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CHARACTERIZATION OF AGRICULTURAL FLOODPLAIN SCOUR USING ONE-DIMENSIONAL HYDRAULIC SIMULATION

by

Riley Mondloch

A thesis submitted in partial fulfillment
of the requirements for the Master of
Science degree in Civil and Environmental Engineering
in the Graduate College of
The University of Iowa

December 2014

Thesis Supervisors: Professor Larry J. Weber
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Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Riley Mondloch

has been approved by the Examining Committee
for the thesis requirement for the Master of Science
degree in Civil and Environmental Engineering at the December 2014
graduation.

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Larry J. Weber, Thesis Supervisor

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Allen A. Bradley

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ABSTRACT

The Iowa Flood Center (IFC), a unit of The University of Iowa's IIHR – Hydroscience & Engineering, and the Iowa Department of Natural Resources are developing a statewide floodplain boundary dataset to provide information that is critical to proper flood mitigation planning. During flooding, soil loss from agricultural land, in addition to inundation, can have a substantial economic impact on an agricultural state like Iowa. The ability to identify areas with a high potential to experience scour during flooding could assist farmers and land owners in making better land management decisions. Currently, the IFC statewide floodplain mapping program is creating annual exceedance probability floodplain data for all Iowa streams. The effort described herein has developed methods to take advantage of this large dataset, applying uniform open channel flow theory to spatially characterize scour potential using custom tools created with GIS model builder. The scour characterization maps produced by the methods described herein will provide a cost effective means of making approximate assessments of scour potential, but more detailed two dimensional modeling will still be required if a high level of precision is required. The results of this thesis are being used by the Iowa Natural Heritage Foundation (INHF) and the IFC to develop a program through which certified crop consultants can help farmers make more informed land management decisions based on risk of flood related soil loss.

PUBLIC ABSTRACT

The Iowa Flood Center (IFC), a unit of The University of Iowa's IIHR – Hydroscience & Engineering, and the Iowa Department of Natural Resources are developing a statewide floodplain boundary dataset to provide information that is critical to proper flood mitigation planning. During flooding, soil loss from agricultural land, in addition to inundation, can have a substantial economic impact on an agricultural state like Iowa. The ability to identify areas with a high potential to experience scour during flooding could assist farmers and land owners in making better land management decisions. Currently, the IFC statewide floodplain mapping program is creating floodplain maps for all Iowa streams. The effort described herein has developed methods to take advantage of this large dataset and use it to characterize scour potential within floodplains. These scour characterization maps will provide a cost effective means of making approximate assessments of scour potential, but more detailed two dimensional modeling will still be required if a high level of precision is required. The results of this thesis are being used by the Iowa Natural Heritage Foundation (INHF) and the IFC to develop a program through which certified crop consultants can help farmers make more informed land management decisions based on risk of flood related soil loss.

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CHAPTER 1. INTRODUCTION

The objective of this project is to create maps that can spatially display shear stress and scour potential within floodplains using one-dimensional (1D) hydraulic model results as inputs. In order to facilitate land management decisions, maps must display data in a two-dimensional (2D) spatial grid. While there are many 2D models available, they are expensive and often not practical for creating large datasets. The Iowa Flood Center (IFC) is using Hydrologic Engineering Center's River Analysis System (HEC-RAS), HEC-GeoRAS, and ESRI's ArcGIS to create one-dimensional (1D) flood inundation maps for the entire state of Iowa as part of the Iowa Statewide Floodplain Mapping (FPM) Program (US Army Corps of Engineers, n.d.), (ESRI, 1999). This thesis has developed methods and ArcGIS tools to create large scour characterization datasets relatively quickly and inexpensively utilizing the readily available results from 1D HEC-RAS models created for the FPM project, but the maps produced will be approximate due to limitations associated with 1D modeling and will not be a substitute for detailed 2D models if highly detailed shear or scour information is needed.

The methods and GIS tools that were developed for this thesis use the depth, slope, water surface elevation, and Manning's n data that result from 1D HEC-RAS models to create approximate pseudo 2D effective shear and velocity maps. The effective shear maps are then related to the Natural Resources Conservation Service (NRCS) soil allowable shear data to assess scour potential within floodplains. Shear and scour maps can be prepared for individual properties or entire reaches faster and less expensively than would be possible with 2D modeling. However, they are subject to some inherent limitations associated with the 1D data that make it difficult to account for the presence of backwater areas, flow obstructions, and continuity between HEC-RAS cross sections. Further methods were developed in this thesis to correct shear and velocity maps for continuity limitations. Maps produced using methods described herein characterize spatial distribution of scour potential but will not be able to quantify the depth of scour.

Chapter 2 provides background information regarding open channel flow theory and hydraulic modeling. Chapter 3 introduces the source data used for this thesis. Methods and tools created to characterize floodplain scour are detailed in Chapter 4. The two Mike21 2D models that were used to validate and compare with the results are discussed in Chapter 5 (DHI, 2011). Chapter 6 discusses how the results should be interpreted to gain useful information. Appendix A contains diagrams for the tools created. Appendix B details the start to finish process of using the methods and GIS tools developed for this thesis to produce shear, velocity, and scour characterization datasets.

CHAPTER 2. BACKGROUND INFORMATION

It is important to understand hydraulic modeling and open channel flow equations in order to create and properly interpret the scour characterization maps. The primary flow property governing scour is the shear stress acting on the soil. Shear stress depends on channel geometry, roughness, slope, and the flow rate of water passing through the channel. Hydraulic models require the flow rate, channel geometry, and surface roughness parameters in order to compute the velocity and shear stress. Hydraulic models are generally classified as three dimensional (3D), two dimensional (2D), or one dimensional (1D). 1D models predict flow characteristics that are averaged along a cross-section of flow in a single direction and are the simplest and coarsest type of model. 2D models predict vertically averaged values in the x and y directions; this is done on a grid and results in a map that shows the spatial distribution of flow properties. 3D models predict the x, y, and z components of flow on a spatial grid.

2.1. Open Channel Flow

2.1.1. Open Channel Flow Basics

Open channel flow refers to a flow in which the surface is open to the atmosphere; therefore, river flow is considered open channel flow. Open channel flow is considered steady when it does not vary with time. Uniform open channel flow describes a flow that has a constant bed slope, cross-sectional area, and roughness. Non-uniform open channel flow has varying bed slopes, cross-sectional area, and shape along the channel. A natural river has non-uniform flow, but a river section can often be approximated as having uniform flow in rough calculations. Figure 1 shows a side view of simple channel flow. The hydraulic grade line is the surface of the water, shown in Figure 1 as “Water surface.” The energy grade line is given as Equation 1 and is shown as “Energy line” in Figure 1. Flow is considered uniform when there is no change in the cross-sectional area of flow, and the bed slope, hydraulic grade line, and energy line slope are all equal (Mohtar, 2010).

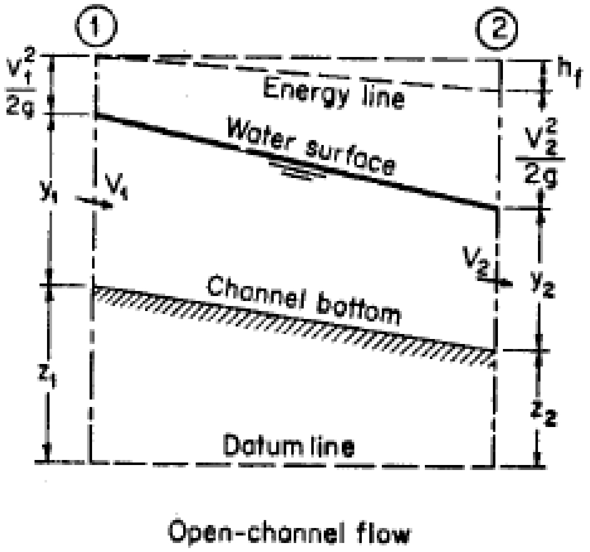


Figure 1: 1D open channel flow profile (Mohtar, 2010)

Equation 1: Energy Equation

$$E = Z + y + \frac{V^2}{2 * g}$$

2.1.2. Manning's Equation

Manning's Equation is a common and simple way to solve for the average velocity or shear across an open channel cross-section. It requires the slope, roughness parameter n, flow area, and wetted perimeter of the cross-section as inputs to solve for average velocity across the cross-section.

Equation 2 shows Manning's Equation for velocity, and Equation 3 shows Manning's Equation for flow rate.

Equation 2: Manning's Equation - Velocity

$$V = \frac{1}{n} * R^{\frac{2}{3}} * S^{0.5}$$

Equation 3: Manning's Equation – Flow Rate

$$\mathrm{Q} = A * \frac{1}{n} * R^{\frac{2}{3}} * S^{0.5}$$

Where, V = Velocity (m/s), A = Area (m^2), R = Area/Wetted Perimeter (m^2/m), n = roughness parameter, and S = energy line slope (decimal slope).

2.1.3. Introduction to Shear and Erosion

Water moving over a surface, in this case the soil and vegetation, will cause a shearing force due to the viscous forces between the surface and water. Water with a higher velocity will impart a higher shear stress on the surface. See Figure 2 for a basic example of shear. The total shear imparted by the water acts on the soil, vegetation, and other objects on the surface. The portion of this total shear that acts on the soil and contributes to erosion is called the effective shear. It takes a minimum effective shear stress, referred to as allowable shear stress, before scour will begin to occur. Allowable shear stress varies among different soil types and depends on properties such as percentage of sand, particle size distribution, and whether or not the soil is consolidated. Scour begins to occur when effective shear exceeds allowable shear, and the amount by which effective shear exceeds allowable shear is referred to as excess shear (USDA NRCS, 2007). Scour depth depends on inundation duration as well as excess shear and cannot be quantified for this project because inundation duration data are not available.

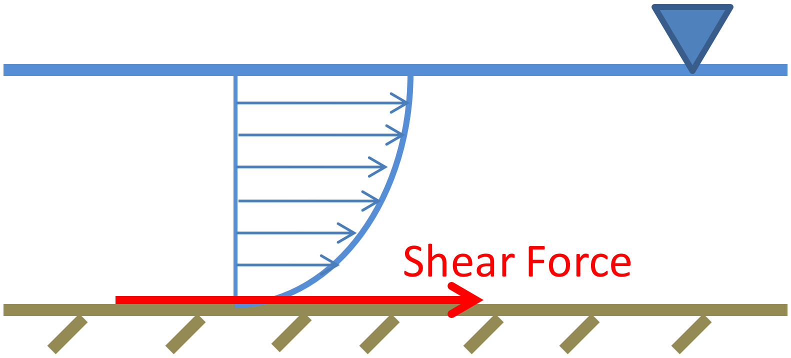


Figure 2: Shear stress diagram showing typical velocity profile and resulting shear

2.1.4. Bed Shear Equation

The open channel flow equation for bed shear is given as Equation 4. This equation yields the total shear stress imparted on the cross-section.

Equation 4: Bed Shear

$$\tau_b = \gamma RS$$

Where, τ_b = Bed shear (N/m^2), γ = Unit weight of water (9810 N/m^2), R = Area/Wetted Perimeter (m^2/m), and S = energy line slope (decimal slope).

2.1.5. Effective Shear Equation

The total bed shear is distributed across vegetation, un-erodible objects, and erodible soils. Effective shear is the portion of the total shear that acts on erodible particles and causes them to detach. Figure 3 illustrates how only a portion of the total shear makes it through the cover to act on the erodible soils. The presence of more vegetation and other roughness elements will result in a lower effective shear because more of the total shear is acting on the vegetation and less is acting on the soil (USDA NRCS, 2007). The effective shear equation is shown as Equation 5.

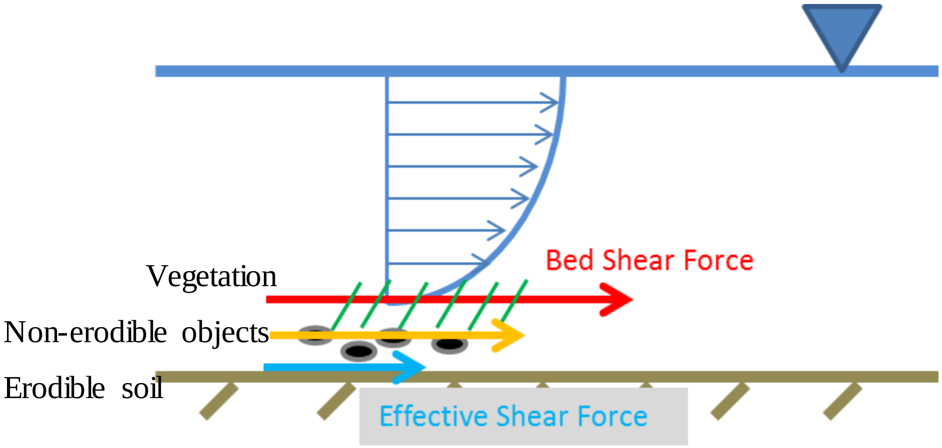


Figure 3: Effective shear diagram demonstrating how only a portion of bed shear acts on erodible soil

Equation 5: Effective Shear

$$\tau_e = \gamma RS(1 - CF)\left(\frac{ns}{n}\right)^2$$

Where, τ_e = Bed shear (N/m^2), γ = Unit weight of water (9810 N/m^2), R = Area/Wetted Perimeter (m^2/m), S = energy line slope (decimal slope), n = roughness parameter, ns = soil grain roughness, and CF = Cover Factor based on vegetation spacing and uniformity (USDA NRCS, 2007).

The effective shear equation is the same as the total bed shear equation, except that it now has corrections to remove the portion of the shear stress acting on the vegetation and the non-erodible bed objects. The cover factor (CF) is an empirical relationship given by (USDA NRCS, 2007) that is related to vegetation density and uniformity. More densely packed vegetation has a higher cover factor, which reduces the portion of the total shear acting on the erodible soils. Cover factor values, ranging from 0.5 to 0.9, were only given for various types of grass in this document because it is intended for the design of grass lined channels. The $(ns/n)^2$ correction adjusts the slope based on the typical erodible soil grain roughness of 0.0156 for agricultural soils related to the total roughness (USDA NRCS, 2007).

2.1.6. Excess Shear Equation

When effective shear exceeds allowable shear, scour begins to occur. Excess shear is the amount by which effective shear exceeds allowable shear. The excess shear equation, shown as Equation 6, predicts scour rate in depth per time using the difference between the effective shear and the critical shear. Inundation duration data are not available for this project, so actual scour depth cannot be predicted.

Equation 6: Excess Shear

$$\varepsilon_r = K_d(\tau_e - \tau_c)$$

Where, εr = Erosion Rate in units of depth/time, K_d = Erodibility coefficient in units of Volume/(Force*Time), and $\tau_e - \tau_c$ = difference in effective and critical stress in units of Force/Area.

2.2. Compound Open Channel Flow

Compound open channel flow can be solved with the same basic equations as regular open channel flow if some assumptions are made. In compound open channel flow, slope is assumed to be constant across the entire cross-section. It is also assumed that the channel can be broken into several sections and that each section can be solved individually with Manning's Equation using the hydraulic radius and area of the section and the average constant slope of the entire cross-section (Ward & Trimble, 2003). Figure 4 shows several different options for dividing the center channel from the two overbanks.

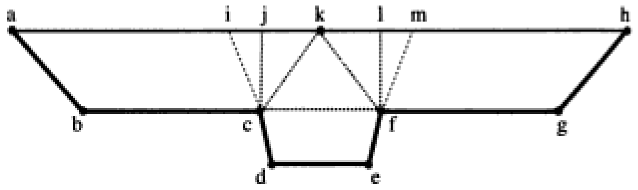


FIGURE 7.4 Compound channel cross section showing possible locations of dummy channel and floodplain sides.

Figure 4: Compound channel cross-section (Ward & Trimble, 2003)

2.3. HEC-RAS 1D Modeling

HEC-RAS is a 1D modeling software which models 1D flow using the standard step backwater method. Results from a steady flow HEC-RAS model are required as inputs for the methods developed for this thesis. The IFC has created HEC-RAS models for all reaches in Iowa draining greater than one square mile as part of the FPM Program, and the water surface elevation, depth raster, and inundation boundary shapefiles results can be used with the methods described herein to create scour characterization maps for any modeled reach in Iowa.

The inputs for HEC-RAS include geometry, elevation, flow rate, and roughness information for each cross-section. These cross-sections are linked together and related to one another spatially. Figure 5 shows the basic model layout, where green lines are the cross-sections with defined geometry and blue lines are connections. Figure 6 shows a typical cross-section view in HEC-RAS.

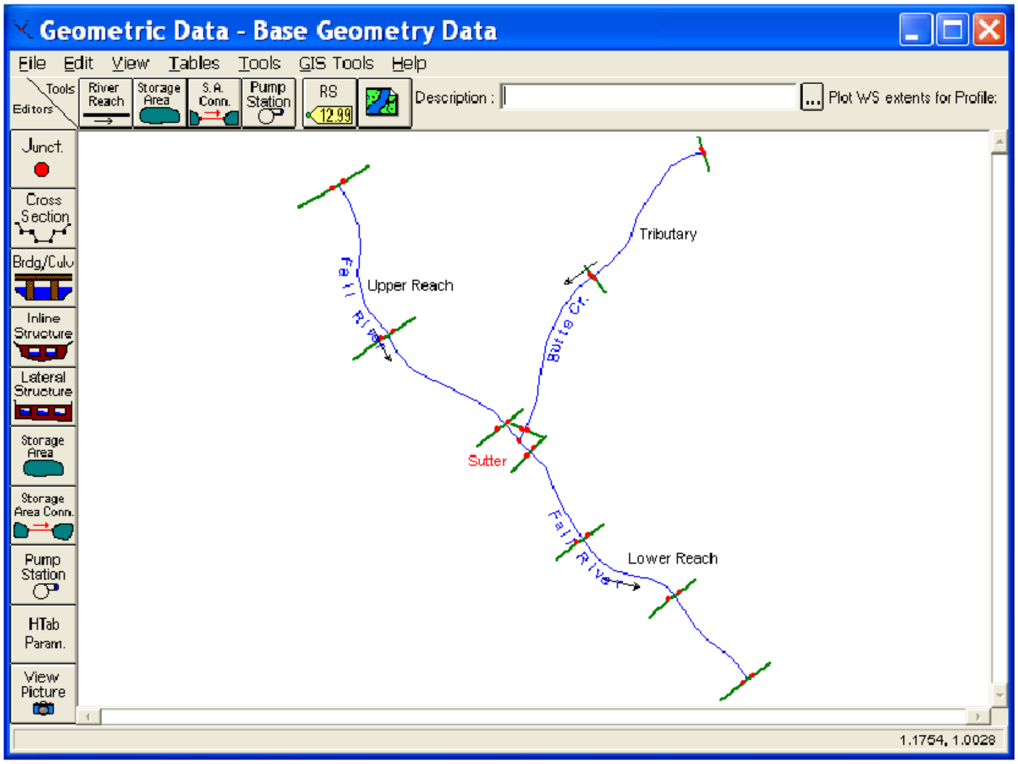
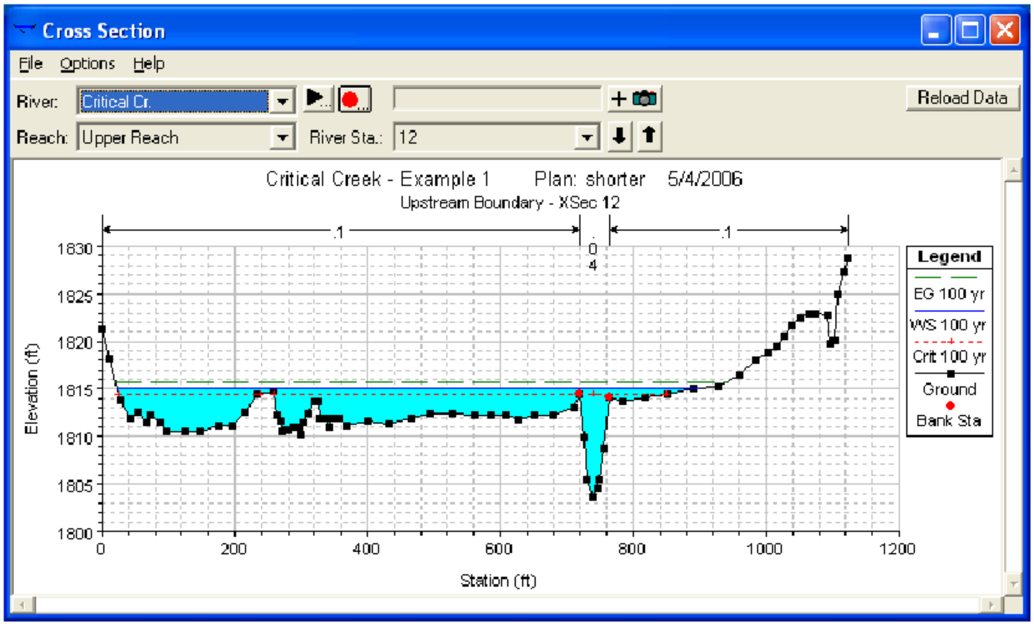


Figure 3-5 Geometric Data Window

Figure 5: HEC-RAS basic model layout – (US Army Corps of Engineers, 2010)



River: Critical Cr.

Reach: Upper Reach

River Sta.: 12

Figure 3-9 Cross Section Plot

Figure 6: HEC-RAS cross-section view – (US Army Corps of Engineers, 2010)

HEC-RAS models result in water surface elevations, average velocities, and average bed shear at each cross-section. The water surface elevations are then interpolated between the cross-sections to create a continuous water surface. Figure 7 shows a profile view of multiple cross-sections in HEC-RAS and the water surface elevation determined between them. Figure 8 shows a 3D view of multiple cross-sections and the calculated water surface elevation.

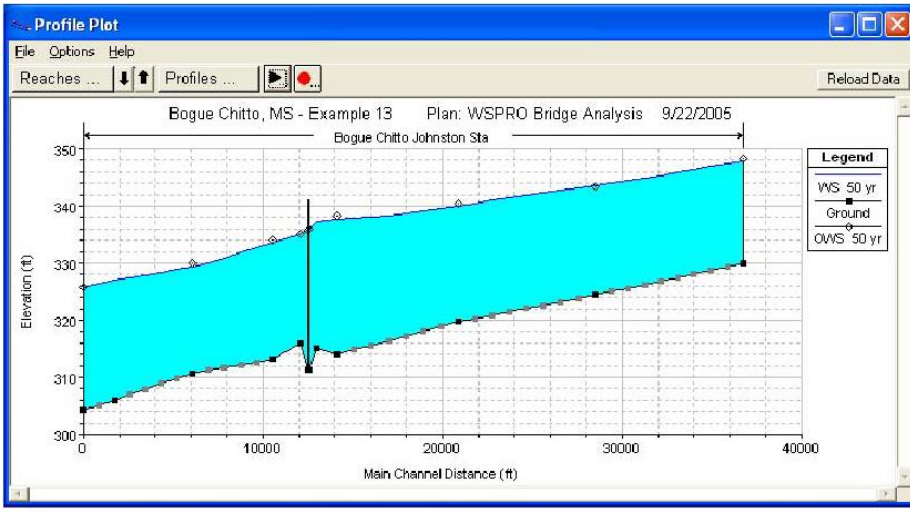
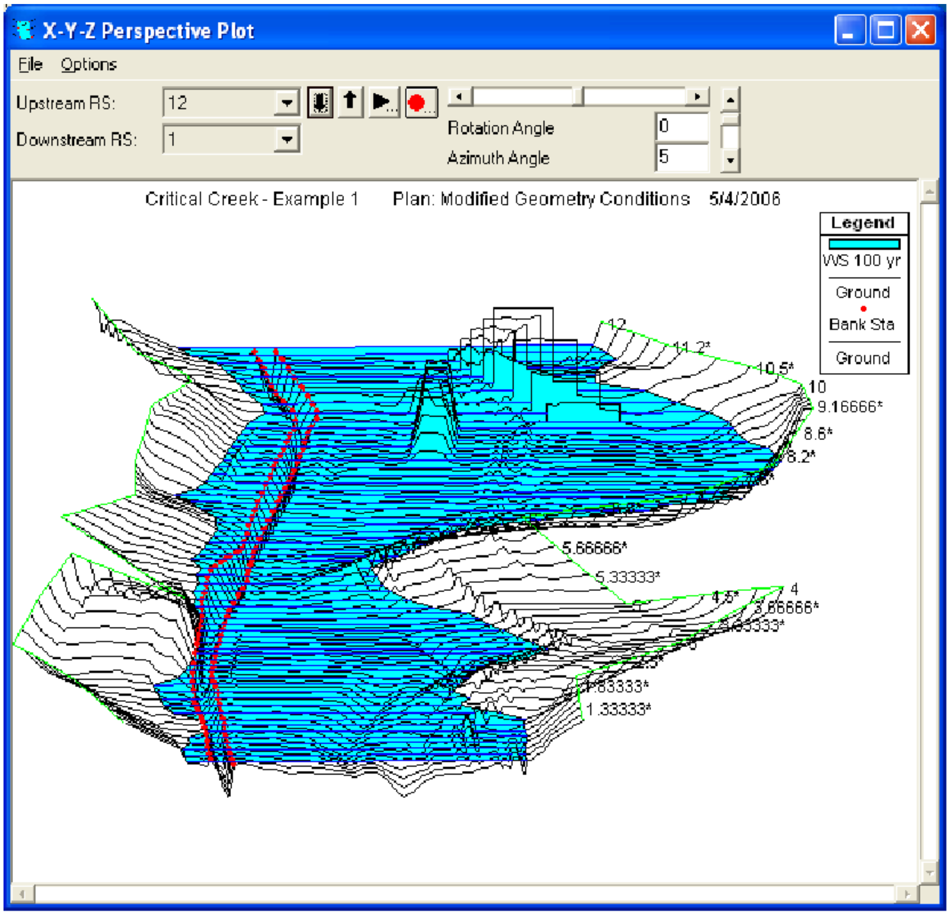


Figure 3-10 Profile Plot

Figure 7: HEC-RAS profile view – (US Army Corps of Engineers, 2010)



Upstream RS: 12
Downstream RS: 1
Rotation Angle 0
Azimuth Angle 5

Figure 3-11 X-Y-Z Perspective Plot of River Reach with a Bridge

Figure 8: HEC-RAS 3D view – (US Army Corps of Engineers, 2010)

The inundation boundary, slope, and depth can be obtained in ArcGIS by using HEC-GeoRAS, a GIS plugin that can interpret HEC-RAS results in the ArcGIS environment, to relate the water surface elevation raster to a digital elevation model for the reach. Average velocity and shear are given by HEC-RAS only at the cross-sections. Slope between cross-sections is based only on the cross-sections. HEC-RAS does not account for bed slope changes, flow area changes, or roughness changes between the cross-sections.

2.4. Floodplain Mapping Project

2.4.1. Introduction

The Iowa Flood Center and Iowa Floodplain Mapping Program were created in response to the 2008 floods that caused millions of dollars of damage across the Midwest. The FPM Program is creating inundation maps to FEMA standards for all streams in Iowa draining greater than one square mile for the 2, 5, 10, 25, 50, 100, 200, and 500 year return periods. The maps are created using the FEMA guidelines for an approximate analysis (Thomas, 2011). Depth raster data and water surface elevation tin data are also created for each of these return periods as part of the floodplain mapping process, and they will be part of the input data for this thesis project and will be discussed further in CHAPTER 3.

2.4.2. FPM Source Data

The FPM project uses a 1 meter digital elevation model (DEM) of Iowa obtained with light detection and ranging (LiDAR) technology. The LiDAR DEM dataset was made available to the IFC through a partnership with the Iowa Department of Natural Resources (IDNR) and is a necessary input for all major mapping processes in the FPM program (Thomas, 2011).

The National Hydrography Dataset (NHD) is a spatial dataset that marks surface water features such as lakes, rivers, ponds, dams, and canals. This dataset is used in the FPM process to identify and name reaches (Thomas, 2011).

The National Land Cover Database (NLCD) is a spatial dataset that classifies land cover types for the entire United States. It is used to determine spatial roughness information (Thomas, 2011).

2.4.3. FPM Hydrography

The hydrography portion of the FPM involves the creation of new stream centerlines that agree with the LiDAR DEM dataset. ArcHydro, manual techniques, and custom scripts are used to create these stream centerlines (Thomas, 2011).

2.4.4. FPM Hydrology

Discharge estimates are made for the 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent annual exceedance probabilities as part of the hydrology portion of the FPM Program. A data point is created every three meters along the stream centerline, and ArcHydro is used to determine the drainage area for each of these points. Regional regression analysis and nearby stream gauge data are used to determine the flow at each of these data points. These flows can then be used as inputs to the HEC-RAS models (Thomas, 2011).

2.4.5. FPM Hydraulics

Water surface elevations are created for the 8 annual exceedance discharges using the HEC-RAS. HEC-RAS needs flow rate data, cross-section geometry data, stream centerline data, and downstream boundary conditions in order to compute water surface elevations. The flow rate and stream centerline data were created in the previous steps of the FPM process. The geometry data are created using HEC-GeoRAS, a GIS plugin that allows for pre-processing and post-processing of HEC-RAS data. HEC-GeoRAS allows the user to draw cross-sections and export DEM elevations along each cross-section to HEC-RAS to serve as the necessary geometry data (Thomas, 2011).

2.4.6. Floodplain Mapping

The floodplain mapping portion of the FPM project creates inundation shapefiles that show a spatial view of the floodplain extents. The HEC-GeoRAS GIS plugin is used to process the HEC-RAS hydraulic model outputs and create inundation shapefiles and depth grids. GeoRAS is first used to create a TIN dataset for the water surface elevation output obtained from HEC-RAS. This TIN dataset contains spatial elevation data much like the DEM raster, except the data are stored using an algorithm instead of as evenly distributed points. The water surface elevation TIN is then overlaid on the LiDAR derived DEM, and the floodplain inundation shapefile is created matching areas where the TIN elevation is greater than the DEM elevation. A depth raster is created using GeoRAS in a similar fashion. The DEM elevations are subtracted from the water surface elevations, and positive values are kept and used to create the depth raster data (Thomas, 2011).

2.4.7. Post Processing

Several post-processing steps are carried out on the resulting floodplain inundation maps. The inundation maps naturally have many small islands and ponds that occur due to the high resolution of the LiDAR derived DEM used to create them. A script is used to remove polygons or holes in polygons that are below a certain area threshold. This script is referred to as the pre-cleaning script and is used on the inundation shapefiles of all 8 annual exceedance discharges.

References in this document to “un-cleaned” shapefiles refer to those shapefiles that have only had the pre-cleaning script run on them.

The 100 year and 500 year return periods are the inundation maps that will be reported to FEMA. These maps are thoroughly cleaned manually to ensure that they best represent reality. The manual cleaning process involves deletion of the hydraulically disconnected features that were too large to be deleted by the script. Manual cleaning adds in inundation boundaries where there is a cutoff due to an error in the boundary used for the HEC-RAS model and where there is error due to LiDAR artifacts in the DEM.

References in this document to “cleaned” shapefiles refer to the shapefiles that have had the pre-cleaning script run *and* have been cleaned by hand.

CHAPTER 3. INPUT DATA

The input data required to create velocity, shear, or excess shear maps that will characterize scour include HEC-RAS water surface elevation TIN data, depth grid raster data, spatial land cover raster data, spatial Manning's n raster data, and spatial allowable shear data. The HEC-RAS data used to develop the methods described herein are obtained from the IFC.

3.1. Water Surface Elevation and Slope Data

The water surface elevation (WSE) TIN data are created using HEC-GeoRAS and are stored by and available from the IFC. The TIN data are organized by reach because the hydraulic models are run individually on reaches. This project uses water surface data to create water surface slope data for use in various tools. Figure 9 shows a water surface elevation TIN dataset, and Figure 10 shows a water surface elevation slope raster created in GIS using the TIN data and slope tool. The GIS slope tool calculates the slope of each cell based on its elevation and the eight cells surrounding it.

Figure 9: WSE TIN data created with HEC-RAS

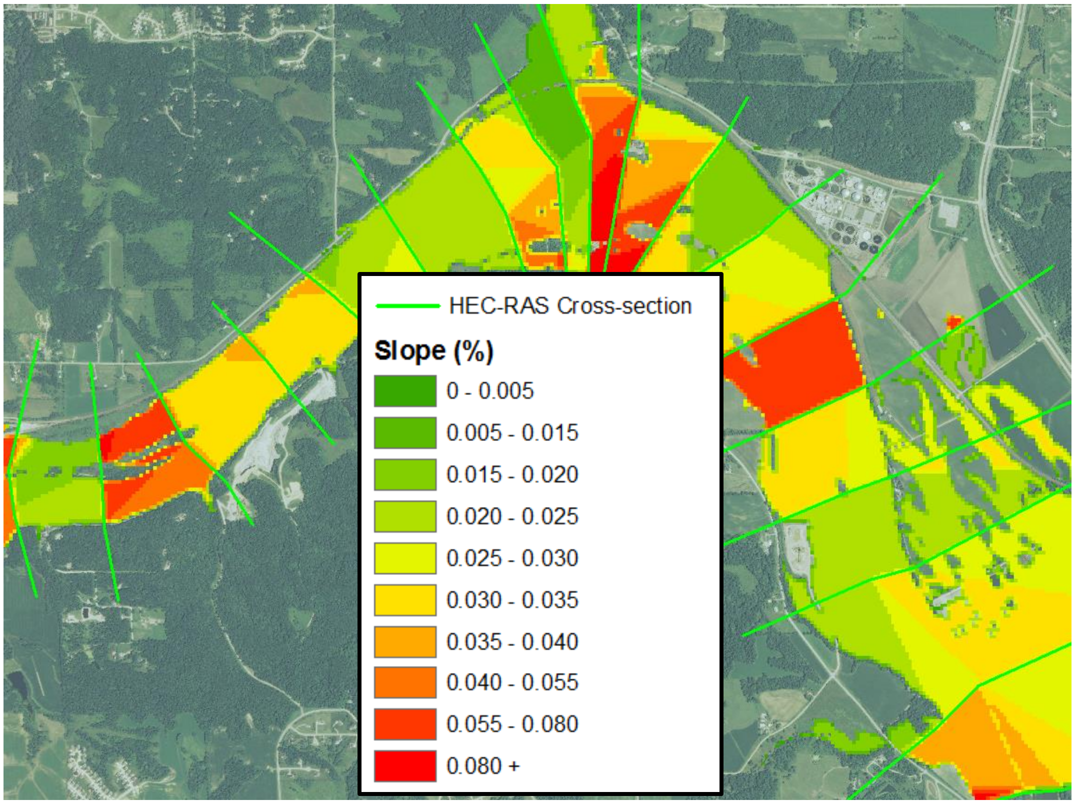


Figure 10: WSE slope raster created from WSE TIN data using the GIS slope tool

3.2. Depth Data

The depth grid raster data are created using HEC-GeoRAS as part of the FPM Program and are also stored by and available from the IFC. The depth data are organized by reach because the hydraulic models are run on reaches individually. The depth data are a required input for most tools and processes developed for this thesis project. Figure 11 shows a depth raster. The depth rasters are not cleaned as part of the FPM process. Several tools were created for this thesis to clean the depth grids, so their small artifacts and disconnected features are removed to match the cleaned shapefiles.

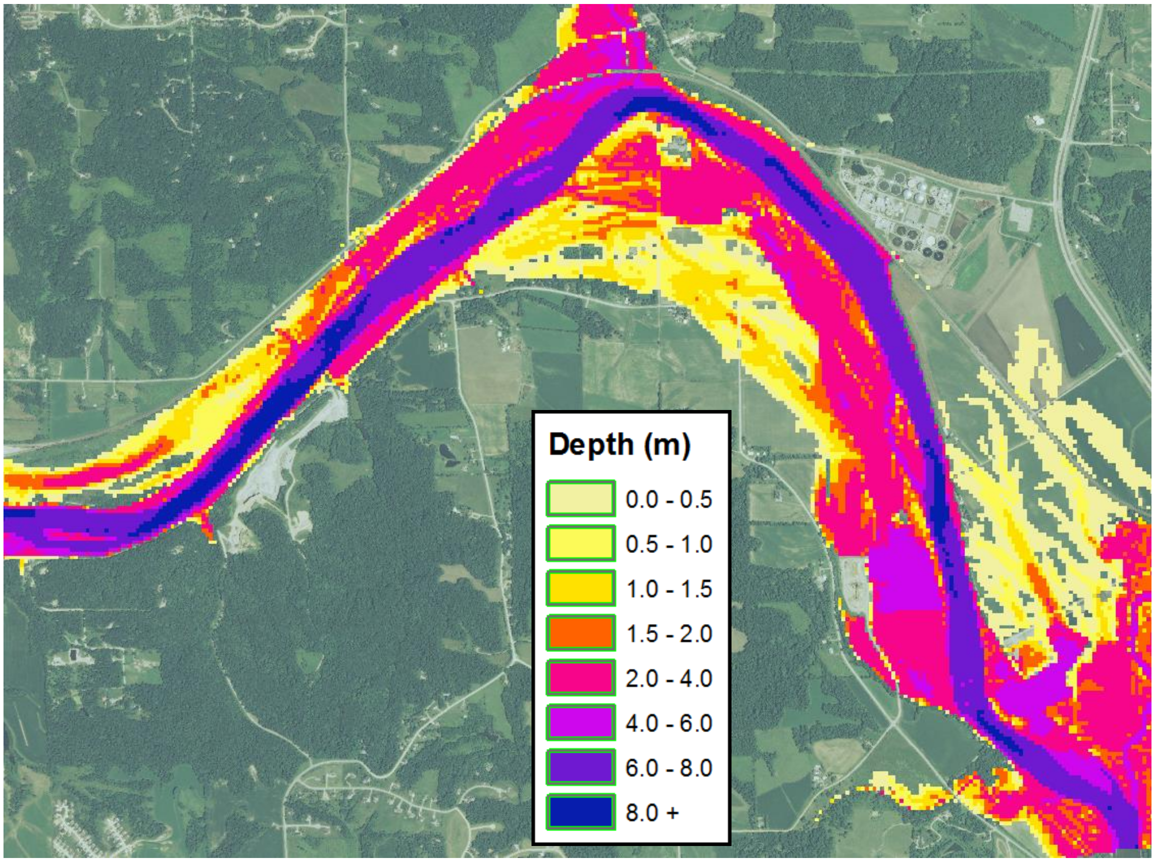


Figure 11: Depth raster created using HEC-GeoRAS

3.3. Land Cover Data

The GIS tools and method developed for this thesis use the same land cover raster data and Manning's n raster data used in the FPM Program. The land cover data are obtained from the 2001 National Land Cover Database (NLCD) (Homer et al, 2007). It is then used to determine spatial Manning's n distribution for the hydraulic modeling as part of the FPM process. The Manning's n values were set by the IFC based on cover type, as indicated in Table 1, and a spatial Manning's n raster was then created. Figure 12 shows the Manning's n raster created using the NLCD raster and values in Table 1. The NLCD raster and NLCD derived Manning's n raster are available from the IFC.

Table 1: NLCD Classifications and Corresponding Roughness Coefficient

<table>
<tr><td colspan="2">Channel Roughness Coefficients</td></tr>
<tr><td>Contributing Drainage Area</td><td>Manning's Roughness Coefficient</td></tr>
<tr><td>Less than 10 Square Miles</td><td>0.045</td></tr>
<tr><td>Greater than 10 Square Miles</td><td>0.035</td></tr>
<tr><td colspan="2">Overbank Roughness Coefficients</td></tr>
<tr><td>NCLD 2001 Classification</td><td>Manning's Roughness Coefficient</td></tr>
<tr><td>11 - Open Water</td><td>0.02</td></tr>
<tr><td>21 - Developed, Open Space</td><td>0.03</td></tr>
<tr><td>22 - Developed, Low Intensity</td><td>0.05</td></tr>
<tr><td>23 - Developed, Medium Intensity</td><td>0.1</td></tr>
<tr><td>24 - Developed, High Intensity</td><td>0.15</td></tr>
<tr><td>31 - Barren Land</td><td>0.05</td></tr>
<tr><td>41 - Deciduous Forest</td><td>0.12</td></tr>
<tr><td>42 - Evergreen Forest</td><td>0.12</td></tr>
<tr><td>43 - Mixed Forest</td><td>0.12</td></tr>
<tr><td>52 - Scrub/Shrub</td><td>0.08</td></tr>
<tr><td>71 - Grassland/Herbaceous</td><td>0.035</td></tr>
<tr><td>81 - Pasture/Hay</td><td>0.035</td></tr>
<tr><td>82 - Cultivated Crops</td><td>0.07</td></tr>
<tr><td>90 - Woody Wetlands</td><td>0.1</td></tr>
<tr><td>95 - Emergent Herbaceous Wetland</td><td>0.045</td></tr>
</table>

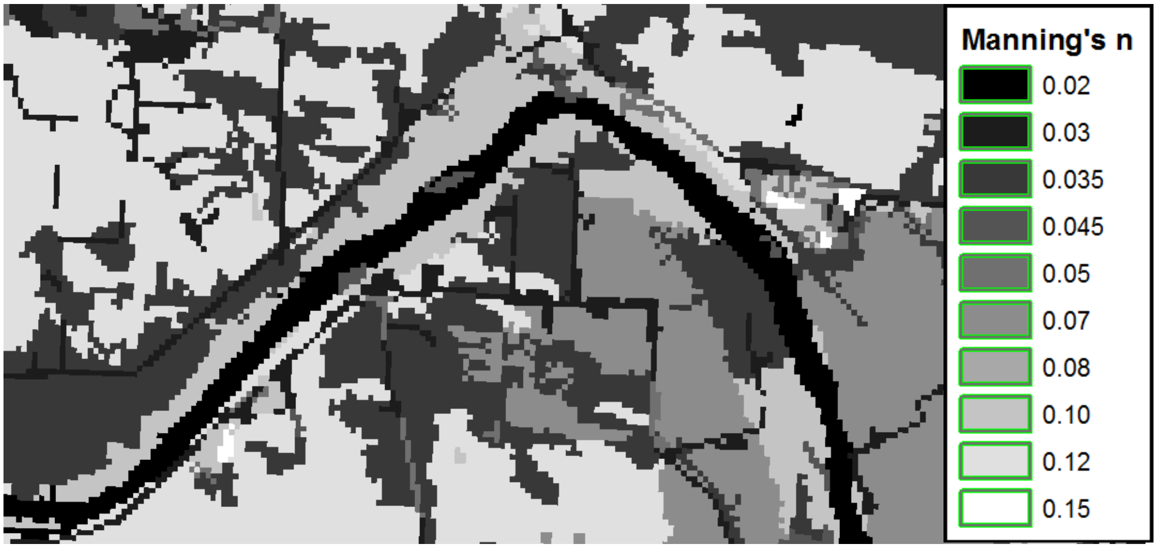


Figure 12: Manning's n raster created from NLCD

Allowable shear spatial data are obtained using the NRCS SSURGO database (Soil Survey Staff, 2013). The SSURGO database contains shapefiles organized by county that classify spatial distribution of top soil. The top soils have number codes corresponding to their soil type. The USDA NRCS (2007) (2011) has given these surface soil types four different erodibility ratings with corresponding allowable shear values. The erodibility classification table is linked to the spatial SSURGO soil type shapefiles in order to create a spatial dataset with allowable shear values of surface soils. Table 2 shows the NRCS erodibility classifications table provided in (USDA NRCS, 2007), and Figure 13 shows the allowable shear raster that was created.

Table 2: NRCS Erodibility Categories and Allowable Shear (USDA NRCS, 2007)

Category	**Allowable Stress (lb/ft^2)**
Easily eroded	0.02
Erodible	0.03
Erosion resistant	0.05
Very erosion resistant	0.07

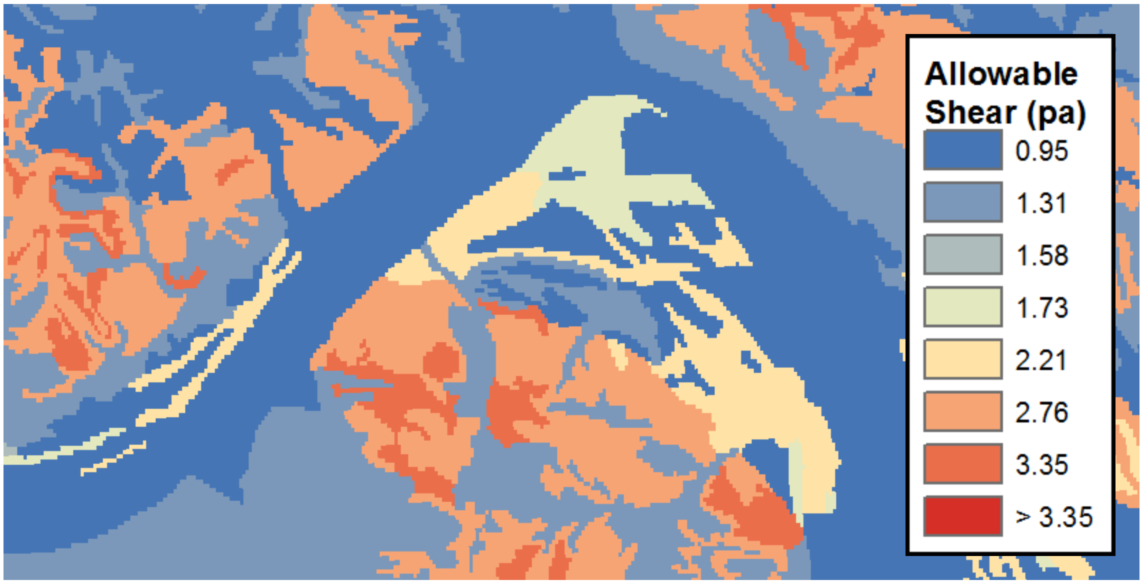


Figure 13: Allowable shear raster

CHAPTER 4. IMPLEMENTATION

4.1. Introduction

The depth, water surface elevation, and slope data generated from HEC-RAS models are spatial raster data, meaning that there is a two-dimensional grid where each cell has a different value. The velocity and shear data output by HEC-RAS are currently only available as average values at the cross-sections themselves, but spatial velocity and shear information are needed to predict spatial scour potential. This thesis develops methods that apply open channel flow equations to the spatial depth and slope raster data generated by HEC-RAS to create spatial shear and velocity maps. Scour can then be spatially characterized by relating spatial effective shear to allowable shear.

This thesis presents two methods to create spatial shear and velocity maps using available 1D HEC-RAS data. The first method is referred to as the cell-by-cell method and applies uniform open channel flow equations on individual raster cells using several common assumptions used in open channel flow computations. The second method is referred to as the Single Cross-section Area (SCA) method and is a continuation of the first method that corrects for continuity along any given cross-section. The cell-by-cell method is simpler and has more limitations but can be easily applied over large datasets. The SCA method corrects some of the limitations caused by the 1D data source but is more complicated and only practical to use over a relatively short section of reach.

A multitude of custom tools were created using GIS model builder to carry out these two methods and produce scour characterization maps. GIS model builder is a visual programming interface that allows the user to join individual GIS tools together in order to create custom tools that can solve full equations. Many figures will be shown of the GIS model builder editor window to demonstrate how tools work. In the editor window of model builder, blue objects are inputs, yellow objects are GIS tools, and green objects are outputs from these GIS tools.

The tools created for this thesis include pre-processing tools that can clean the depth rasters and create slope rasters and tools to create velocity and shear data using both the cell-by-cell-method and the SCA method. There are also tools to post-process the data and create final scour maps that can be reported. The use of these tools is explained in detail in Appendix B. The following sections, 4.2, 4.3, 4.4, and 4.5, will explain the theory and creation of each GIS tool created for this thesis. It is assumed that the reader has a basic understanding of GIS.

4.2. Pre-Processing GIS Tools

4.2.1. Depth Data Cleaning Tools

Inundation shapefiles created from HEC-RAS results will have many small disconnected features and many small islands due to the high resolution of the DEM. The inundation shapefiles are cleaned as part of the FPM process using a script to remove these small disconnected shapefiles and fill islands below a certain area threshold. The shapefiles for the 100 and 500 year return period are then further cleaned by hand, which results in the removal of hydraulically disconnected features and the addition of new features. A custom GIS tool was created to clean the depth rasters to match the cleaned inundation shapefiles. Cleaning the depth rasters results in more visually appealing maps that match the cleaned shapefiles and are more representative of the flood conditions that would really exist. There are two depth raster cleaning tools created for this thesis project. These depth cleaning tools are set up to work specifically with data obtained from the IFC.

4.2.1.1. "Depth Cleaner" tool

Figure A1 in Appendix A shows a complete diagram of the "Depth Cleaner" tool as it appears in the GIS model builder editor window. This tool is set up to clean depth rasters for a single frequency of a single reach in order to make the depth raster match the cleaned shapefile. Features removed from the shapefile are removed from the depth grid, and features added to the shapefile are added to the depth grid. Features added to the depth grids are given a default value of 0.

Figure 14 shows the three basic inputs for this tool. These three inputs are present in almost every custom GIS tool and will not be discussed again because their function is exactly the same in all tools. The "Temp Folder" and "Output Folder" inputs are for specifying the file paths where intermediary files and final files, respectively, are stored. The intermediate files are kept if the tool is run from within the editor window, so it is convenient to place them in a separate folder from the output files so they can be accessed if necessary. The "FileName" input is a string parameter that allows the user to specify the file name of the final output file. The file name field must follow normal GIS raster naming conventions and cannot exceed 13 characters or contain any spaces.

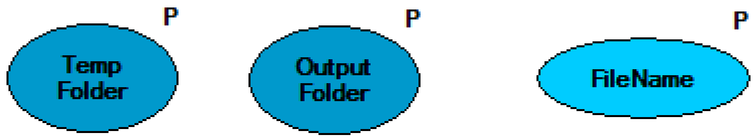


Figure 14: Folder and file name inputs for "Depth Cleaner" tool

Figure 15 shows the shapefile input and select tool used to separate the shapefile for the reach of interest from the total watershed shapefile. The "Main Shapefile" input is for the main shapefile of the entire watershed that the reach being cleaned lies within. This main shapefile should contain all of the inundation features added and should not contain deleted features.

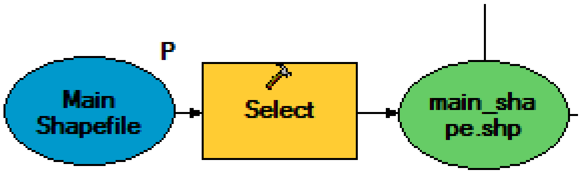
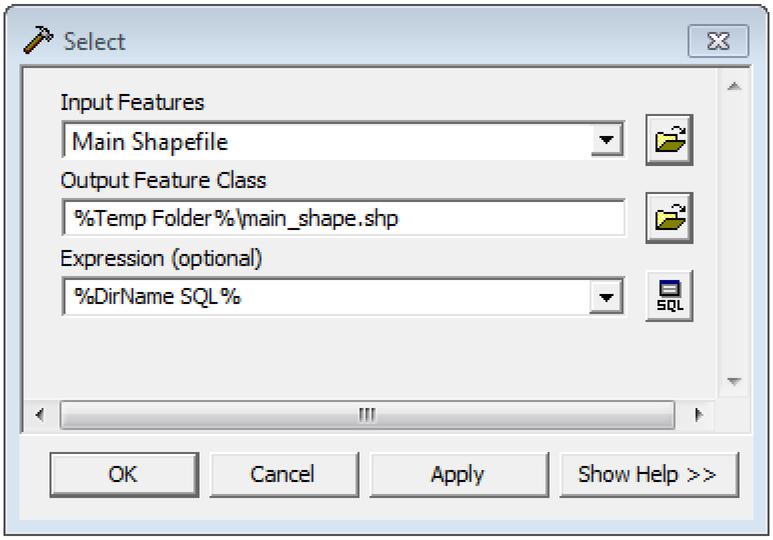


Figure 15: Model builder diagram for shapefile input section of "Depth Cleaner" tool

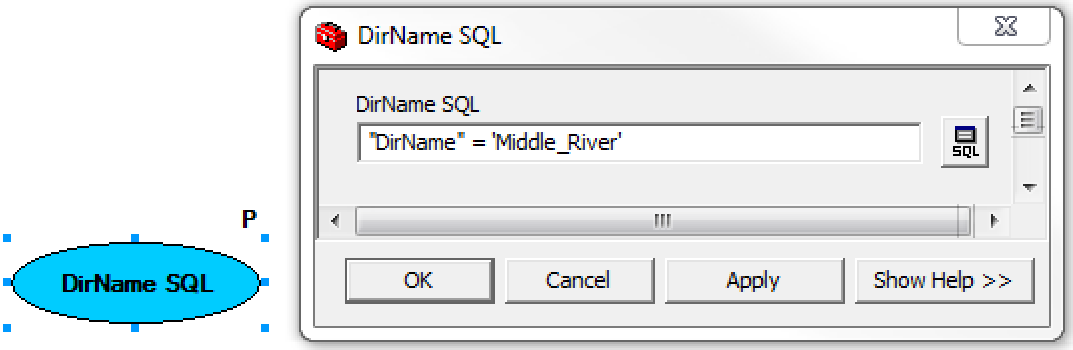
The shapefiles available from the IFC are grouped into HUC8 watersheds with an attribute table column that displays identifiers for individual reaches. Each HUC8 has an inundation shapefile for each of the eight frequencies modeled as part of the FPM process. The depth rasters are currently stored as individual reaches because storing them as entire watersheds would result in unmanageable file sizes. This means that the depth raster to be cleaned needs to have the shapefile corresponding to the same reach separated from the main HUC8 shapefile. The select tool in Figure 15 uses an SQL statement to remove the shapefile polygons that have the correct reach identifier from the HUC8 main shapefile and create a new shapefile for the reach that is being cleaned. Figure 16 shows how the SQL expression within the select tool dialog references the "DirName SQL" input shown in Figure 17. The SQL input allows the user to specify the correct reach without going into the model builder editor window.



Input Features
Main Shapefile
Output Feature Class
%Temp Folder%\main_shape.shp
Expression (optional)
%DirName SQL%

Figure 16: GIS Select tool dialog box

Figure 17 shows the “DirName SQL” input parameter and the required syntax. A column holding reach identifiers in the HUC8 shapefiles obtained from the IFC is labeled “DirName.” This is the first part of the SQL statement and should always be the same. The ‘Middle_River’ string is the identifier for the reach that is to be selected in this example. The user can change the reach identifier from the input prompt box. The reach identifier must be spelled exactly as it is in the “DirName” column of the attribute table.



DirName SQL
"DirName" = 'Middle_River'

Figure 17: DirName SQL input parameter of “Depth Cleaner” tool

The next step in the depth cleaner tool converts the reach shapefile into a raster. Figure 18 shows the polygon to raster tools used to create two separate rasters from the reach shapefile. The "Cell Size" parameter allows the user to specify the cell size for the final cleaned depth raster that is output. Rasters with smaller cell sizes show more detail, but take longer to compute. The "Polygon to Raster" tool creates a raster matching the inundation shapefile with every cell holding the value of 1. The "Polygon to Raster (3)" tool creates a raster matching the inundation shapefile with every cell equal to 0.

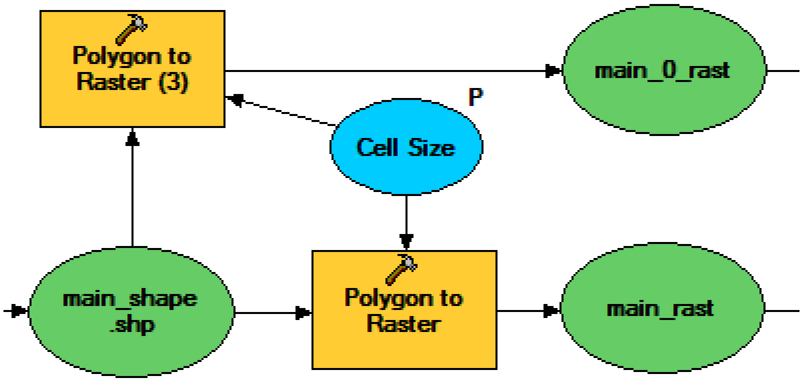
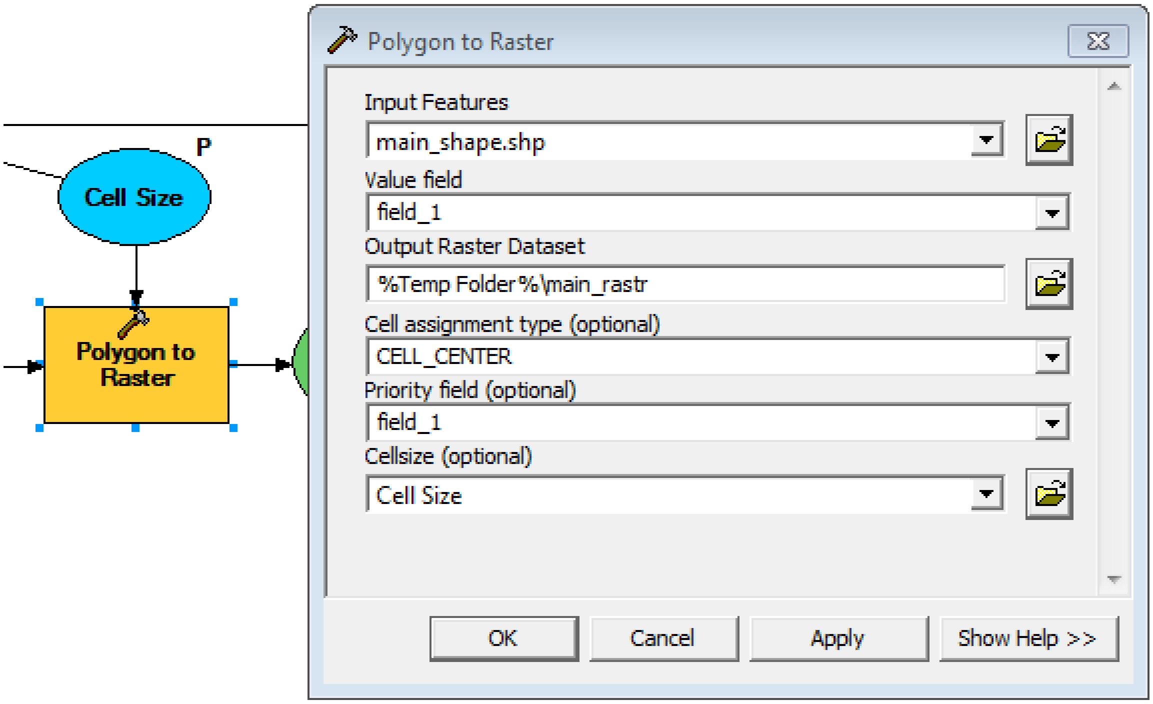


Figure 18: Model builder diagram for shapefile to raster conversion section of the "Depth Cleaner" tool

Figure 19 shows the dialog that appears when clicking on the "Polygon to Raster" tool within the editor window. The "Value field" and "Priority field" input boxes are both populated with the "field_1" column. The "field_1" column will hold the value 1, indicating to the tool that it should fill the raster cells with the value of 1. The "Polygon to Raster (3)" tools uses "field_0" to create the "main_0_rast" raster with the value of 0 in every cell. The "field_1" and "field_0" columns must be created by the user. The "Depth Cleaner" tool will crash GIS if shapefiles without the correctly named "field_1" and "field_0" columns are used as inputs.



Input Features: main_shape.shp
Value field: field_1
Output Raster Dataset: %Temp Folder%\main_rastr
Cell assignment type (optional): CELL_CENTER
Priority field (optional): field_1
Cellsize (optional): Cell Size

Figure 19: Polygon to Raster tool dialog box

In the next step of the tool, the main shapefile derived raster containing values of 1, named “main_rast”, is multiplied by the un-cleaned depth raster input, as shown in Figure 20. Multiplying the input depth raster by the main shapefile raster results in a new depth raster with the same inundation extent as the cleaned shapefile, meaning that any features deleted from the main shapefile are removed from the resulting depth raster. This multiplication cleaning process works because when a raster cell with a value is multiplied by a raster cell with no data, a no data raster cell results. The depth values that remain from the original raster will be unchanged because they were multiplied by 1. Figure 21 shows an un-cleaned depth grid input, and Figure 22 shows how the disconnected features are removed by multiplying it by the main features derived shapefile.

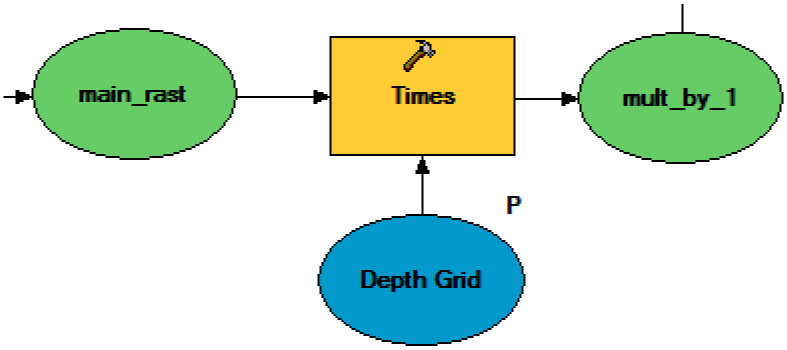


Figure 20: Model builder diagram for multiplying un-cleaned depth raster by cleaned shapefile derived raster

Figure 21: Un-cleaned depth raster to be multiplied by cleaned shapefile derived raster

Figure 22: Cleaned depth raster output from process shown in Figure 20

The last step of the "Depth Cleaner" tool, shown in Figure 23, uses a single output map algebra tool to add in features that were added to the shapefile during the FPM project cleaning process. The Single Output Map Algebra tool takes the 0 value raster created from the main shapefile and uses it to fill in any islands in the depth raster that were filled in on the shapefile during the pre-cleaning script process of the FPM Program and any areas that were manually added to the inundation shapefile.

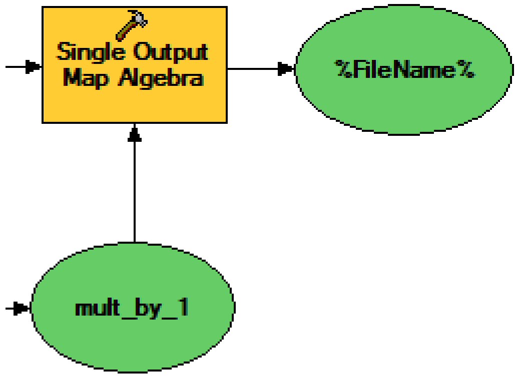
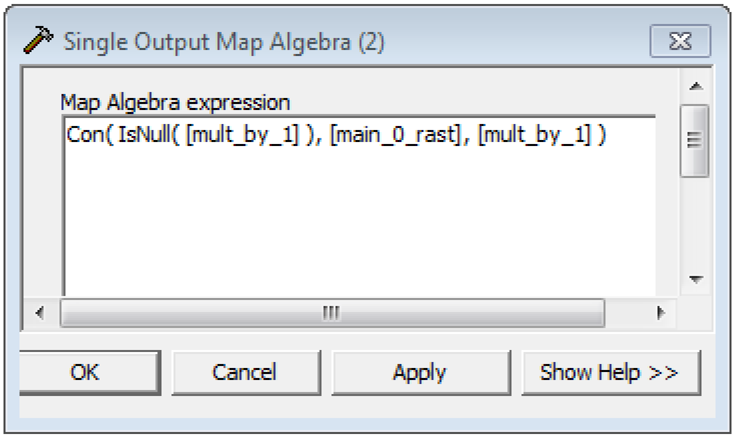


Figure 23: Model builder diagram for section of "Depth Cleaner" tool that adds in the add-features

Figure 24 shows the dialog that appears after clicking the "Single Output Map Algebra" tool in the editor window. A conditional statement is used with the inputs being the 0 raster created from the main shapefile, named "main_0_rast," and the raster created by multiplying the un-cleaned depth raster by the "main_rast" raster, named "mult_by_1." This conditional statement determines whether or not each "mult_by_1" cell has a value. The value from "mult_by_1" is kept if the cell has a value. The value from the "main_0_rast" is used when the "mult_by_1" cell does not have a value. This conditional statement results in a new raster where any small islands or add-features that were filled in on the main shapefile during the cleaning process of the FPM project are also filled in on the resulting raster. The raster cell values in these added areas will be 0.

The purpose of this step is to make the depth raster data visually match the cleaned shapefiles. Figure 25 shows a depth raster prior to this conditional statement step. Figure 26 shows a depth raster after this step in which small islands have been filled in with depth values of 0 in order to visually match the inundation shapefiles.



Map Algebra expression

```
Con( IsNull( [mult_by_1] ), [main_0_rast], [mult_by_1] )
```

Figure 24: Single Output Map Algebra Dialog box

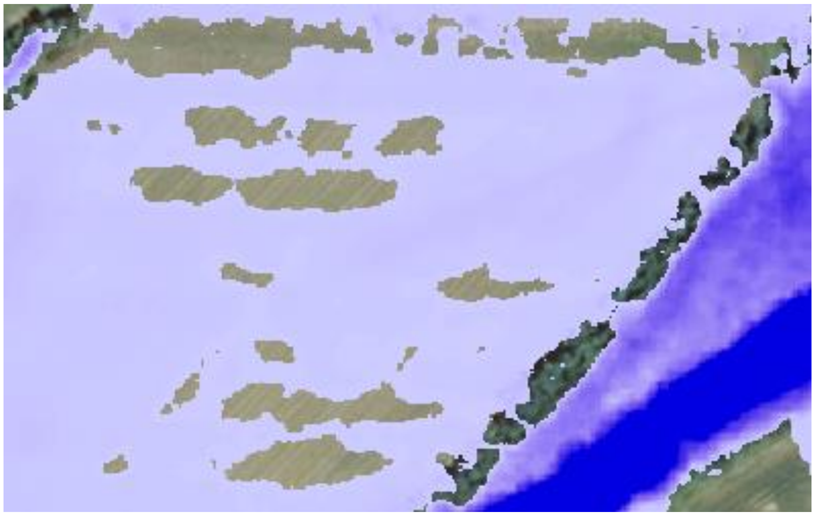


Figure 25: Un-cleaned depth raster prior to addition of add-features

Figure 26: Depth raster after addition of add-features

4.2.1.2. “Depth Cleaner – Multiple” tool

The “Depth Cleaner – Multiple” tool can clean multiple depth raster frequencies at once as long as they are all from the same reach with the same Directory Name. This tool functions the same as the “Depth Cleaner” tool, except it can take multiple inundation shapefiles and depth inputs. The tool will create a cleaned depth raster output for each set of inputs. Figure A2 in Appendix A shows the complete model builder diagram for the “Depth Cleaner – Multiple” tool.

4.2.2. Water Surface Elevation and Slope Raster Creator Tool

The water surface elevation (WSE) data is in TIN format when it is output from HEC-RAS and it must be converted to raster form to be used in other processes. The slope raster is then created from the water surface elevation raster. The “WSE and Slope(%) Raster Creator” tool implements both of these processes at once. Figure 27 shows the complete model within the editor window. The “SlpFileName” and “WSEFileName” input parameters are strings where the user can specify the file names of the slope raster and WSE raster that will be outputted. The “WSE TIN” input parameter is where the water surface elevation TIN data obtained from the HEC-RAS output are added to the model. The "Sampling Distance" input parameter is used to set the cell size of the output rasters. The First tool, "TIN to Raster," is a GIS tool that converts the WSE TIN dataset into a WSE raster. The "Slope" tool is a GIS tool that calculates the slope of each cell in the input raster based on its value and the values in the eight cells surrounding it. This tool uses the created WSE raster as the input and creates an output raster holding the water surface slope values. A version of this tool, named "WSE and Slope(%) Raster Creator – Multiple," was also developed to process multiple TIN input files simultaneously.

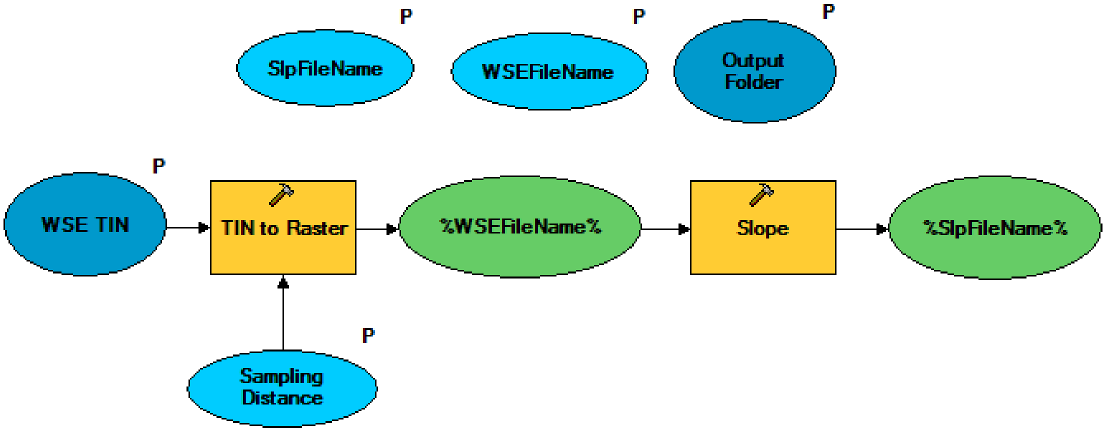


Figure 27: "WSE and Slope(%) Raster Creator" tool complete model builder diagram

4.3. Cell-by-Cell Method

The first of the two methods developed to create spatial shear and velocity maps, the cell-by-cell method, involves running uniform open channel flow equations on each individual raster cell using several key assumptions. The depth, slope, and Manning's n rasters are used as inputs. Each cell that has a depth, slope, and Manning's n value can have its velocity or shear computed using the equations shown in Section 2.1. Figure 28 shows a visual example of the cell-by-cell method.

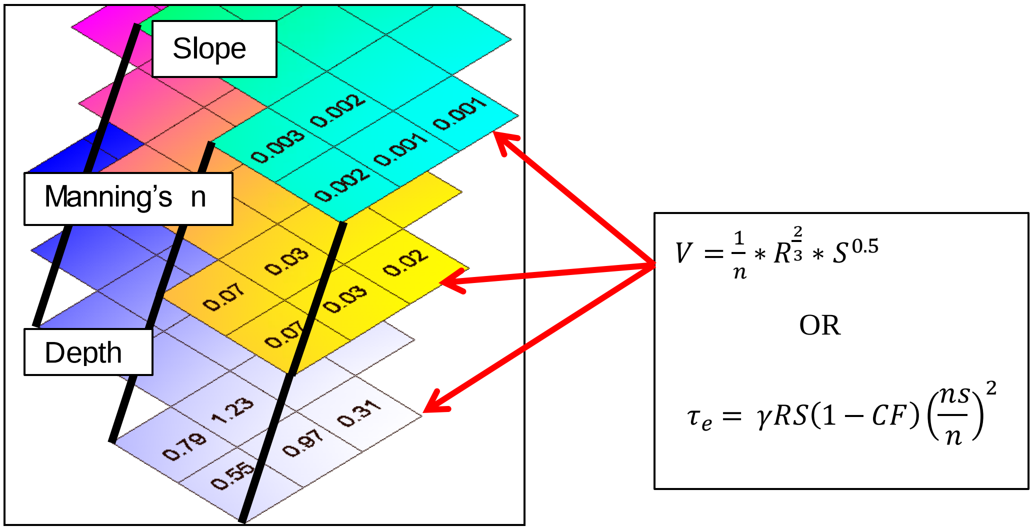


Figure 28: Cell-by-cell method illustration

4.3.1. Cell-by-Cell Method Assumptions

When using the cell-by-cell method, it must be assumed that each raster cell can be treated as a section of the compound open channel cross-section it lies on. Compound open channel flow calculations commonly assume that each overbank can be treated as a separate section from the main channel and calculated separately. The same assumption is used in the cell-by-cell method, except each raster cell is treated as a separate section. Figure 4 in Section 2.2 illustrates the typical ways in which compound open channels have their overbanks separated from the main channel. Figure 29 illustrates how each raster cell is treated as a separate section of the channel in the cell-by-cell method.

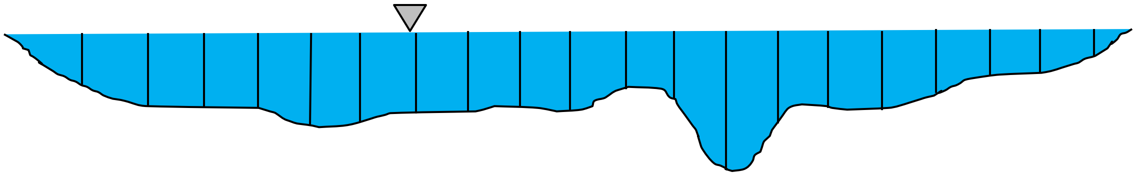


Figure 29: Cell-by-cell method cross-section division example where each division is a separate raster cell

Only the water surface slope data are obtainable from the FPM HEC-RAS data. Since the bed slope or energy slope cannot be obtained, it is necessary to assume uniform flow and use the water surface slope as the energy slope. The water surface slope is relatively constant across the width of a cross-section due to the nature of HEC-RAS, and it is assumed that this is acceptable because the same assumption is used in compound open channel flow calculations.

The open channel flow equations use hydraulic radius as input. The hydraulic radius is area divided by wetted perimeter. It is assumed that the wetted perimeter of each cell is the cell size rather than the cell size plus two times the depth, because most wetted cells are adjacent to other wetted cells, so their sides are contacting the flowing water of another cell rather than a flow boundary. The area of a raster cell cross-section is the depth times the cell size, and the wetted perimeter is the cell size. The hydraulic radius is equal to the depth after the cell size values cancel out under this assumption, so the cell-by-cell method can use the depth raster values in place of hydraulic radius.

4.3.2. Cell-by-Cell Method Limitations

The open channel flow equations are intended for use in relatively straight and uniform channels. Using the open channel flow equations in floodplains where there are backwater areas, variable flow paths, and changes in land cover presents several limitations. The fact that the water surface slope obtained from HEC-RAS is relatively constant in-between upstream and downstream HEC-RAS cross-sections is the cause of most limitations of the cell-by-cell method. The 1D slope data can cause loss of continuity and unrealistically high shear readings in ineffective flow areas. Section 5.2.2 and 5.3.1 further discuss the limitations that the 1D data impose on the cell-by-cell method.

4.3.3. Cell-by-Cell Method GIS Tools

The cell-by-cell method includes several tools that create velocity and shear rasters using the assumptions previously outlined.

4.3.3.1. “Bed Shear” tool

The “Bed Shear” tool calculates bed shear. Bed shear is automatically calculated as part of the effective shear tools, but this tool is made available in case the user wants to calculate bed shear separately. Figure 30 shows the complete model builder diagram for the “Bed Shear” tool. This tool carries out the basic uniform open channel flow bed shear equation, shown as Equation 4 in Section 2.1.4.

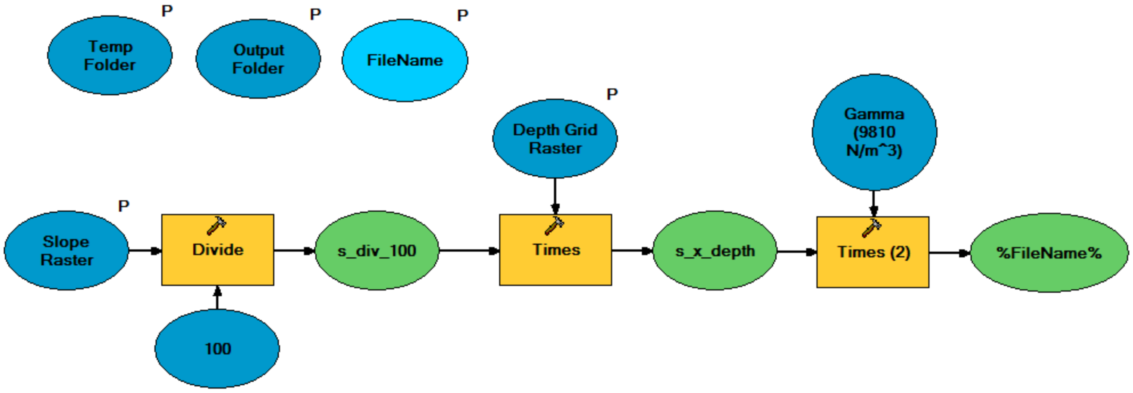


Figure 30: "Bed Shear" tool complete model builder diagram

The bed shear tool only needs slope and depth raster inputs along with the standard file name and folder location inputs. The first GIS tool in the process is “Divide.” This tool divides the slope raster input by 100 to convert the units from percent slope to decimal slope. The next two GIS tools are multiplication tools that multiply the decimal slope by the depth and then the unit weight of water. The depth raster data obtained from the IFC is in units of meters, and the unit weight of water is in units of Newtons per meter cubed. The output bed shear has units of pascals.

4.3.3.2. “Velocity – Manning Equation” tool

The “Velocity – Manning Equation” tool calculates the velocity of each raster cell using Manning’s Equation and the standard cell-by-cell method assumptions. This tool creates a spatial velocity map that is useful on its own and is also a required input for the SCA method. Figure 31 shows the complete model builder diagram for the “Velocity – Manning Equation” tool.

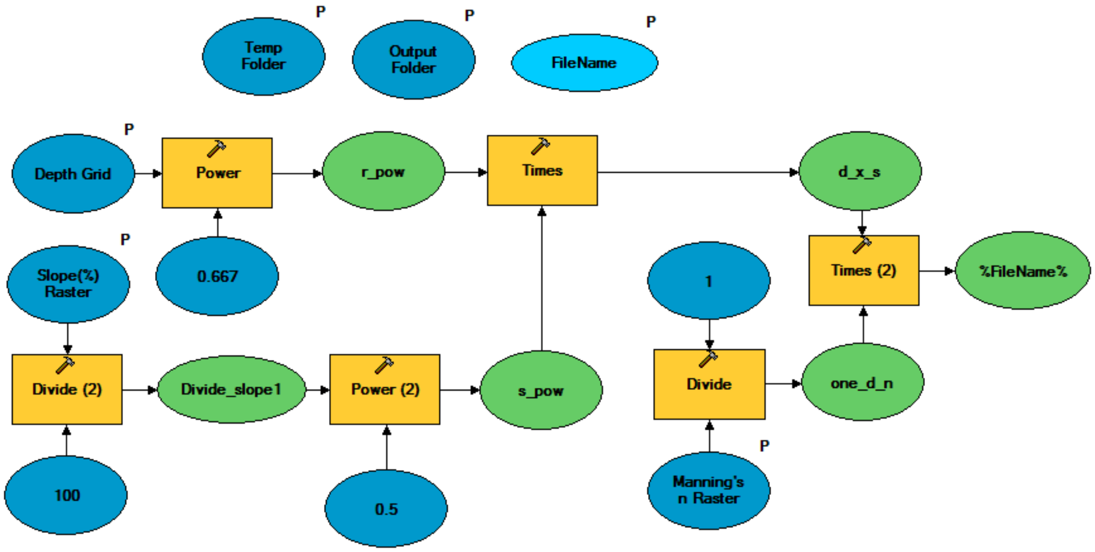


Figure 31: "Velocity - Manning Equation" tool complete model builder diagram

The Manning's velocity tool takes the depth raster, slope raster, and Manning's n raster in addition to the standard folder and file name inputs. The slope input is first divided by 100 using the GIS division tool in order to convert it from percent slope to decimal slope. The newly created slope raster is then raised to the 0.5 power using the GIS power tool, as per Manning's Equation. The depth grid input is raised to the 0.667 power, as per Manning's Equation. The Manning's n raster is divided by 1 using the GIS division tool, as per Manning's Equation with metric units. These three created rasters are then multiplied together using the GIS multiplication tool to create the final output velocity raster. The depth input must be in units of meters and the slope input must be in percent, because the tool divides it by 100 to obtain decimal slope. The output velocity raster will be in units of meters per second.

4.3.3.3. Tool Name: "Effective Shear – n unchanged"

The "Effective Shear – n unchanged" tool calculates the effective shear using Equation 5 in Section 2.1.5. This tool uses the same Manning's n and land cover data used in the HEC-RAS hydraulic model representing the worst case scenario for flooding: vegetated/planted cropland. This means that the "Effective Shear – n unchanged" tool actually calculates the best case scenario for scour by using the same Manning's n values because the presence of vegetation reduces the effective shear stress acting on the soil, which reduces scour. There are other effective shear tools that modify the Manning's n value of crop lands to calculate shear and scour for bare fields.

The complete GIS model builder diagram for the "Effective Shear – n unchanged" tool is shown in Figure A3 in Appendix A. Figure 32 shows the bed shear portion of the tool, which is the same as the basic uniform bed shear equation shown as Equation 4.

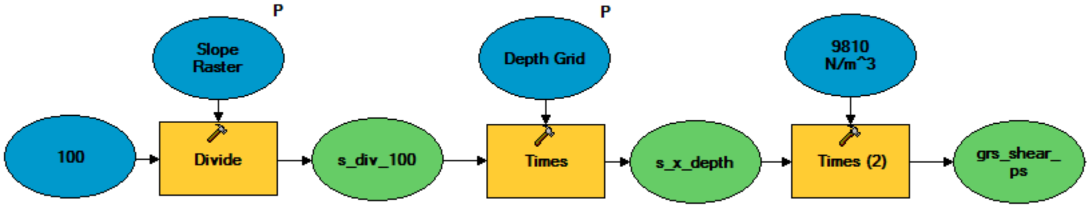


Figure 32: Model builder diagram for bed shear portion of effective shear equation

Figure 33 shows the portion of the "Effective Shear – n unchanged" tool that creates the cover factor correction (1-CF) raster. The NLCD raster is used as the input for this section, and this raster holds integer values corresponding to different cover types. The cover types corresponding to each value can be seen in Table 1. Two GIS "Single Output Map Algebra" tools are used to assign cover factors to different areas. The first of these tools uses the conditional statement, shown as Equation 7, which checks the NLCD raster for cover type keys that correspond to Deciduous Forest, Evergreen Forest, Mixed Forest, or Wood Wetlands. Where these values are found, a CF value of 0.25 is added. Where these specific cover types are not found, a value of 0 is added. The output raster holding these values is named "nlcd_c2." The cover factor depends on density and uniformity of cover spacing. The USDA NRCS (2007) gives CF values of 0.5 or higher for grassed areas but does not provide CF values for forested areas or wetlands. It was deemed appropriate to use a lower CF value for forested areas than was given for grass because forested areas are generally less dense and more irregularly spaced than grassed areas. Consequently, the CF value of 0.25 was chosen.

The second map algebra tool uses the conditional statement shown as Equation 8, which checks the NLCD raster for cover type keys that correspond to Grassland/Herbaceous and Pasture/Hay areas. A CF value of 0.5 is added to these areas, and a value of 0 is added to all other areas. A CF value of 0.5 or higher is typical of grassed areas, according to (USDA NRCS, 2007).

The two cover factor rasters created by the map algebra tools are then combined by adding them together using the GIS "Plus" tool. The raster that results from the "Plus" tool is then subtracted from 1 to create the 1-CF term of the effective shear equation.

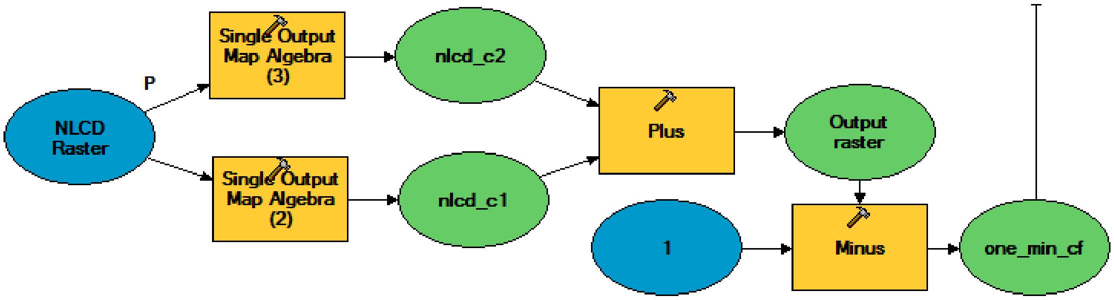


Figure 33: Model builder diagram for cover factor raster creation

Equation 7: Cover Factor Conditional Statement for "Single Output Map Algebra (3)"

$$CON(\ [NLCD\ Raster]\ ==\ 90\ OR\ [NLCD\ Raster]\ ==\ 41\ OR\ [NLCD\ Raster]\ ==\ 42\ OR\ [NLCD\ Raster]\ ==\ 43, 0.25, 0)$$

Equation 8: Cover Factor Conditional Statement for "Single Output Map Algebra (2)"

$$CON(\ [NLCD\ Raster]\ ==\ 71\ OR\ [NLCD\ Raster]\ ==\ 81, 0.5, 0)$$

Figure 34 shows the portion of the tool that creates the soil grain roughness correction factor. The soil grain roughness constant, given as 0.0156 by the USDA NRCS (2007), is first divided by the Manning's n input raster. The resulting raster is then squared using the GIS "Power" tool to create the $(ns/n)^2$ correction factor. The calculated bed shear is then multiplied by both the (1-CF) and $(ns/n)^2$ correction factor rasters to create the final effective shear raster output in units of pascals.

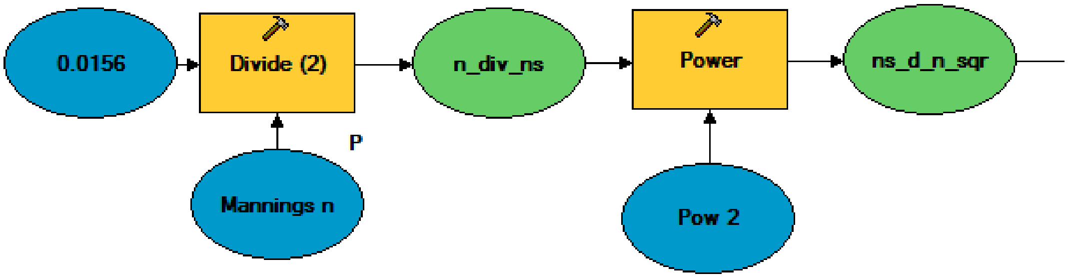


Figure 34: Model builder diagram for soil grain roughness correction factor creation

4.3.3.4. *"Effective Shear – n unchanged – Bed Shear Input" tool*

The "Effective Shear – n unchanged – Bed Shear Input" tool is exactly the same as the "Effective Shear – n unchanged" tool except that it takes a bed shear raster as an input instead of calculating bed shear within the tool. This tool exists because the SCA method corrects bed shear, not effective shear. An SCA corrected bed shear raster can be used as an input to the "Effective Shear – n unchanged – Bed Shear Input" tool to obtain an SCA corrected effective shear. Figure A4 in Appendix A shows then entire GIS model builder diagram for the "Effective Shear – n unchanged – Bed Shear Input" tool.

4.3.3.5. *"Effective Shear – Field n = 0.03" tool*

The "Effective Shear – Field n = 0.03" tool calculates shear as if there was no crop cover in areas classified by the NLCD as cultivated crops. The purpose of this tool is to estimate the worst case scenario effective shear when there are no crops preventing erosion on fields, because floods often happen in the spring when no crops are planted. This is the effective shear calculation method that will be used for this project.

The Manning's n data used by the IFC to create the 1D hydraulic models for the FPM project assign a value of 0.07 areas designated cultivated crops. The value of 0.07 corresponds to planted crops because that provides the worst case scenario for flooding.

A Manning's n value of 0.03 corresponds to bare agricultural soil and will replace the value of 0.07 in cultivated crop classified areas for this tool (ODOT, 2011).

The slope and depth rasters were calculated by HEC-RAS using the Manning's n data representing planted fields and other types of cover. Changing Manning's n in the HEC-RAS model would result in different flow depths and slopes. It would be impractical to re-run the HEC-RAS models with new Manning's n data, so the depth must be adjusted for the new assumed Manning's n of 0.03 within the "Effective Shear – Field n = 0.03" tool, or the effective shear estimate will be too high. The slope and depth would both change as a result of changing Manning's n in non-uniform flow, but only the depth would change under the uniform flow assumption. This depth correction will ensure that the same flow rate will be going through the cell before and after the Manning's n change. The depth correction equation is shown as Equation 9, which assumes that only depth, not slope, changes when the Manning's n value changes. The depth correction equation also assumes that depth can approximate hydraulic radius. The derivation for Equation 9 is shown below. This depth correction is approximate and only changes the depth in the areas classified by the NLCD as cultivated crop where Manning's n is changed. In reality, changing Manning's n in part of a cross-section would change the depth of the entire cross-section and would change the inundation extent, but this can't be calculated with the available data. Adjusting Manning's n from 0.07 to 0.03 using Equation 9 reduces the depth to about 60% of the original depth.

Starting with Manning's Equation:

$$Q = A * \frac{1}{n} * R^{\frac{2}{3}} * S^{0.5}$$

Rearranging:

$$n * \frac{Q}{S^{0.5}} = A * R^{\frac{2}{3}}$$

Depth is assumed equal to R, and area equals depth multiplied by cell width:

$$d * cellwidth * d^{\frac{2}{3}} = n * \frac{Q}{S^{0.5}}$$

Simplifying:

$$d^{\frac{5}{3}} = n * \left(\frac{Q}{S^{0.5} * cellwidth}\right)$$

Q, S, and cell width are assumed constants, so:

$$d^{\frac{5}{3}} = n * (Constant)$$

Depth is proportional to n raised to the 3/5 power.

$$d \propto n^{\frac{3}{5}}$$

So:

Equation 9: Depth Correction Equation

$$d_{new} = d_{old} \left(\frac{n_{new}}{n_{old}}\right)^{\frac{3}{5}}$$

Figure A5 in Appendix A shows the entire model builder diagram for the "Effective Shear – Field n = 0.03" tool. The portions that calculate the (1-CF) and $(ns/n)^2$ correction factors are the same as in the previous effective shear tool.

Figure 35 shows the section of the tool that adjusts Manning's n from 0.07 to 0.03 in cultivated crop areas and carries out the depth correction equation, Equation 9. The new assumed n value for bare soil is divided by the actual Manning's n raster. The resulting raster is then raised to the 3/5 power and multiplied by the original depth raster input. This process creates an adjusted depth raster that is then used as the depth input for the bed shear portion of the tool.

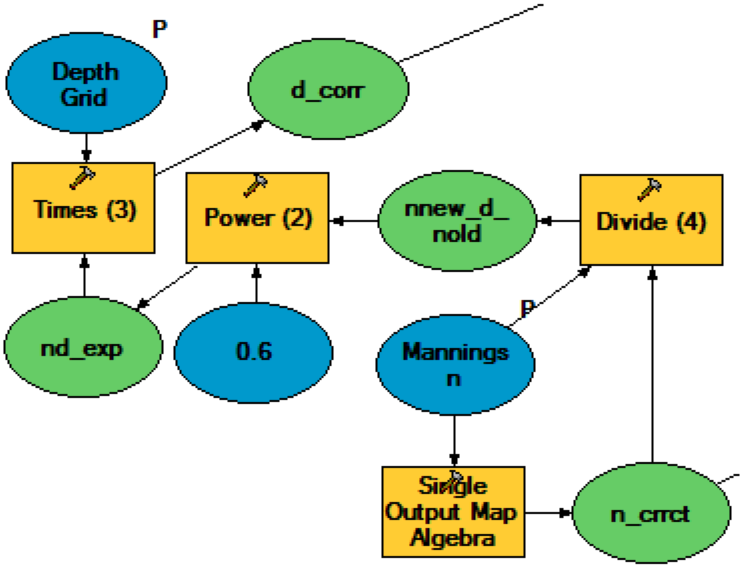


Figure 35: Model builder diagram for depth correction portion of "Effective Shear – CF = 0 and n = 0.03 everywhere" tool

4.3.3.6. *"Effective Shear – Field n = 0.03 – Bed Shear Input" tool*

The "Effective Shear – Field n = 0.03 – Bed Shear Input" tool functions the same as the "Effective Shear – Field n = 0.03" tool, except the bed shear raster is added as an input instead of calculated as a part of the tool. The bed shear input must first be adjusted based on the corrected depth divided by the original depth, as was done with the "Effective Shear – CF = 0 and n = 0.03 everywhere – Bed Shear Input" tool. Figure A6 in Appendix A shows the entire GIS model builder diagram for the "Effective Shear – Field n = 0.03 – Bed Shear Input" tool.

4.3.3.7. *"Velocity – Manning Equation – n changed" tool*

The "Velocity – Manning Equation – n changed" tool functions exactly the same as the "Velocity – Manning Equation" tool, except it can calculate velocity with different Manning's n data than were used in the HEC-RAS model. It calculates and applies the depth correction factor using the same process as in the effective shear tools. The model builder diagram for this tool is shown as Figure A7 in Appendix A.

4.3.3.8. “Bed Shear – n changed” tool

The “Bed Shear – n changed” tool functions exactly the same as the “Bed Shear” tool, except it can calculate bed shear with different Manning’s n data than were used in the HEC-RAS model. It calculates and applies the depth correction factor using the same process as in the effective shear tools. The model builder diagram for this tool is shown as Figure A8 in Appendix A.

4.4. <u>SCA Method</u>

4.4.1. Introduction

The single cross-section area (SCA) method aims to correct for continuity loss that can occur with the cell-by-cell methods. The SCA method first creates a single cell width cross-section holding depth values. The location of the new depth cross-section is determined by the water surface elevation specified by the user and can be anywhere in the reach, even in-between HEC-RAS cross-sections. The approximate area of this cross-section can then be obtained using GIS statistics tools to multiply the number of cells in the cross-section by the cell width. The “true” flow rate for the cross-section is obtained from the HEC-RAS model, and velocity or shear values on the cross-section obtained with the cell-by-cell method tools are then scaled to ensure that the “true” flow rate is obtained. The cell-by-cell methods still predict the spatial distribution of velocity or shear, and the SCA method scales them up or down to ensure that continuity is preserved along each cross-section. The SCA tool produces a single cross-section for each water surface elevation input. These individual cross-sections must then be mosaicked together to create a continuous map. Figure 36 shows a velocity cross-section created using the SCA method.

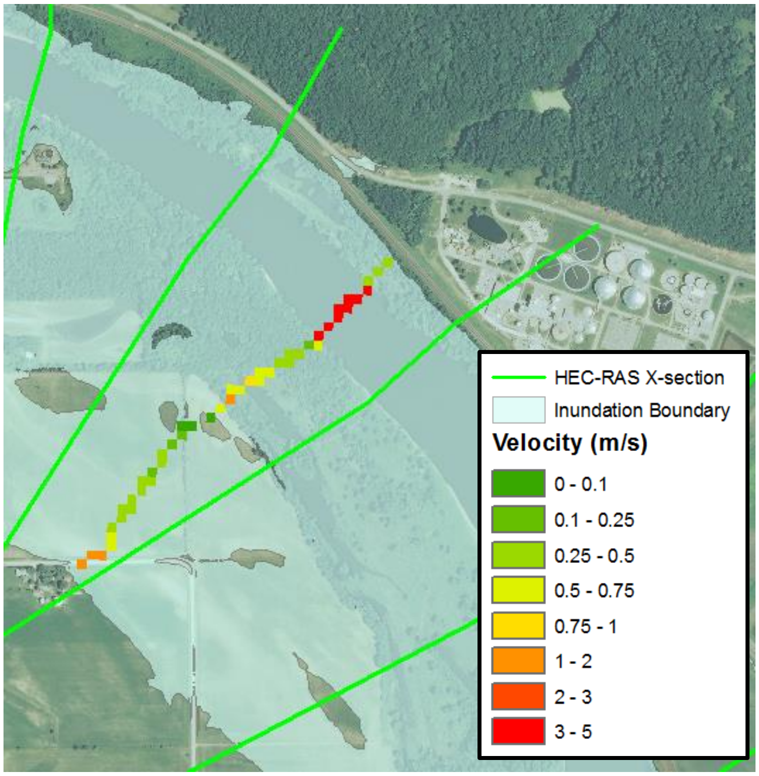


Figure 36: SCA method scaled velocity cross-section raster output

4.4.2. SCA Method Assumptions

The SCA method uses the cell-by-cell method derived velocity map as an input to determine the vertically averaged velocity distribution across the cross-section. The SCA tools assume that this spatial velocity distribution is correct and that all cells are in the effective flow area. Presence of backwater areas along the cross-section can make this assumption incorrect, so large backwater areas need to be removed manually prior to running the SCA tools. The SCA method assumes that average flow direction is approximately perpendicular to the cross-sections. The SCA method additionally uses the same assumptions that the cell-by-cell methods use because the cell-by-cell method velocity output is used as an input to the SCA tools.

4.4.3. SCA Method Limitations

The SCA method only corrects for continuity and is still subject to the aforementioned limitations associated with the cell-by-cell method.

Backwater areas can reduce the effectiveness of the SCA method. It is assumed that all cells are effective flow areas when the single cross-section is separated from the main raster and the area is computed, but this will not actually be the case if part of the area is a backwater area. The presence of a backwater area along a cross-section will result in lower than realistic shear or velocity values in the effective flow area because the SCA method assumes that the velocity distribution along the cross-section, obtained from the cell-by-cell velocity map input, is correct and simply scales it. Backwater areas can be removed manually to prevent these errors. The SCA method can be run without manual removal of backwater areas in sections where backwaters are minimal or nonexistent.

The depth errors that are attributable to constant slope will likely have a small effect on the accuracy of the cross-section area calculation performed as part of the SCA method. The exact amount of error this causes in cross-sectional area is variable and depends on channel uniformity.

Meandering channels can also introduce errors into the SCA method. The SCA cross-sections will always be parallel to the HEC-RAS cross-sections because they are obtained using the HEC-RAS water surface elevation. The results of an SCA cross-section will be inaccurate if the cross-section lies in an area where the main channel is perpendicular to the general direction of flow in the floodplain. Figure 37 shows an example of an SCA cross-section that lies on a channel meander that is perpendicular to the normal flow direction. The SCA method will calculate the effective flow area of this cross-section to be higher than it is in reality and will output lower than realistic shear or velocity. The SCA method should be used carefully, or not at all, on sections where there are many channel meanders, because there is no easy way to correct for this limitation.

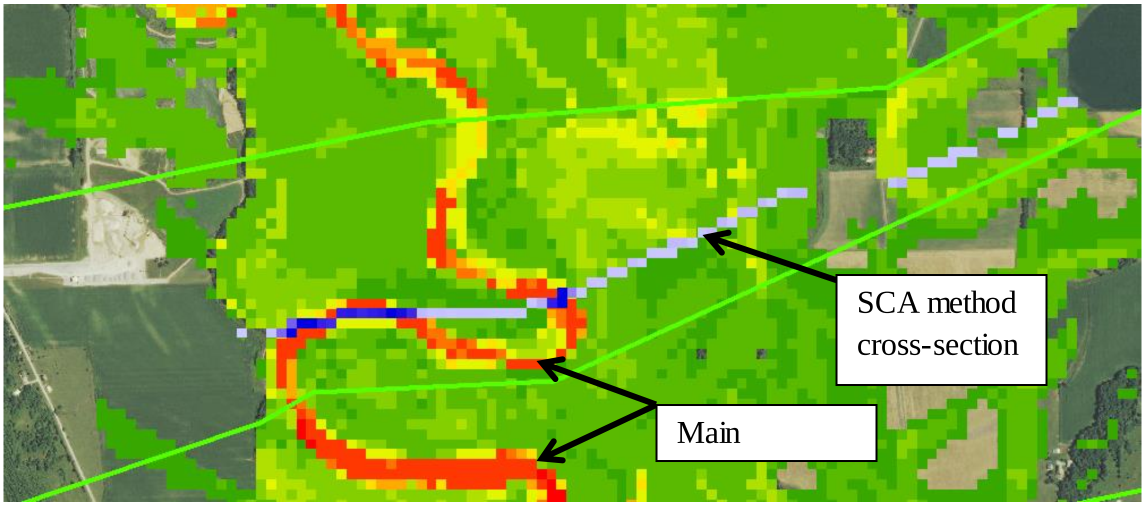


Figure 37: SCA method meandering channel limitation example

The SCA tools are set up to use a fixed flow rate, so the tool can only be run over sections that are short enough for the flow rate to be constant. Multiple SCA created rasters could be combined to overcome this issue.

The SCA method creates a new raster file for each cross-section, so the tools create many individual cross-section rasters for even a small reach. These individual files must be stored and then mosaicked together, so performing the SCA process over a reach much larger than 5 – 10 miles becomes impractical due to the large volume of files created. There are “wide” versions of the SCA tools that create cross-sections several cells wide instead of a single cell wide to reduce the number of separate cross-section rasters that need to be created, but the SCA method can still be tedious due to the large number of files that must be managed.

4.4.4. GIS Tools and Methods Developed for the SCA Method

Four SCA tools were created and are included in the “Scour Characterization Tools” toolbox. The first two tools carry out the SCA method on the cell-by-cell velocity or bed shear results. These tools create single cross-sections that are 1 cell wide. Figure 36 shows an example of a 1 cell wide SCA method cross-section. The second set of tools carry out the SCA method on the velocity and bed shear in the same manner as the first tools, except they output single cross-sections that have a user specified cell width. Figure 38 shows an SCA method cross-section that is 3 cells wide. The SCA method tools do not directly output effective shear. As a result, it is necessary to run the SCA tools on the bed shear then use the SCA corrected bed shear raster as an input to the effective shear tool in order to obtain SCA method continuity corrected effective shear.

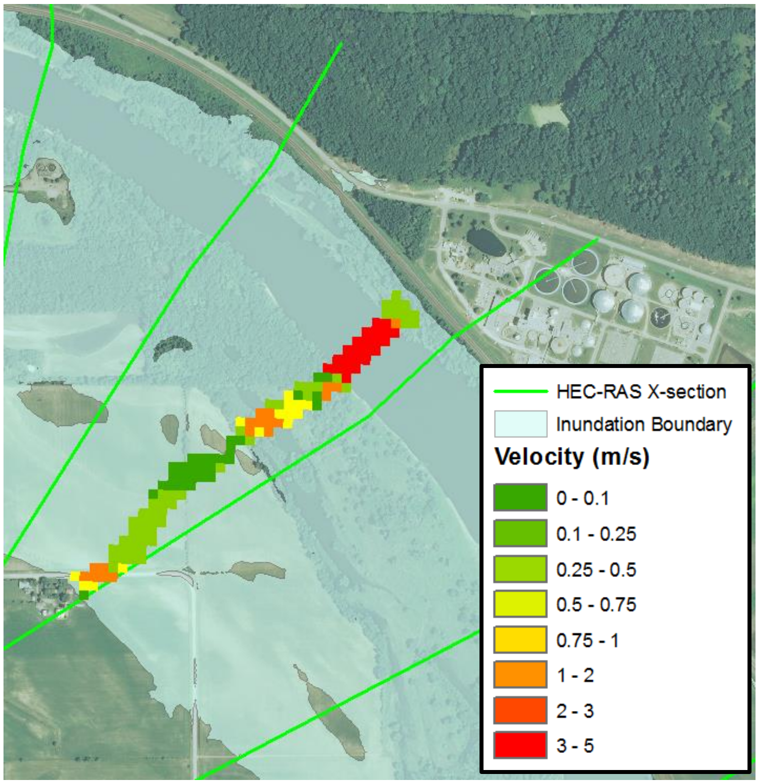


Figure 38: SCA method velocity cross-section output with 3 cell width

4.4.4.1. "SCA – Velocity" tool

Figure A9 and Figure A10 in Appendix A show the entire "SCA – Velocity" tool. Figure A9 shows the first half of the tool that creates the single cell wide cross-section holding depth values. This process is relatively similar for all four SCA tools. Figure A10 shows the second part of the "SCA – Velocity" tool, which is responsible for scaling the velocity and creating the velocity cross-section raster output.

All SCA method tools first create a single raster cross-section holding depth values. This depth cross-section raster is created using Equation 10 to separate out a single cross-section within a 1 cell width range of the user specified water surface elevation. The range of water surface elevations that lie within 1 cell of the specified elevation is a function of the water surface elevation and the slope of the individual cell.

Raster cells that have water surface elevations within the range determined by Equation 10 are added to the output raster cross-section by the SCA tools.

Equation 10: SCA Method WSE Range Equation

$$WSE\ range = I\_WSE \pm \frac{C}{2} * S$$

Where, I_WSE = User input water surface elevation, C = cell size (m), and S = slope (decimal)

Equation 11 shows Equation 10 converted to a complete GIS conditional statement that creates the single cross-section raster holding depth values. The actual SCA tools simplify this conditional statement into two conditional statements and several preliminary calculations.

Equation 11: WSE Range Equation in GIS Conditional Statement Format

*CON ((Input WSE + Cell Size/2 * [slope raster]) > [WSE raster] > (Input WSE – Cell Size/2 * [slope raster]), [depth raster])*

Figure 39 shows the first section of the “SCA – Velocity” SCA tool. This section is present in all SCA tools. It first takes the slope raster input and divides it by 100 to convert from units of percent slope to units of decimal slope. The decimal slope is multiplied by the cell size and divided by 2 to create the S*C/2 parameter of Equation 10 and Equation 11.

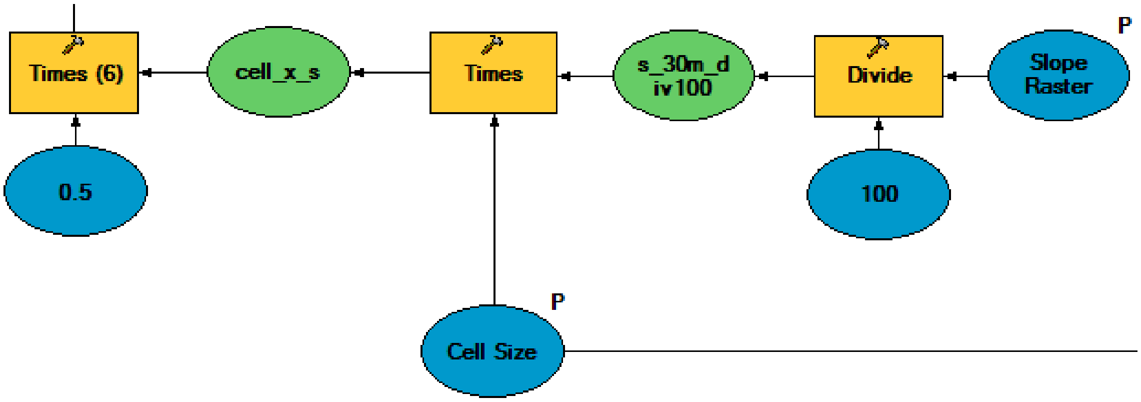


Figure 39: Model builder diagram for S*C/2 parameter calculation section of SCA method tools

Figure 40 shows the next portion of the SCA tool. This section takes the "cell_div_2" raster that represents the S*C/2 parameter of Equation 10 and creates two new rasters by adding it to, and subtracting it from, the "Elevation" input. This step creates the WSE input + S*C/2 and the WSE input – S*C/2 rasters named "e_plus_i" and "e_min_i," respectively. The "Elevation" input parameter is set up to take multiple elevation inputs, and the model will create an SCA continuity scaled cross-section for each elevation input. Two conditional statements are then used to ascertain which cells fall within the water surface elevation range.

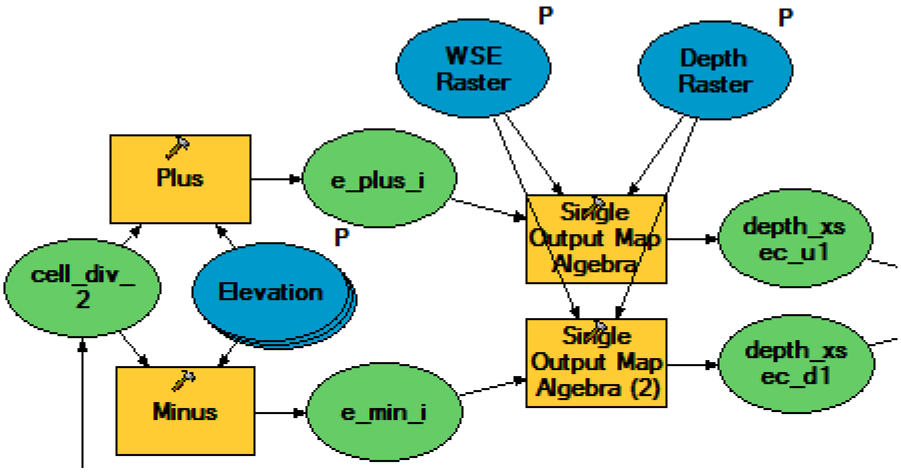


Figure 40: Model builder diagram for WSE range calculation section of SCA method tools

Equation 12 shows the GIS conditional statement in the first of these tools, “Single Output Map Algebra.” This conditional statement determines which cells in the total water surface elevation raster input, “WSE Raster,” are lower than the upper WSE range calculated with the previous steps. A raster containing all of the cells with water surface elevations **below** the upper WSE range is created, and this raster is given the values from the depth raster input.

Equation 12: Conditional Statement for "Single Output Map Algebra"

$$CON\ ([e\_plus\_i] > [WSE\ Raster], [Depth\ Raster])$$

Equation 13 shows the GIS conditional statement in the second map algebra tool, “Single Output Map Algebra (2).” This conditional statement does the opposite of the previous one: it determines which cells in the total water surface elevation raster input, “WSE Raster,” are higher than the minimum WSE range calculated with previous steps. A raster containing all cells with a water surface elevation **above** the lower WSE range is created, and this raster is also given the values from the depth raster input.

Equation 13: Conditional Statement for "Single Output Map Algebra (2)"

$$CON\ ([WSE\ Raster] > [e\_min\_i], [Depth\ Raster])$$

Figure 41 shows the next section of the SCA tool. This section first adds together the “depth_xsec_u1” and “depth_xsec_d1” rasters that resulted from the previous Single Output Map Algebra tools. The only cells that these two rasters have in common are the desired single cell wide cross-section. Adding these rasters together gives all other cells null values and leaves only the desired cross-section. The resulting cross-section is then divided by two because adding the rasters together caused it to have values that were twice what they should be. Figure 42 shows a raster dataset going through the process shown in Figure 41.

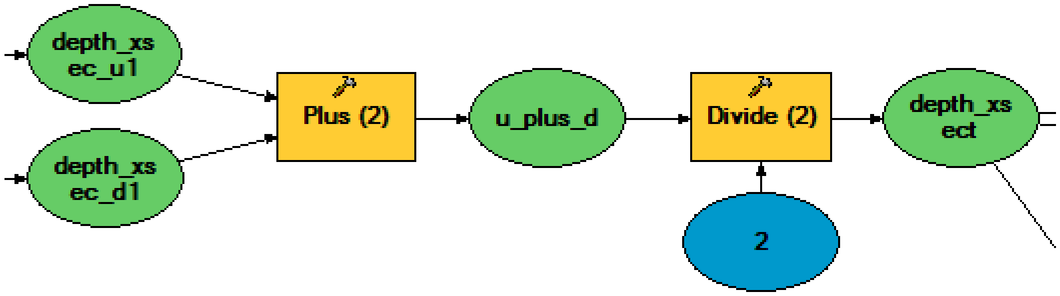


Figure 41: Model builder diagram for section of SCA method tools that creates a cross-section raster holding depth values

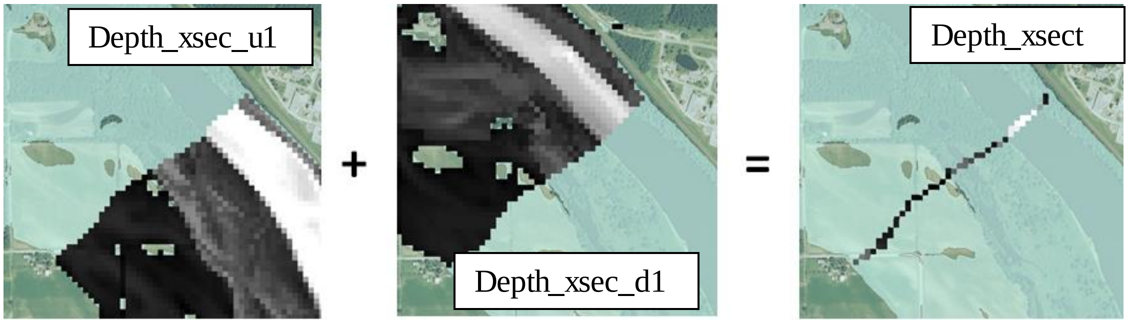


Figure 42: SCA method depth cross-section creation process

The aforementioned process used to create a depth raster cross-section is used in all of the SCA tools and will not be discussed in detail again.

Figure A10 in Appendix A shows the second half of the “SCA – Velocity” tool. This portion is responsible for taking the depth cross-section raster and creating a scaled velocity raster.

Figure 43 shows the portion of the tool that is responsible for taking the depth cross-section and creating a cross-section holding velocity values from the cell-by-cell method. The depth cross-section is first divided by itself to create a cross-section with values of 1. The cross-section holding 1 values is then multiplied by the cell-by-cell method velocity raster input, “Velocity(Manning),” to create a cross-section with the cell-by-cell method velocity values.

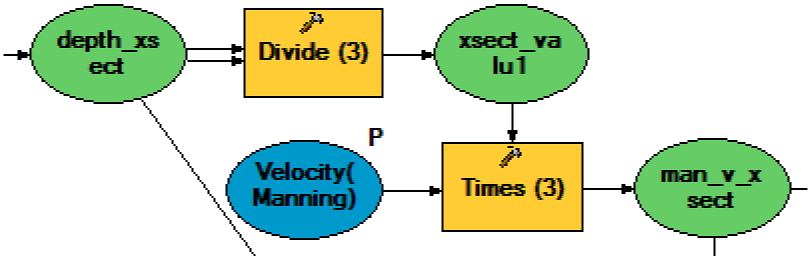


Figure 43: Model builder diagram for cell-by-cell method velocity cross-section creation portion of SCA method tools

Figure 44 shows the section of the tool that is responsible for creating rasters holding the cross-sectional area and average cell-by-cell method velocity for the cross-section. The section of the tool shown in the square uses the GIS Zonal Statistics tool to sum the values of all cells in the depth cross-section raster, and this sum is then multiplied by the cell size to obtain the cross-sectional area. The section of the tool shown in the circle uses the GIS Zonal Statistics tool to compute the average velocity obtained with the cell-by-cell method. The “ZSBounds” input is a shapefile that indicates the spatial area in which the zonal statistics are to be applied. This shapefile is created by the user and must completely enclose areas in which the SCA method cross-sections are being created.

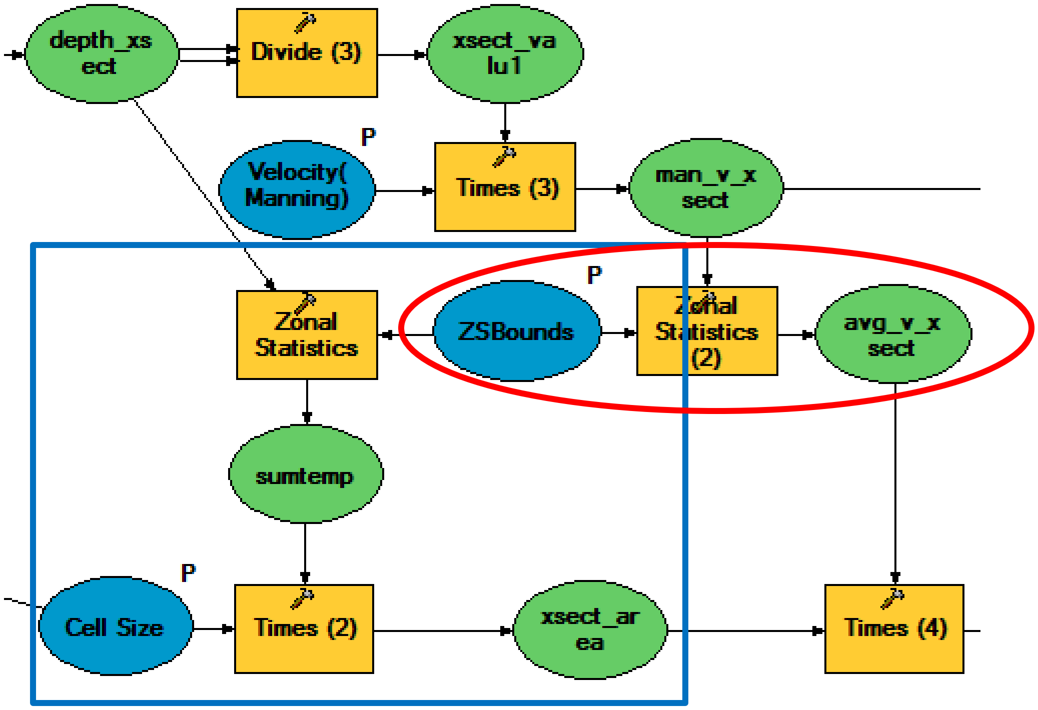


Figure 44: Model builder diagram for cross-section area and average velocity calculation portion of SCA method tools. Tools in the circle calculate average velocity along of the cross-section, and tools in the square calculate the area of the cross-section

Figure 45 shows the final section of the tool that creates the scaling factor and uses it to scale the cell-by-cell method velocity to preserve continuity. The section shown in the square multiplies the average cell-by-cell method velocity by the cross-sectional area to determine the cell-by-cell method’s predicted flow rate. The section shown in the circle takes the “true” flow rate used in the HEC-RAS model and divides it by the cell-by-cell method flow rate in order to create a scaling factor. The final process of the “SCA – Velocity” tool, “Times (5),” multiplies the scaling factor by the cell-by-cell method velocity cross-section to create a cross-section with velocity values that have been scaled to result in the correct flow rate used in the HEC-RAS model. Creating continuous maps of individual velocity or shear cross-sections involves mosaicking the individual cross-section outputs together.

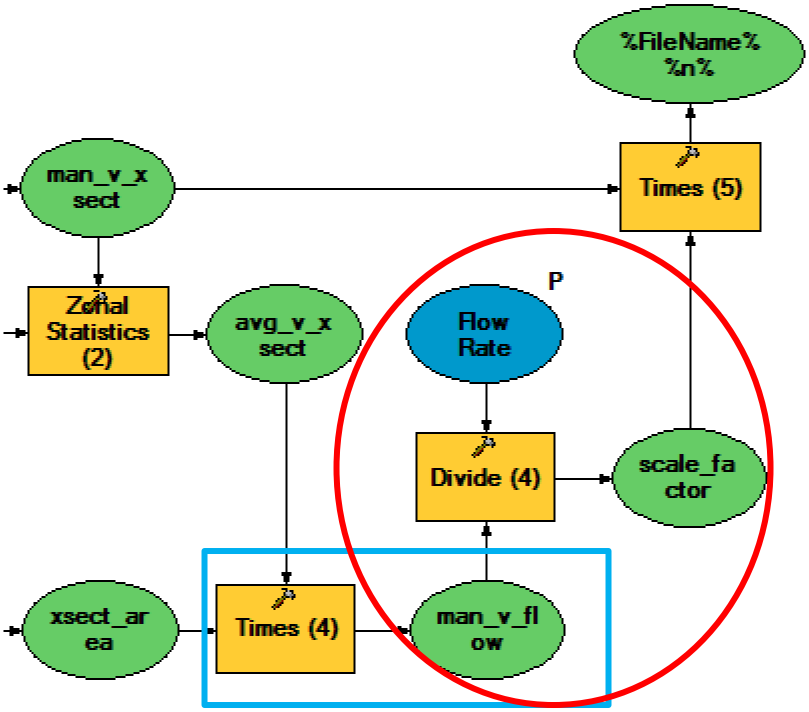


Figure 45: Model builder diagram for creation and application of scaling factor section of SCA method tools. Tools in the square multiply the area by average velocity to calculate the cell-by-cell method predicted flow rate, and tools in the circle divide the "true" flowrate by it to create the scaling factor

4.4.4.2. *"SCA – Velocity – Wide" tool*

The "SCA – Velocity – Wide" tool functions the same as the "SCA – Velocity" tool, but it can create cross-sections that are several cells wide instead of only one cell wide. The width of cross-sections, in number of cells, is user specified in the "SCA – Velocity – Wide" tool. The purpose of this tool is to allow for the faster creation of continuous velocity maps. Creating wider cross-sections means that there are fewer individual raster files that need to be mosaicked together. The entire tool is shown as two parts in Figure A11 and Figure A12 in Appendix A. Figure A11 shows the section of the tool responsible for creating the depth cross-section, and Figure A12 shows the section of the tool responsible for creating the continuity scaled velocity cross-section. Only the elements of the "SCA – Velocity – Wide" tool that are different from the "SCA – Velocity" tool will be discussed.

The water surface elevation range is larger in the "SCA – Velocity – Wide" tool in order to capture more cells in the cross-section. Equation 14 is used to calculate the wider water surface elevation range. The S*C/2 parameter is multiplied by the width of the cross-section, in number of cells, but is otherwise the same as Equation 10.

Equation 14: WSE Range Equation for "SCA - Velocity - Wide" Tool

$$WSE\ range = I\_WSE \pm \frac{C}{2} * S * W$$

Where, I_WSE = User input water surface elevation, C = cell size (m), S = slope (decimal), and W = width of cross section (number of cells).

Figure 46 shows the section that is responsible for calculating the S*C/2*W parameter of Equation 14. This parameter is then used in the same way as it was in the "SCA – Velocity" tool.

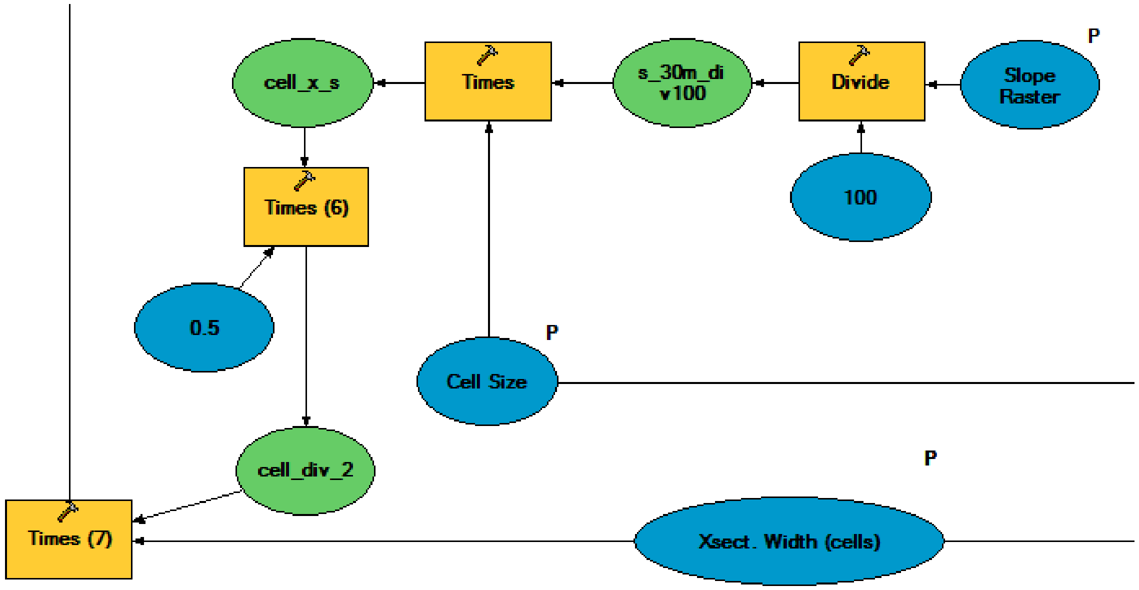


Figure 46: Model builder diagram for S*C/2*W parameter calculation of "Wide" versions of SCA method tools

Figure 47 shows the portion of the tool that is responsible for calculating the cross-sectional area. The cross-sectional area of the multiple cell wide cross-section is the average area of each individual single cell wide cross-section making up the total cross-section. The depth values are summed and multiplied by the cell size. They are then divided by the user specified cross-section thickness, in number of cells, in order to obtain the average cross-sectional area. The scaling factor is created and applied in the same way as was done in the "SCA – Velocity" tool. The average areas calculated for these wide cross-sections can potentially be less accurate than they would be for the single cell wide cross-section.

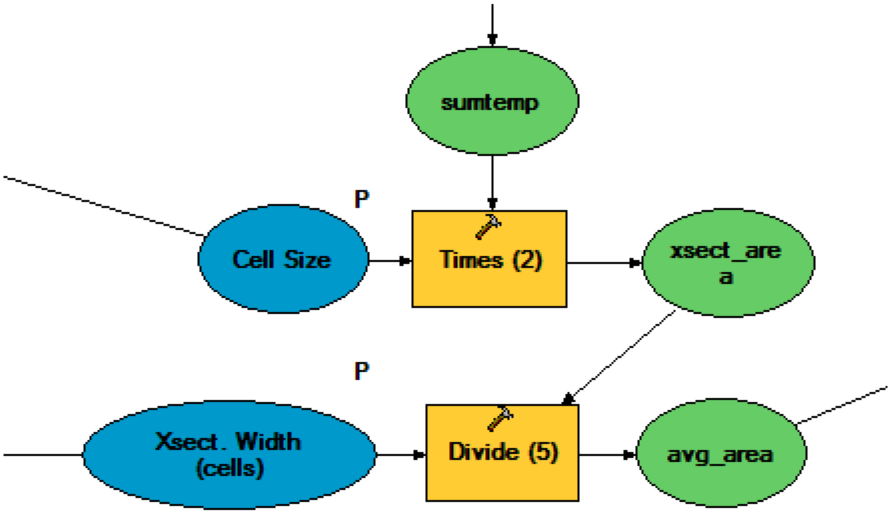


Figure 47: Model builder diagram for cross-sectional area calculation section of "Wide" versions of SCA method tools

4.4.4.3. *"SCA – Bed Shear" tool*

The "SCA – Bed Shear" tool adjusts the cell-by-cell method bed shear data to ensure that continuity along a cross-section is preserved. The SCA continuity adjusted bed shear can then be inputted into one of the effective shear tools in order to obtain the continuity corrected effective shear. The "SCA – Bed Shear" tool functions very similarly to the "SCA – Velocity" tool. The bed shear scaling factor is different from the velocity scaling factor and is shown as Equation 15. The derivation below demonstrates how the bed shear scaling factor is obtained and why it is different from the velocity scaling factor.

$$\tau_b = \frac{\rho * g * n^2 * V^2}{h^{\frac{1}{3}}}$$

$$\tau_b \propto V^2$$

$$\tau_{b_{scale}} = (V_{scale})^2$$

$$V_{scale} = \frac{Q_{Actual}}{Q_{cell-by-cell}}$$

Equation 15: Bed Shear Scaling Factor

$$\tau_{b_{scale}} = \left(\frac{Q_{Actual}}{Q_{cell-by-cell}}\right)^2$$

Figure A13 and Figure A14 in Appendix A show the "SCA – Bed Shear" tool in two sections. Figure A13 shows the first part of the tool that separates out a cross-section with depth values. This portion of the tool functions exactly the same as the velocity SCA tools. Figure A14 shows the second portion of the tool that creates the scaling factor for bed shear and the scaled bed shear cross-section output. Figure 48 and Figure 49 show the only portions of the "SCA – Bed Shear" tool that are different from the "SCA - Velocity" tool.

Figure 48 shows the portion of the tool that takes the bed shear input and trims it to the single cross-section by multiplying by the depth cross-section that has been divided by itself.

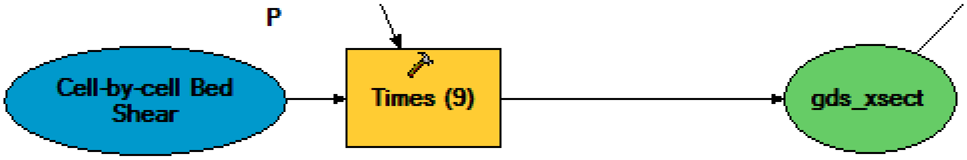


Figure 48: Model builder diagram for bed shear calculation portion of "SCA – Bed Shear" tool

Figure 49 shows the final portion of the tool. The scaling factor is created by dividing the "true" flow rate by the cell-by-cell method calculated flow rate and squaring the result, as per Equation 15. The bed shear cross-section is then multiplied by the scaling factor to create the final scaled bed shear cross-section.

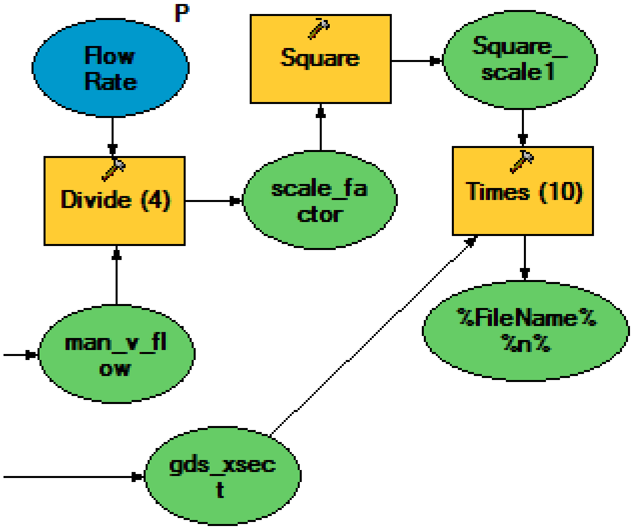


Figure 49: Model builder diagram for scaling factor creation and application section of "SCA – Bed Shear" tool

4.4.4.4. "SCA – Bed Shear – Wide" tool

The "SCA – Bed Shear – Wide" tool creates a scaled bed shear cross-section raster that is several cells wide instead of a single cell wide. This is done using the exact same procedure as was used with the "SCA – Velocity – Wide" tool. The Figure A15 and Figure A16 in Appendix A show the first and second portions of this tool.

4.5. Post-Processing GIS Tools

Several additional tools were created to carry out the final processes needed to prepare the final maps. These post-processing tools include a tool to prepare the allowable shear raster, a tool to create the excess shear ratio map that will be reported in the final map packet, and a unit conversion tool that can convert units from Metric to Imperial.

4.5.1.1. "Allowable Shear Creator" tool

The "Allowable Shear Creator" tool takes the allowable shear feature shapefile and converts it to a raster. Figure 50 shows the entire GIS model builder diagram for the tool. There is a version of this tool for creating allowable shear rasters in both pascals and pounds per square foot (psf). The units are indicated by the suffix in the tool's name. The allowable shear shapefile input, "SSURGO MUSYM," is created by linking the provided NRCS erodibility classifications database file with the SSURGO surface soil type shapefile.

The erodibility classifications database file has allowable shear columns in both Pascal's and psf, and the correct column must be chosen as the "Field" input for the tool being run. Several of the soil categories do not have critical shear data assigned, which can cause small portions of the resulting critical shear raster to contain "NoData" values. The "Allowable Shear Creator" tool also uses a GIS Single Output Map Algebra tool to carry out the conditional statement, shown as Equation 16. This statement takes the areas of the raster with "NoData" values and assigns them a worst case scenario critical shear value of 0.02 psf or 0.95 Pa, depending on the tool version.

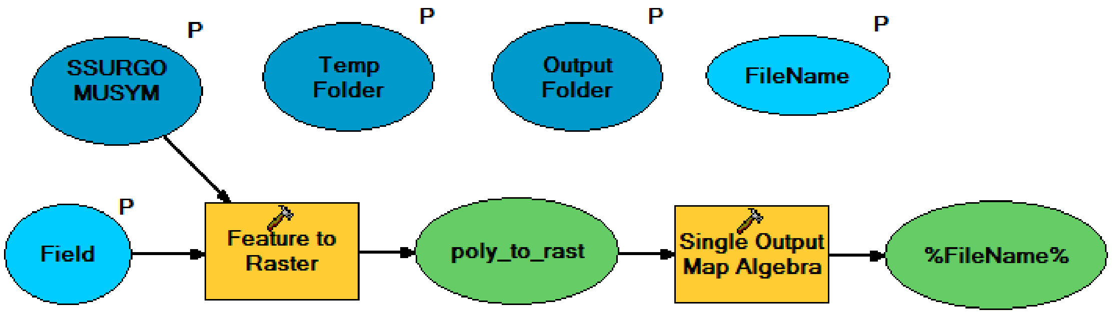


Figure 50: "Allowable Shear Creator" tool complete model builder diagram

Equation 16: Allowable Shear Creator Map Algebra Conditional Statement

$$CON\ (\ ISNULL([poly\_to\_rast]), 0.095, [poly\_to\_rast]\ )$$

4.5.1.2. "Excess Shear Ratio" tool

The "Excess Shear Ratio" tool divides the effective shear raster by the allowable shear raster, which creates a raster with the effective shear to critical shear ratio. Figure 51 shows the GIS model builder diagram for the "Excess Shear Ratio" tool. The excess shear ratio raster is the primary map that will characterize scour. Values of 1 or higher indicate that effective shear has exceeded allowable shear, which means that scour is expected to occur. The further above 1 the values are, the more likely and more severe scour will be. Areas where this map is showing values near 1 could potentially experience scour, and areas where values are well under 1 do not have significant potential for scour.

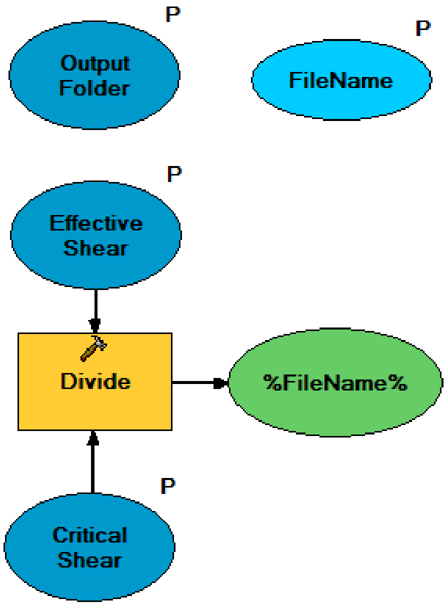


Figure 51: "Excess Shear Ratio" tool complete model builder diagram

4.5.1.3. “Excess Shear Ratio - Multiple” tool

The “Excess Shear Ratio – Multiple” tool functions exactly the same as the “Excess Shear Ratio” tool, except it can take multiple effective shear raster inputs to produce multiple outputs. This version of the tool will be able to produce multiple excess shear ratio rasters more efficiently than the regular version.

4.5.1.4. “Depth and Shear Unit Converter” tool

The input data for this project are in the Metric system of units. The final maps that are reported to the INHF need to be in Imperial units because that is what most land management personnel and farmers are familiar with. The “Depth and Shear Unit Converter” tool takes a depth raster in meters and shear raster in pascals as inputs and outputs a depth raster in feet and shear raster in pounds per square foot. Figure 52 shows the GIS model builder diagram for the “Depth and Shear Unit Converter” tool.

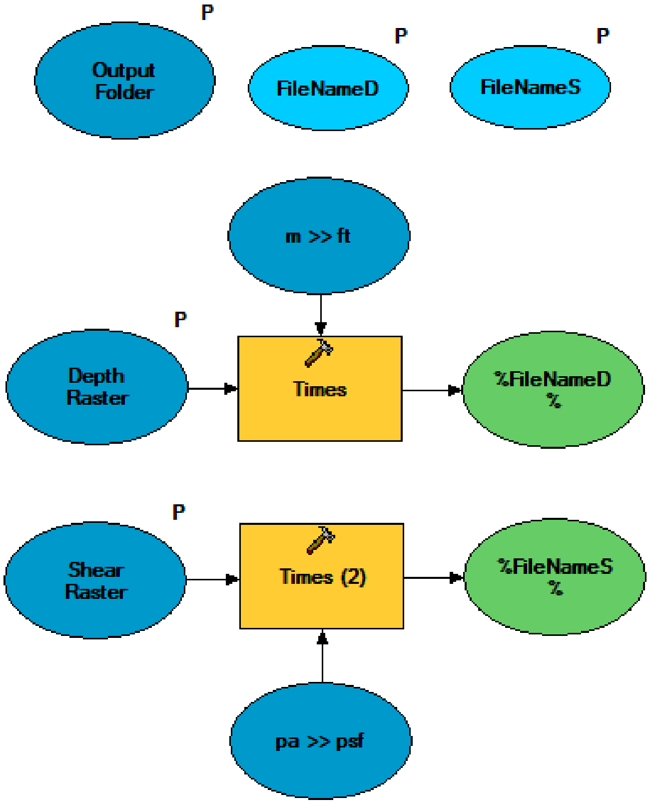


Figure 52: “Depth and Shear Unit Converter” tool complete model builder diagram

CHAPTER 5. VERIFICATION AND DISCUSSION

5.1. Introduction

There were two two-dimensional (2D) models created using DHI's Mike21. The first was for a 14 km reach of the Cedar River south of Cedar Rapids, IA, and the second was for a 22 km reach of the Iowa River south of Iowa City, IA. 1D HEC-RAS models used the FPM process for the same reaches. The cell-by-cell and SCA methods were used on the 1D HEC-RAS results to create velocity, bed shear, effective shear, and excess shear ratio maps to compare to the 2D results. Both the Cedar Rapids and Iowa City models were created for the 100 year return period. Both the 1D and 2D Cedar Rapids models use a flow rate of 2665 cubic meters per second (cms), while both Iowa City models use a flow rate of 1048 cms. The 1D and 2D models also use the same Manning's n data. The Cedar Rapids model is representative of typical floodplains, whereas the Iowa City model is more representative of wide floodplains that occur in very flat areas.

Visual comparison between the 2D models and the methods developed for this thesis is often the best method to assess how well the developed methods are working. Quantitative analysis is conducted where possible but does not always represent actual usefulness of the methods created for this thesis. The methods created aim to characterize scour and estimate general areas where scour is likely to occur, but they will not produce velocity or shear maps that perfectly match the 2D models results due to limitations with the 1D input data. This section will focus primarily on qualitatively determining and discussing how useful the produced maps are in terms of distinguishing areas that are prone to scour.

Figure 53 shows the inundation boundary map for the Cedar Rapids model, while Figure 54 shows the inundation boundary map for the Iowa City model.

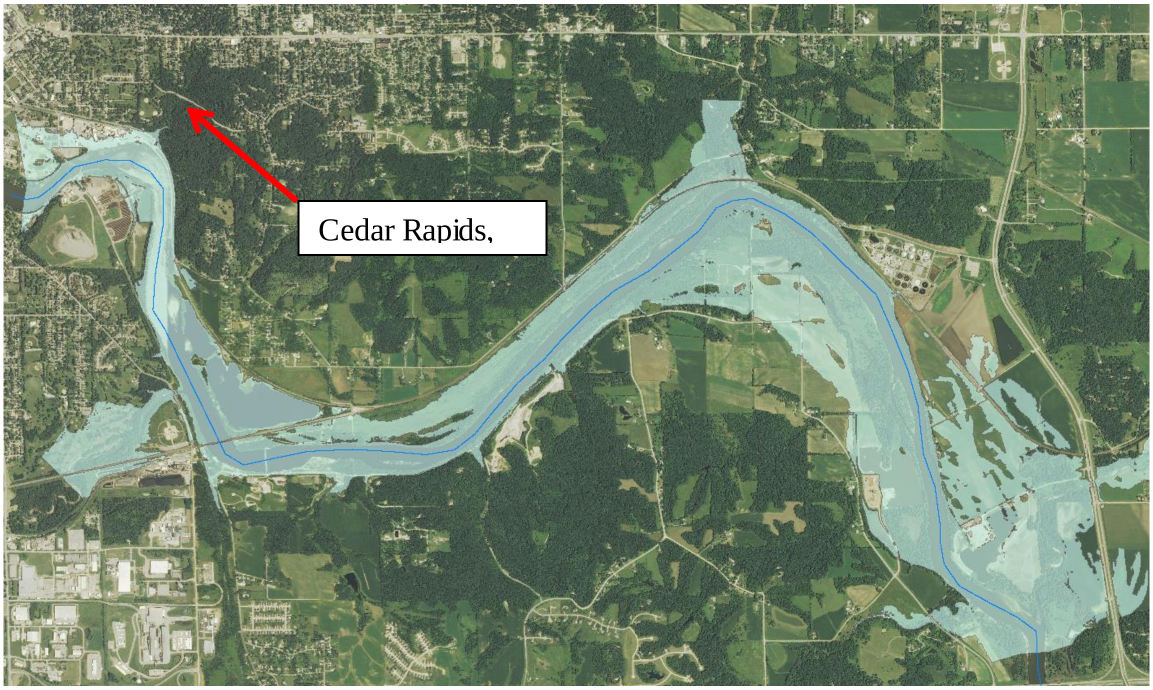


Figure 53: Cedar Rapids model inundation boundary shapefile

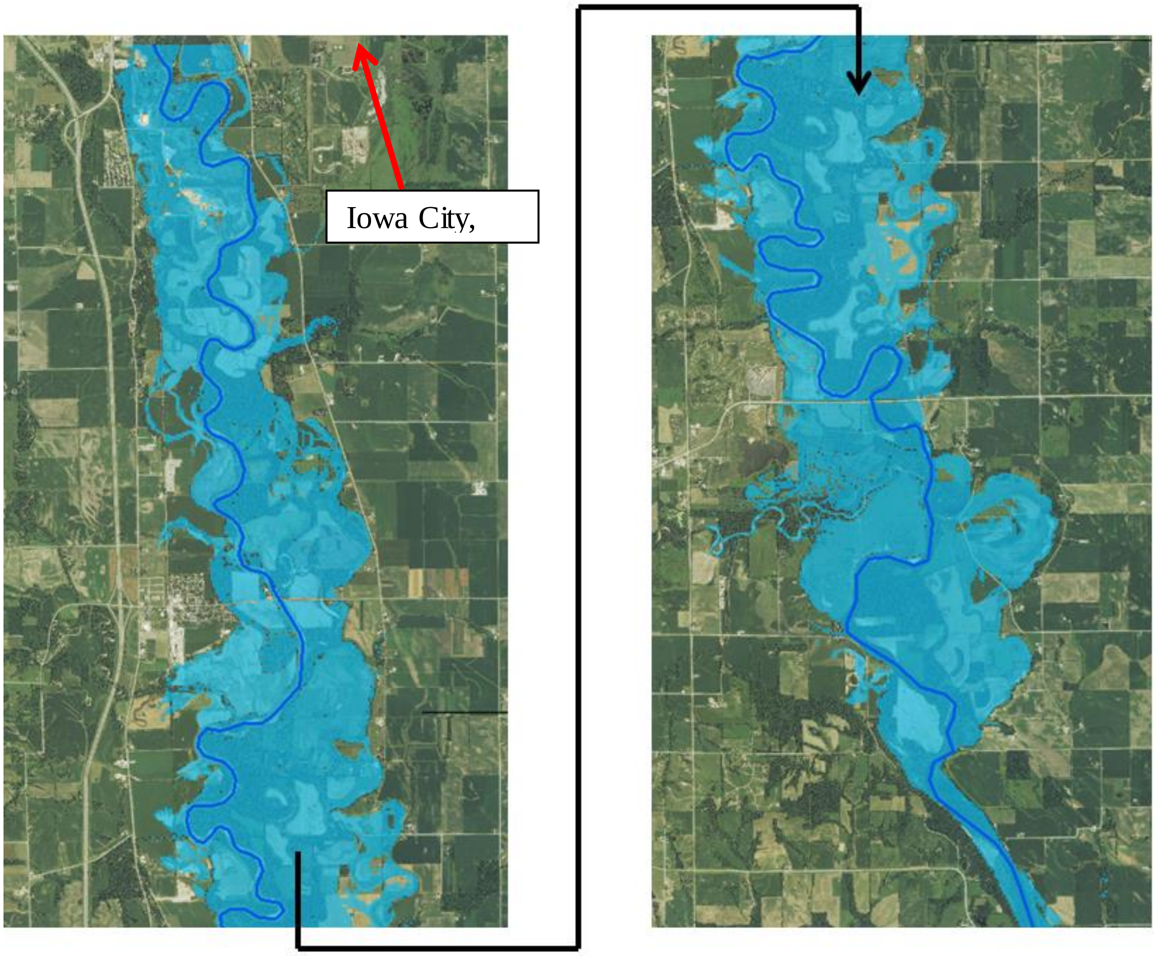


Figure 54: Iowa City model inundation boundary shapefile

5.2. Water Surface Elevation and Slope

5.2.1. 1D HEC-RAS vs 2D Mike21 Slope

The differences in 1D and 2D slope and depth lead to differences in depth, velocity, and shear. Figure 55 and Figure 56 show the 1D and 2D slope for the Cedar Rapids model, respectively.

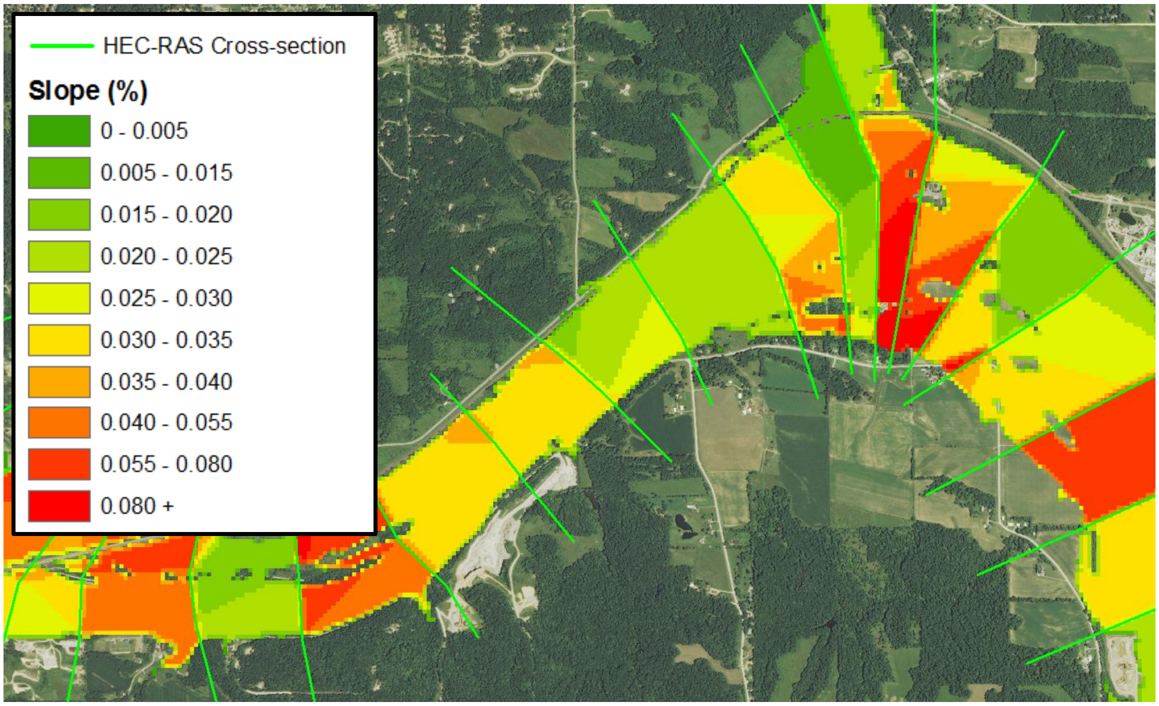


Figure 55: 1D HEC-RAS slope

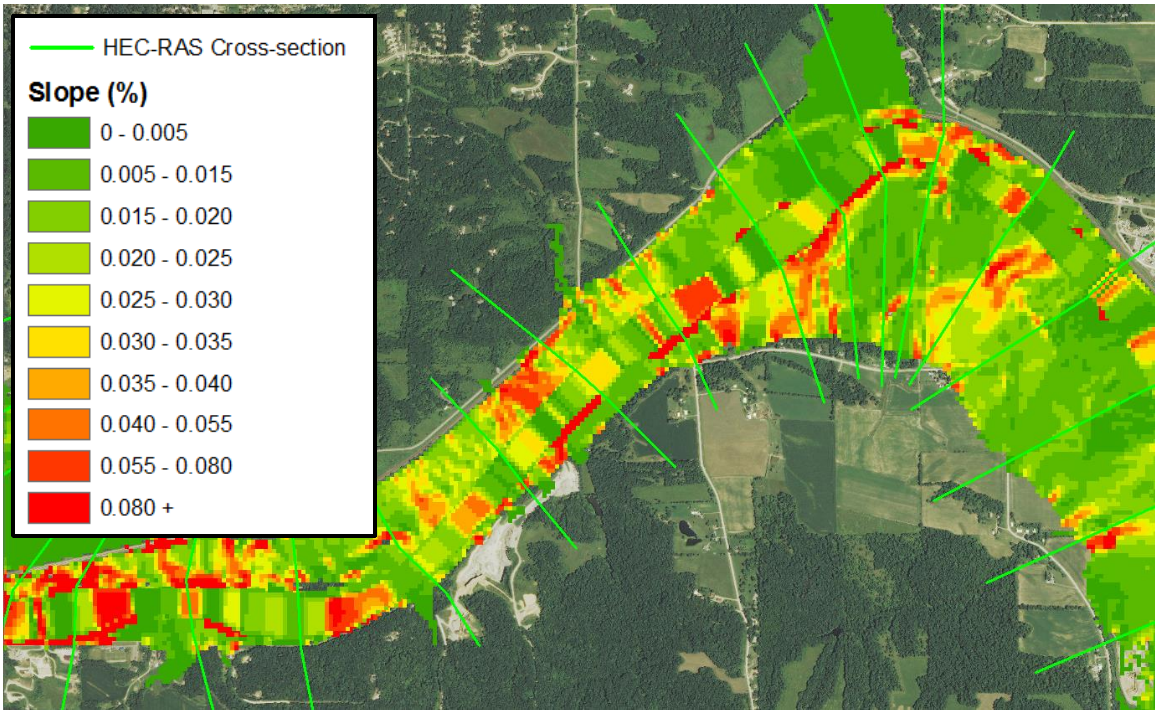
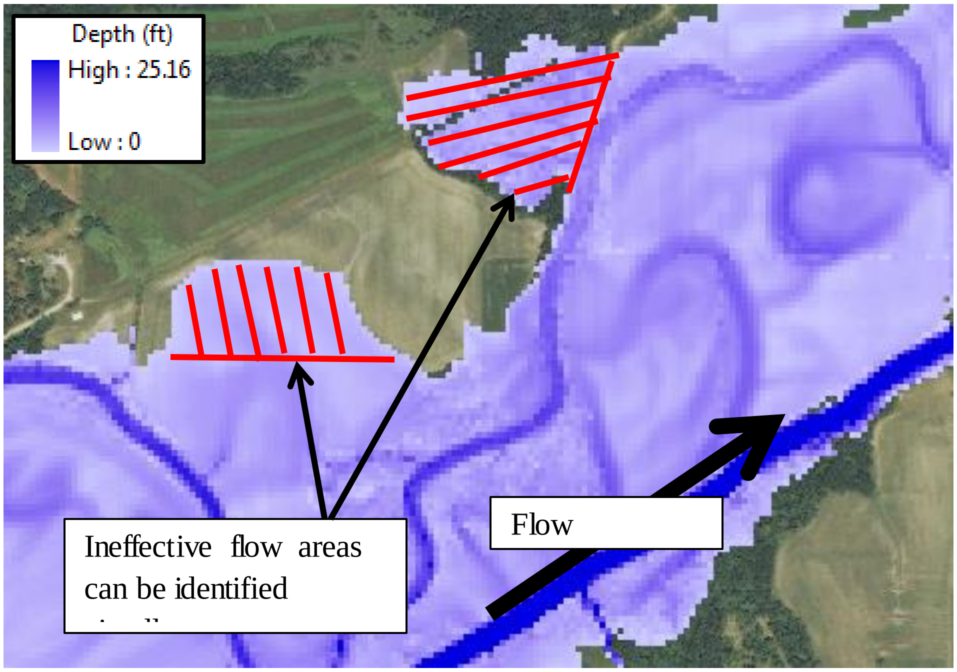


Figure 56: 2D Mike21 slope

The primary difference between these two datasets is that the 1D slope is relatively constant in-between the HEC-RAS cross-sections and is relatively constant across the width of the channel at any given cross-section. The 1D slope is calculated using only the geometry and elevations at the HEC-RAS cross-sections, which are typically around 200 to 500 meters apart. The HEC-RAS model does not know what is occurring in-between these cross-sections, so the resulting water surface has a constant slope between them. The Mike21 2D model accounts for bed elevation and roughness everywhere, which is why the 2D slope data have higher spatial resolution. HEC-RAS is not aware of most of the topography that is causing the 2D model to produce its water surface elevation results. The approximately constant 1D slopes between cross-sections and the fact that HEC-RAS does not model what is occurring between its cross-sections is the primary source of errors encountered when using the 1D hydraulic data to create spatial velocity and shear maps.

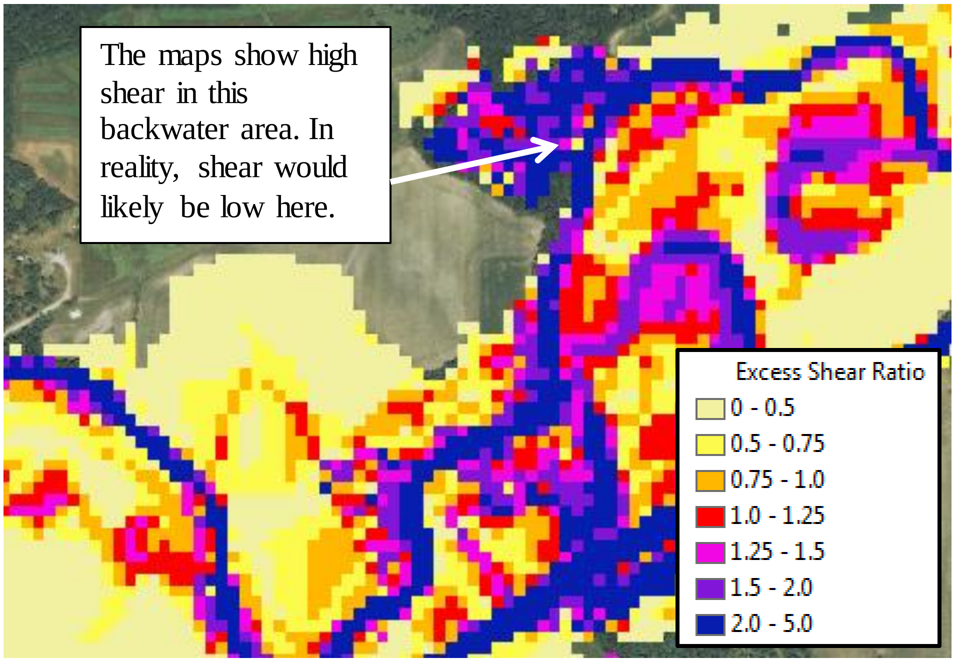
5.2.2. 1D HEC-RAS Slope Limitation Effects

Velocity and shear should be zero or very low in ineffective flow backwater areas, but they will often be high in the maps produced by the cell-by-cell method because the 1D HEC-RAS slope doesn’t reflect the ineffective flow area. It is important for the map user to understand this limitation and discount velocity or shear readings that occur in backwater areas. Figure 57 shows an example of backwater areas, and Figure 58 shows how the cell-by-cell method predicted shear can be unrealistically high in these areas due to the limitations of the HEC-RAS slope.



Ineffective flow areas can be identified

Figure 57: Example of ineffective flow areas



The maps show high shear in this backwater area. In reality, shear would likely be low here.

Figure 58: Example of unrealistically high shear in ineffective flow area

The constant slopes can also result in higher than realistic shear or velocity values in areas where there is a depression in the bed, ineffective flow channel, or oxbow. This error occurs because the cell-by-cell method applies the open channel flow equations assuming the full depth is effective flow area. Figure 59 shows an example of how the cell-by-cell method predicted shear can be higher than is expected in ineffective flow channels.

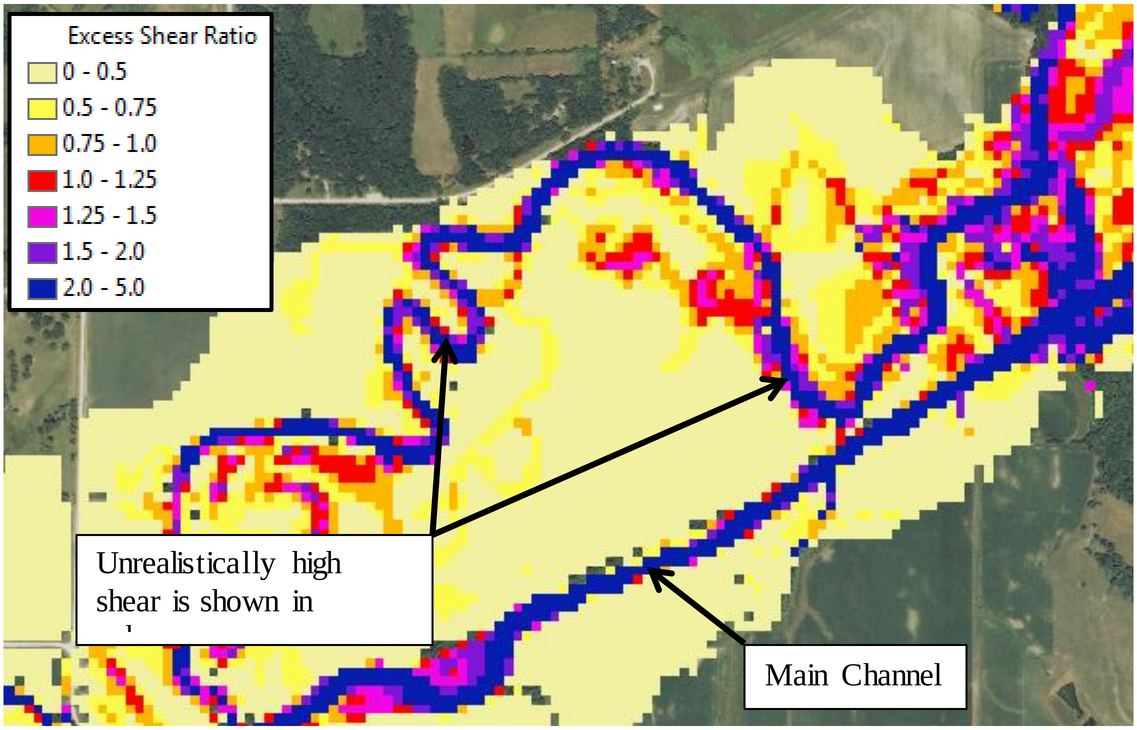


Figure 59: Example of unrealistically high shear in ineffective flow channels

The relatively constant 1D slopes can also result in a loss of continuity in-between the HEC-RAS cross-sections. A decrease in flow area or change in roughness will normally change the slope and velocity of that area of the river. This change in slope is not reflected by the HEC-RAS model if the change in area or roughness occurs only in-between the HEC-RAS cross-sections. An example of this loss of continuity error can be seen when using Manning’s Equation with the cell-by-cell method in a location where there is a decrease in flow area in-between the upstream and downstream HEC-RAS cross-sections. Using Manning’s Equation will result in lower than realistic velocities in a contraction area because the depth and flow area decreased but the slope did not change to reflect the smaller area. Summing the cell-by-cell method calculated flow rate from each cell along a cross-section going through such a contraction would result in a total flow rate that is less than the true flow rate that was used in the HEC-RAS model. The loss of continuity equally affects shear calculations because the shear is also based on slope and depth. This loss of continuity limitation is most prevalent in areas where there are wide floodplains with variable depths and obstructions. Major loss of continuity does not usually occur in sections where the channel is relatively straight and uniform.

5.3. Depth

5.3.1. 1D HEC-RAS Depth Limitations

The constant slopes between HEC-RAS cross-sections can also result in depth errors when there is a rise or fall in the bed slope that occurs between HEC-RAS cross-sections. The water surface slope would normally change based on changes in bed elevation, but this does not occur when HEC-RAS is not aware of bed slope changes occurring in-between its cross-sections. It is difficult to tell where these depth errors could be occurring and by how much because there are a number of factors that influence the relationship between bed elevation and water surface elevation. Figure 60 shows an illustration of this limitation. The water surface slope should change when actual bed slope changes, but it remains constant because HEC-RAS is not aware of the bed slope changes that occur in-between its upstream and downstream cross-sections.

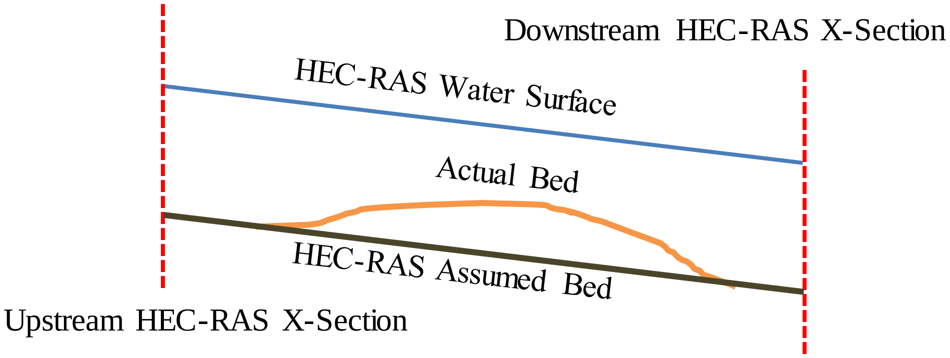


Figure 60: Depth limitation illustration showing that changes occurring in between HEC-RAS cross-section are not reflected by the water surface output

5.3.2. 1D HEC-RAS vs 2D Mike21 Depth: Cedar Rapids

The 2D depth raster for the Cedar Rapids model has values around 1.5 times higher than the 1D depth raster, which is likely due to the fact that there are several overpasses and bridges in the area that act as controls and back water up. The inundation boundary for the 1D model is less than that of the 2D model as a result of the difference in depths. These overpasses and bridges are only modeled by the 2D model; the 1D model does not account for them because the floodplain mapping process does not lay out the HEC-RAS cross-sections in such a way that the model will consider these types of structures. Spatial distribution of high and low depth areas agree well despite the differing magnitudes. The flow rate used in the 1D and 2D model is the same, so the 2D model shows velocities and shear stresses with magnitudes less than the 1D model due to this depth difference. Spatial distribution of shear and velocity should not be significantly impacted by the difference in depth except where the 2D model shows inundation and the 1D model does not. Figure 61 and Figure 62 show the depth rasters for the 1D and 2D Cedar Rapids models, respectively. Figure 63 shows the Cedar Rapids 2D model depth results divided by the 1D results.

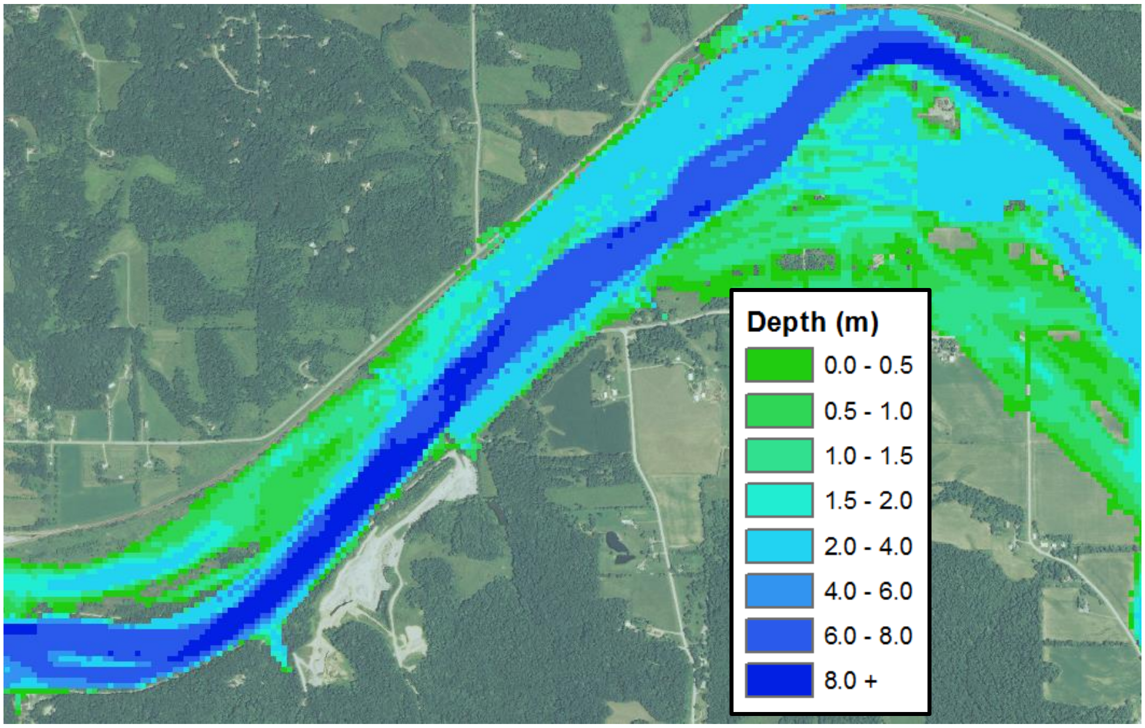


Figure 61: Cedar Rapids 1D HEC-RAS model depth raster

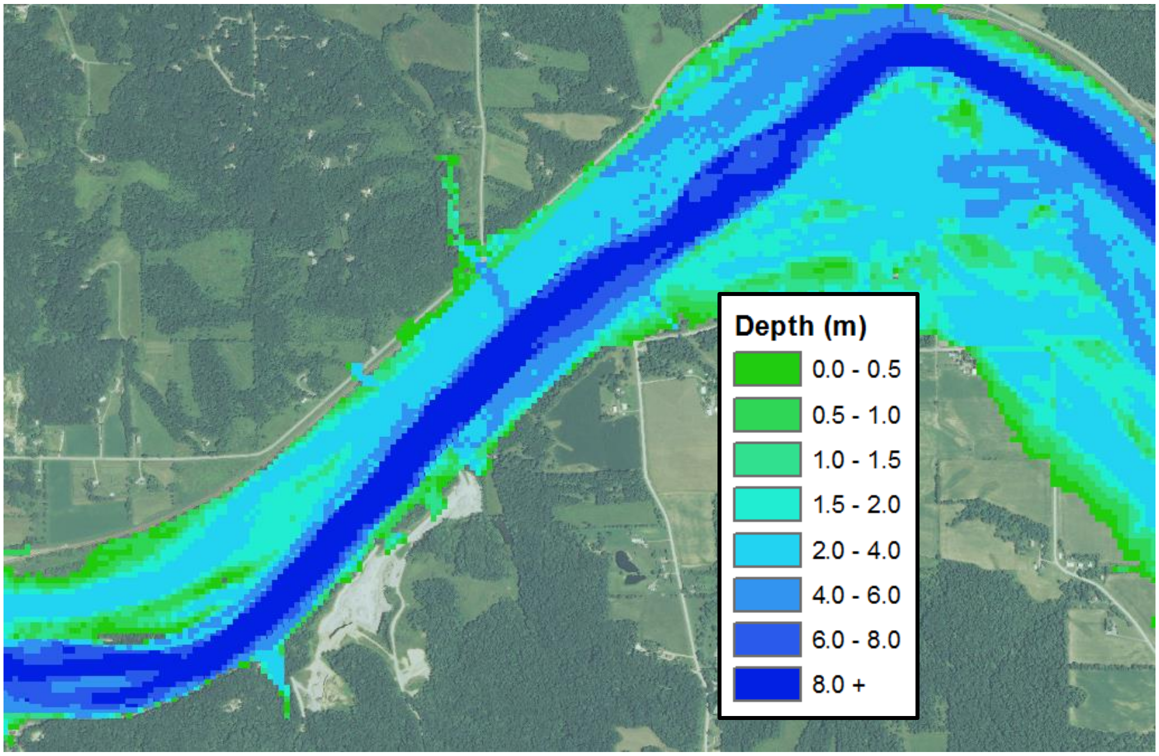


Figure 62: Cedar Rapids 2D Mike21 model depth raster

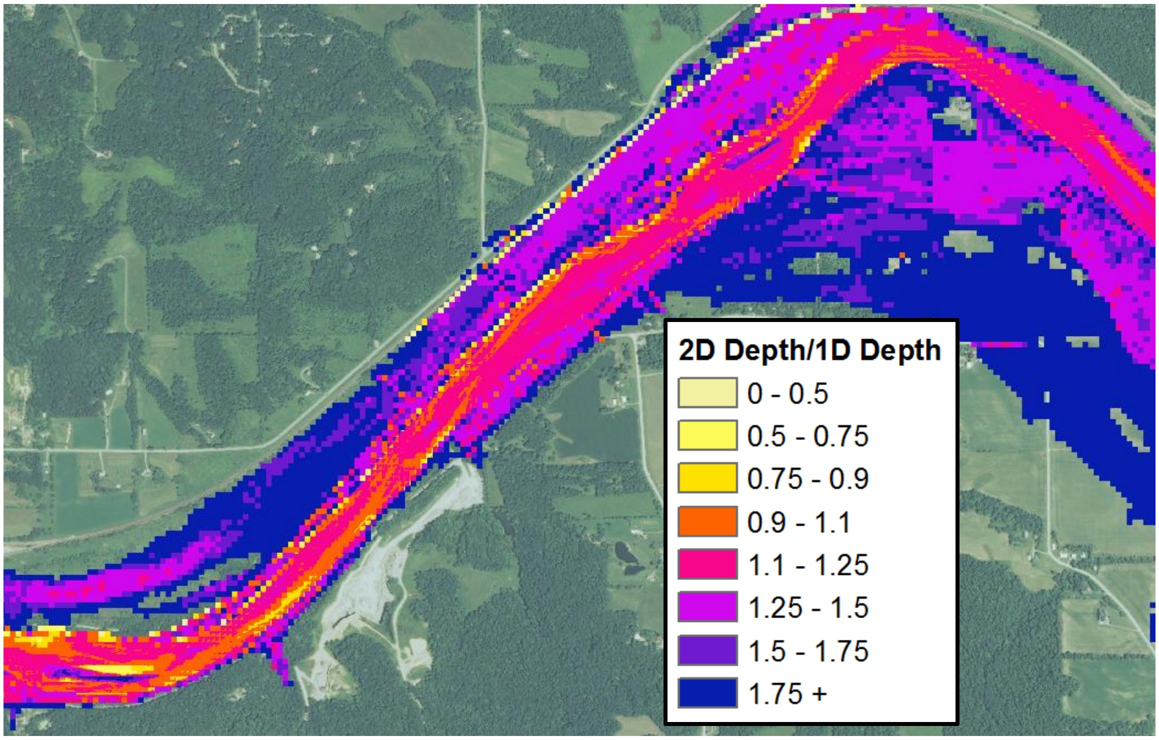


Figure 63: Cedar Rapids model 2D depth divided by 1D depth raster

5.3.3. 1D HEC-RAS vs 2D Mike21 Depth: Iowa City

The Iowa City 2D Mike21 model has depth values that are slightly higher than the 1D HEC-RAS model in some areas and slightly lower in others. These differences occur due to the differences in modeling methods, primarily the way water surface elevation is handled by the 1D model. Figure 64 shows the 2D Mike21 depth divided by the 1D HEC-RAS depth for the Iowa City model.

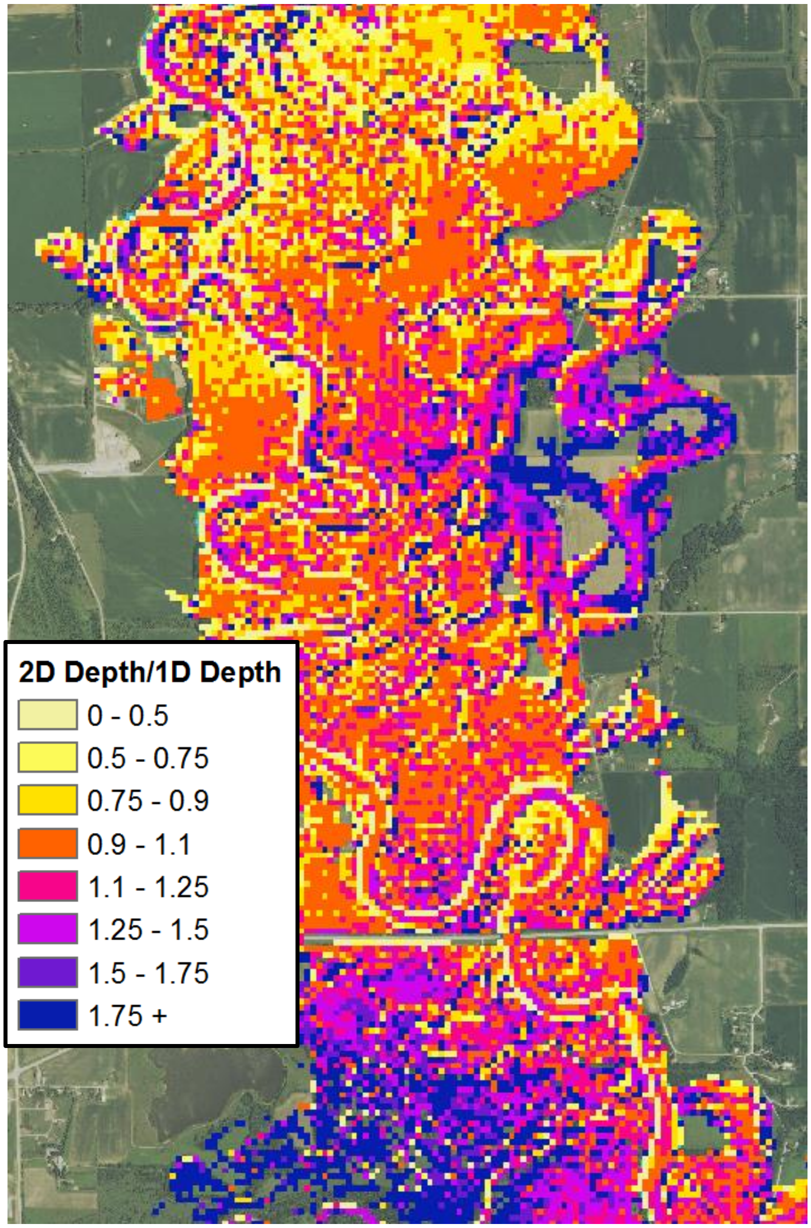


Figure 64: Iowa City model 2D depth divided by 1D depth raster

5.4. Cell-by-Cell Method Velocity

Cell-by-cell method velocity does not need to be calculated to obtain effective shear maps that can predict scour, but it is a required input for the SCA method and may be useful for other projects. Comparing 2D velocity results with the velocity obtained using the cell-by-cell method is also a good way to assess how effective the cell-by-cell method is in general.

5.4.1. Cell-by-Cell vs. 2D Mike21 Velocity: Cedar Rapids Model

Figure 65 and Figure 66 show the velocity raster results from the cell-by-cell method separated into two sections. Figure 67 and Figure 68 show the velocity results from the 2D Mike21 model separated into two sections. The same scale is used for both figures to visually display how well the velocity magnitudes agree between the two models. The 2D model does not have results for the main channel. The flow direction is from West to East in this model.

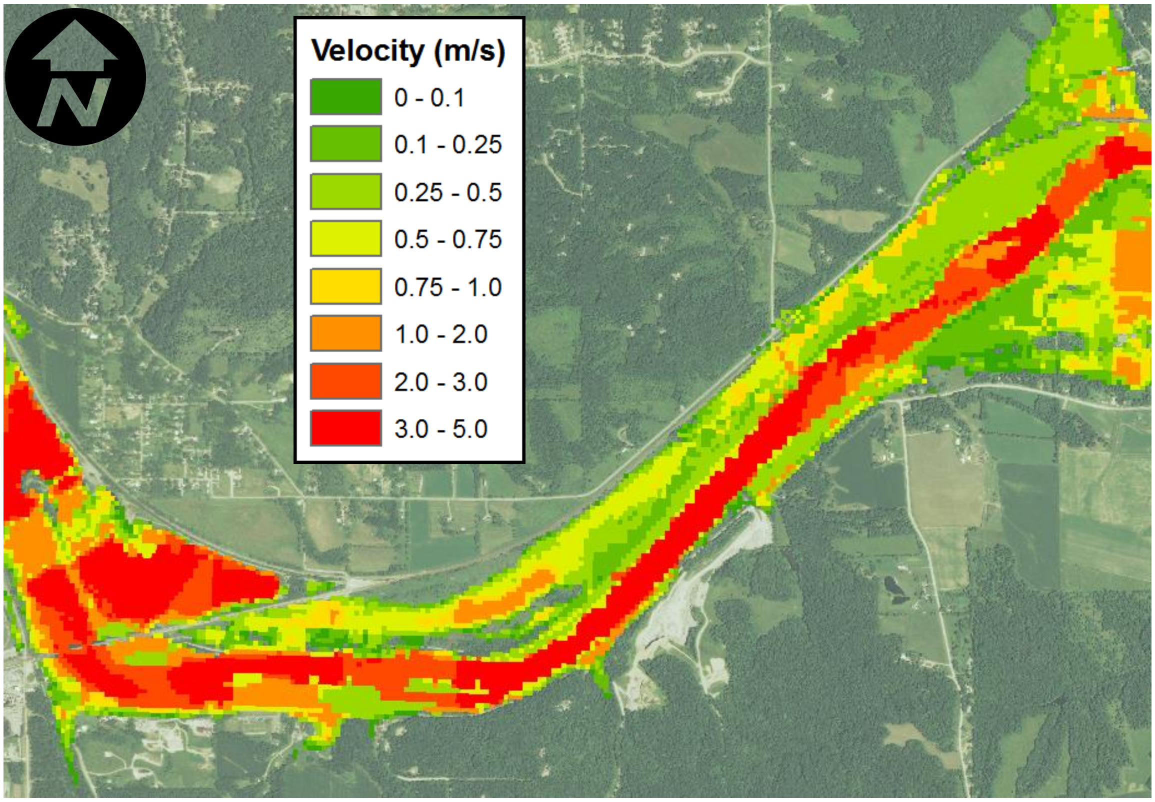


Figure 65: Cell-by-cell method velocity raster - Section 1

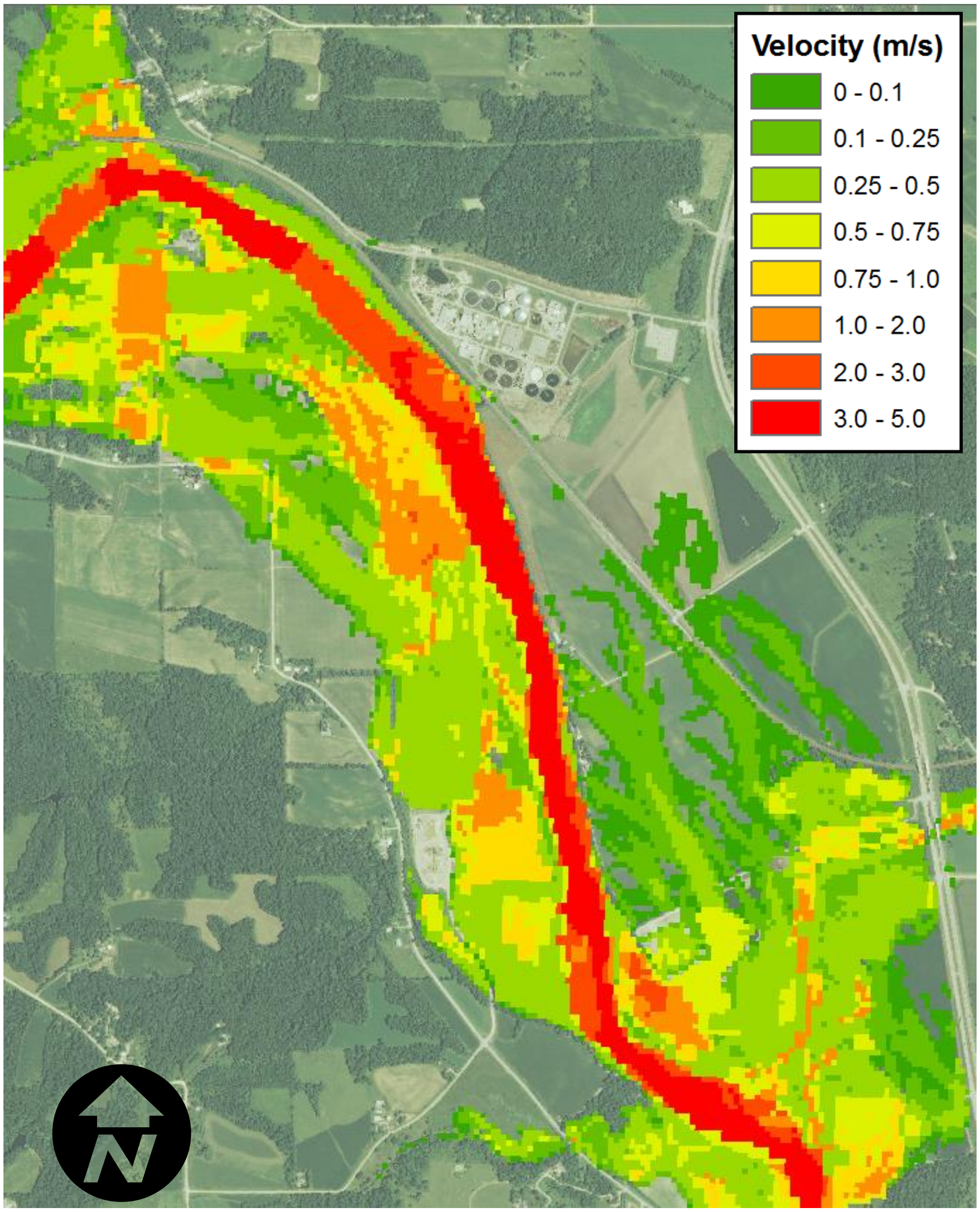


Figure 66: Cell-by-cell method velocity raster - Section 2

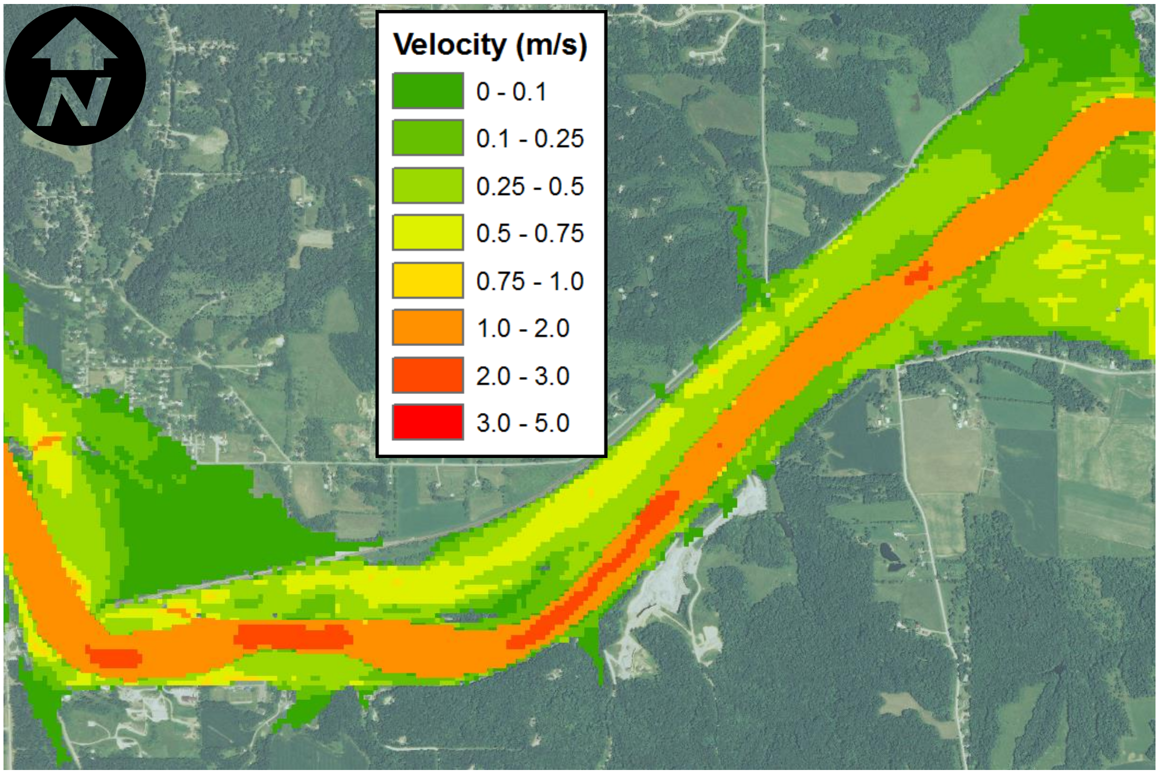


Figure 67: Mike21 2D velocity raster - Section 1

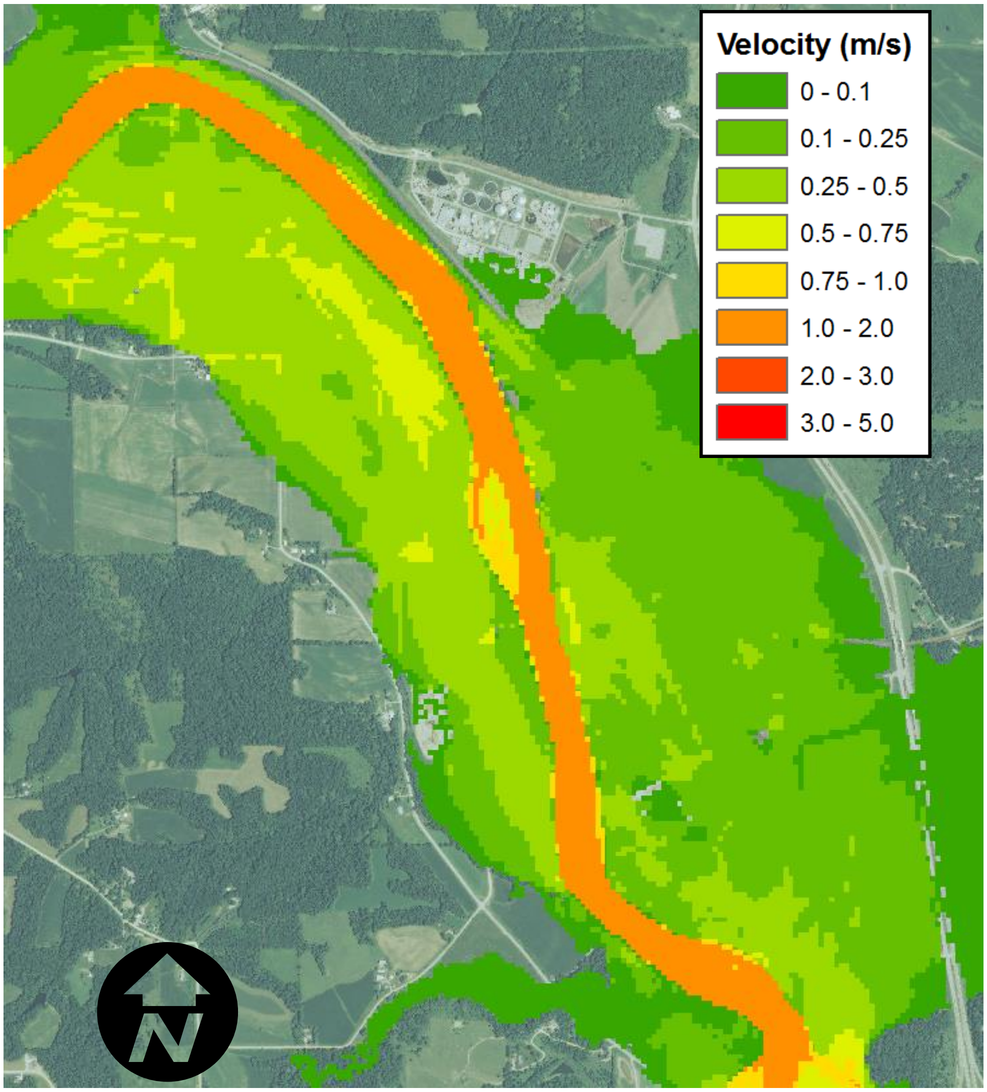


Figure 68: Mike21 2D velocity raster - Section 2

Figure 65, Figure 66, Figure 67, and Figure 68 show that there is a discrepancy in the velocity magnitudes between the 1D and 2D models by a factor of approximately 1.5. This discrepancy occurs because the flow rate and roughness are the same for both models, but the 2D model is showing higher depths due to the reasons discussed previously in Sections 5.3 and 5.4. The 2D model should be showing lower velocities than the 1D model to preserve continuity because the effective flow area is higher for the 2D model and the flow rate and roughness is the same. The depths should agree better in most reaches where fewer overpasses and flow obstructions are present, so it is not a major concern that velocity magnitudes are off by a factor of 1.5 in this model. The main purpose of this comparison is to assess how well the velocity spatial distribution agrees between the cell-by-cell methods and the 2D model. The scale was changed on the 2D results so that their spatial distribution could be better compared to the cell-by-cell method results, as is shown in Figure 69 and Figure 70.

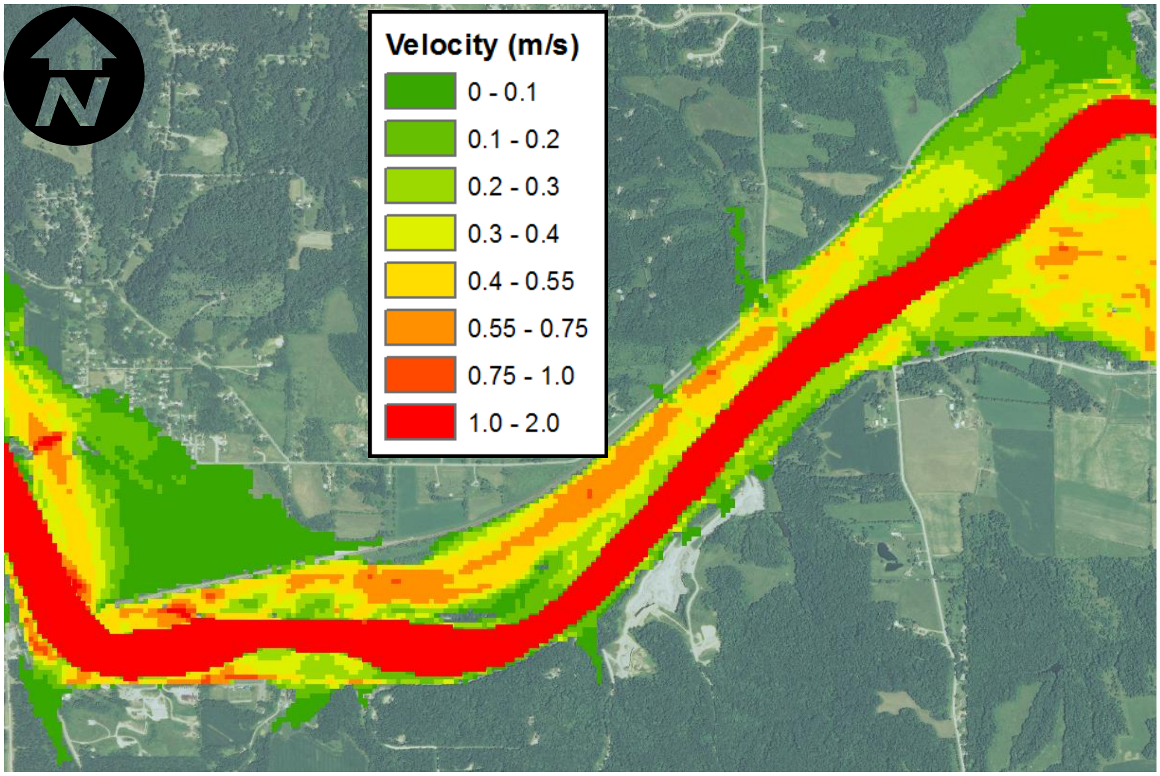


Figure 69: Mike21 2D velocity raster with different scale - Section 1

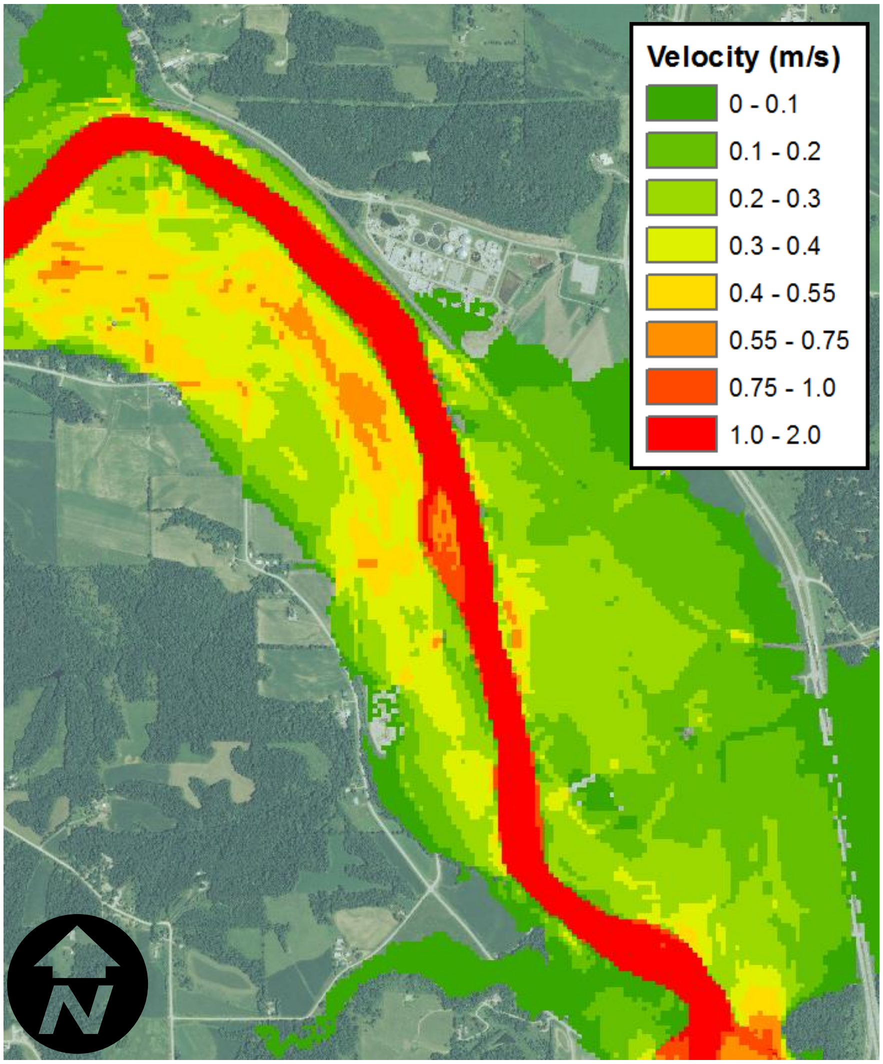


Figure 70: Mike21 2D velocity raster with different scale - Section 2

Figure 65, Figure 66, Figure 69, and Figure 70 show that the spatial distribution of velocity appears to be fairly similar in most areas. Areas of high and low velocity generally agree between the two models. This spatial agreement is good considering the number of assumptions that went into the cell-by-cell method. There are a few areas where a clear problem exists with the cell-by-cell method velocity. These problems are due to the limitations with the 1D HEC-RAS input data. Figure 71 shows the complete cell-by-cell model results and highlights the areas where velocity does not agree well with the 2D model.

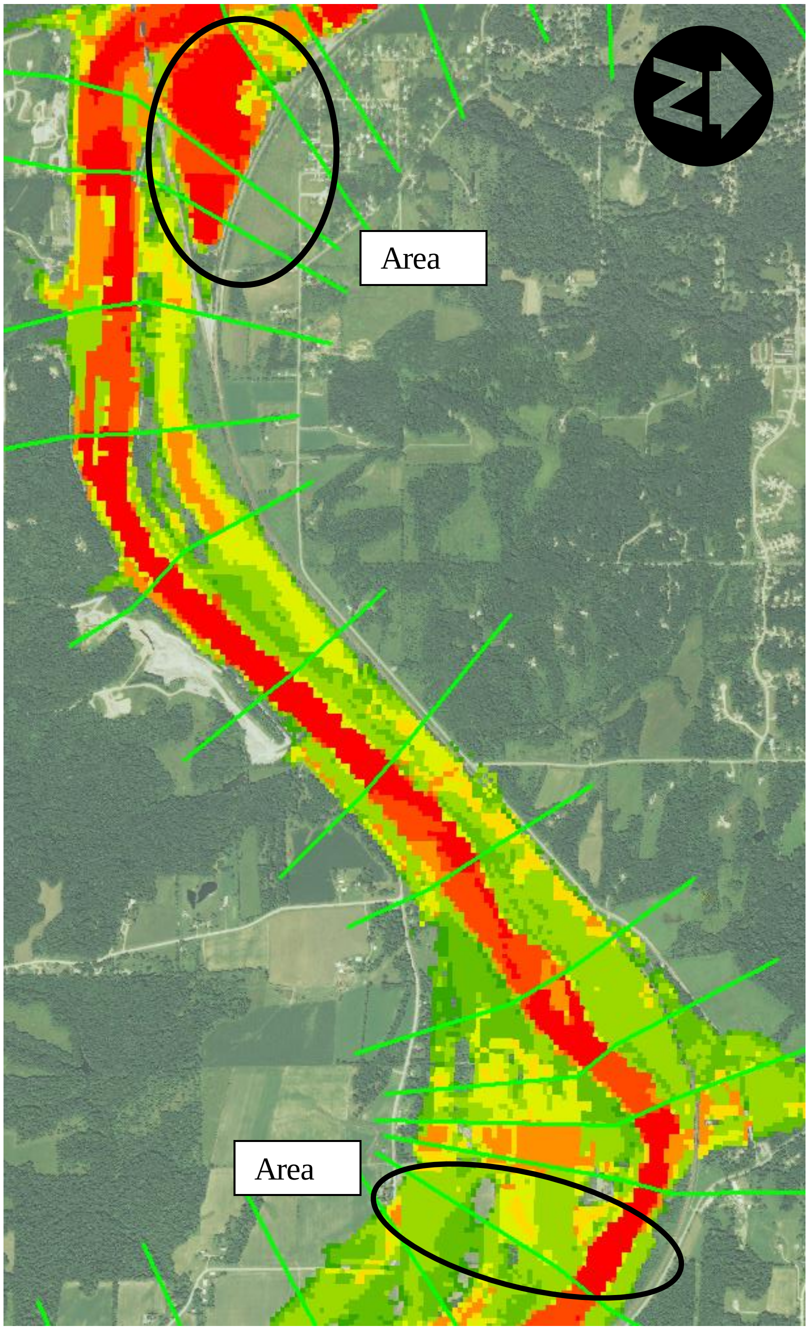


Figure 71: Cell-by-cell method velocity problem areas. Area 1 is showing unrealistically high velocity in an ineffective flow area. Area 2 is showing cell-by-cell method velocities much lower than the 2D Mike21 model velocities, indicating loss of continuity

The cell-by-cell method velocities are far too high in Area 1 because this area is normally a pond with a road obstructing flow downstream from it. The 2D model accounts for this obstruction, but the 1D HEC-RAS model does not, so the 1D slope does not reflect it. The user would be able to visually identify this area as inaccurate and discount the values.

Area 2 is an area where spatial agreement between the cell-by-cell model and 2D Mike21 model is poor due to loss of continuity. The depth rasters show that there is a decrease in flow area in this area. Area 2 is in-between HEC-RAS cross-sections, so the 1D water surface elevation data do not reflect this decrease in flow area. The slope is constant and doesn't reflect the contraction, so depth decreases. This causes the cell-by-cell method to predict lower velocities, whereas velocity should actually increase in this area. Section 5.8 will look at Area 2 more quantitatively.

The 1D cell-by-cell method velocity raster is divided by the 2D Mike21 raster to display agreement between magnitude and spatial distribution, as shown in Figure 72. The cell-by-cell method velocities are, on average, higher than the 2D velocities due to the differences in depth between the two models. This map further demonstrates that the velocity distribution tends to agree better in areas where the channel is more uniform and straight between HEC-RAS cross-sections. The 1D cell-by-cell method velocities are less than a factor of 1.5 away from the 2D Mike21 velocities in the majority of areas.

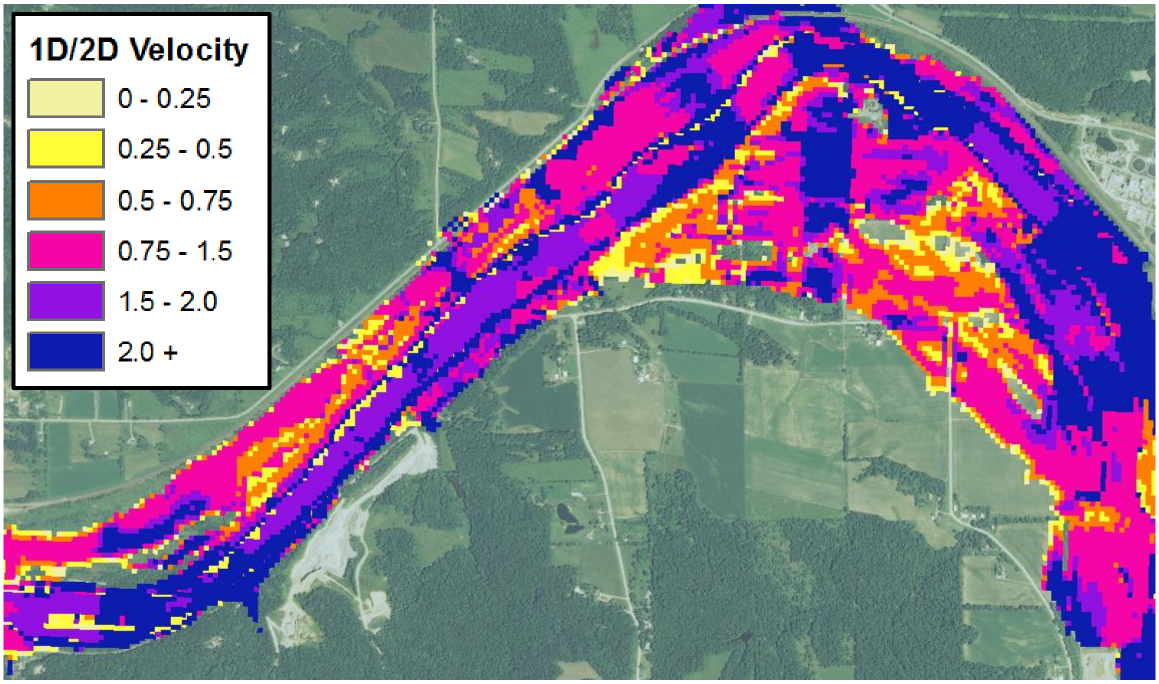


Figure 72: 1D cell-by-cell method velocity divided by 2D Mike21 velocity raster

Figure 73 shows a histogram of the raster shown in Figure 72. This histogram shows that around 1/3 of the cells have cell-by-cell method velocity values within a factor of 1.5 of the 2D Mike21 velocity values. There are some cells that have a 1D/2D velocity ratio well over 3, but these cells occur in backwater and other areas where the cell-by-cell method is not expected to work well due to limitations with the 1D input data. This thesis is most interested in general areas of high velocity or shear. The histogram in Figure 73 only demonstrates how well individual cells agree but does not fully demonstrate how well larger areas of high and low velocity spatially agree. Comparing general spatial agreement between high and low velocity areas is best accomplished visually by looking at Figure 65 through Figure 70.

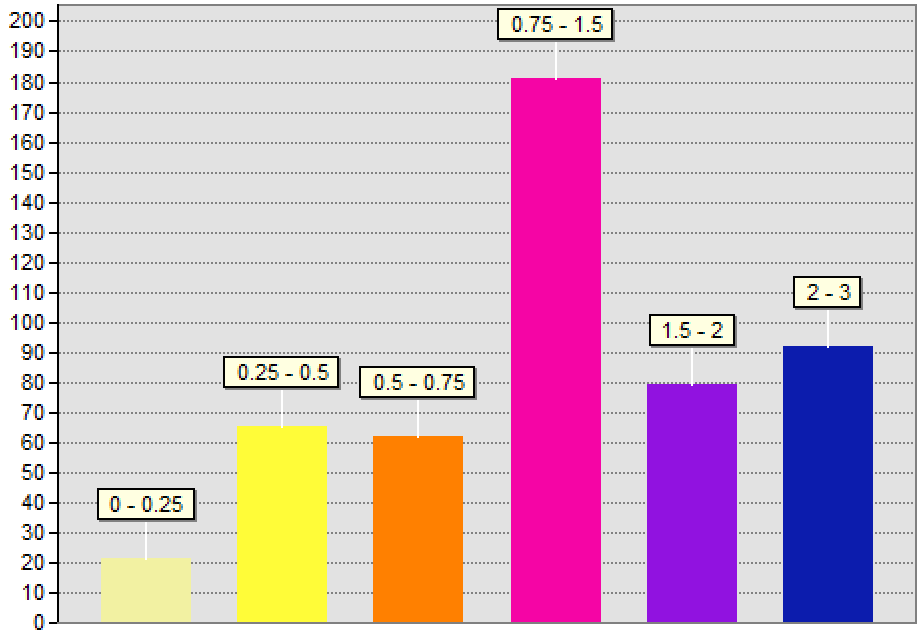


Figure 73: 1D cell-by-cell method velocity divided by 2D Mike21 velocity histogram

5.4.2. Cell-by-Cell vs. 2D Mike21 Velocity: Iowa City Model

Figure 74 and Figure 75 show the cell-by-cell method and Mike21 2D velocity results, respectively, for a section of the Iowa City model. The velocity spatial distribution agreement between the two models is a bit worse in this area than in most areas of the Cedar Rapids model because the channel is very wide and not uniform. The cell-by-cell method still does a decent job of predicting general areas of higher velocity. The areas where the cell-by-cell method predicts high velocity generally agree with the areas where the 2D model predicts high velocity; these areas are circled in Figure 74. The cell-by-cell method velocity is high in some areas that are clearly ineffective flow areas due to limitations with the 1D slope. Wide and shallow floodplains such as this will generally have more ineffective flow areas and variability in-between the HEC-RAS cross-sections. The user will need to be knowledgeable enough to recognize areas where results are likely wrong and discount them.

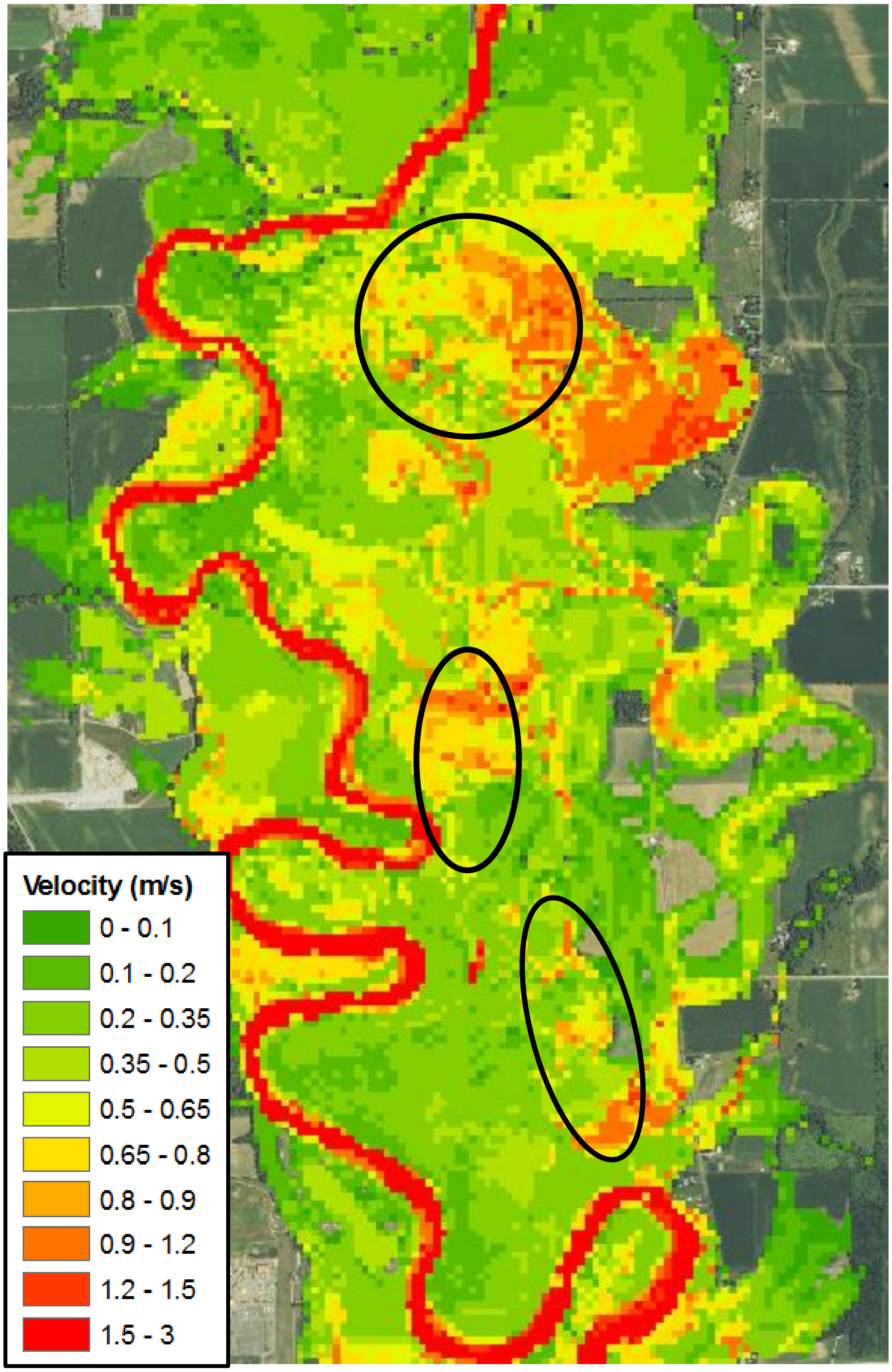


Figure 74: Cell-by-cell method velocity raster

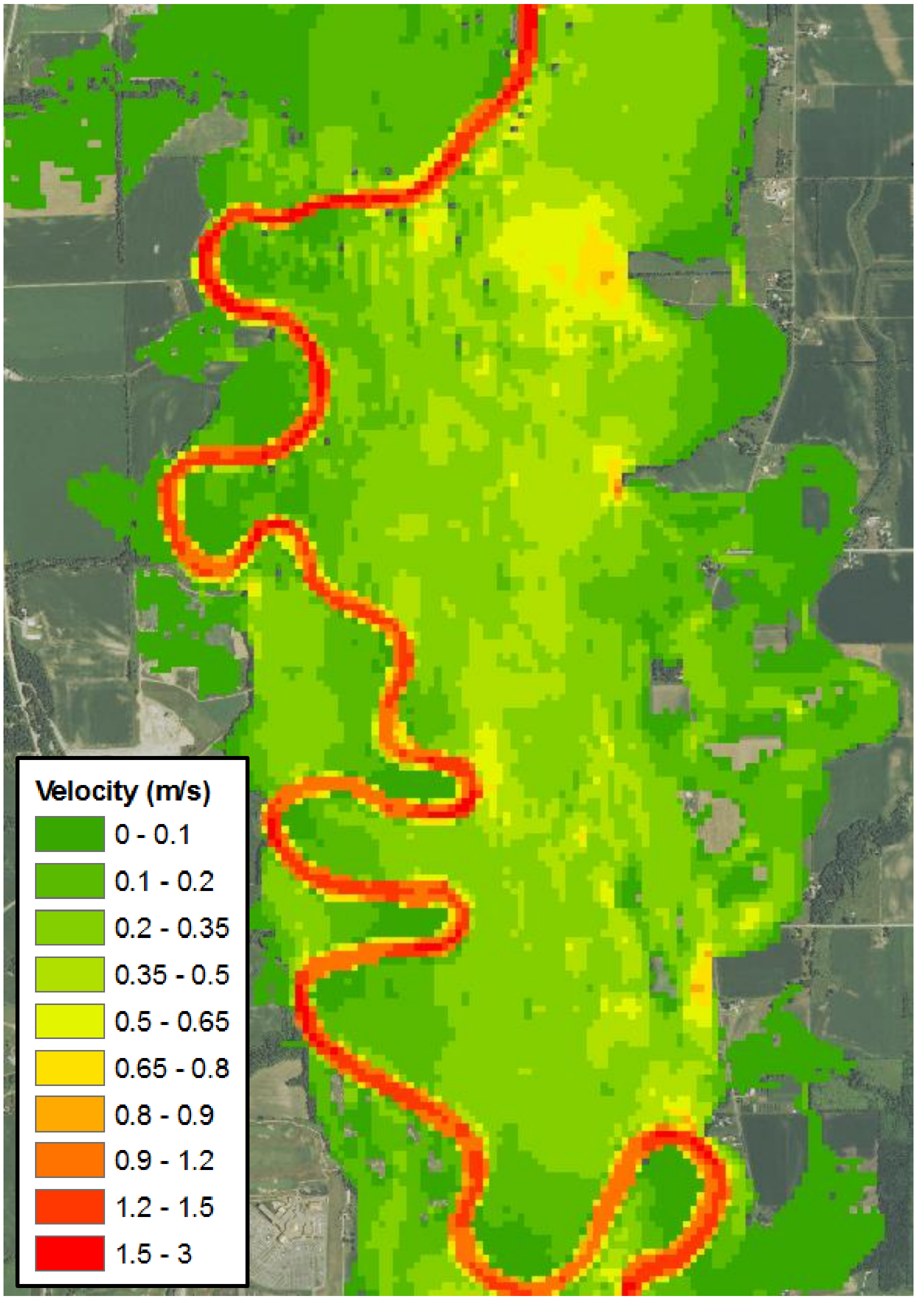


Figure 75: Mike21 2D velocity raster

Figure 76 shows the cell-by-cell method velocity raster divided by the 2D Mike21 velocity raster, and Figure 77 shows the histogram. Figure 76 shows that the cell-by-cell method generally predicts velocity magnitudes well in the center of the floodplain channel but tends to over predict velocity values in low flow and ineffective flow areas near the edges of the floodplain due to the 1D slope limitations discussed previously. The limitation of constant slopes in-between HEC-RAS cross-sections seems to have a more significant negative impact on results when the floodplain is very wide and shallow, as it is in this area.

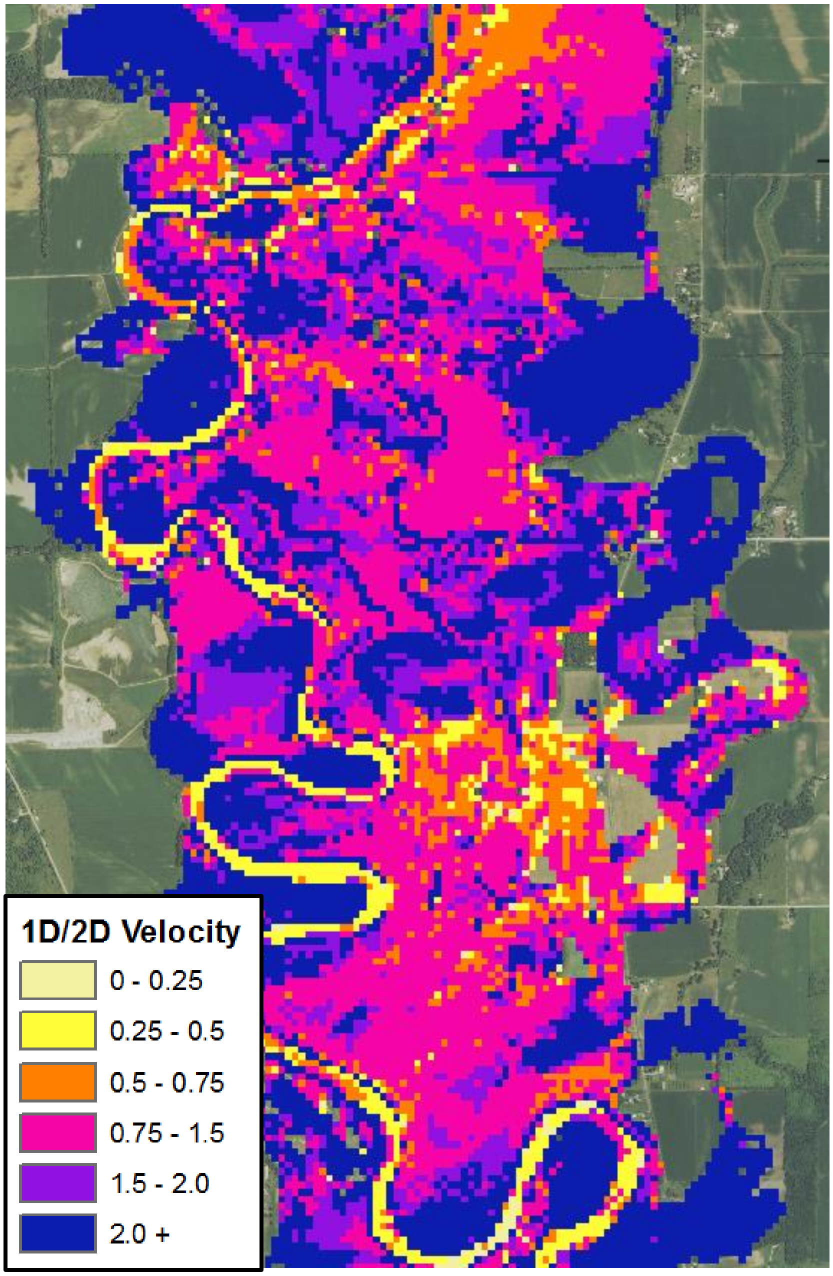


Figure 76: 1D Cell-by-cell method velocity divided by 2D Mike21 velocity raster

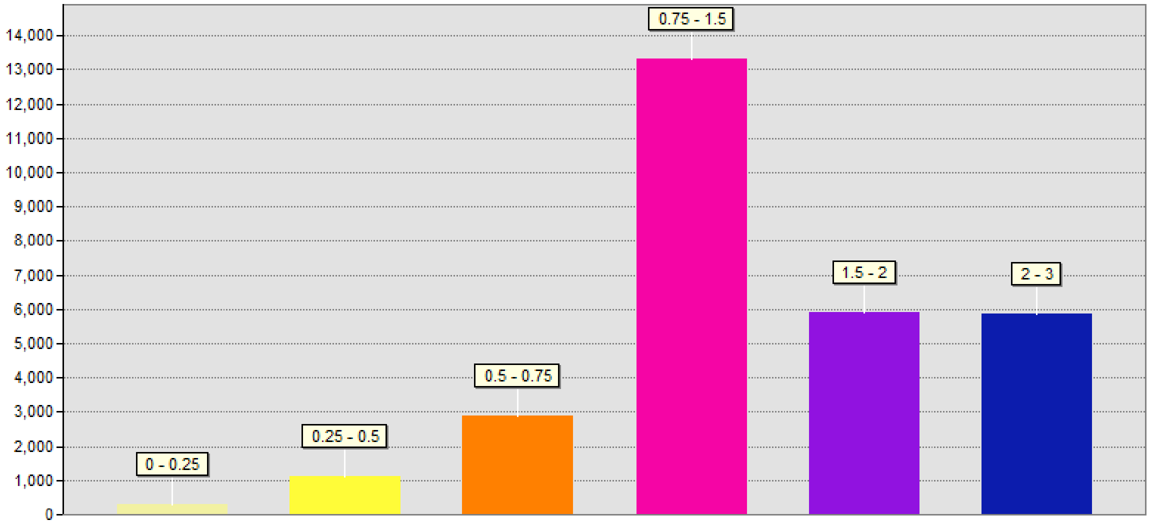


Figure 77: Histogram for cell-by-cell velocity divided by Mike21 2D velocity

5.4.3. Cell-by-Cell Method Velocity Conclusions

It is clear that the cell-by-cell method works better in areas where the channel is relatively straight and uniform in-between the upstream and downstream cross-sections. This is expected because the cell-by-cell method uses uniform open channel flow equations. Errors can result where there are significant changes in channel area or roughness in-between the HEC-RAS cross-sections, but it is usually possible to visually identify areas where errors are most likely to occur. The spatial distribution of high and low velocity areas generally agrees well between both the Cedar Rapids and Iowa City cell-by-cell and 2D models, but it is better in the Cedar Rapids model because the floodplain is closer to uniform flow than the Iowa City model floodplain.

5.5. Cell-by-Cell Method Effective Shear

The effective shear is the portion of the bed shear that acts on erodible soil particles. The cell-by-cell method “Effective Shear – Field n = 0.03” tool was run using the Cedar Rapids and Iowa City HEC-RAS model results as inputs. The “Effective Shear –Field n = 0.03– Bed Shear Input” tool was run using the Mike21 2D bed shear raster as an input with the assumption that the uniform flow effective shear equation, soil grain roughness, and cover factor corrections could be applied to the 2D bed shear in the same way they are applied to the 1D bed shear.

5.5.1. Cell-by-Cell vs Mike21 2D Effective Shear: Cedar Rapids Model

Figure 78 and Figure 79 show the Cedar Rapids model effective shear raster results from the cell-by-cell method separated into two sections. Figure 80 and Figure 81 show the effective shear results from the 2D Mike21 model separated into two sections. The same scale is used for both figures to visually display how well the effective shear magnitudes agree between the two models. The 2D model does not have results for the main channel. The flow direction is from West to East in this model.

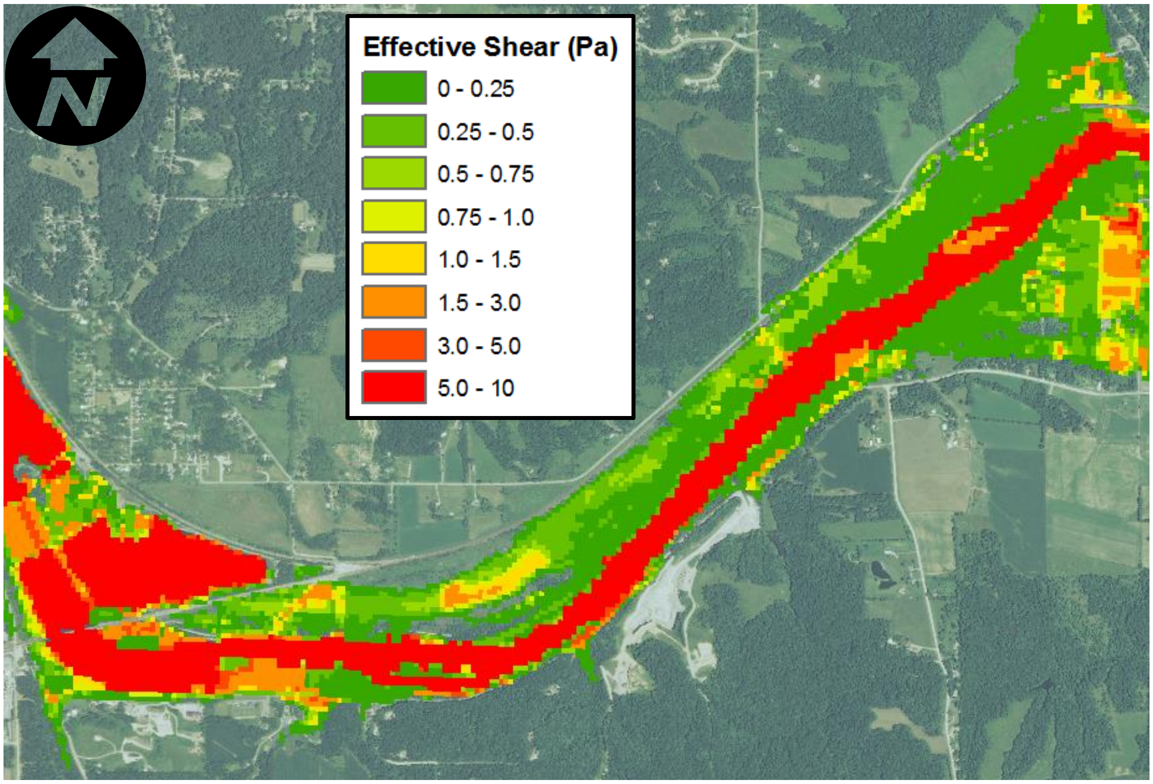


Figure 78: Cell-by-cell method effective shear raster - Section 1

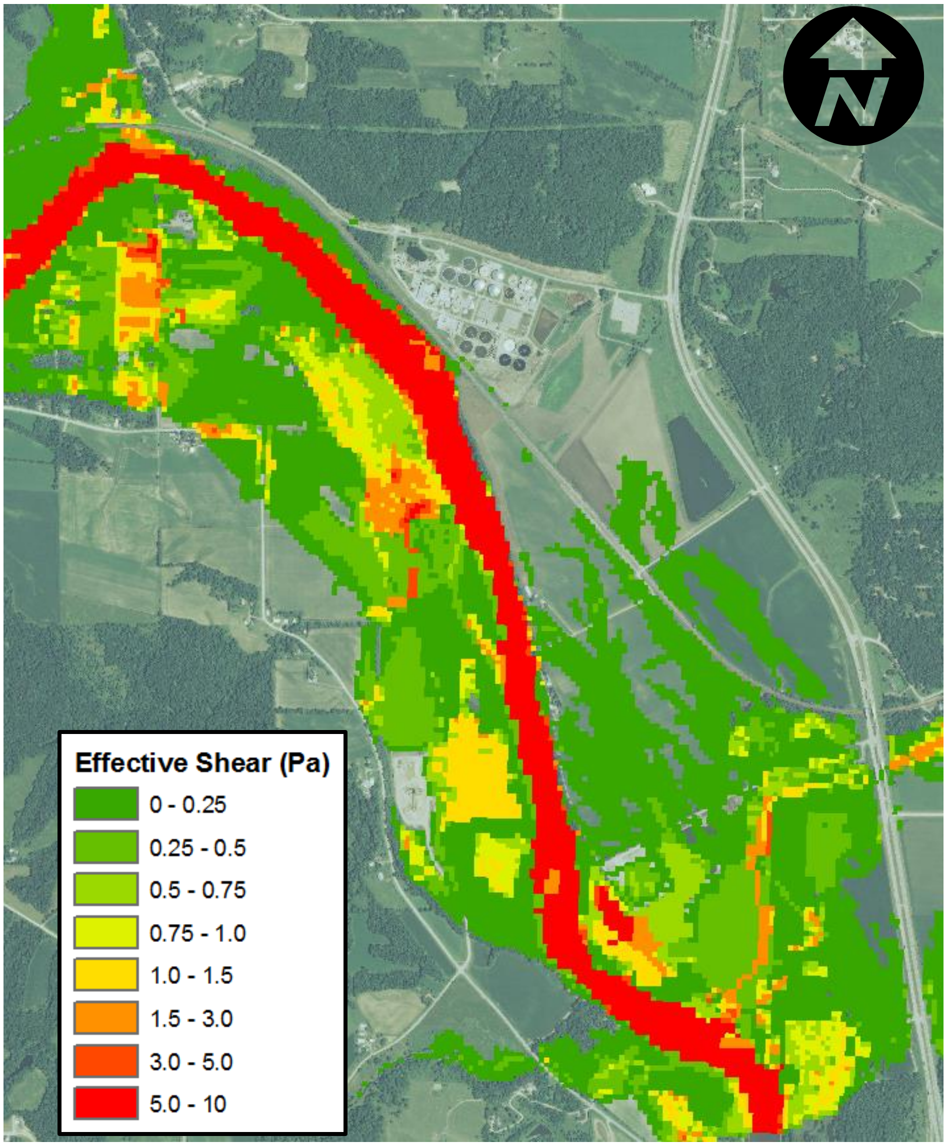


Figure 79: Cell-by-cell method effective shear raster - section 2

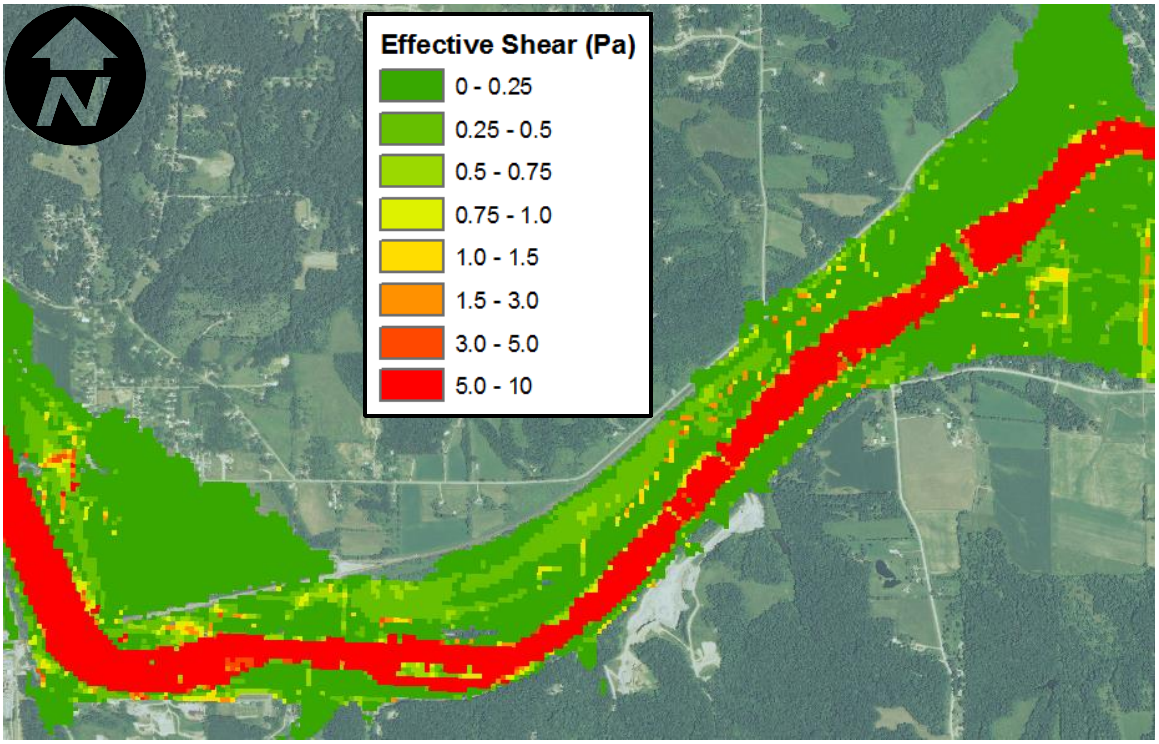


Figure 80: Mike21 2D effective shear raster - Section 1

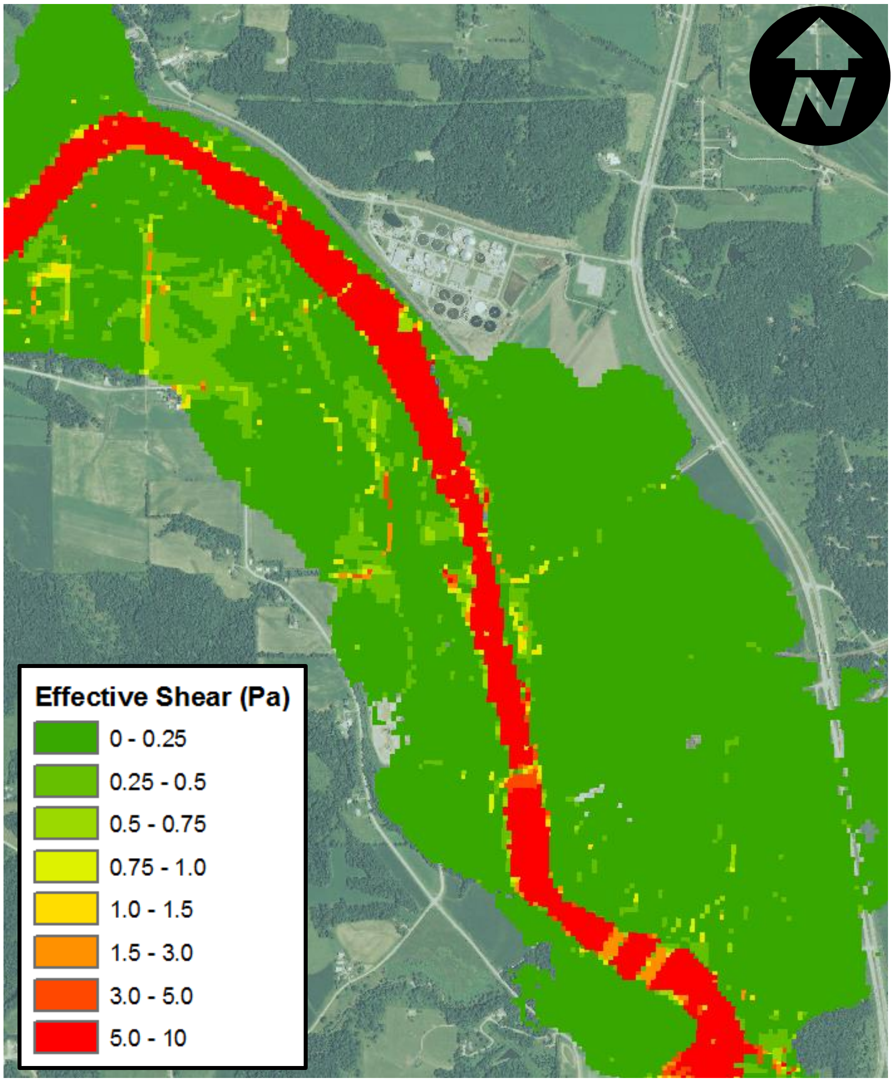


Figure 81: Mike21 2D effective shear raster - Section 2

Figure 78, Figure 79, Figure 80, and Figure 81 show a discrepancy in the effective shear magnitudes between the 1D and 2D models. This discrepancy is because the flow rate and roughness are the same for both models, but the 2D model shows higher depths due to reasons discussed previously in Sections 5.3 and 5.4. The 2D model should show lower effective shear than the 1D model because the 2D model shows lower velocities. The depths should agree better in most reaches with fewer overpasses and flow obstructions, so it is not a major concern that effective shear magnitudes are off in this model. The scale was changed on the 2D effective shear results so that their spatial distribution could be better compared to the cell-by-cell method results, as is shown in Figure 82 and Figure 83.

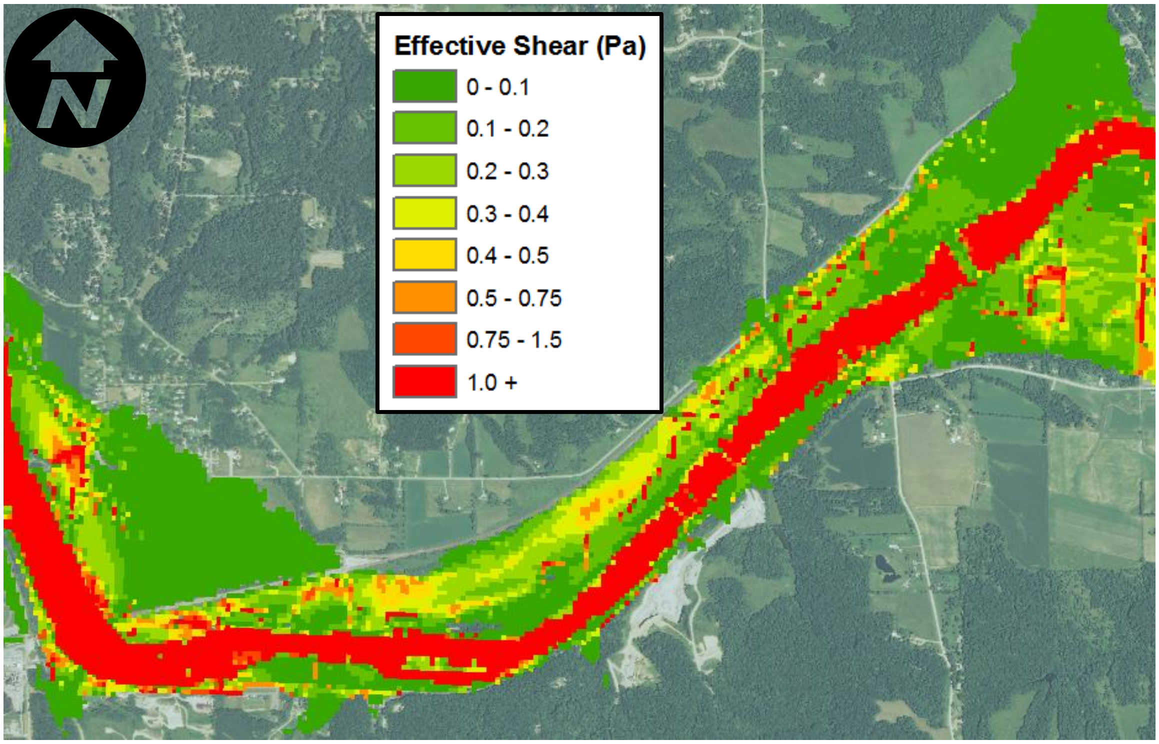


Figure 82: Mike21 2D effective shear raster - Section 1 - Different scale from cell-by-cell method

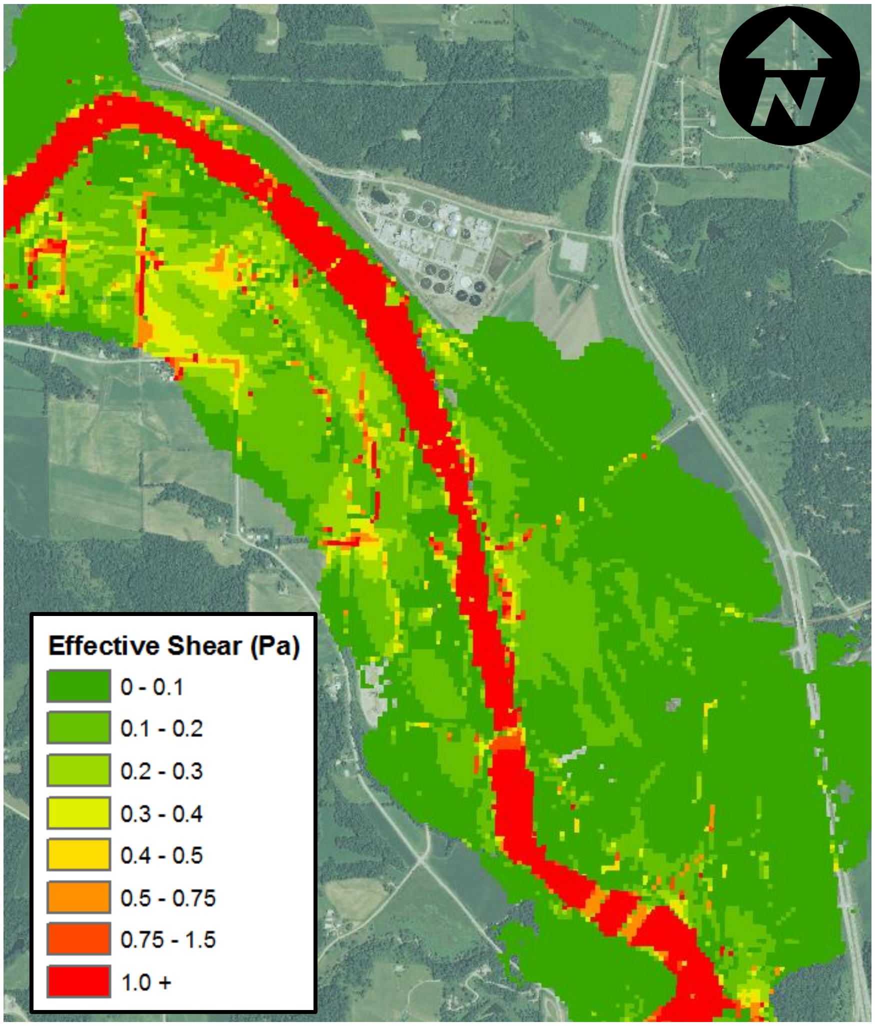


Figure 83: Mike21 2D effective shear raster - Section 2 - Different scale from cell-by-cell method

Figure 78, Figure 79, Figure 82, and Figure 83 show that the spatial distribution of effective shear appears to be similar in most areas. Areas of high and low effective shear generally agree between the two models. This spatial agreement is good considering the number of assumptions that went into the cell-by-cell method. The same areas that had obvious errors with the cell-by-cell velocity results also show unrealistic effective shear values. The cause of errors in these areas is the same for both velocity and shear.

Figure 84 and Figure 85 show the cell-by-cell method effective shear raster divided by the Mike21 2D effective shear raster. The cell-by-cell effective shear is around two to three times higher than the Mike21 effective shear in most areas due to the previously discussed differences in depth between the 1D and 2D models. This map shows that the cell-by-cell method effective shear is consistently the same amount higher than the Mike21 effective shear in most areas of high shear areas, indicating decent spatial agreement. The circled areas show higher effective shear in in the 2D model than the cell-by-cell model. These areas are likely experiencing loss of continuity in the cell-by-cell model, and their effective shear values could be improved by using the SCA method.

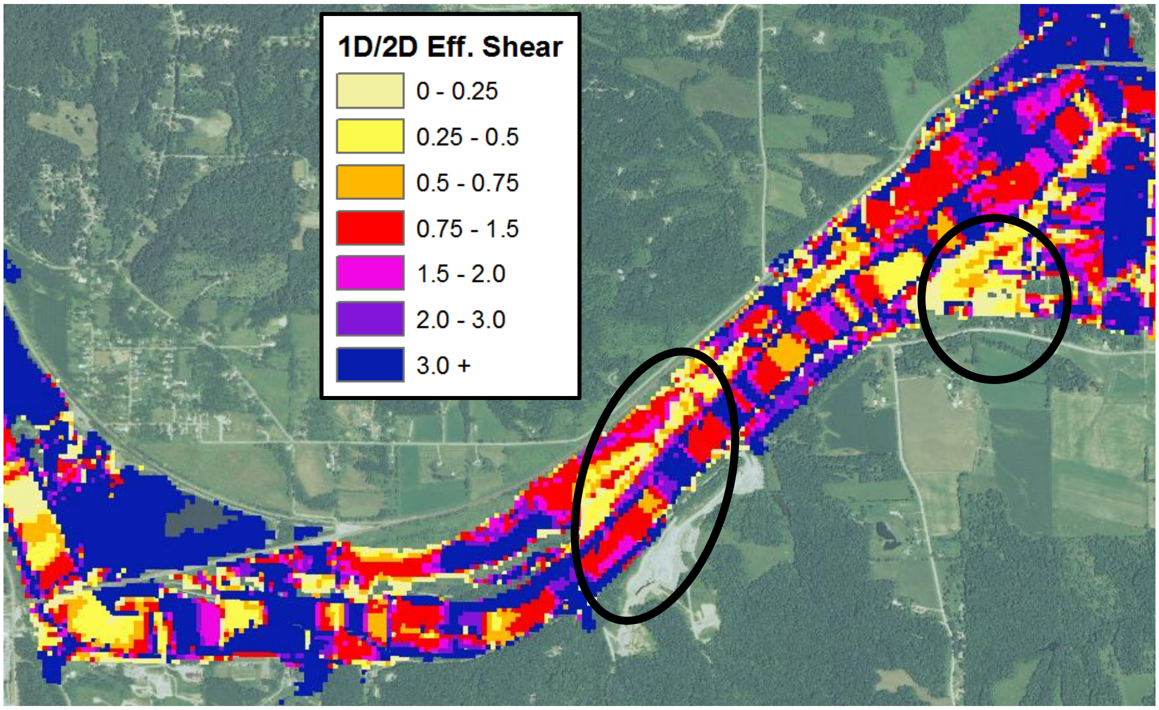


Figure 84: Cell-by-cell effective shear divided by Mike21 2D effective shear raster - Section 1

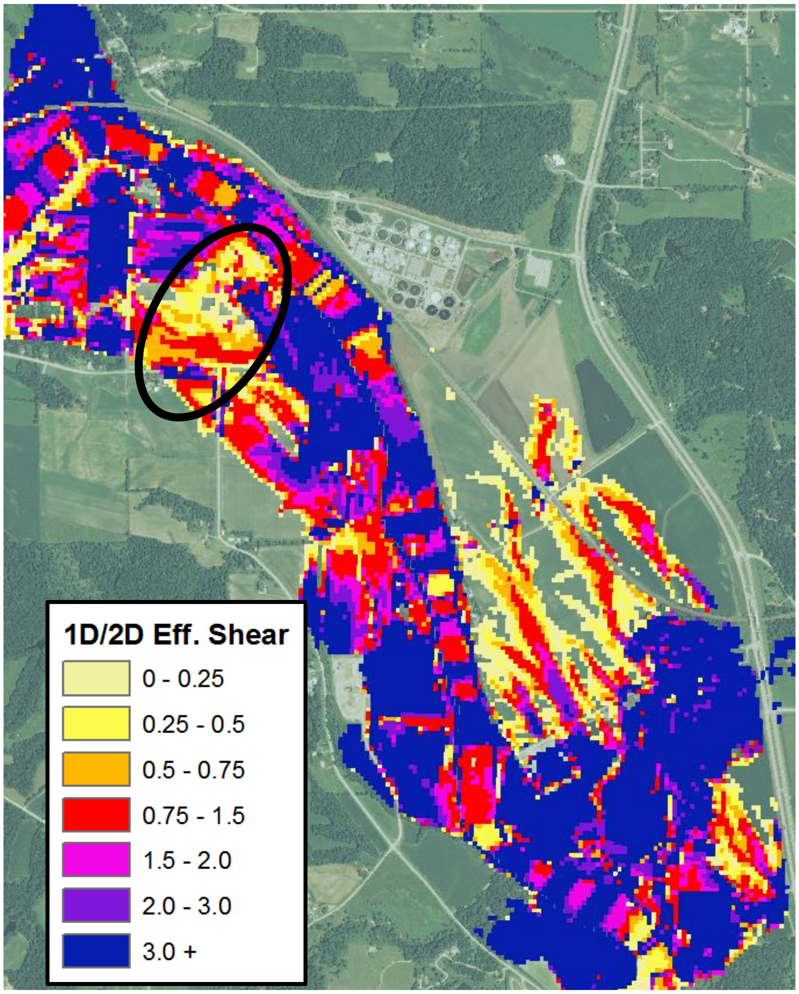


Figure 85: Cell-by-cell effective shear divided by Mike21 2D effective shear raster - Section 2

5.5.2. Cell-by-Cell vs Mike21 2D Effective Shear: Iowa City Model

Figure 86 and Figure 87 show the cell-by-cell method and Mike21 2D effective shear, respectively, for a section of the Iowa City model. These figures demonstrate a good agreement between magnitude and spatial distribution of the effective shear values. The spatial agreement seems to be better for effective shear than for velocity, likely because the effective shear is based largely on the cover factor and Manning's n correction factors obtained from the land cover data. This land cover data are the same for both the cell-by-cell and Mike21 2D models because the Mike21 2D model only outputs bed shear.

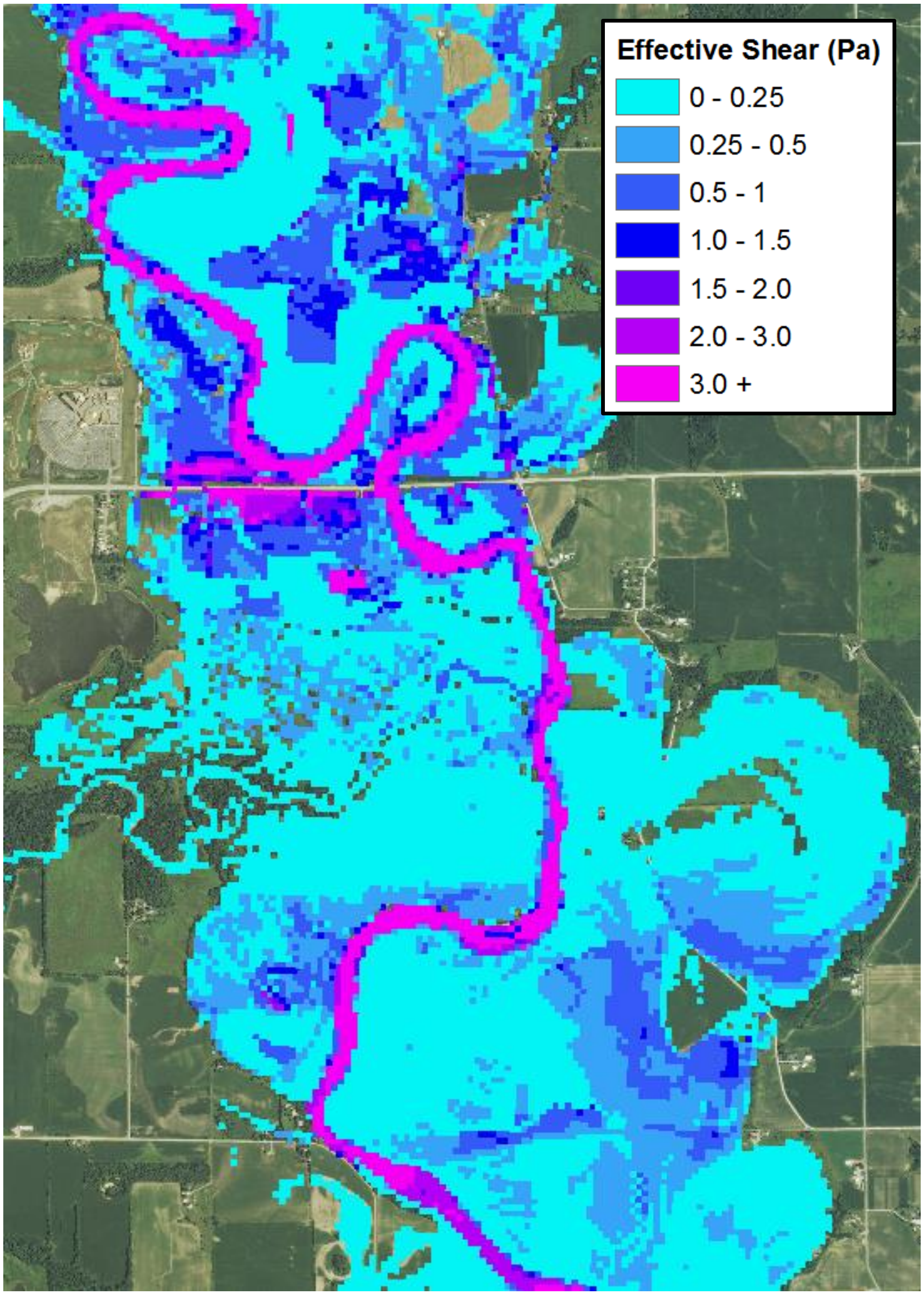


Figure 86: Cell-by-cell method effective shear raster

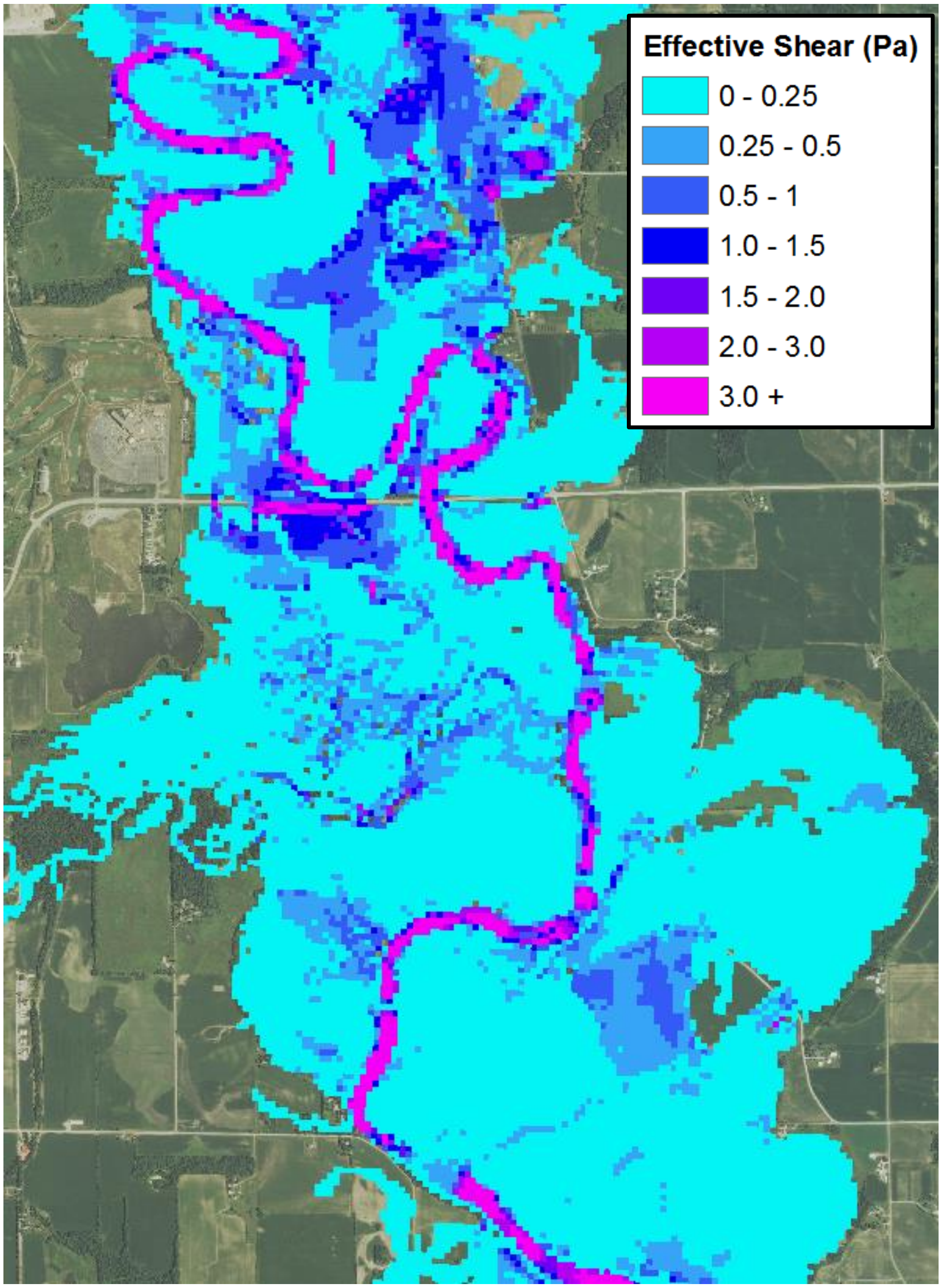


Figure 87: Mike21 2D effective shear raster

Figure 88 shows the cell-by-cell effective shear divided by the Mike21 2D effective shear, and Figure 89 presents the histogram for this map. These figures further demonstrate that the cell-by-cell method is better in the center of the channel and worse near the edges when a floodplain is very flat and wide, because there are more ineffective flow areas and obstructions near the edges of the channel.

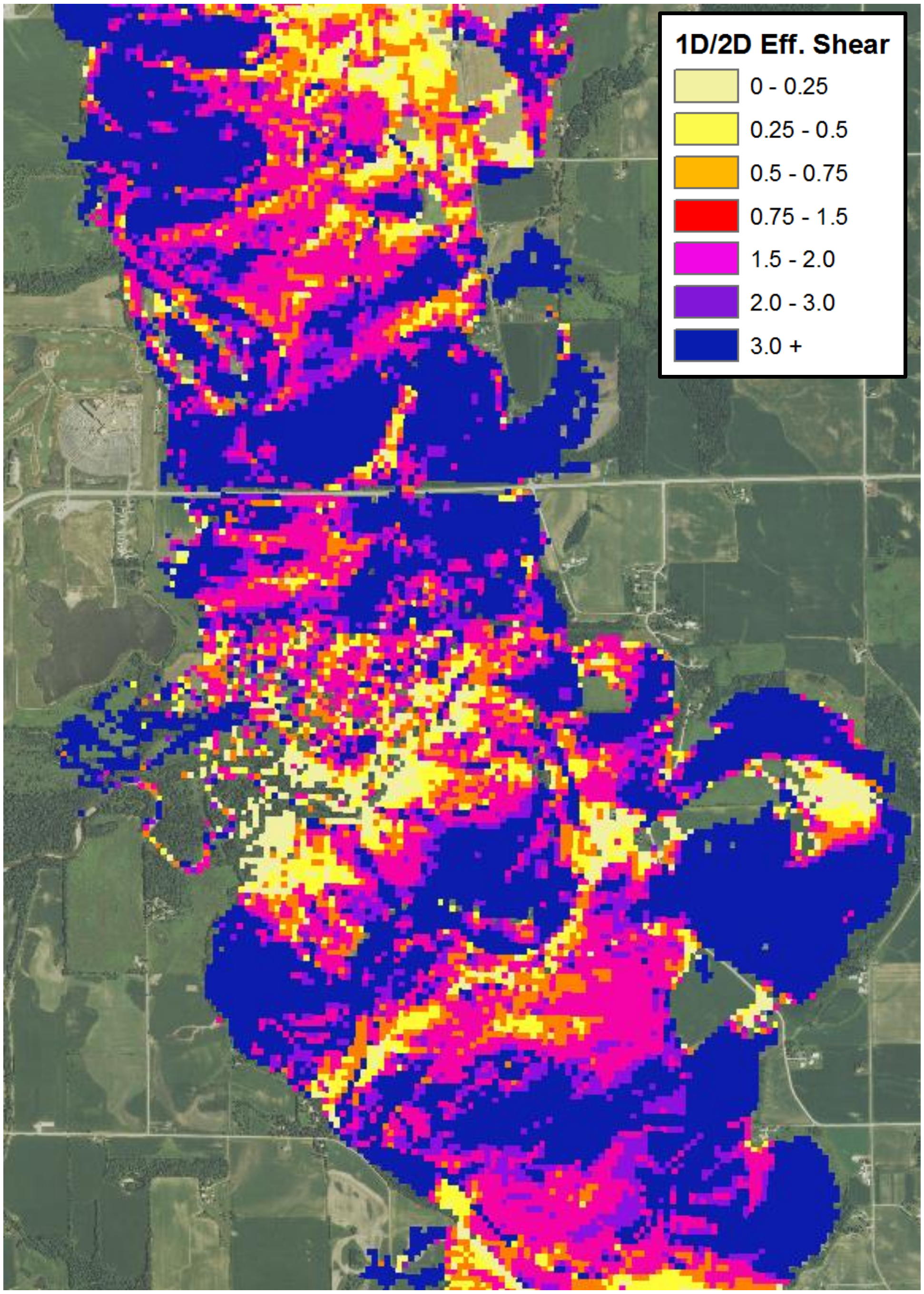


Figure 88: Cell-by-cell effective shear divided by Mike21 2D effective shear raster

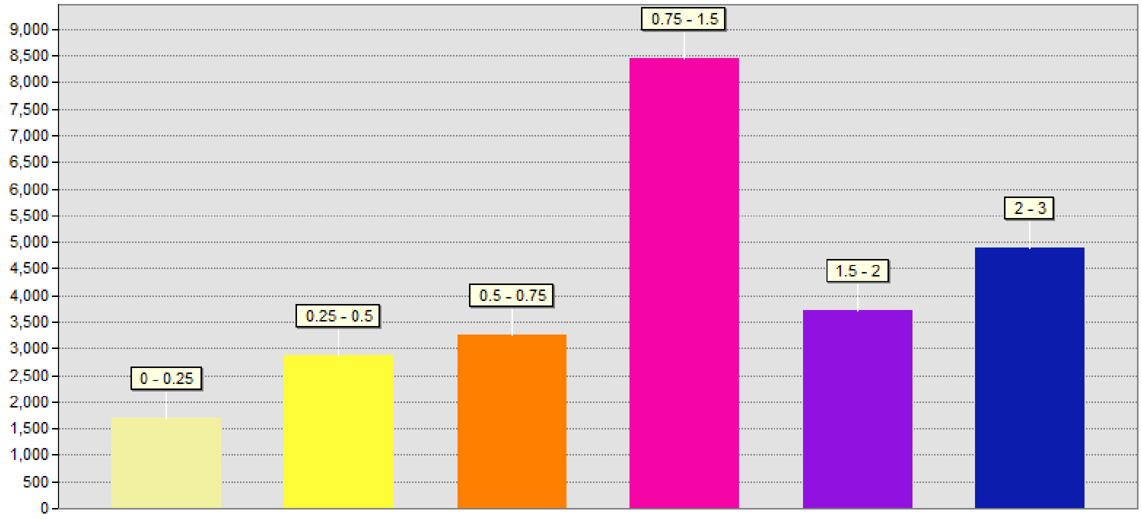


Figure 89: Histogram for cell-by-cell effective shear divided by 2D effective shear

5.5.3. Cell-by-Cell Effective Shear Conclusions

The spatial agreement between the cell-by-cell and Mike21 models seems to be better for effective shear than for velocity, especially with the Iowa City model, because the effective shear largely depends on land cover data which is the same for both the cell-by-cell and Mike21 models. Both the cover factor and Manning's n parameters of the effective shear equation are the same both the cell-by-cell method and Mike21 2D model. This means that three out of the five variables, assuming Manning's n counts as two variables because it is squared, are dependent on the NLCD instead of the 1D HEC-RAS model. The fact that effective shear depends largely on land cover data means that the accuracy of the effective shear results depend heavily on the statewide NLCD in addition to the cell-by-cell method developed for this thesis. The cell-by-cell method appears to be capturing almost all areas of high effective shear, but it does also show unrealistically high shear in some areas due to limitations with the 1D source data. A knowledgeable user should be able to visually identify most areas where the maps are showing unrealistic effective shear values.

5.6. Cell-by-Cell Excess Shear Ratio

The spatial agreement between the cell-by-cell method and Mike21 2D excess shear ratio maps is good, which is partly because both are based on the same allowable shear dataset. The excess shear ratio maps are created by dividing the effective shear by the allowable shear. The excess shear ratio results depend on the SSURGO database derived allowable shear values in addition to the NLCD derived cover factor and roughness values. The excess shear ratio results depend even further on statewide spatial data, with four out of the six variables being dependent on statewide datasets and only two variables originating from the 1D HEC-RAS model. A 2D model will offer more accurate excess shear ratio results when it is based on the same land cover data as is used in the 1D model, but there will be a lot of similarity between the two methods. Figure 90 shows the excess shear ratio for the cell-by-cell Iowa City model, and Figure 91 shows the excess shear ratio for the Mike21 2D Iowa City model.

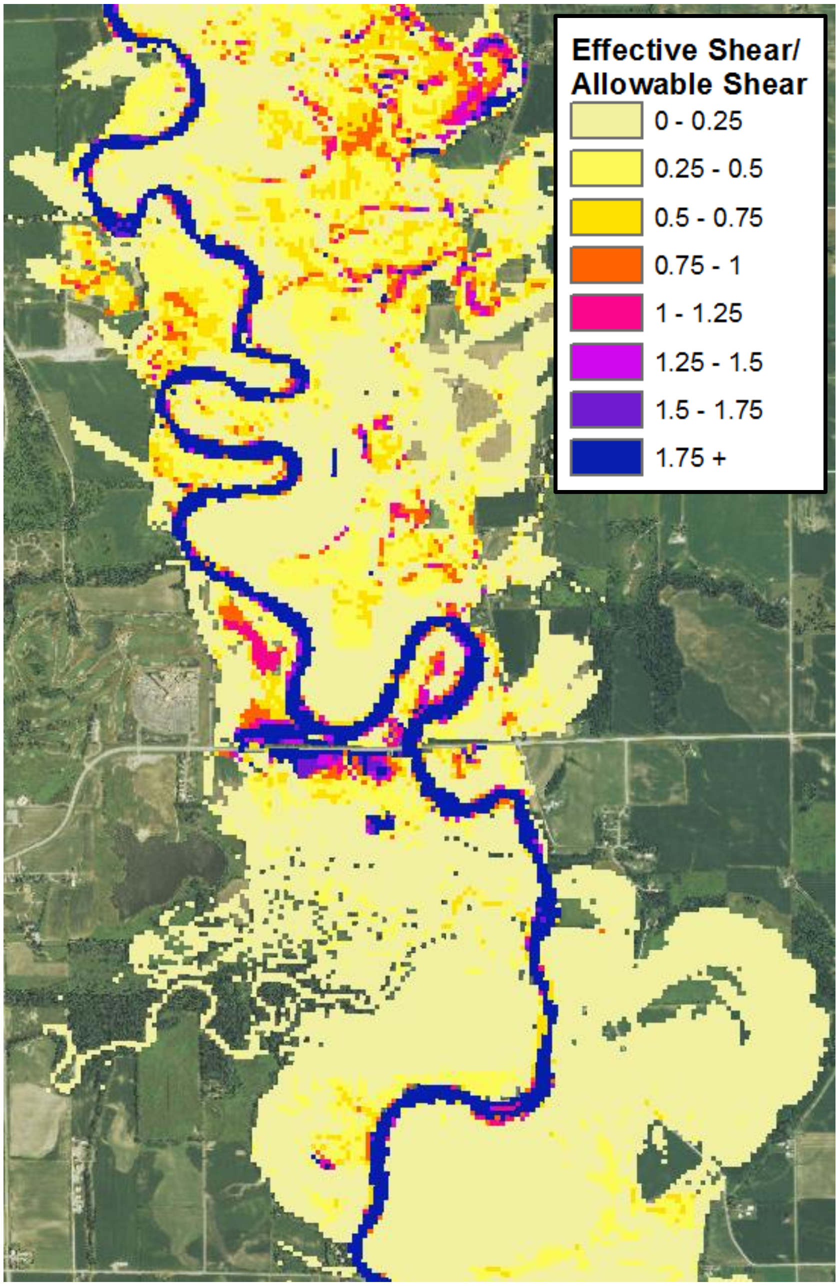


Figure 90: Cell-by-cell excess shear ratio raster

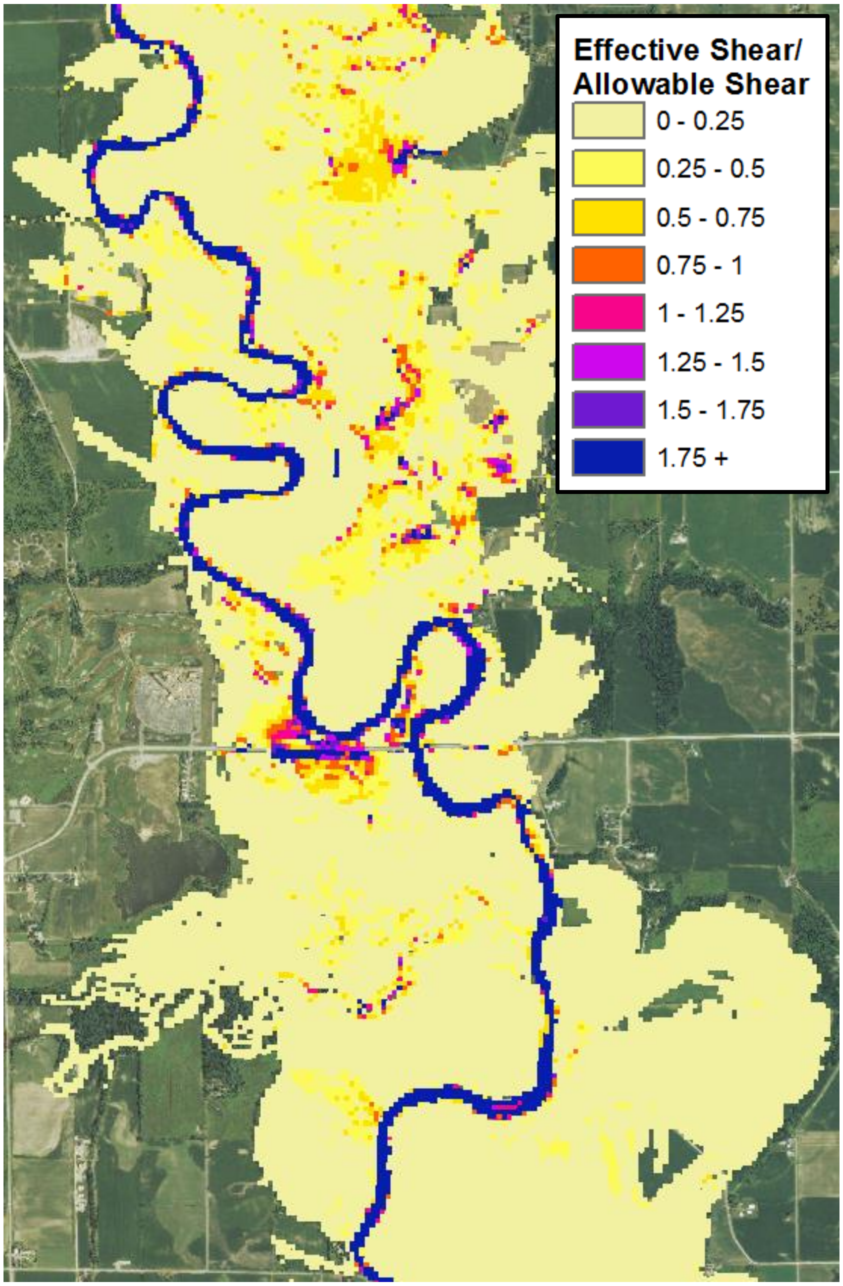


Figure 91: Mike21 2D excess shear ratio raster

5.7. Cell-by-Cell Method Conclusions

Based on comparison with the 2D model results, the cell-by-cell method appears to be producing maps that will be capable of identifying general areas of high scour potential. These maps could be used for course land management decisions or targeting areas that might warrant a more detailed study. The constant 1D slope data are the primary cause of limitations with the cell-by-cell method. The 1D slope data can cause unrealistic values in backwater areas and loss of continuity. The cell-by-cell method becomes less effective as channel uniformity decreases due to the approximately constant water surface slopes. Narrower and deeper floodplains will most likely have better results than floodplains where flow is very wide and shallow. The accuracy of the excess shear ratio maps created by the cell-by-cell method depends largely on the NLCD and SSURGO datasets in addition to the 1D HEC-RAS data.

If high precision spatial shear information is required, a 2D model should be used over the cell-by-cell method. The 2D models that are based off the statewide land cover and allowable shear datasets are better than the cell-by-cell method, but not by a significant amount in most areas because they are relying on much of the same land cover input data. The 2D model would not have errors such as high shear readings in backwater areas because it is not limited by the water surface slope data. A detailed site study would likely have to be done to obtain land cover data that could result in a 2D model being significantly better than the cell-by-cell method.

The cell-by-cell method provides a cost effective alternative to 2D modeling when high precision is not required or large areas need to be modeled. If high precision is required, the cell-by-cell method could still be used as a first pass targeting tool to identify areas to that warrant more costly detailed studies.

5.8. SCA Methods

5.8.1. Cross-Sectional Area Calculation Verification

The effectiveness of the SCA method largely depends on how well it can predict the area of a cross-section. The assumption also has to be made that the average flow is perpendicular to the cross-section, that there are no non-effective flow areas in the cross-section, and that the 1D depth is accurate. Significant ineffective flow areas should be manually removed prior to running the SCA tools.

All SCA method tools create a cross-section and determine its area to calculate the flow rate predicted by the cell-by-cell method. The cross-sectional area computing the ability of the SCA method was tested by creating SCA method cross-sections at the same location as HEC-RAS cross-sections. The area of the SCA method cross-sections was then compared to the area of the corresponding HEC-RAS cross-section. Figure 92 shows an example of how the SCA cross-sections lined up with the HEC-RAS cross-sections. The SCA method was run at 12 different HEC-RAS cross-sections.

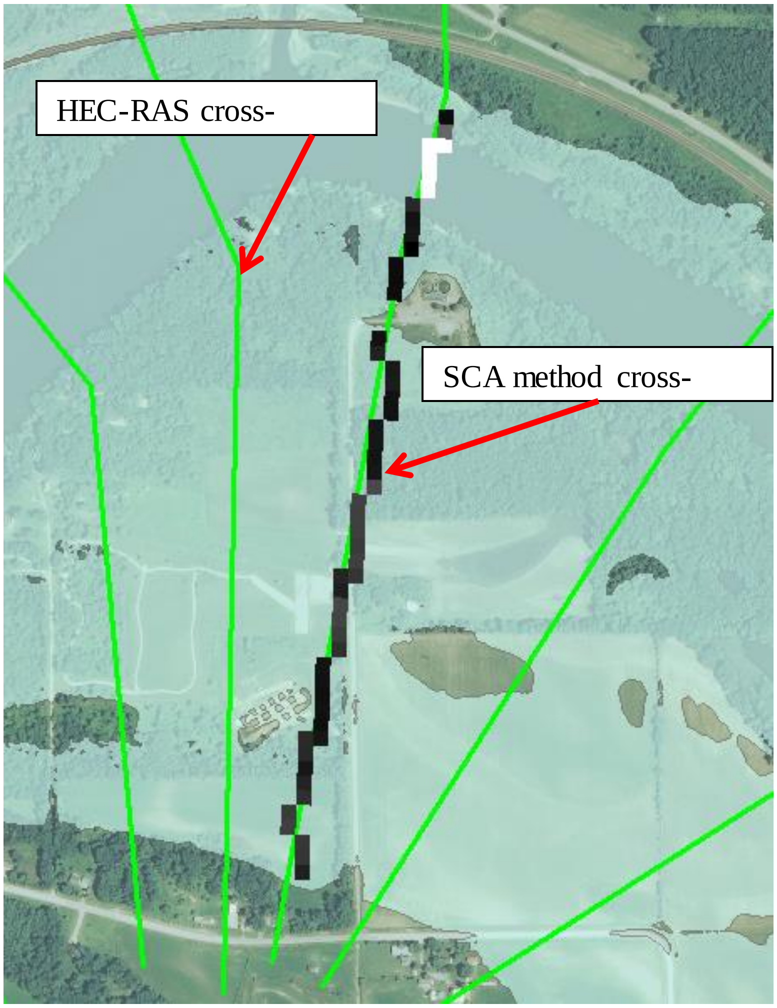


Figure 92: Example of SCA method cross-section raster near HEC-RAS cross-section

The computed areas of these cross-sections are compared with the areas of their corresponding HEC-RAS cross-sections to determine the area calculating accuracy of the SCA method, as shown in Table 3. Most SCA method cross-sections have less than 10% error in area. Several SCA method cross-sections have up to 20% error.

The SCA method area testing was done on a raster with 20 meter wide cells on a reach that is 500-1000 meters wide. The results would likely be more accurate with a smaller cell size raster or a wider reach. A cell size of 10 meters is recommended for creating raster data for this project. However, the reaches are often narrower than this test region, so a larger cell size was chosen to compensate and provide an idea of how well the SCA method calculates area under a worst case scenario.

Table 3: SCA Method Cross-sectional Area vs HEC-RAS Cross-sectional Area

Elevation	HEC-RAS Area	SCA Method Area	% Error
219.61	1261.31	1344.02	6.56
219.07	1124.82	1097.44	2.43
218.85	2123.91	2533	19.26
218.31	2554.01	2426.79	4.98
217.95	1852.24	2049.81	10.67
217.43	1588.72	1615.74	1.70
217.13	1999.57	1917.8	4.09
216.88	2704.64	3120.36	15.37
216.7	2185.71	2331.2	6.66
216.45	2503.76	2770.21	10.64
215.99	2084.95	2451.68	17.59
215.71	3579.35	3444.6	3.76

5.8.2. SCA Method Velocity

The velocity results of the cell-by-cell method are analyzed in two areas in the Cedar Rapids model to assess the functionality of the SCA method. In the first area, the cell-by-cell method velocity results preserve continuity and agree well spatially with the

2D model results. In the second area, the cell-by-cell model results do not preserve continuity well. Figure 93 shows the two SCA method velocity cross-sections in detail on top of the cell-by-cell method velocity raster. Figure 94 is a zoomed out version of Figure 93 that provides a spatial reference of the location of the SCA cross-sections in the Cedar Rapids model.

The 2D Cedar Rapids model results in higher depths for reasons discussed previously, which means that the 2D velocities are lower on average because the flow rate used in the 2D and 1D models is the same. The velocity of the 2D model was scaled on each of these two cross-sections using the fixed flow rate of the HEC-RAS model, and the 1D flow area that was calculated as a part of the SCA method. This normalizes the 2D velocity values and corrects the depth disparity between the 2D and 1D models to allow comparison of both spatial distribution and magnitude of velocity.

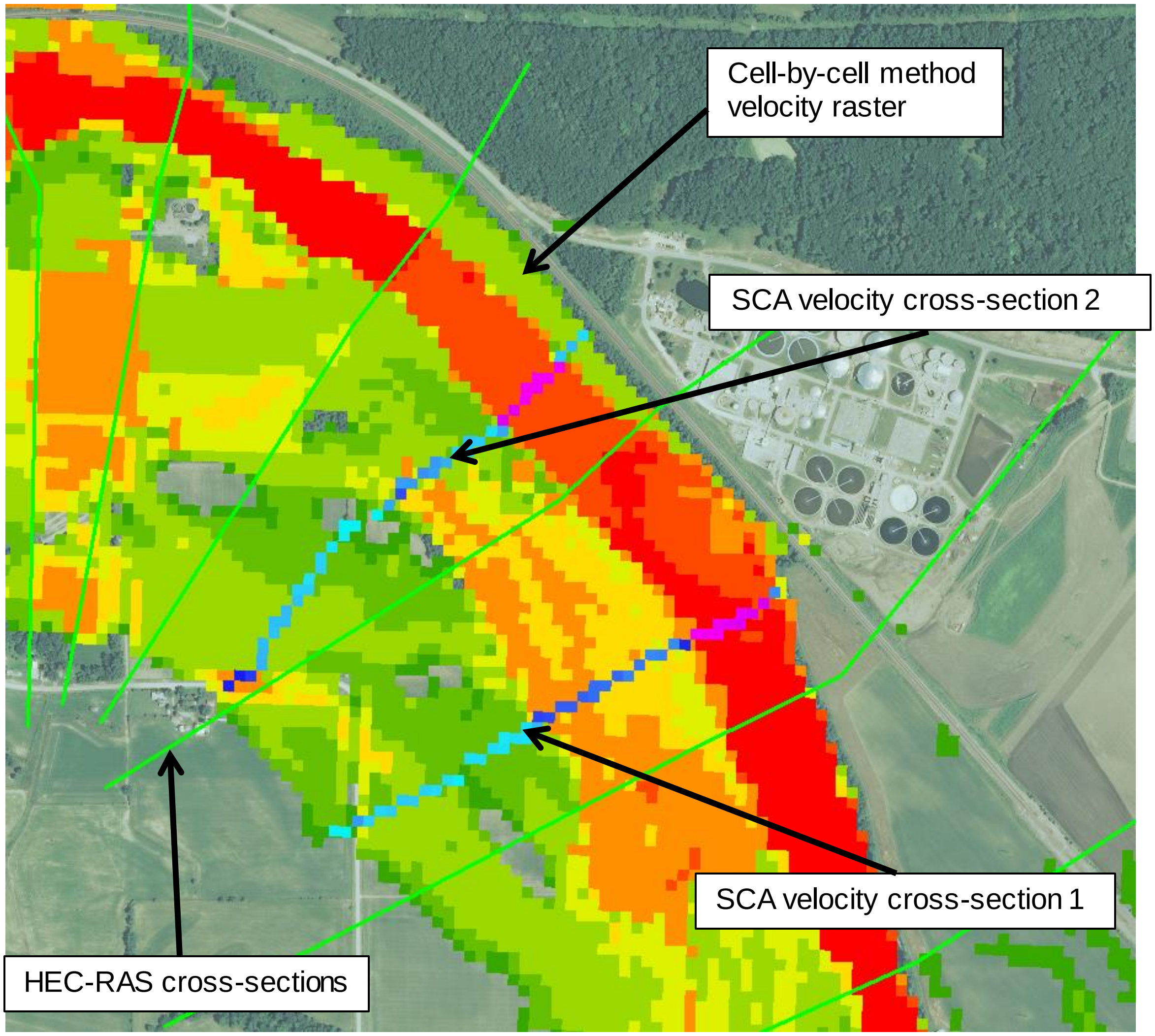


Figure 93: SCA method velocity cross-section rasters overlaid on cell-by-cell method velocity raster

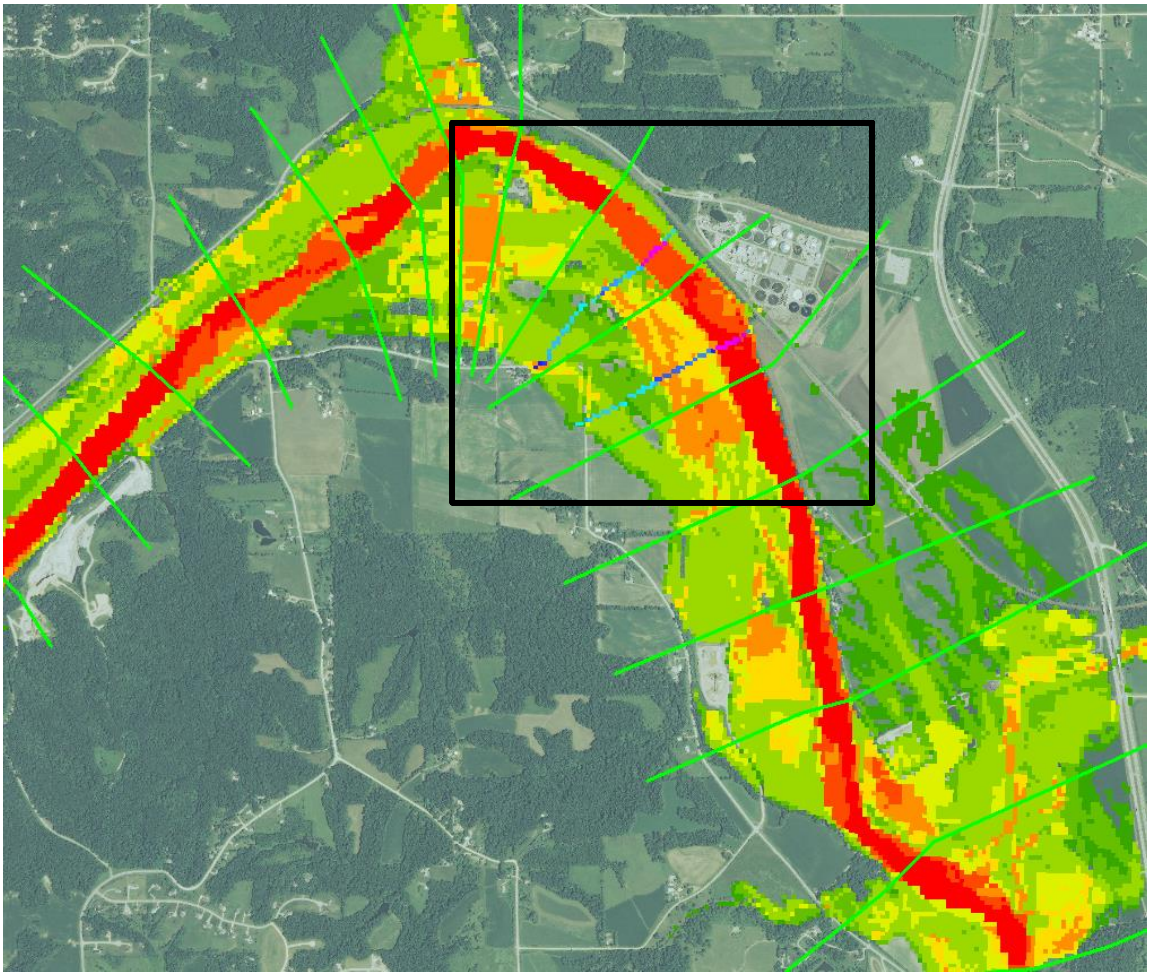


Figure 94: Location of SCA method velocity cross-sections shown in Figure 99

“Cross-section 1” in Figure 93 is in an area where the cell-by-cell method velocity does an excellent job of preserving continuity and agrees well spatially with the 2D model. Table 4 shows the flow area calculated by the SCA method, the “true” HEC-RAS flow rate, the cell-by-cell method predicted flow rate, and SCA method scaling factor for this cross-section. The cell-by-cell method predicted flow rate is determined by averaging the velocity values of each cell in the cross-section and multiplying by the area. The “true” flow rate is the flow rate that was used in the HEC-RAS model. The scale factor is 1.02 for this cross-section, so the SCA method only scales the cell-by-cell velocity values by 1.02.

Table 4: Flow Rates for Cross-Section 1

Cross-section 1	
Flow Area (m^2)	2491
HEC-RAS Flow Rate (cms)	2665
Cell-by-cell method predicted flow rate (cms)	2617
Scaling Factor	1.02

Figure 95 shows the velocity profiles for the Mike21 2D model, the cell-by-cell method, and the SCA method on "Cross-section 1." The SCA method scaling does not have a major effect on the velocities of this cross-section because the cell-by-cell method predicted flow rate was only 2% away from the actual flow rate. The velocity spatial distribution was also well predicted by the cell-by-cell method; the high areas are in the same location of the cross-section as they are in the 2D model. Figure 95 and the velocity maps shown in Section 5.4 indicate that the basic cell-by-cell method works well in areas where the channel is relatively straight and uniform.

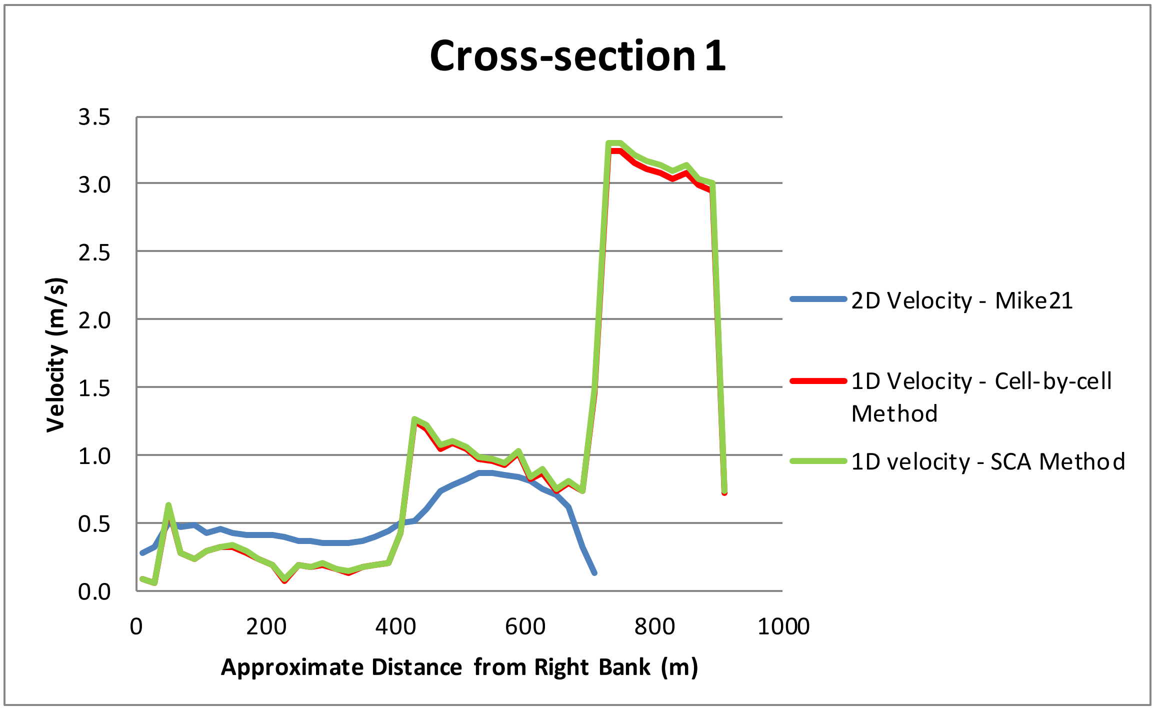


Figure 95: Velocity profiles for cross-section 1

"Cross-section 2" is in an area where the cell-by-cell method does not preserve continuity well. Table 5 shows the SCA method calculated flow area, "true" flow rate, cell-by-cell method predicted flow rate, and SCA method scaling factor for this cross-section. The scale factor is 1.52, which means that the SCA method tool will multiply the cell-by-cell method velocities in this cross-section by 1.52 in order to achieve the correct flow rate and preserve continuity.

Table 5: Flow Rates for Cross-Section 2

Cross-section 2	
Flow Area (m^2)	2353
HEC-RAS Flow Rate (cms)	2665
Cell-by-cell method predicted flow rate (cms)	1749
Scaling Factor	1.52

Figure 96 shows the velocity profiles for the Mike21 2D model, the cell-by-cell method, and the SCA method on “cross-section 2.” The scaling factor for this cross-section indicates that the cell-by-cell method under predicted the velocities and flow rate by 33 percent on “cross-section 2.” Continuity along this section was not preserved well because there are several islands and areas of decreasing depth that occur in-between the upstream and downstream HEC-RAS cross-sections. The HEC-RAS model isn’t aware of these flow area changes when they occur in-between its cross-sections, so the water surface and slope do not change to reflect the decrease in flow area, which causes errors with the cell-by-cell method. The SCA method scales the cell-by-cell method velocities along this cross-section up so that the correct flow rate is passing through the cross-section. The velocity magnitudes better match the 2D model after scaling by the SCA method. The spatial distribution of velocity or shear is unchanged by the SCA method. Scaling the velocity values makes it clear that the cell-by-cell method velocity distribution generally matches the 2D model velocity distribution on this cross-section. The high and low velocities occur in the same areas in both the cell-by-cell and Mike21 2D models.

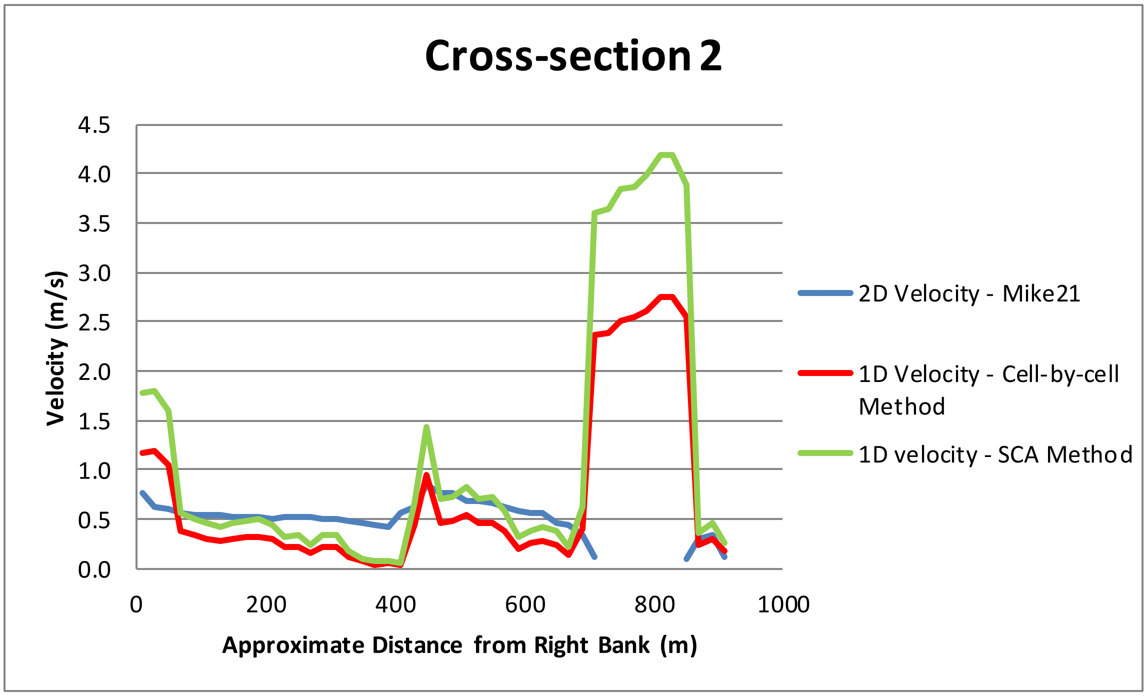


Figure 96: Velocity profiles for cross-section 2

5.8.3. SCA Method Shear

The SCA method scales shear in the same way as velocity, except the scaling factor is the velocity scaling factor raised to the power of 2. See Equation 15 for further explanation of how the SCA method scales shear. The SCA method should be just as effective at correcting errors in shear magnitudes due to continuity as it was in correcting velocity.

5.8.4. SCA Method Conclusions

The SCA method does well correcting for continuity errors associated with the cell-by-cell method. However, it is more time consuming to set up and run than the basic cell-by-cell method, and it is not practical to use to create maps for sections of reach longer than 10-20 kilometers. The SCA method only scales magnitudes, so it is still subject to the limitations of the 1D slope data. This means that presence of large backwater areas can make the SCA method results worse than the basic cell-by-cell method, so large backwater areas need to be removed manually in areas where SCA cross-sections are to be created. The SCA method shouldn't be used where the main channel has a meander perpendicular to the main direction of floodplain flow because this only occurs in very flat areas where the floodplain is wide. The SCA method only corrects velocity or shear for errors due to continuity loss, but it does not adjust spatial distribution or correct for any other limitations associated with the cell-by-cell methods. The SCA method is useful when the user wishes to create data for a short section of reach and requires the additional accuracy that preserving continuity provides.

5.9. Uncertainty

It is not possible to determine a quantitative uncertainty for the methods developed. The uncertainty of the cell-by-cell or SCA method results depends on local channel characteristics. The velocity or shear readings will have lower uncertainty if the channel is relatively straight and uniform in-between the HEC-RAS cross-sections, and they will have higher uncertainty if there is more variation in channel geometry or roughness between the upstream and downstream HEC-RAS cross-sections.

The uncertainty of the effective shear results also depends largely on the NLCD and the assumptions made regarding Manning's n and cover factor assignments to the different land cover types. The excess shear ratio maps additionally depend on the allowable shear maps, which are based on the USDA SSURGO soil database and erodibility classifications provided by the NRCS, so their accuracy is dependent on that data in addition to the NLCD and 1D HEC-RAS data.

CHAPTER 6. INTERPRETING MAPS

The methods developed for this thesis produce shear and scour maps that have some noise and errors due to the nature and limitations of the source data. The raster cell size can make the maps appear to have higher resolution and accuracy regarding scour location and magnitude than they actually do. Proper interpretation of the maps requires an experienced person who understands the limitations and modeling process used to create them. Any velocity, shear, or excess shear maps will need to be interpreted and cleaned by an experienced user prior to release to the public. Even after this first pass cleaning, the end user will have to understand that the maps are intended to predict general areas where high shear or velocity will occur, but are not intended to make precise spatial readings. This chapter provides an example of how the maps will be cleaned and interpreted by an experienced modeler and will provide different possibilities for cleaning the maps to a level that could be presented to a lay person.

The excess shear ratio maps show effective shear divided by allowable shear and will be the primary tool used to predict scour. When the excess shear ratio is near or exceeding a value of 1, scour is expected to occur. The higher above 1 this ratio is, scour is more likely to occur and more likely to be severe. Due to the limitations of the source data, it is difficult to be more quantitative regarding severity of scour. The depth and Manning’s n maps will also assist the user in determining where the excess shear ratio maps are correct and incorrect.

A script was created to enclose areas where the excess shear ratio is greater than a certain value, such as 0.9, in a polygon. This script makes it easy for the interpreter to identify areas of high scour. Figure 97 shows an excess shear ratio map in its raw form overlaid with the polygons around the high excess shear areas that were created via this script. The interpreter will then manually draw ovals around areas that are expected to have high shear.

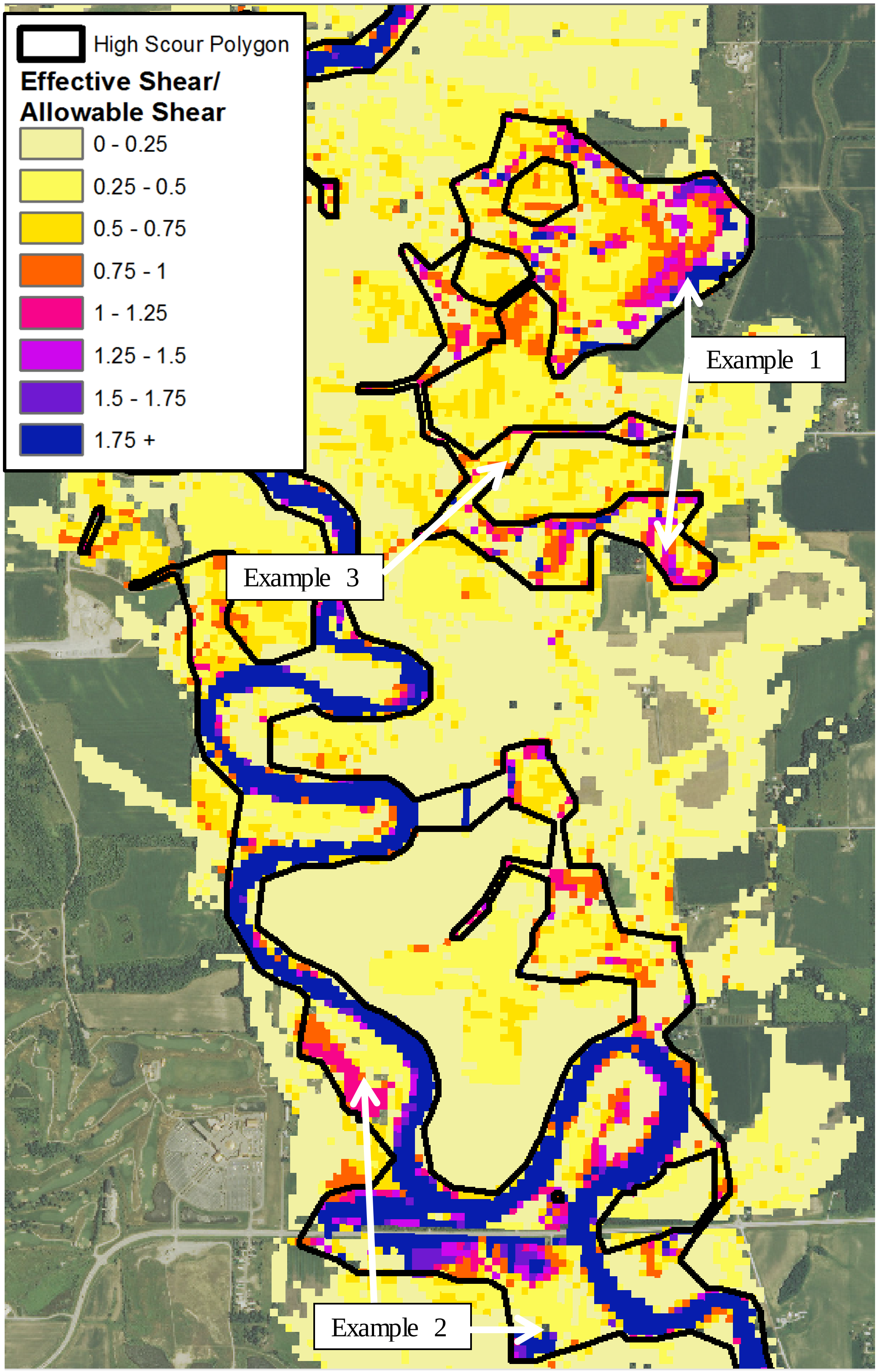


Figure 97: Excess shear ratio and polygon created to identify high scour areas

The polgyons in Figure 97 are drawn around all high areas and the main channel. The user will need to look at the excess shear ratio, depth, and roughness maps to determine which areas are showing legitimate scour potential and which are showing false scour potential.

Example 1 is showing areas with high scour potential that are occurring in backwater areas. High excess shear ratios can appear in backwater areas on the maps because the 1D HEC-RAS model does not model what occurs in between its cross-sections, so slope data does not reflect backwater areas and other changes in between the cross-sections. These backwater areas are usually easy to identify visually.

Example 2 is showing areas with high scour potential; however, looking at the depth and roughness maps reveals that these areas are ponds with standing water, so the high scour readings are not accurate. Ponds have low Manning's n and greater depths than surrounding topography, leading to unrealistically high shear values.

Example 3 is showing small areas of high excess shear scattered along a line because there is a dry streambed running perpendicular to the channel. The extra depth causes the shear readings to be high, but the extra depth would not actually be conveying water, so the readings are too high.

The high excess shear ratio readings that are not in one of the above type of areas where limitations commonly occur are likely legitimate high scour potential areas.

It will also be important for the user to look for areas where the maps may be under predicting scour, such areas include roadways that might overtop and contractions caused by topography or surface roughness changes that may not considered by the 1D model if they occur in between HEC-RAS cross-sections.

The realistic high excess shear areas will have ovals drawn around them to indicate the general area of high scour potential. The end user cannot conclude that scour will occur in these areas exactly as shown on the maps, but can conclude that scour is likely somewhere in the general vicinity of these areas. Ovals are drawn in the general areas of high excess shear ratios because confidence is not high enough to delineate exact areas of where scour will occur.

Figure 98 shows the manually drawn ovals overlaid on the excess shear ratio map. Figure 99 shows the ovals overlaid on the depth maps. This methodology can be used to create maps showing ovals for a single or several different levels of scour potential, such as moderate and high scour potential. These different levels will be determined by setting the minimum excess shear ratio threshold in the script that identifies high scour areas and by user judgment. The example maps in Figures 98 and 99 are showing two different levels of scour potential. The purple ovals are indicating moderate scour potential, because the excess shear ratios in these areas were near or slightly above 1. The orange oval is indicating a high scour potential area because the excess shear ratio values in the area are well above 1. The area with the orange oval will likely be experiencing overtopping due the road, which could cause high scour. This is also a complex area due to the road way and the nature of 1D modeling, so it is difficult to be confident in the results and would be a good area to perform a more detailed study.

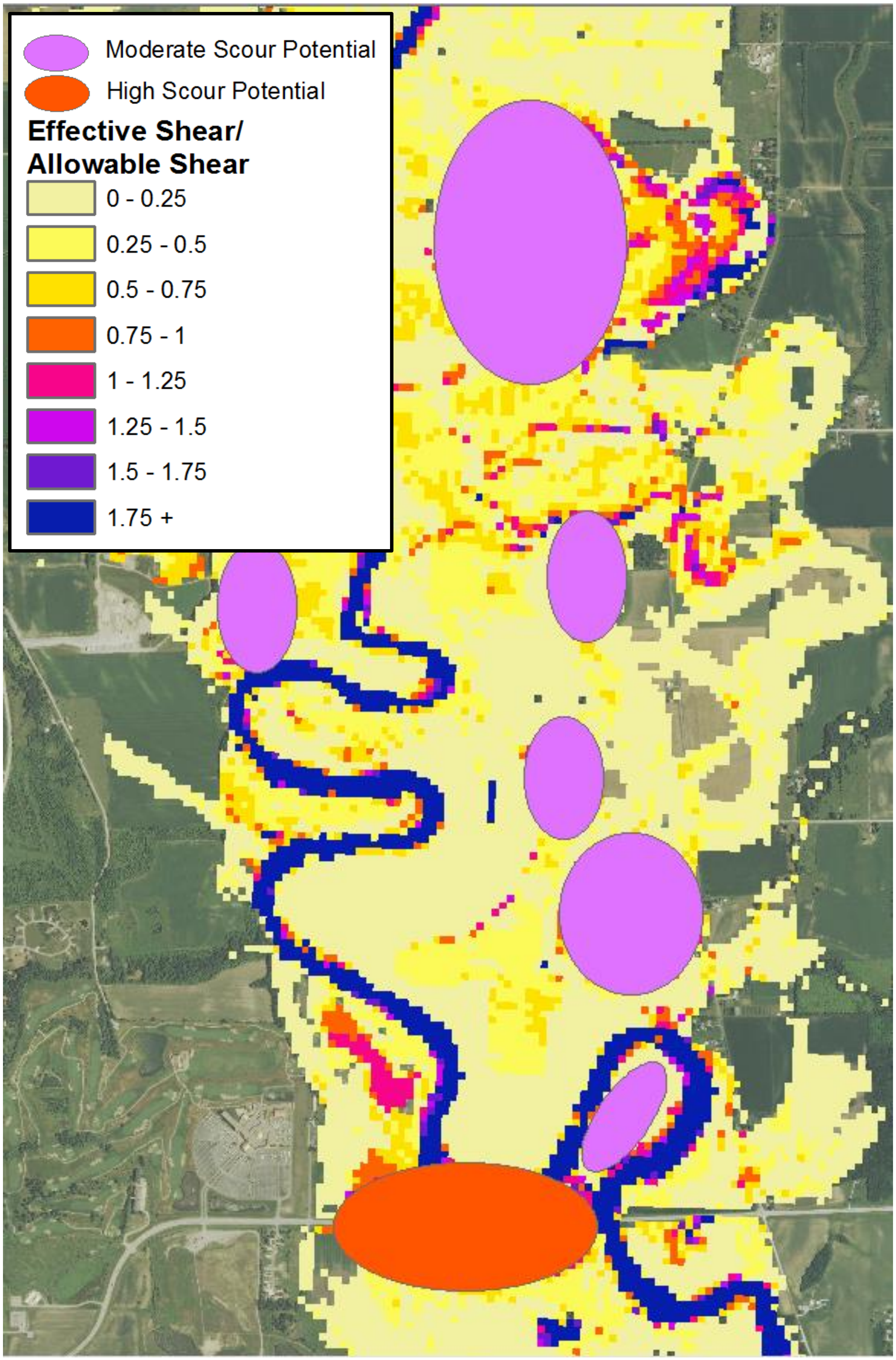


Figure 98: Excess shear ratio map with manually drawn ovals indicating high scour potential areas

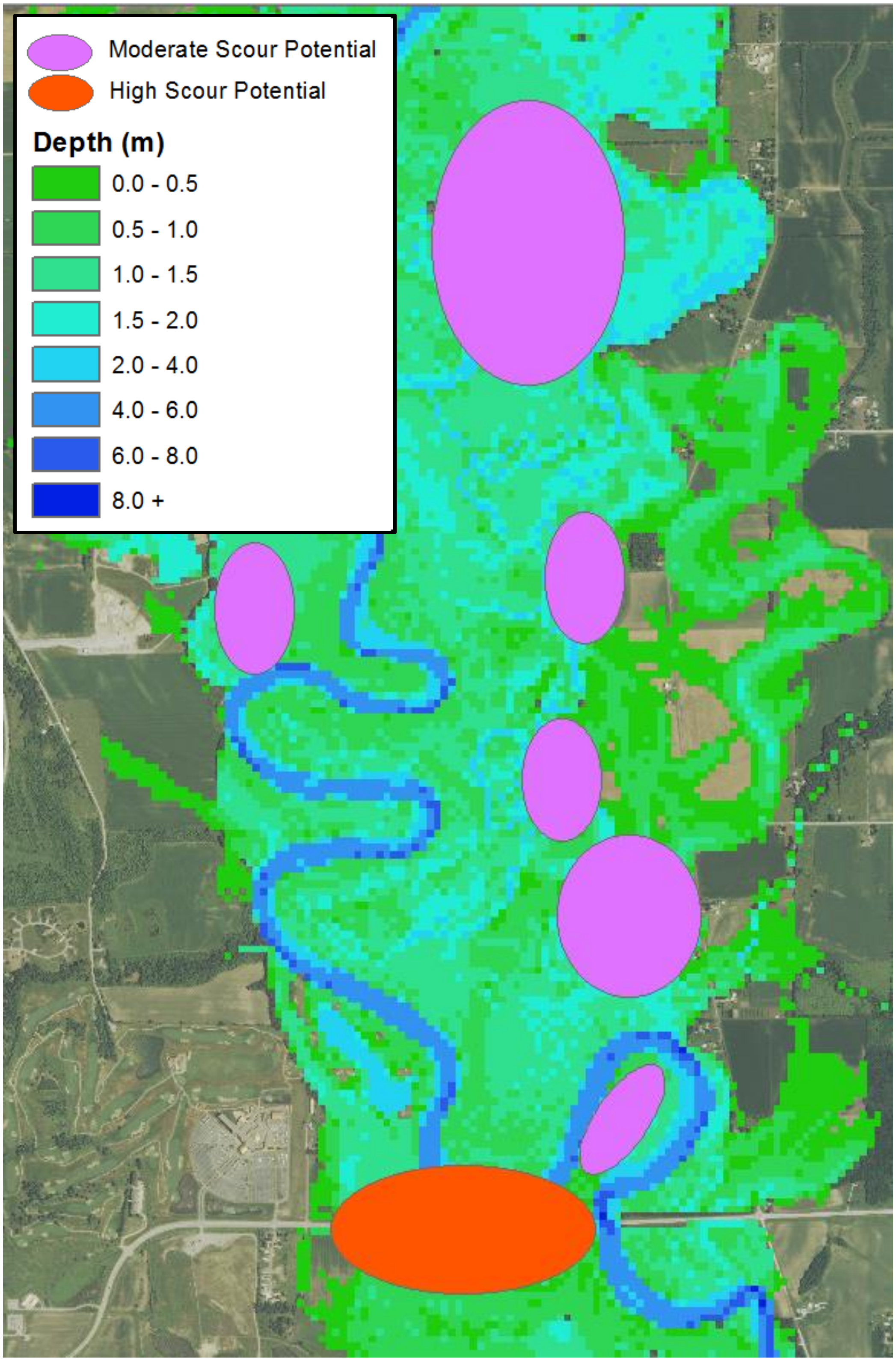


Figure 99: Depth map with manually drawn ovals indicating high scour potential areas

Maps can also be used to simply identify sections of a river that would be ideal for a more detailed 2D study. For example, in some rivers, the excess shear will be well under 1 in most sections, but well above 1 in a few short sections of the river. The maps could help facilitate a decision to only run a 2D model on the sections of the reach that are actually showing high scour potential. The benefit the cell-by-cell scour potential maps would have in this scenario would be saving money by better targeting areas where more advanced modeling should be applied.

CHAPTER 7. SUMMARY

The cell-by-cell method was developed to take readily available 1D HEC-RAS data and apply uniform open channel flow equations to individual raster cells in order to create spatial velocity or effective shear maps. The effective shear maps are then compared to spatial allowable shear data obtained from the USDA NRCS to create maps that display the effective shear to allowable shear ratio and can be used to assess scour potential within a floodplain. The cell-by-cell method offers a method that can quickly and cost effectively create large datasets that provide an approximate assessment of where scour is likely to occur. The cell-by-cell method is subject to some limitations associated with the 1D hydraulic model data used as inputs, primarily the 1D water surface slope data. The cell-by-cell method relies heavily on the statewide NLCD and SSURGO datasets, so it is also subject to limitations associated with those datasets. An experienced user will need to interpret the maps produced by the cell-by-cell method due to the limitations it is subject to. The SCA method was developed to correct for some of the continuity errors associated with the cell-by-cell method, but it is not capable of generating large datasets and will have limited uses.

The cell-by-cell method produces maps that are capable of identifying general areas of high scour potential and could potentially be used for approximate, large scale, land management decisions. The cell-by-cell method could also be used as a first pass tool to target areas that might warrant a more detailed study. The cell-by-cell method provides a viable option if rough velocity or shear information is sufficient, but it is not a substitute for a more detailed 2D model if highly detailed information is required. The cell-by-cell method is a first attempt to obtain more spatial data from a 1D model and its ability to create large datasets quickly and cost effectively offers a unique tool that did not previously exist.

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Ward, A. D., and Trimble, S.W. *Environmental Hydrology*. 2nd ed. N.p.: CRC, 2003. 214-16. <http://books.google.com/books?id=yANwmTjf588C&pg=PA214&lpg=PA214&dq=manning%27s+equation+compound+channel&source=bl&ots=65o88ex1gY&sig=S5fA-MWBayE9VVuJh4gA10c_Gps&hl=en&sa=X&ei=2ZTYUv28FMiHqAG1x4CIBw&ved=0CC0Q6AEwAQ#v=onepage&q=manning's%20equation%20compound%20channel&f=false>.

APPENDIX A. GIS TOOL DIAGRAMS

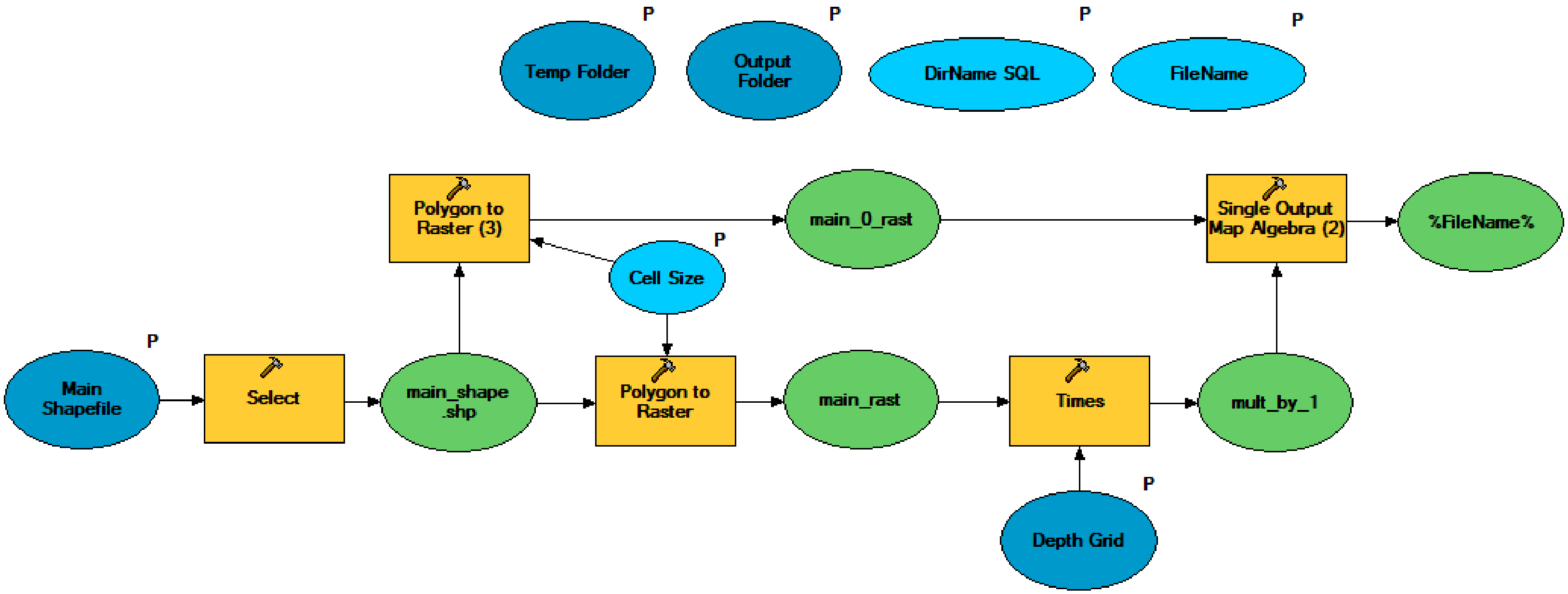


Figure A1: “Depth Cleaner” tool

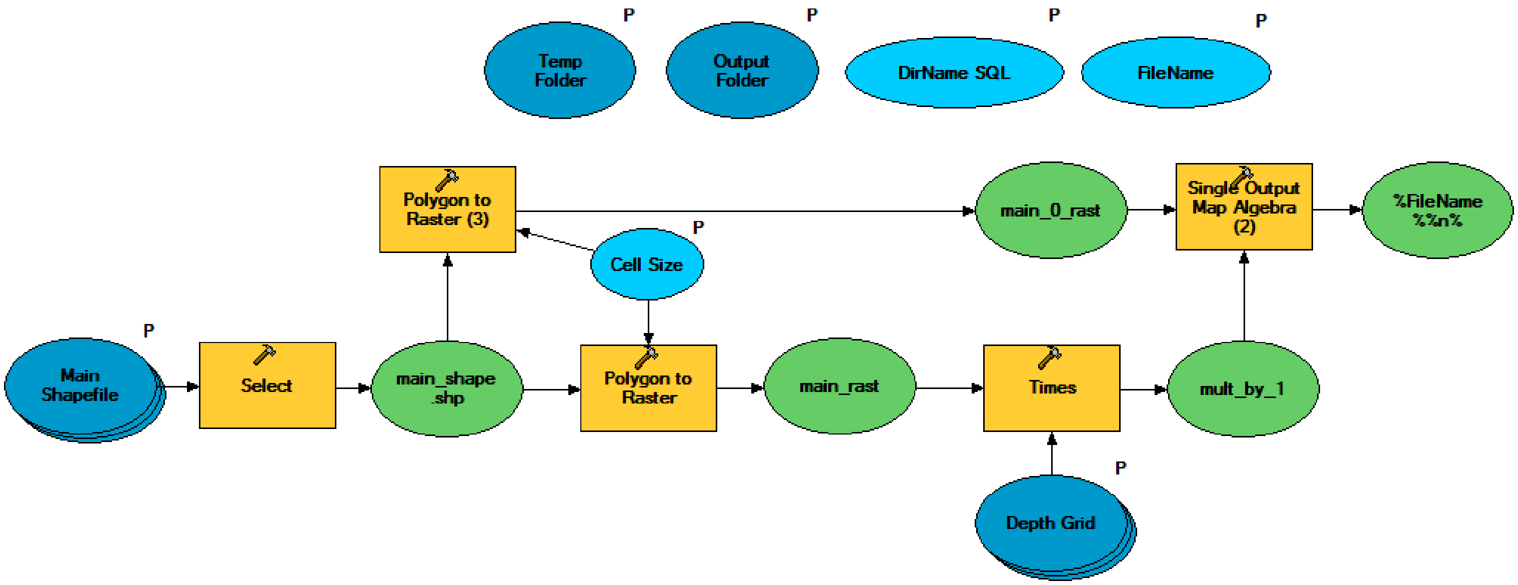


Figure A2: “Depth Cleaner Multiple” tool

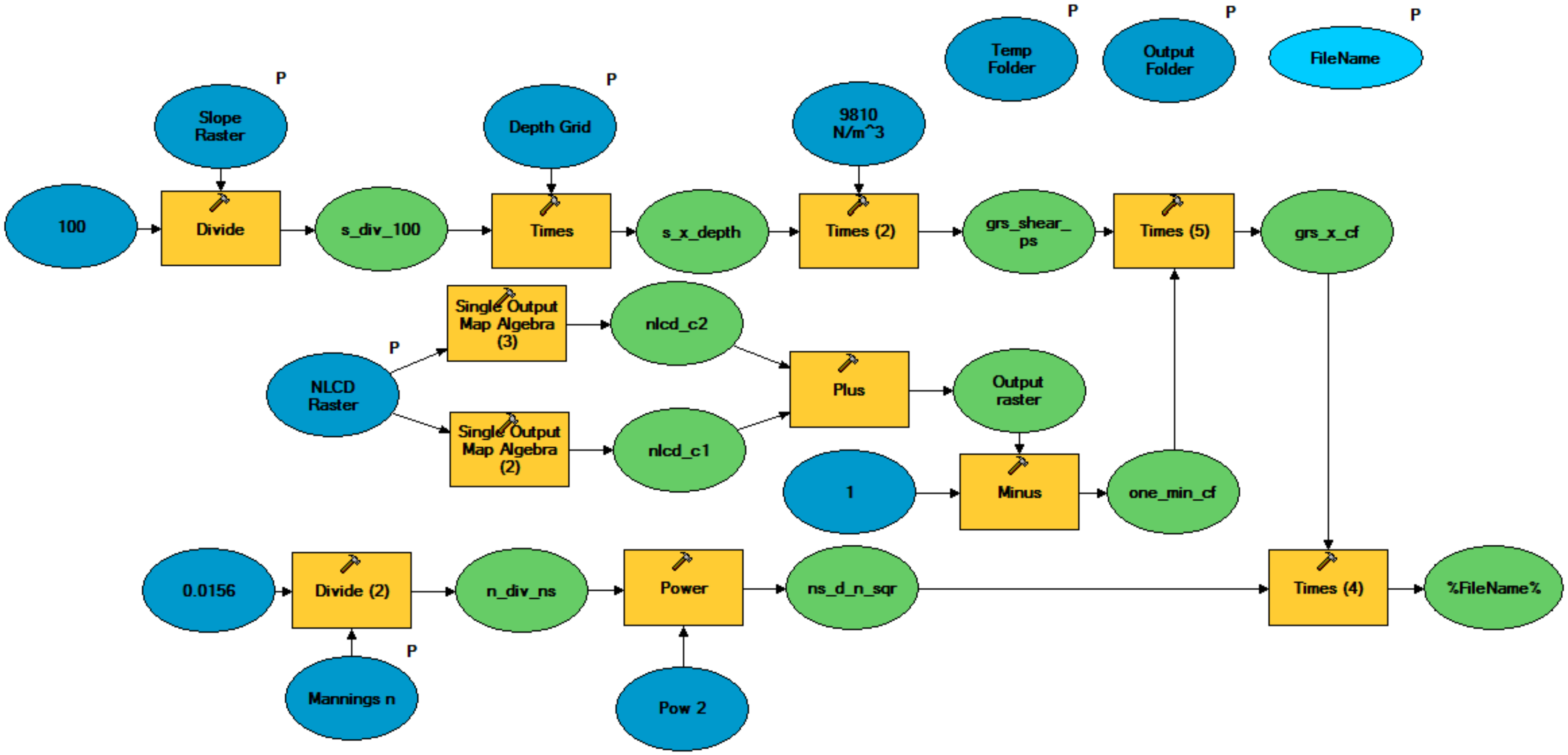


Figure A3: “Effective Shear – n unchanged” tool

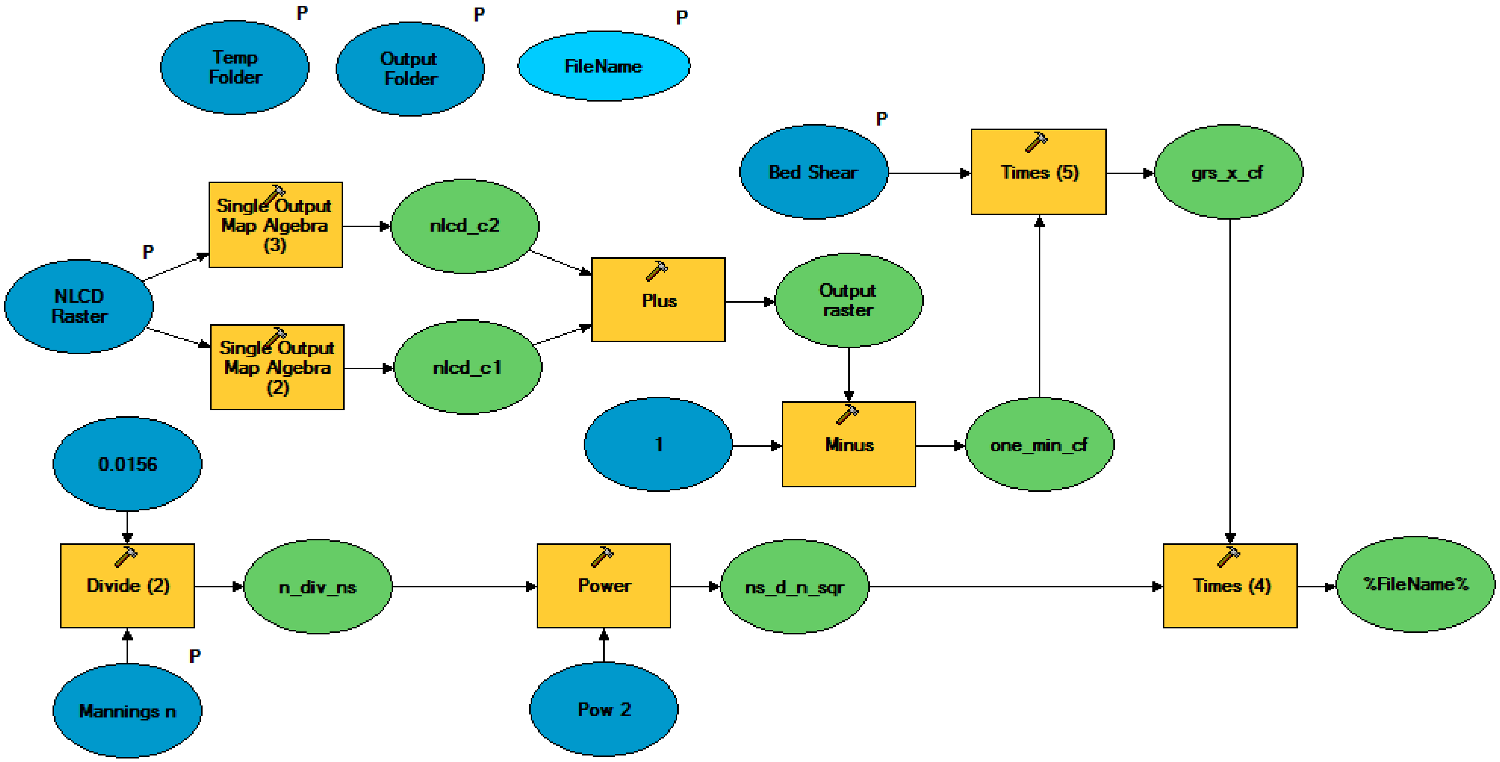


Figure A4: “Effective Shear – n unchanged – Bed Shear Input” tool

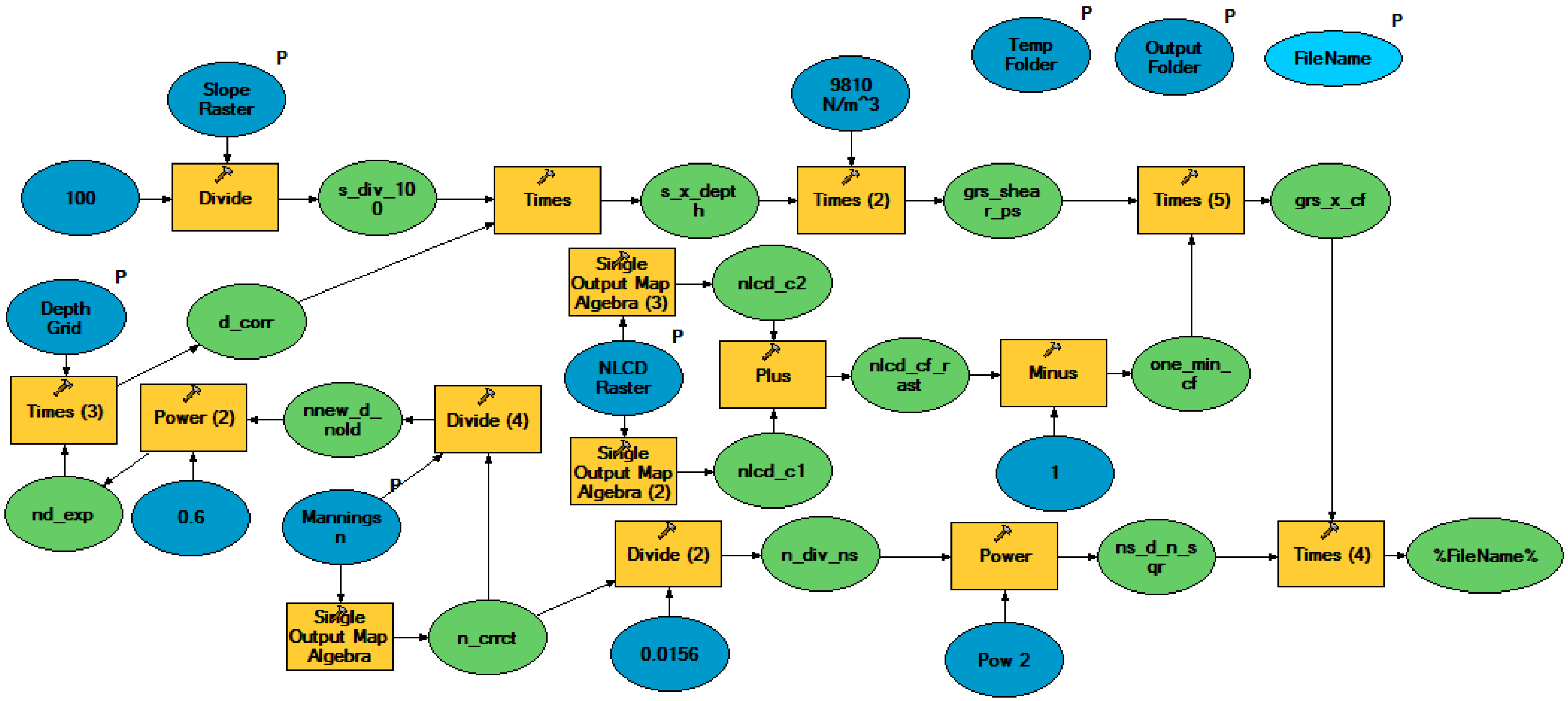


Figure A5: “Effective Shear – Field n = 0.03” tool

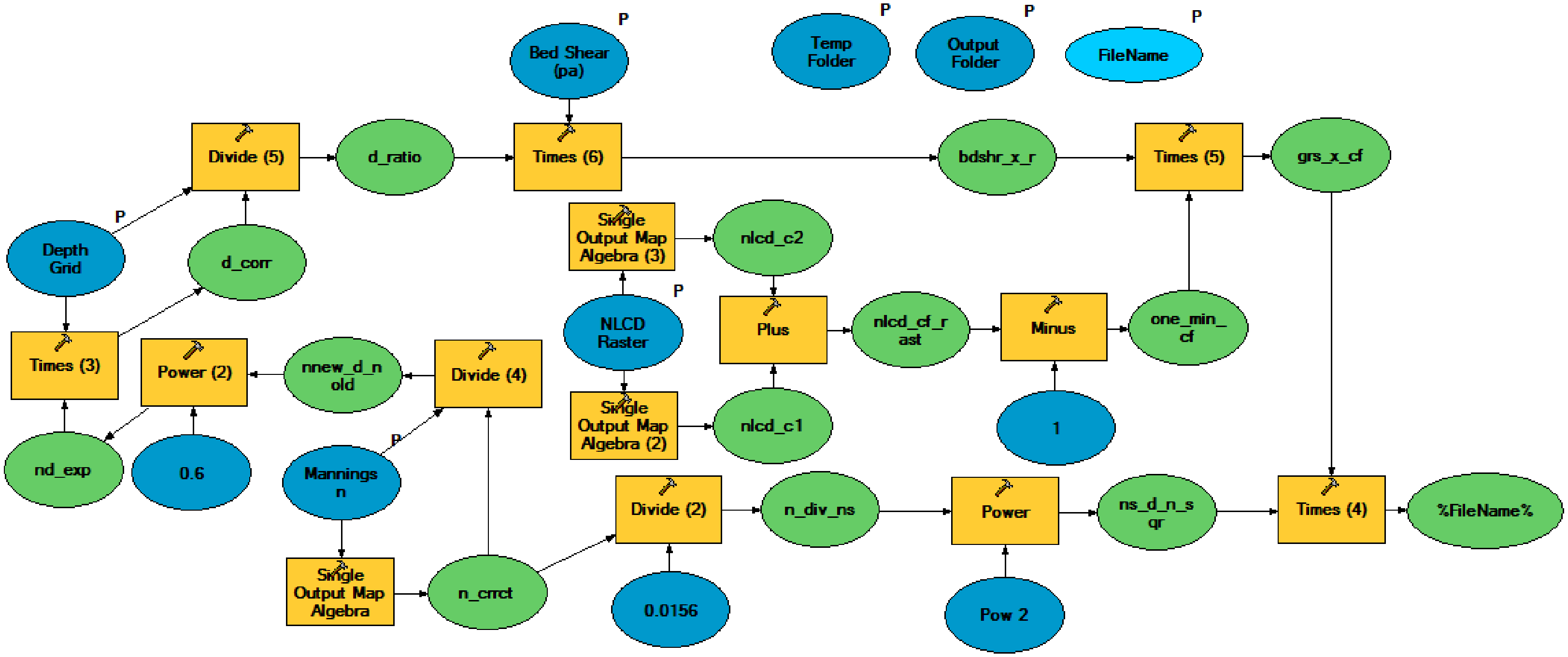


Figure A6: “Effective Shear – Field n = 0.03 – Bed Shear Input” tool

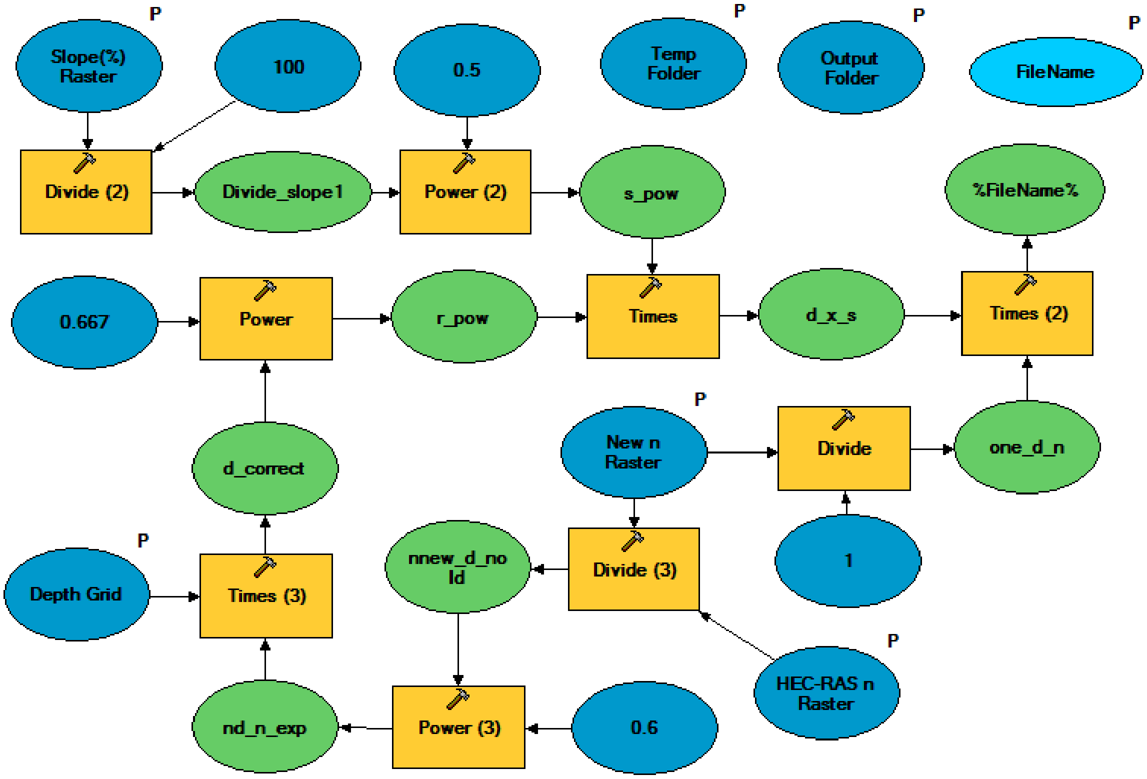


Figure A7: "Velocity - Manning Equation - n changed" tool

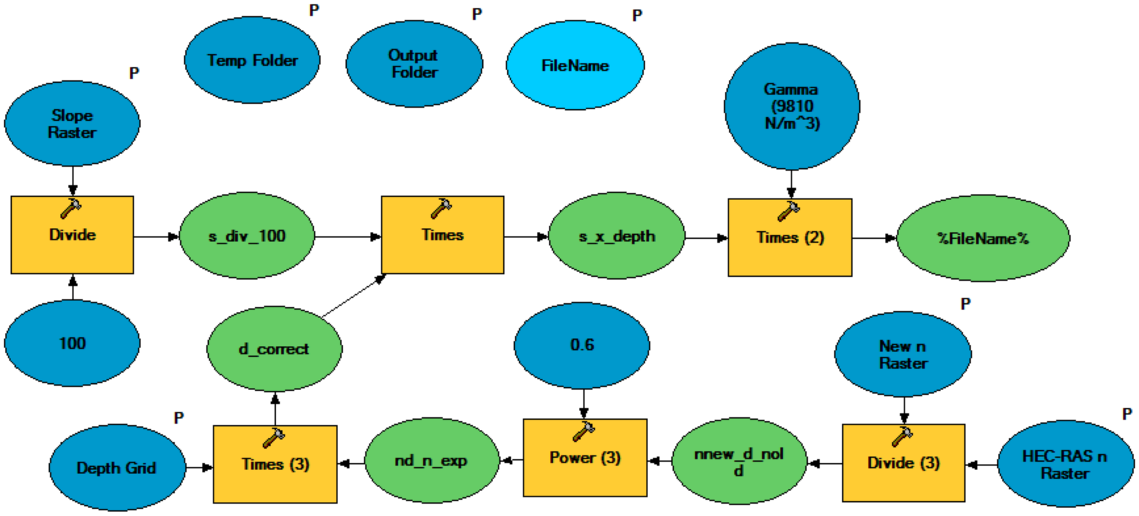


Figure A8: "Bed Shear - n changed" tool

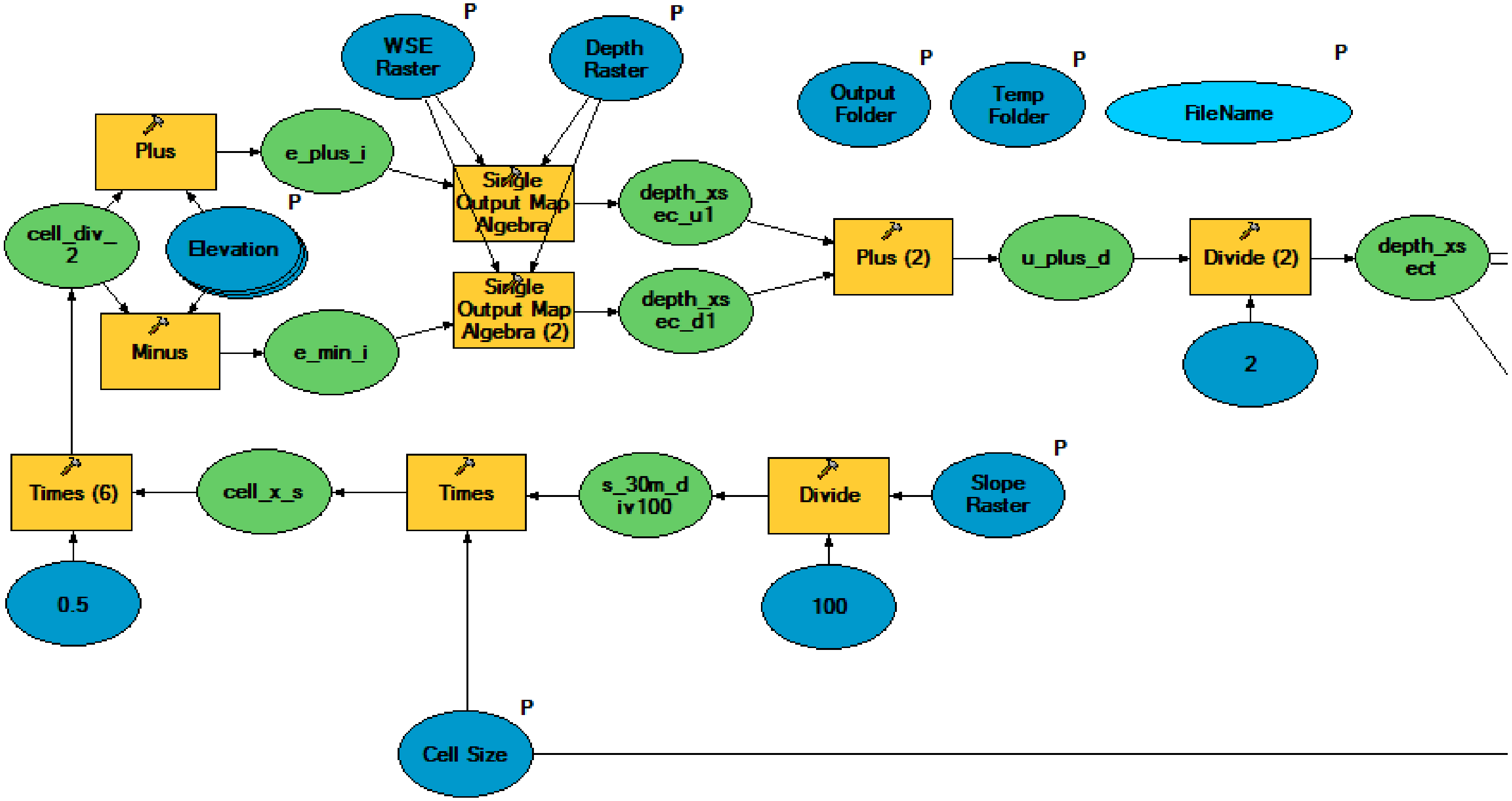


Figure A9: “SCA – Velocity” tool – Part 1

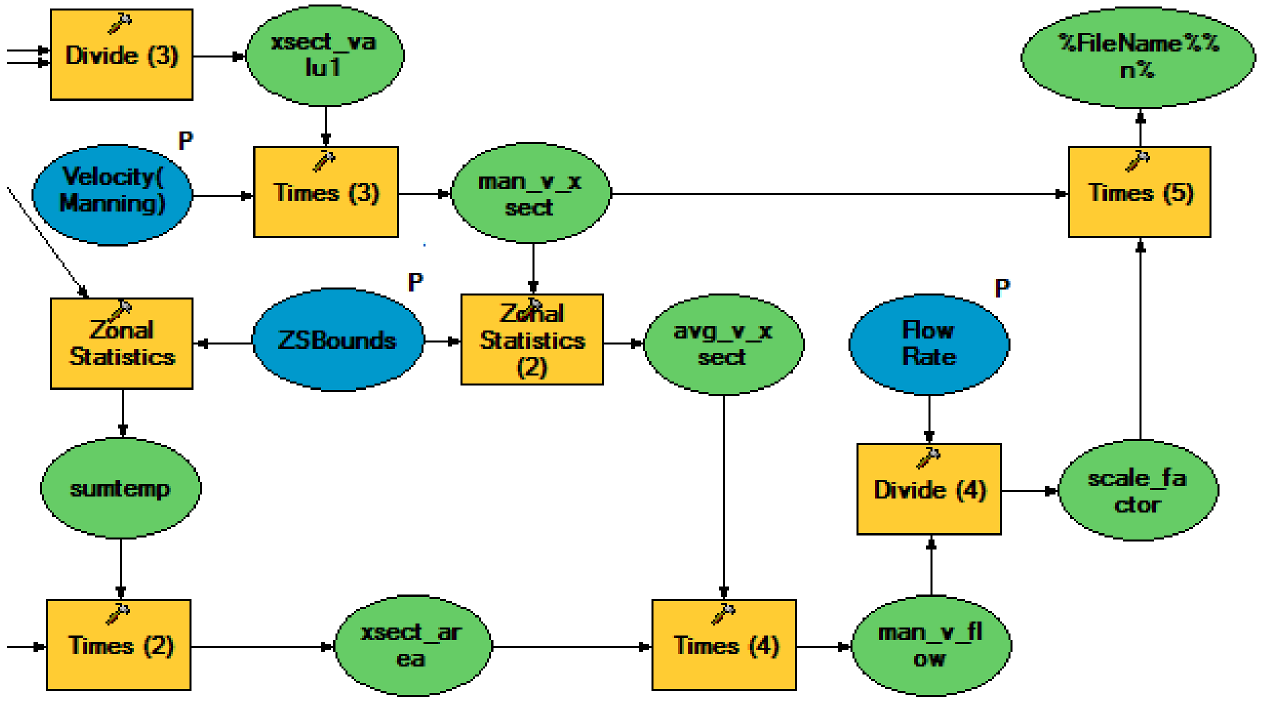


Figure A10: “SCA Velocity” tool – Part 2

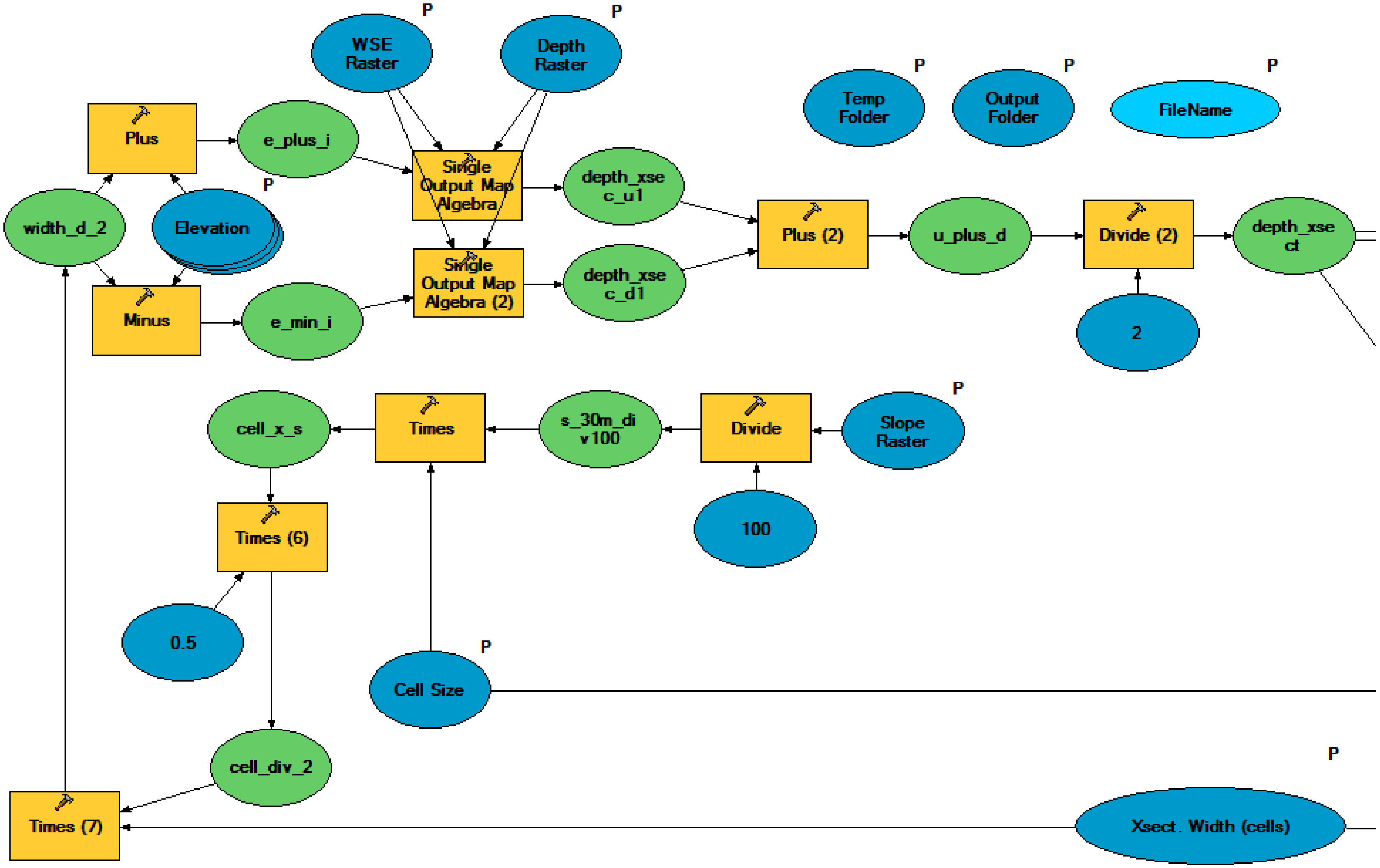


Figure A11: “SCA Velocity – Wide” tool – Part 1

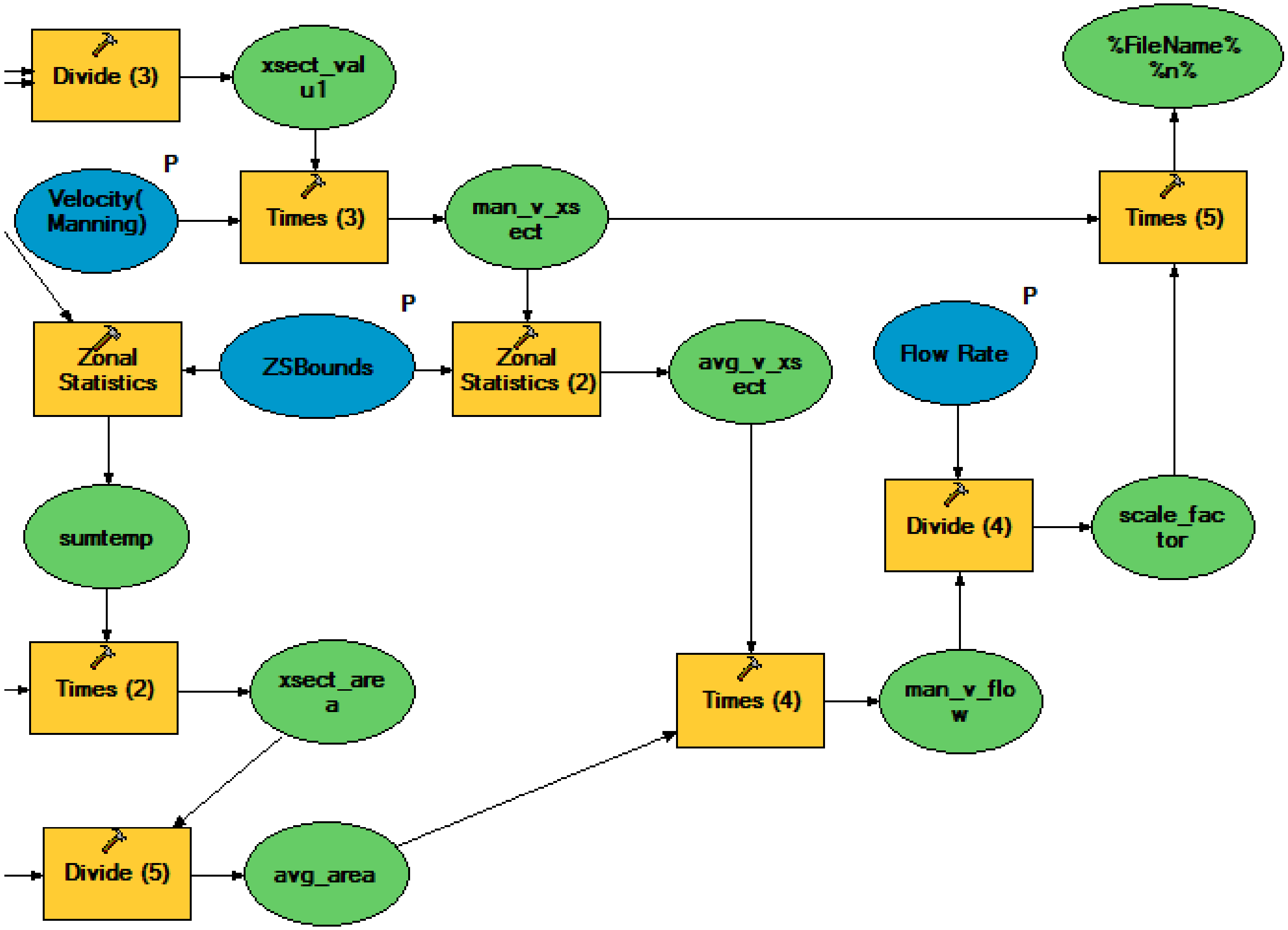


Figure A12: “SCA Velocity – Wide” tool – Part 2

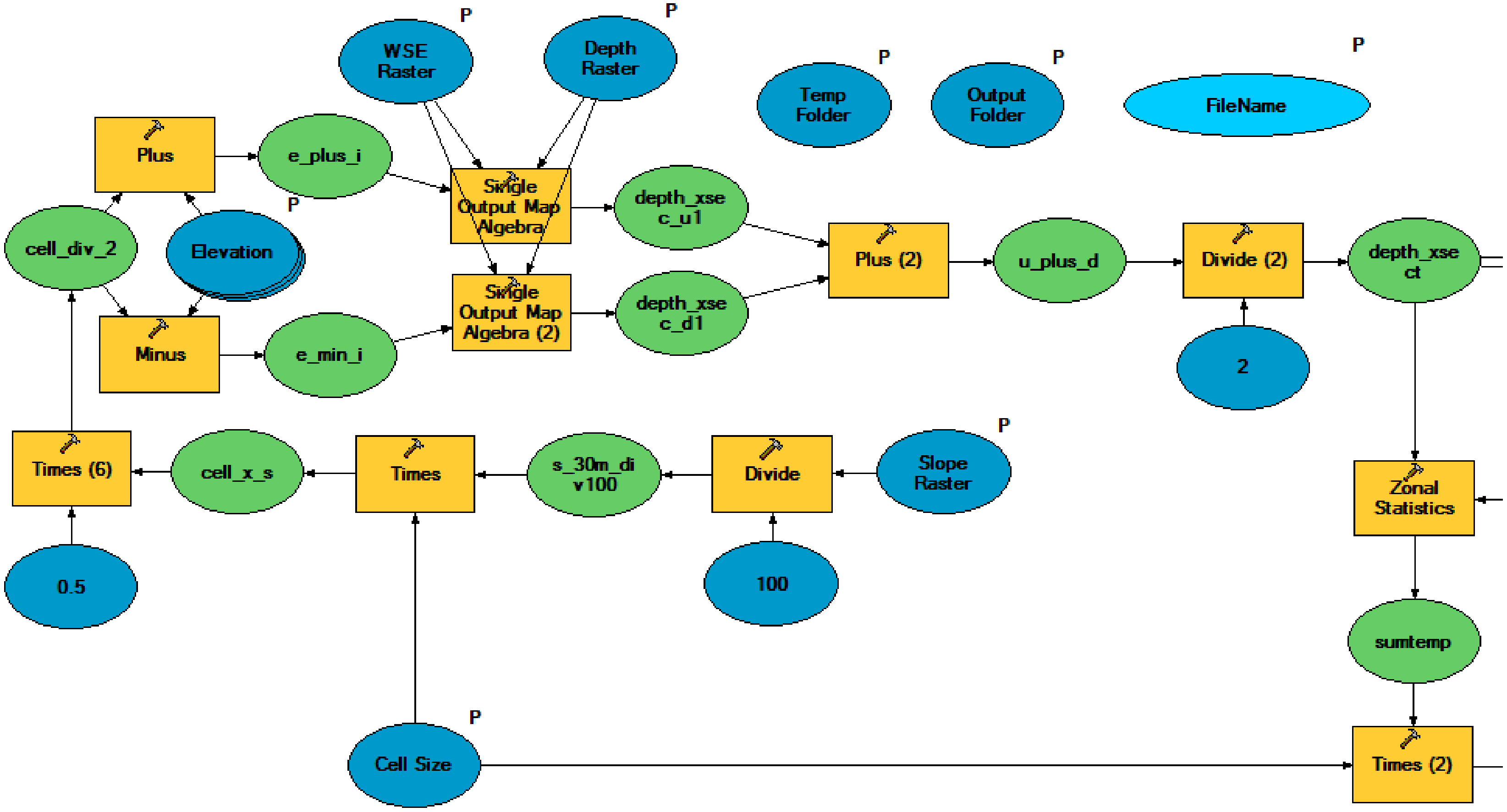


Figure A13: “SCA Bed Shear” tool – Part 1

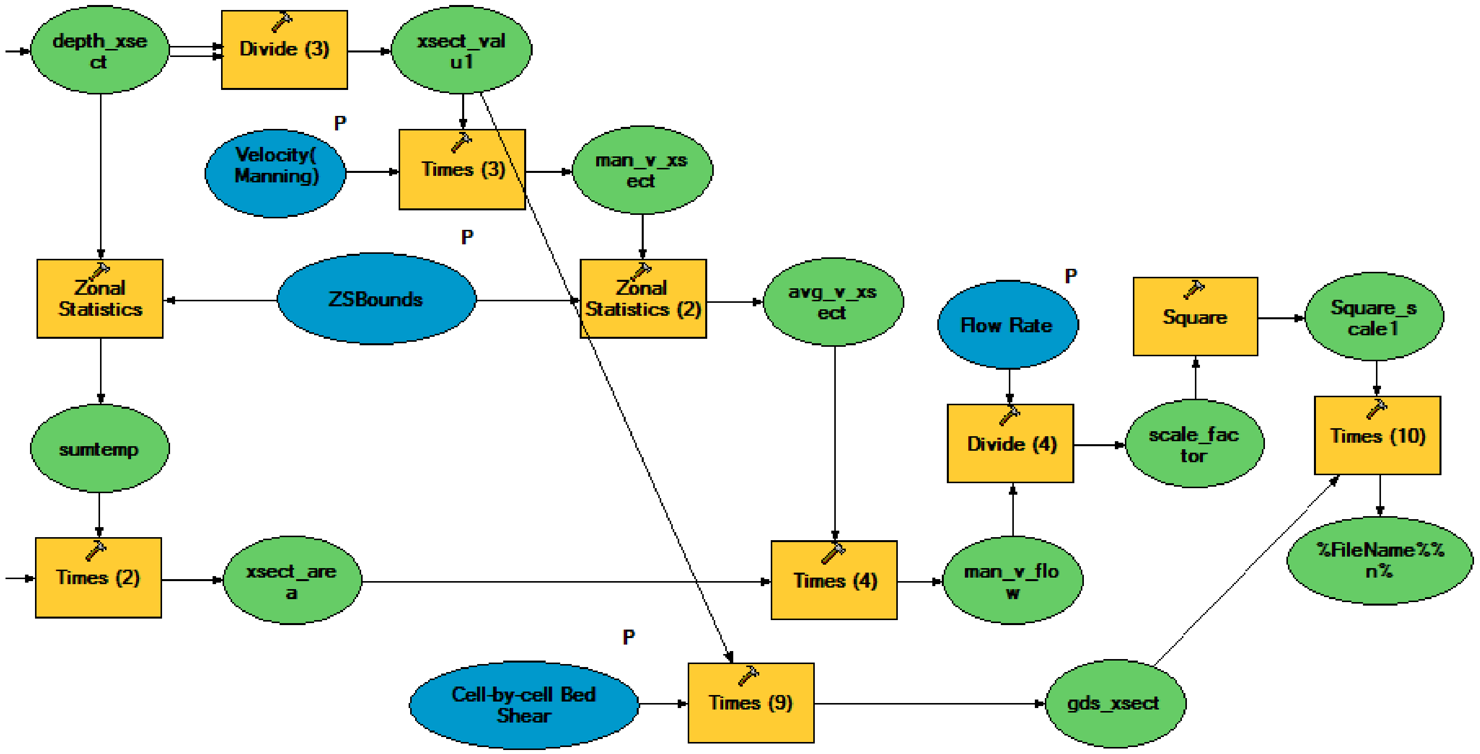


Figure A14: "SCA Bed Shear" tool – Part 2

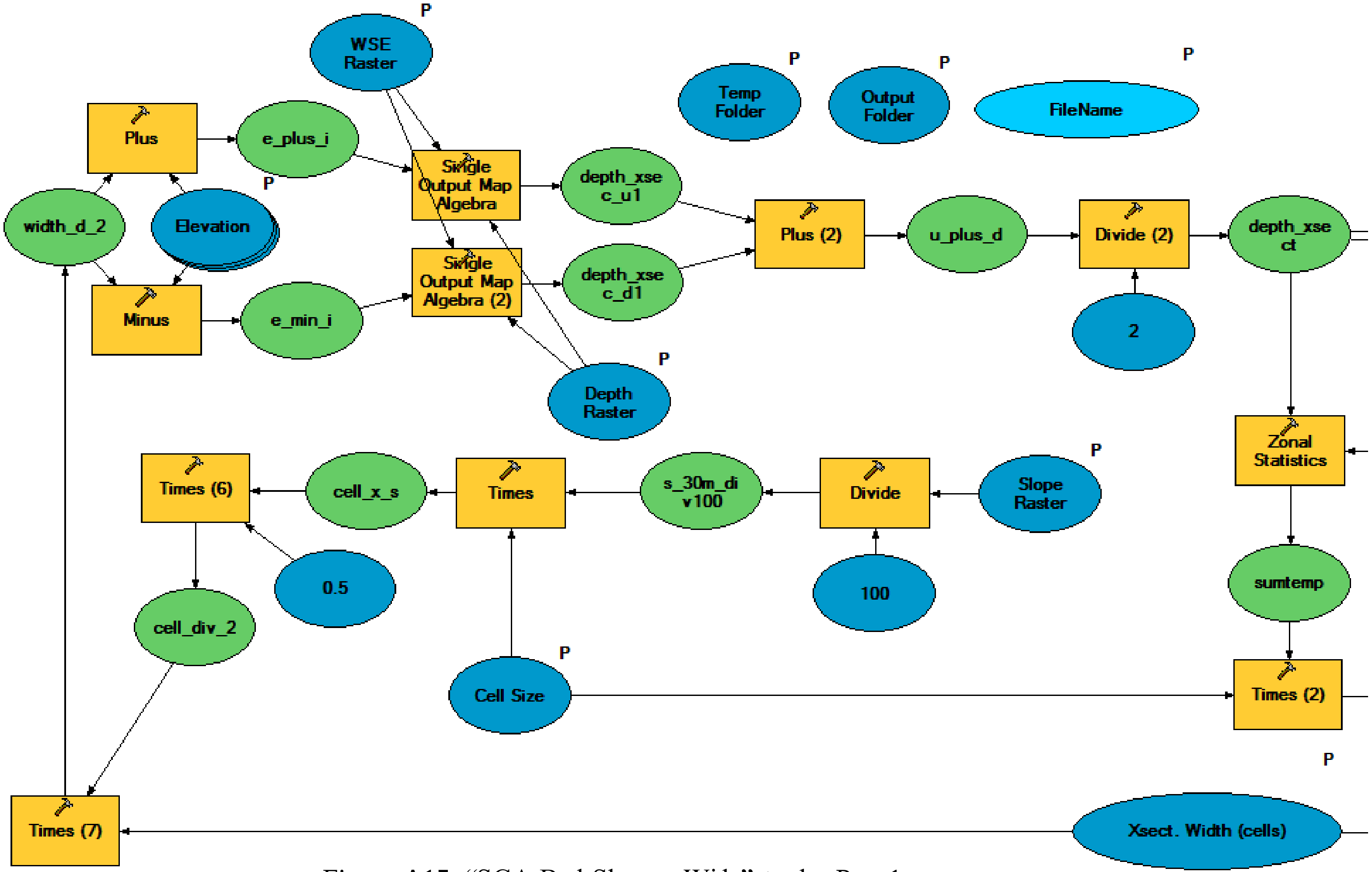


Figure A15: “SCA Bed Shear – Wide” tool – Part 1

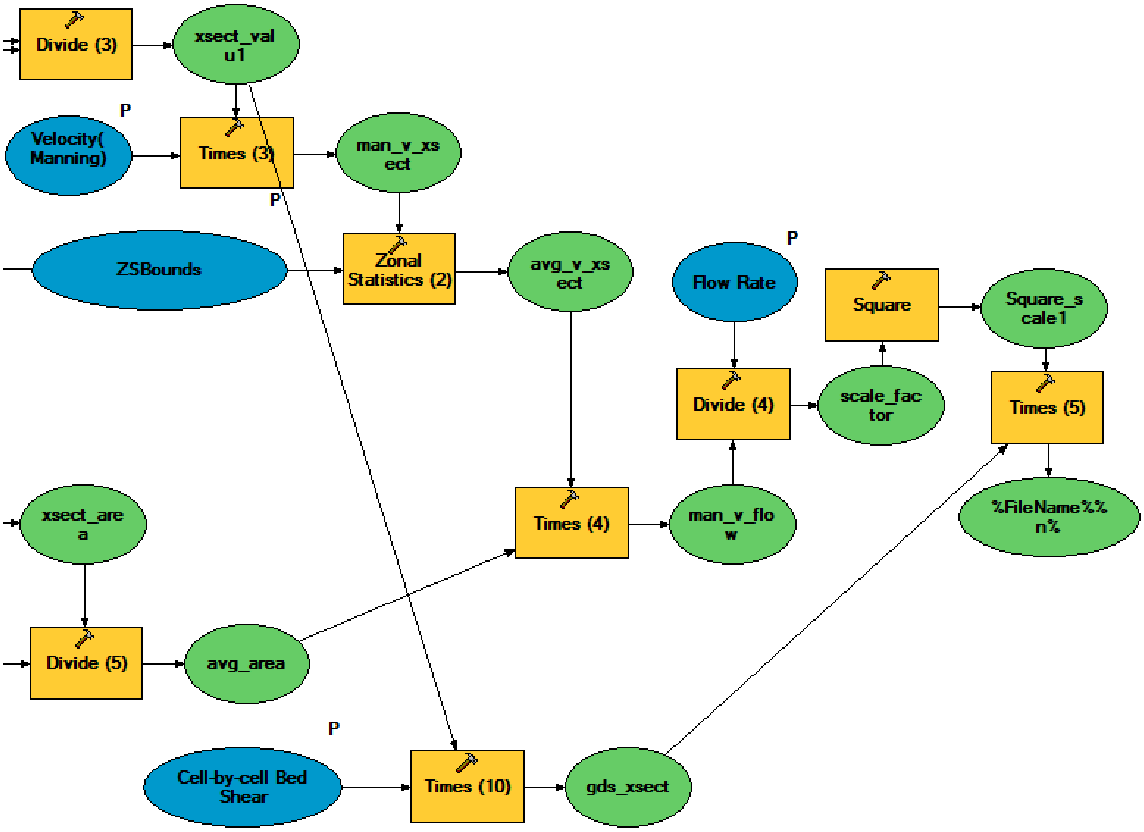


Figure A16: “SCA Bed Shear - Wide” tool – Part 2

APPENDIX B. USING METHODS DEVELOPED

B.1. Introduction

Producing the finished scour characterization products includes many steps with respect to applying the various tools created for this thesis project. This thesis has presented two methods to create velocity, effective shear, and excess shear ratio maps that can characterize scour potential. The cell-by-cell method is simpler and has more limitations associated with the 1D HEC-RAS input data but can be run relatively quickly and easily on a larger dataset. The SCA method further modifies the outputs from the cell-by-cell method but can only be run on short sections of a reach due to its being procedurally and computationally more complex. This section will detail how to use by the cell-by-cell and SCA methods to create effective shear, excess shear ratio, and depth datasets and present them in a standard map format using data available from the IFC. The tools created for this thesis can also be used to create velocity or shear data for other purposes.

B.2. Requirements

ArcGIS is required in order to manage the required data and run the tools created for this project. It is assumed that the user will already have a basic understanding of GIS. The user will also need 1D HEC-RAS models for any reaches of interest. Necessary HEC-RAS model data is available from the IFC for rivers in Iowa.

The user will need the SSURGO soils data, custom GIS tools, and land cover data that are necessary for the creation of scour characterization maps.

B.3. Setting Up

A new project folder should be created because many files will need to be obtained and organized. The scour characterization and supporting tools process single reaches at a time, and a separate folder that can hold all the output files should be created for each reach being processed. Using spaces in file names can sometimes cause problems with GIS and should be avoided.

B.3.1. Getting Input Data

B.3.1.1. Getting Shape File Data

Each watershed contains inundation shapefiles for the eight different return periods being created for the FPM project. These inundation shapefiles will consist of five different shapefiles. The shapefile with the frequency identifier followed by the reach identifier is the main inundation shapefile. The shapefile with the "_Add_Features" suffix contains any features that were manually added during the manual shapefile cleaning process. The shapefiles with "_Holes" and "_Ponds" suffixes hold features that were removed by the pre-cleaning script. The shapefile with the "_Remove_Features" suffix holds features that were manually deleted or removed. Figure B1 shows how each watershed has eight return periods, each of which contains five shapefiles.

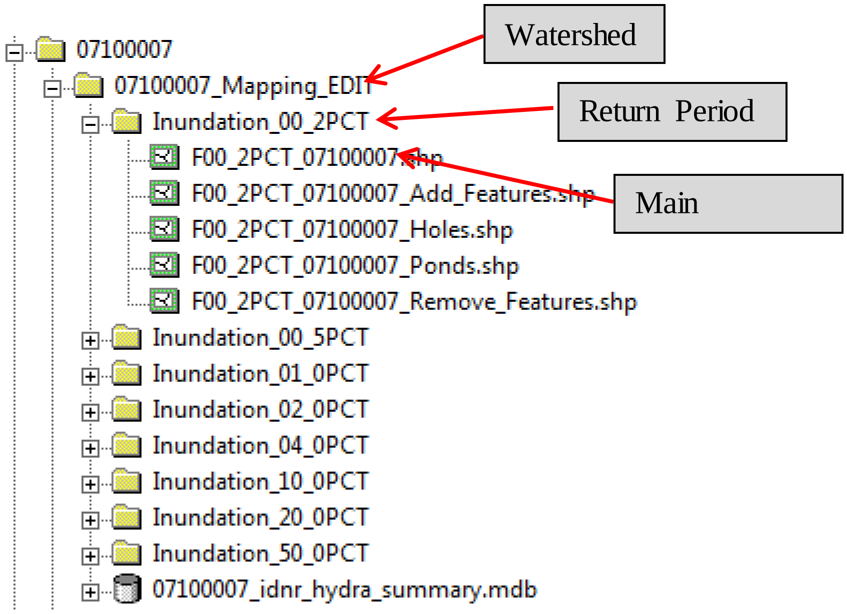


Figure B1: Inundation shapefile file structure

The inundation shapefiles for Iowa are currently available from the IFC in several different levels of completeness because the FPM project is ongoing.

The lowest level of completeness is inundation shapefiles that have only had the pre-cleaning script run on them to fill in islands and delete small ponds. These shapefiles have not been manually cleaned and do not have any features in their Add_Features shapefile.

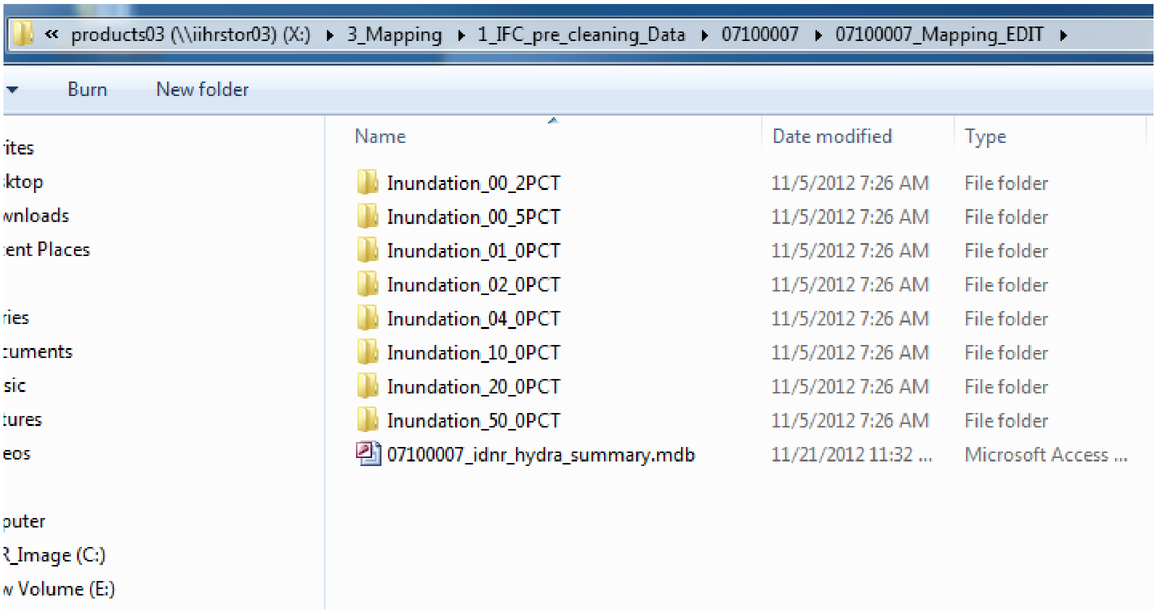
The second level of completeness is inundation shapefiles that have been manually cleaned to delete unwanted features and add new features where necessary. These shapefiles will contain features in their add-features shapefile. These features will also contain features in their Remove_Features shapefile and may have a sixth shapefile with the suffix "_Delete_Features" containing deleted features.

The third and highest level of completeness is inundation shapefiles that have been manually cleaned and have been reviewed by the IFC.

Ideally, the most complete version of the shapefiles should be used to produce scour characterization maps. Only the 100 and 500 year return periods are at the second or third level of completeness as of summer 2014. The other 6 return periods are still at the lowest level of completeness.

These inundation shapefiles can be obtained from the IFC. Download the entire watershed folder and add it to the project folder that was created on the local machine. Within this watershed folder, there are separate folders for each of the eight frequencies, as shown in Figure B2. Inundation_00_2PCT corresponds to the 0.2% annual exceedance probability; Inundation_00_5PCT corresponds to the 0.5% annual exceedance probability; Inundation_01_0PCT corresponds to the 1% annual exceedance probability; Inundation_02_0PCT corresponds to the 2% annual exceedance probability; Inundation_04_0PCT corresponds to the 4% annual exceedance probability; Inundation_10_0PCT corresponds to the 10% annual exceedance probability;

Inundation_20_0PCT corresponds to the 20% annual exceedance probability; and Inundation_50_0PCT corresponds to the 50% annual exceedance probability.



« products03 (\\iihrstor03) (X:) ▸ 3_Mapping ▸ 1_IFC_pre_cleaning_Data ▸ 07100007 ▸ 07100007_Mapping_EDIT ▸

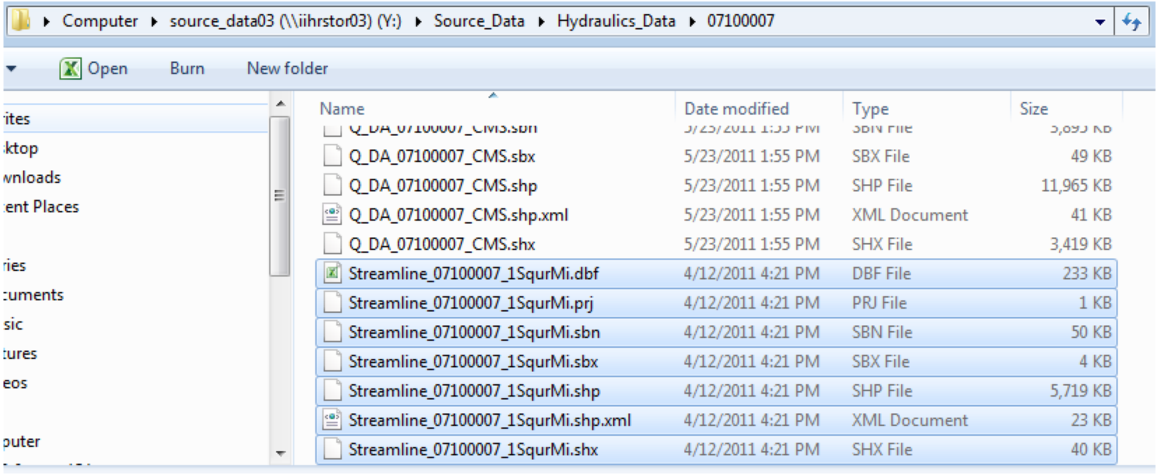
Name	Date modified	Type
Inundation_00_2PCT	11/5/2012 7:26 AM	File folder
Inundation_00_5PCT	11/5/2012 7:26 AM	File folder
Inundation_01_0PCT	11/5/2012 7:26 AM	File folder
Inundation_02_0PCT	11/5/2012 7:26 AM	File folder
Inundation_04_0PCT	11/5/2012 7:26 AM	File folder
Inundation_10_0PCT	11/5/2012 7:26 AM	File folder
Inundation_20_0PCT	11/5/2012 7:26 AM	File folder
Inundation_50_0PCT	11/5/2012 7:26 AM	File folder
07100007_idnr_hydra_summary.mdb	11/21/2012 11:32 ...	Microsoft Access ...

Figure B2: Example of inundation shapefile folders within each HUC8 watershed

B.3.1.2. Getting Stream Center Lines

Stream center lines are used to indicate on the maps where the main channel is located. The stream centerline shapefile is organized by HUC8 and can be obtained from the IFC.

Select and download all of the files associated with the streamlines, as demonstrated in Figure B3, where 07100007 is the identifier number corresponding to this particular watershed.



Name	Date modified	Type	Size
Q_DA_07100007_CMS.sbx	5/23/2011 1:55 PM	SBX File	49 KB
Q_DA_07100007_CMS.shp	5/23/2011 1:55 PM	SHP File	11,965 KB
Q_DA_07100007_CMS.shp.xml	5/23/2011 1:55 PM	XML Document	41 KB
Q_DA_07100007_CMS.shx	5/23/2011 1:55 PM	SHX File	3,419 KB
Streamline_07100007_1SqurMi.dbf	4/12/2011 4:21 PM	DBF File	233 KB
Streamline_07100007_1SqurMi.prj	4/12/2011 4:21 PM	PRJ File	1 KB
Streamline_07100007_1SqurMi.sbn	4/12/2011 4:21 PM	SBN File	50 KB
Streamline_07100007_1SqurMi.sbx	4/12/2011 4:21 PM	SBX File	4 KB
Streamline_07100007_1SqurMi.shp	4/12/2011 4:21 PM	SHP File	5,719 KB
Streamline_07100007_1SqurMi.shp.xml	4/12/2011 4:21 PM	XML Document	23 KB
Streamline_07100007_1SqurMi.shx	4/12/2011 4:21 PM	SHX File	40 KB

Figure B3: Example of streamline file names and location

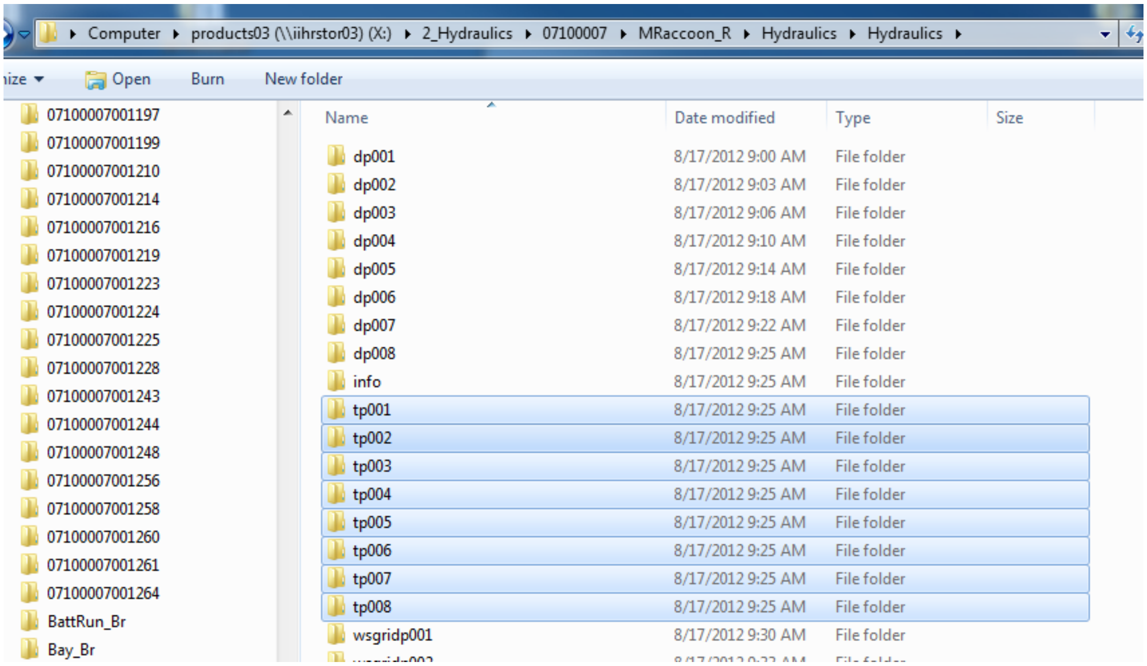
B.3.1.3. Getting Water Surface Elevation TIN

The water surface elevation TIN file is a required input and is available from the IFC. The water surface elevation TIN data are separated by reach. There are eight files, labeled tp001 to tp008 for each reach, that correspond to the eight return periods. The file suffixes and the return periods they represent are shown in Table B1. These file suffixes are the same for the depth raster files.

Table B1: Water Surface TIN and Depth Raster File Name Suffixes

001	2 year / 50 percent annual exceedance probability
002	5 year / 20 percent annual exceedance probability
003	10 year / 10 percent annual exceedance probability
004	25 year / 4 percent annual exceedance probability
005	50 year / 2 percent annual exceedance probability
006	100 year / 1 percent annual exceedance probability
007	200 year / 0.5 percent annual exceedance probability
008	500 year / 0.2 percent annual exceedance probability

Each TIN folder contains several important files. Download the entire TIN folder for each frequency of interest, as shown in Figure B4. Referencing the TIN files directly from their location on the shared drive does not work, so they must be downloaded.



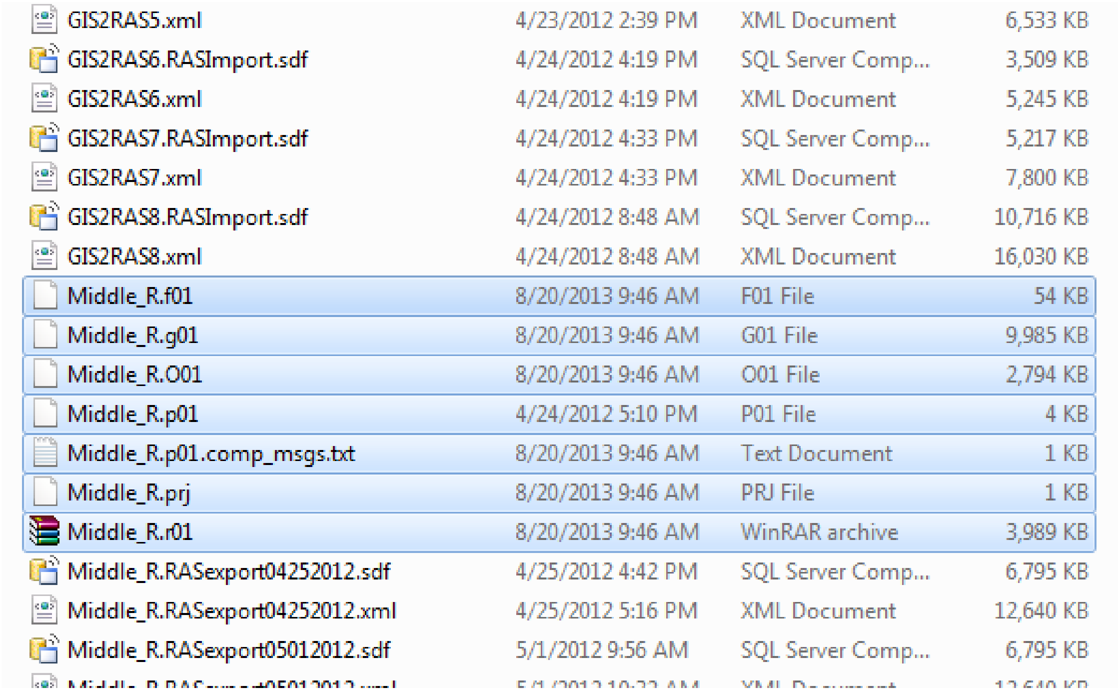
Name	Date modified	Type	Size
dp001	8/17/2012 9:00 AM	File folder	
dp002	8/17/2012 9:03 AM	File folder	
dp003	8/17/2012 9:06 AM	File folder	
dp004	8/17/2012 9:10 AM	File folder	
dp005	8/17/2012 9:14 AM	File folder	
dp006	8/17/2012 9:18 AM	File folder	
dp007	8/17/2012 9:22 AM	File folder	
dp008	8/17/2012 9:25 AM	File folder	
info	8/17/2012 9:25 AM	File folder	
tp001	8/17/2012 9:25 AM	File folder	
tp002	8/17/2012 9:25 AM	File folder	
tp003	8/17/2012 9:25 AM	File folder	
tp004	8/17/2012 9:25 AM	File folder	
tp005	8/17/2012 9:25 AM	File folder	
tp006	8/17/2012 9:25 AM	File folder	
tp007	8/17/2012 9:25 AM	File folder	
tp008	8/17/2012 9:25 AM	File folder	
wsgridp001	8/17/2012 9:30 AM	File folder	

Figure B4: Example of water surface elevation TIN folder names and location

B.3.1.4. Getting HEC-RAS Cross-Sections and Hydraulic Data

The HEC-RAS model and cross-section shapefiles are only needed for the SCA method. The hydraulics data are available from the IFC and are organized by reach.

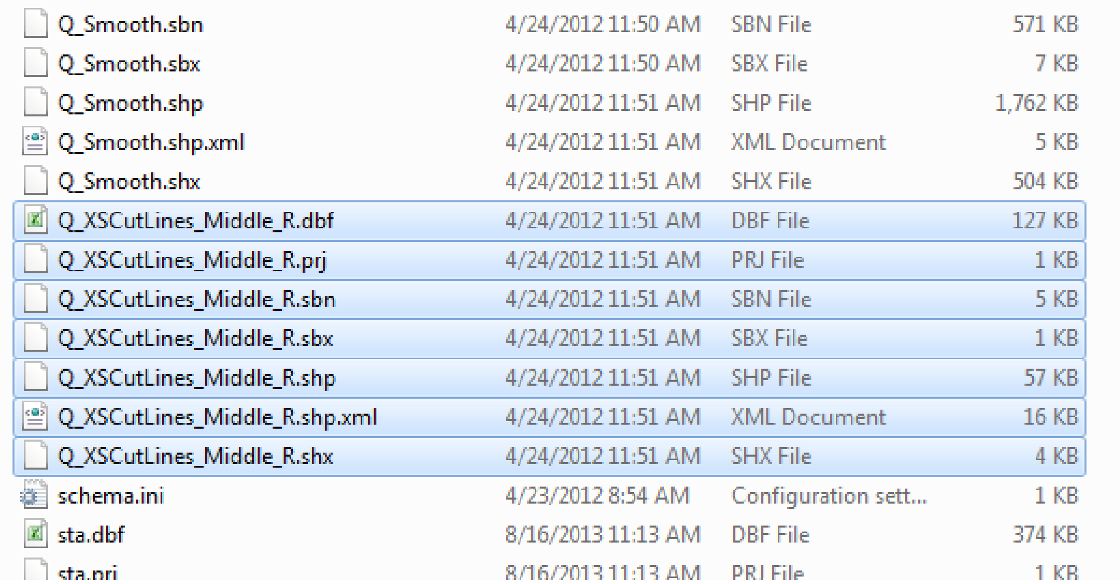
Download the files associated with the HEC-RAS project, as shown in Figure B5. “Middle_R” is the name of the reach in this example.



GIS2RAS5.xml	4/23/2012 2:39 PM	XML Document	6,533 KB
GIS2RAS6.RASImport.sdf	4/24/2012 4:19 PM	SQL Server Comp...	3,509 KB
GIS2RAS6.xml	4/24/2012 4:19 PM	XML Document	5,245 KB
GIS2RAS7.RASImport.sdf	4/24/2012 4:33 PM	SQL Server Comp...	5,217 KB
GIS2RAS7.xml	4/24/2012 4:33 PM	XML Document	7,800 KB
GIS2RAS8.RASImport.sdf	4/24/2012 8:48 AM	SQL Server Comp...	10,716 KB
GIS2RAS8.xml	4/24/2012 8:48 AM	XML Document	16,030 KB
Middle_R.f01	8/20/2013 9:46 AM	F01 File	54 KB
Middle_R.g01	8/20/2013 9:46 AM	G01 File	9,985 KB
Middle_R.O01	8/20/2013 9:46 AM	O01 File	2,794 KB
Middle_R.p01	4/24/2012 5:10 PM	P01 File	4 KB
Middle_R.p01.comp_msgs.txt	8/20/2013 9:46 AM	Text Document	1 KB
Middle_R.prj	8/20/2013 9:46 AM	PRJ File	1 KB
Middle_R.r01	8/20/2013 9:46 AM	WinRAR archive	3,989 KB
Middle_R.RASexport04252012.sdf	4/25/2012 4:42 PM	SQL Server Comp...	6,795 KB
Middle_R.RASexport04252012.xml	4/25/2012 5:16 PM	XML Document	12,640 KB
Middle_R.RASexport05012012.sdf	5/1/2012 9:56 AM	SQL Server Comp...	6,795 KB

Figure B5: Example of HEC-RAS model file location

Download the “Q_XSCutLines_REACH_ID” files. The correct files to be downloaded can be seen in Figure B6. “Middle_R” is the name of the reach in this example.



Q_Smooth.sbn	4/24/2012 11:50 AM	SBN File	571 KB
Q_Smooth.sbx	4/24/2012 11:50 AM	SBX File	7 KB
Q_Smooth.shp	4/24/2012 11:51 AM	SHP File	1,762 KB
Q_Smooth.shp.xml	4/24/2012 11:51 AM	XML Document	5 KB
Q_Smooth.shx	4/24/2012 11:51 AM	SHX File	504 KB
Q_XSCutLines_Middle_R.dbf	4/24/2012 11:51 AM	DBF File	127 KB
Q_XSCutLines_Middle_R.prj	4/24/2012 11:51 AM	PRJ File	1 KB
Q_XSCutLines_Middle_R.sbn	4/24/2012 11:51 AM	SBN File	5 KB
Q_XSCutLines_Middle_R.sbx	4/24/2012 11:51 AM	SBX File	1 KB
Q_XSCutLines_Middle_R.shp	4/24/2012 11:51 AM	SHP File	57 KB
Q_XSCutLines_Middle_R.shp.xml	4/24/2012 11:51 AM	XML Document	16 KB
Q_XSCutLines_Middle_R.shx	4/24/2012 11:51 AM	SHX File	4 KB
schema.ini	4/23/2012 8:54 AM	Configuration sett...	1 KB
sta.dbf	8/16/2013 11:13 AM	DBF File	374 KB
sta.prj	8/16/2013 11:13 AM	PRJ File	1 KB

Figure B6: Example of HEC-RAS cross-section shapefile location

B.3.1.5. Getting Manning's n and Land Cover Data

Manning's n and NLCD rasters for the entire state of Iowa are available from the IFC. These rasters can be copied to the project folder or left where they are if no modifications will be made to them.

B.3.1.6. Getting Pre-Calculated Land Cover Data

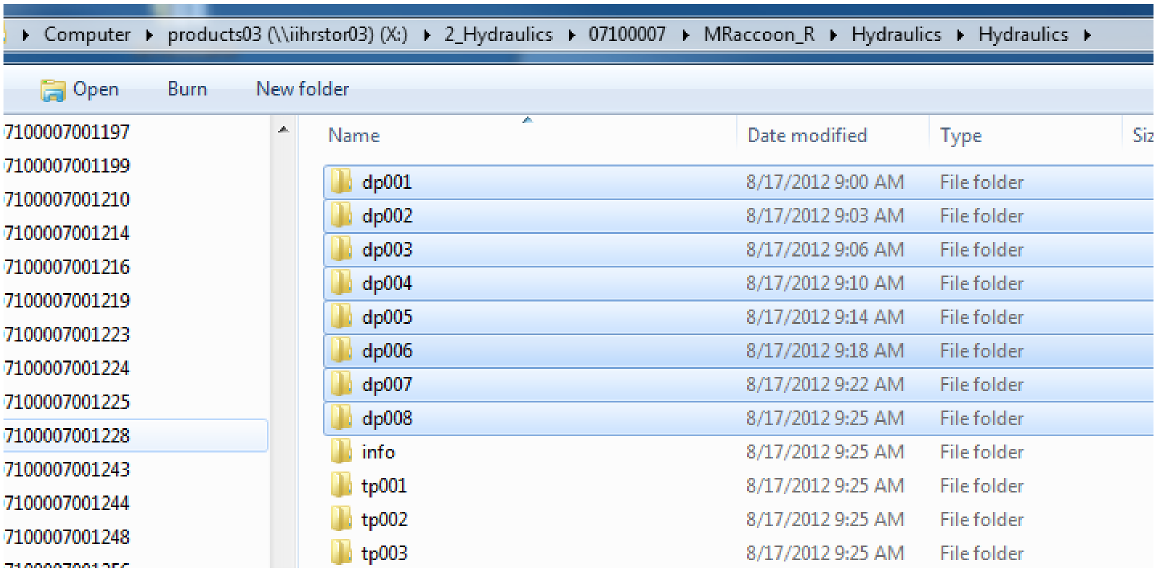
Four statewide raster datasets have been created from the statewide NLCD and Manning's n rasters. These rasters are named "ns_n_fnchanged," "ns_n_unchanged," "one_min_cf," and "n_d_oldn_pow" and are available from the IFC. These rasters are required inputs for the various effective shear tools and were calculated separately to improve efficiency.

B.3.1.7. Getting Aerial Photography

Statewide aerial photos are available on the Iowa State GIS server and from the IFC. Aerial photos can be loaded into GIS directly using ArcCatalog.

B.3.1.8. Getting the Un-Cleaned Depth Grids

The un-cleaned depth grids are available from the IFC and are organized by reach. The depth raster file names start with “dp” and are followed by the same numerical code corresponding to return period as is used with the TIN files. Figure B7 shows the depth rasters on the IFC shared drive. The depth rasters are often gigabytes in size and can take up much file space if copied to the local machine. It should be possible to reference the files from a shared drive when they are needed as an input to a GIS tool, but this can sometimes cause problems with GIS. The depth rasters will need to be downloaded to the local machine if referencing them in their shared drive location does not work.



Name	Date modified	Type	Siz
dp001	8/17/2012 9:00 AM	File folder	
dp002	8/17/2012 9:03 AM	File folder	
dp003	8/17/2012 9:06 AM	File folder	
dp004	8/17/2012 9:10 AM	File folder	
dp005	8/17/2012 9:14 AM	File folder	
dp006	8/17/2012 9:18 AM	File folder	
dp007	8/17/2012 9:22 AM	File folder	
dp008	8/17/2012 9:25 AM	File folder	
info	8/17/2012 9:25 AM	File folder	
tp001	8/17/2012 9:25 AM	File folder	
tp002	8/17/2012 9:25 AM	File folder	
tp003	8/17/2012 9:25 AM	File folder	

Figure B7: Example of un-cleaned depth raster folder location

B.3.1.9. Getting the SSURGO Shapefile and Allowable Shear Table

The statewide SSURGO soils data are available from the USDA NRCS. The SSURGO soils data contain shapefiles that spatially classify different types of surface soil. These shapefiles originally contain many features that result in memory errors when using them in GIS. A dissolved version of each county's SSURGO soil shapefile was created for this project and is available from the IFC. See (Soil Survey Staff, 2013) for more information on the SSURGO data.

B.4. Setting up the GIS File

A GIS template file is available from the IFC and should be used if maps are being prepared for the INHF because it contains a template layout for displaying the final maps. A blank GIS file can be created if data are going to be processed for another purpose. A map template is included with the general format and text boxes created under the layout view of the template file. The layout view will also have several graphics that can be modified and used as needed.

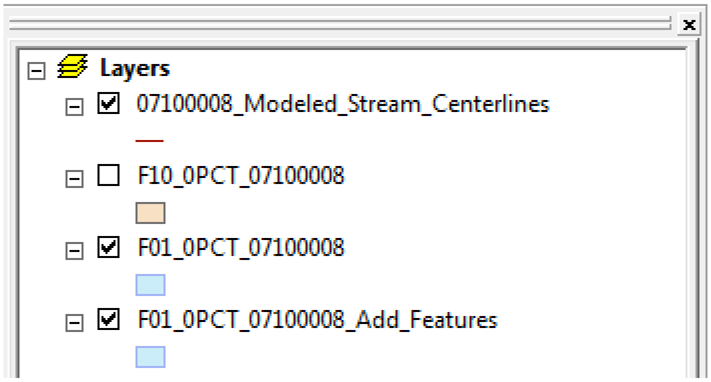
B.4.1. Loading Custom GIS Tools

The custom toolbox created for this project will need to be loaded into GIS. Add a new toolbox to ArcToolbox and navigate to the toolbox named "Scour Characterization Tools" toolbox obtained from the IFC. A copy of this toolbox should be made if any of the tools are going to be modified.

B.4.2. Loading the Input Data into GIS

B.4.2.1. Adding Inundation Shapefiles

Open ArcCatalog and use it to navigate to the folder where the inundation shapefiles were placed and drag the shape files with the desired frequencies into the project. Only the main shapefile is needed if working with shapefiles that haven't been manually cleaned and are in the lowest level of completeness. The add-features and remove-features shapefiles for the frequency should also be added if working with manually cleaned shapefiles. Figure B8 shows an example of a GIS project where the 10 and 100 year return period shapefiles were added. The 10 year shapefile has not been manually cleaned, so only the main shapefile has been added. The 100 year has been manually cleaned and is in the second level of completeness, so the add_features shapefile has also been added.

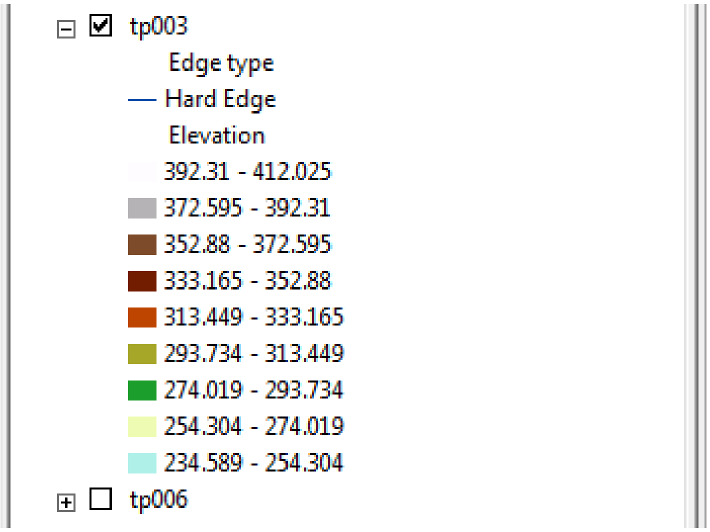


Layers
- ☑ 07100008_Modeled_Stream_Centerlines
- ☐ F10_0PCT_07100008
- ☑ F01_0PCT_07100008
- ☑ F01_0PCT_07100008_Add_Features

Figure B8: Inundation shapefiles added to GIS for 10 and 100 year return periods

B.4.2.2. Adding Water Surface Elevations – Optional

The WSE TIN files can optionally be loaded into GIS. Figure B9 shows the sample project where tp003 was added for the 10 year return period and tp006 was added for the 100 year return period.



⊟ ☑ tp003
Edge type
— Hard Edge
Elevation
■ 392.31 - 412.025
■ 372.595 - 392.31
■ 352.88 - 372.595
■ 333.165 - 352.88
■ 313.449 - 333.165
■ 293.734 - 313.449
■ 274.019 - 293.734
■ 254.304 - 274.019
■ 234.589 - 254.304
⊞ ☐ tp006

Figure B9: Water surface elevation TIN files added to GIS project for 10 and 100 year return periods

B.4.2.3. Adding Stream Centerline Data

Add the stream centerline data by dragging it into the project from ArcCatalog.

B.4.2.4. Adding n and Land Cover Data – Optional

The Manning's n and land cover maps can be left where they are or added to GIS. It can be convenient to have the Manning's n and land cover data in the project when analyzing results, but is not necessary for map creation.

B.4.2.5. Adding SSURGO Data and Allowable Shear Table

The SSURGO soils maps are separated by county and are numbered 1-197, with even numbers skipped. The counties in Iowa are numbered from 01 to 99. Identify the number corresponding to the county of interest using Figure B10.

IOWA COUNTIES AND COUNTY CODES NUMBERS

01-ADAIR
02-ADAMS
03-ALLAMAKEE
04-APPANOOSE
05-AUDUBON
06-BENTON
07-BLACK HAWK
08-BOONE
09-BREMER
10-BUCHANAN
11-BUENA VISTA
12-BUTLER
13-CALHOUN
14-CARROLL
15-CASS
16-CEDAR
17-CERRO GORDO
18-CHEROKEE
19-CHICKASAW
20-CLARKE
21-CLAY
22-CLAYTON
23-CLINTON
24-CRAWFORD
25-DALLAS
26-DAVIS
27-DECATUR
28-DELAWARE
29-DES MOINES
30-DICKINSON
31-DUBUQUE
32-EMMET
33-FAYETTE
34-FLOYD
35-FRANKLIN
36-FREMONT
37-GREENE
38-GRUNDY
39-GUTHRIE
40-HAMILTON
41-HANCOCK
42-HARDIN
43-HARRISON
44-HENRY
45-HOWARD
46-HUMBOLDT
47-IDA
48-IOWA
49-JACKSON
50-JASPER
51-JEFFERSON
52-JOHNSON
53-JONES
54-KEOKUK
55-KOSSUTH
56-LEE
57-LINN
58-LOUISA
59-LUCAS
60-LYON
61-MADISON
62-MAHASKA
63-MARION
64-MARSHALL
65-MILLS
66-MITCHELL
67-MONONA
68-MONROE
69-MONTGOMERY
70-MUSCATINE
71-O'BRIEN
72-OSCEOLA
73-PAGE
74-PALO ALTO
75-PLYMOUTH
76-POCAHONTAS
77-POLK
78-POTTAWATTAMIE
79-POWESHIEK
80-RINGGOLD
81-SAC
82-SCOTT
83-SHELBY
84-SIOUX
85-STORY
86-TAMA
87-TAYLOR
88-UNION
89-VAN BUREN
90-WAPELLO
91-WARREN
92-WASHINGTON
93-WAYNE
94-WEBSTER
95-WINNEBAGO
96-WINNESHIEK
97-WOODBURY
98-WORTH
99-WRIGHT

Figure B10: Iowa county codes

Multiply the county number by 2 and subtract 1 to obtain the number corresponding to the correct county in the SSURGO data.

Use ArcCatalog to navigate to the correct county; go to the “spatial” folder; and add the “soilmu_a_iaXXX_Dissolve.shp” file to GIS. The XXX is the county number calculated in the previous step. Figure B11 shows an example of the SSURGO soil data layout in ArcCatalog.

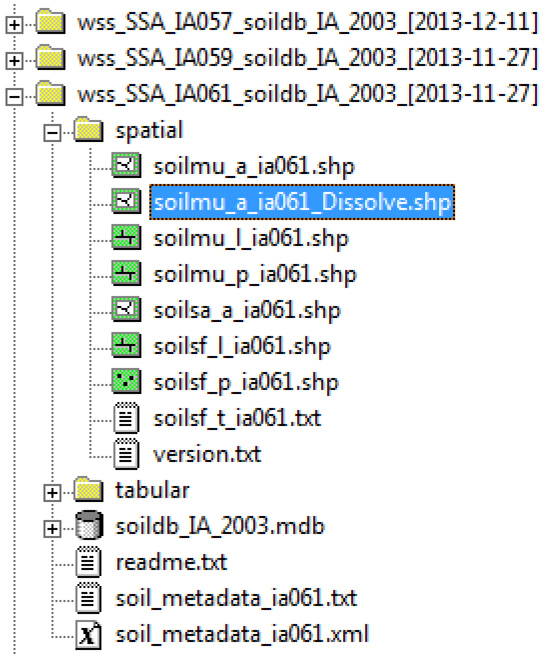


Figure B11: SSURGO soils data file structure in ArcCatalog

The SSURGO data are comprised of shapefiles containing map unit symbols that refer to the surface soil type. The surface soil types have been given allowable shear values by the USDA NRCS (2007). A database table was created that can be used to link the surface soil types in the SSURGO shapefiles to the NRCS allowable shear values.

This allowable shear database file is called “ALLOWSHR.dbf” and is available from the IFC. Add the “ALLOWSHR.dbf” file into GIS using ArcCatalog.

B.4.2.6. Adding the Aerial Photo

There are two ways to add the aerial photo. The aerial photo can be added to the project with ArcCatalog if the photo for a specific county was obtained from the IFC shared drive. It is also possible to link to an aerial photo of the entire state located on the Iowa State Geographic map server. The following steps demonstrate how to link to the statewide aerial photo.

Click on the GIS Servers folder in ArcCatalog and then Add ArcGIS Server as shown in Figure B12.

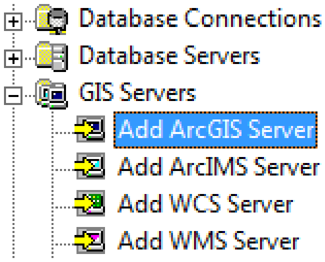
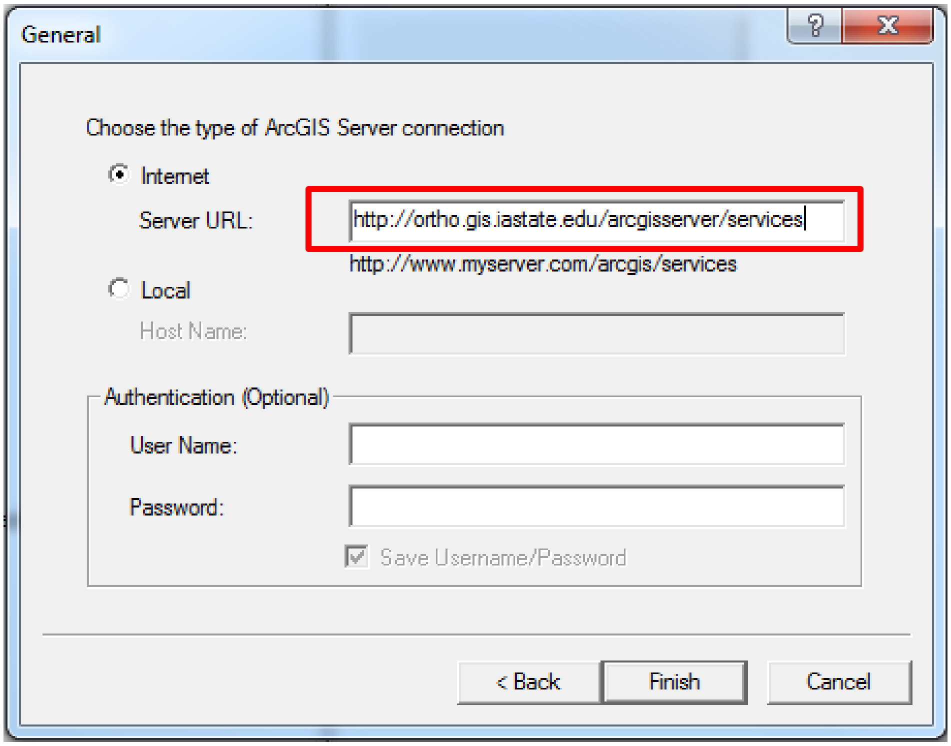


Figure B12: Adding ArcGIS server

Select the "Use GIS Services" button and click "Next". Add http://ortho.gis.iastate.edu/arcgisserver/services, as shown in Figure B13.



● Internet

Server URL: http://ortho.gis.iastate.edu/arcgisserver/services

Figure B13: ArcGIS Server connection URL window with the correct server URL entered in the red box

Select the “naip_2013_nc” aerial photo from within the “ortho” folder of this server, and add it to the GIS project.

B.5. Pre-Processing the Input Data

A sample project will demonstrate how to use the input data to create shear, velocity, cleaned depth, and scour characterization data and maps for reporting to the INHF. All custom tools discussed are located in the “Scour Characterization Tools” toolbox.

B.5.1. Determining Cell Size

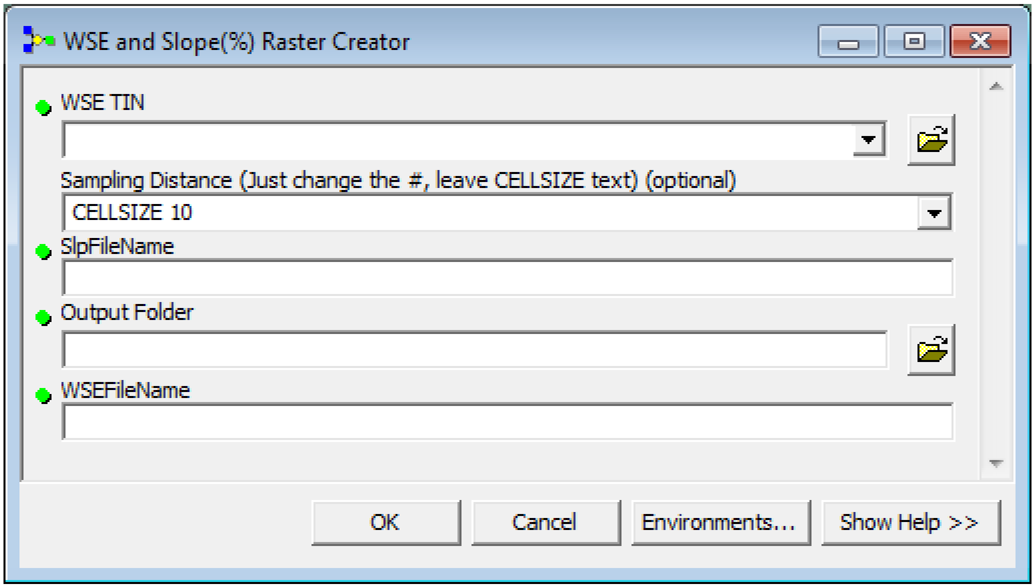
The recommended cell size for creating velocity, shear, or scour maps is 10 meters. Smaller cell sizes result in longer computation times and do not usually provide any benefit over using a cell size of 10 meters. A reach is likely too small or narrow to create accurate maps for if a cell size of 10 meters seems too large.

The un-cleaned depth grid inputs have a cell size of 1 meter. Depth grid cleaning can be conducted at a larger cell size or at the original cell size of 1 meter. It is recommended that depth grid cleaning be conducted at 1m so the resulting files can be useful for other projects.

B.5.2. Creating WSE and Slope Rasters

B.5.2.1. Using the “WSE and Slope(%) Raster Creator” Tool

It is necessary to create a water surface elevation raster and a slope raster, which can be done using the “WSE and Slope(%) Raster Creator” tool. This tool has the input prompt box shown as Figure B14.



WSE and Slope(%) Raster Creator

WSE TIN

Sampling Distance (Just change the #, leave CELLSIZE text) (optional)

CELLSIZE 10

SlpFileName

Output Folder

WSEFileName

Figure B14: "WSE and Slope(%) Raster Creator" tool input window

The TIN file for the WSE should be used as the input for the “WSE TIN” field. The “Sampling Distance” field sets the output cell size. It is important to only change the number and leave the “CELLSIZE” text as is. The “SlpFileName” field is for entering the desired file name of the slope raster output, and the “WSEFileName” is for entering the name of the WSE raster output. These names must have 13 or fewer characters and no spaces, which is also true when naming a raster file in any of the GIS tools. The “Output Folder” input is where the created WSE and slope rasters will be created.

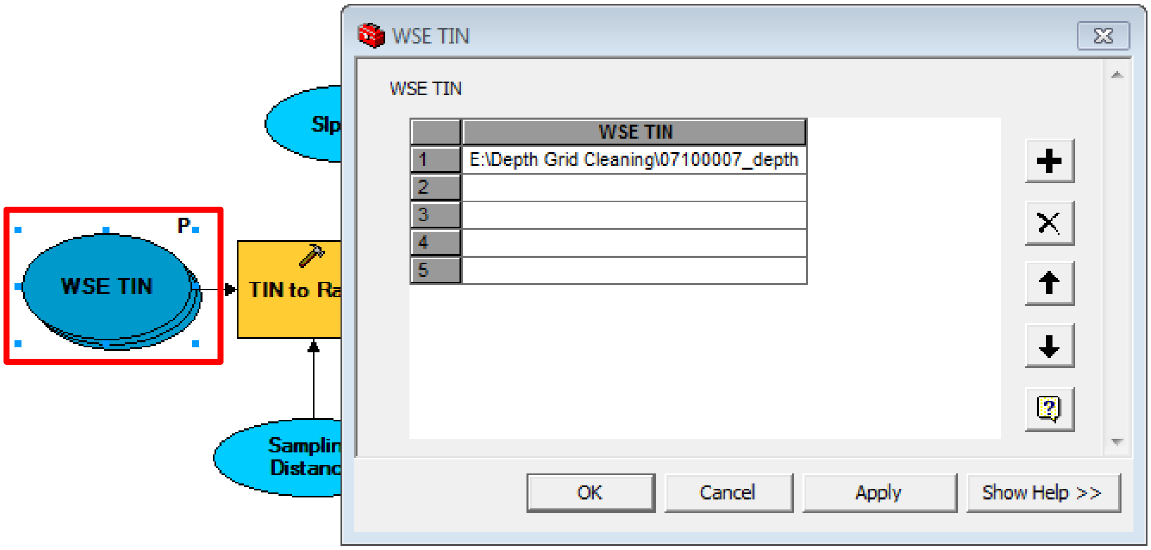
The slope raster output is in percent slope, which is important because the slope raster input for all tools in the “Scour Characterization Tools” toolbox is assumed to be in units of percent slope. The water surface elevation is in units of meters. The created water surface elevation and slope rasters can be added to the project or left in the output folder.

The tool is set to create the WSE and Slope rasters with the NAD_1983_UTM_Zone_15N geographic coordinate system, which is the same coordinate system as the inundation shapefiles. The coordinate system can be changed by right clicking on the “WSE and Slope(%) Raster Creator” tool, selecting edit, and changing the value in the “Result Coordinate System” variable.

B.5.2.2. Using the “WSE and Slope(%) Raster Creator - Multiple” Tool

Multiple water surface elevation TIN files can be processed simultaneously by using the “WSE and Slope(%) Raster Creator – Multiple” tool. This tool functions the same as its single output counterpart, except it can run for any number of TIN inputs. The output file names will all be the same as specified in the input window followed by an iteration number, so it should only be run for up to eight frequencies of the same reach at a time to prevent confusing file names. Adding the WSE TIN files for eight return periods will result in eight slope raster outputs and eight water surface elevation raster outputs.

The input files must be set up in the editor window by right clicking the tool and selecting edit. Once in the editor window, double click the “WSE TIN” input and use the plus sign to add the correct number of input fields, as shown in Figure B15. The input fields can then be populated by double clicking on the table. The WSE TIN file input in the “1” row will have a 0 iteration number at the end of the resulting file names; the WSE TIN file input in the “2” row will have a 1 iteration number at the end of the resulting file names, etc. The order of input files should be noted by the user to ensure that they can identify which output files correspond to which input files. To avoid confusion, input TIN files should be ordered consistently when producing files for multiple return periods of multiple reaches.



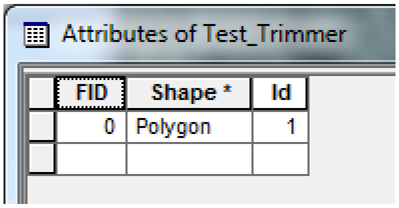
WSE TIN

	WSE TIN
1	E:\Depth Grid Cleaning\07100007_depth
2	
3	
4	
5	

Figure B15: Example of adding input files to "WSE and Slope(%) Raster Creator - Multiple" tool. The WSE TIN input in the rectangle must be double clicked to add multiple files

B.5.3. Creating a Bounding Polygon - Optional

Several of the SCA tools depend on zonal statistics to function. The zonal statistics tool needs a polygon to indicate the area where the statistics are to be applied. Create a new polygon that completely encloses the area that is being modeled. Change the Id field of the attribute table to 1 because the zonal statistics tools within the custom tools need a field in the attribute table to have the value 1 in order to function properly. The name of this polygon must not contain spaces. Figure B16 shows the Id field of the attribute table changed from the default of 0 to the new value of 1. Figure B17 shows an example bounding polygon. A coordinate system must also be added to the bounding polygon shapefile. Go the properties of the shapefile in ArcCatalog and select import under the XY Coordinate System tab. Import the coordinate system from one of the inundation shapefiles or water surface elevation TIN. This way the bounding polygon shapefile will be in the same coordinate system as the 1D HEC-RAS data. Creating a boundary polygon is necessary when using the SCA method, but this does not need to be done for the cell-by-cell method.


Attributes of Test_Trimmer

FID	Shape *	Id
0	Polygon	1

Figure B16: Bounding polygon Id field changed to 1

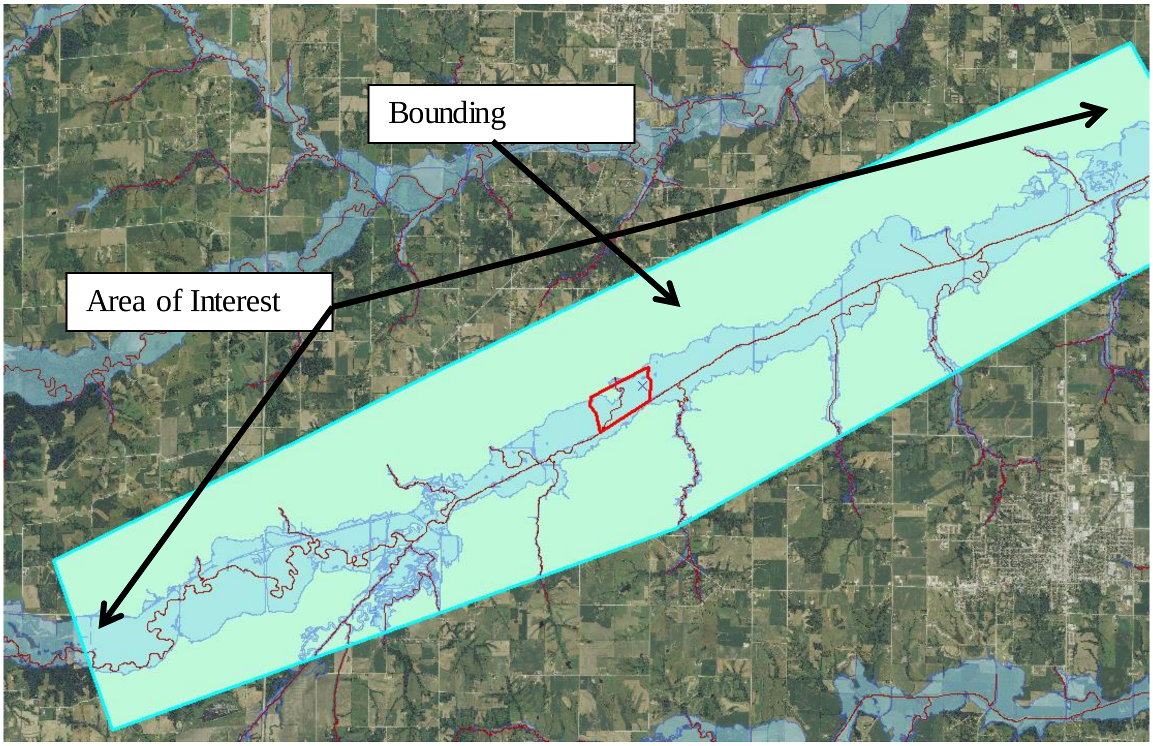
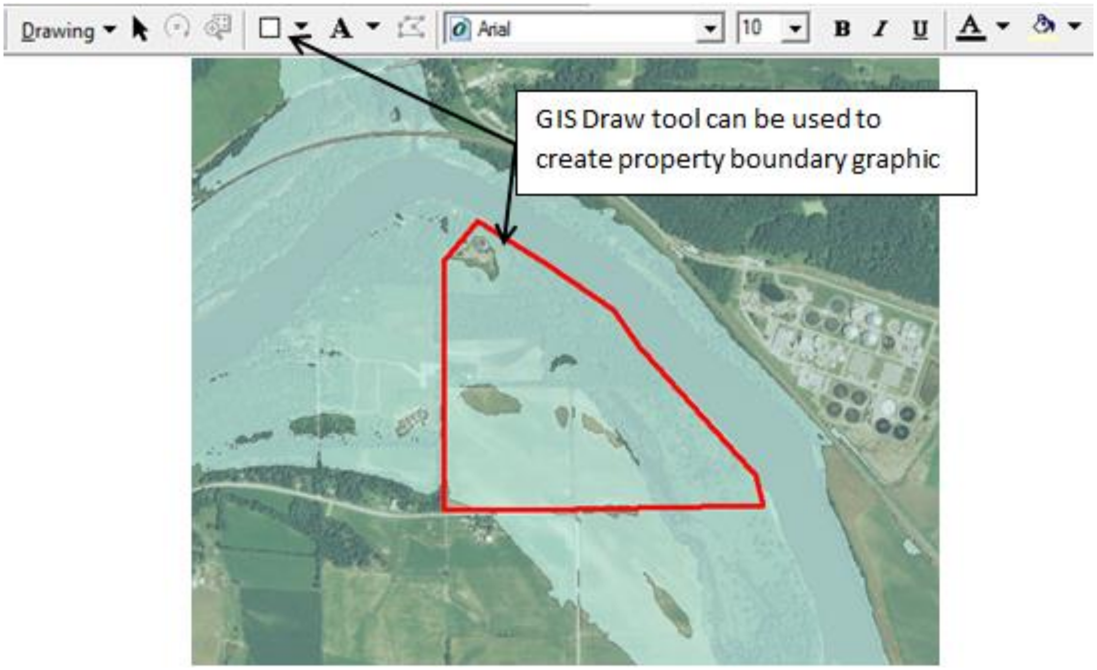


Figure B17: Bounding polygon created for area of interest

B.6. Creating Property Boundary

The GIS draw tool can be used to create lines around the property boundary if the maps are being prepared for the INHF and property boundary information is desired, as shown in Figure B18.



GIS Draw tool can be used to create property boundary graphic

Figure B18: Property boundary

B.7. Inundation Shapefile Setup

The map packet for the INHF will include a map that shows the basic floodplain inundation boundaries and that makes it easier to identify landmarks and interpret the depth and shear maps.

The inundation shapefiles will contain separate add-feature shapefiles if they have been manually cleaned. These add-features shapefiles must be combined with the main HUC8 shapefile. Use the GIS "Merge" tool to combine the main and add-features shapefiles, as shown in Figure B19. The add-features must have "DirName" values that correctly match the river they belong to.

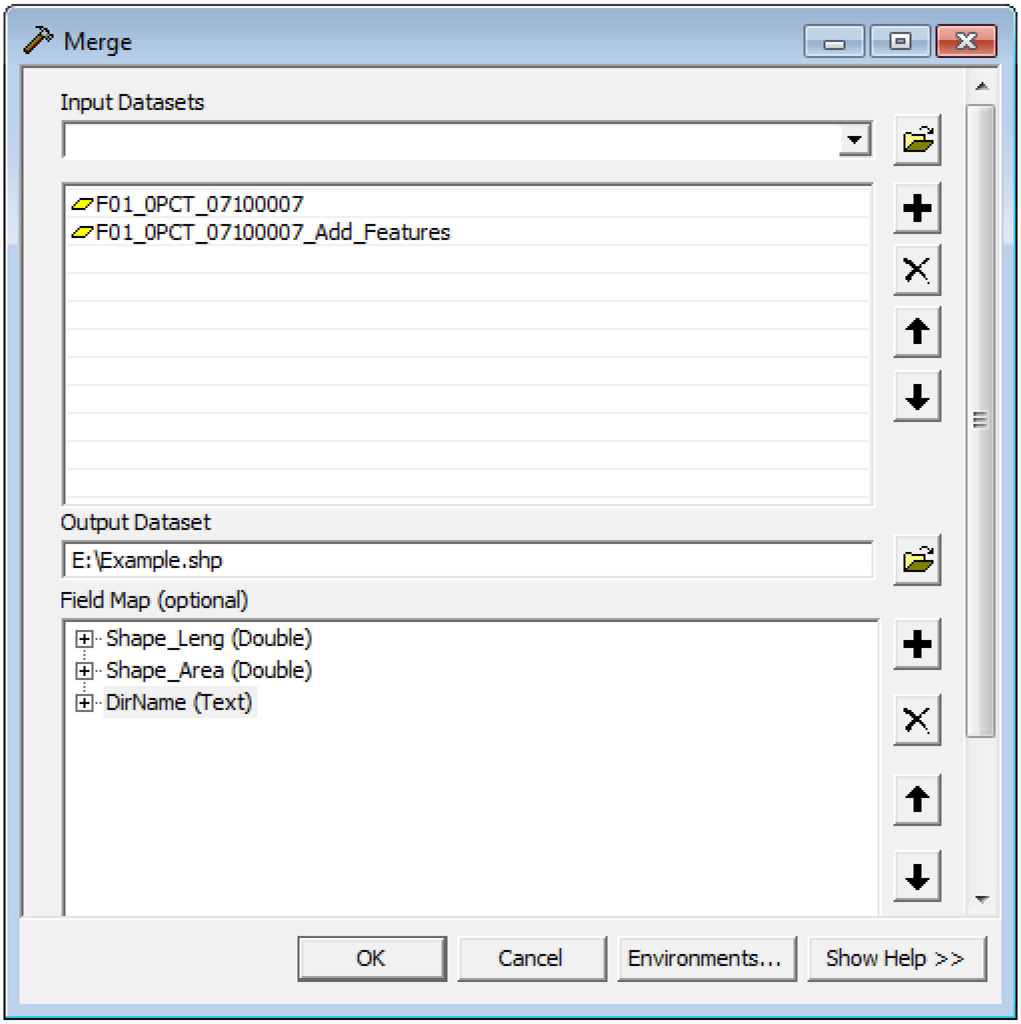


Figure B19: Input window of GIS Merge tool used to combine the main and add-features shapefiles

Inundation shapefiles for the 100 and 500 year return periods that were manually cleaned may have their delete features located in their "_Remove_Features" shapefile instead of in the "_Delete_Features" shapefile. The user should always determine whether this is the case and ensure that "Remove_Features" polygons have also been removed from the main shapefile. These remove features must be removed from the main shapefile using the GIS "Erase" tool if they have not already been removed.

Change the color of the inundation shapefile to light blue. Set the transparency of the shapefiles to ~50%. The stream centerlines should also be shown to make the maps easier to interpret. Figure B20 shows an inundation shapefile, with stream centerlines, that is ready to be used to create a map for the INHF.

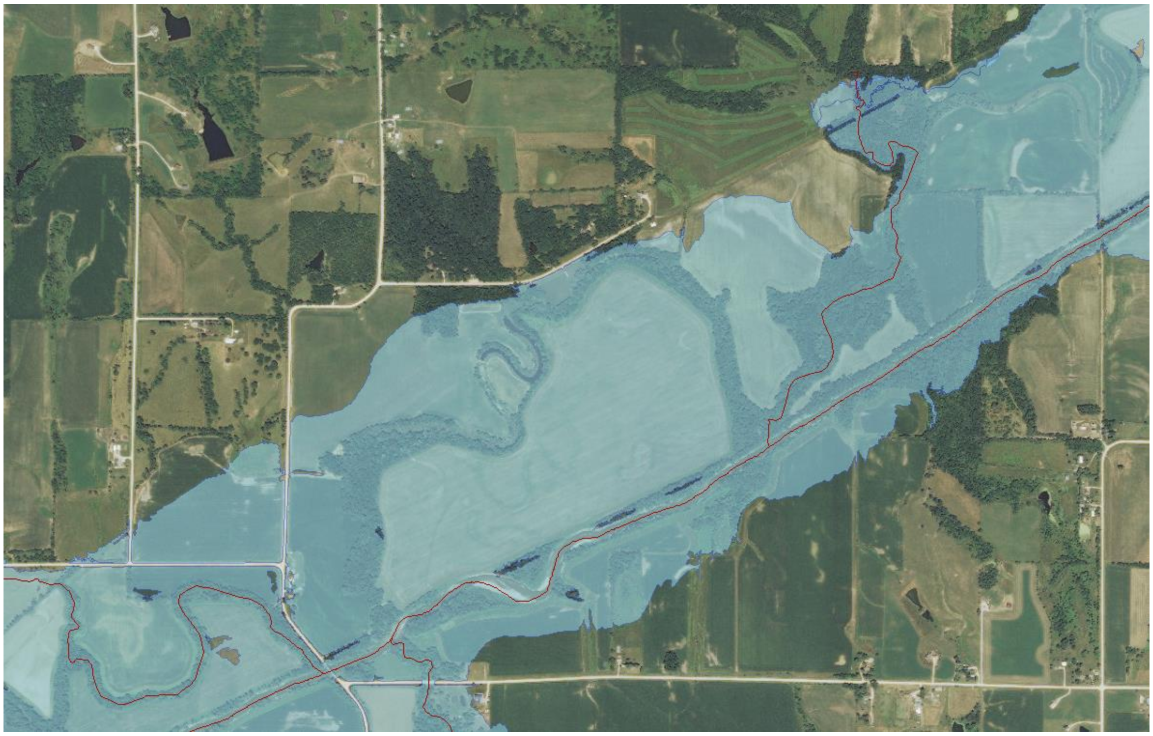


Figure B20: Inundation shapefile prepared for map creation

B.8. Cleaning Depth Grids

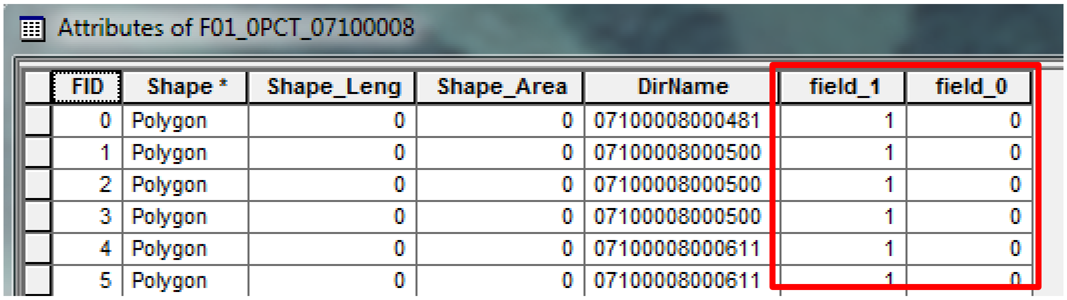
The depth grid cleaning tool removes areas from the depth raster that were removed from the shapefiles during the cleaning process and adds raster data to areas where the inundation shapefile contains additions. Depth raster cleaning can be done with the "un-cleaned" shapefiles or manually cleaned shapefiles. All un-cleaned shapefiles have still had small ponds and holes filled using a script, so using them to clean the depth grids will maintain the benefit of removing this small "noise" in the depth grid.

The manually cleaned shapefiles that have had their edits reviewed by the IFC should be used when possible. Un-cleaned shapefiles or shapefiles that have been cleaned manually, but have not been reviewed, can still be used to clean depth rasters, but the depth data created will not be official and should only be used for appropriate projects.

B.8.1. Setting up Shapefiles for Depth Raster Cleaning

It is possible to manually clean near the specific property of interest if the shapefiles have not yet been cleaned. Start editing the inundation shapefile and simply delete unwanted areas. Normally, deleted features would be added to another shapefile for review by the IFC, but in this case, there is no reason to do this when only a specific area is being cleaned for creation of maps for the INHF. Create a separate add-features shapefile, and use it to draw in any features that need to be added, if necessary. Shapefile cleaning guidelines can be found in (Iowa Flood Center, n.d.). It is crucial to follow these cleaning guidelines when creating add-features, particularly the instructions regarding setting up the shapefiles with the correct "DirName" field. Contact the IFC to obtain this document. Shapefiles cleaned in this unofficial manner should not be used to create depth rasters that might be used for other projects. Merge any added features into the main shapefile.

Add two short integer fields called "field_1" and "field_0" to the HUC8 inundation shapefile. These fields **must** be named exactly as specified to prevent failure of the depth raster cleaning tools. Calculate "field_1" so that all of the values are equal to 1. Calculate "field_0" so that all of the values are equal to 0. Figure B21 shows an example of the attribute table of an inundation shapefile after it has had the correct fields added.



Attributes of F01_0PCT_07100008

FID	Shape *	Shape_Leng	Shape_Area	DirName	field_1	field_0
0	Polygon	0	0	07100008000481	1	0
1	Polygon	0	0	07100008000500	1	0
2	Polygon	0	0	07100008000500	1	0
3	Polygon	0	0	07100008000500	1	0
4	Polygon	0	0	07100008000611	1	0
5	Polygon	0	0	07100008000611	1	0

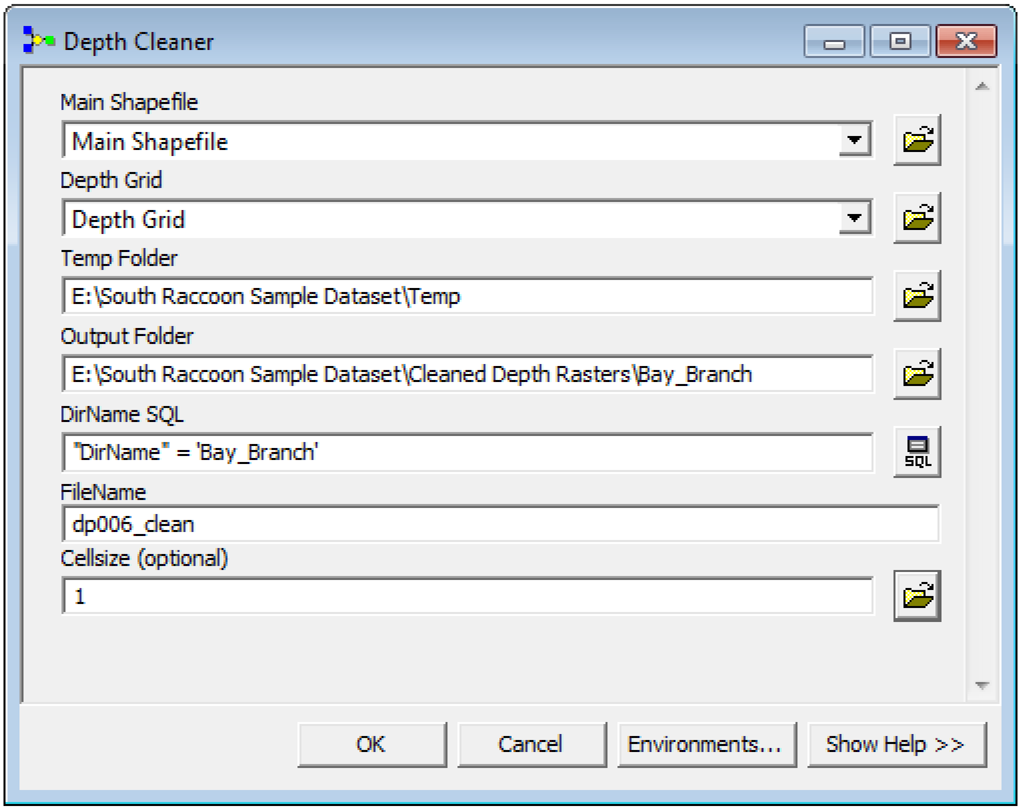
Figure B21: Attribute table of HUC8 shapefile after addition of the required fields, shown in the rectangle

B.8.2. Depth Raster Cleaning Tools

There are two depth cleaning tools. The first tool is named “Depth Cleaner” and runs a frequency of a single reach. The second tool is named “Depth Cleaner – Multiple” and runs multiple frequencies of a single reach. It is currently only possible to clean the depth rasters of a single reach at a time because the depth rasters are separated by reach.

B.8.2.1. Using the “Depth Cleaner” Tool

Click the “Depth Cleaner” tool to start it. The input dialog box is shown in Figure B22. The fields have already been populated to show an example for the 100 year return period of the river named Bay Branch, but they will normally be blank upon starting the tool.



Main Shapefile: Main Shapefile

Depth Grid: Depth Grid

Temp Folder: E:\South Raccoon Sample Dataset\Temp

Output Folder: E:\South Raccoon Sample Dataset\Cleaned Depth Rasters\Bay_Branch

DirName SQL: "DirName" = 'Bay_Branch'

FileName: dp006_clean

Cellsize (optional): 1

Figure B22: "Depth Cleaner" tool input window

The “Main Shapefile” field is where the main inundation shapefile is added. The main shapefile **must** have “field_1” and “field_0” added as per the instructions in Section B.8.1 or the tool will crash GIS.

The “Depth Grid” field is where the un-cleaned depth raster is added.

“Temp Folder” and “Output Folder” are the folder paths to the desired folder for temporary files and final output files.

“DirName SQL” is a statement used to select the shapefile of the reach to be cleaned from the main HUC8 shapefile. Check in the attribute table to ensure that the correct name is used for the reach to be cleaned. The DirName of the sample reach that is being cleaned is “Bay_Branch”.

“FileName” is the field that holds the desired file name of the final output file. This file name must be 13 characters or fewer and contain no spaces or special characters.

The “Cell Size” field holds the desired cell size. It is recommended that the depth rasters be cleaned at a 1 meter cell size if they are being added to a database or might be used for other projects. A cell size of up to 5 meters can be used if the depth rasters are only being used to create scour characterization maps or prepare depth maps for the INHF.

B.8.2.2. Using the “Depth Cleaner – Multiple” Tool

The “Depth Cleaner – Multiple” tool can be used to clean multiple depth rasters at once. These rasters have to be different return periods of the same reach with the same “DirName.” The tool can clean up to eight depth rasters at once, one for each return period of a reach.

The tool must be modified in the model editor depending on the number of depth rasters to be cleaned. Right click the tool and select edit, and the following tool layout shown as Figure B23 will appear. The two inputs that need to be modified within the editor window are shown in the red squares.

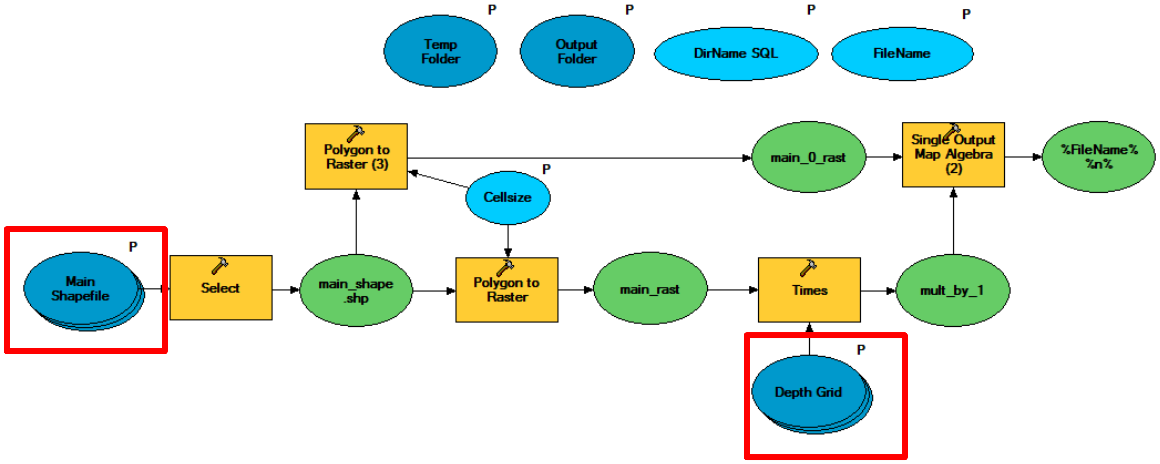


Figure B23: "Depth Cleaner - Multiple" tool editor window with two inputs that require their inputs to be added from within the editor window indicated with rectangles

Double click on the “Main Shapefile” input, and the input box shown in Figure B24 should appear.

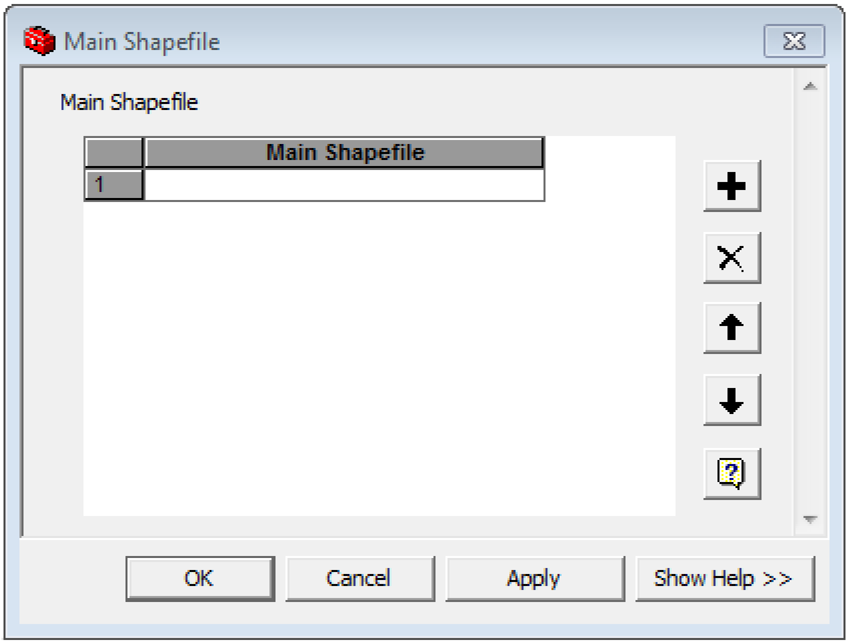
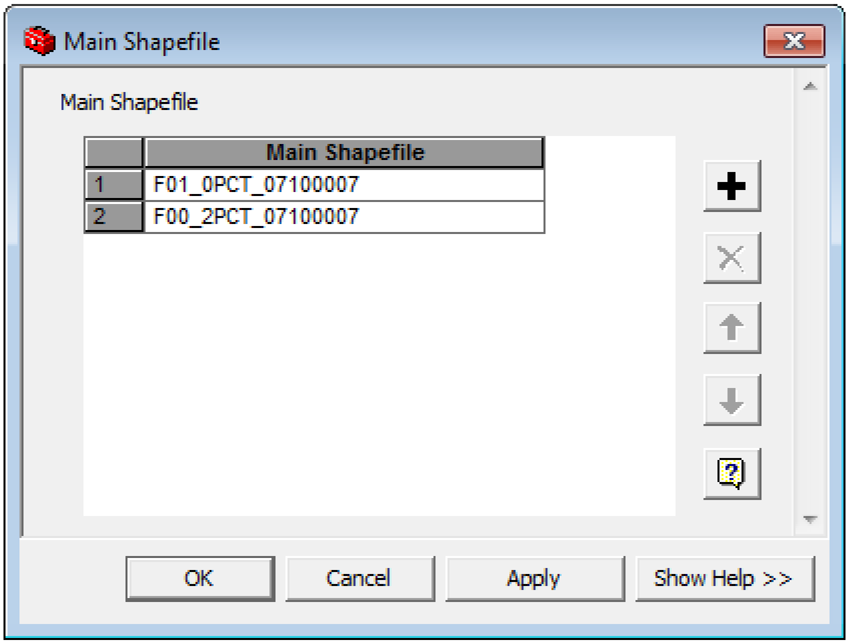


Figure B24: Main shapefile input table

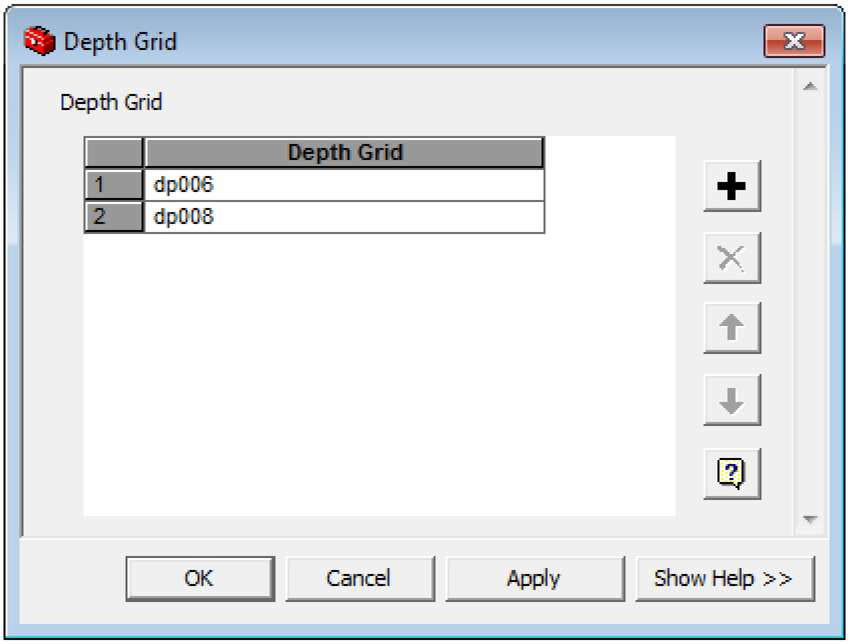
Click the plus sign so that the number of rows increases to the number of files to be run. Populate the rows by double clicking on each row and selecting the main shapefiles corresponding to the frequency of each depth raster to be cleaned. Figure B25 shows the "Main Shapefile" input setup for a project where the tool will be run for the 500 and 100 year return periods.



	Main Shapefile
1	F01_0PCT_07100007
2	F00_2PCT_07100007

Figure B25: Main shapefile input example

Double click the "Depth Grid" input and click the plus sign to add the correct number of rows. The number of rows must be the same as the number of rows in the "Main Shapefile" input. Add the depth rasters to be cleaned by double clicking on each row. The depth rasters must be in the same order as their corresponding shapefiles. Figure B26 shows a sample project where the 100 and 500 year return period depth rasters were added. The 100 year return period depth raster is listed first because the 100 year return period shapefile was also listed first in the "Main Shapefile" tool.



	Depth Grid
1	dp006
2	dp008

Figure B26: Depth raster input example

Save and exit the editor window after the “Main Shapefile” and “Depth Grid” inputs have been added. The tool can now be clicked from the GIS tools window and the other input parameters can be filled in normally. The input box for the “Depth Cleaner – Multiple” tools is the same as the input box for the “Depth Cleaner” tool.

The “Main Shapefile” and “Depth Grid” fields should not be modified from this input window because they were already modified from within the editor view and should already be populated.

The “FileName” field needs 12 or fewer characters because an iteration number will be added to the end of the file name of each output raster, and the total character length of a raster name cannot exceed 13.

B.9. Creating Cell-by-Cell Method Velocity Maps

Cell-by-cell method velocity maps are a required input for the SCA method but are not needed to create effective shear or excess shear ratio maps using the cell-by-cell method. The tool that creates velocity maps using the cell-by-cell method and Manning's Equation is called the "Velocity – Manning Equation." This tool requires the depth raster, slope raster, and Manning's n raster as inputs. The "Velocity – Manning Equation – n changed" version of the tool should be used instead if the Manning's n input data have been changed from that which was used in the HEC-RAS model. Click on the tool in the GIS toolbox and the command prompt shown in Figure B27 will appear.

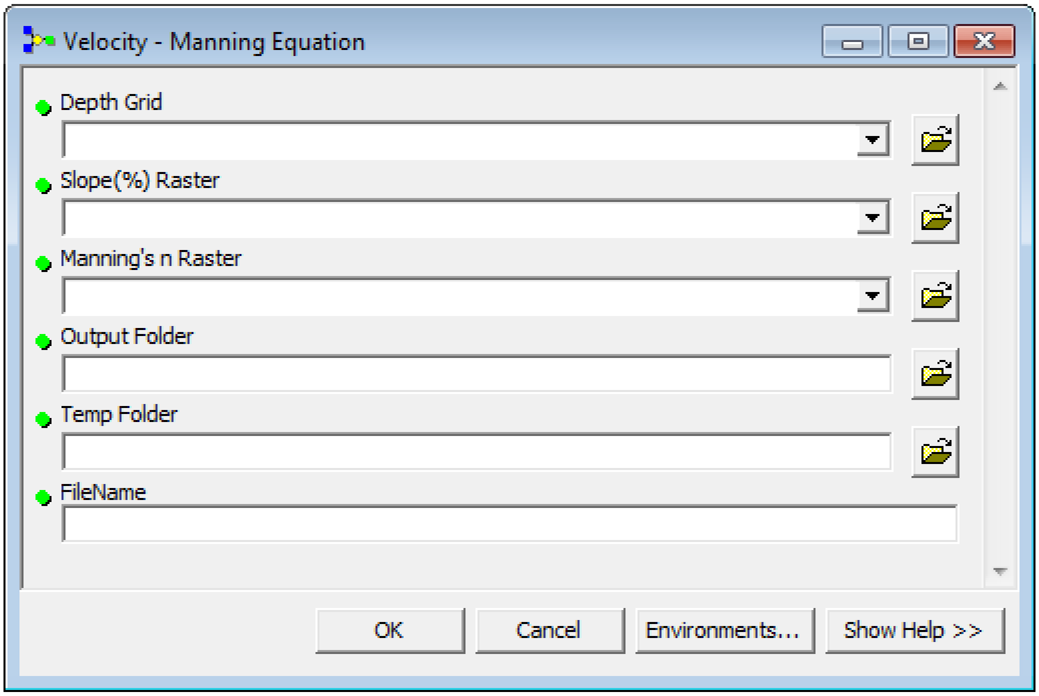


Figure B27: "Velocity - Manning Equation" tool input window

The "Depth Grid" field is where the depth raster input should be added. The cell size of the depth raster can be reduced prior to using it as this input if it causes run times to be too long.

The "Slope(%) Raster" field is where the slope raster should be added. The slope raster must be in units of percent slope.

The “Manning’s n Raster” field is where the Manning’s n raster should be added.

The “Output Folder” and “Temp Folder” fields are for selecting where the final files and temporary files should be placed.

The “FileName” field is for entering the name of the final velocity raster. The name must follow normal GIS raster naming conventions.

The cell size is determined by the cell size of the slope raster input, so it will be 10 meters if the slope raster was created at a size of 10 meters. The cell size can also be user specified by right clicking on the tool and selecting edit. Go to file >> model environment settings >> raster settings >> show values >> select “as specified below” >> and enter the correct cell size, in meters, in the field.

The “Velocity – Manning Equation” tool outputs velocity in units of meters per second.

B.10. Creating Cell-by-Cell Method Bed Shear Maps

Cell-by-cell bed shear maps can be created in the same way the velocity maps were created in the previous section. Click on the “Bed Shear” tool in the toolbox, and the input window shown in Figure B28 should appear.

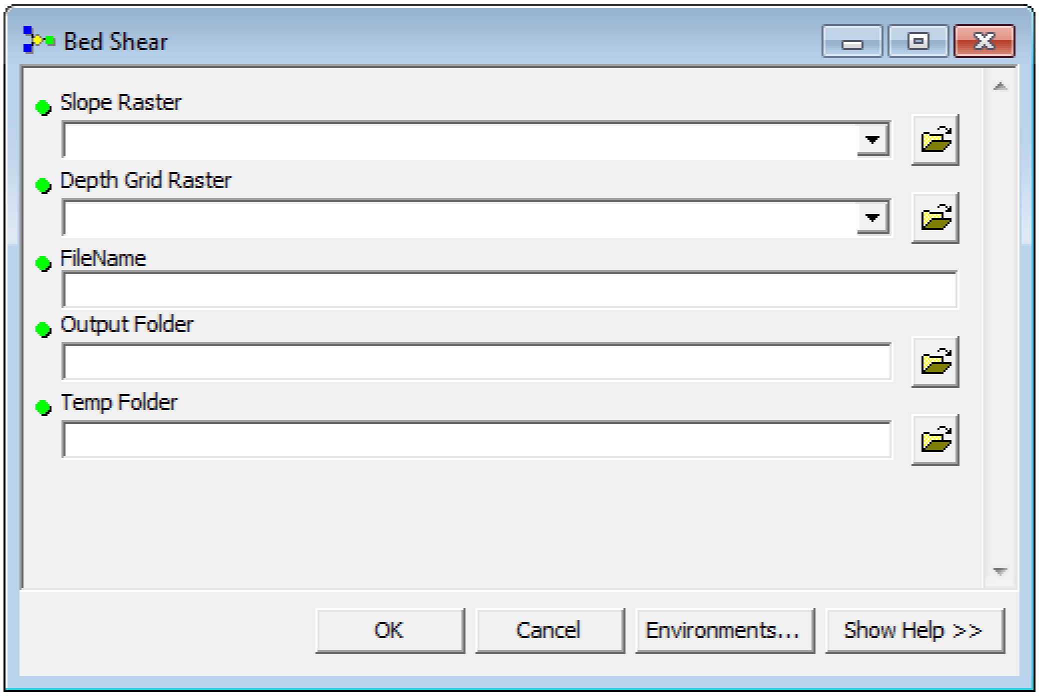


Figure B28: "Bed Shear" tool input window

The input fields all function the same as they did in the “Velocity – Manning Equation” tool.

The cell size of the output raster is determined by the slope raster input. The cell size can also be user specified by right clicking on the tool and selecting edit. Go to file >> model environment settings >> raster settings >> show values >> select “as specified below” >> and enter the correct cell size, in meters, in the field. The “Bed Shear” tool outputs the bed shear in units of N/m^2, a.k.a. pascals (Pa).

The “Bed Shear – n changed” version of the bed shear tools should be used instead if the Manning’s n input data have been changed from that which was used in the HEC-RAS model.

B.11. Creating Cell-by-Cell Method Effective Shear Maps

Three different types of effective shear tools have been made. These tools are set up to make different assumptions about the roughness and cover type. Each of these three tools has two variations. The variation of each tool with the suffix "_Bed_Shear_Input" uses a bed shear raster as an input, whereas the variation without this suffix calculates bed shear within the tool using the slope and depth raster inputs. The bed shear input variants of these tools exist because the SCA continuity correction tools made for shear only create bed shear raster outputs. These SCA method tool bed shear outputs can be used as inputs for these effective shear tools in order to create continuity corrected effective shear rasters.

The effective shear tool named "Effective Shear – n unchanged" is intended to predict the effective shear as it would be with the current land cover and Manning's n data that were used by the IFC to create the floodplain inundation maps for the FPM project. A cover factor is assigned based on cover type. The n value for the field cover type is left at 0.07, as was used by the HEC-RAS model. This n value corresponds to a planted field, so effective shear values will be lower than they would be for a bare field.

The effective shear tool named "Effective Shear – CF = 0 and n = 0.03 everywhere" assumes that there is a constant Manning's n everywhere. This assumption can be used to make effective shear maps as though bare soil were present everywhere to show the worst case scenario for scour. Changing n values changes depth and slope, so this tool also applies a correction factor to the depth input to ensure that continuity is preserved after Manning's n is changed. See Section 4.3.3 for more information on this process.

The effective shear tool named "Effective Shear – Field n = 0.03" changes the Manning's n value for field areas to 0.03 and uses a CF for field areas of 0. A Manning's n of 0.03 corresponds to bare agricultural fields (ODOT, 2011), whereas the original value of 0.07 was for planted agricultural fields. The new roughness value makes this tool create effective shear maps that reflect conditions where the fields are bare and unplanted, but other cover conditions are vegetated as indicated by the National Land Cover Dataset. To preserve continuity, the depth is also corrected where the Manning's n values are changed. A version of the "Effective Shear – Field n = 0.03" with the suffix "Multiple" is also included, and this tool can take multiple inputs to create multiple effective shear outputs.

B.11.1.1. Running the "Effective Shear – Field n = 0.03" Tool

The "Effective Shear – Field n = 0.03" tool or its "Multiple" variant should be used to create effective shear maps for the INHF. This tool produces effective shear data that are representative of what would occur during spring or fall when agricultural fields are unplanted.

Click on the "Effective Shear – Field n = 0.03" tool in Arc Toolbox, and the input box shown in Figure B29 should appear.

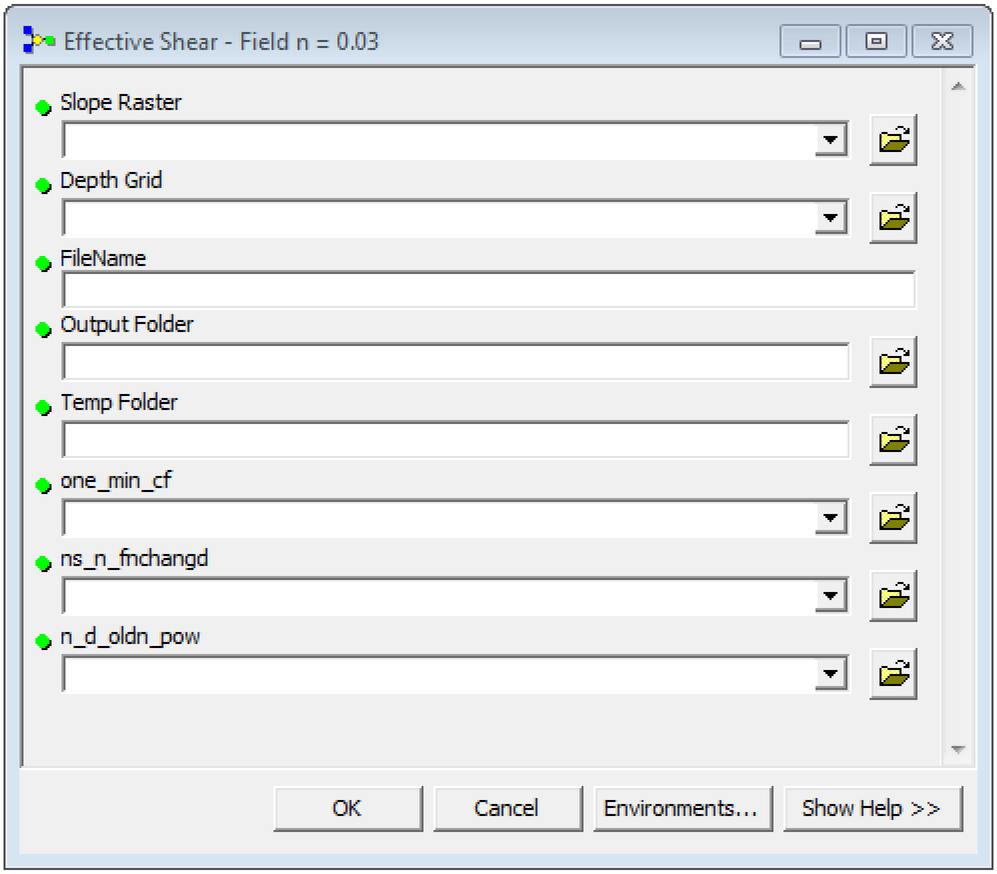


Figure B29: "Effective Shear - Field n = 0.03" tool input window

The “Slope Raster,” “Depth Grid,” and “Manning’s n” fields are for their respective raster file inputs. The “FileName” and “Output Folder” fields are the same as in all other tools.

The “one_min_cf” field is for the (1-CF) constant statewide raster that was made with the “Effective Shear Constant Creator” tool. This input raster is named “one_min_cf”.

The “ns_n_fnchanged” field is for the $(ns/n)^2$ raster that was made with the “Effective Shear Constant Creator” tool. This input raster is named “ns_n_fnchanged”.

The “n_d_oldn_pow” field is for the depth correction raster that was made with the “Effective Shear Constant Creator” tool. This input raster is named “n_d_oldn_pow”.

The cell size of the output effective shear raster will be the same as the slope raster input. The cell size can also be user specified by right clicking on the tool and selecting edit. Go to file >> model environment settings >> raster settings >> show values >> select "as specified below" >> and enter the correct cell size, in meters, in the field.

The effective shear tools outputs all have units of pascals.

It is crucial to select the correct input files for the "ns_n_fnchanged" and "n_d_oldn_pow" fields because there are different versions of these input files for different Manning's n assumptions.

B.11.1.2. Running the "Effective Shear – Field n = 0.03 - Multiple" Tool

The "Effective Shear – Field n = 0.03 – Multiple" tool functions the same as its single output counterpart, except it can take multiple inputs to create multiple effective shear outputs. This tool can take as many inputs as the user would like. However, it is recommended that only inputs for a single reach be used together because the output file names will be as specified followed by an iteration number. Creating effective shear rasters for multiple reaches at once would result in confusing file names.

The inputs for this tool that can take multiple files are the "Slope Raster" and "Depth Grid." These inputs can be set up by entering the editor window and double clicking on the input to add multiple files, as was done with the "Depth Cleaner – Multiple" tool. The same number of files must be added to each of these inputs, and the order of corresponding files must be the same. The depth rasters must have a coordinate system assigned, which will have been done automatically when the depth rasters were cleaned. Un-cleaned depth rasters will need to have a coordinate system added manually, or the tool will fail. The other input files can be added within the editor window or added normally by left clicking on the tool in the ArcToolbox. Figure B30 shows the two inputs that must have their multiple files added within the editor window. The other effective shear tools do not have multiple versions, but they can be modified by the user to run multiple files if necessary.

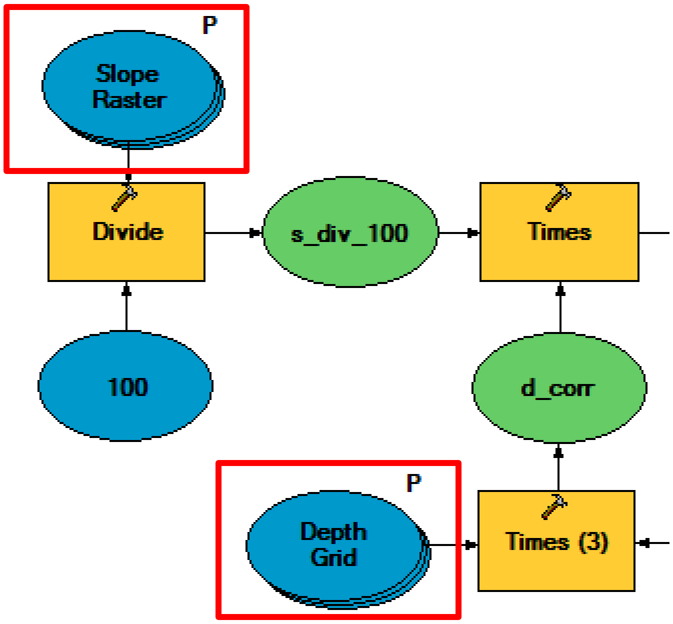


Figure B30: "Effective Shear - Field n = 0.03 - Multiple" tool editor window. The slope and depth rater inputs shown in rectangles must be added in the editor window

B.11.2. Running the “Bed Shear Input” Effective Shear Tools

The versions of the effective shear tool with the “-Bed Shear Input” suffix take an already calculated bed shear raster as an input. These tools are useful to create SCA method effective shear maps because the SCA tools only adjust bed shear for continuity. The bed shear input tools are used in the same way as their regular version except that they take the bed shear input instead of slope and depth inputs.

When running the “Bed Shear Input” versions of the effective shear tools, only the regular “Bed Shear” tool should be used to calculate the bed shear input. Do not use the “Bed Shear – n changed” tool to calculate the bed shear input for these tools because they are set up to apply any Manning's n corrections and associated depth corrections to the bed shear input within the tool.

B.11.3. Running the Other Effective Shear Tools

The other effective shear tools are run in the same way as the "Effective Shear – Field n = 0.03" tool. However, they use different input files for the $(ns/n)^2$ and depth correction factors because each tool makes different assumptions regarding Manning's n. The name of the input window dialog box for these correction factor files always exactly matches the name of the required raster file.

B.12. SCA Method Continuity Correction - Optional

The SCA method aims to correct for continuity by separating out a single cross-section, calculating the area, calculating the flow rate of the cross-section predicted by the cell-by-cell method, and then using the known flow rate to scale the velocity or shear values predicted by the cell-by-cell-method up or down so that continuity is preserved across the cross-section. See Section 4.4 for more information on how the SCA method works and what benefits it can have. The SCA tools take a range of water surface elevation inputs and create continuity scaled velocity or shear cross-sections for each one. These cross-sections can then be mosaicked together to create a continuous map.

There are four SCA tools: two of these tools create scaled velocity cross-sections and the other two create scaled bed shear cross-sections. The continuity corrected bed shear can then be used as an input into the effective shear tools in order to create continuity corrected effective shear maps. Both the velocity and bed shear SCA tools have a normal version and a version designated as "Wide." The wide version processes several cross-sections at once and creates output cross-sections that are several cells wide instead of a single cell wide. These tools allow for faster creation of maps using the SCA method and reduce the total number of output files that need to be managed.

B.12.1. Setting Up for SCA Continuity Correction

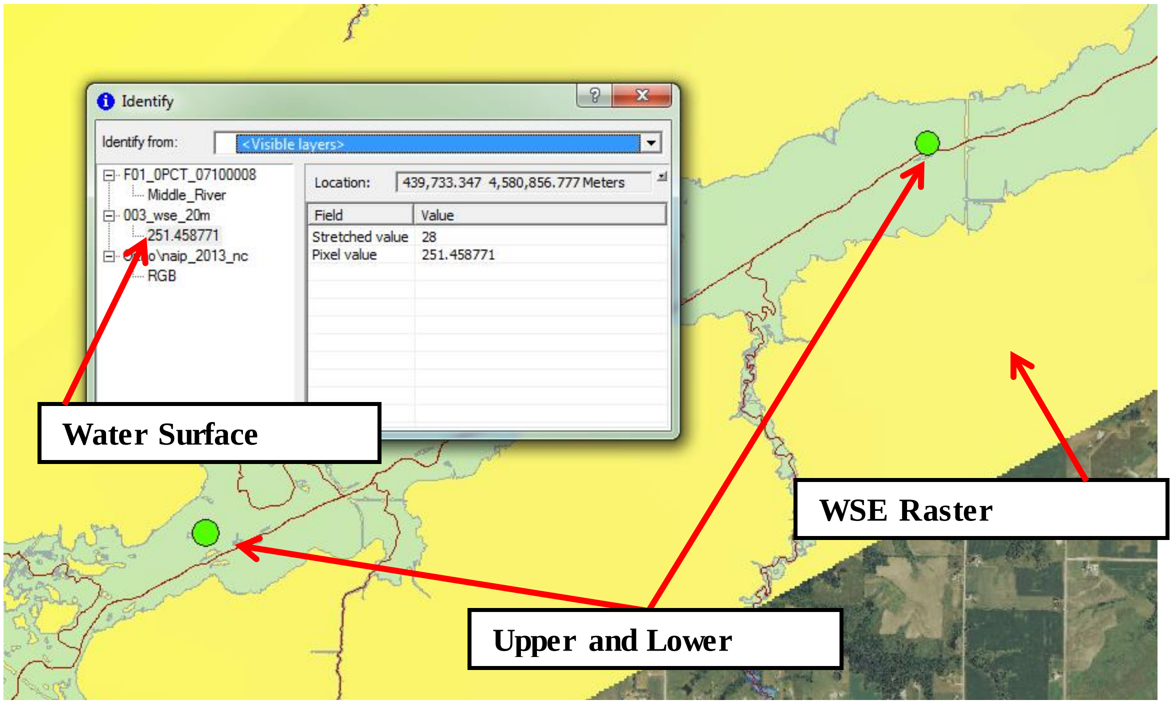
B.12.1.1. Folder Setup

The SCA tool can result in many raster files, each holding a single cross-section. A separate folder should be created to hold the outputs for each reach.

B.12.1.2. Setting up Elevation Inputs

The SCA tools take inputs of water surface elevation, which is how the user designates which cross-section should be created. The SCA tool is only practical over relatively short (less than 10 miles) reaches. Creating the water surface elevation inputs is best done using Excel.

First, add water surface elevation raster to GIS. Next, identify the upper and lower bounds of the area of interest. Use the Identify tool to determine the water surface elevation of the upper and lower bounds. Figure B31 shows an example of a typical reach length on which to run the SCA method and its user specified upper and lower bounds.



Location: 439,733.347 4,580,856.777 Meters

Field	Value
Stretched value	28
Pixel value	251.458771

Figure B31: SCA method example reach

Measure the horizontal distance between the upper and lower bounds using the measure tool in GIS. Use Equation B1 to get the elevation interval.

Equation B1: SCA Method Elevation Interval

$$Elevation\ Interval = \frac{(UElev - LElev)}{\left(\frac{D}{(CW)\ *\ (XSectT)}\right)} * \left(\frac{1}{C}\right)$$

Where,

- “UElev” is the upper water surface elevation and “LElev” is the lower water surface elevation, in units of meters, that mark the starting and ending points of the section where the SCA method is to be run.
- “D” is the horizontal distance between the upper and lower elevations, in meters.
- CW is the cell size, in meters.

- XSecT is the width of the cross-section, in number of cells. This number is automatically 1 when using the versions of the SCA tools without the "Wide" designation. The cross-section cell width is user specified when running the "Wide" versions of the SCA tools.
- "C" is a general correction factor that accounts for the fact that slope is not constant between the upper and lower bounds. There will be gaps in-between SCA cross-sections in areas where the slope is less than the average slope if the correction factor is not applied. The ideal correction factor depends on the variability of the slope in the reach of interest. A higher correction factor is needed to avoid excessive gaps in-between the individual cross-sections if there is a high variability in slope in the area of interest. A larger correction factor will result in more cross-sections spaced closer together. A value of 1.5 is a good correction factor for most reaches, and this value can then be adjusted if the cross-section spacing is too close or too far apart.

Excel should next be used to create a table of water surface input variables by starting with the *lower elevation* and incrementing to the *upper elevation* by the *elevation interval.*

Equation B2 shows how the elevation interval was calculated for the example area shown in Figure B31. At least four or more decimal places should be used with the water surface elevation. Table B2 shows a section of the table made for the example area. This table begins at the lower water surface elevation of 246.9090 meters and continues until it reaches a value near the upper water surface elevation of 251.4588 meters. There are approximately 100 values in the table, which means that around 100 individual rasters will be created and need to be mosaicked together in order to create a continuity adjusted map for this short reach. The number of individual cross-sections is three times lower than it would have been if a width of 1 cell were used instead of 3.

Equation B2: Elevation Interval Example

$$Elevation\ Interval = \frac{(251.4588\,m - 246.9090\,m)}{\left(\frac{6550\,m}{(20\,m)\,*\,(3\,cells)}\right)} * \left(\frac{1}{1.5}\right) = 0.02779\ meters$$

Table B2: Portion of Elevation Input Table

246.909
246.95068
246.99236
247.03404
247.07572

B.12.2. Trimming Backwater Areas Manually

Areas where velocity is 0 due to obstructions downstream are called ineffective flow areas or backwater areas. Manual removal of ineffective flow areas may be necessary in certain areas to get the best results with the SCA method tools. Removing these ineffective backwater areas from the depth raster will prevent those cells from contributing to the flow area and will ensure that the velocity or shear is scaled using only the effective flow area.

B.12.2.1. When Backwater Areas Need Cleaning

An ineffective flow area that lies in the reach being mapped with the SCA method should be removed if it is large enough to potentially have a noticeable impact on the results. Ineffective flow areas this bad are not common in most reaches. The user will have to use his or her best judgment when deciding whether or not an ineffective flow area should be removed.

B.12.2.2. How to Remove Ineffective Flow Areas

Create a new polygon shapefile; assign it a coordinate system in ArcCatalog matching the coordinate system of the depth raster; begin editing it; and draw a feature around the areas to be retained. Figure B32 shows how this was done on the sample project. The areas of the depth raster outside of the polygon were determined to be ineffective flow areas that were large enough to potentially cause errors with the SCA method. Be sure that the trimmed depth raster maps are not used for anything other than the SCA method.

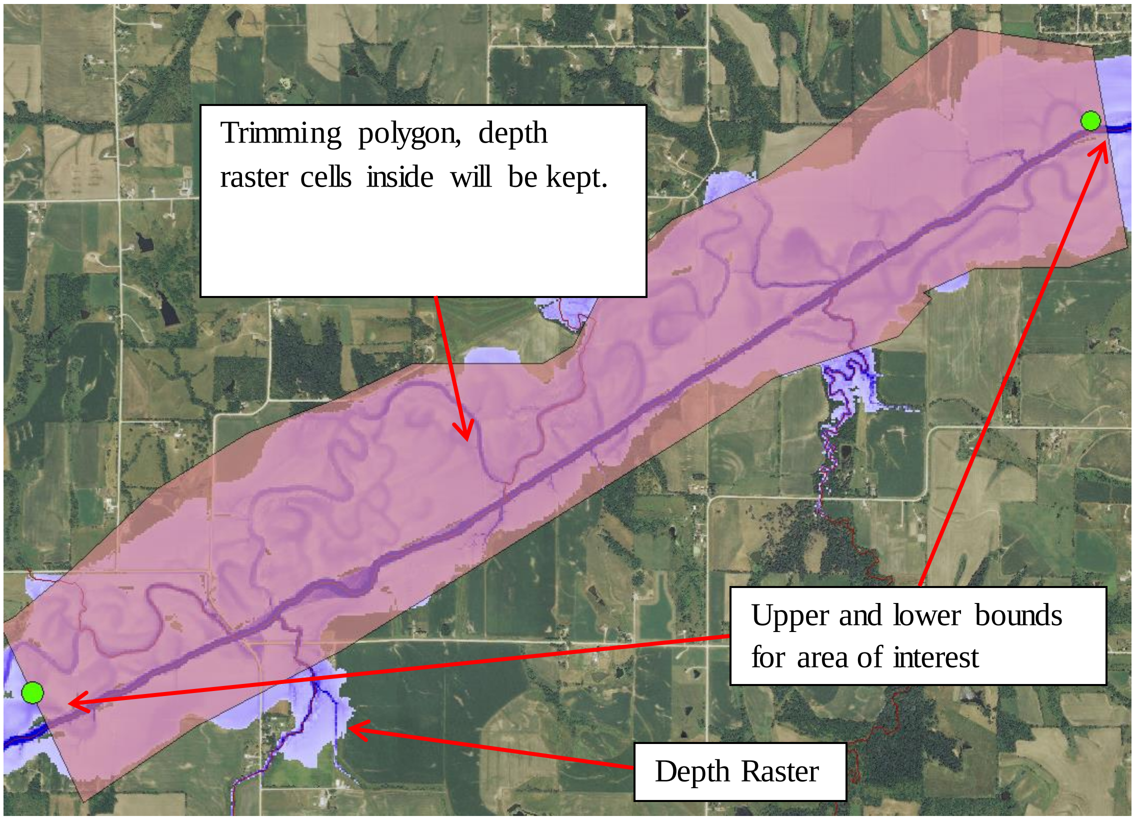
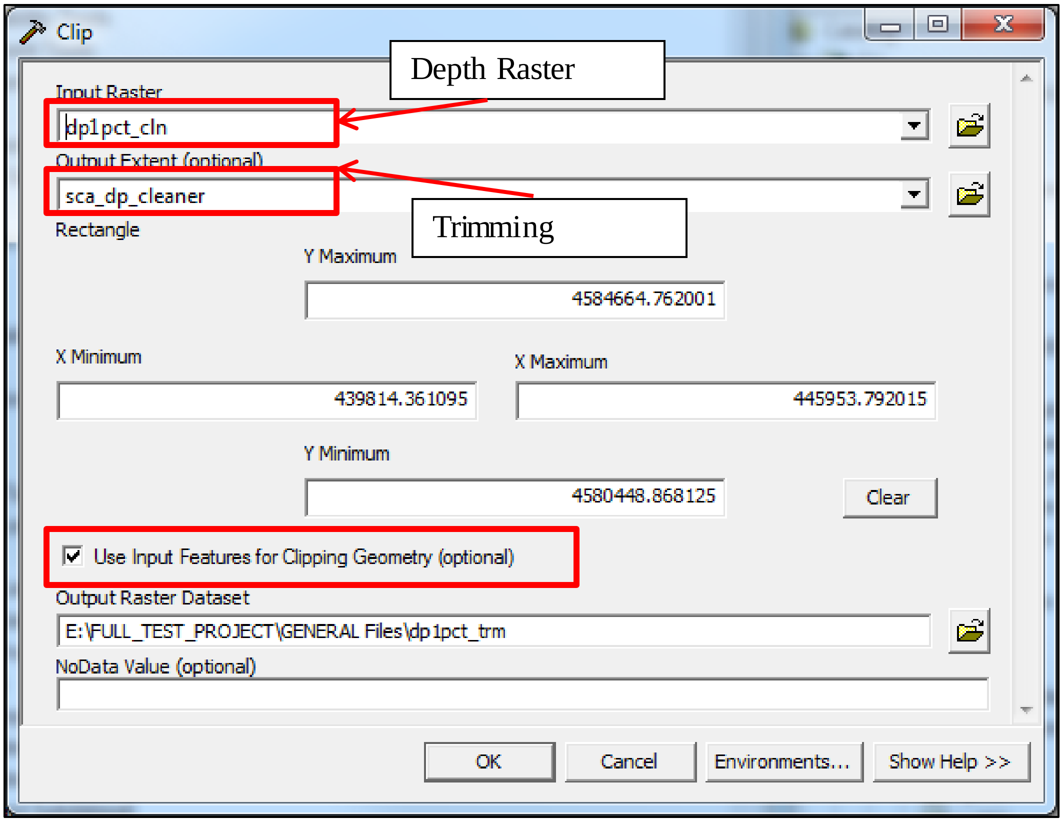


Figure B32: Ineffective flow areas get removed with the trimming polygon

The depth raster cells inside the polygon will be retained, so the polygon must be drawn around the entire area that is to be modeled with the SCA tool, excluding the ineffective flow areas that are to be removed. The example in Figure B32 shows that only the large ineffective flow areas are being removed. Small ineffective flow areas are left intact because removing them will not have a significant impact on results.

The GIS “Clip” tool should next be used to clip the depth raster to the polygon. The clip tool is located at *Data Management Tools >> Raster >> Raster Processing >> Clip* in the GIS toolbox.

Click the Clip tool and the dialog, shown as Figure B33, should appear. Check the “Use Input Features for Clipping Geometry” box and add the depth raster and trimming polygon, as indicated in the figure. Run the tool and use the resulting depth raster as the depth input for the various SCA method tools. The resulting continuity corrected shear or velocity maps will not show cells in the areas that were removed.



Input Raster
dp1pct_cln

Output Extent (optional)
sca_dp_cleaner

Rectangle

Y Maximum
4584664.762001

X Minimum
439814.361095

X Maximum
445953.792015

Y Minimum
4580448.868125

☑ Use Input Features for Clipping Geometry (optional)

Output Raster Dataset
E:\FULL_TEST_PROJECT\GENERAL Files\dp1pct_trm

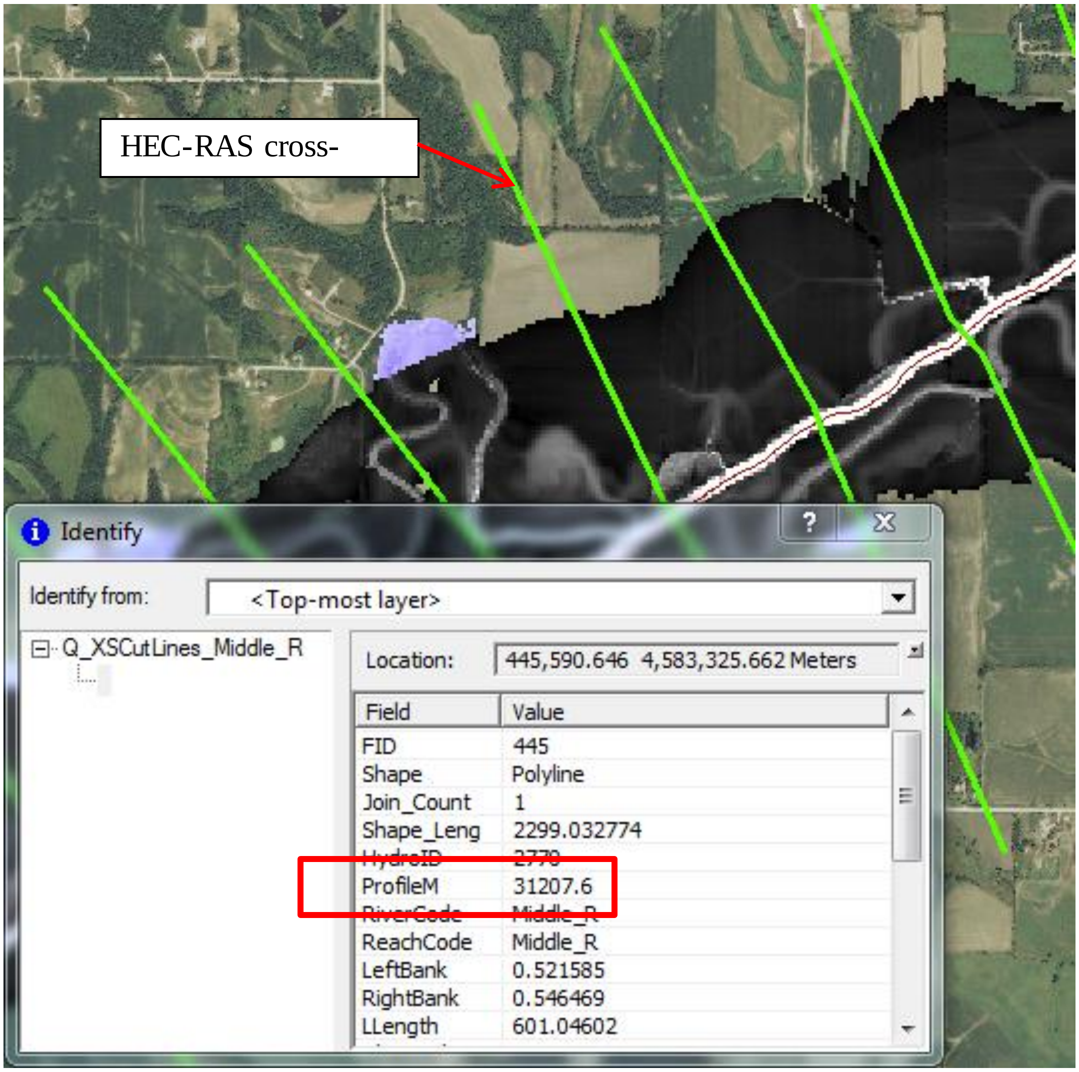
NoData Value (optional)

Figure B33: Clip tool dialog window for trimming ineffective flow areas with rectangles indicating fields the user must modify

B.12.3. Identifying the “True” Flow Rate

The SCA tools require the flow rate used by the HEC-RAS model in order to create a scaling factor for velocity or shear. The flow rate changes along a reach or when tributaries add to the reach. The SCA method tools only function with a fixed flow rate input, so they must be used over a section of reach where the flow rate does not change drastically. The SCA tool must be run separately above and below the confluence if there is a confluence in the area of interest.

Add the HEC-RAS cross-section shapefile for the reach to GIS. Use the identify tool on a cross-section and look at the “ProfileM” field, which is the station number for the cross-section. Figure B34 shows how to identify the station number of a HEC-RAS cross-section within GIS.



Identify from: <Top-most layer>

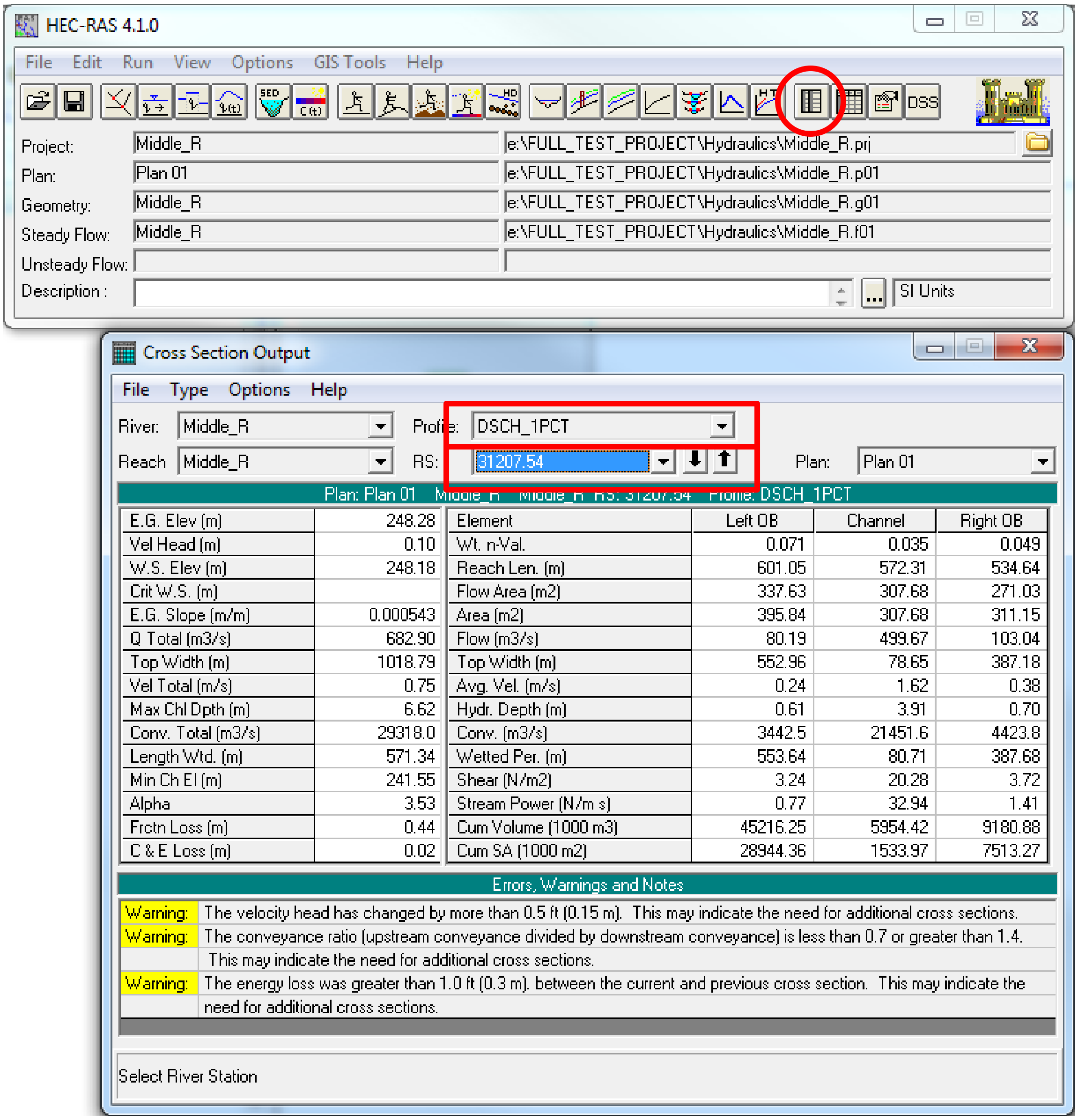
Q_XSCutLines_Middle_R

Location: 445,590.646 4,583,325.662 Meters

Field	Value
FID	445
Shape	Polyline
Join_Count	1
Shape_Leng	2299.032774
HydroID	2770
ProfileM	31207.6
RiverCode	Middle_R
ReachCode	Middle_R
LeftBank	0.521585
RightBank	0.546469
LLength	601.04602

Figure B34: Example of identifying station number of a HEC-RAS cross-section with the station number indicated by the rectangle

Open the HEC-RAS project for the reach after identifying a cross-section station in GIS. Open the HEC-RAS output table, as shown in the circle in Figure B35. Select the correct return period and then navigate to the cross-section using the station obtained in GIS, as shown with the rectangles in Figure B35.



Project:	Middle_R	e:\FULL_TEST_PROJECT\Hydraulics\Middle_R.prj
Plan:	Plan 01	e:\FULL_TEST_PROJECT\Hydraulics\Middle_R.p01
Geometry:	Middle_R	e:\FULL_TEST_PROJECT\Hydraulics\Middle_R.g01
Steady Flow:	Middle_R	e:\FULL_TEST_PROJECT\Hydraulics\Middle_R.f01
Unsteady Flow:		
Description :		SI Units

River: Middle_R
Reach Middle_R
Profile: DSCH_1PCT
RS: 31207.54
Plan: Plan 01

Plan: Plan 01 Middle_R Middle_R RS: 31207.54 Profile: DSCH_1PCT

E.G. Elev (m)	248.28
Vel Head (m)	0.10
W.S. Elev (m)	248.18
Crit W.S. (m)	
E.G. Slope (m/m)	0.000543
Q Total (m3/s)	682.90
Top Width (m)	1018.79
Vel Total (m/s)	0.75
Max Chl Dpth (m)	6.62
Conv. Total (m3/s)	29318.0
Length Wtd. (m)	571.34
Min Ch El (m)	241.55
Alpha	3.53
Frctn Loss (m)	0.44
C & E Loss (m)	0.02

Element	Left OB	Channel	Right OB
Wt. n-Val.	0.071	0.035	0.049
Reach Len. (m)	601.05	572.31	534.64
Flow Area (m2)	337.63	307.68	271.03
Area (m2)	395.84	307.68	311.15
Flow (m3/s)	80.19	499.67	103.04
Top Width (m)	552.96	78.65	387.18
Avg. Vel. (m/s)	0.24	1.62	0.38
Hydr. Depth (m)	0.61	3.91	0.70
Conv. (m3/s)	3442.5	21451.6	4423.8
Wetted Per. (m)	553.64	80.71	387.68
Shear (N/m2)	3.24	20.28	3.72
Stream Power (N/m s)	0.77	32.94	1.41
Cum Volume (1000 m3)	45216.25	5954.42	9180.88
Cum SA (1000 m2)	28944.36	1533.97	7513.27

Errors, Warnings and Notes

Warning:	The velocity head has changed by more than 0.5 ft (0.15 m). This may indicate the need for additional cross sections.
Warning:	The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than 0.7 or greater than 1.4. This may indicate the need for additional cross sections.
Warning:	The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross section. This may indicate the need for additional cross sections.

Figure B35: HEC-RAS project window with the buttons to view the table and select the correct return period and cross-section indicated by rectangles

The flow rate can be determined from the “Flow” field in this table. Sum the channel, left OB, and right OB flow values to get the total flow rate.

Check the HEC-RAS flow rate at the cross-sections up and down stream of the area of interest to ensure that the flow rate is not changing significantly. To minimize error, the flow rate change should ideally be less than 5%. The SCA method will have to be run over a shorter section of reach if the change in flow rate is too high. Use the average of the upstream and downstream flow rate as the flow rate input if there is a difference between them.

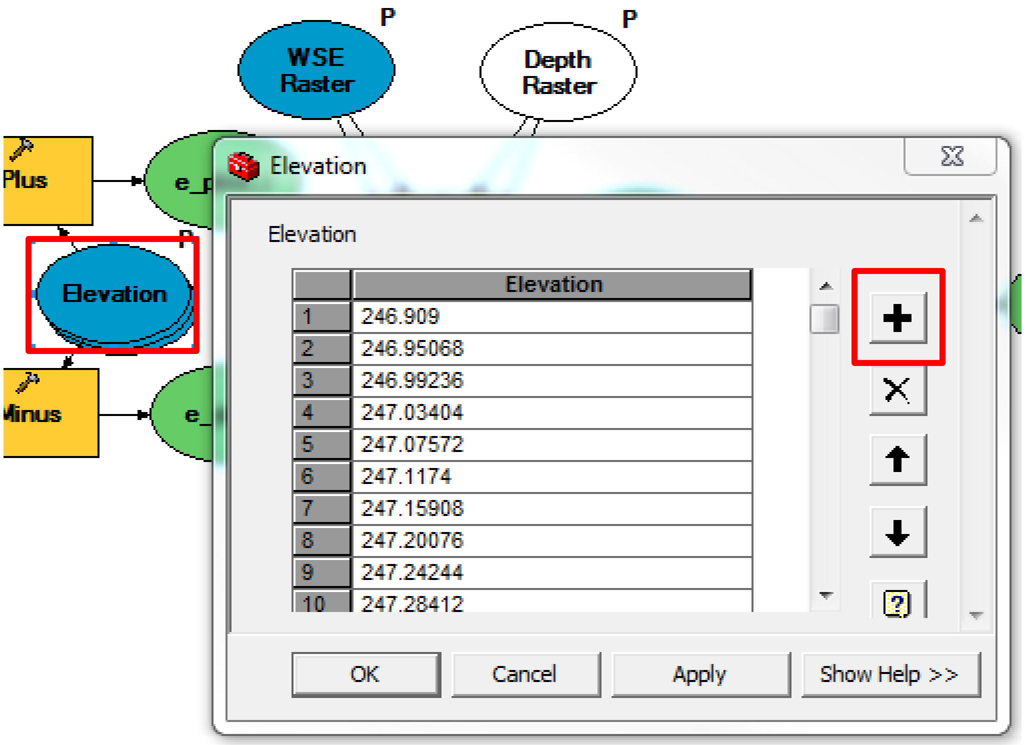
The flow rate at the bottom of the test area was determined to be 683 cm. The flow rate at the top of the section is also 683 cm, and this value can now be used as the flow rate input for the SCA tools.

B.12.4. SCA Velocity

This section will explain how to use the “SCA – Velocity – Wide” tool for velocity continuity correction. The “SCA – Velocity” tool functions exactly the same, except the width will always be one cell instead of a user specified value.

The elevation input table must be modified from within the tool. Right click the tool and select edit.

Double click the “Elevation” input and click the plus sign to add the correct number of fields in the table. Paste the elevation values created into the table, as shown in Figure B36.



Elevation

Elevation

	Elevation
1	246.909
2	246.95068
3	246.99236
4	247.03404
5	247.07572
6	247.1174
7	247.15908
8	247.20076
9	247.24244
10	247.28412

Figure B36: Populating elevation table

The zonal statistics bounding input polygon, named “ZSBounds,” can be added from within the edit window of the model. The zonal statistics tools located to the left and right of the bounding polygon input can also be set up from within the model editor. Figure B37 shows the bounding polygon input and the two zonal statistics tools. Adding the bounding polygon normally from the input dialog box should also work but can potentially cause problems.

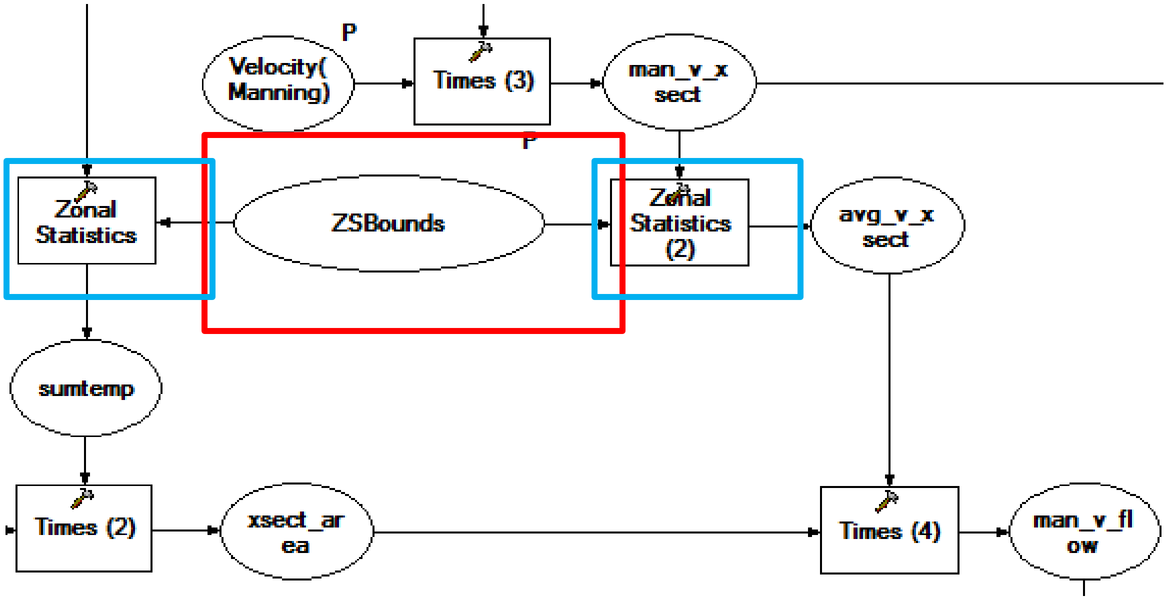
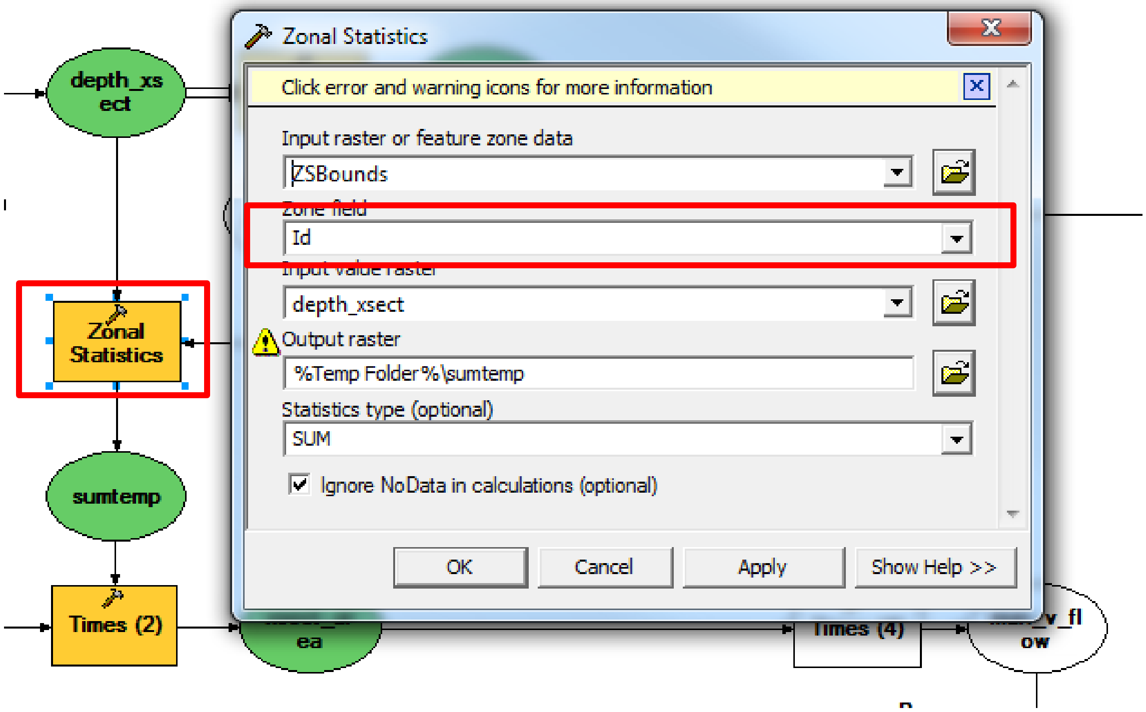


Figure B37: Bounding polygon location in editor window

First, double click on the “ZSBounds” tool and select the bounding polygon that was created. The bounding polygon must completely enclose the area within which the SCA method will be applied.

Next, click on both of the zonal statistics tools and verify that the “Id” field is selected under “Zone Field.” This should be done automatically when the bounding polygon is added. The other fields in this dialog should not be changed. Figure B38 shows this step.



Zonal Statistics

Click error and warning icons for more information

Input raster or feature zone data: ZSBounds

Zone field: Id

Input value raster: depth_xsect

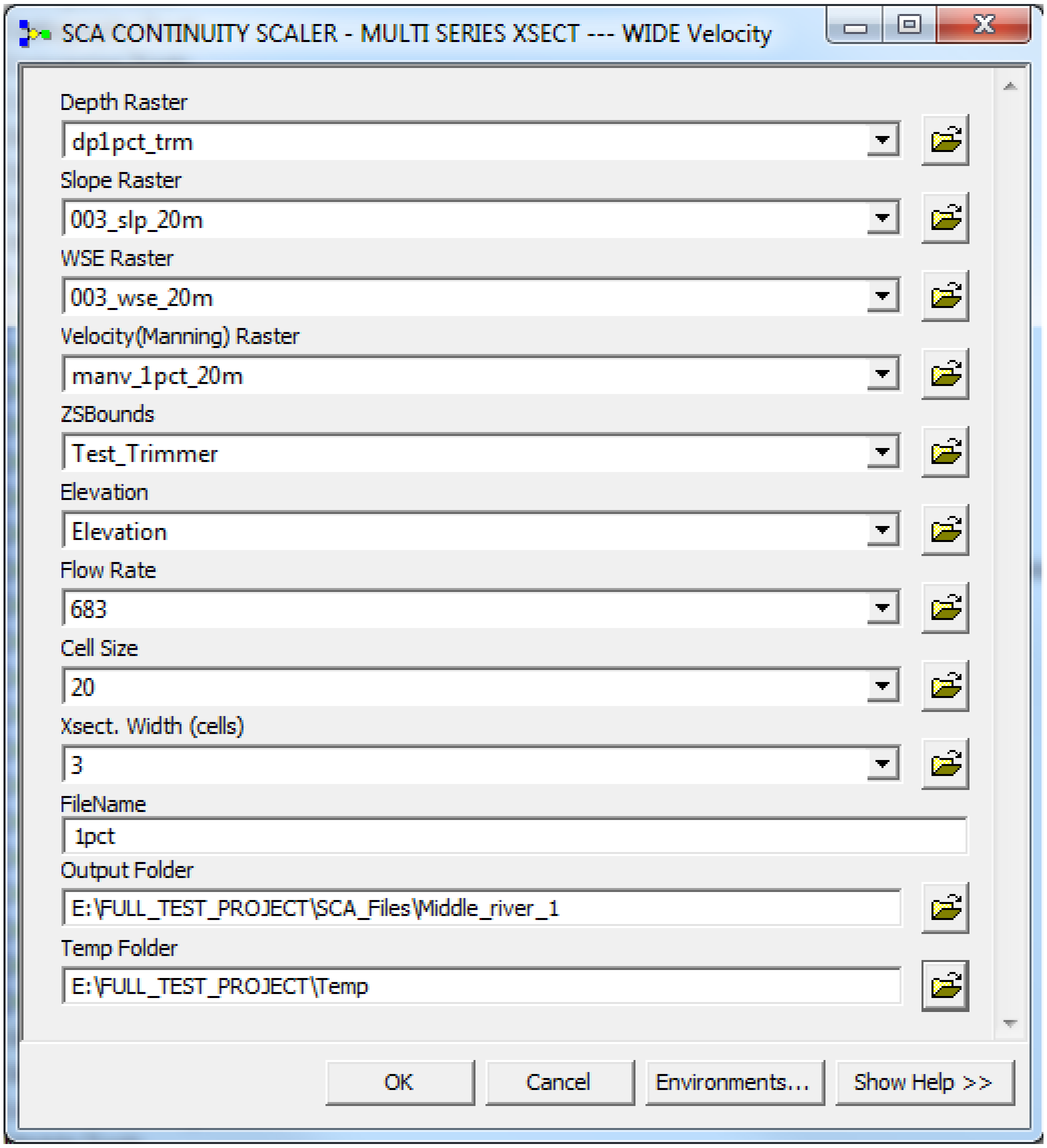
Output raster: %Temp Folder%\sumtemp

Statistics type (optional): SUM

☑ Ignore NoData in calculations (optional)

Figure B38: Bounding polygon setup

Save and exit the model after adding the elevations and bounding polygon. The other values could also be entered from within the model, or they can be entered normally by left clicking on the model in the toolbox window. Figure B39 shows the input window that appears after clicking the “SCA – Velocity – Wide” tool. The fields have already been filled in for the test project.



SCA CONTINUITY SCALER - MULTI SERIES XSECT --- WIDE Velocity

Depth Raster
dp1pct_trm

Slope Raster
003_slp_20m

WSE Raster
003_wse_20m

Velocity(Manning) Raster
manv_1pct_20m

ZSBounds
Test_Trimmer

Elevation
Elevation

Flow Rate
683

Cell Size
20

Xsect. Width (cells)
3

FileName
1pct

Output Folder
E:\FULL_TEST_PROJECT\SCA_Files\Middle_river_1

Temp Folder
E:\FULL_TEST_PROJECT\Temp

Figure B39: "SCA - Velocity - Wide" tool input window

The “Depth Raster” field has been populated with the trimmed depth raster that was created. The cell size of the trimmed depth raster should be the same as the slope raster to minimize computation time.

The “Slope Raster” and “WSE Raster” fields should be populated with the slope and water surface elevation rasters.

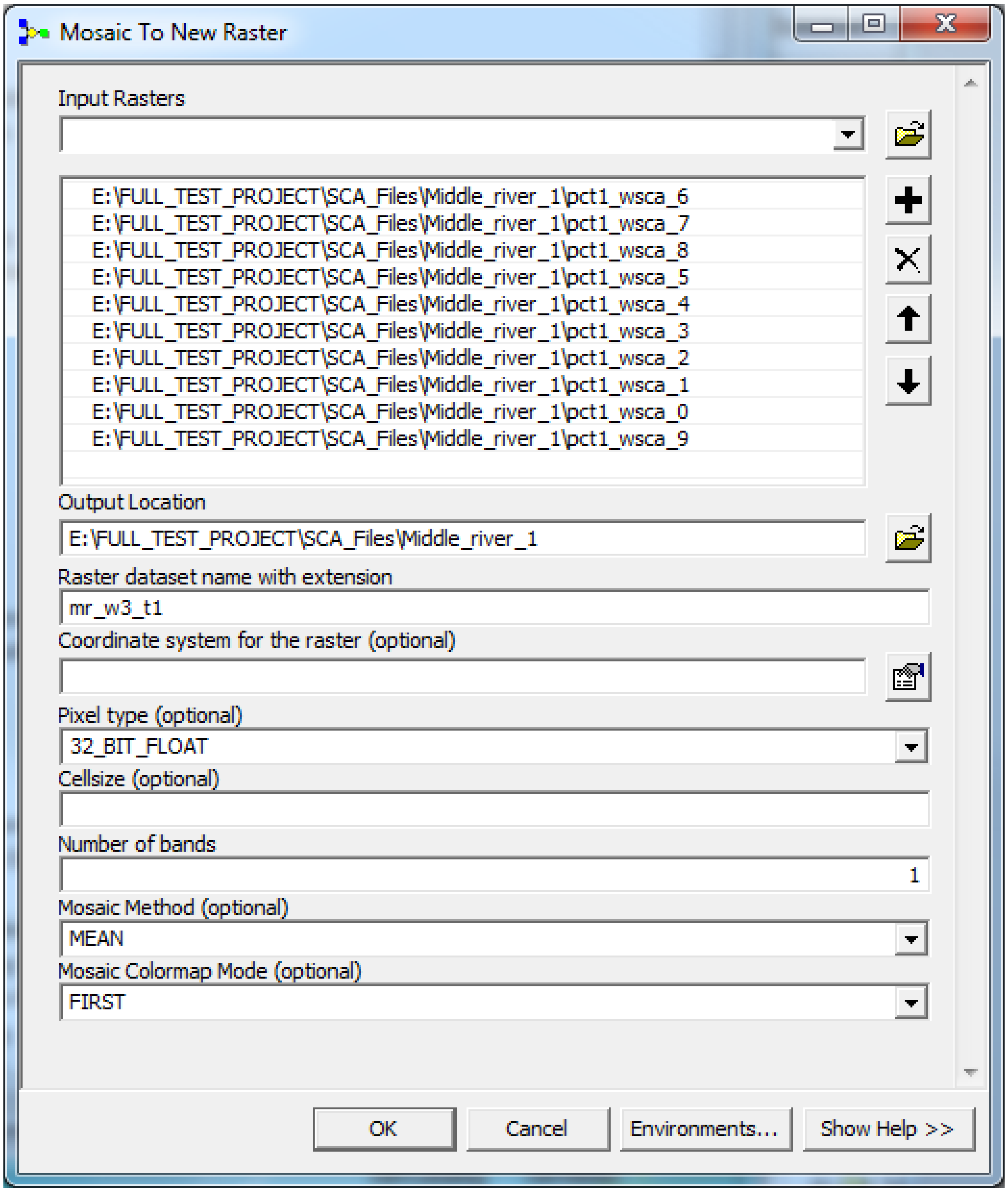
The “Velocity (Manning) Raster” field should be populated with the cell-by-cell method derived Manning’s velocity raster. Either the regular or “n changed” version of the “Velocity – Manning Equation” tool can be used to create this velocity input. The output continuity corrected velocity raster will reflect changed Manning’s n values if the “Velocity – Manning Equation – n changed” tool was used to create the velocity input raster.

The “ZSBounds” field is for the bounding shapefile that should enclose the entire area of interest.

The “Flow Rate” field should be populated with the fixed flow rate from the HEC-RAS model.

The “FileName” field is for specifying the file name. This tool iterates through the input elevation and creates a new file for each one. The tool adds a value starting at 0 and increasing by 1 to the end of this file name for each new output file. The character length of the file name cannot exceed 13 and must take this into account.

There will be a separate raster created for each elevation input. Each of these rasters holds a single cross-section, and they must be mosaicked together to create a continuous map. The GIS “Mosaic” tool can be found in the ArcToolbox at *Data Management Tools >> Raster >> Raster Dataset >> Mosaic to New Raster***.** Figure B40 shows how the mosaic tool should be set up.



Input Rasters

E:\FULL_TEST_PROJECT\SCA_Files\Middle_river_1\pct1_wsca_6
E:\FULL_TEST_PROJECT\SCA_Files\Middle_river_1\pct1_wsca_7
E:\FULL_TEST_PROJECT\SCA_Files\Middle_river_1\pct1_wsca_8
E:\FULL_TEST_PROJECT\SCA_Files\Middle_river_1\pct1_wsca_5
E:\FULL_TEST_PROJECT\SCA_Files\Middle_river_1\pct1_wsca_4
E:\FULL_TEST_PROJECT\SCA_Files\Middle_river_1\pct1_wsca_3
E:\FULL_TEST_PROJECT\SCA_Files\Middle_river_1\pct1_wsca_2
E:\FULL_TEST_PROJECT\SCA_Files\Middle_river_1\pct1_wsca_1
E:\FULL_TEST_PROJECT\SCA_Files\Middle_river_1\pct1_wsca_0
E:\FULL_TEST_PROJECT\SCA_Files\Middle_river_1\pct1_wsca_9

Output Location: E:\FULL_TEST_PROJECT\SCA_Files\Middle_river_1
Raster dataset name with extension: mr_w3_t1
Coordinate system for the raster (optional):
Pixel type (optional): 32_BIT_FLOAT
Cellsize (optional):
Number of bands: 1
Mosaic Method (optional): MEAN
Mosaic Colormap Mode (optional): FIRST

Figure B40: Mosaic tool setup for combining SCA method cross-sections

The input rasters are all the individual cross-section rasters created with the SCA tool. The output location is the folder into which the final mosaicked raster will be placed. The “Raster dataset name with extension” field is where the user can name the new raster file. The “Pixel type” field must be changed to 32_BIT_FLOAT. The “Mosaic

Method" field should be changed to MEAN. The other fields can be left at their default setting.

B.12.5. SCA Method for Bed Shear

The SCA tools for continuity correction of bed shear function exactly the same way as the SCA tools for velocity. The bed shear SCA tools have all the same inputs as the velocity SCA tools discussed previously. The cell-by-cell method velocity is still used to get the scaling factor. The SCA bed shear tools output continuity corrected bed shear in units of pascals (pa). The SCA method continuity scaled bed shear can then be used as an input to the effective shear tools in order to create continuity scaled effective shear.

The SCA bed shear tools also require a cell-by-cell method created bed shear raster as an input. Either the regular or "n changed" version of the "Bed Shear" tool can be used to create the required bed shear input. The output continuity corrected bed shear raster will reflect changed Manning's n values if the "Bed Shear – n changed" tool was used to create the bed shear input raster. The "Velocity – Manning Equation – n changed" must also be used to create the velocity raster input data if the "Bed Shear – n changed" tool is used to make the bed shear input raster.

B.13. Creating Allowable Shear Raster Data

The SSURGO soil classification shapefile and allowable shear database file should have been added to the GIS project. Make sure the SSURGO shapefile has a projected coordinate system. The allowable shear database file has a column for allowable shear in both pounds per square foot and pascals.

Go to the attribute table of the county SSURGO shapefile table and join it with the allowable shear database using the MUSYM field.

The "Allowable Shear Creator - (Pa)" tool can be used to convert this shapefile into a raster containing allowable shear values in units of pascals. The "Allowable Shear

Creator - (Pa)" tool performs the polygon-to-raster conversion tool and then runs a conditional statement to fill in areas with no allowable shear data with a worst case scenario value of 0.95 pa. The allowable shear of 0.95 corresponds to the "easily eroded" classification in (USDA NRCS, 2007). There is also an allowable shear creator tool for English units named "Allowable Shear Creator - (psf)" which outputs allowable shear in units of pounds per square foot. Figure B41 shows an example of the input window for the allowable shear creation tools.

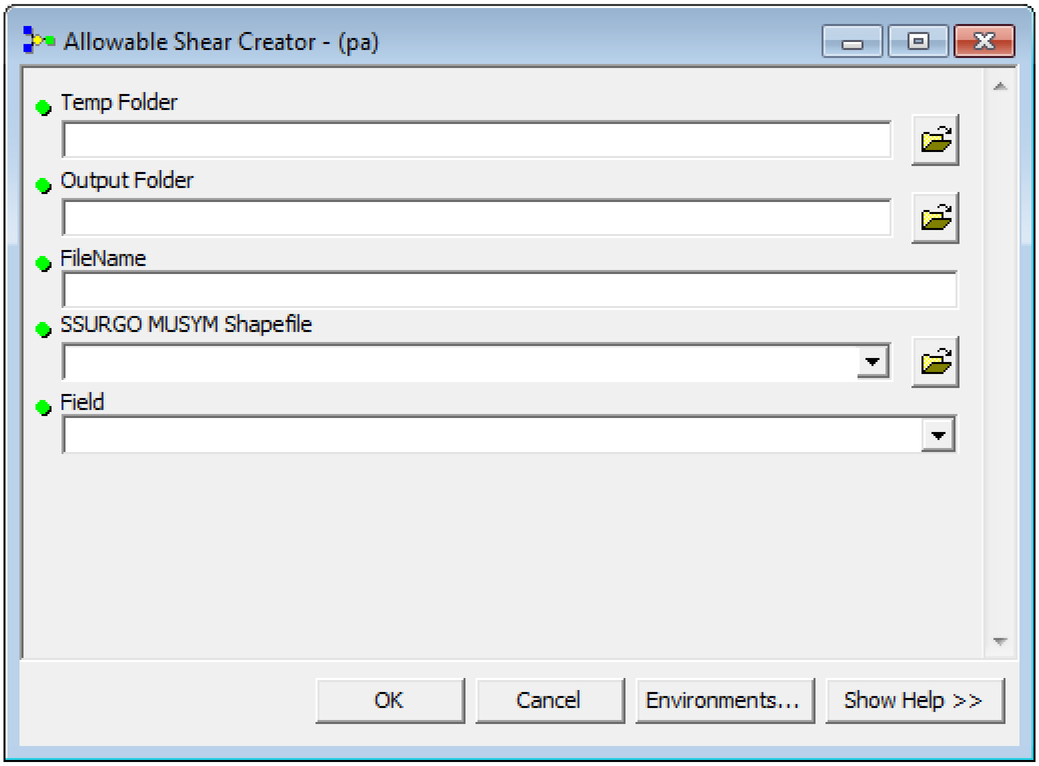


Figure B41: "Allowable Shear Creator - (Pa)" tool

The "Temp Folder" and "Output Folder" are the temporary and output folders into which files will be placed.

The “FileName” field is where the file name should be entered. This file name must be 13 characters or fewer and contain no spaces.

The “SSURGO MYSYM Shapefile” field is for the SSURGO shapefile that was linked with the allowable shear data.

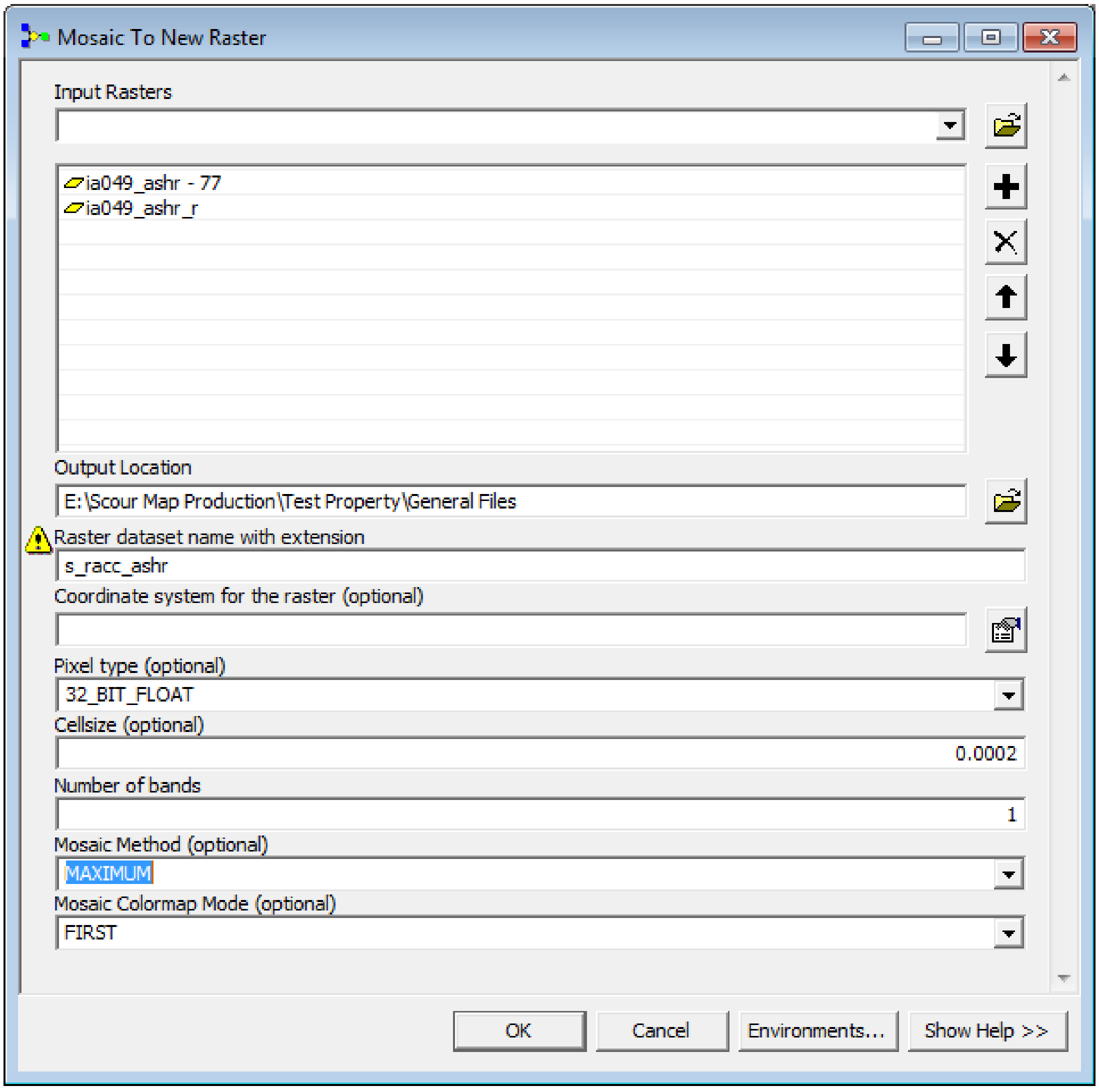
The “Field” field is where the user should specify the column of the SSURGO shapefile that holds the allowable shear values with the correct units. The “ALLOWSHR.PA_ALLOW” column should be selected when using the metric version of the “Allowable Shear Creator” tool, and the “ALLOWSHR.PSF_ALLOW” column should be selected when using the Imperial version of the tool.

The cell size of this tool defaults to 0.0002 degrees, which can be changed within the editor window by clicking on the GIS “Feature to Raster” tool and changing the value. The cell size of 0.0002 degrees is roughly equivalent to 15 meters, which is larger than the cell size of 10 meters typically used to create other maps, but using a smaller cell size does not significantly improve accuracy or appearance of the final maps.

Running the allowable shear creator tools will result in an allowable shear raster for a single county.

B.13.1. Merging Allowable Shear Rasters

Running a reach that crosses multiple counties will require the creation of allowable shear rasters for each county that the reach crosses. The allowable shear rasters for each county that the reach crosses will need to be combined using the GIS “Mosaic To New Raster” tool. Figure B42 shows the diagram for the GIS “Mosaic to New Raster” tool.



Input Rasters

ia049_ashr - 77
ia049_ashr_r

Output Location: E:\Scour Map Production\Test Property\General Files

Raster dataset name with extension: s_racc_ashr

Coordinate system for the raster (optional):

Pixel type (optional): 32_BIT_FLOAT

Cellsize (optional): 0.0002

Number of bands: 1

Mosaic Method (optional): MAXIMUM

Mosaic Colormap Mode (optional): FIRST

Figure B42: Mosaic to New Raster tool setup for combining multiple allowable shear rasters

Add the allowable shear rasters for all counties that the reach crosses to the "Input Rasters" table.

The "Output Location" field is for specifying the folder where the final raster will be placed.

The "Raster dataset name with extension" field is for specifying the name of the final raster file. A file extension is not actually needed.

The “Coordinate system for the raster” field can be left blank and will use the input coordinate system.

The “Pixel type” field must be changed to 32_BIT_FLOAT.

The “Cellsize” field should be set to the cell size of the input rasters.

The “Number of bands” field can be left at the default value of 1.

The “Mosaic Method” field should be changed to MAXIMUM. The only place where the county allowable shear rasters overlap is near edges where one raster may have had the worst case scenario shear value filled in because no data were present. Setting this value to “MAXIMUM” ensures that the correct allowable shear value will be used where the county rasters overlap.

The “Mosaic Colormap Mode” field can be left at its default setting.

B.14. Creating Excess Shear Ratio Maps

Running the “Excess Shear Ratio” tool will result in an inundation map showing the ratio of effective shear divided by allowable shear. The value will be greater than one when there is excess shear and less than one when there is no excess shear. This excess shear ratio map will be the primary map used to characterize scour potential. Figure B43 shows the input window that appears when clicking on the “Excess Shear Ratio” tool.

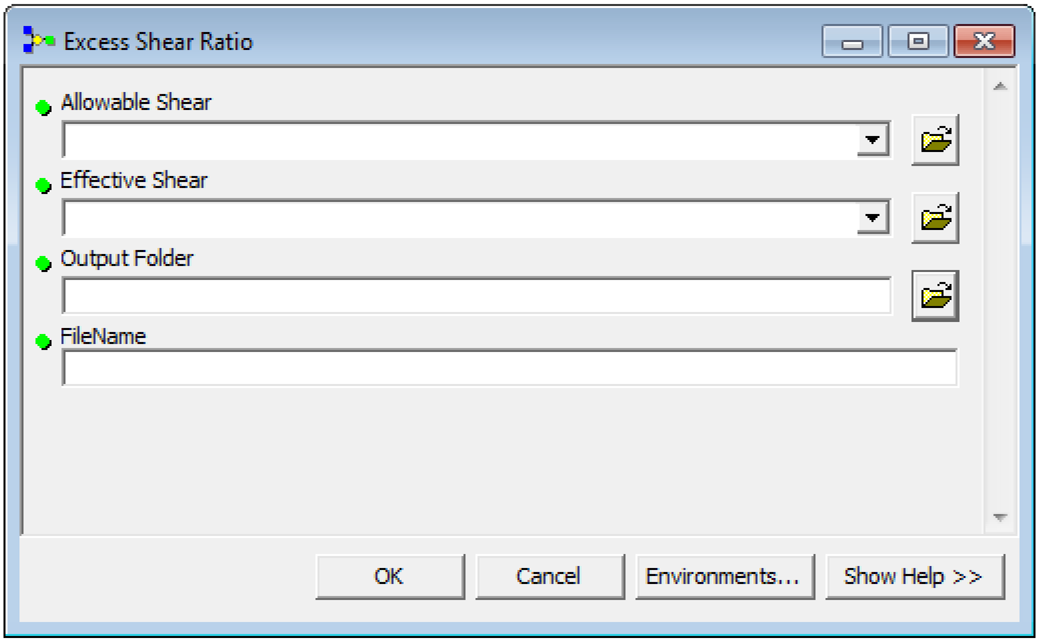


Figure B43: "Excess Shear Ratio" tool input window

The "Allowable Shear" and "Effective Shear" fields are for the critical and effective shear raster inputs, respectively.

The "Output Folder" field is for specifying the output folder path.

The "FileName" field is for specifying the file name, which must be 13 or fewer characters and contain no spaces.

The "Excess Shear Ratio – Multiple" tool functions the same as its single output counterpart, but it takes multiple effective shear raster inputs to create multiple excess shear ratio outputs. The multiple effective shear inputs need to be added in the editor window, as was done with other "multiple" tools. The "Excess Shear Ratio – Multiple" tool should only be run up to eight frequencies of a single reach at a time. Running the tool for multiple reaches at once will result in confusing file names.

B.15. Creating the Final Maps for Reporting

This section explains how to create maps and report them to the INHF. The data reported to the INHF could change at a later time. Four maps are prepared for the INHF for each frequency. The maps prepared are the inundation boundary map, depth map, effective shear map, and excess shear stress ratio map.

B.15.1. Converting Units

The data have been created using metric units because the FPM data are readily available in metric. The units need to be changed to Imperial units when preparing the final maps for the INHF, and this unit change is performed because most farmers and land owners are more familiar with the Imperial system of units.

The "Depth and Shear unit Converter" tool simultaneously converts a depth raster from meters to feet and a shear raster from pascals to pounds per square foot. Figure B44 shows the dialog that appears when clicking this tool.

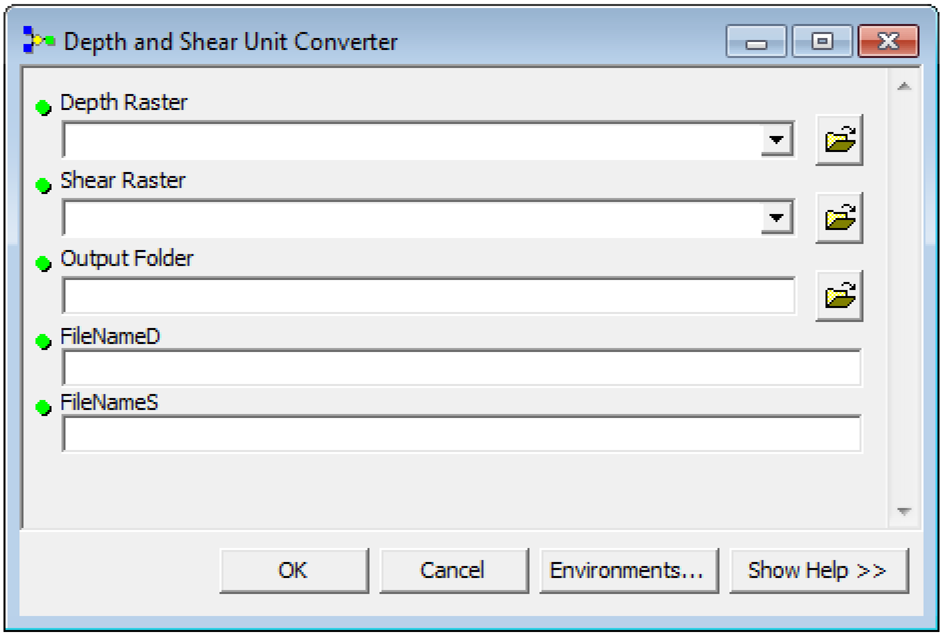


Figure B44: "Depth and Shear Unit Converter" tool input window

The “Depth Raster” and “Shear Raster” fields are for the input depth and shear rasters in units of meters and pascals, respectively.

The “Output Folder” field is for specifying the output folder path.

The “FileNameD” field is for inputting the file name of the new depth raster with units of feet.

The “FileNameS” field is for inputting the file name of the new shear raster with units of psf.

The excess shear ratio map does not have units to be converted.

B.15.2. General Map Setup

The GIS template file contains a map frame that is already set up with the correct layout and graphics. The maps have an information box located at the bottom, as shown in Figure B45. The center box displays a length scale, includes property information, and indicates the annual exceedance probability of the map. The center box is also where the map specific legends will be placed. Change the property and annual exceedance probability text as necessary for the individual map. The box on the right holds logos for the IFC and INHF, and the box on the left can be used to write any additional information.

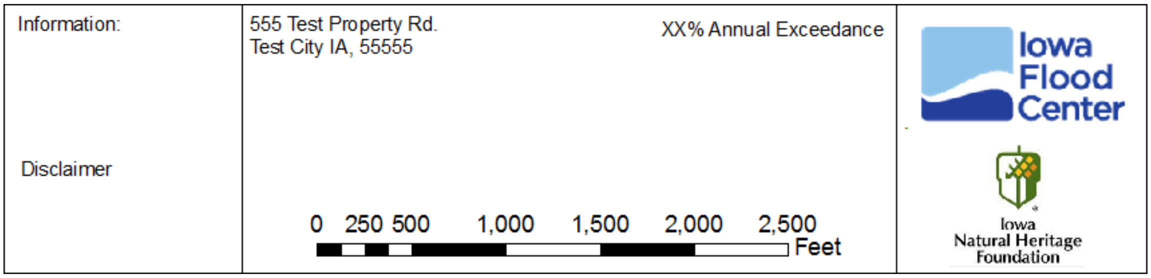
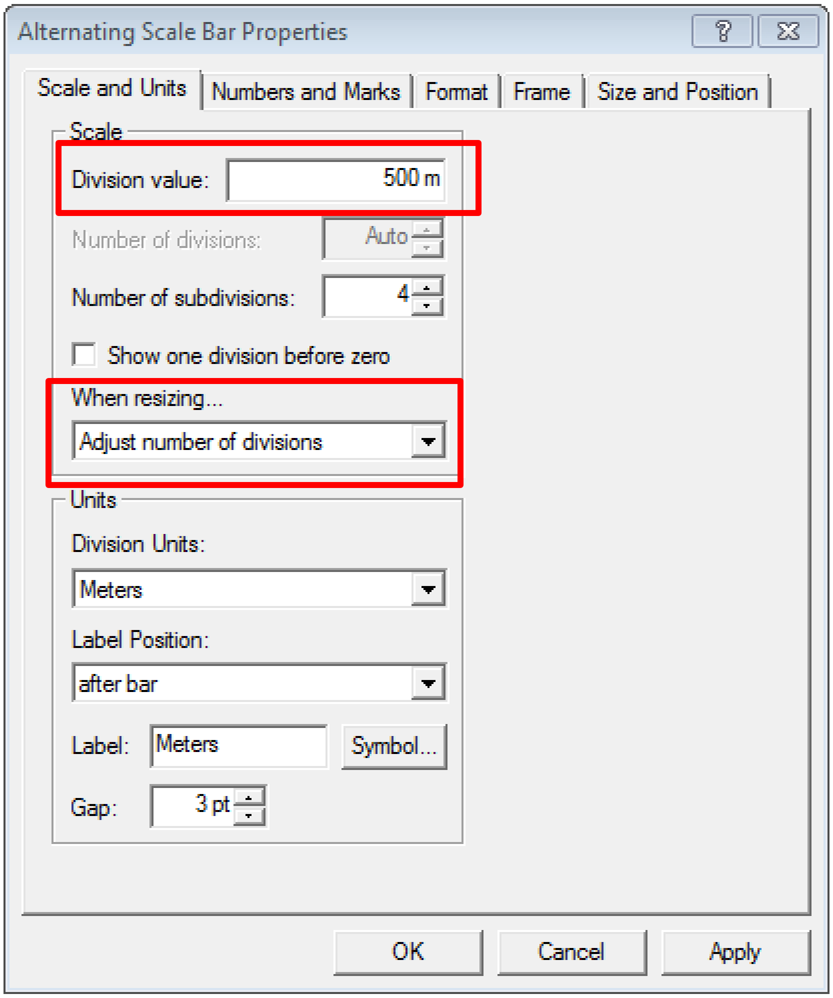


Figure B45: Map template data frame

For best appearance, the length scale should be set up to have length intervals that are multiples of 50 or larger. Right click on the legend and select properties. Change the “When resizing…” dialog box value to “Adjust number of divisions” and set an appropriate division value, as shown in Figure B46.



Division value: 500 m
Number of divisions: Auto
Number of subdivisions: 4
☐ Show one division before zero
When resizing... Adjust number of divisions
Division Units: Meters
Label Position: after bar
Label: Meters
Gap: 3 pt

Figure B46: Length scale bar setup with rectangles indicating fields to be changed

B.15.3. Creating Inundation Maps

Make the inundation boundary active. The stream centerlines should also be shown to make it easier to identify where the main channel lies. Make the weight and color of the stream centerlines visible. Change the view to layout and center the property or area of interest in the map frame. Property boundaries can optionally be shown if desired by the INHF.

The following graphic, shown in Figure B47, should be moved to the center of the information map. The graphic is set up for a light blue colored inundation shapefile, dark blue centerlines, and red property boundaries. The graphic can be ungrouped and modified if necessary. A new legend can also be created if different colors are being used for any of the objects being shown in the map. Figure B48 shows where the legend should be placed for the Inundation map. Figure B53 at the end of Appendix B shows a sample completed inundation boundary map for the 1% annual exceedance probability.

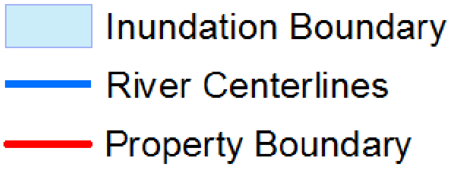


Figure B47: Suggested inundation boundary map legend

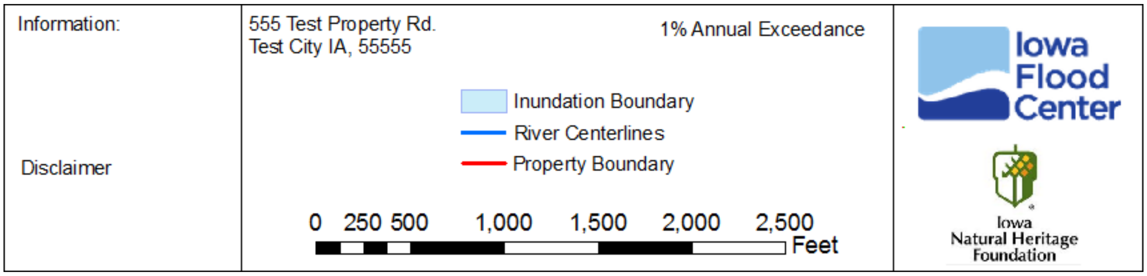
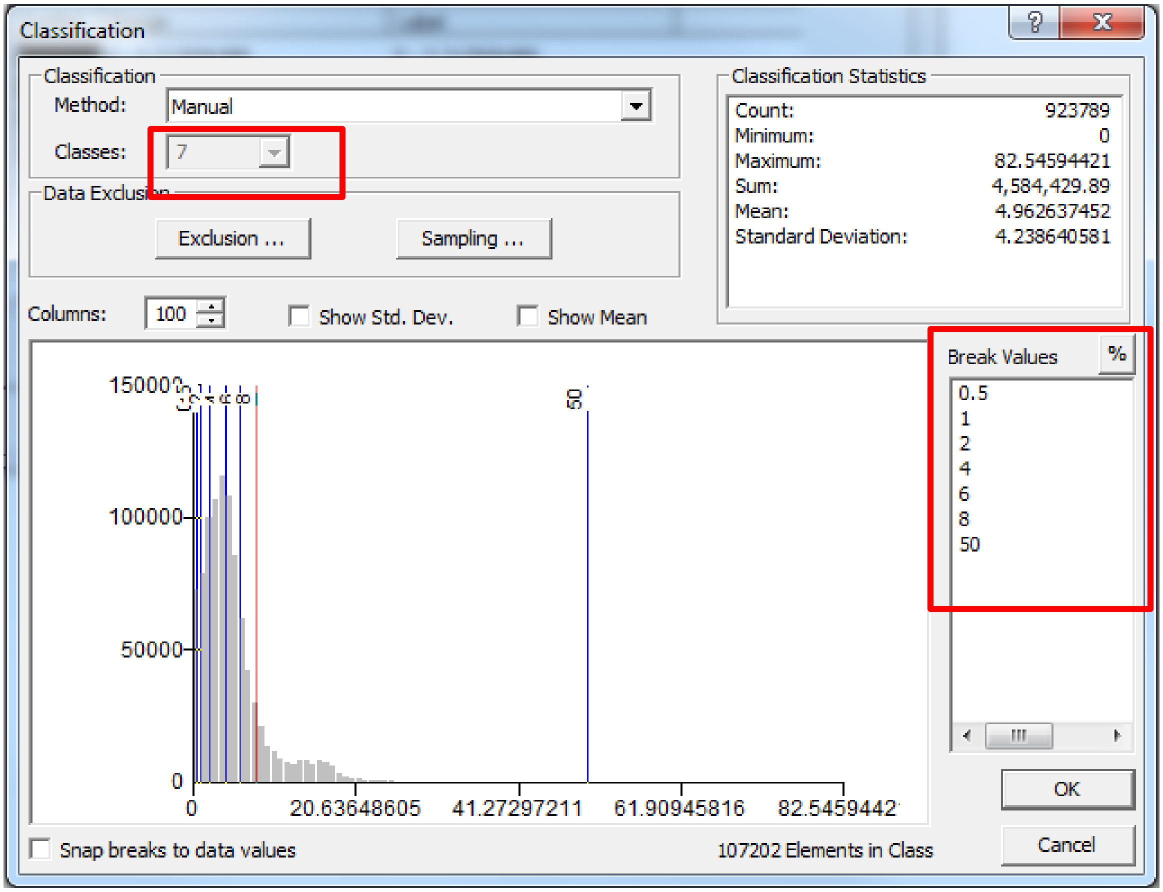


Figure B48: Map data frame with inundation map legend

B.15.4. Depth Maps

The depth maps should use a classified symbology to display the following depth ranges: 0-0.5, 0.5-1, 1-2, 2-4, 4-6, 6-8, and 8+ feet. Go the layer properties window for the raster, select "Classified" in the left box, then click classify. Change the number of classes to 7 in the classification window. Fill in the Break Values, as is shown in Figure B49, and click OK.



Method: Manual

Classes: 7

Columns: 100

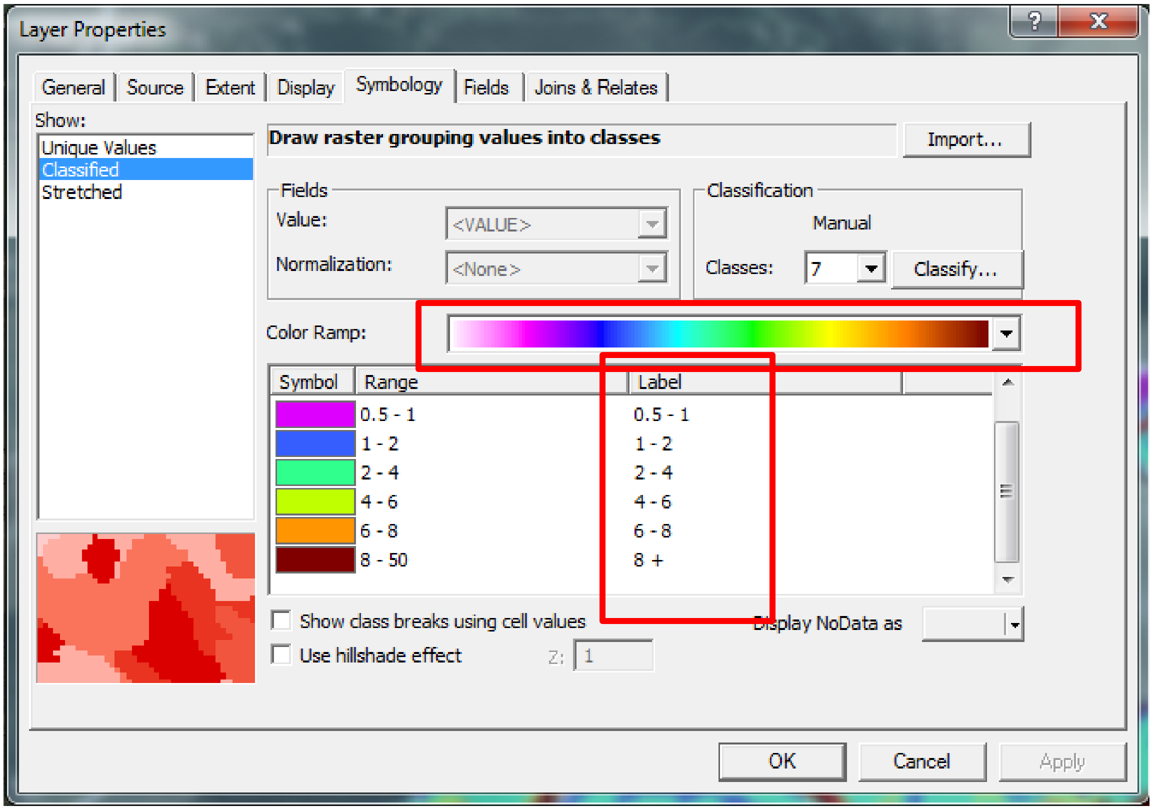
Count: 923789
Minimum: 0
Maximum: 82.54594421
Sum: 4,584,429.89
Mean: 4.962637452
Standard Deviation: 4.238640581

Break Values
0.5
1
2
4
6
8
50

107202 Elements in Class

Figure B49: Depth map classified symbology setup with rectangles indicating fields to be changed

Change the color scheme and depth range labels in the Layer properties window, as shown in Figure B50. The color scheme chosen should be one that results in easy to read depth maps.



Show:
- Unique Values
- Classified
- Stretched

Draw raster grouping values into classes

Fields

Value: <VALUE>

Normalization: <None>

Classification

Manual

Classes: 7

Color Ramp:

Symbol	Range	Label
🟪	0.5 - 1	0.5 - 1
🟦	1 - 2	1 - 2
🟩	2 - 4	2 - 4
🟨	4 - 6	4 - 6
🟧	6 - 8	6 - 8
🟥	8 - 50	8 +

☐ Show class breaks using cell values

☐ Use hillshade effect Z: 1

Display NoData as

Figure B50: Color ramp and labels of depth map classifications with rectangles indicating fields to be changed

There should be several pre-made depth legend graphics for several of the better color schemes located to the left of the map in the layout view. There is also text reading "Depth (ft)." Drag the "Depth (ft)" text and the correct premade graphic to the center of the information box, as shown in Figure B51. A new legend graphic will have to be created if a custom color scheme was used. Figure B54 at the end of Appendix B shows a complete depth map.

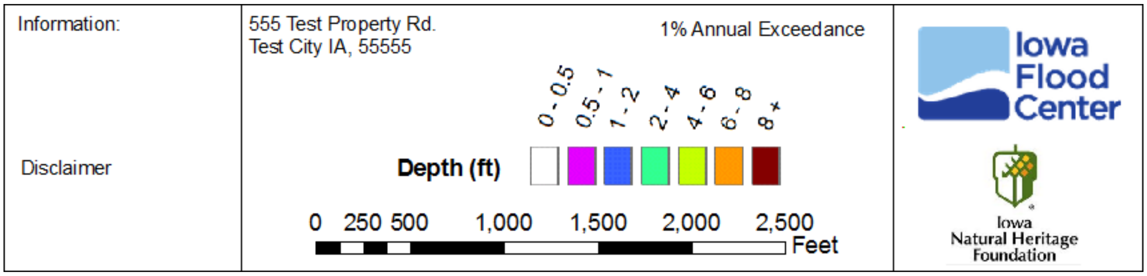


Figure B51: Map data frame with depth map legend

B.15.5. Excess Shear Maps

The excess shear maps will not be released to the public in their raw form. Instead, an experienced user will use them to create polygons that identify moderate and high scour potential areas can easily be understood by a lay person.

Figure B52 shows the information box with the premade legend graphic for the excess shear ratio map. Figure B55 at the end of Appendix B shows an example where the high scour potential polygons have been overlaid on an inundation map. The high scour potential polygons can also be overlaid on a depth map.

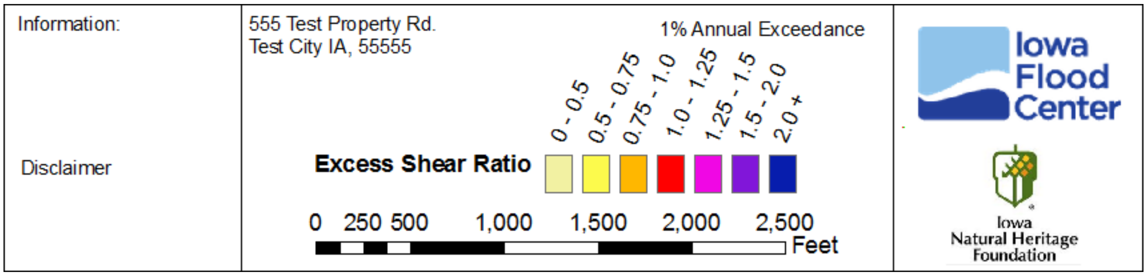


Figure B52: Map data frame with excess shear ratio map legend

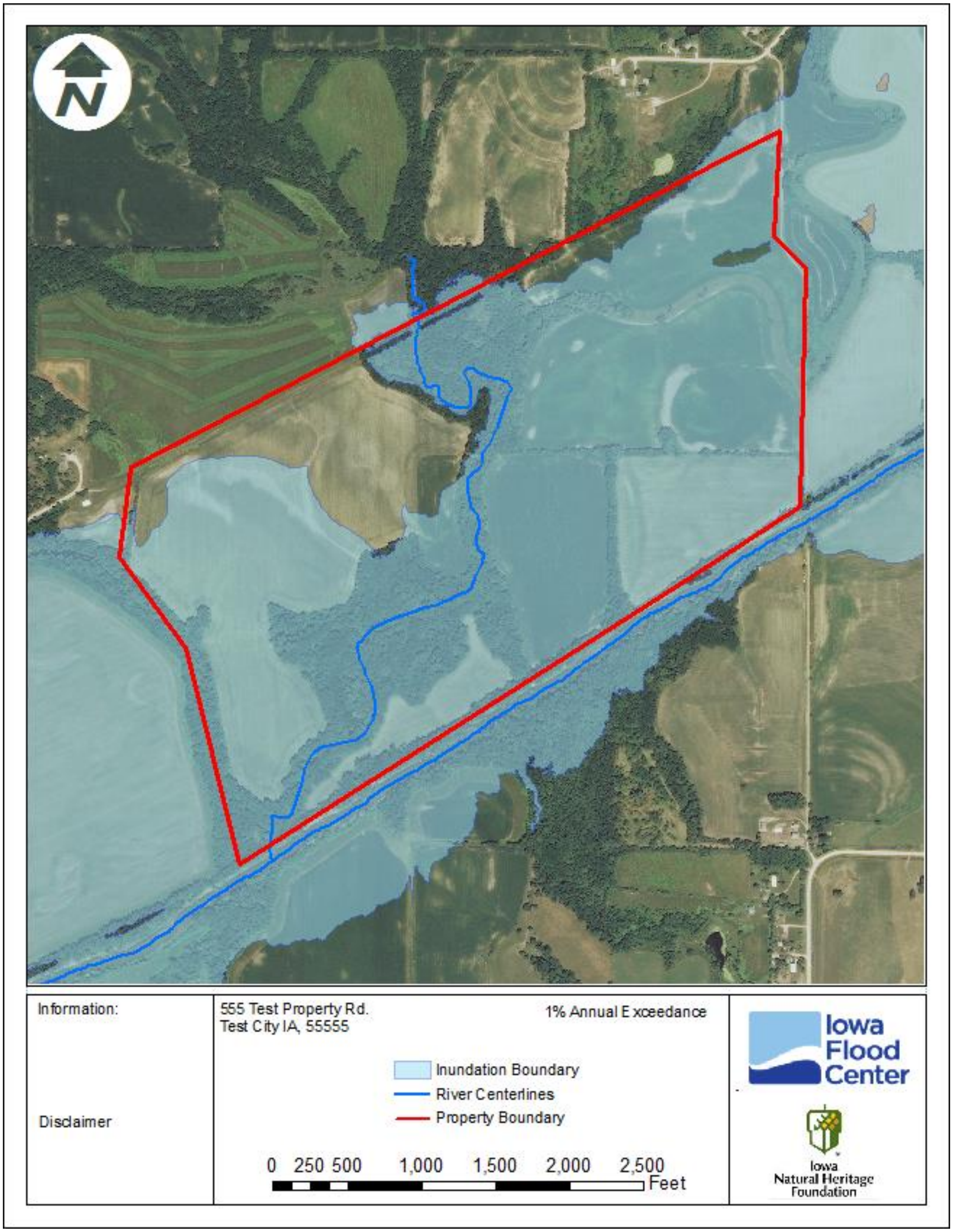


Figure B53: Inundation boundary map

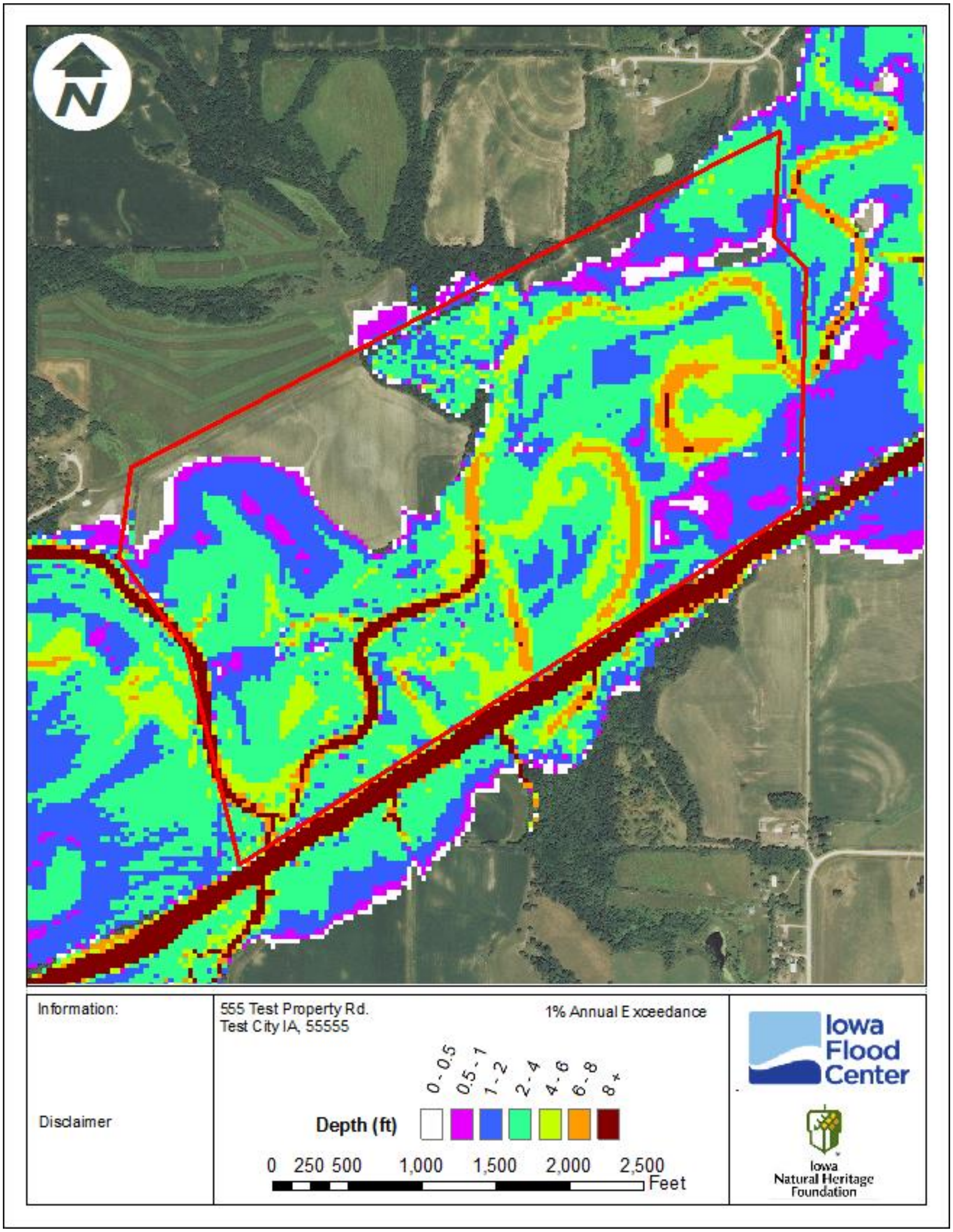


Figure B54: Depth map

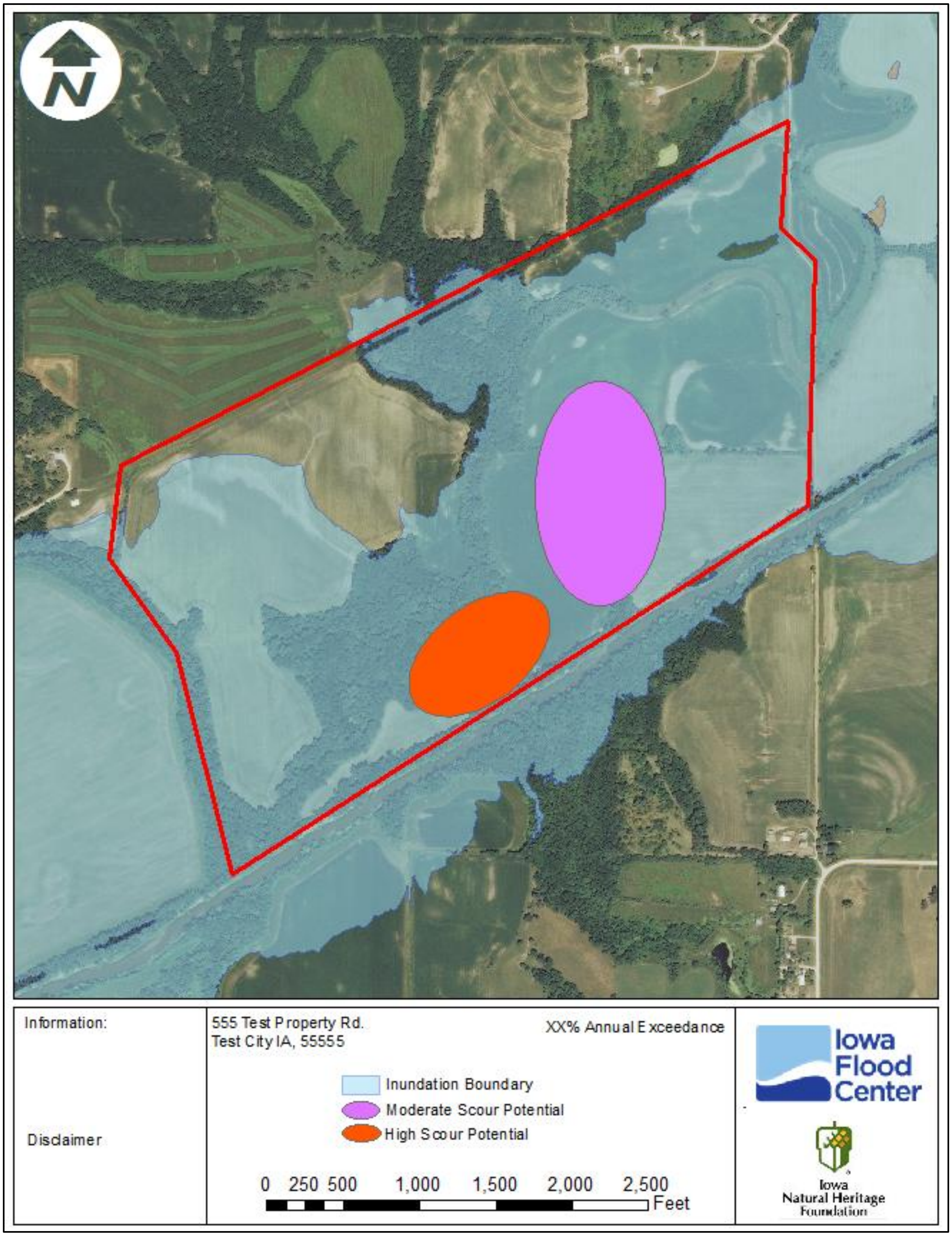


Figure B55: Excess shear ratio map