Using open-access GIS to address issues in spatial hydrological modelling

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http://www.uoguelph.ca/~hydrogeo/index.html

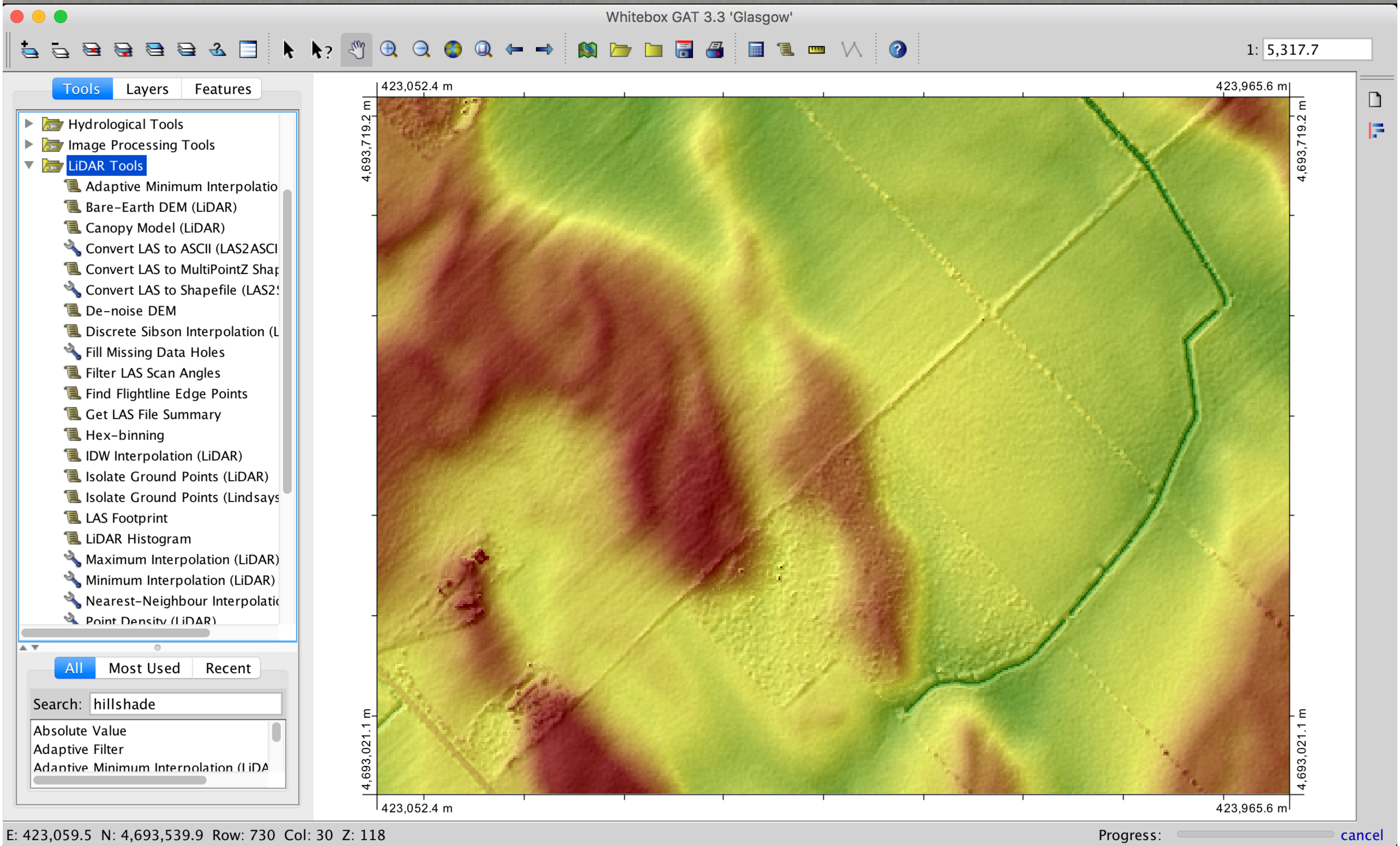
The Importance of Topography

- *Geomorphometry* is a sub-discipline of geomatics concerned with extracting information from digital topographic data (DEMs) to model or better understand landscape processes.

Elements of Topography		Environmental Phenomena
Slope Gradient	Partial control on abundance and distribution →	Wind Exposure
Surface Orientation		Precipitation
Relative Landscape Position		Temperature
Ruggedness		Incidence of Solar Radiation
Upslope Drainage Area		Surface Waters

My Research…

- …focuses on *producing and evaluating innovative geomorphometric techniques* to solve real world problems and to make contribution to geomorphometric theory.
- Much of this could be described as spatial hydrology or hydrogeomatics.
- I develop GIS software to serve as a platform for *experimenting* with novel geospatial analysis methods and to *disseminate these contributions to practitioners*.

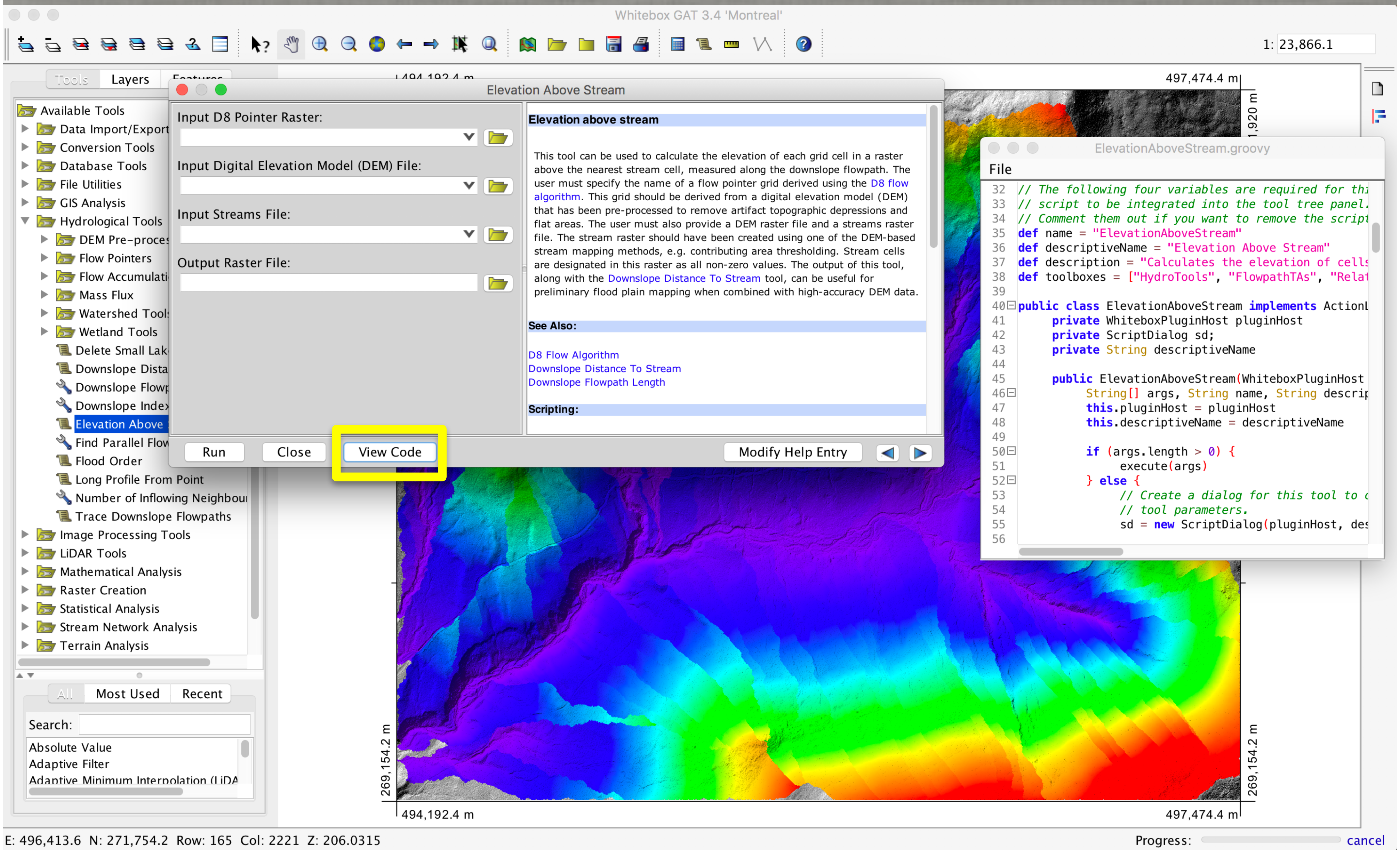


Whitebox GAT 3.3 'Glasgow'
1: 5,317.7
Tools
Layers
Features
Hydrological Tools
Image Processing Tools
LiDAR Tools
Adaptive Minimum Interpolatio
Bare-Earth DEM (LiDAR)
Canopy Model (LiDAR)
Convert LAS to ASCII (LAS2ASCI
Convert LAS to MultiPointZ Shap
Convert LAS to Shapefile (LAS2
De-noise DEM
Discrete Sibson Interpolation (L
Fill Missing Data Holes
Filter LAS Scan Angles
Find Flightline Edge Points
Get LAS File Summary
Hex-binning
IDW Interpolation (LiDAR)
Isolate Ground Points (LiDAR)
Isolate Ground Points (Lindsays
LAS Footprint
LiDAR Histogram
Maximum Interpolation (LiDAR)
Minimum Interpolation (LiDAR)
Nearest-Neighbour Interpolatic
All
Most Used
Recent
Search: hillshade
Absolute Value
Adaptive Filter
423,052.4 m
423,965.6 m
4,693,719.2 m
4,693,021.1 m
E: 423,059.5 N: 4,693,539.9 Row: 730 Col: 30 Z: 118
Progress:
cancel

Whitebox

Geospatial Analysis Tools

- A desktop GIS and remote sensing software package, started in 2009.
- A platform for advanced geospatial data analysis and visualization.
- Whitebox GAT is an *open-access* GIS...


Whitebox GAT 3.4 'Montreal'
1: 23,866.1
Tools
Layers
Available Tools
Data Import/Export
Conversion Tools
Database Tools
File Utilities
GIS Analysis
Hydrological Tools
DEM Pre-proces
Flow Pointers
Flow Accumulati
Mass Flux
Watershed Tool
Wetland Tools
Delete Small Lak
Downslope Dista
Downslope Flowp
Downslope Index
Elevation Above
Find Parallel Flow
Flood Order
Long Profile From Point
Number of Inflowing Neighbou
Trace Downslope Flowpaths
Image Processing Tools
LiDAR Tools
Mathematical Analysis
Raster Creation
Statistical Analysis
Stream Network Analysis
Terrain Analysis
All
Most Used
Recent
Search:
Absolute Value
Adaptive Filter
Elevation Above Stream
Input D8 Pointer Raster:
Input Digital Elevation Model (DEM) File:
Input Streams File:
Output Raster File:
Elevation above stream
This tool can be used to calculate the elevation of each grid cell in a raster above the nearest stream cell, measured along the downslope flowpath. The user must specify the name of a flow pointer grid derived using the D8 flow algorithm. This grid should be derived from a digital elevation model (DEM) that has been pre-processed to remove artifact topographic depressions and flat areas. The user must also provide a DEM raster file and a streams raster file. The stream raster should have been created using one of the DEM-based stream mapping methods, e.g. contributing area thresholding. Stream cells are designated in this raster as all non-zero values. The output of this tool, along with the Downslope Distance To Stream tool, can be useful for preliminary flood plain mapping when combined with high-accuracy DEM data.
See Also:
D8 Flow Algorithm
Downslope Distance To Stream
Downslope Flowpath Length
Scripting:
Run
Close
View Code
Modify Help Entry
ElevationAboveStream.groovy
File
// The following four variables are required for thi
// script to be integrated into the tool tree panel.
// Comment them out if you want to remove the script
def name = "ElevationAboveStream"
def descriptiveName = "Elevation Above Stream"
def description = "Calculates the elevation of cells
def toolboxes = ["HydroTools", "FlowpathTAs", "Relat
public class ElevationAboveStream implements ActionL
private WhiteboxPluginHost pluginHost
private ScriptDialog sd;
private String descriptiveName
public ElevationAboveStream(WhiteboxPluginHost
String[] args, String name, String descrip
this.pluginHost = pluginHost
this.descriptiveName = descriptiveName
if (args.length > 0) {
execute(args)
} else {
// Create a dialog for this tool to c
// tool parameters.
sd = new ScriptDialog(pluginHost, des
494,192.4 m
497,474.4 m
269,154.2 m
E: 496,413.6 N: 271,754.2 Row: 165 Col: 2221 Z: 206.0315
Progress:
cancel

Open-access GIS

- Distinct from OSS in that it has an explicitly stated design goal of *reducing barriers to the transfer of knowledge to the user community*.

- Designed to reduce barriers that discourage end-users from examining the algorithm and implementation details.

Open-access GIS

- Allows for educational opportunities and increases the *potential for rapid innovation, experimentation with algorithms, and community-directed development*.
- The View Code button is the embodiment of a design philosophy that is intended to empower the user community.
- Have I succeeded in this goal?

Open-access GIS

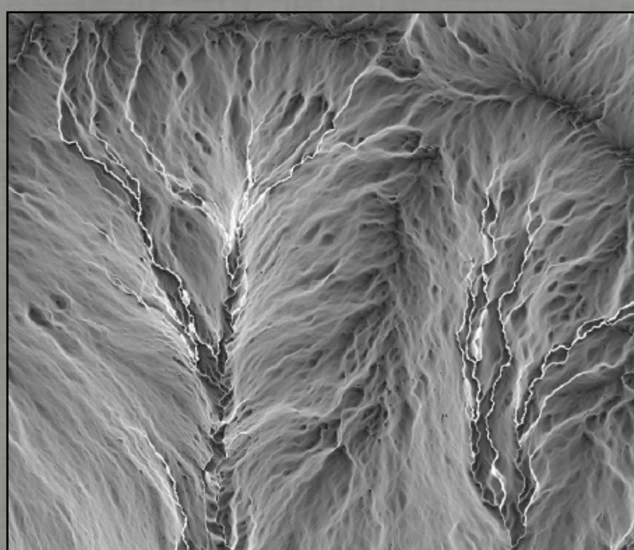
- One of the areas that OAGIS has the greatest potential benefit is *spatial hydrology*.

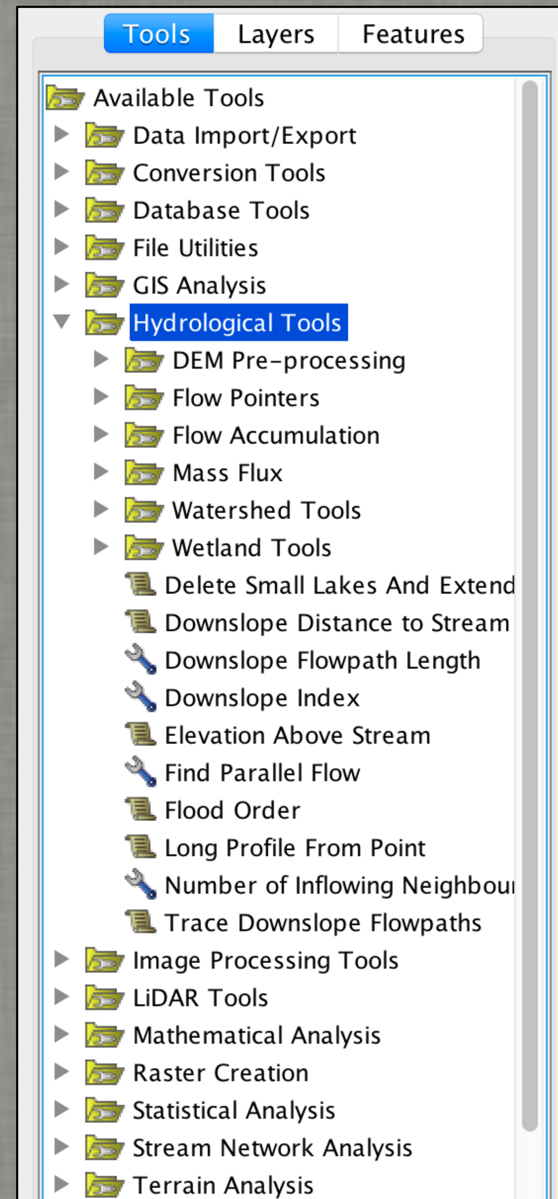
- Many SH algorithms are complex and are strongly affected by implementation details.

- Multiple competing algorithms for the same tasks (e.g. flow-path modelling) and the choice of one method over another can greatly impact the outcome.

Whitebox GAT for Hydrological Analyses

- Whitebox GAT is particularly capable for LiDAR data analysis, terrain analysis, and *spatial hydrology*.

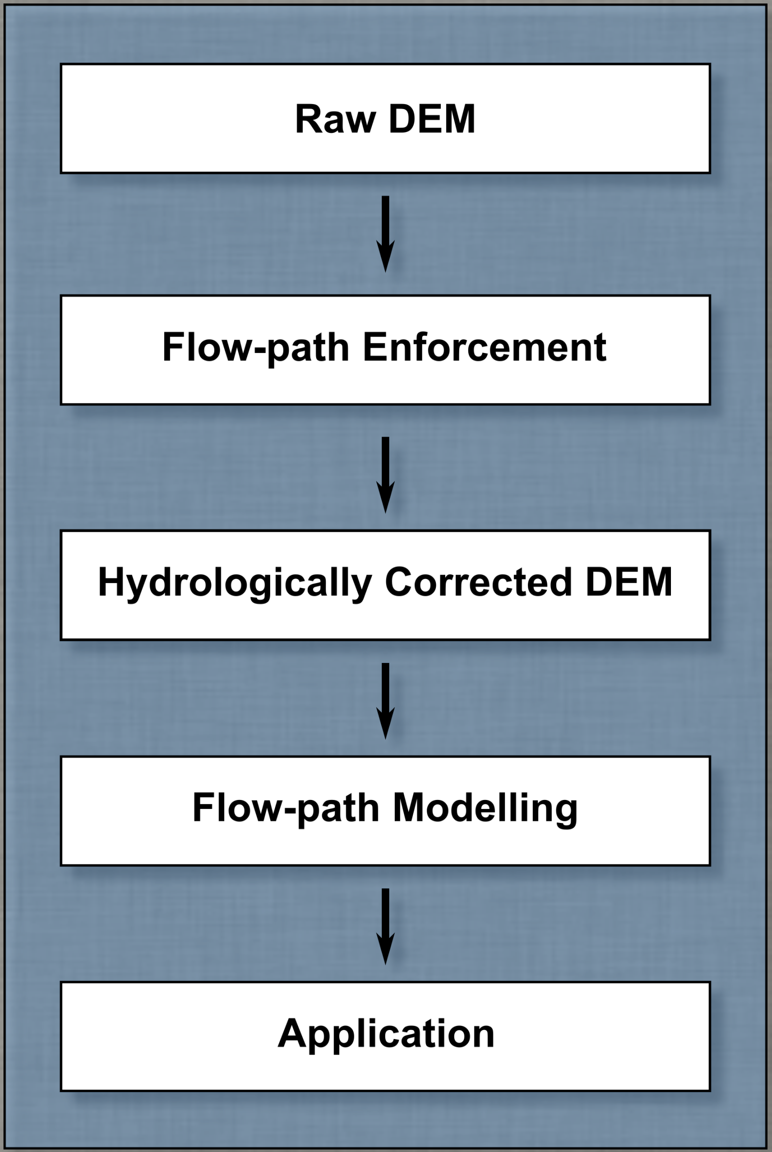


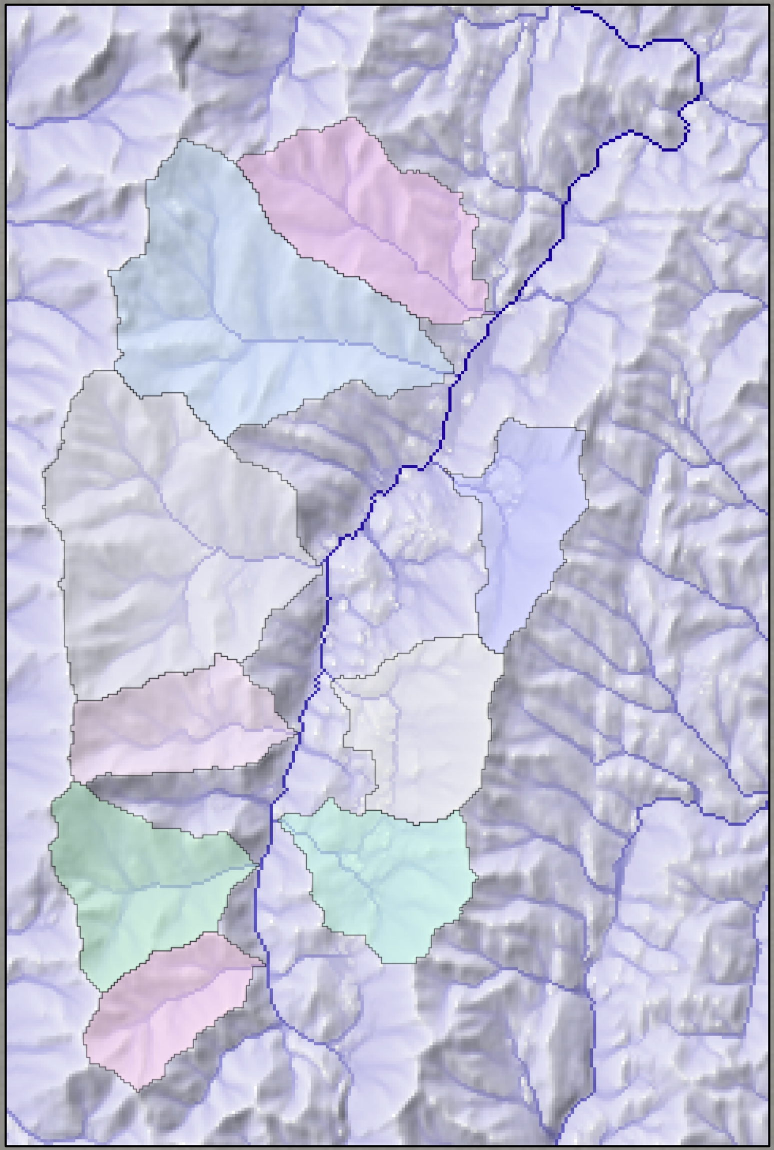


DEMs are used to model surface drainage

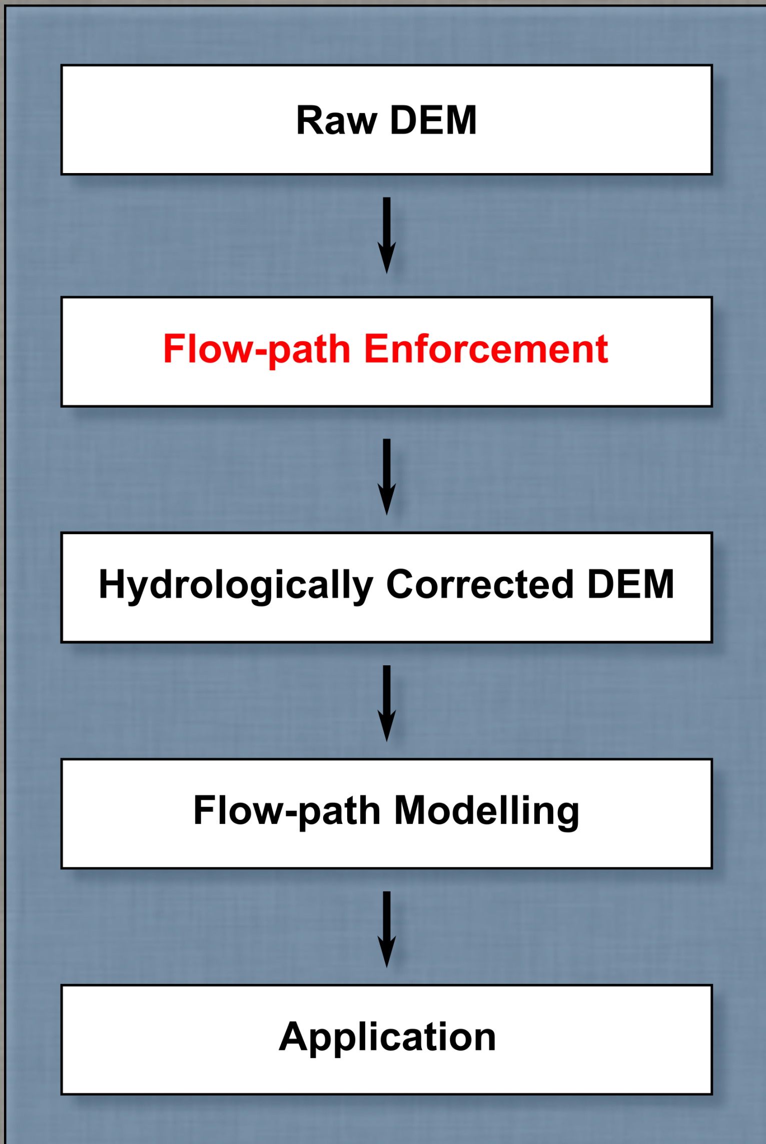
- Surface flow-path information is used to:
  - Delineate watershed divides and sub-basins,
  - Map landforms and soils,
  - Analyze stream networks,
  - Model variable source areas, runoff, and flooding,
  - Model sediment transport, erosion sources, and contaminant migration.

The spatial hydrology workflow





The spatial hydrology workflow



Enforcement techniques:

1. Stream burning
2. Sink removal

Lindsay JB. 2016. The practice of DEM stream burning revisited. Earth Surface Processes and Landforms, 41(5): 658–668.

Lindsay JB. 2016. Efficient hybrid breaching-filling sink removal methods for flow path enforcement in digital elevation models. Hydrological Processes, 30(6): 846–857.

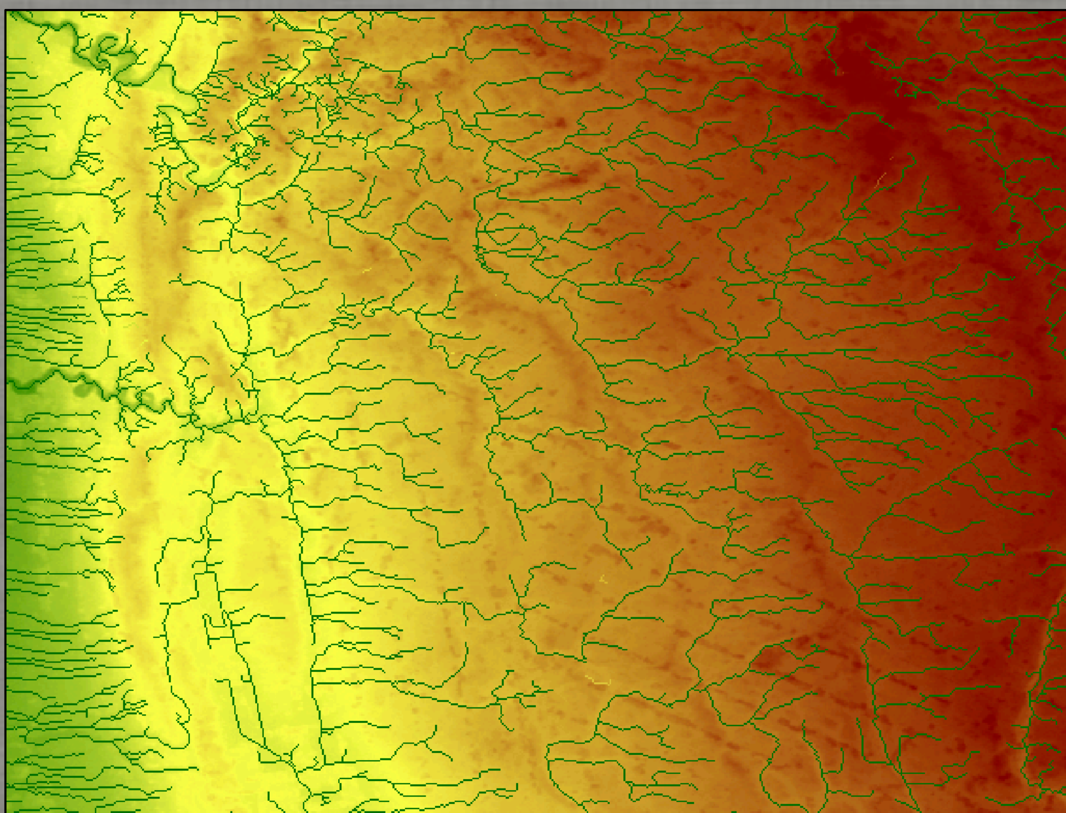
Flow-path enforcement: stream burning

- Sometimes the 'digital stream' in the DEM doesn't align with existing mapped stream data.

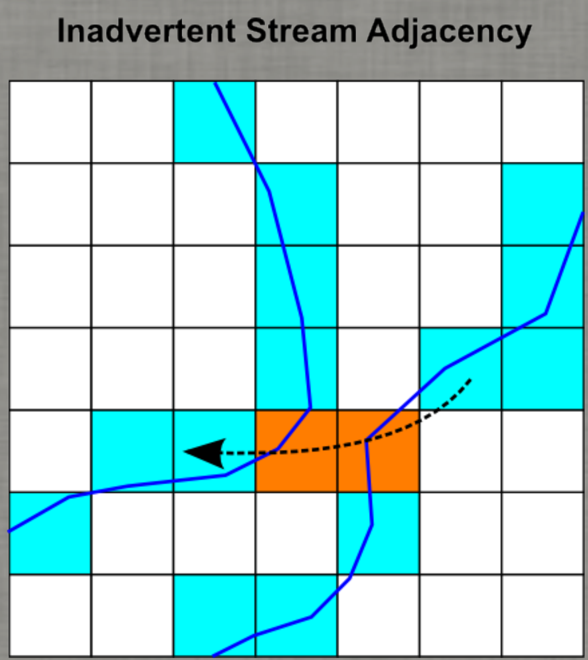
- When this happens, practitioners can:
  - Rasterize the vector streams layer;
  - Thin the raster stream lines;
  - Decrement elevations along the raster streams;
  - This is the *FillBurn* stream burning method.

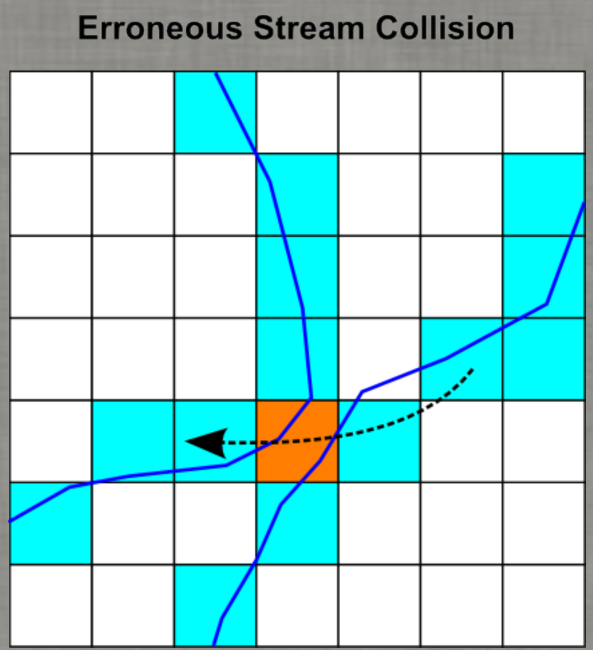
Stream burning

- Etching a mapped vector stream network into a raster DEM can be accomplished in any GIS software.



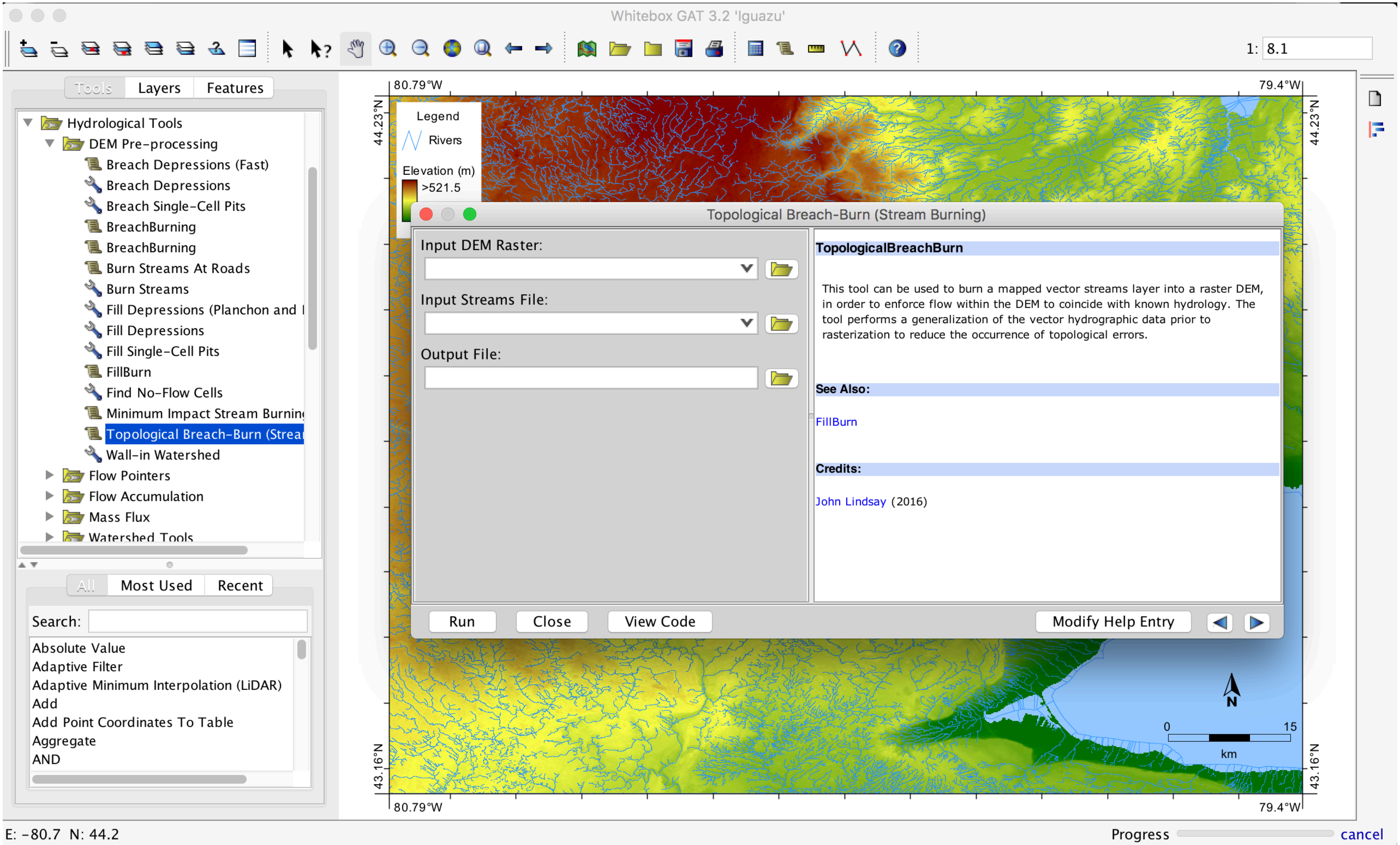
Topological errors due to rasterization





- The result of erroneous adjacency and collisions is the *spurious piracy of upslope areas*.
- The occurrence of these errors increases with stream density relative to the grid cell size.

Lindsay JB. 2016. The practice of DEM stream burning revisited. Earth Surface Processes and Landforms, 41(5): 658–668.



Topological Breach-Burn (TBB) aims to reduce the occurrence and impact of topological errors during stream burning by pruning headwater streams.

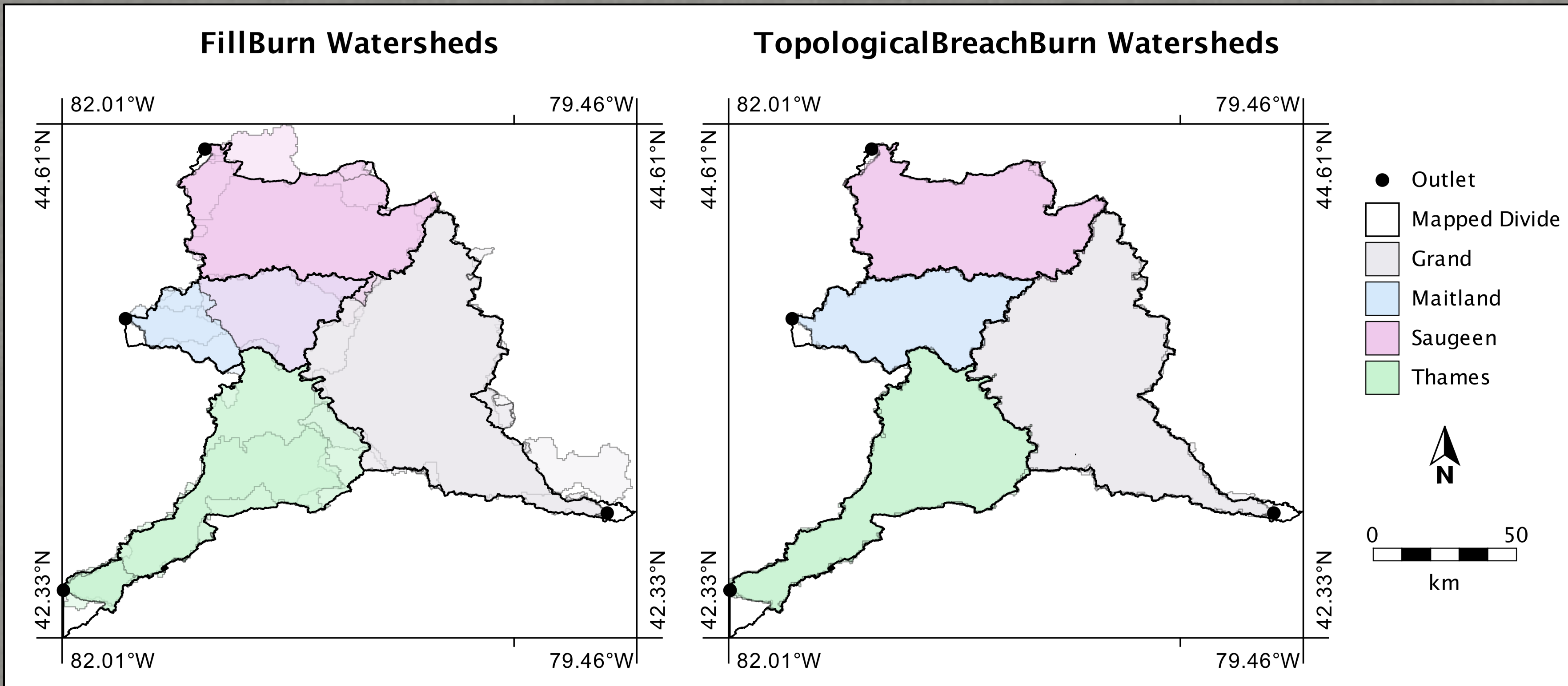
Study sites and data

Source DEM	Resolution	Rows	Columns
SRTM-1	1.0	10,801	10,801
SRTM-3	3.0	3601	3601
GMTED-7.5	7.5	1442	1442
GMTED-15	15.0	722	722
GTOPO-30	30.0	362	362

- Used 5 DEM data sources and the Ontario Hydro Network (OHN) watercourse data set.

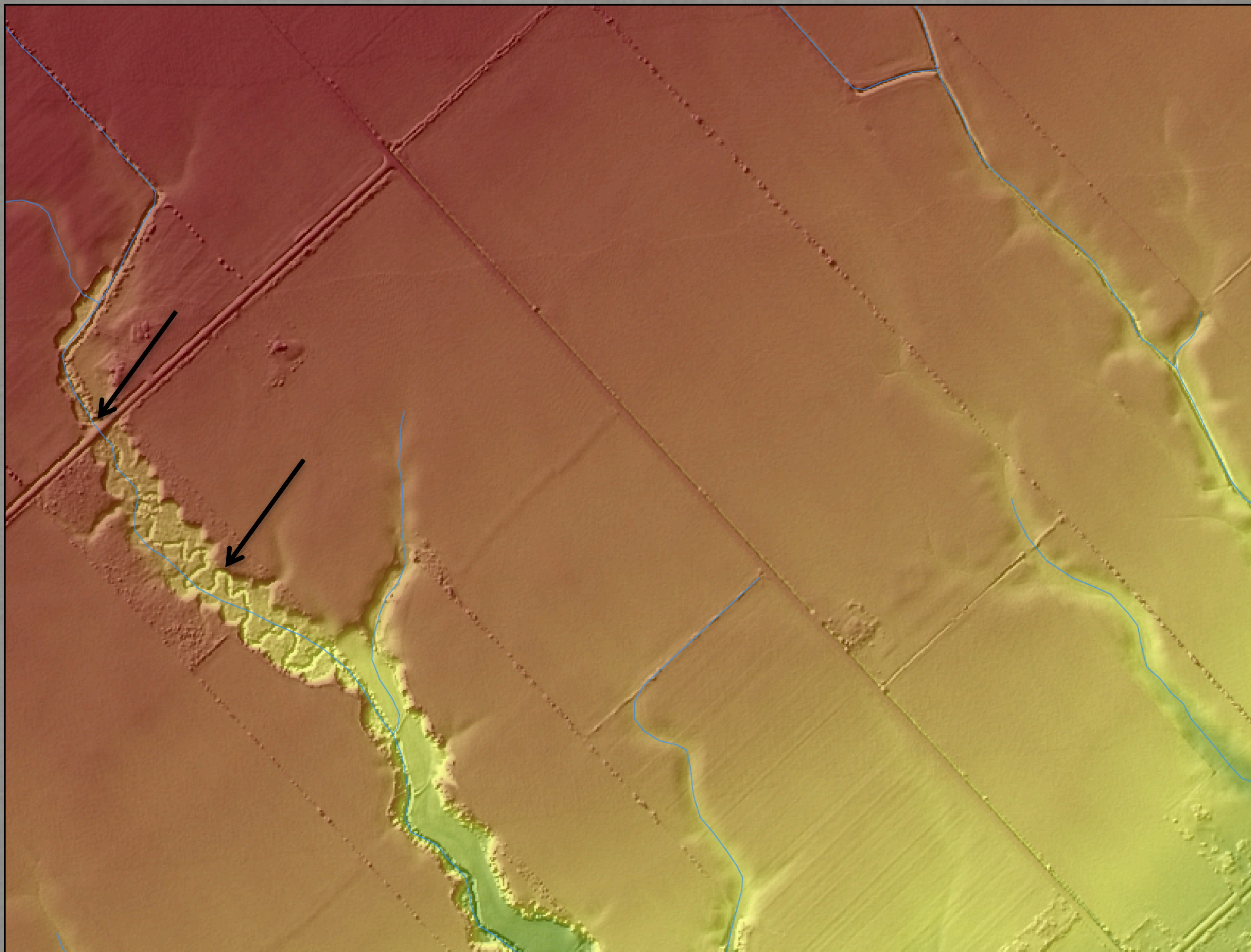
- Compared watershed boundaries for the Grand, Maitland, Saugeen, and Thames rivers extracted from each DEM processed with FB and TBB.

Comparison of watershed boundaries



DEM	TBB Kappa	TBB Accuracy	FB Kappa	FB Accuracy
SRTM-1	0.952	96.51	0.953	96.59
SRTM-3	0.949	96.30	0.940	95.62
GMTED-7.5	0.948	96.23	0.536	63.84
GMTED-15	0.935	95.22	0.724	79.72
GTOPO-30	0.921	94.19	0.490	60.04

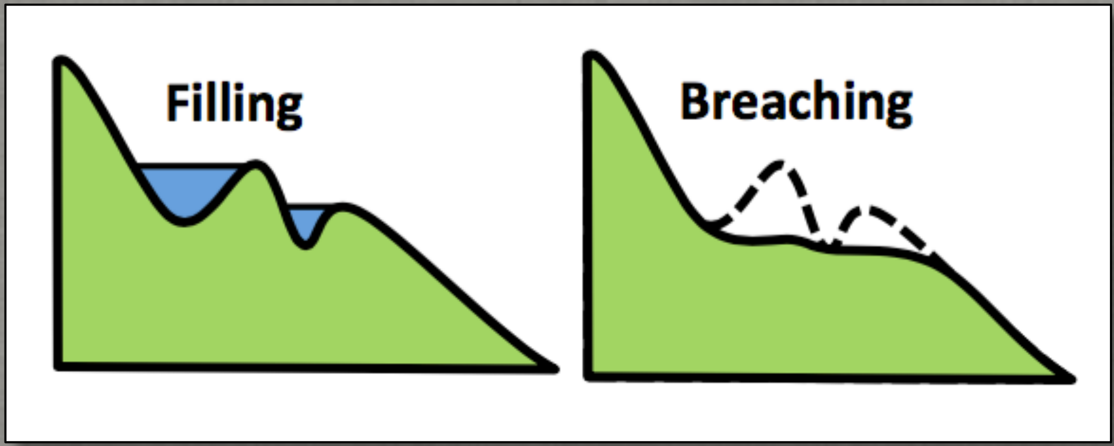
LiDAR and stream burning



Flow-path enforcement: sink removal

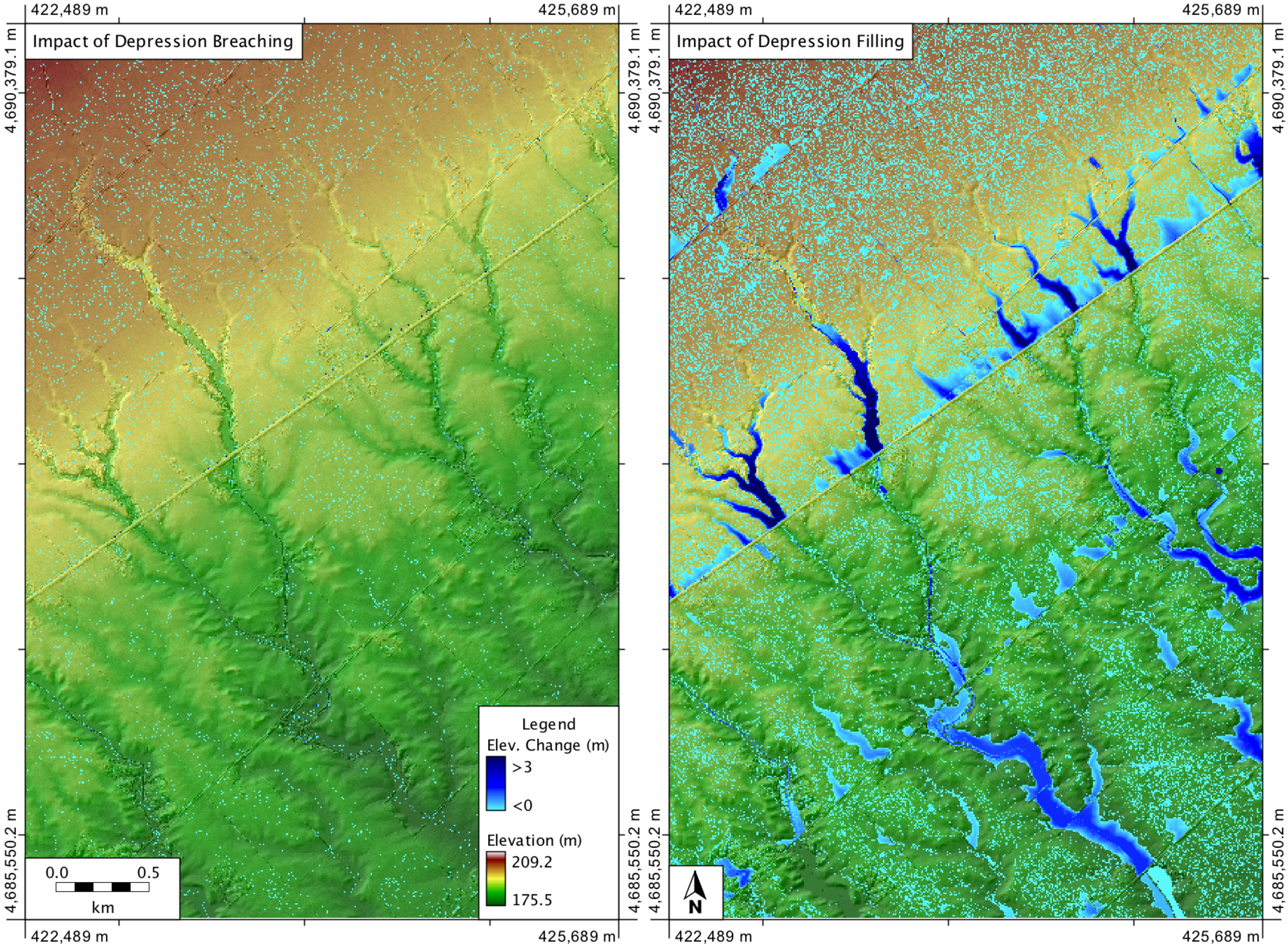
- DEMs will contain sinks, i.e. topographic depressions and flats.

- Sinks must be removed from DEMs used in hydrological applications.



The impact of sink removal

- Sink removal methods should alter the source data minimally.
- Academics have been telling practitioners for years that *depression filling impacts DEMs far more than breaching* methods.
  - Rieger 1998; Martz & Garbrecht 1999; Soille 2004; Lindsay & Creed 2005; Lindsay & Dhun 2015.

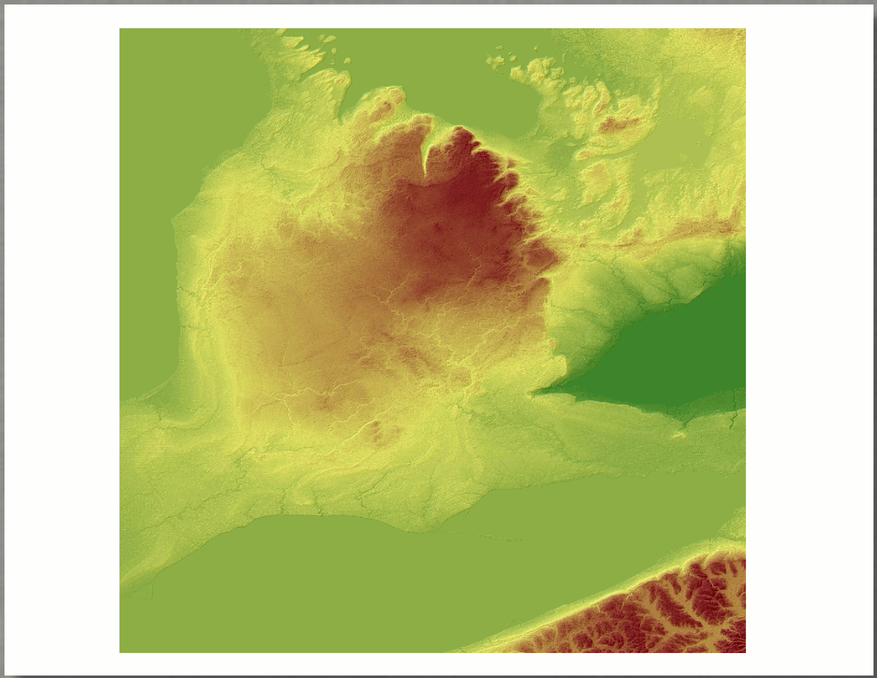

Impact of Depression Breaching
Impact of Depression Filling
422,489 m
425,689 m
4,690,379.1 m
4,685,550.2 m
Legend
Elev. Change (m)
>3
<0
Elevation (m)
209.2
175.5
0.0
0.5
km
N

Why do practitioners continue to fill depressions?

- There's a longer *history* to depression filling.
- Filling tools are *available* in every GIS.
- All filling algorithms give the same solution.
- New algorithms focus on improved *efficiency*:
  - Jenson & Domingue 1988; Planchon & Darboux 2002; Wang & Liu 2006; Wallis et al. 2009; Barnes et al. 2014; Yu et al. 2014; Barnes 2016; Zhou et al. 2016; Zhou et al. 2017

Efficient breaching-based enforcement

- The highly efficient priority-flood algorithm was used to visit DEM cells in the flood order.



- The new method operates in breaching (B), selective breaching (SB), and constrained breaching (CB) modes.

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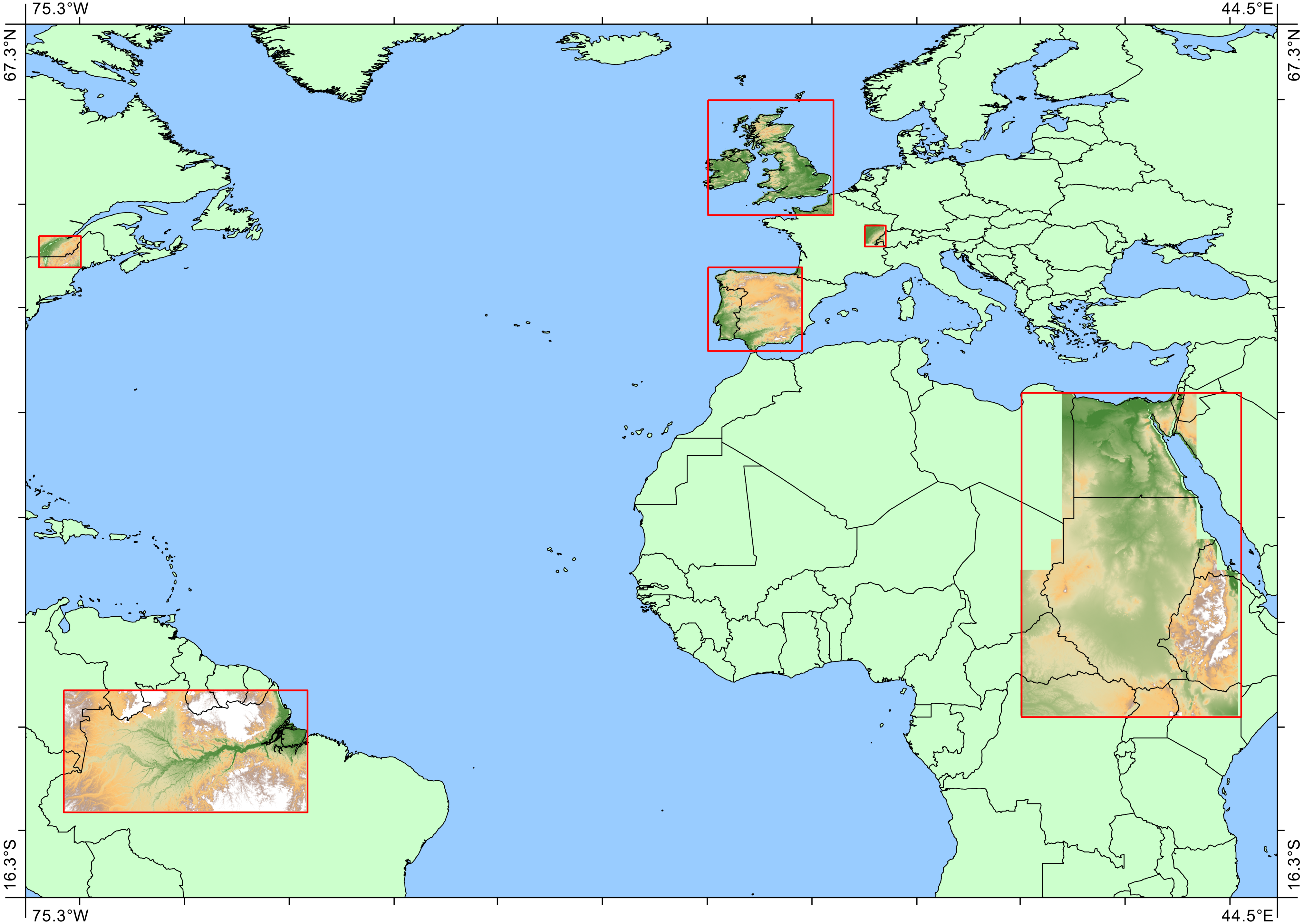
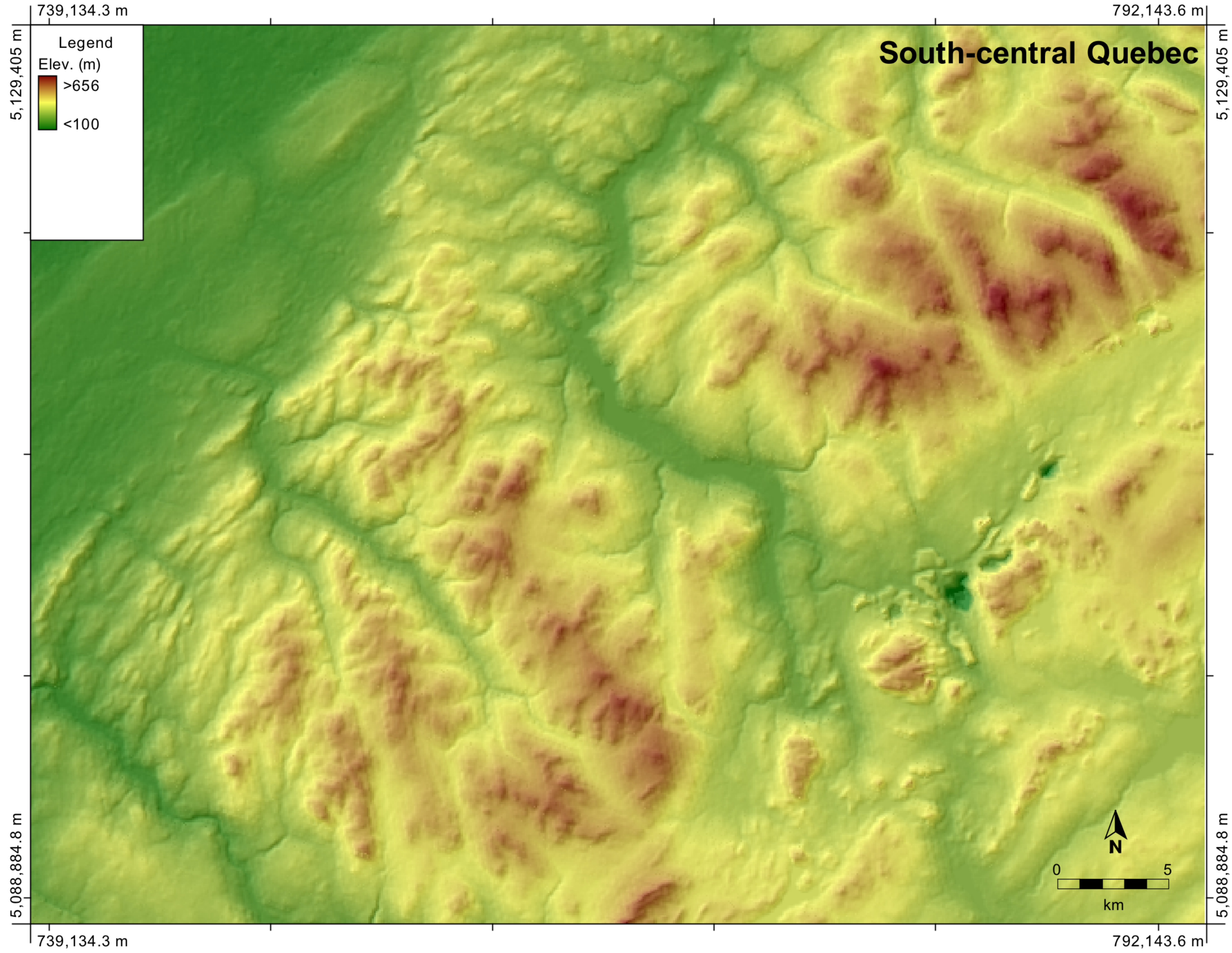
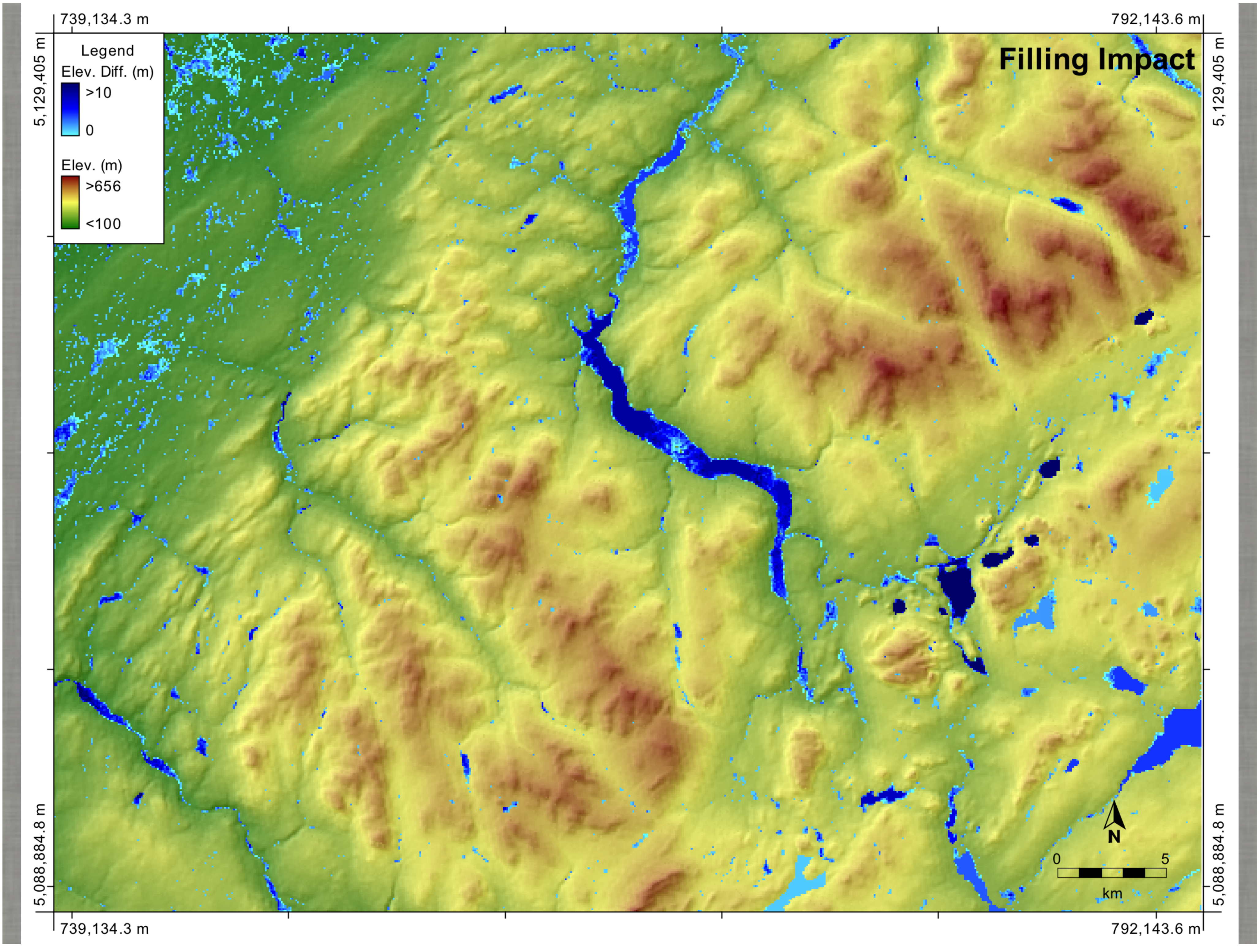

75.3°W
44.5°E
67.3°N
16.3°S

Region	F[1]	B[1]	SB1[1]	SB2[1]	CB1[1]	CB2[1]
Western Alps	35.4	29.6	34.9	36.8	35.3	136.9
Quebec, Canada	104.5	94.8	113.5	118.3	116.1	147.5
British Isles	57.9	48.7	59.1	59.0	58.4	62.1
Amazon Basin	344.9	310.6	365.1	367.5	363.8	909.3
Iberian Peninsula	586.4	519.2	657.9	659.8	658.5	689.9
Nile Basin	627.9	519.3	780.3	658.6	2012.3	2434.5
Mean Percent of F	100.0%	86.6%	108.3%	107.1%	127.2%	203.2%

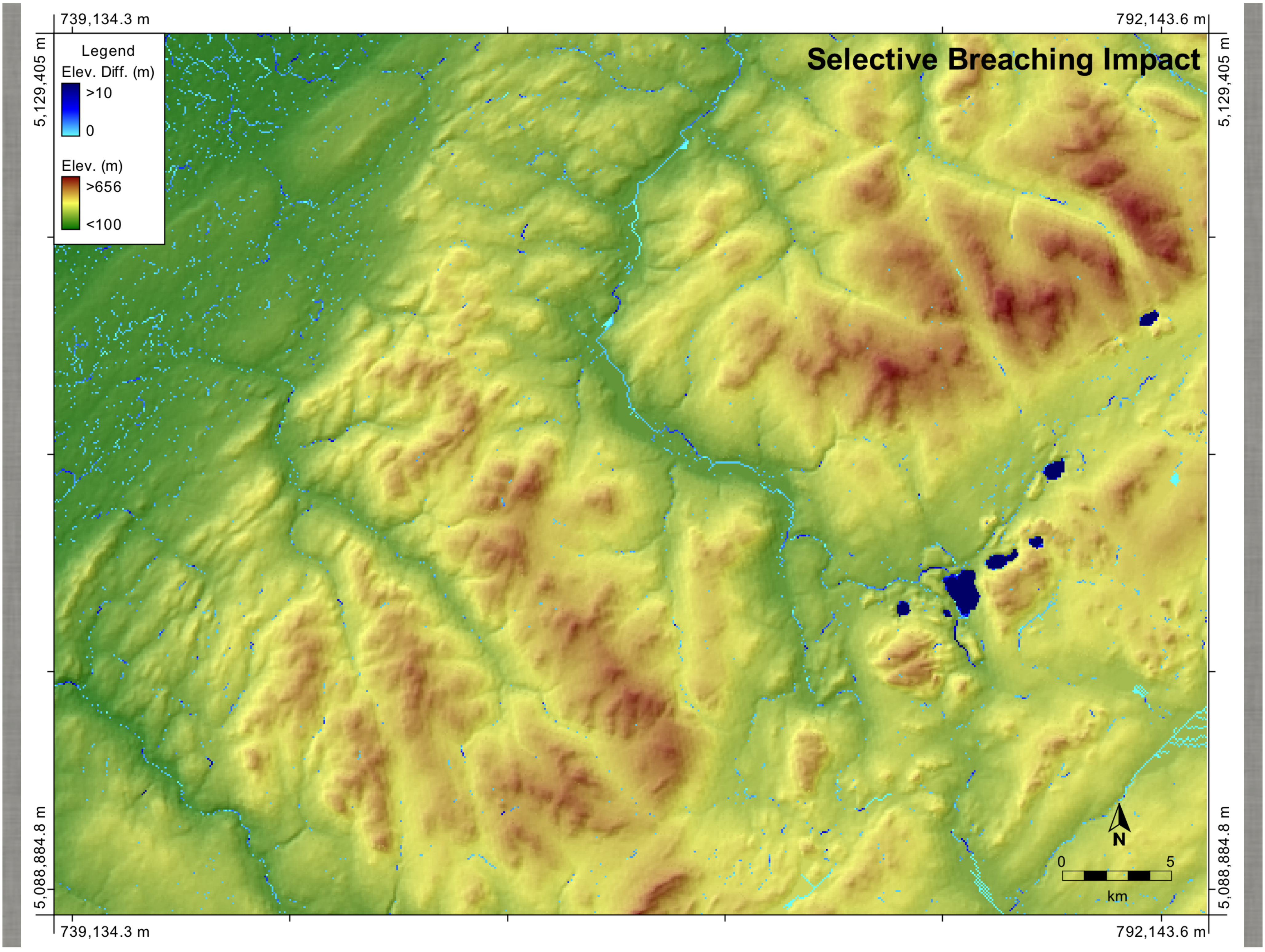
1. Notes: F = Wang and Liu depression filling algorithm; B = new algorithm; complete depression breach mode; SB1 = new algorithm; selective breaching mode, 20 m max. depth; SB2 = selective breaching mode, 20 m max. depth, 100 cell max. length; CB1 = constrained breaching mode, 20 m max. depth; CB2 = constrained breaching mode, 20 m max. depth, 100 cell max. length



739,134.3 m
792,143.6 m
5,129,405 m
5,088,884.8 m
Legend
Elev. (m)
>656
<100
South-central Quebec
N
0
5
km



739,134.3 m
792,143.6 m
5,129,405 m
5,088,884.8 m
Legend
Elev. Diff. (m)
>10
0
Elev. (m)
>656
<100
Filling Impact
N
0
5
km



Selective Breaching Impact
Legend
Elev. Diff. (m)
>10
0
Elev. (m)
>656
<100
739,134.3 m
792,143.6 m
5,129,405 m
5,088,884.8 m
N
0
5
km

Conclusions

- Spatial hydrological practice is strongly impacted by algorithm design and implementation details.
- Academics need to maintain a two-way dialog with practitioners to ensure usage of best practices and to understand why certain methods are adopted and others are not.
- OAGIS can provide an environment that fosters rapid innovation and adoption.

Thank you!

- I would like to thank the University of Waterloo Water Institute and the Department of Civil and Environmental Engineering for inviting me here today.
- I'd be happy to answer any questions.
- Research support has been provided by:

NSERC CRSNG