile curvature allowed. Recommended values range from -1.5 to -3, the minimum allowed value is -0.5. Curvature thresholds closer to 0 will allow less-curved features to be included in the result, thus; trial-and-error is suggested in selecting a threshold value.

Curvature values are in one hundredth (1/100) of a z-unit. The Z-Factor input controls the relationship between the X-Y coordinate system and the vertical units of elevation, which are often centimeters in ACPF file-geodatabases. If X-Y coordinates are in meters and the z-units of the elevation raster (DEM) are centimeter, then the Z-Factor = 0.01.

There are options that can be used to reduce the number of non-agricultural features from the output.

- If the field boundary feature class is input, it will be used to mask areas of inclusion and exclude road ditches and other curvy features near the field edge.
- A stream feature class can be used to exclude stream banks and other curved features within the Stream Buffer Distance value.
- The script was developed with the ACPF in mind, so the field boundaries and stream reach feature classes are expected to be present. That said, any stream-related feature class added will be used to exclude curvature cells in proximity.
- If the end points of two line features are within the End-point Snap Distance, the end points will be snapped together and a single feature will be created.
- After the line features are created and aggregated using the End-point Snap Distance, the features will be extended in both directions by the Feature Extend Distance, if two features intersect, the features will create a vertex and a single feature will be created. A large value for this threshold may cause spurious features to be created.

The output of the Find Terraces tool is a polyline feature class that represents sharply curved features that are associated with man-made agricultural conservation practices, such as terraces. It is expected that the output feature class will also contain other natural or non-agricultural features that may not be of specific interest. The output feature class is expected to be edited to remove unwanted features.

7. Evaluating and Using ACPF Results

This Section provides brief advice towards using the ACPF results you have developed and placing them in context with and incorporating them into the watershed planning process. As a part of this, you need to ask yourself (and/or your planning team) five questions:

Do I have all the data I need to complete my inventory of conservation opportunities in this watershed? You should assume the answer to this is 'no'. Several states have information on locations of springs, tile drainage systems, biological resources (rare species), and wetlands. Planning must be done in a multi-resource context. Learn about other sources of information affecting water and other resources and be sure to access them. When we have considered that conservation opportunities beyond what ACPF map products can show in test watersheds may exist, we consistently identified features ranging from springs to gravel pits that could further considered for uniquely designed water quality improvement opportunities. Several of these appeared to be important, or even critical, opportunities.

Are there conservation opportunities concerning land use and/or land use conversion in this watershed? This is probably the case, and the ACPF output should again be supplemented here. Essentially, what you have done in applying the ACPF toolbox is to identify where specific conservation practices can be used to interrupt and/or detain water flows at landscape and field scales, and you have conducted a riparian assessment that can be used to evaluate current, and to identify options for improving, riparian management in your watershed. Land use (agricultural) practices and land cover suitability are also critical topics for improvement of soil health and of watershed management (see Tomer et al., 2013), but we have not (yet) pushed these considerations in any specific direction within the ACPF toolbox. Be aware that additional geographic analysis to identify vulnerable lands will be beneficial to planning in many if not all watersheds. Soil survey and slope information may be used, as well as secondary terrain attributes (topographic wetness index, sediment delivery index) to help identify vulnerable lands and prioritize additional opportunities for watershed improvement. The TauDEM tools provide an excellent set of terrain analysis products that can help, and working with erosion-prediction tools will provide good information as well. Vulnerable lands assessment is being considered for future tool development as part of the ACPF. Increasingly, it is also possible to utilize high resolution DEMs with erosion prediction tools including RUSLE2 and WEPP.

How should I go about verifying the information I have developed? By using these tools (and analyzing other data gathered to address the above two questions), you have developed a unique data resource that is customized to the subject landscape and watershed. As with all data sources used in resource planning, their utility and accuracy should be evaluated. The ACPF toolbox provides users multiple opportunities to alter site selections by modifying search criteria. Utilize these selections to customize ACPF results for your watershed! We have found detailed field reviews to be very helpful in this process in test watersheds. In some watersheds, it will be helpful to locate culverts or other drainage infrastructure to validate your edits to the LiDAR-based DEM to enforce hydrologic routing. If the ACPF results are to be followed by use of additional tools that enable engineered practice designs to be developed, then the accuracy of the LiDAR-based DEMs may not be sufficient for engineering design needs and ground based topographic surveys may be required.

What are the current distributions and types of conservation practices already present in this watershed? Farmers have been implementing conservation practices on cropland for more than 70 years, and the types of practices being used has shifted as agricultural management systems have changed. Information about where practices have already been implemented in the watershed can help you assess ACPF results, and help prioritize where to focus planning and producer engagement efforts. While this information can be difficult to obtain, the State of Iowa has undertaken mapping existing locations of several types of practices, statewide. Recent aerial photographs and the 'Find terraces' utility are places to begin if you wish to develop data on placements of existing practices in the watershed.

How do I go about using these results to engage stakeholders towards participation in watershed planning and implementation? Briefly, with a sense of open-mindedness. There are as many ways to approach the question of stakeholder engagement as there are watersheds. We have found producers who are able to verify and endorse several results from ACPF planning tools, and others who have said some practice suggestions were not realistic. Expect to see a range of stakeholder responses to ACPF outputs. Ideally, ACPF results might best be used by landowners in a community-based and adaptive effort towards watershed improvement. However, in reality, conservation practices are installed by placing one practice in one field or one riparian setting at a time. Schemes to incorporate watershed scale information into farm-scale planning can now be developed using your ACPF results as well. Understanding each of your farmers/landowners as individual businessmen and conservationists will help you determine a pathway towards watershed planning involving collaborative teamwork and individual decision making.

Please let us hear your feedback and lessons you learn in using these tools and applying them towards management of agricultural watersheds.

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