Designing an Optimized Pit Removal Tool for Digital Elevation Models

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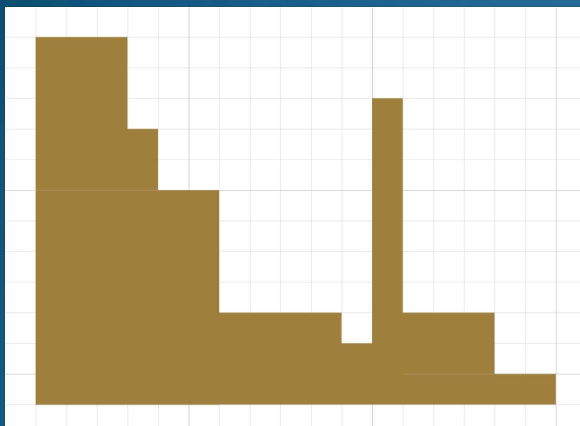
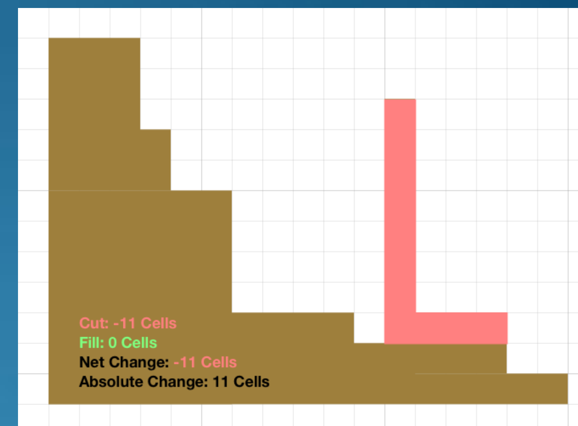
Optimization Criteria

Original Pit



Pit Removed Using Fill

Pit Removed Using Cut

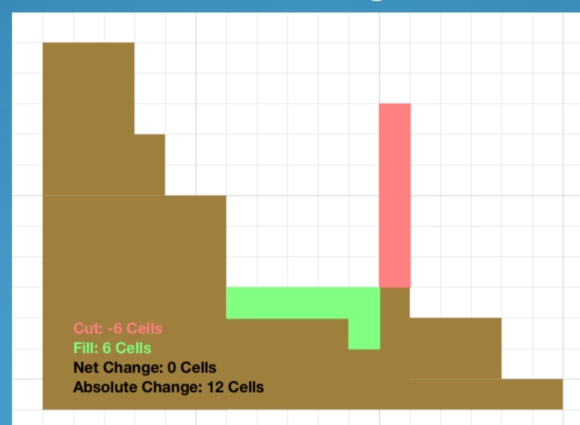


Two Possible Standards For Optimization

Net Change = $\sum_{cells} \Delta z$

Absolute Change = $\sum_{cells} |\Delta z|$

Pit Removed Minimizing Net Change



Pit Removed Minimizing Absolute Change

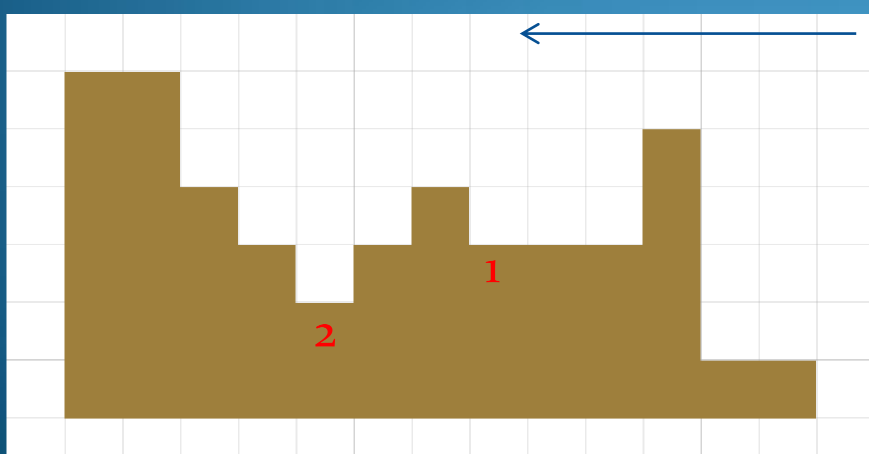
Definition of Pit

Pits are identified by simulating a rising flood from the border .

Criteria for Pits:

- All neighboring cells are of greater or equal elevation
- All neighboring cells of equal elevation have already been flooded
- A path traced back along direction of flooding contains at least one cell of greater elevation

Compound Depressions



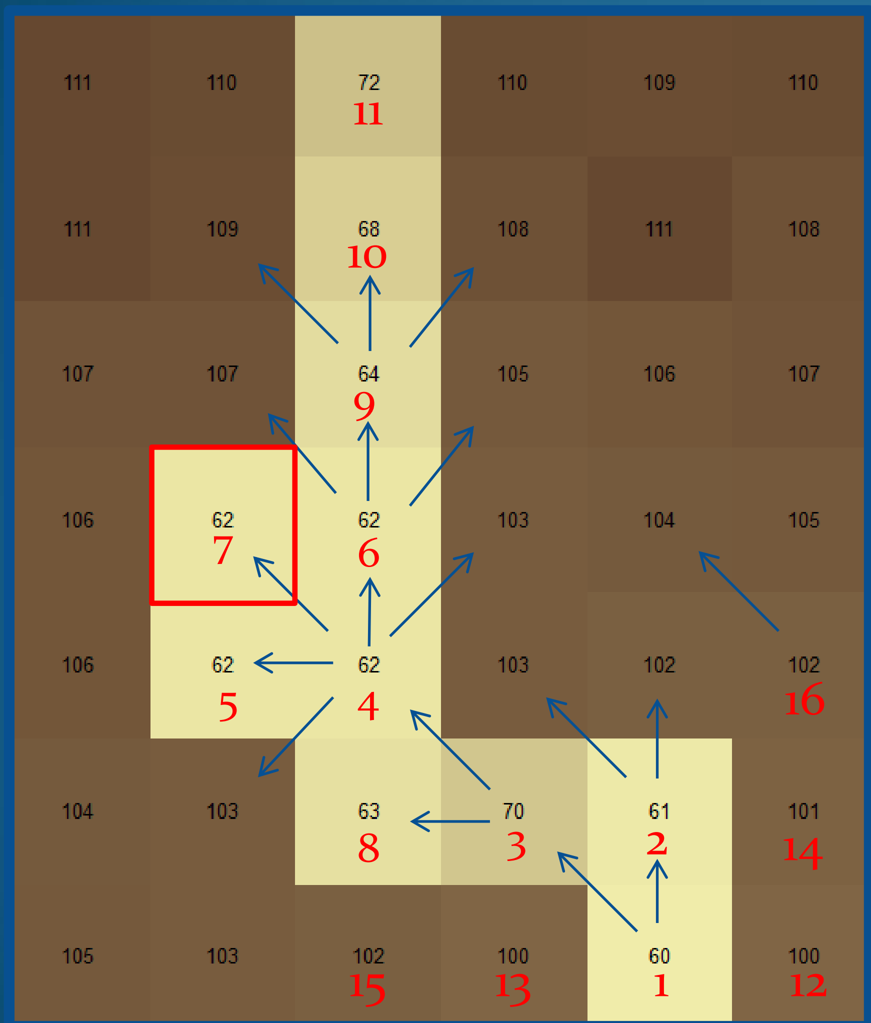
Compound depressions are treated as separate pits and removed in the order of flooding.

<u>Legend</u>

← Direction of Flooding

1 Order of Pit Removal

Rising Flood Algorithm



Initialization: Add all border cells to priority queue, mark as flooded

Iterate until queue is empty:

- Remove lowest cell from queue
- Determine if cell is a pit
- If cell is a pit, run Pit Removal Algorithm
- For each unflooded neighbor cell
  - Add cell to priority queue
  - Mark as flooded
  - Record which cell caused it to flood

<u>Legend</u>

100 Elevation

1 Order of Removal

Initialized Cells

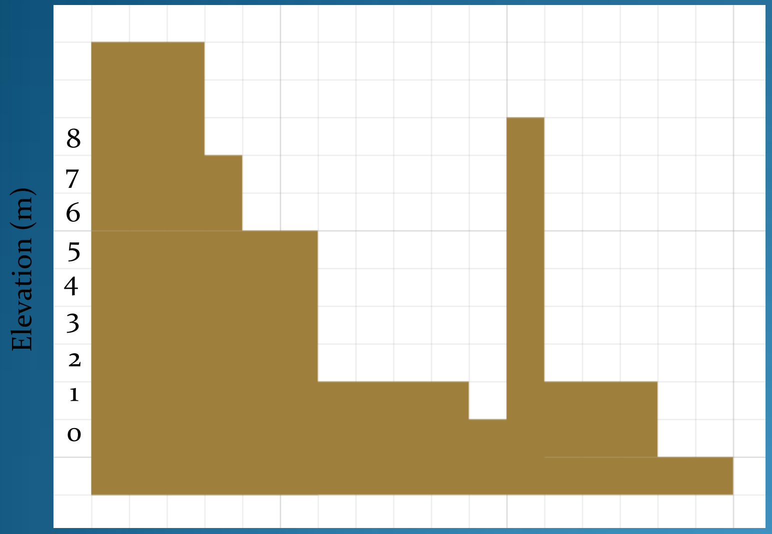
Pit Location

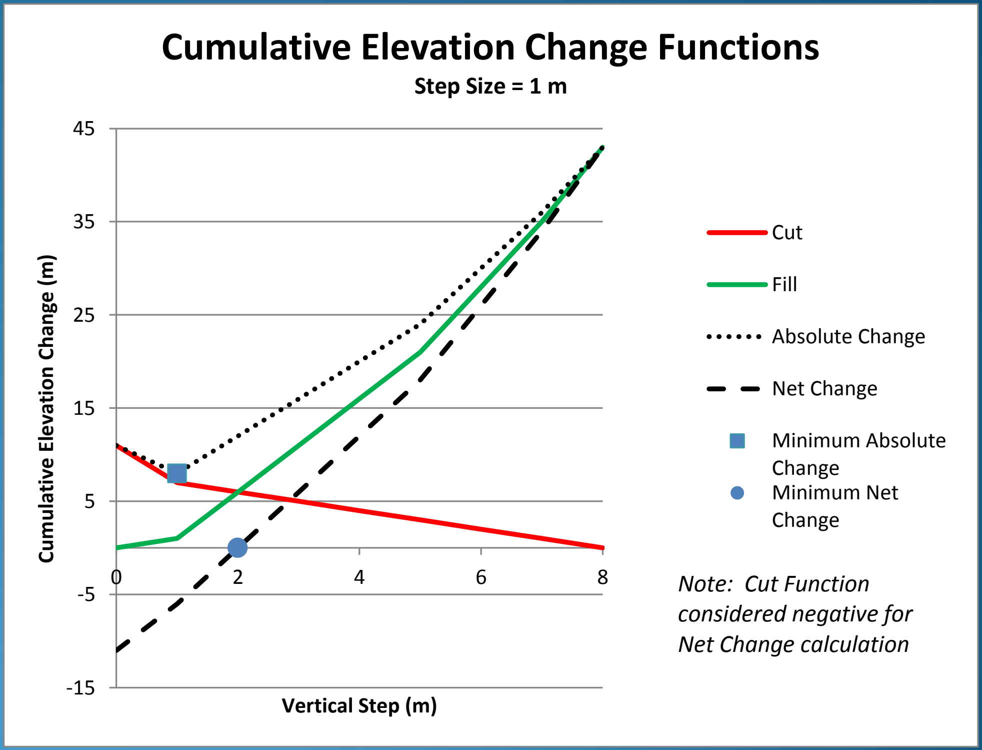
Flooding of Neighbor

Pit Removal Algorithm

- Identify Crest Elevation
  - Crest Elevation = highest elevation on path to outlet)
- Determine Depression Extent
  - Depression Extent = list of cells which drain towards current pit
- Create Cut and Fill Elevation Change Functions
  - Discrete function from Pit elevation to Crest elevation incremented by user-selected step size
  - Fill Elevation Change = summation of elevation change to fill depression up to a given minimum elevation
  - Cut Elevation Change = summation of elevation change to cut a path from the pit to an outlet down to a given maximum elevation
- Select Ideal Fill Level based on Optimization Criteria
- Fill Depression up to Ideal Fill Level
- Cut Path down to Ideal Fill Level

Sample Elevation Change Functions

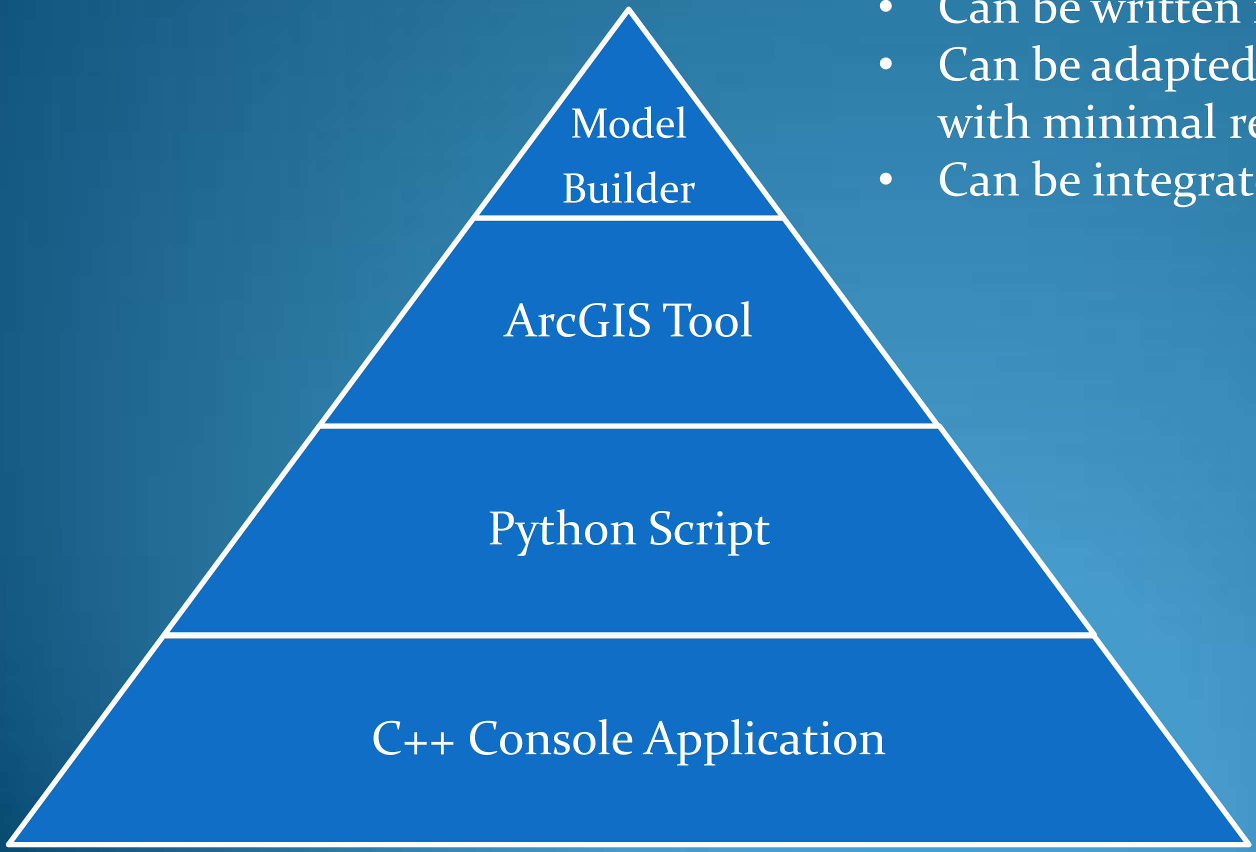




$$\text{Net Change} = \sum_{cells} \Delta z$$

$$\text{Absolute Change} = \sum_{cells} |\Delta z|$$

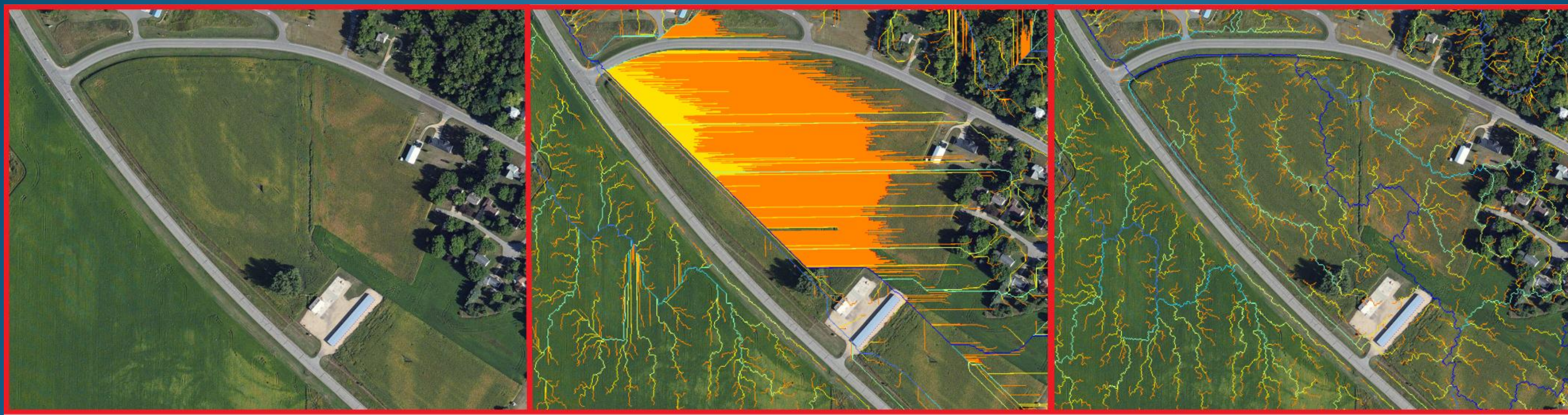
Tool Structure



<u>Benefits of using Console Application:</u>

- Can be run from command line without ArcGIS installed or running
- Can be written in any language
- Can be adapted to future changes in ArcGIS with minimal revisions
- Can be integrated with other GIS software

Optimal Pit Fill Tool Results



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

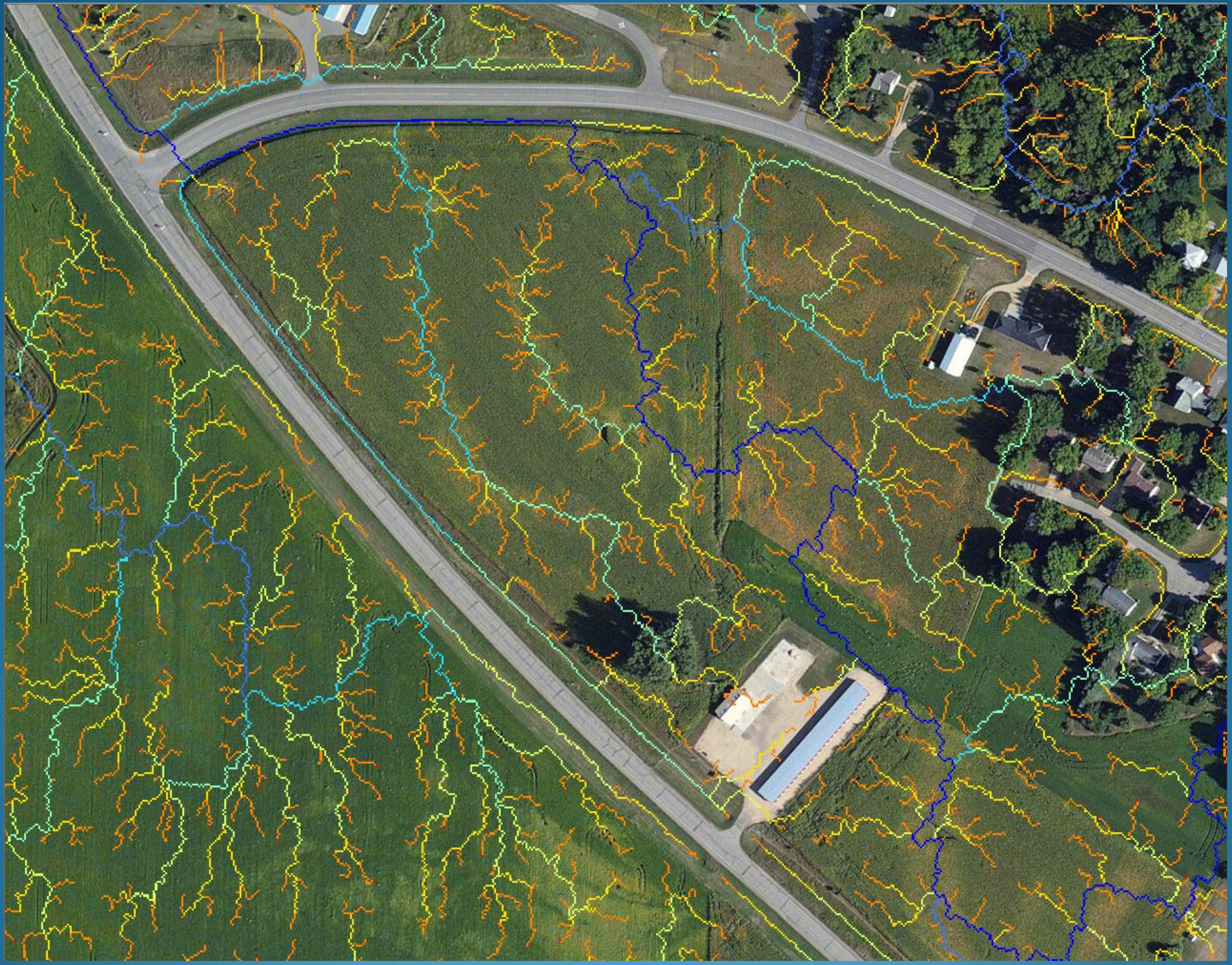
Flow Accumulation Results
(Pits Removed Using Fill Tool)

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

Flow paths shown with drainage areas greater than 100 m^2. Flow paths derived using Optimized Pit Removal tool follow vegetation coloration patterns, building lot lines, and even the curves of cul-de-sacs.

Source:
1 m GRID DEM, Tile 4342-30-05
LiDAR Elevation, Blue Earth County, Minnesota, 2012
AeroMetric, Inc. and Minnesota Department of Natural Resources
http://www.mngeo.state.mn.us/chouse/elevation/lidar.html

Optimal Pit Fill Tool Results



Flow Accumulation Results – Enlarged View

Optimal Pit Fill Tool Results

Sample DEM: Blue Earth, MN Tile 4342-30-05

Dimensions: 2580 x 3530 cells   Number of Cells: 9,107,400   Cell Size: 1 m x 1 m

DEM Modification	Fill Tool	Optimized Tool (Minimize Net Change)	Optimized Tool (Minimize Absolute Change)
Percent Cells Changed:	24.1%	9.0%	8.0%
Volume Change (Cut):	0 m^3	-14,832.93 m^3	-14,804.1 m^3
Volume Change (Fill):	782,842.5 m^3	9,398.01 m^3	14,673.0 m^3
Net Volume Change:	782,842.5 m^3	-5,434.92 m^3	-131.1 m^3
Absolute Volume Change:	782,842.5 m^3	24,230.94 m^3	29,477.1 m^3
Maximum Cut:	0 m	-3.03 m	-2.9 m
Maximum Fill:	3.21 m	0.89 m	0.96 m
Average Cut:	N/A	-0.03 m	-0.03 m
Average Fill:	0.36 m	0.03 m	0.05 m

Volume Change = Total Elevation Change * Cell Area
Average Cut = Total Cut Elevation / Number of Cells Cut
Average Fill = Total Fill Elevation / Number of Cells Filled

Unexpected Result: Minimizing Net Change on a pit by pit basis did not minimize the Net Change when aggregated across all pits. This is likely due to a programmatic bias to prefer cutting when the step size is too coarse, but warrants further study.

Further Work and Acknowledgements

Further Work:

- Experiment with more LiDAR datasets
- Compare calculated flow paths with observed field conditions
- Add optimization option to minimize the number of cells changed
- Modify code to use multiple processors and different input file types

Acknowledgements:

- Pierre Soille (Joint Research Centre, European Commission, Italy)
- Dr. Tarboton (Utah State University)
- Dr. Maidment and the GIS Research Group (University of Texas at Austin)

Soille, Pierre. "Optimal removal of spurious pits in grid digital elevation models." *Water Resources Research* 40, W12509 (2004): 1-9.

Tarboton, David. "TauDEM Toolbox." *Utah State University*. Web. 15 October 2012 <http://hydrology.usu.edu/taudem/taudem5.0/>

Questions?

The tool is available to download for free from the Center for Research in Water Resources, with additional documentation and sample files. Feedback, including interesting case studies and suggested improvements for future versions of the tool, can be directed to Stephen Jackson (srj9@utexas.edu).

http://tools.crwr.utexas.edu/