Optimized Pit Removal V1.5.1 Tutorial

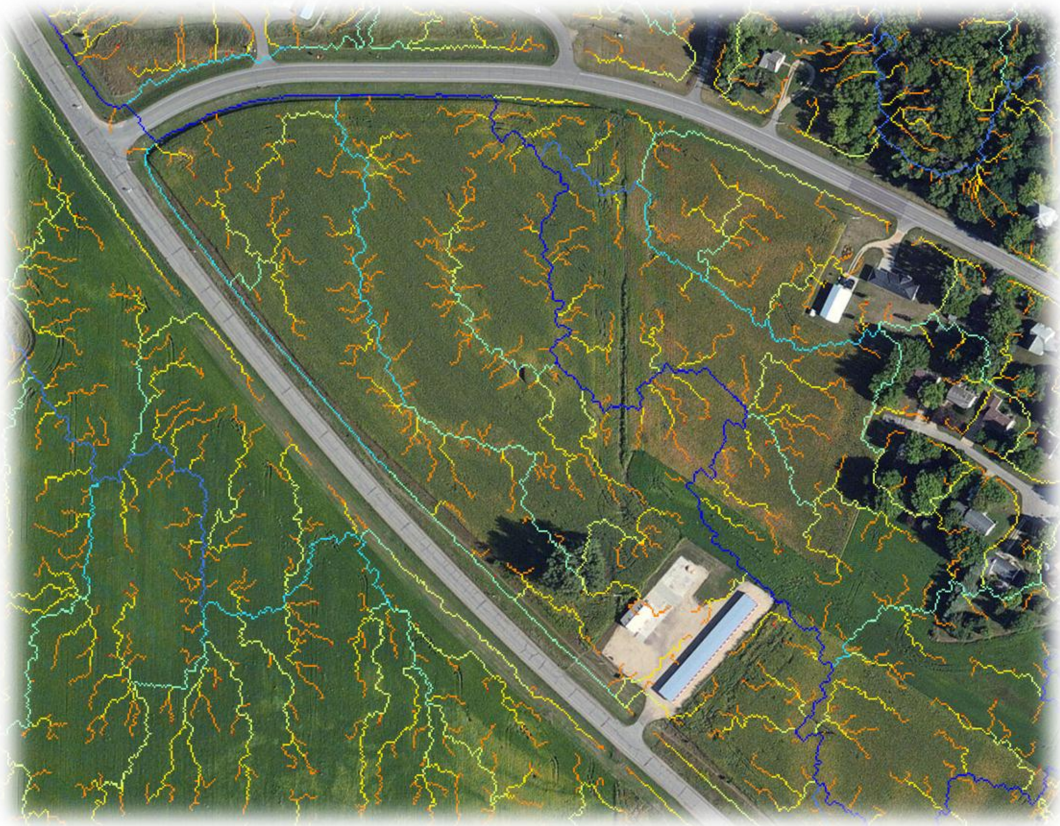

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Table of Contents

I. Introduction

1. System Requirements

The Optimized Pit Removal tool is available to download for free at http://tools.crwr.utexas.edu/, which includes installation instructions and the Tutorial sample files. The tool was designed for ArcMap 10.1 and Windows 7 64-bit and has not been tested in other environments. Most hydrologic conditioning workflows also require the ArcGIS Spatial Analyst Extension.

The current maximum grid size is approximately 50,000,000 cells, with a practical limit of approximately 25,000,000 cells (5 square km. at 1 meter resolution). Files exceeding the practical limit will take considerably longer to process.[1] Files exceeding the maximum will generate an error message at the start of the processing. This file size limit will be expanded in future versions of the tool.

2. Description of tool

Extracting hydrologic features such as stream centerlines and watershed extents from a Digital Elevation Model (DEM) typically requires first hydrologically conditioning the DEM. In this process the elevations are modified in order to clearly establish flow directions. Operations such as Flow Direction and Flow Accumulation can then be performed on the conditioned DEM. The Optimized Pit Removal tool provides an alternative to the standard ArcGIS Fill method of removing pits from a Digital Elevation Model (DEM).

A pit is the lowest point of a depression with no outlet. This may be a real aspect of the terrain or an artifact of pre-processing operations on the raw terrain data, such as the removal of trees to create a bare earth LiDAR model. As localized points with no outlet, pits hinder the automated detection of regional flow paths.

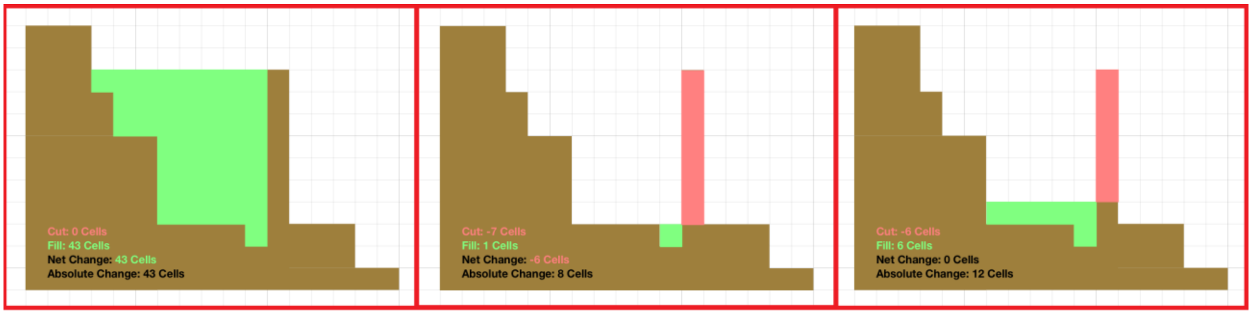
- ➢ The term Pit is used here rather than the ArcGIS term Sink. Both are conceptually the same, but the method of detection varies, as does the specific cells identified. A grid which has had all Pits removed will also be free of Sinks.

One downside of the standard ArcGIS Fill method of removing pits is that it tends to obscure meaningful elevation data for wide areas upstream of any dam-like feature. This is especially prevalent when the terrain is flat and when working with high resolution data such as LiDAR. The Optimized Pit Removal tool uses a combination of cut and fill to remove all undesired pits while minimizing the overall changes to the landscape. The user can choose to either minimize the absolute change in landscape elevation summed across all cells, or to minimize the net change in landscape elevation (effectively balancing cut and fill). An option is also provided to exclusively use cut.

3. Description of Updates

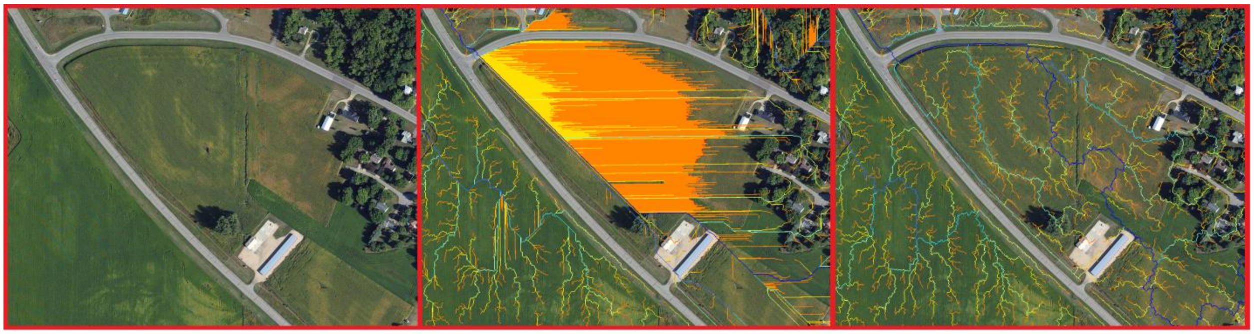
Version 1.5.1 includes an added Stream Delineation Model to simplify the analysis of the results. A default location was defined for the Temporary Output DEM (ASCII) in the Optimized Pit Removal Model.

[1] The Tutorial sample file of 2580 x 3530 cells processes in under five minutes. A 7000 x 7000 cell file was successfully processed in an hour.



Pit Removed Using Fill | **Pit Removed Minimizing Absolute Change** | **Pit Removed Minimizing Net Change**

Figure 1: Pit Removal Strategies



City of St. Clair, Blue Earth County, MN
Imagery Credits: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Flow Accumulation Results
(Pits Removed Using Fill Tool)

Flow Accumulation Results
(Pits Removed Using Optimized Pit Removal Tool)

Figure 2: Benefits of Optimizing Pit Removal

4. ASCII/Raster Conversions

The basic **Optimized Pit Removal V1.5** tool uses ASCII files for input and output. Included in the package is a model which automates the conversion process. For most cases, it is recommended that this **Optimized Pit Removal (Raster)** model be used, rather than the basic tool itself.

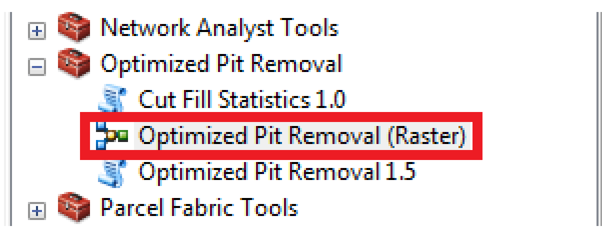


Figure 3: Preferred Tool

If the basic tool is used, file conversions must be done manually. ArcGIS includes the tools **Raster To ASCII** and **ASCII To Raster**, which can be used to prepare files for use. When converting from ASCII to Raster, it is important to change the Output data type from INTEGER to FLOAT. After conversion, the coordinate system must be manually defined through the raster properties in ArcCatalog.

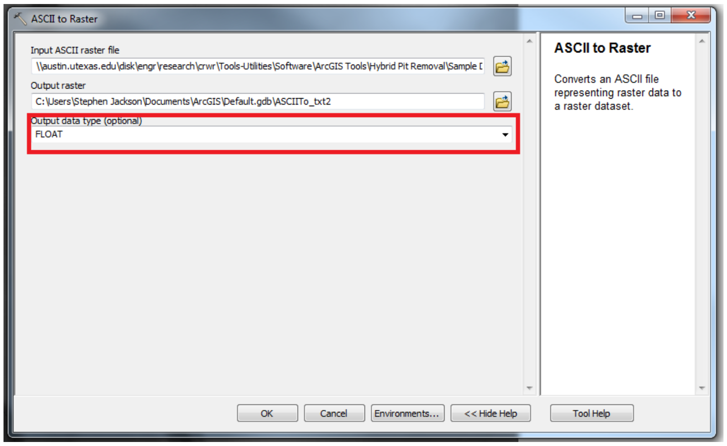


Figure 4: Select Output Data Type

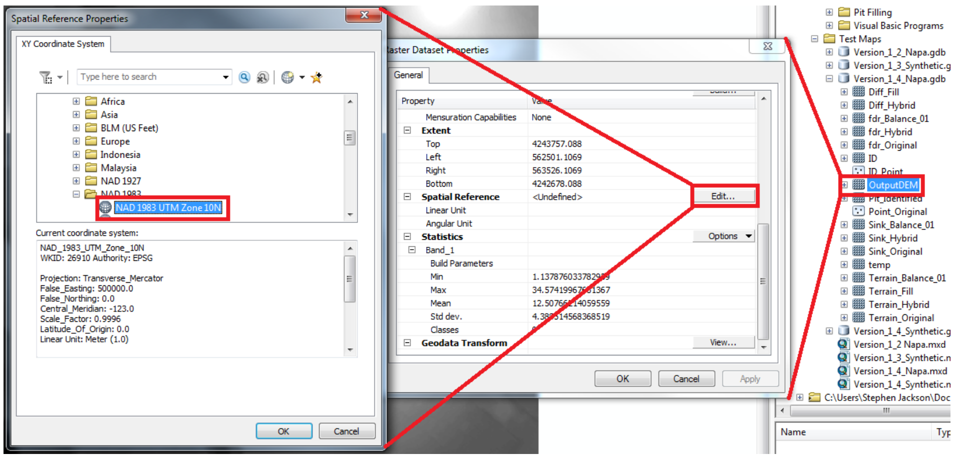


Figure 5: Define Raster Coordinate System

II. Pit Removal Procedure

For this tutorial, a sample DEM is provided in both ASCII and GRID form named DEM_Orig (located in \Tutorial\Sample Files). The file is a bare earth LiDAR terrain of 2580 x 3530 cells with 1 meter horizontal resolution located in the City of St. Clair, Blue Earth County MN[2]. The coordinate system used is NAD83 (HARN) UTM Zone 15N.

1. Create new file

- Start ArcMap using a new blank map.
- Use the 'Connect to Folder' tool and connect to the Tutorial folder. (e.g. "C:\Software\Optimized Pit Removal V1.5\Tutorial")
- Save this file in the Tutorial\Sample Files folder and name it "Pit Removal Comparison.mxd".
- Using the Catalog, navigate to the selected folder and create a new File Geodatabase and name it "Pit Removal Files.gdb".
- Set this as the Default Geodatabase.

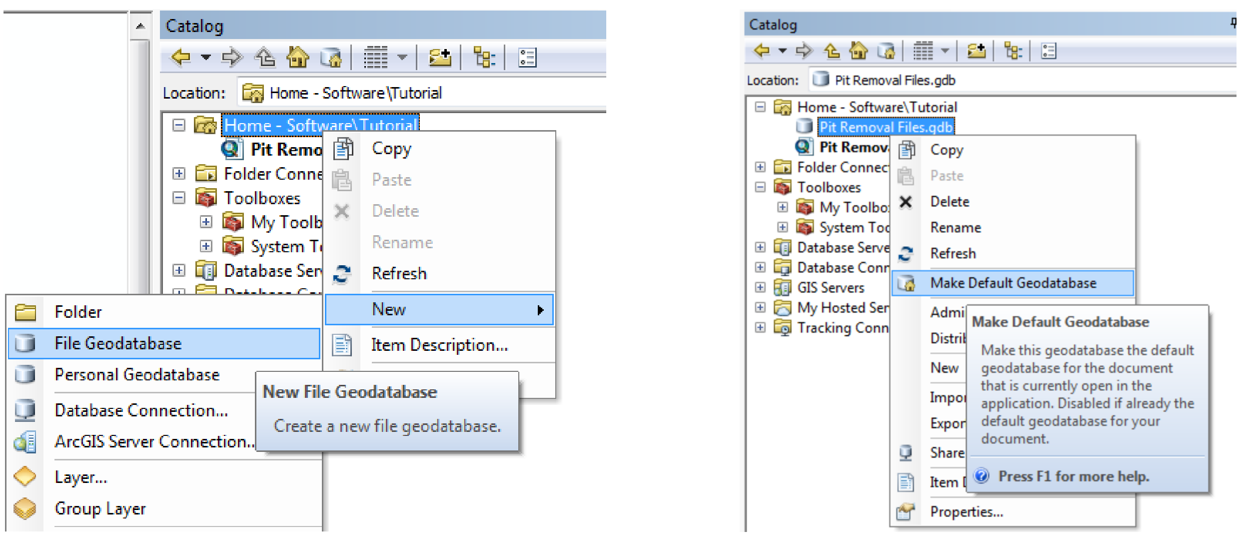


Figure 6: Create New Default Geodatabase

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[2] Source: Tile Number: 4342-30-05, "LiDAR Elevation, Blue Earth County, Minnesota, 2012." AeroMetric, Inc. and Minnesota Department of Natural Resources. April 6, 2012. http://www.mngeo.state.mn.us/chouse/elevation/lidar.html

2. Import Sample DEM

- Using the Copy Raster tool (Data Management Tools → Raster → Raster Dataset) to import the DEM_Orig grid into the Geodatabase.
- Other values can remain at their defaults.

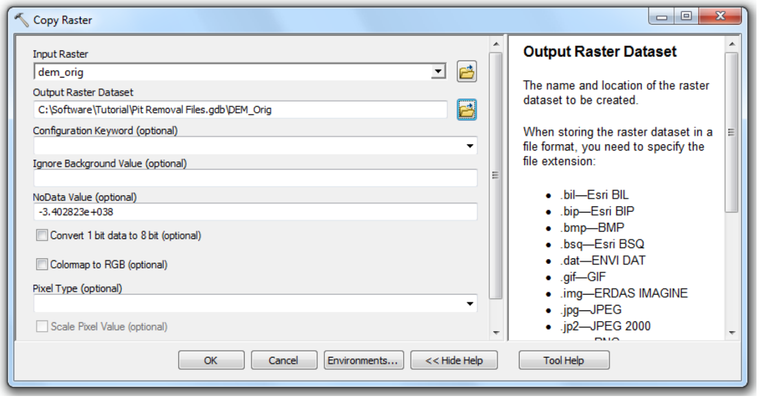

Figure 7: Import GRID DEM

3. Remove Pits using the Optimized Pit Removal (Raster) Model

- Open ArcToolbox and find the Optimized Pit Removal toolbox
  - If the toolbox is not there, see "Installation Instructions.pdf" for information on how to load the toolbox.

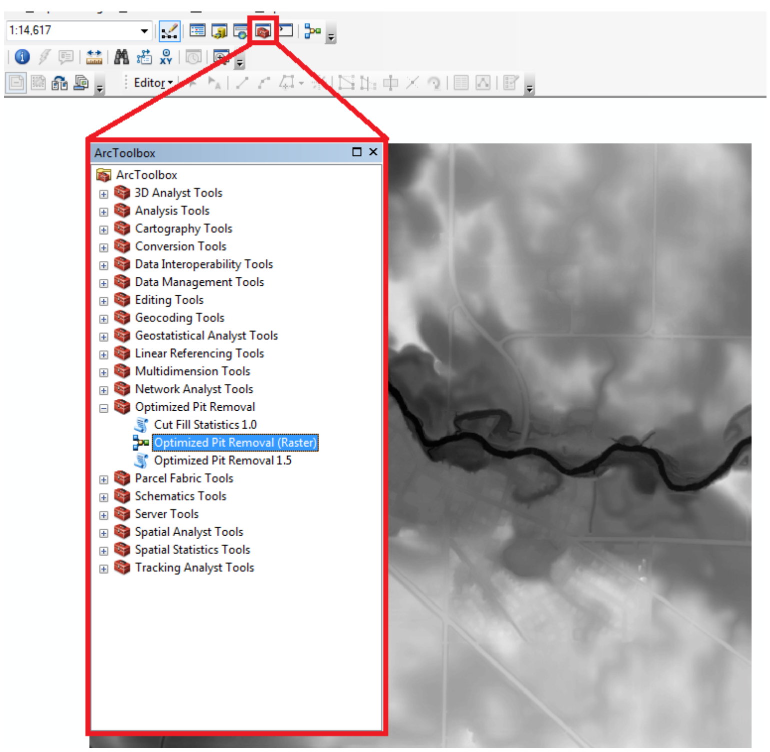

Figure 8: Locate Tool

- Run the Optimized Pit Removal (Raster) model.
    - Set the Input DEM to DEM_Orig
    - Set the Output DEM to DEM_MinAbs (to signify which mode was used)
    - Set the Step Size to 0.01
        - This is a high resolution LiDAR file, so we are interested in features at the vertical scale of 0.01 meters.
    - Use the default Mode of Minimize Absolute Elevation Change
    - Set the Output DEM (Temporary ASCII) to \Tutorial\Sample Files\junk.txt
        - This file is required to be set manually because of the way ArcGIS handles conversions, and will be deleted automatically.

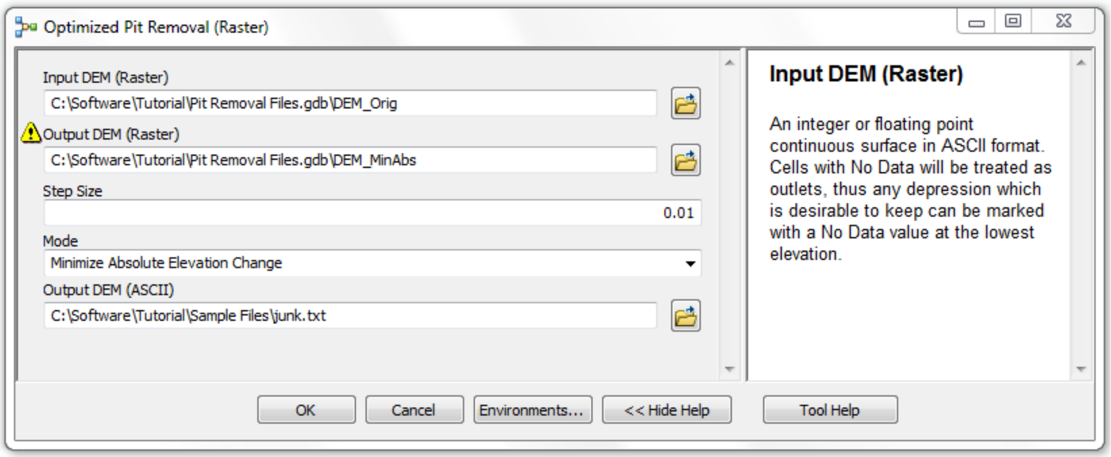

Figure 9: Optimized Pit Removal Options

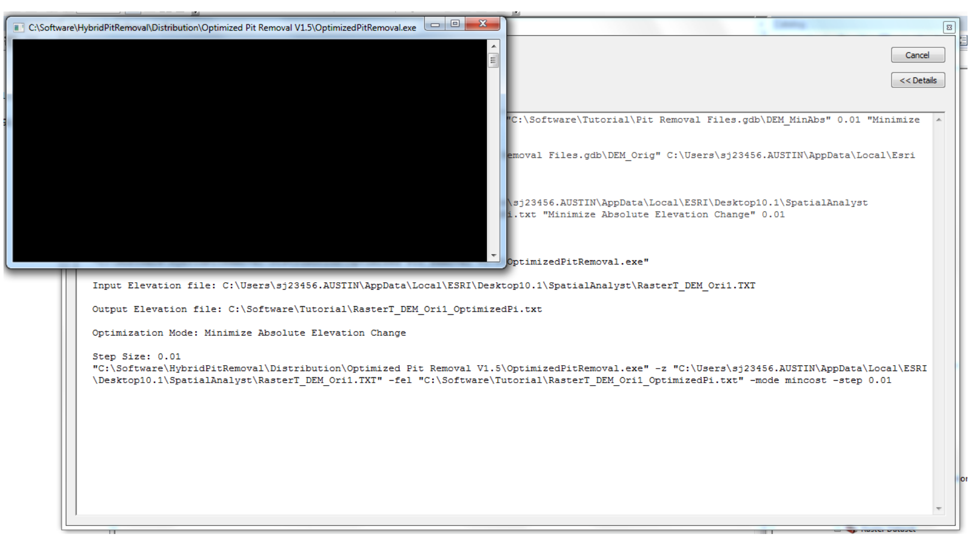

Figure 10: View While Tool is Operating

- The model will perform the required conversions as well as running the Pit Removal tool.
    - For the sample file, this process should complete in approximately five minutes, depending on computer specifications.

- When completed, a new raster will be automatically added to the map.

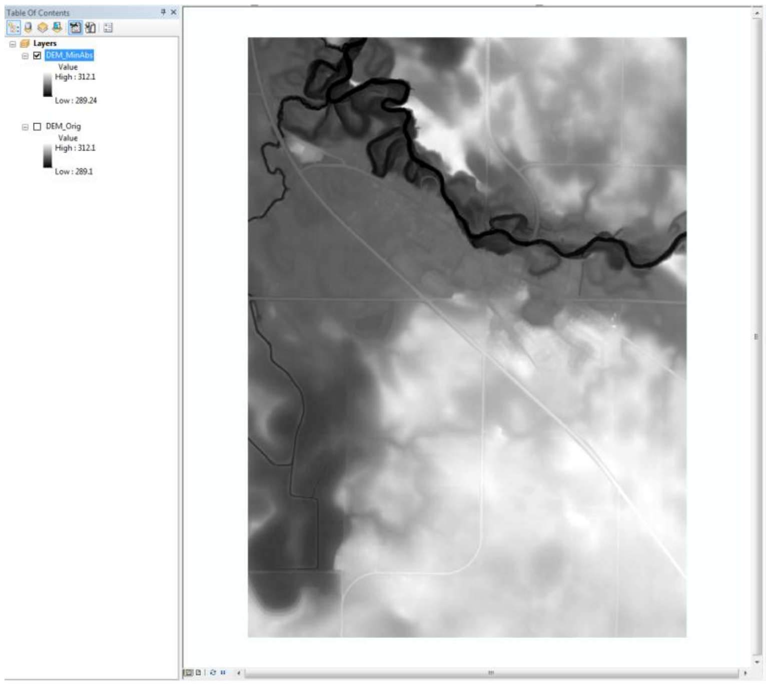

Figure 11: Pit Removed DEM

➢ For more information on evaluating the results, see Section IV.

III. Optional Advanced Procedures

These are optional features of the Optimized Pit Removal tool which can be used to increase the functionality.

1. Marking depressions

The Optimized Pit Removal tool treats any cell with No Data as an outlet. This means that cells which drain towards a region of No Data will not be considered depressions to be removed. This allows the user to mark depressions which should remain in the modified DEM. This can be used to define features such as **reservoirs** or known drainage features such as **storm sewer inlets**.

- Setting the lowest cell in a depression to have No Data will prevent that depression from being removed by the tool.

2. Using the Console Application

The ArcGIS Optimized Pit Removal tool uses a console application to perform the actual DEM modifications. This application can be accessed directly using a command line input.

Advantages of using the Console Application rather than the ArcGIS tool:

- This console application can be run independent of ArcGIS using only an ASCII file for input.
- The console application provides more realtime feedback to indicate operation, which can be used while troubleshooting.
- An additional option for saving a file with all the pit locations is provided with the console application, which is not currently implemented in the ArcGIS tool.

Running the Console Application:

- From the Start Menu, type “cmd” to bring up a command line.
- Enter “cd DIRECTORY”
    - DIRECTORY is the path where the Optimized Pit Removal tool is located
- Enter “OptimizedPitRemoval –z “INPUT DEM” –fel “OUTPUT DEM” –pit “OUTPUT PIT” –mode “MODE” –step “STEPSIZE”
    - INPUT DEM: The complete filepath of the input ASCII DEM
    - OUTPUT DEM: The complete filepath of the output ASCII DEM
    - OUTPUT PIT (Optional): The complete filepath of the ASCII Pit Locations file
    - MODE (Optional – “mincost” is default):
        - “mincost” for Minimize Absolute Elevation Change
        - “bal” for Minimize Net Elevation Change
        - “cut” for Cut Only
    - STEPSIZE (Optional – “0.1” is default): A positive number greater than 0. (Variable type is DOUBLE).

Example:

Input: OptimizedPitRemoval -z "C:\Software\Tutorial\dem_orig.txt" -fel "C:\Software\Tutorial\dem_minabs.txt" -pit "C:\Software\Tutorial\pits.txt" -mode mincost -step 0.01

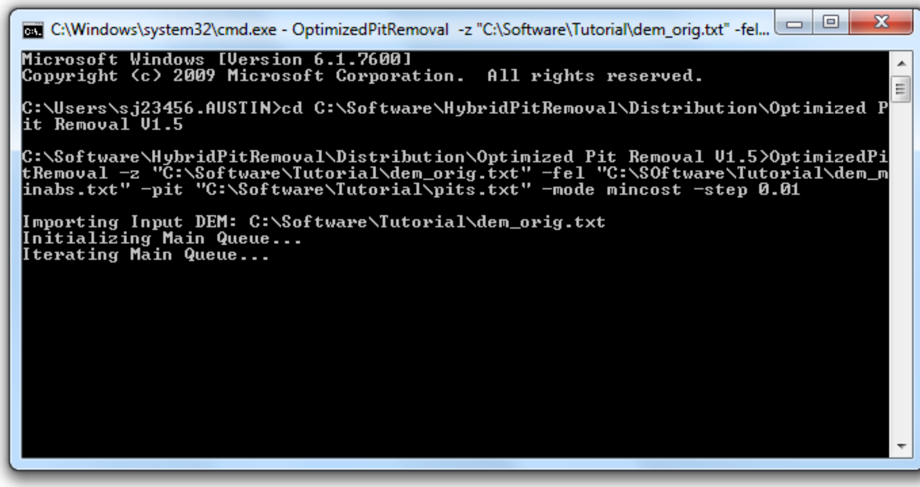

Figure 12: Console Application

IV. Using the Results

Notes of Caution

- The current version of the tool treats all border cells as outlets. This may lead to unrealistic flow paths near the DEM edges. For best results, the watershed of interest should fit entirely within the DEM boundaries. Future versions will address the issue of processing mosaicked DEM files.
- Remember that a hydrologically conditioned DEM has been modified such that it no longer matches the raw elevation data. If the conditioned DEM is intended for a use other than determining flow direction, the user should carefully consider whether the adjustments to the terrain would adversely impact the results.
- On highly detailed DEMs, the accumulated flow paths along larger streams and rivers may show an excessive number of bends, which overestimates stream lengths during flood conditions. It may be desirable to vectorize and smooth out the delineated rivers before further use.

➢ **Optimized Pit Removal Version 1.5.1 includes a Model for Stream Delineation which simplifies the following procedure.** This model takes as an input an Original DEM and a Pit Removed DEM (which can either be the output of the Optimized Pit Removal tool or the Fill tool). It is recommended to apply the symbologies described below to the model outputs.

1. Flow Direction

- Apply the Flow Direction tool (Spatial Analyst Tools → Hydrology)
    - Input: DEM_MinAbs
    - Output: fdr_MinAbs

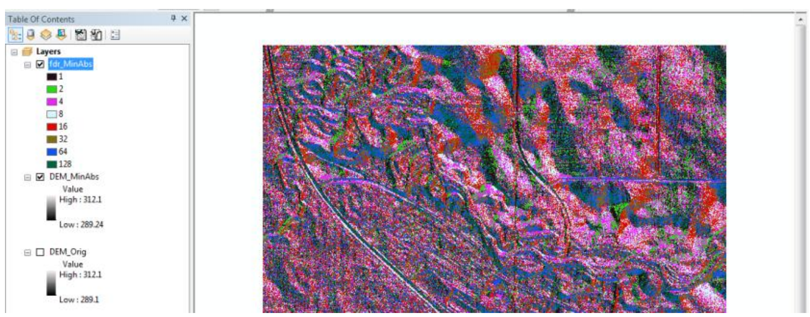

Figure 13: Flow Direction Results

2. Confirm complete sink removal

- Apply the Sink tool (Spatial Analyst Tools → Hydrology)
    - Input: fdr_MinAbs
    - Output: sink_MinAbs
    - If all sinks (pits) have been successfully removed, the resulting raster file will be blank and the symbology will show a range of -2147483648 to 2147483647
    - If any sinks remain, they will be given integer values.

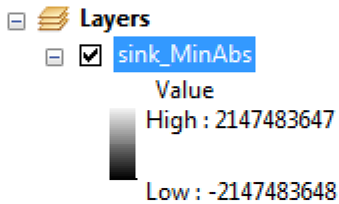

Figure 14: Sink Results

3. Flow Accumulation

- Apply the Flow Accumulation tool (Spatial Analyst Tools → Hydrology)
  - Input: fdr_MinAbs
  - Output: fac_MinAbs
- This step can be fairly time consuming.

4. View Flow Paths

- Apply the Raster Calculator tool (Spatial Analyst Tools → Map Algebra)
  - Formula: SetNull("fac_MinAbs" < 100,"fac_MinAbs")
  - Output: Flow_MinAbs
  - The value of 100 can be adjusted based on the minimum drainage area scale of interest.

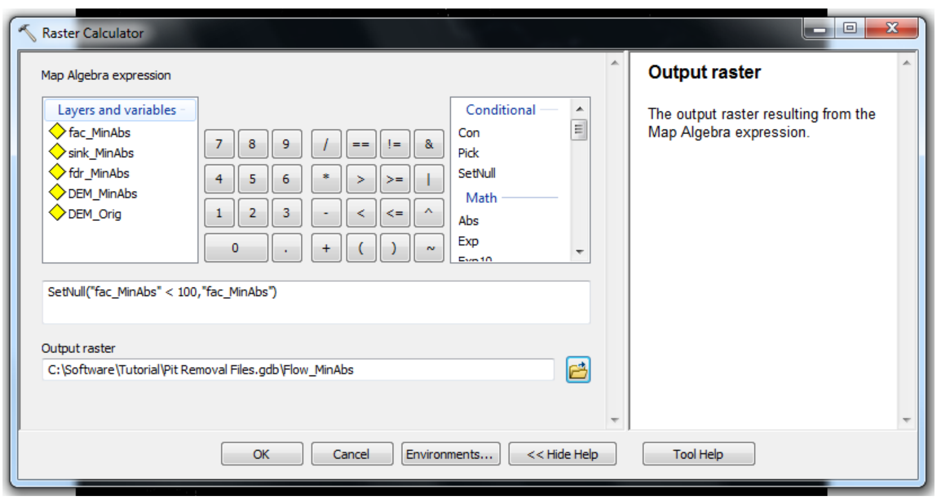

Figure 15: Flow Path Inputs

- Adjust the symbology as shown below.

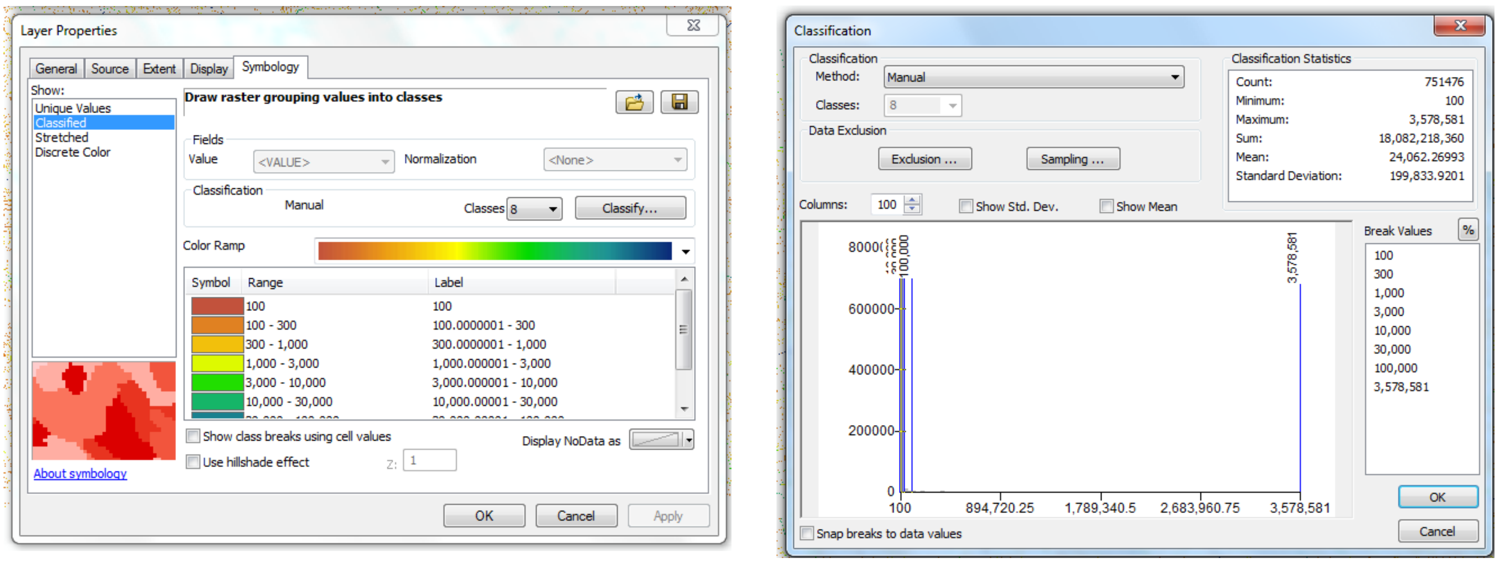

Figure 16: Flow Path Symbology

5. View Modified Cells

- Apply the Raster Calculator tool (Spatial Analyst Tools → Map Algebra)
  - Formula: SetNull("DEM_MinAbs" == "DEM_Orig","DEM_MinAbs" - "DEM_Orig")
  - Output: diff_MinAbs
  - Adjust the symbology as shown below, where Red represents cells which have been lowered (cut) and Green represents cells which have been raised (fill).

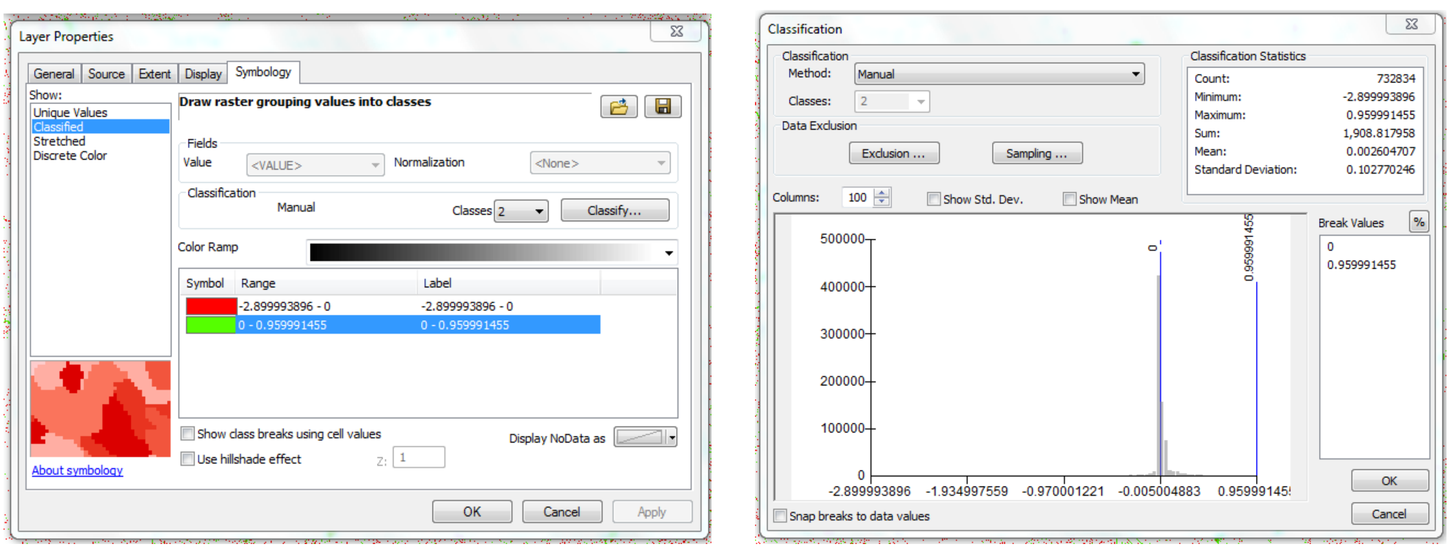

Figure 17: Modified Cells Symbology

6. Cut Fill Statistics

The Cut Fill Statistics tool takes an original DEM and a modified DEM in ASCII form and compares the elevation changes cell by cell, and outputs a summary text file.

- Use the Raster to ASCII tool (Conversion Tools → From Raster)
    - Input: DEM_Orig
    - Output: Dem_Orig.txt
    - Input: DEM_MinAbs
    - Output: DEM_MinAbs.txt
- Use the Cut Fill Statistics tool

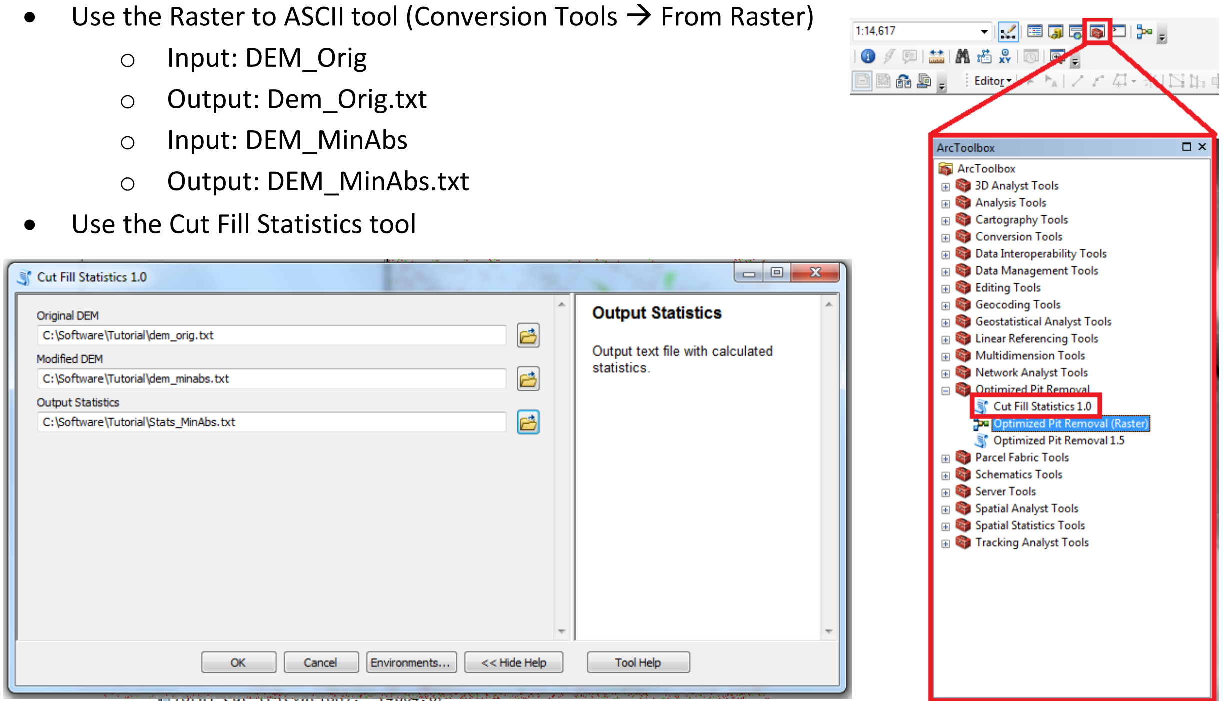

Figure 18: Cut Fill Statistics Inputs

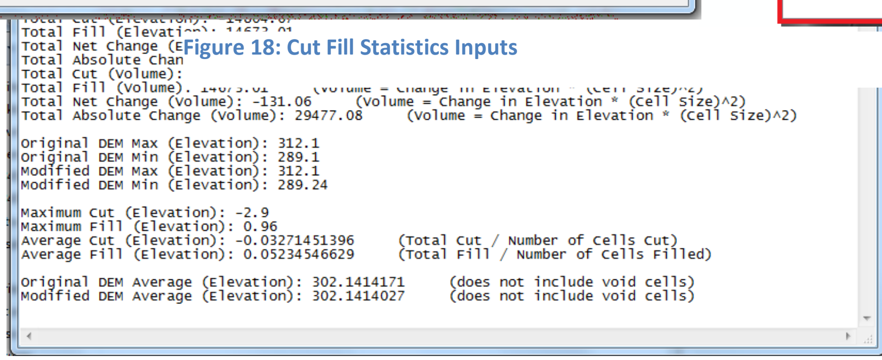

Figure 19: Cut Fill Statistics Results

7. Compare Optimized Pit Removal tool to Fill tool

- Remove the pits from the original DEM using the ArcGIS Fill tool (Spatial Analyst Tools → Hydrology)
    - Input: DEM_Orig
    - Output: DEM_Fill
- Repeat steps 2-7 using DEM_Fill

The following images compare the results, zoomed in to the same sample region.

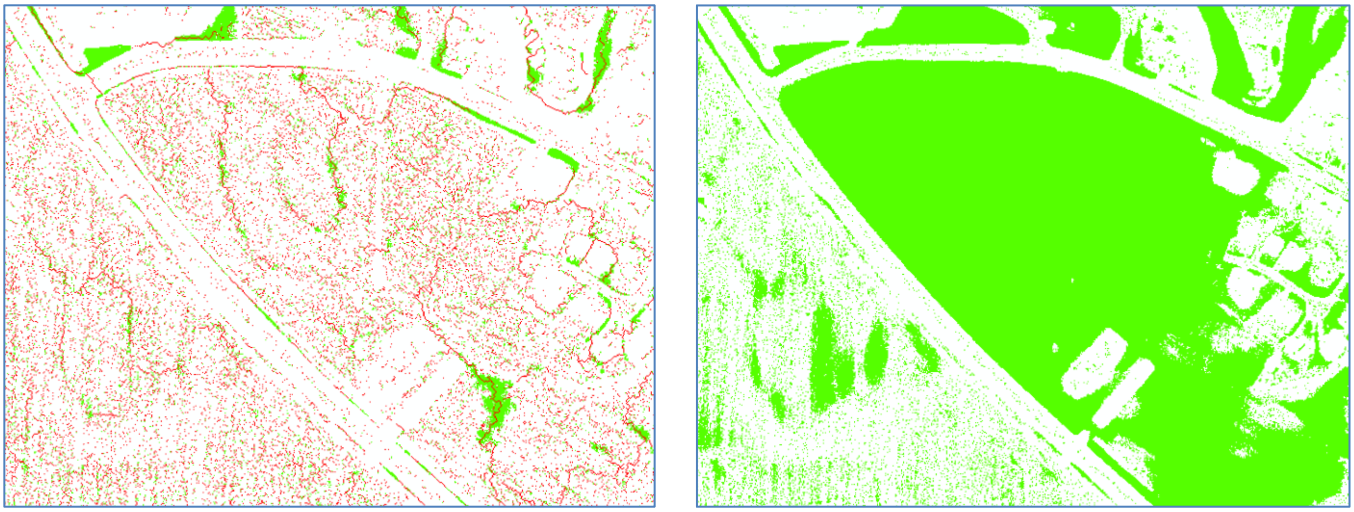

Figure 20: Cells Modified Using Optimized Pit Removal (left) vs. Cells Modified Using Fill (right)

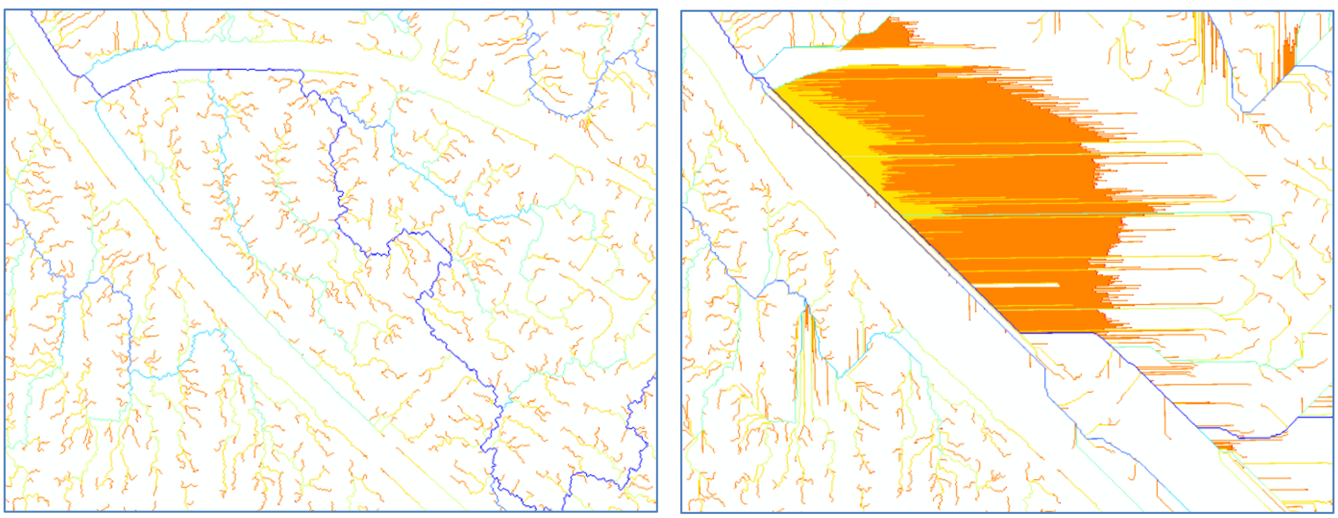

Figure 21: Flow Paths Determined Using Optimized Pit Removal (left) vs. Flow Paths Determined Using Fill (right)

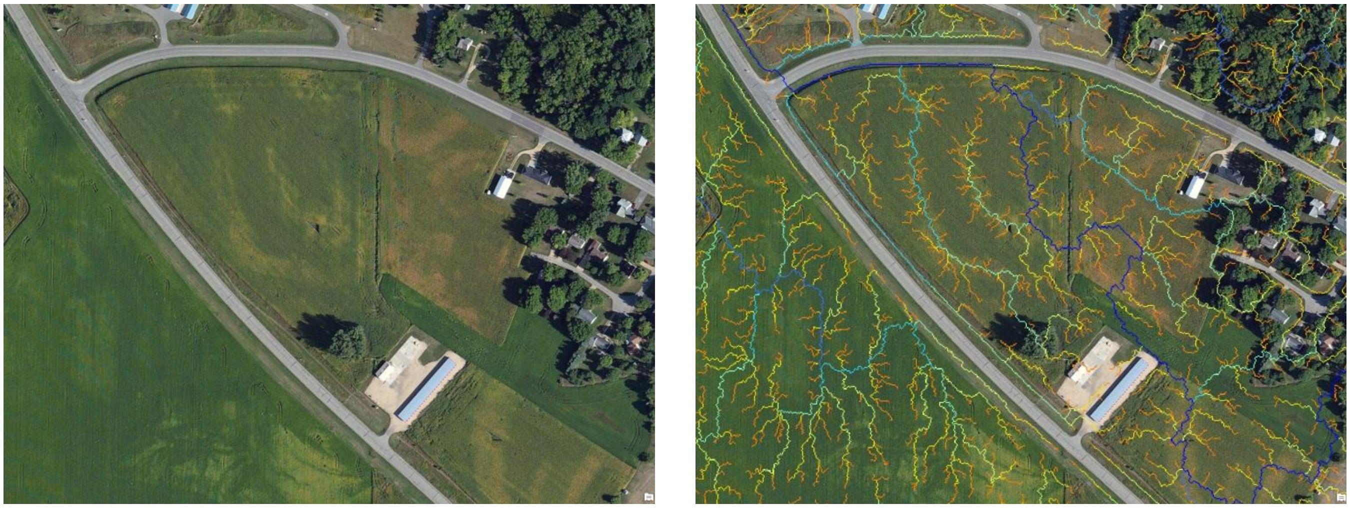

Figure 22: Aerial Imagery (left) vs. Aerial Imagery with Flow Paths Determined Using Optimized Pit Removal (right)

- While further study will be needed to verify the accuracy of the generated flow paths, it can be seen that the results follow vegetation coloration patterns, building lot lines, roadway swales, and even the curves of cul-de-sacs.