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An evaluation of automated GIS tools for delineating karst sinkholes and closed depressions from 1-meter LiDAR-derived digital elevation data

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U.S. Geological Survey

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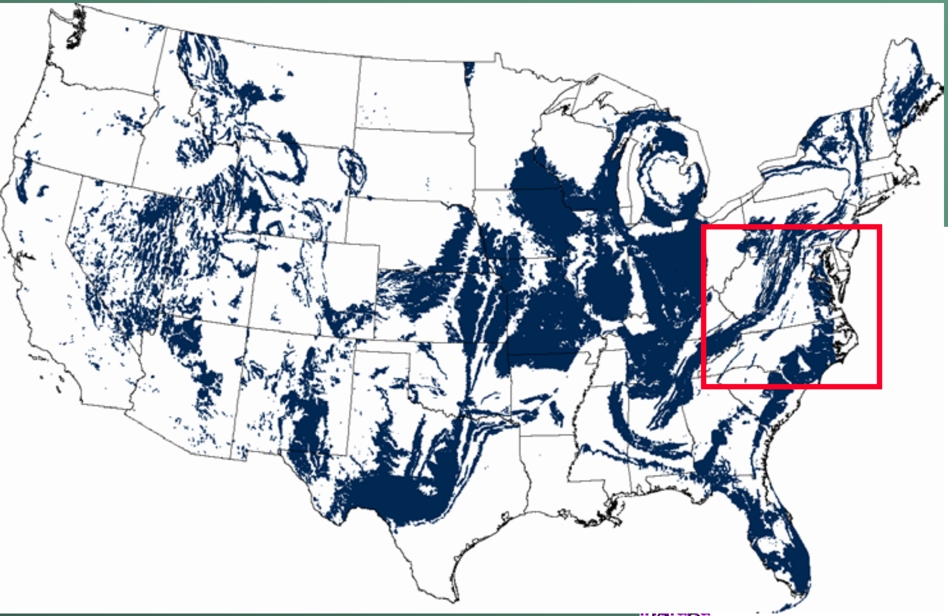
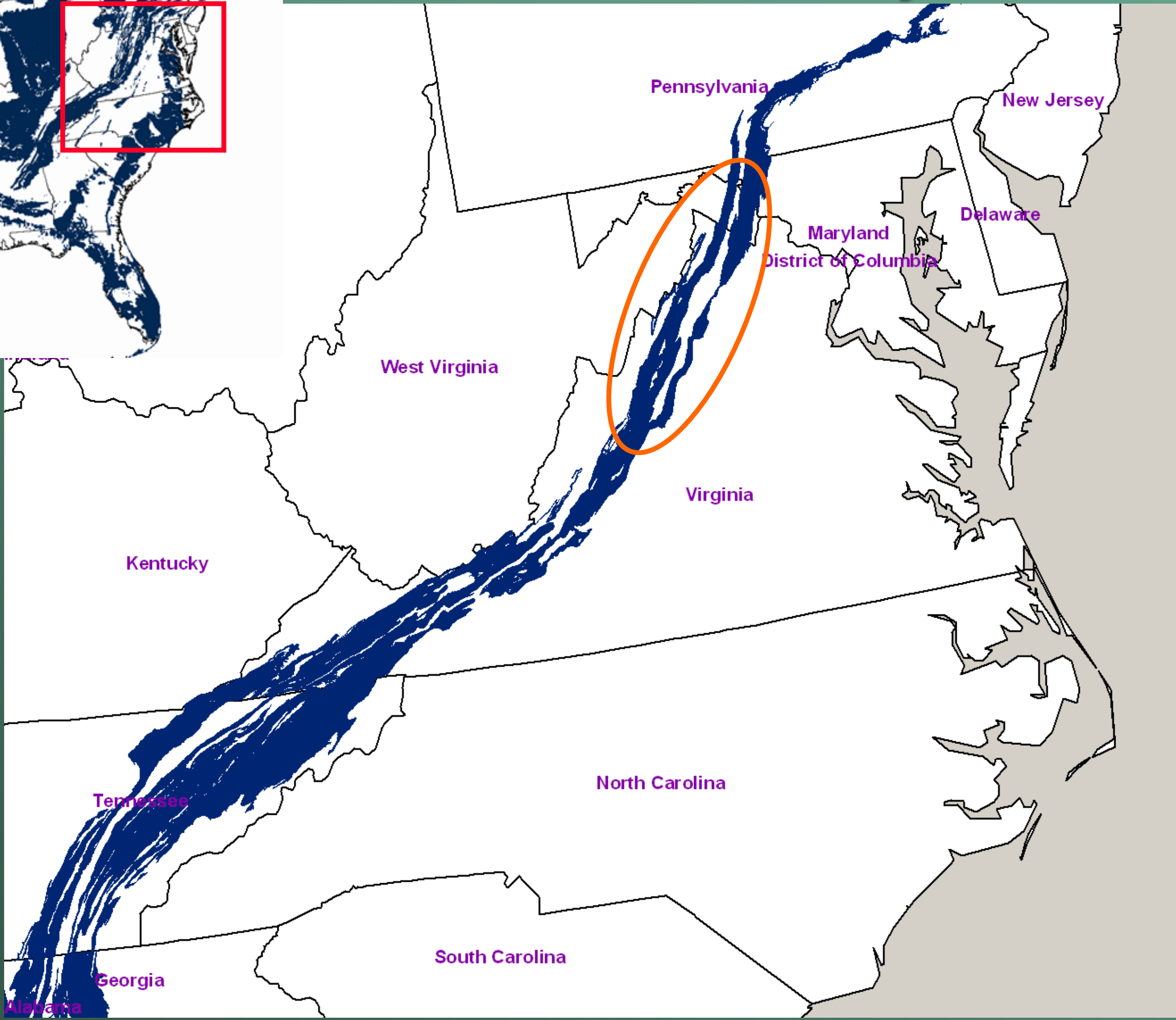
U.S. Department of the Interior
U.S. Geological Survey

Karst in the United States



Karst in the Appalachian Great Valley



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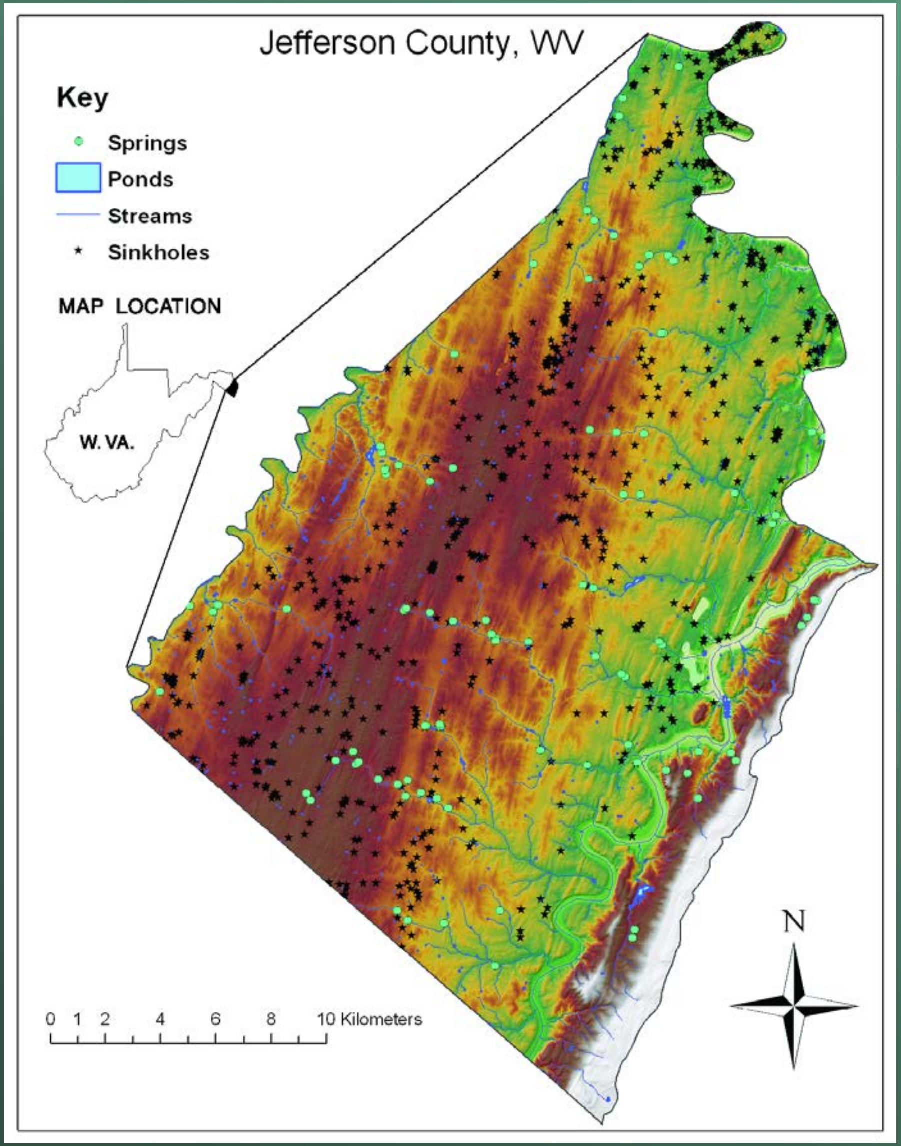
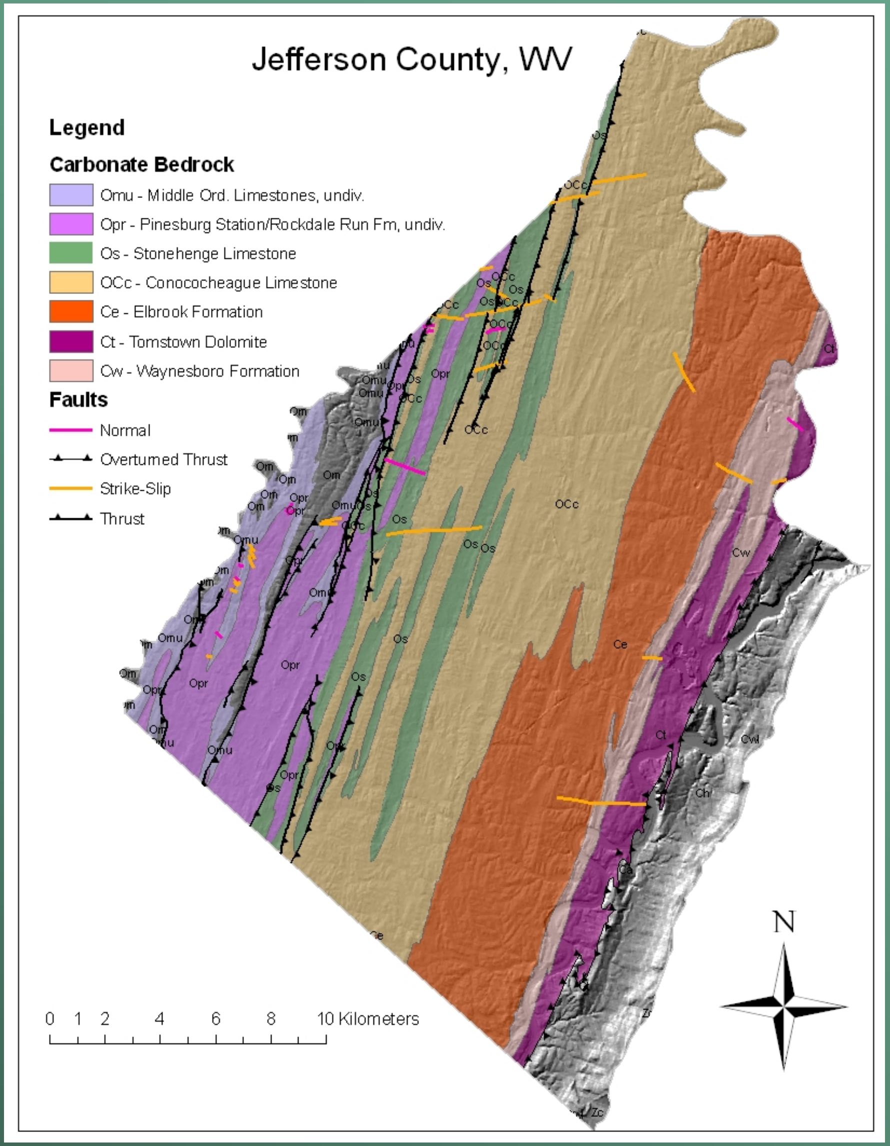
Sinkhole susceptibility mapping





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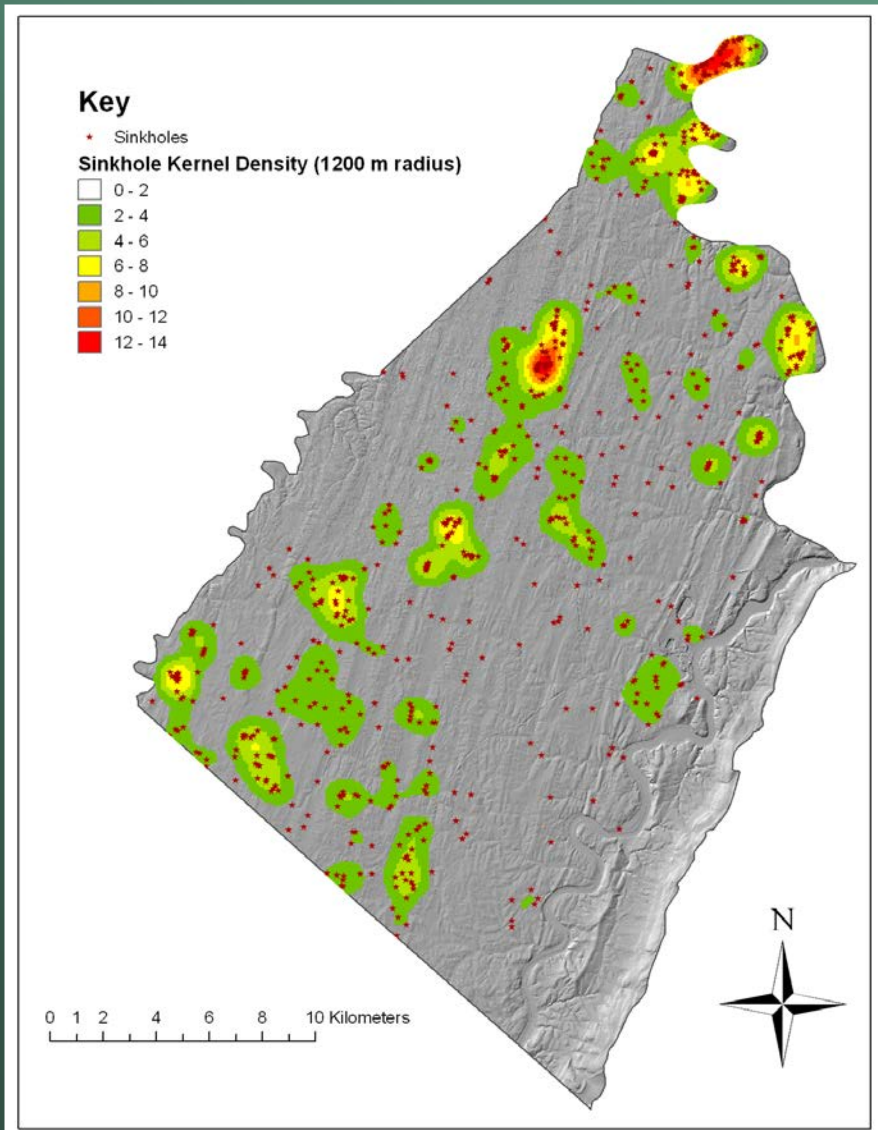
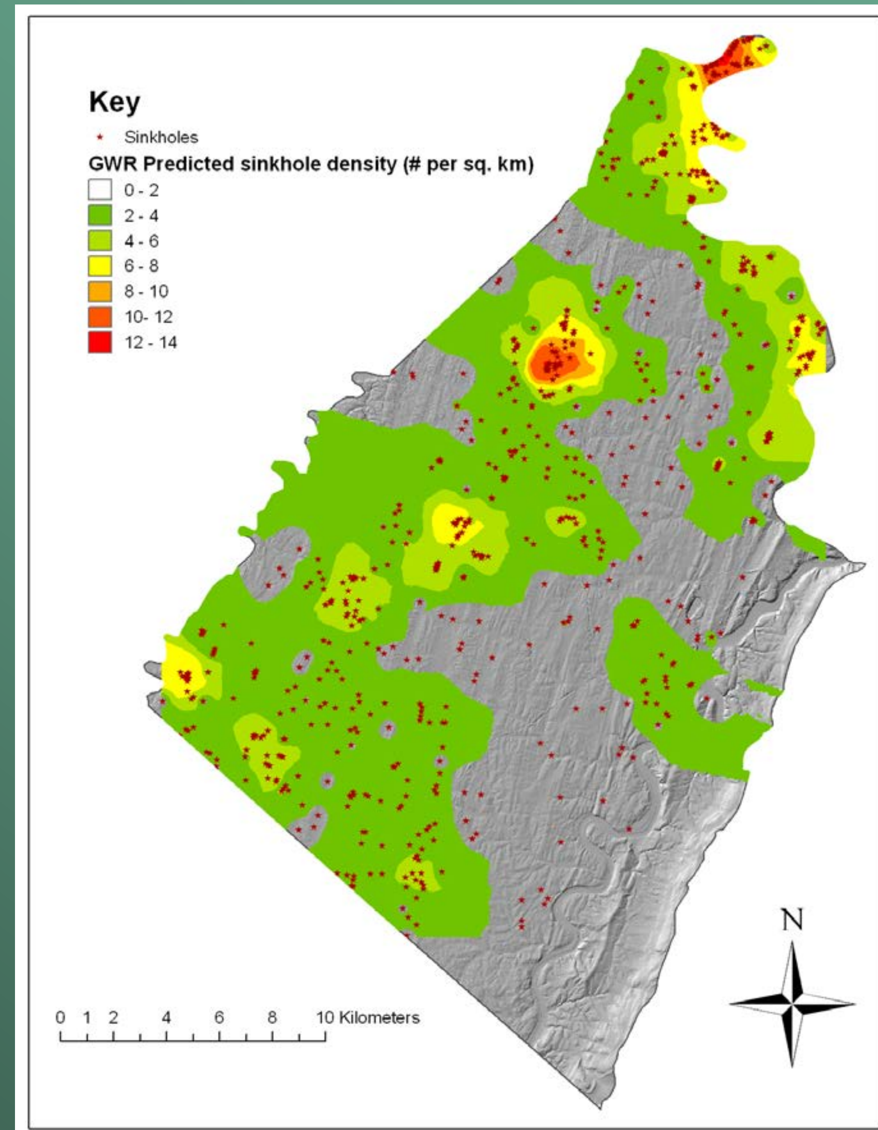
Doctor and Doctor, Carbonates and Evaporites, 2012

Sinkhole susceptibility mapping





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Doctor and Doctor, Carbonates and Evaporites, 2012

Sinkhole susceptibility mapping

GOAL:
Construct maps of relative sinkhole susceptibility by relating locations of known sinkholes to underlying hydrogeologic factors that influence sinkhole formation

NEED:

- Accurate geologic information
  - ✓ field mapping
- Precise location, shape, and hydrologic information of closed depressions
  - ✓ field mapping (but tedious)
- A rapid, reliable method for mapping closed depressions (LIDAR?)

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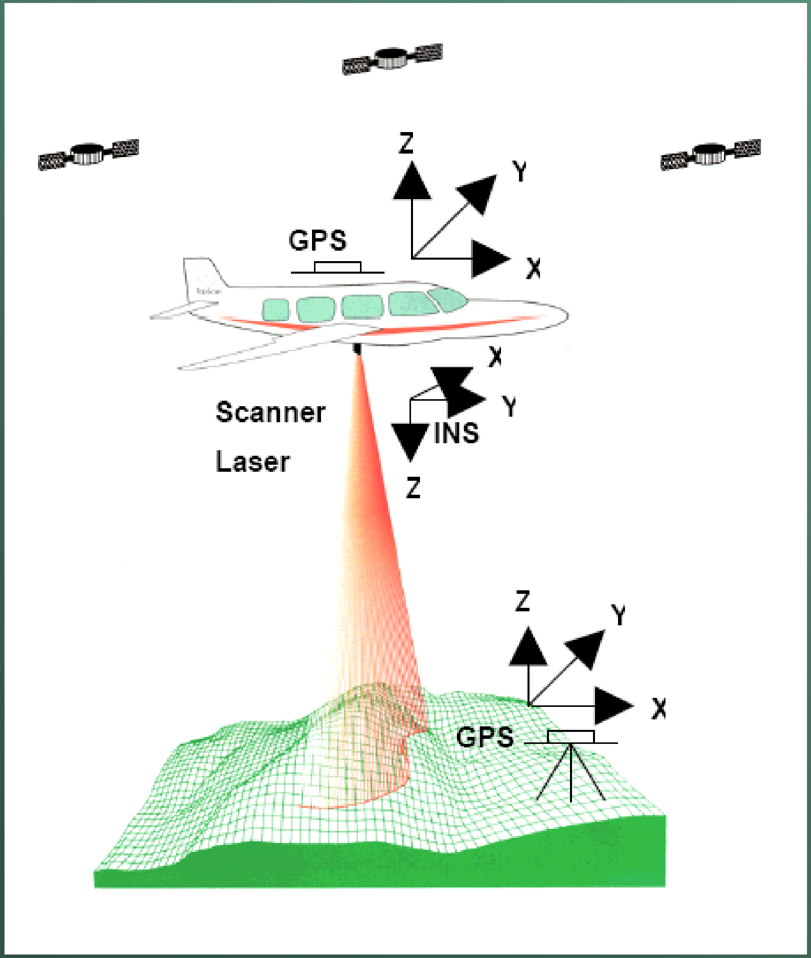
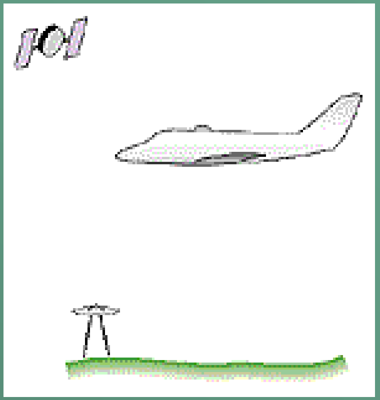
What is LiDAR?

"Light Detection and Ranging" or "light radar"





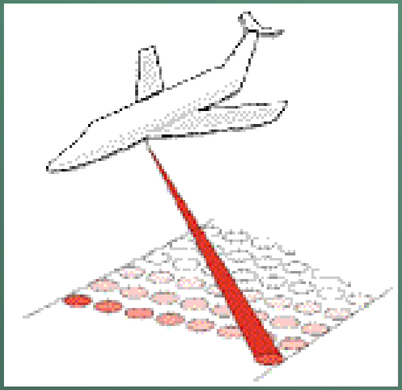


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Image credits: T. Hohl (http://lazarus.elte.hu/mc/11icom/tg.ppt)

1m resolution aerial NAIP imagery

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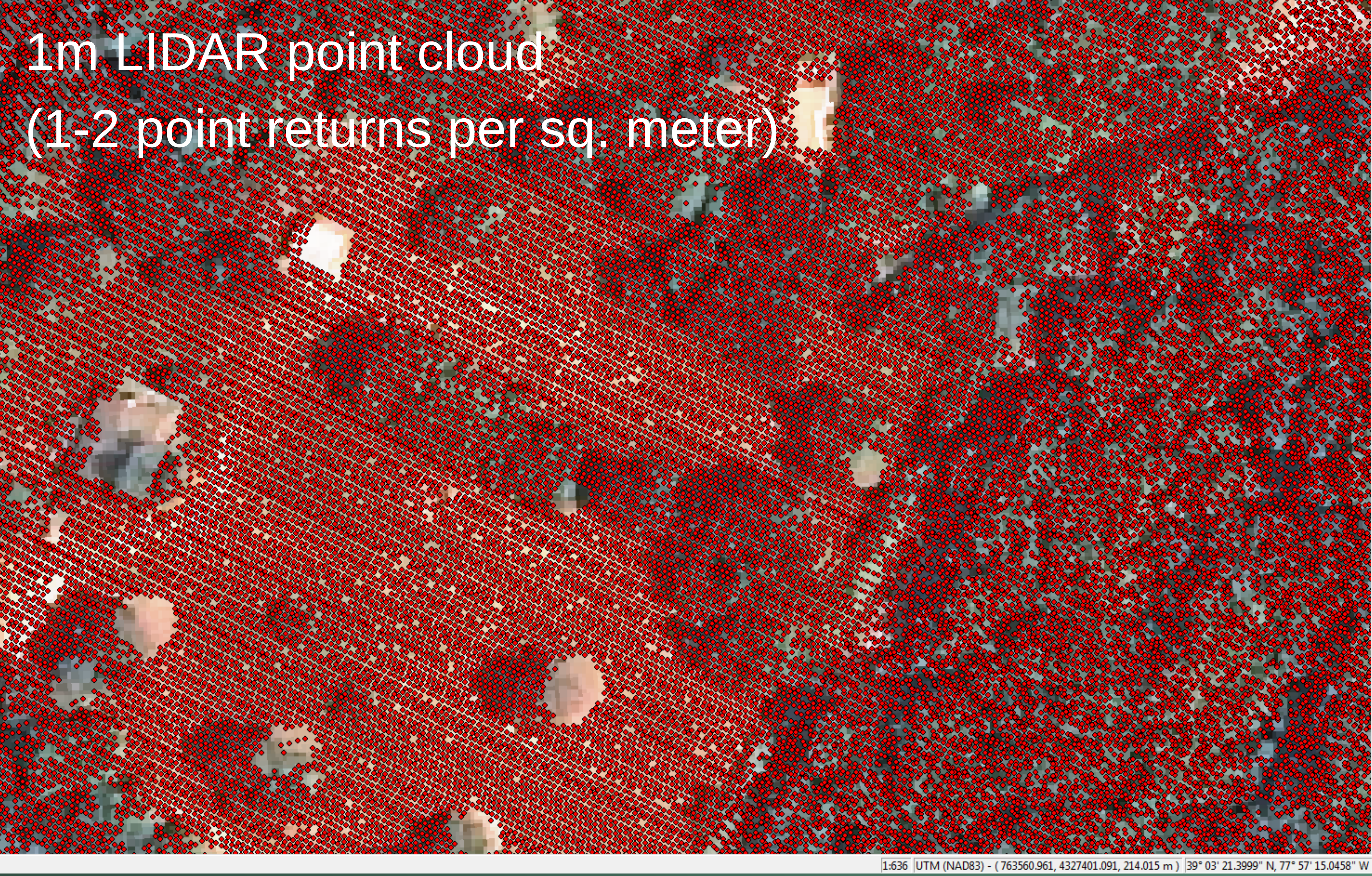
1m LIDAR point cloud
(1-2 point returns per sq. meter)



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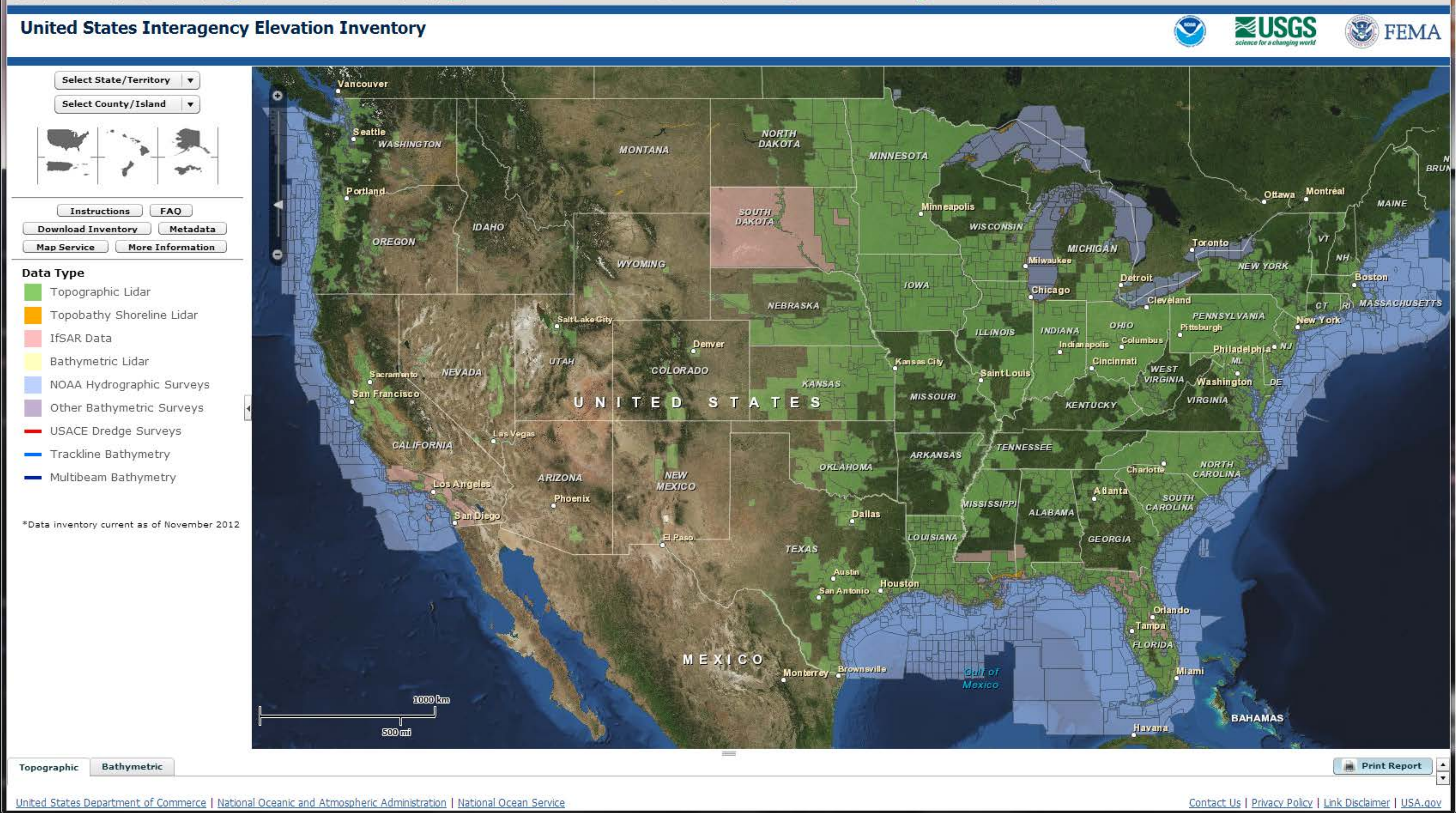

National Lidar coverage (as of November, 2012)

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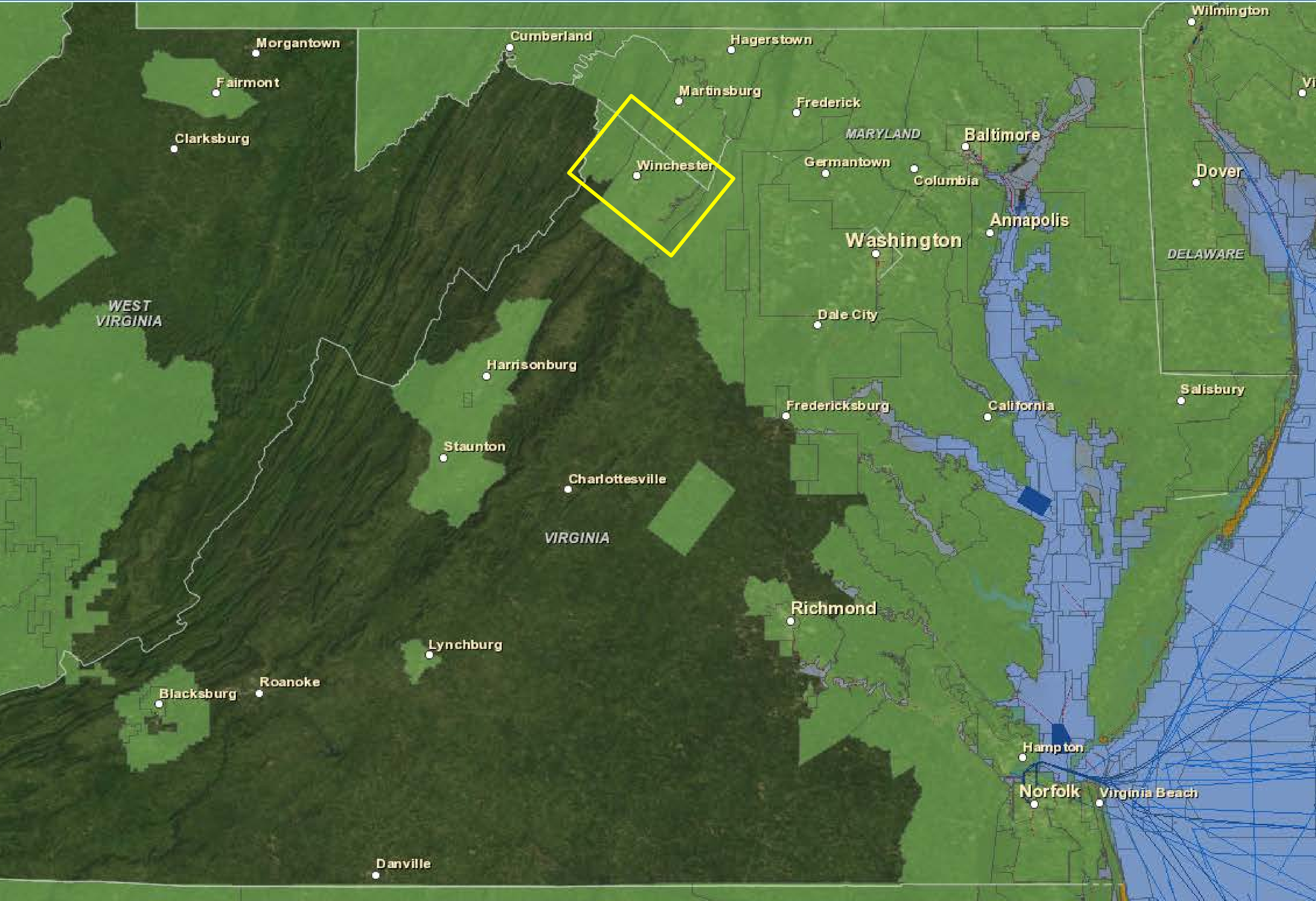
OTHER LINKS:

http://en.wikipedia.org/wiki/National_Lidar_Dataset_(United_States)

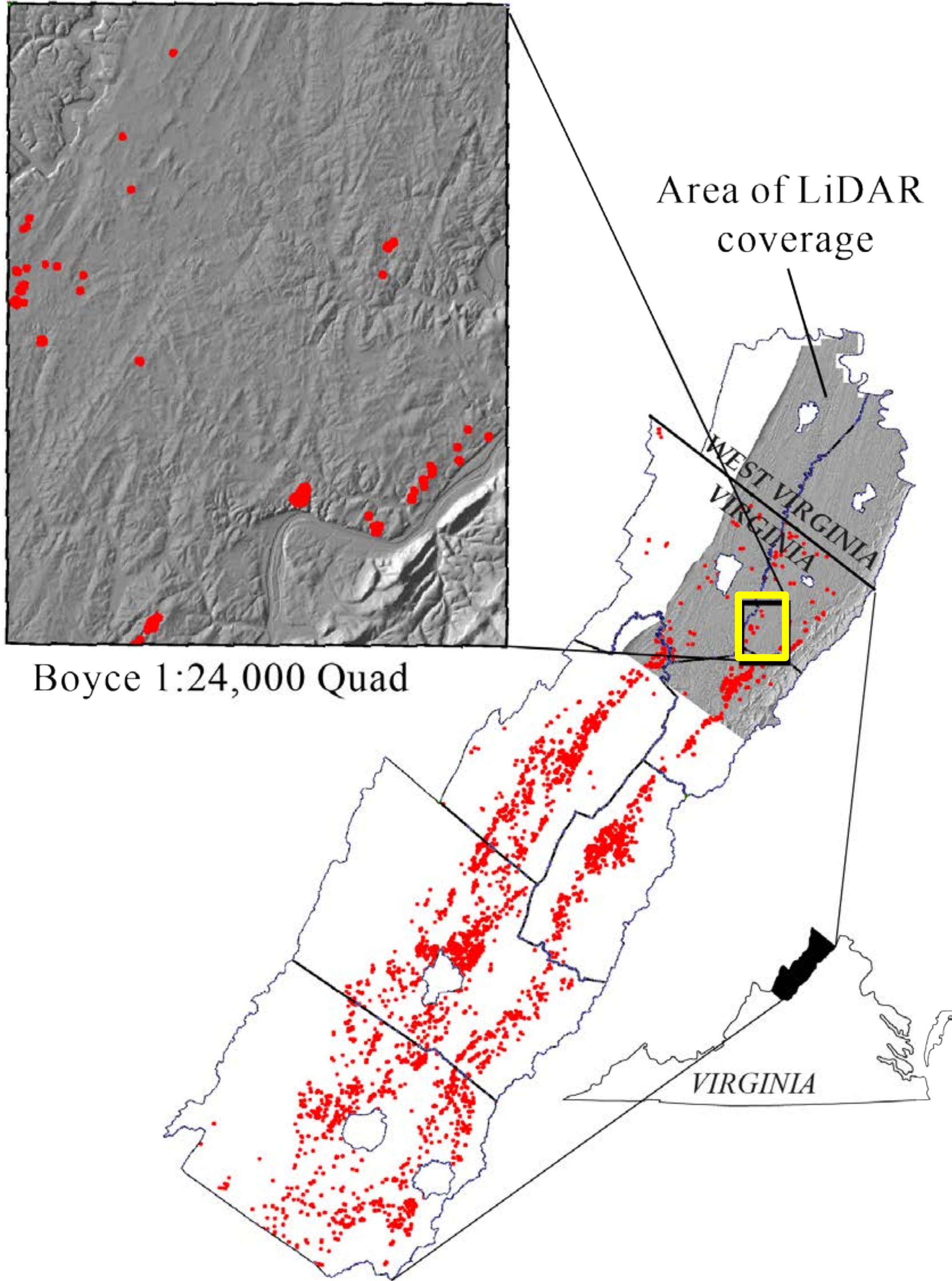
http://www.opentopography.org/


Wilmington
Morgantown
Cumberland
Hagerstown
Fairmont
Martinsburg
Frederick
Clarksburg
MARYLAND
Baltimore
Winchester
Germantown
Columbia
Dover
Annapolis
Washington
DELAWARE
WEST VIRGINIA
Dale City
Harrisonburg
Salisbury
Fredericksburg
California
Staunton
Charlottesville
VIRGINIA
Richmond
Lynchburg
Roanoke
Blacksburg
Hampton
Norfolk
Virginia Beach
Danville

LIDAR coverage of northern Shenandoah Valley (2012)

Red dots are closed depressions identified from aerial stereophotos in VA-DMME dataset (by D. Hubbard)

Boyce 1:24k quad in yellow



Red dots are closed depressions in VA-DMME dataset (by D. Hubbard)

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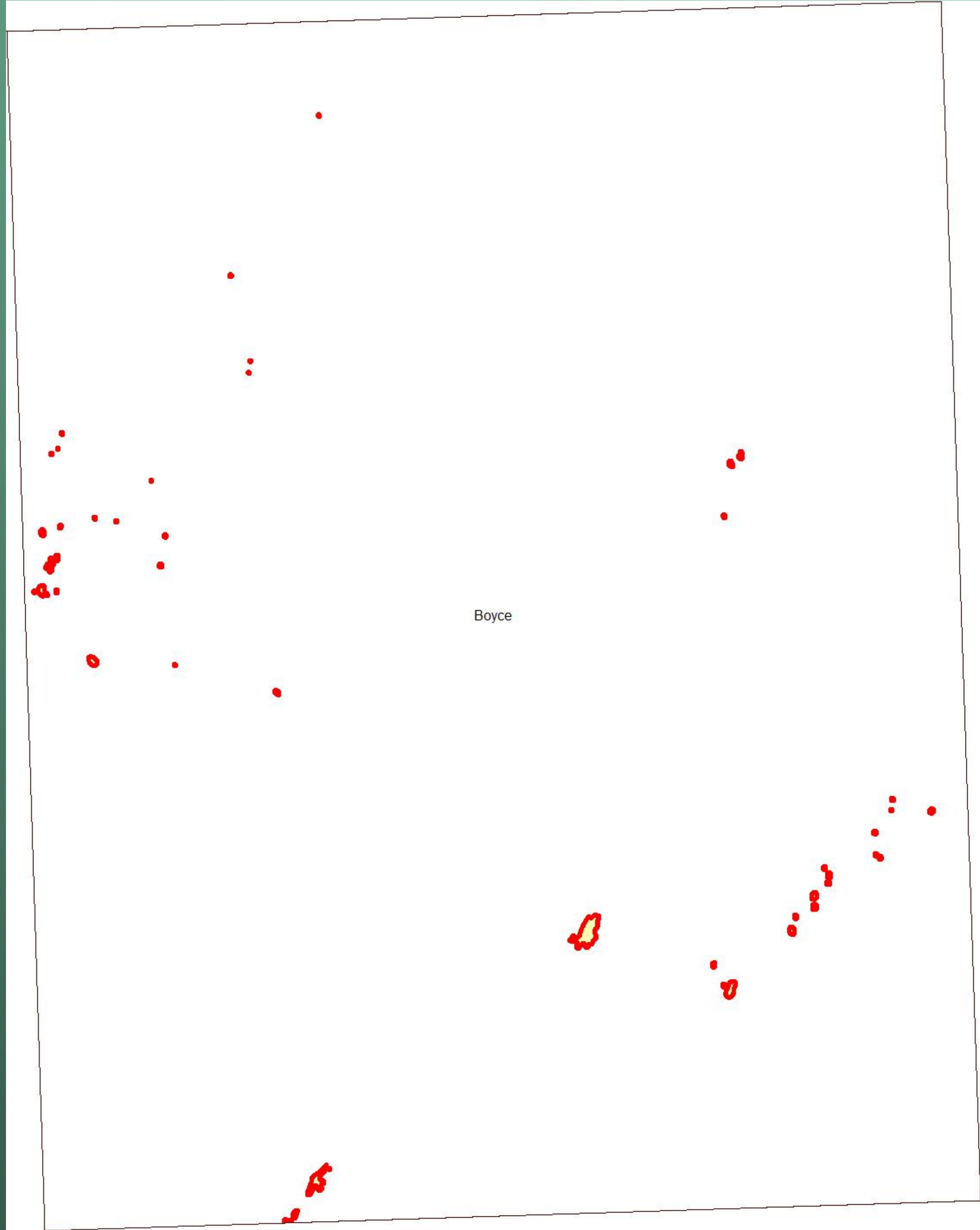
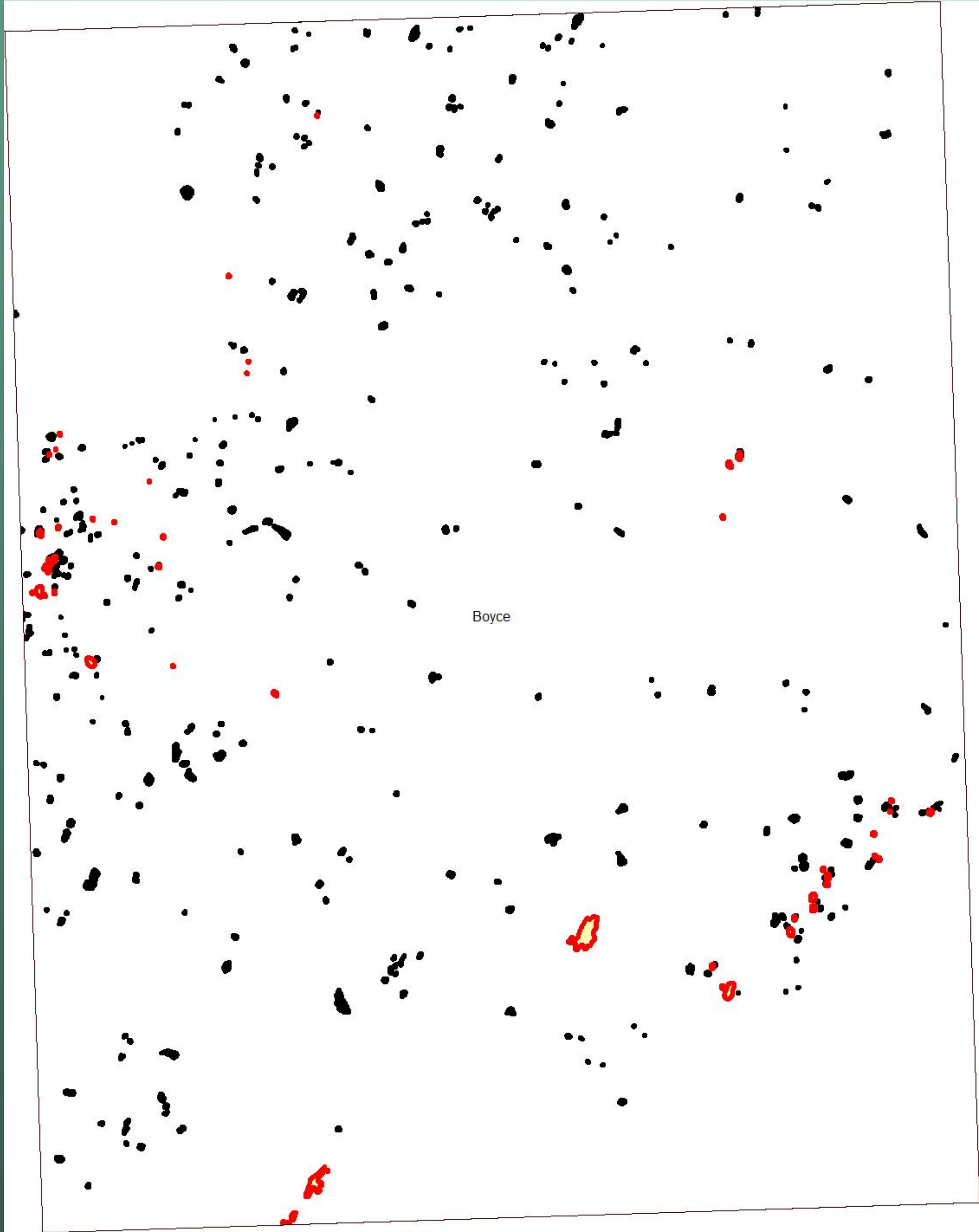


Red dots are closed depressions in VA-DMME dataset (by D. Hubbard)

Black dots are closed depressions manually delineated from aerial imagery in concert with LIDAR hillshade

Is there an easier way?



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AUTOMATING DETECTION OF CLOSED DEPRESSIONS WORKFLOW:

Sub-region

Manually create closed depression dataset

- Optimize LIDAR imagery for digitization
- Combine with aerial imagery when digitizing

Field-check questionable manual data

Full region

Use GIS tools to “fill” depressions in elevation model based on a flow routing algorithm

- Remove artifacts
- Remove “dams” at roads and driveways by adding culverts to recondition original DEM
- Remove false depressions in streams and near structures

Use validated manual dataset to refine depth and shape thresholds for retaining depressions

Evaluate final data

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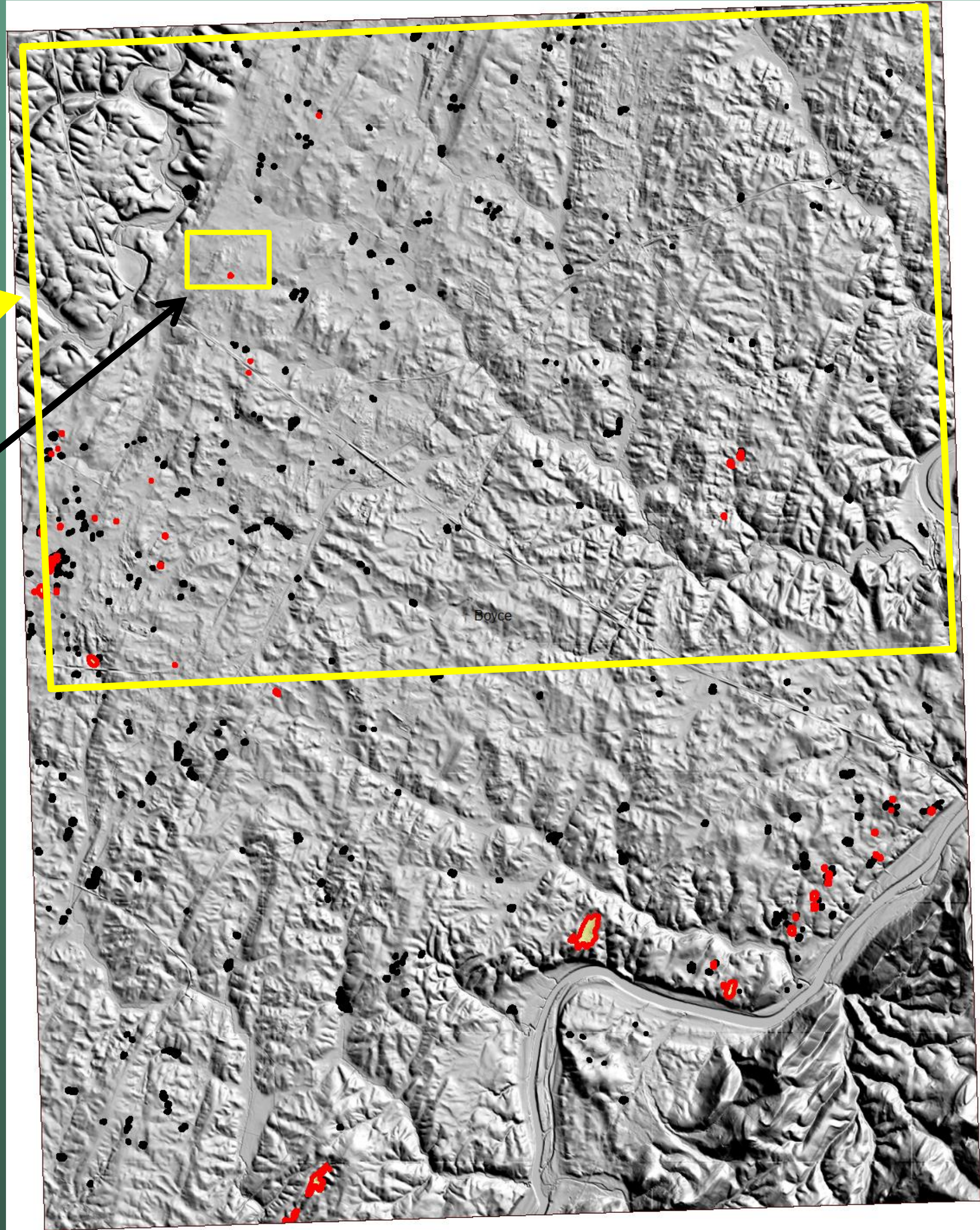
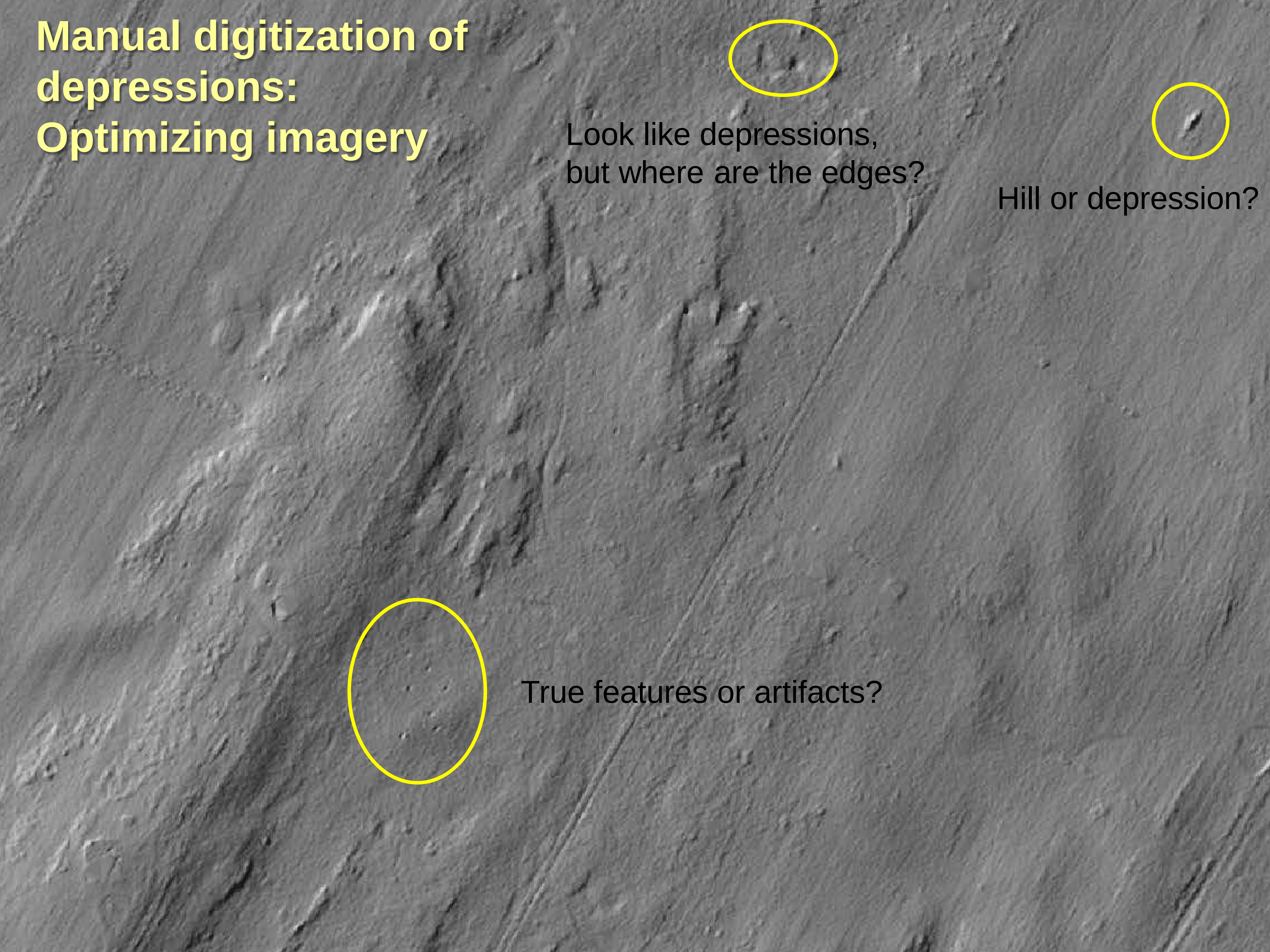
Region used for analysis

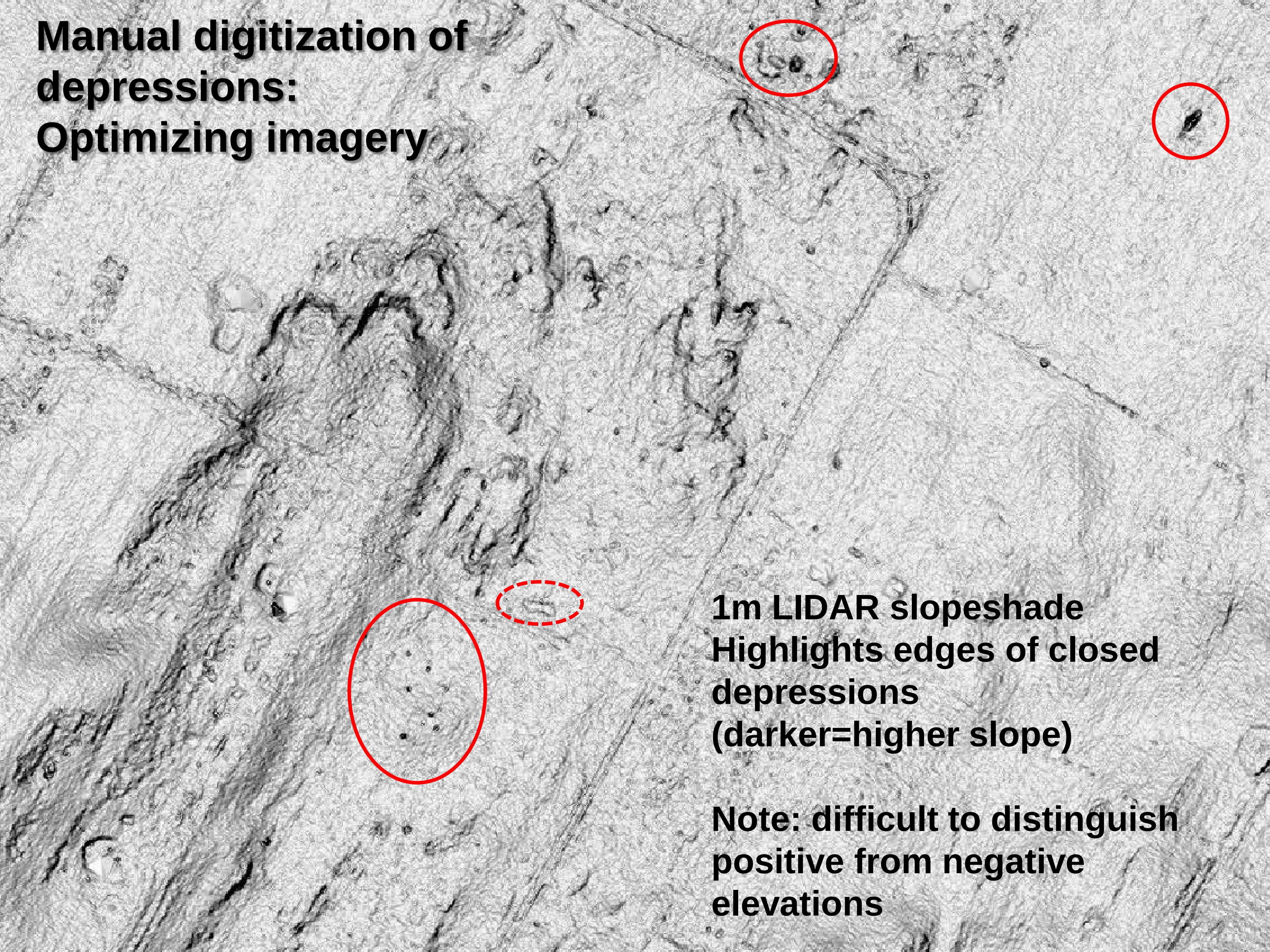
Region shown in following slides



Manual digitization of depressions: Optimizing imagery



Manual digitization of depressions: Optimizing imagery

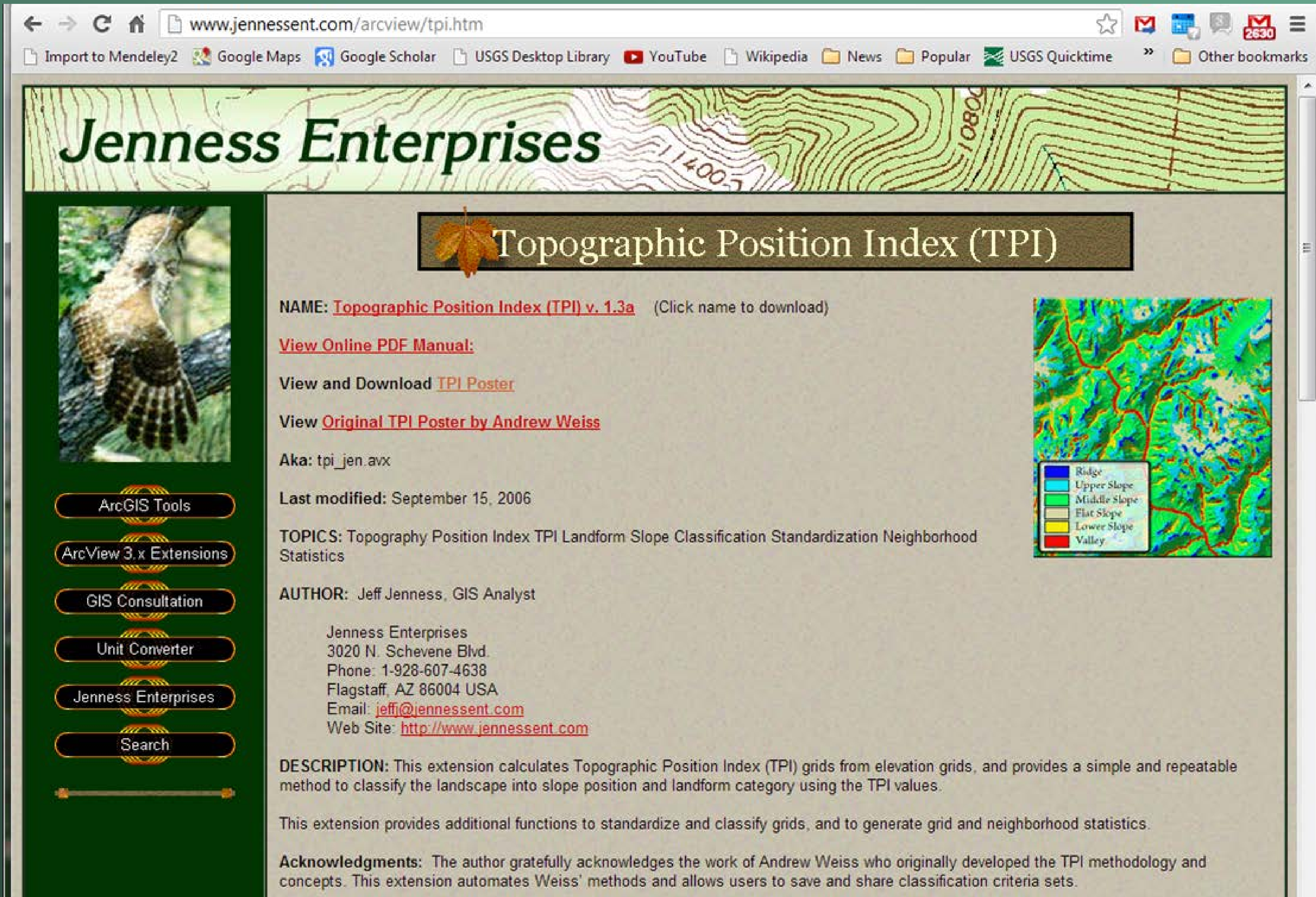


1m LIDAR slopeshade
Highlights edges of closed depressions (darker=higher slope)

Note: difficult to distinguish positive from negative elevations

Topographic Position Index (TPI):

A useful tool for landscape shape classification



www.jennessent.com/arcview/tpi.htm

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Jenness Enterprises

ArcGIS Tools
ArcView 3.x Extensions
GIS Consultation
Unit Converter
Jenness Enterprises
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Topographic Position Index (TPI)

NAME: Topographic Position Index (TPI) v. 1.3a (Click name to download)

View Online PDF Manual:

View and Download TPI Poster

View Original TPI Poster by Andrew Weiss

Aka: tpi_jen.avx

Last modified: September 15, 2006

TOPICS: Topography Position Index TPI Landform Slope Classification Standardization Neighborhood Statistics

Ridge
Upper Slope
Middle Slope
Flat Slope
Lower Slope
Valley

AUTHOR: Jeff Jenness, GIS Analyst

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Flagstaff, AZ 86004 USA
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Web Site: http://www.jennessent.com

DESCRIPTION: This extension calculates Topographic Position Index (TPI) grids from elevation grids, and provides a simple and repeatable method to classify the landscape into slope position and landform category using the TPI values.

This extension provides additional functions to standardize and classify grids, and to generate grid and neighborhood statistics.

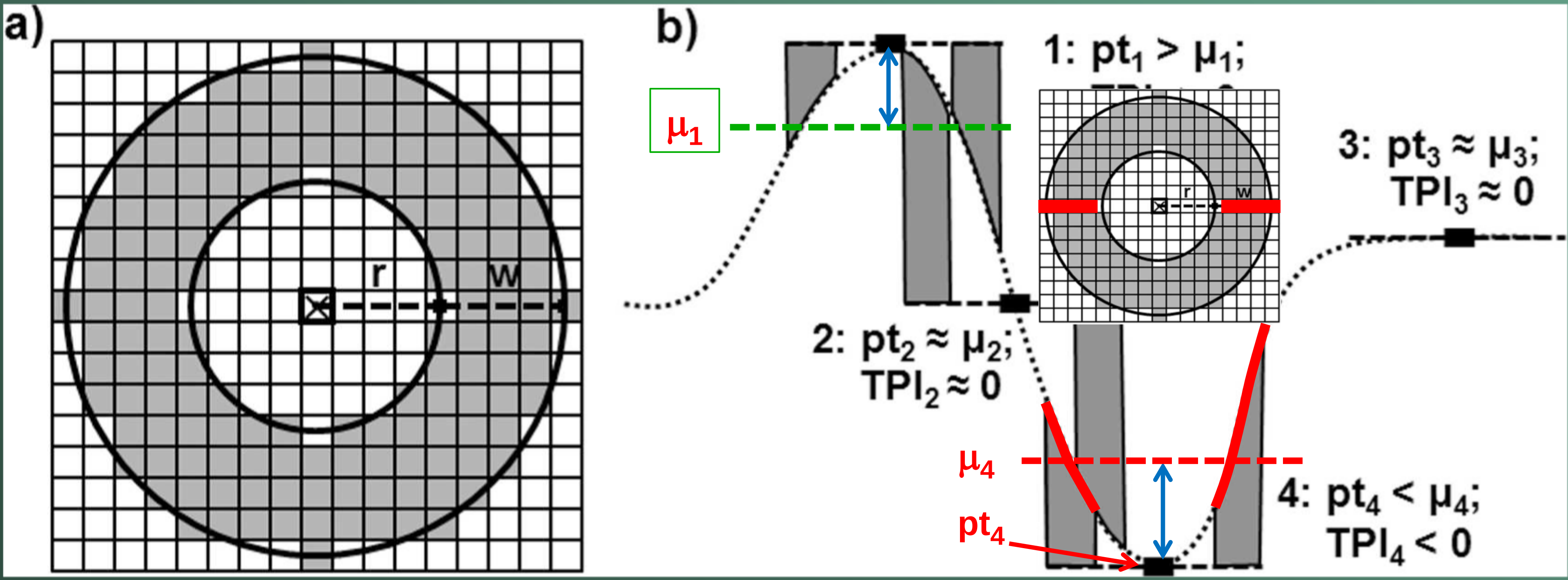
Acknowledgments: The author gratefully acknowledges the work of Andrew Weiss who originally developed the TPI methodology and concepts. This extension automates Weiss' methods and allows users to save and share classification criteria sets.

Topographic Position Index (TPI):

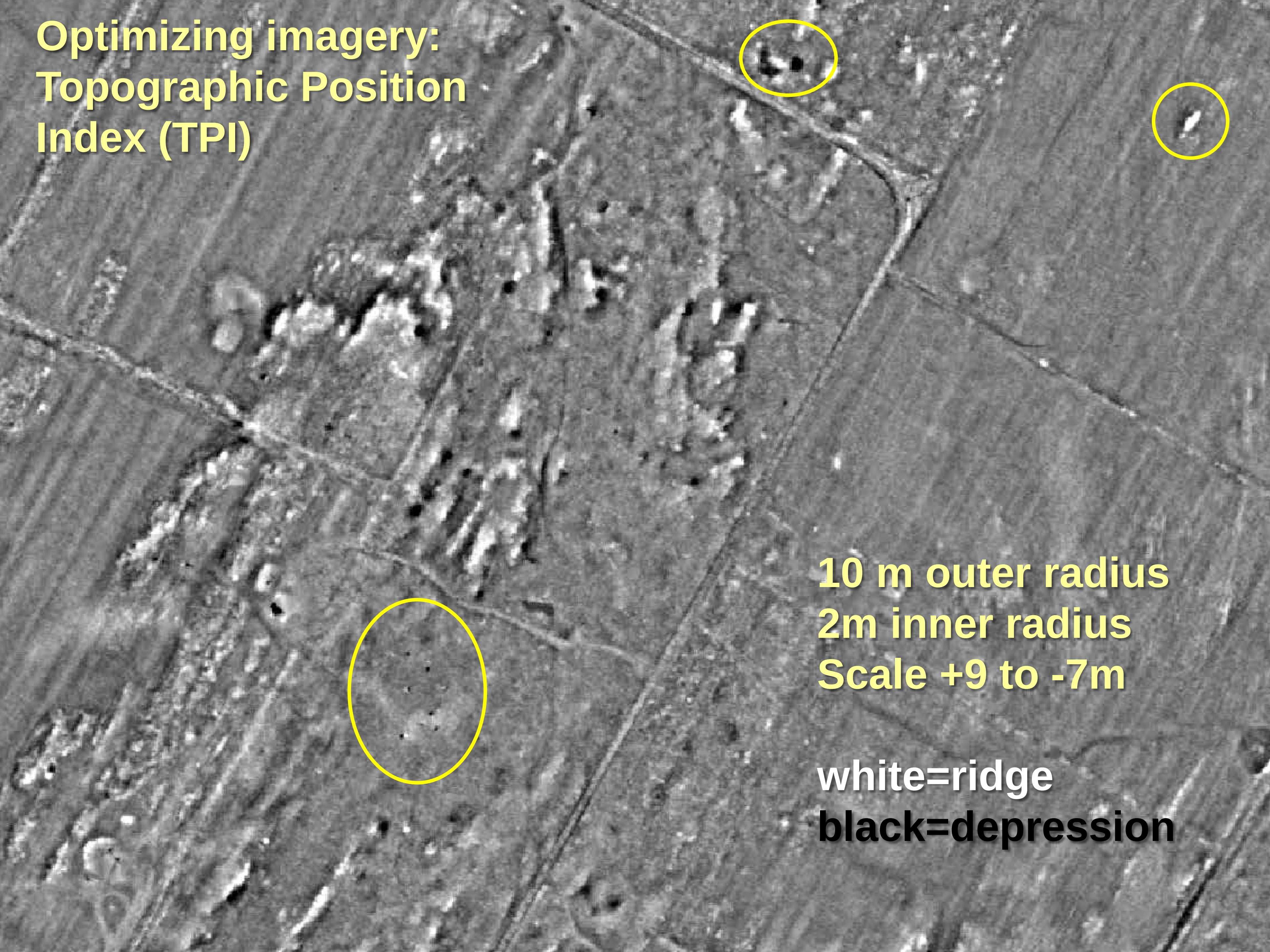
- An elevation dataset derived from a moving window calculation on the original DEM

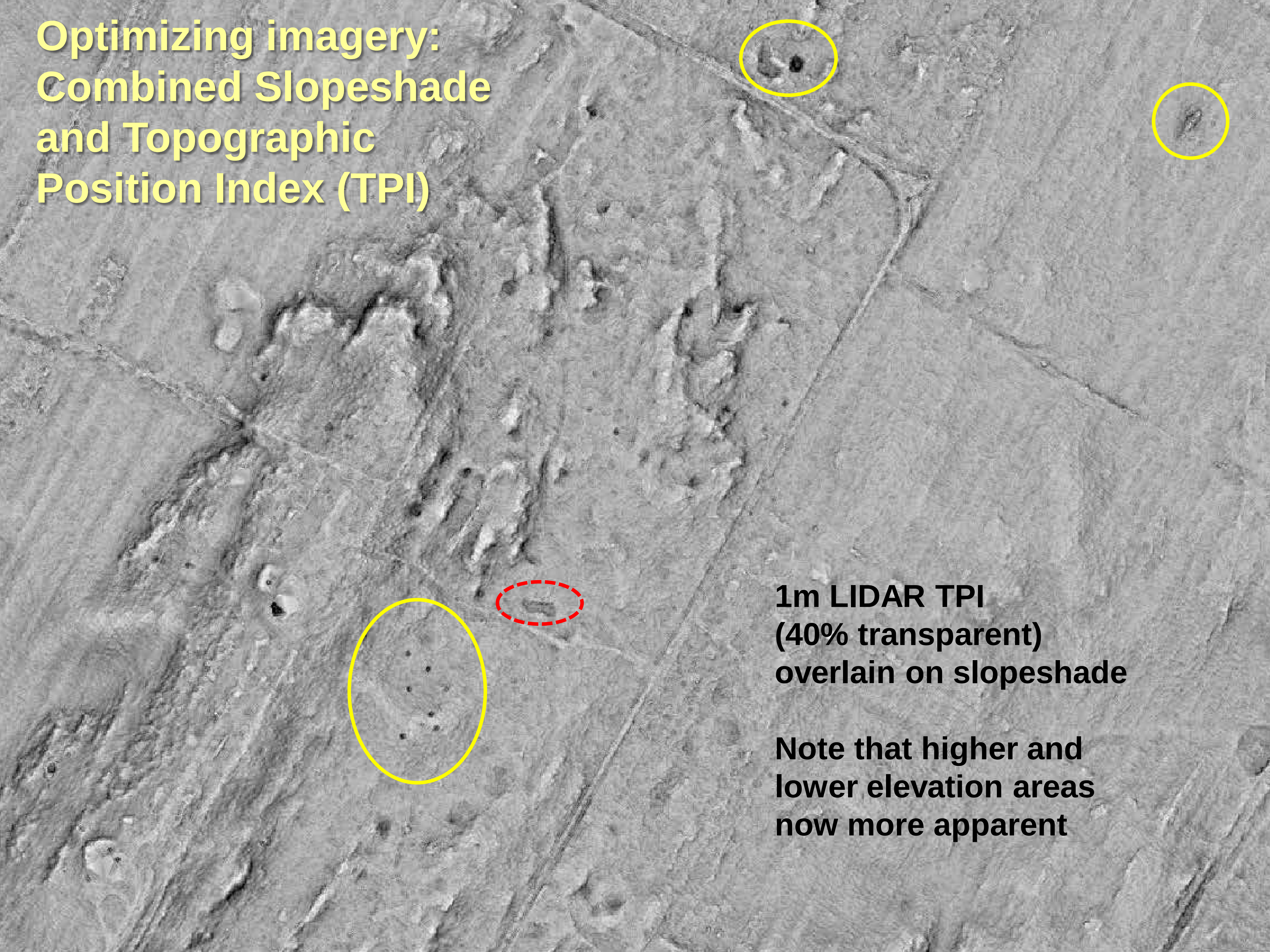
- Mean elevation of the new dataset is ~ 0

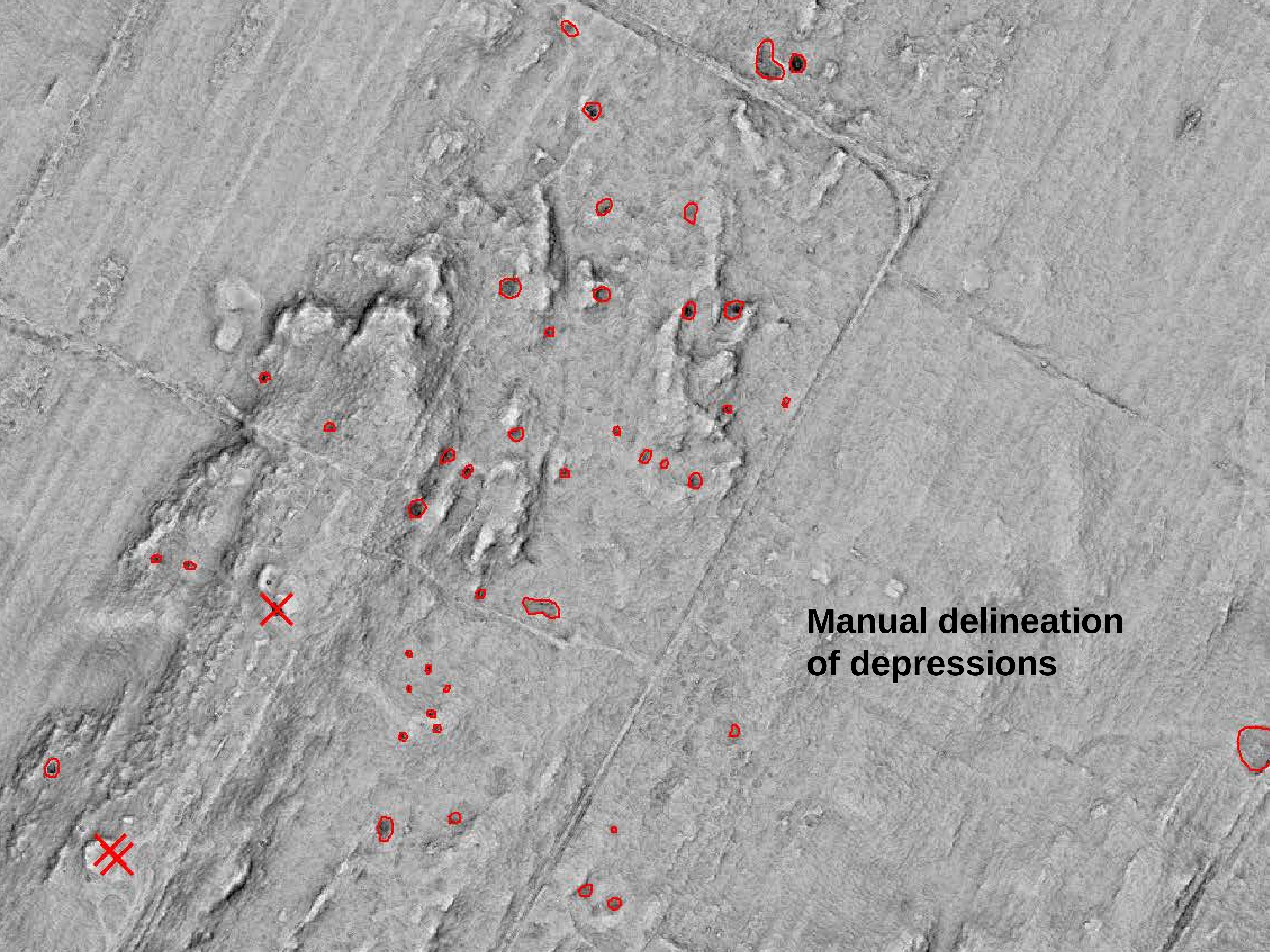
- New elevations are locally positive (highs) or negative (lows) with respect to the localized mean of a ring of cells surrounding the target cell

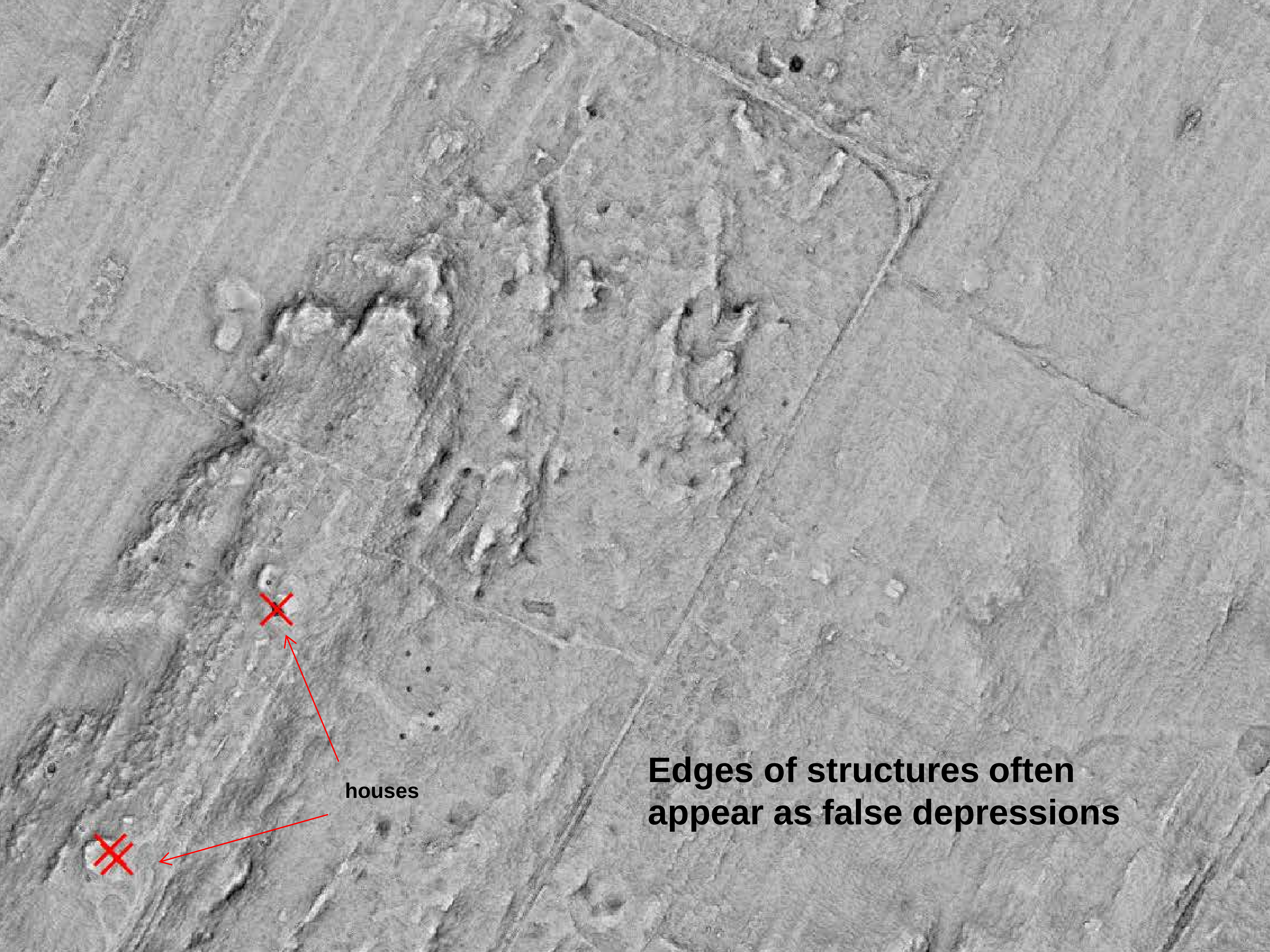


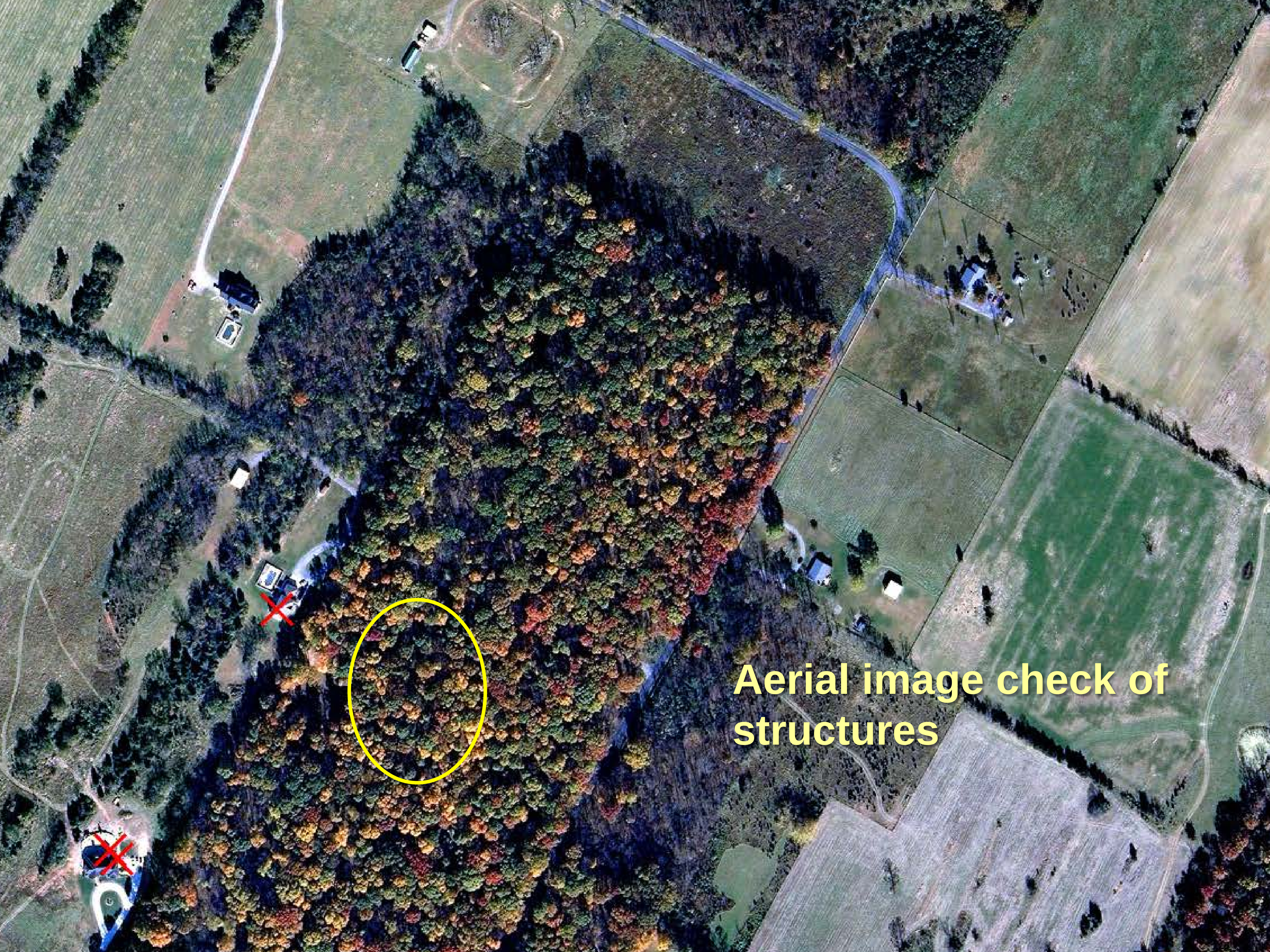
From Weishampel et al., 2011


Optimizing imagery:
Topographic Position
Index (TPI)
10 m outer radius
2m inner radius
Scale +9 to -7m
white=ridge
black=depression

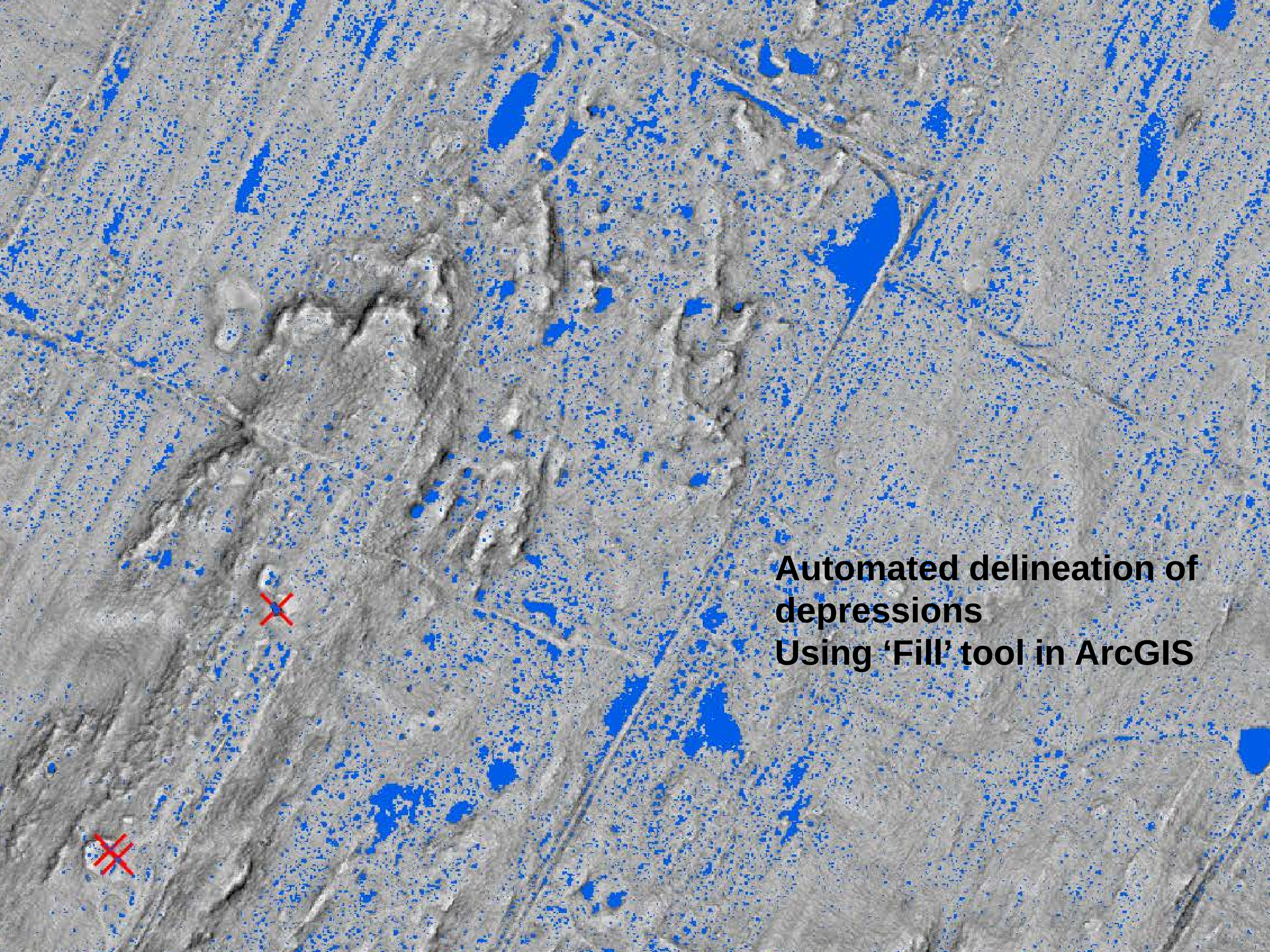

Optimizing imagery:
Combined Slopeshade
and Topographic
Position Index (TPI)
1m LIDAR TPI
(40% transparent)
overlain on slopeshade
Note that higher and
lower elevation areas
now more apparent

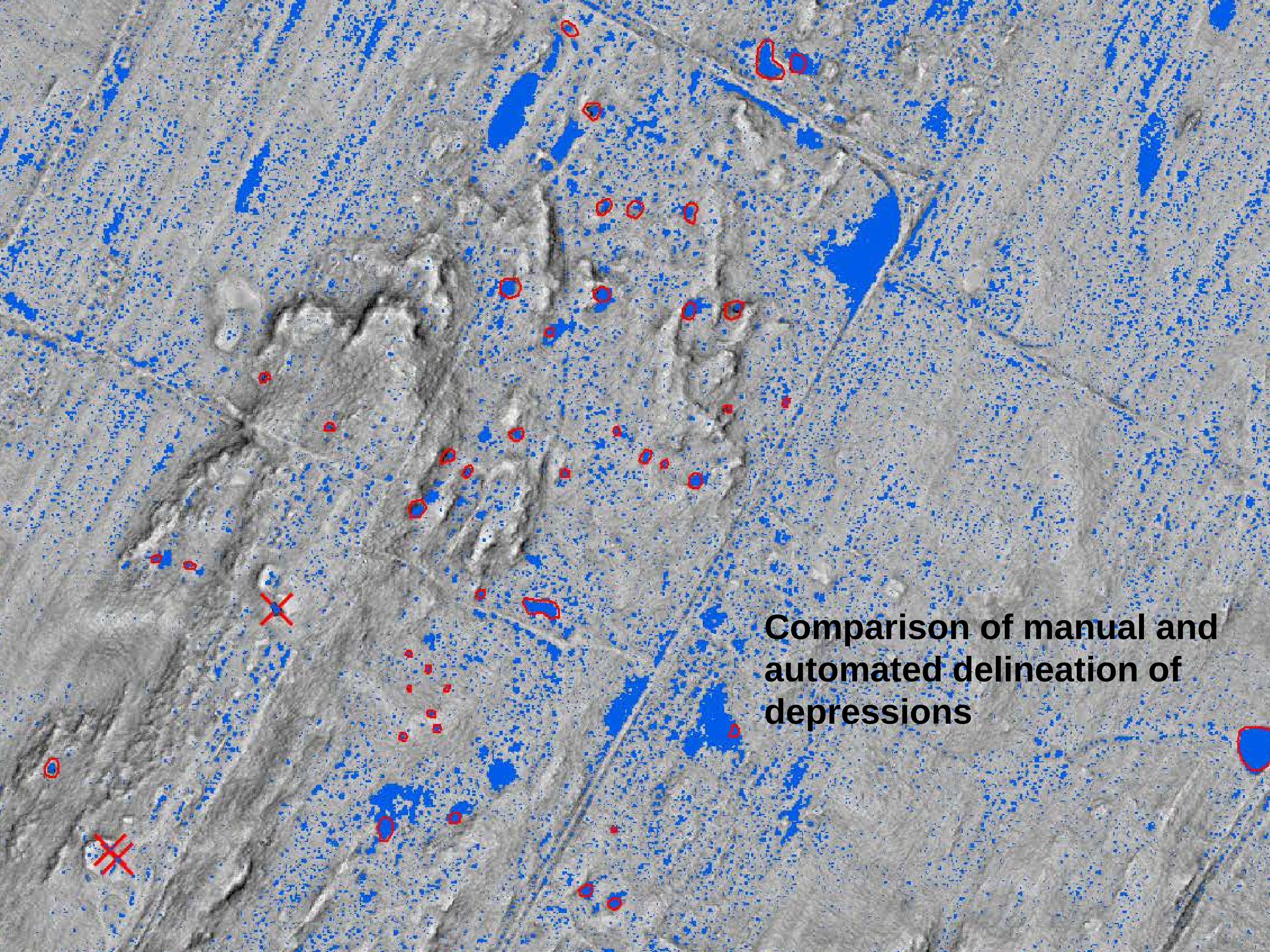

Manual delineation
of depressions

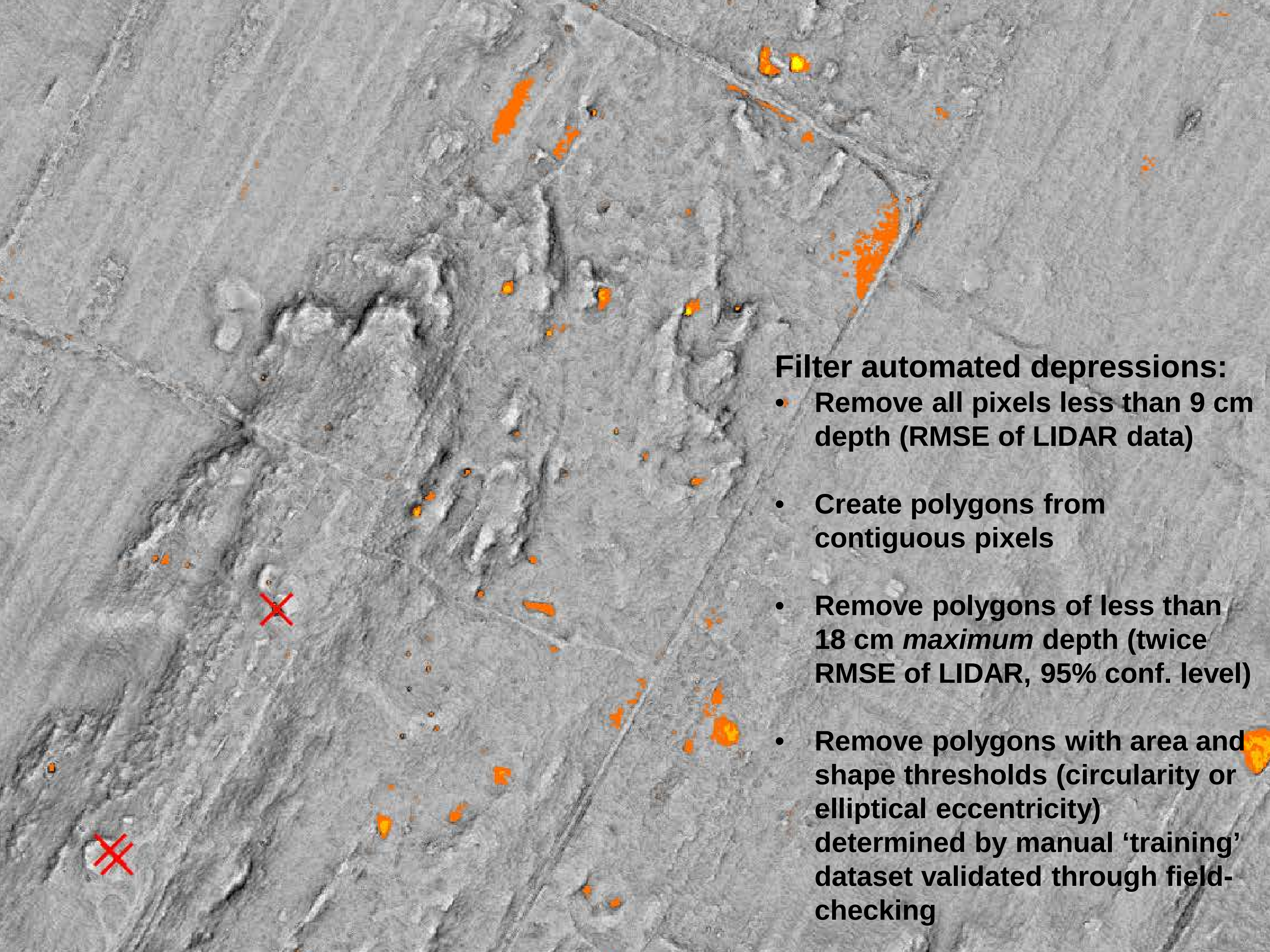

houses
Edges of structures often appear as false depressions


Aerial image check of structures


Structures digitized for
removal of artifacts

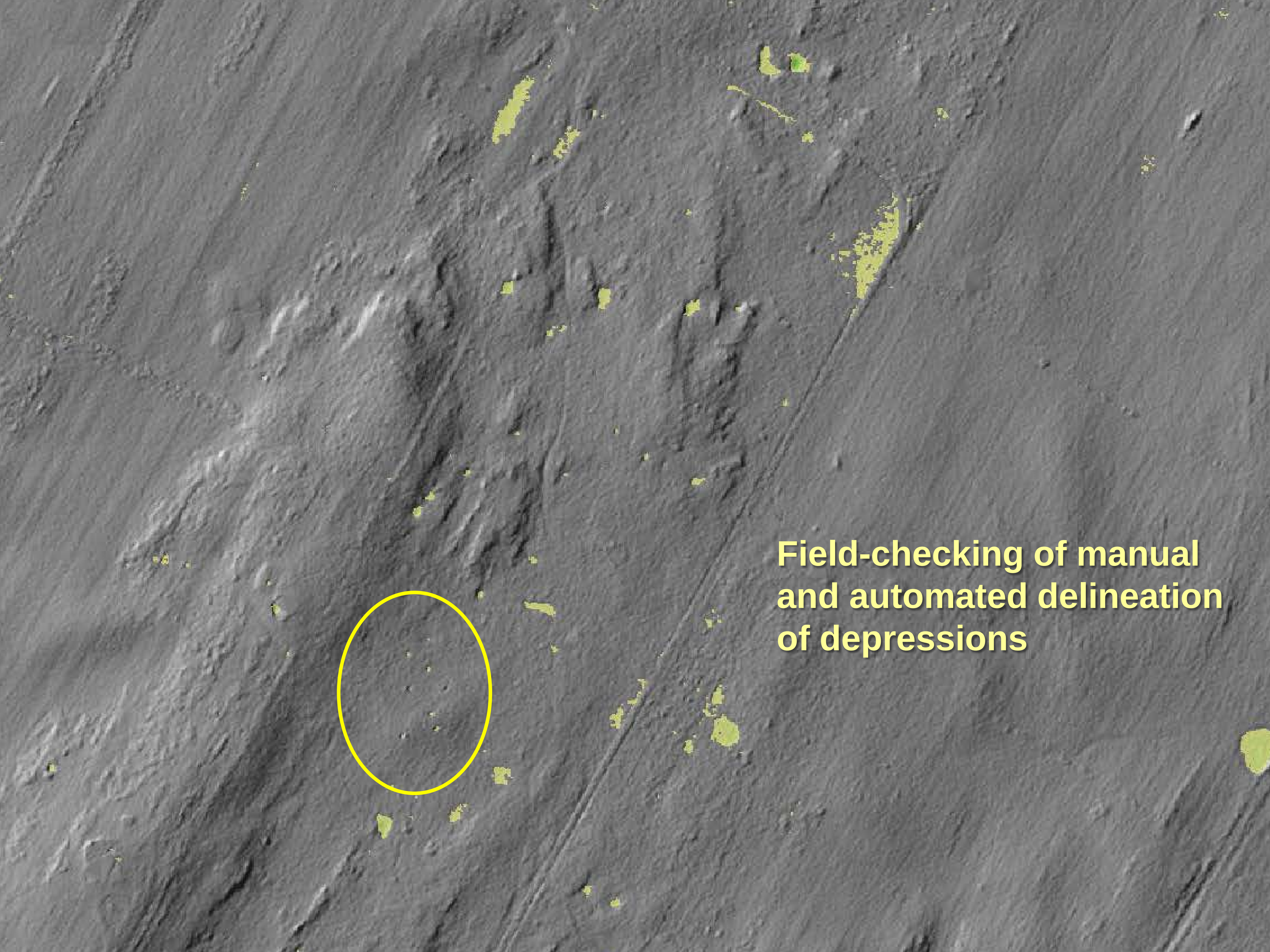

Automated delineation of
depressions
Using ‘Fill’ tool in ArcGIS


Comparison of manual and automated delineation of depressions



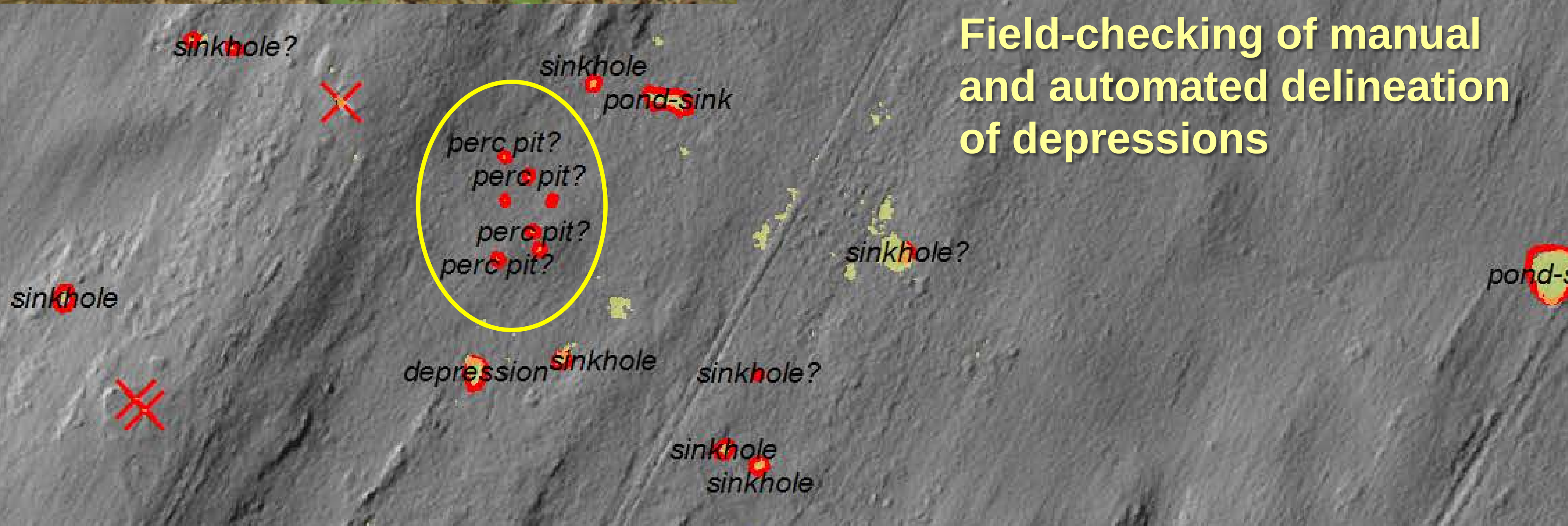
Filter automated depressions:

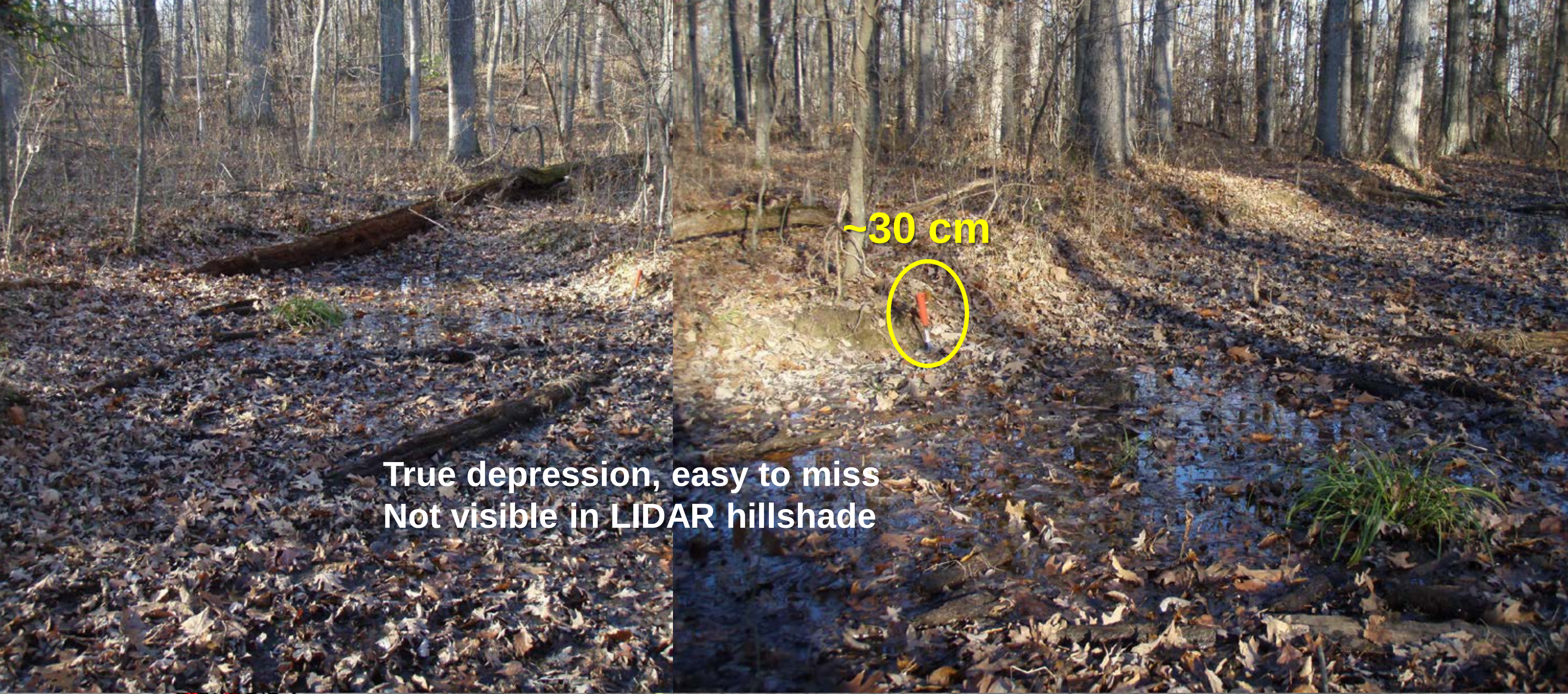
- **Remove all pixels less than 9 cm depth (RMSE of LIDAR data)**
- **Create polygons from contiguous pixels**
- **Remove polygons of less than 18 cm *maximum* depth (twice RMSE of LIDAR, 95% conf. level)**
- **Remove polygons with area and shape thresholds (circularity or elliptical eccentricity) determined by manual ‘training’ dataset validated through field-checking**

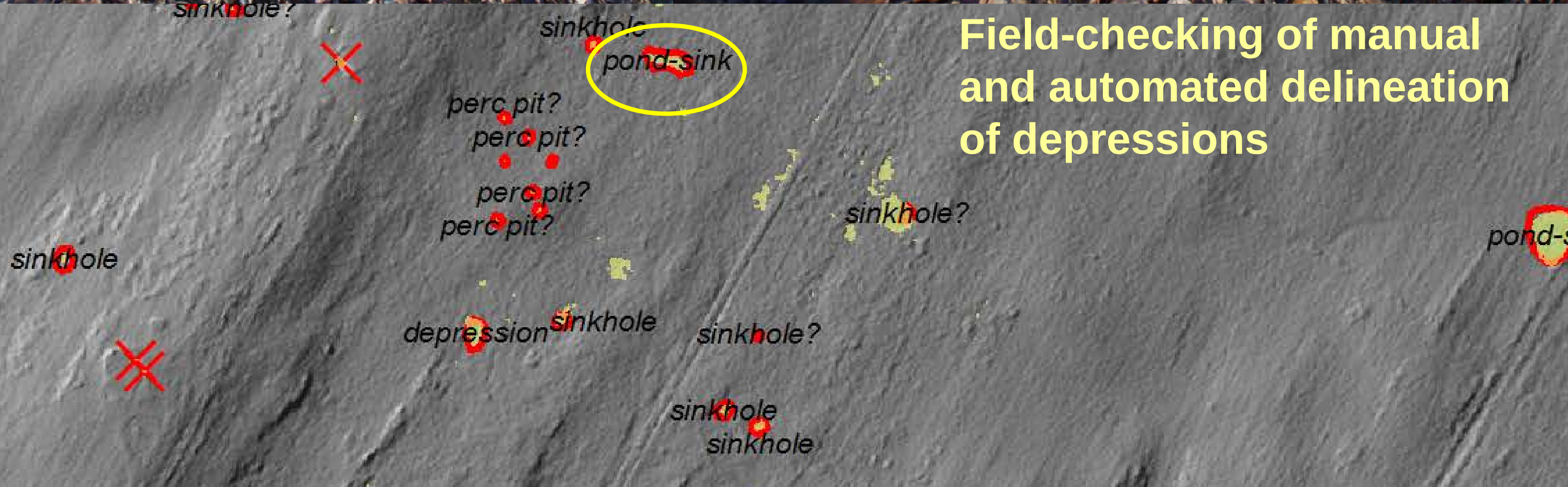

Field-checking of manual and automated delineation of depressions

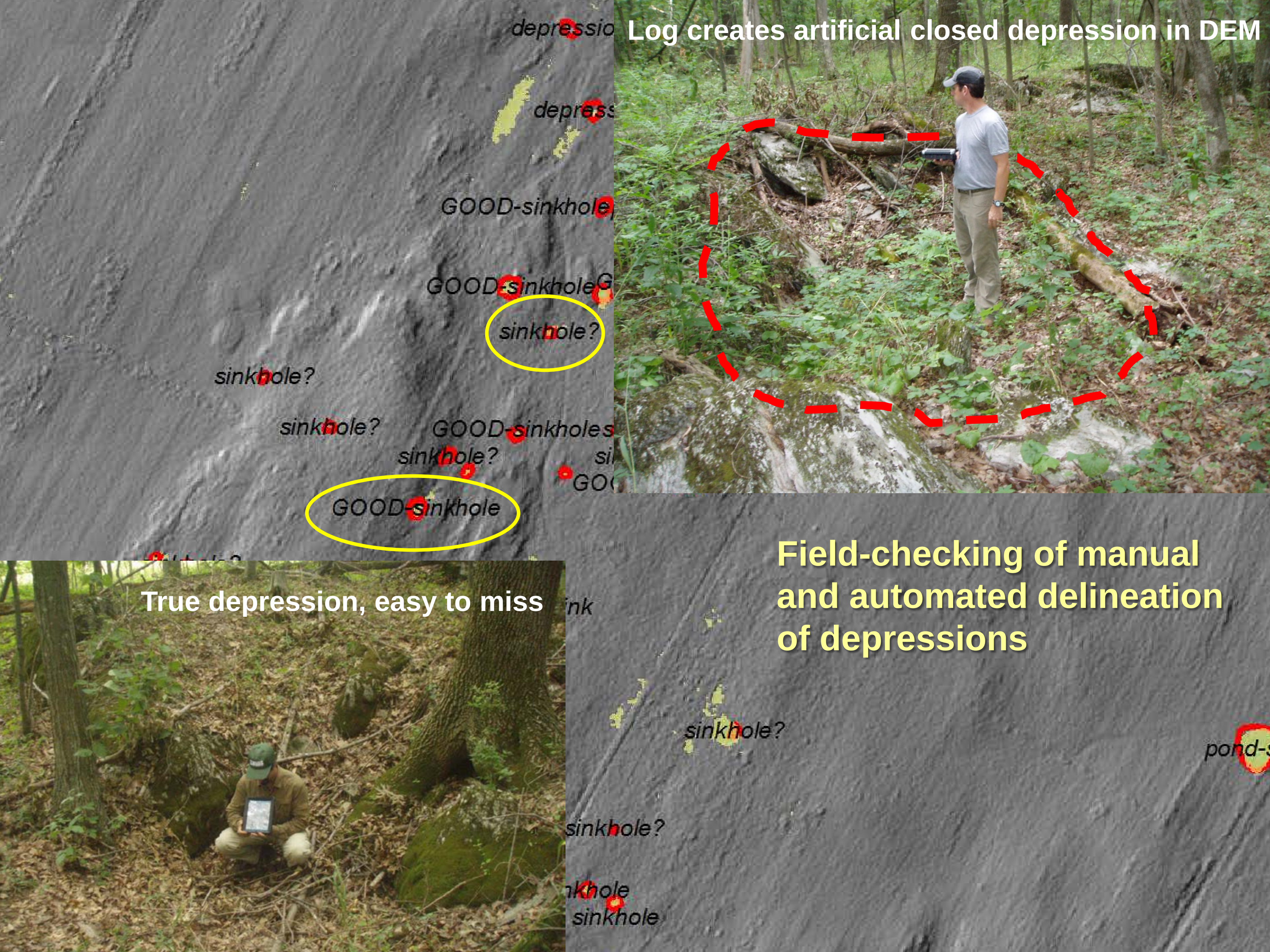
True depressions, but manmade

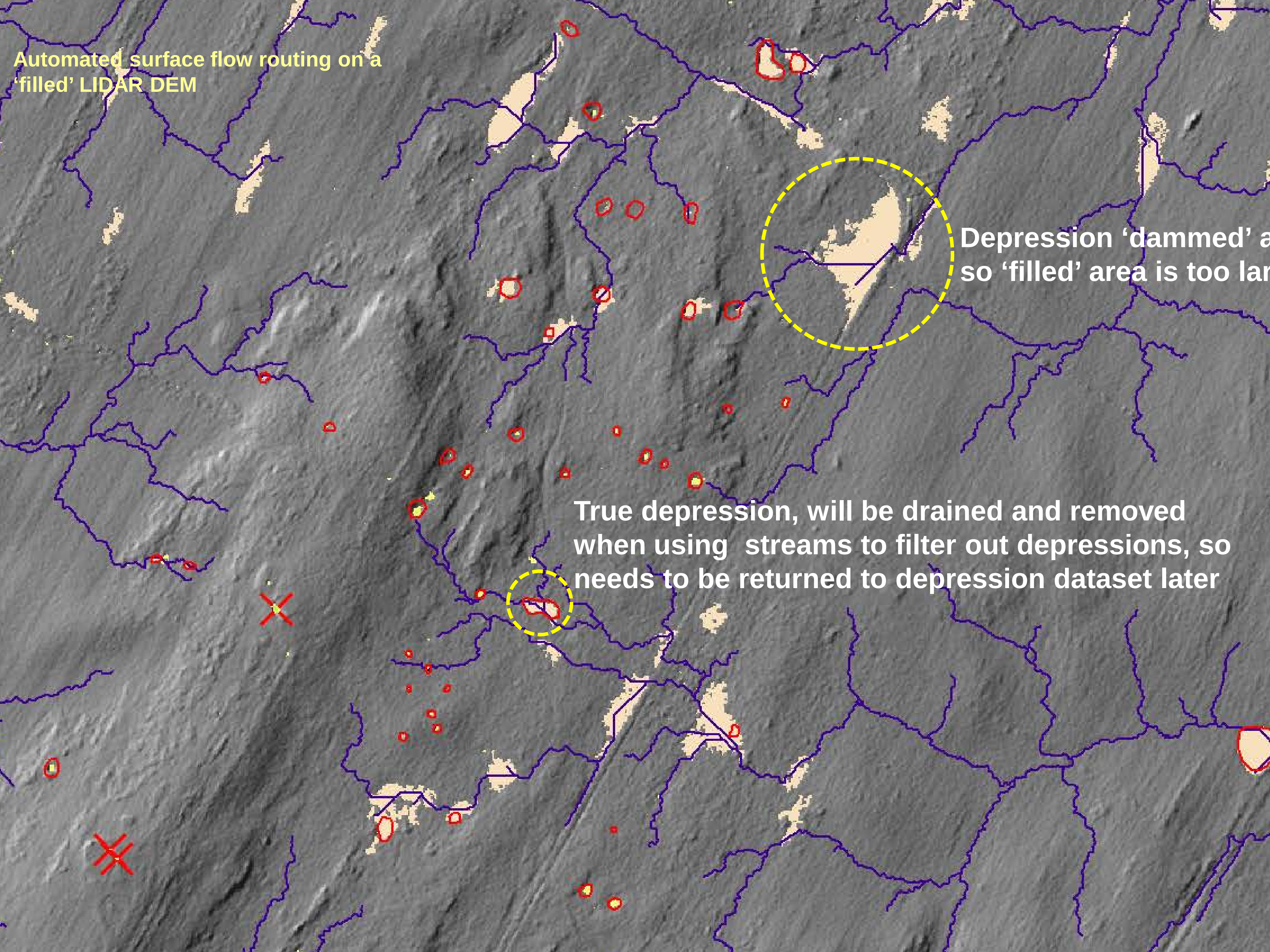
Field-checking of manual and automated delineation of depressions




~30 cm
True depression, easy to miss
Not visible in LIDAR hillshade


Field-checking of manual and automated delineation of depressions
sinkhole
pond-sink
perc pit?
perc pit?
perc pit?
perc pit?
sinkhole?
sinkhole
depression
sinkhole
sinkhole?
sinkhole
sinkhole

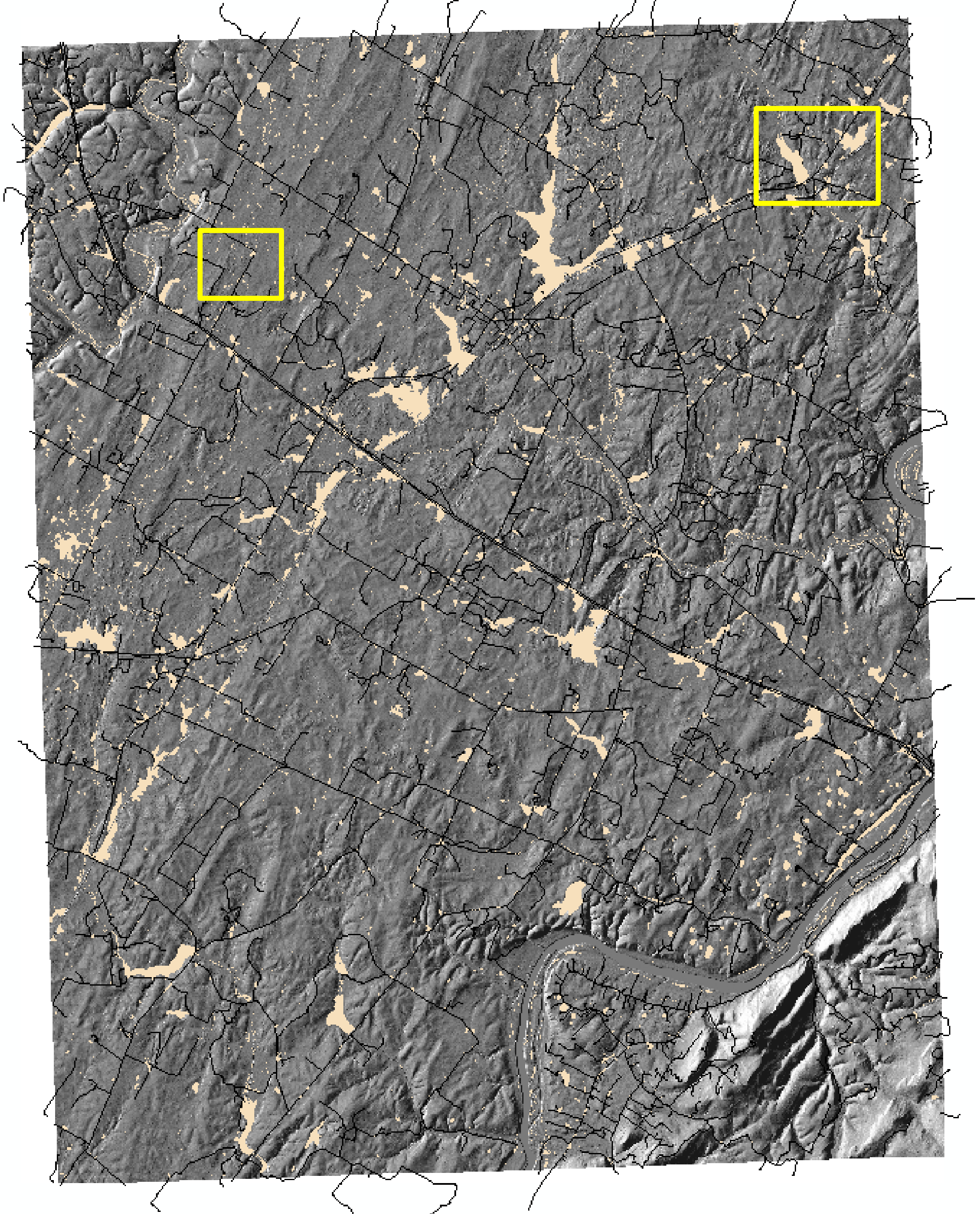

Log creates artificial closed depression in DEM
True depression, easy to miss
Field-checking of manual and automated delineation of depressions
GOOD-sinkhole
GOOD-sinkhole
sinkhole?
sinkhole?
sinkhole?
GOOD-sinkholes
sinkhole?
GOOD-sinkhole
sinkhole?
sinkhole?
sinkhole



Automated surface flow routing on a
'filled' LIDAR DEM
Depression 'dammed' a
so 'filled' area is too lar
True depression, will be drained and removed
when using streams to filter out depressions, so
needs to be returned to depression dataset later

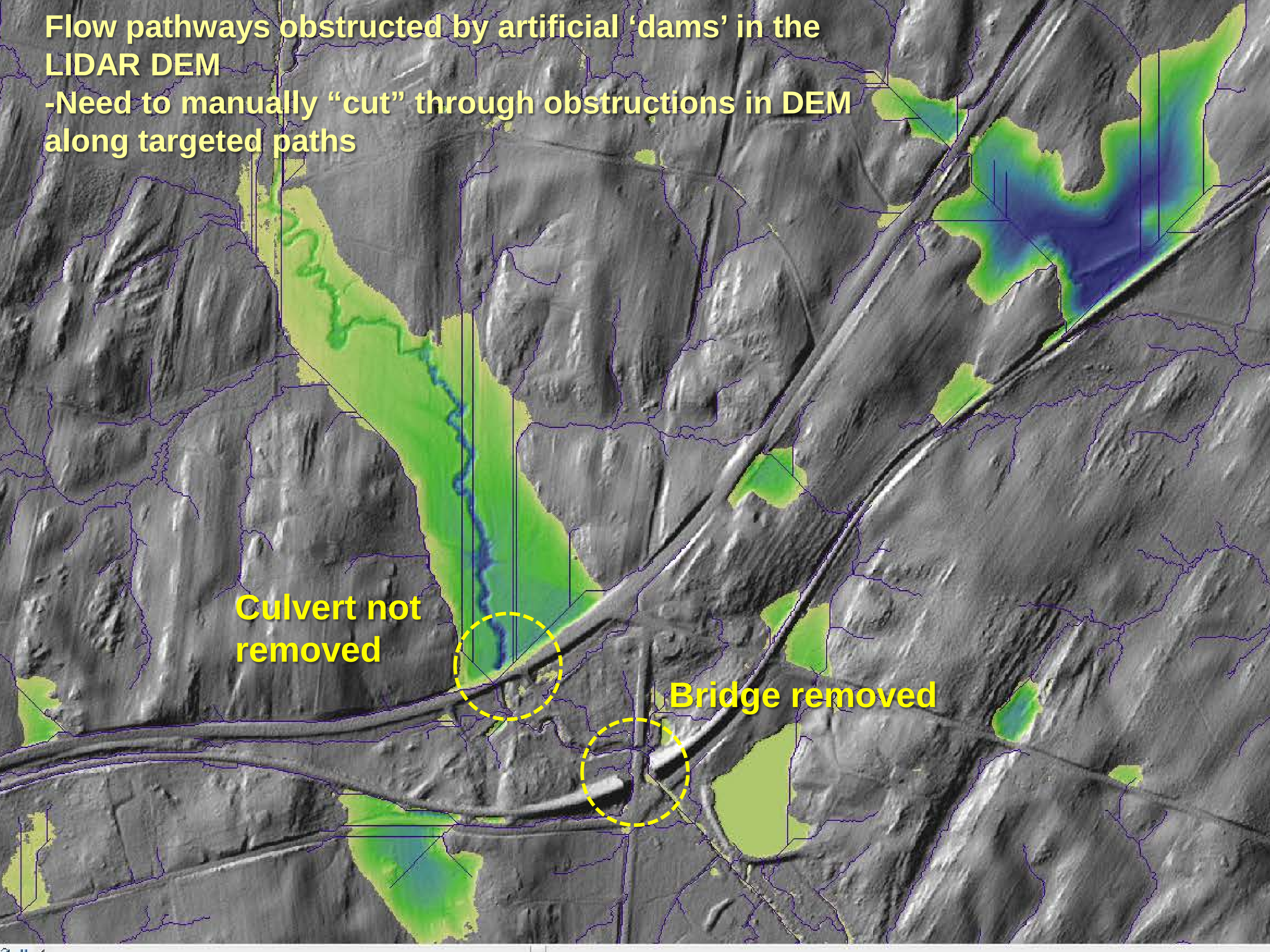
Automated surface flow routing on a ‘filled’ LIDAR DEM

NOTE that largest (artificial) depressions are ‘dammed’ against roads

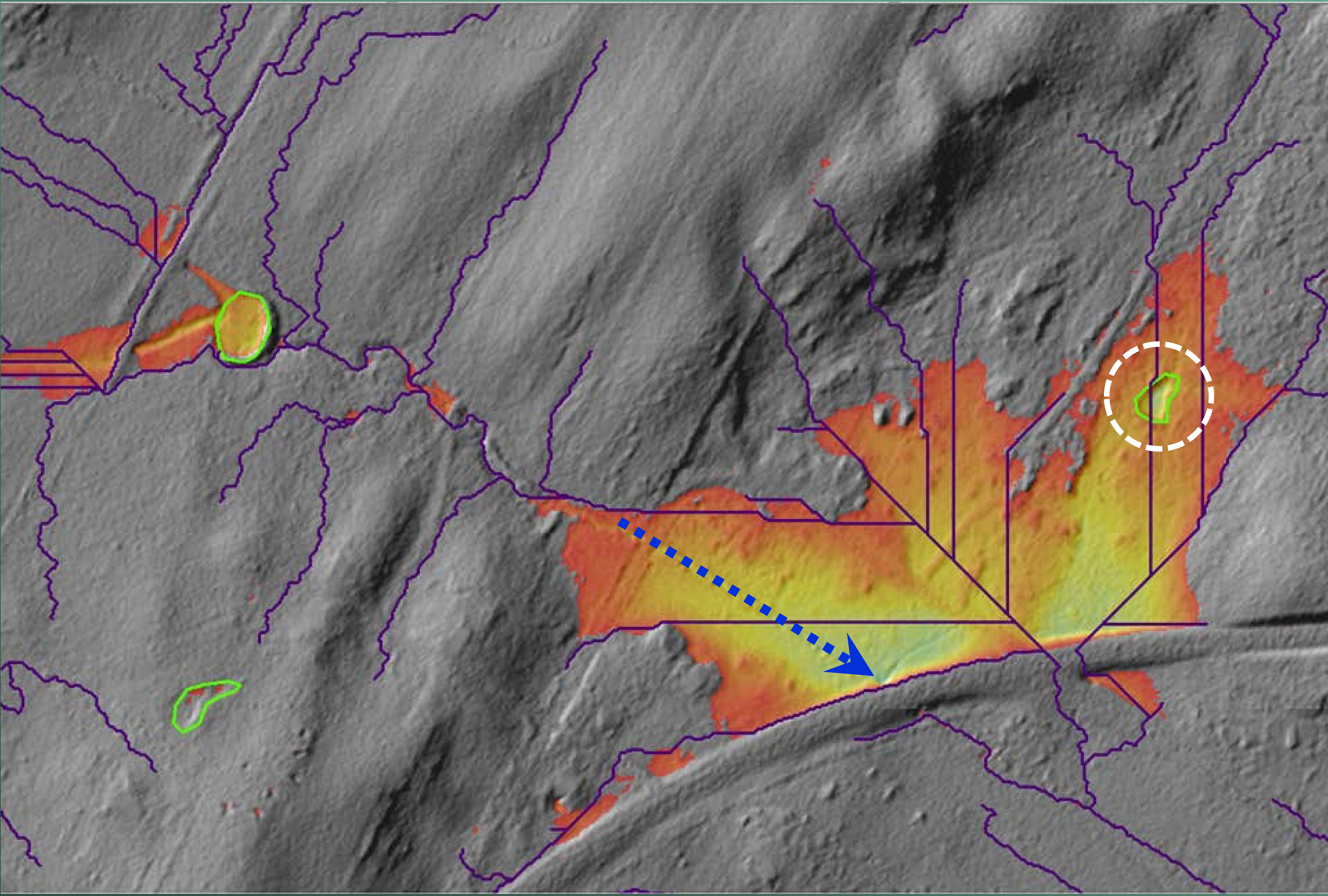


Flow pathways obstructed by artificial ‘dams’ in the LIDAR DEM

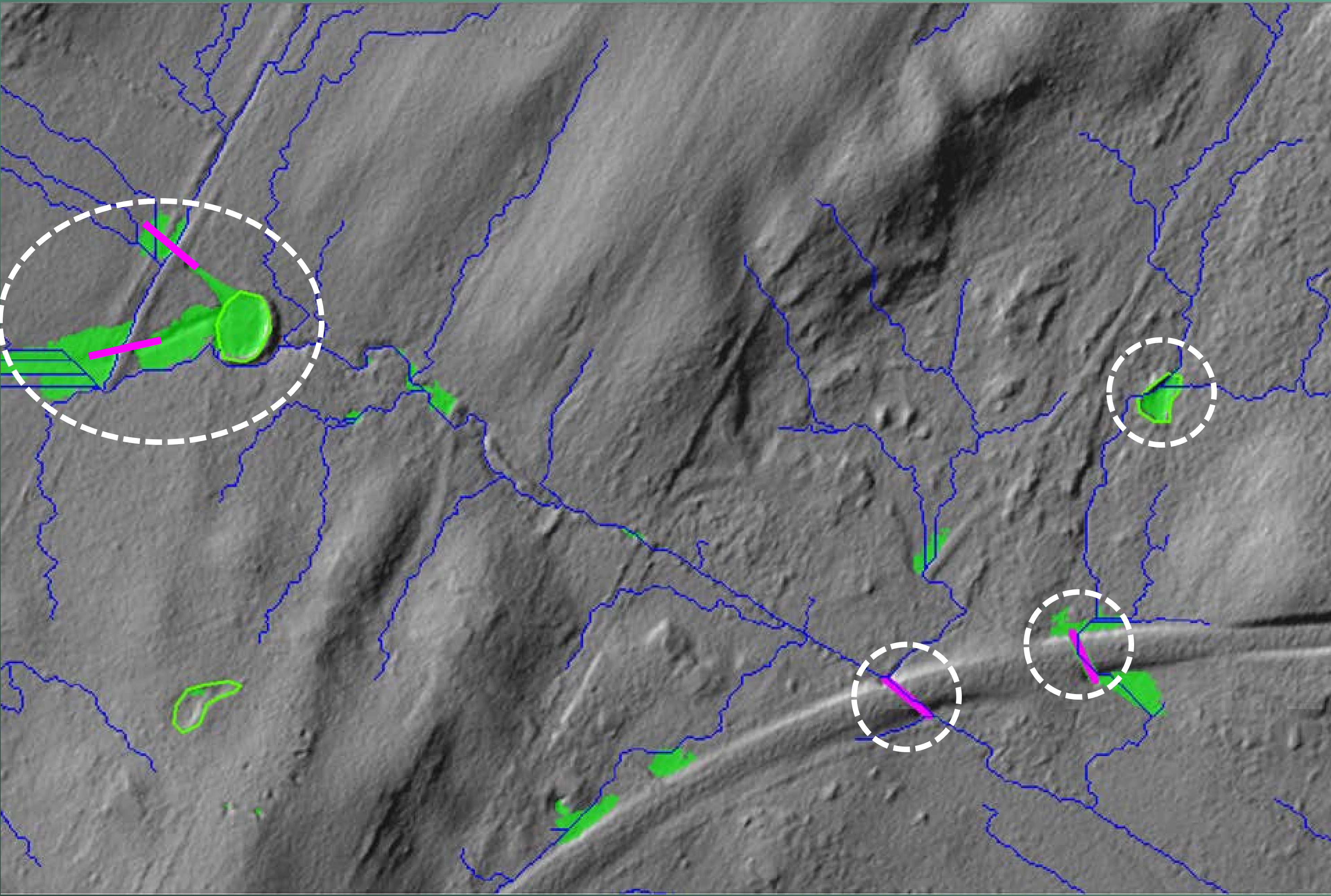
-Need to manually “cut” through obstructions in DEM along targeted paths



Problem areas of nested depressions require multiple iterations to ‘drain’ artificially dammed depressions

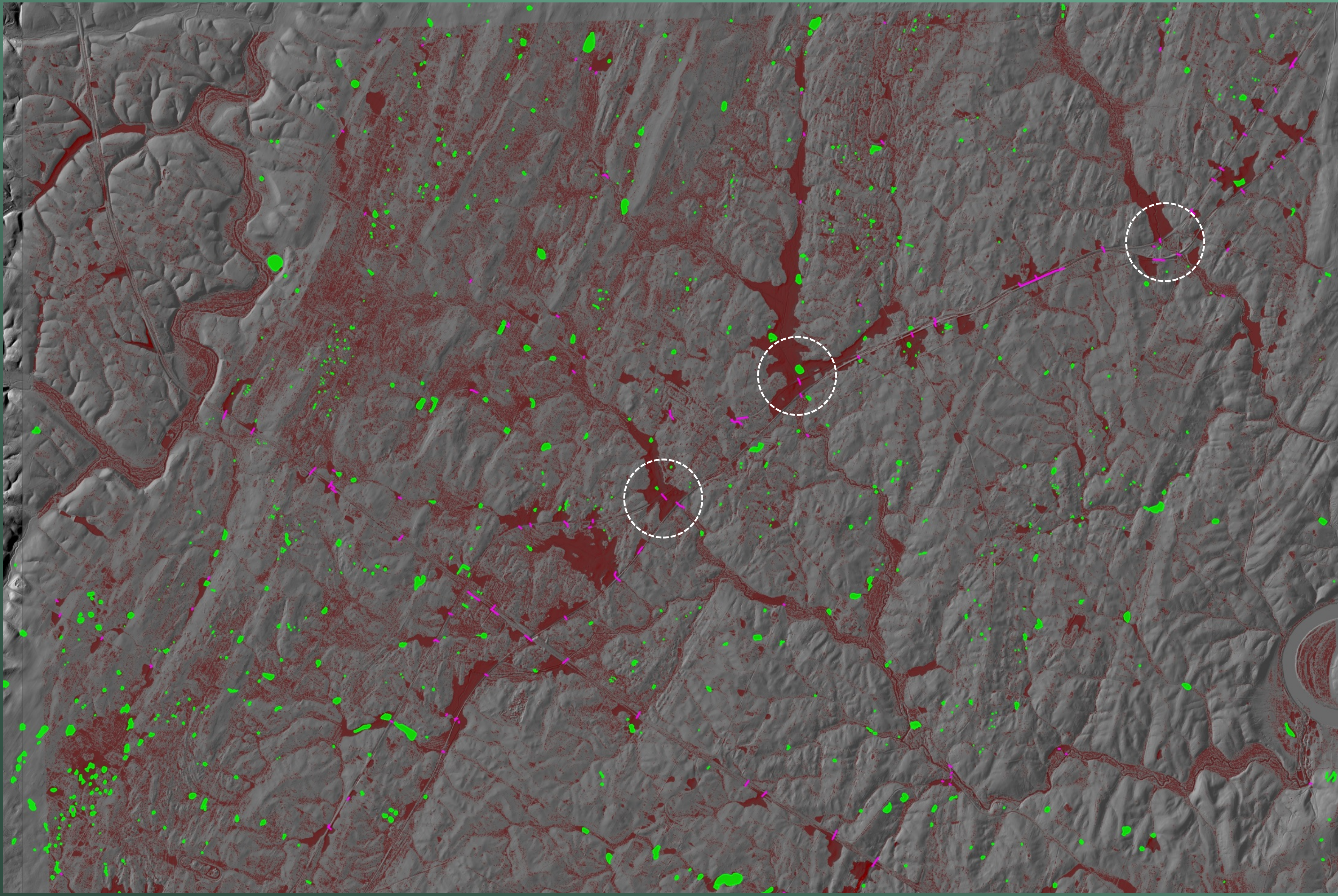


Problem areas of nested depressions require multiple iterations to 'drain' artificially dammed depressions

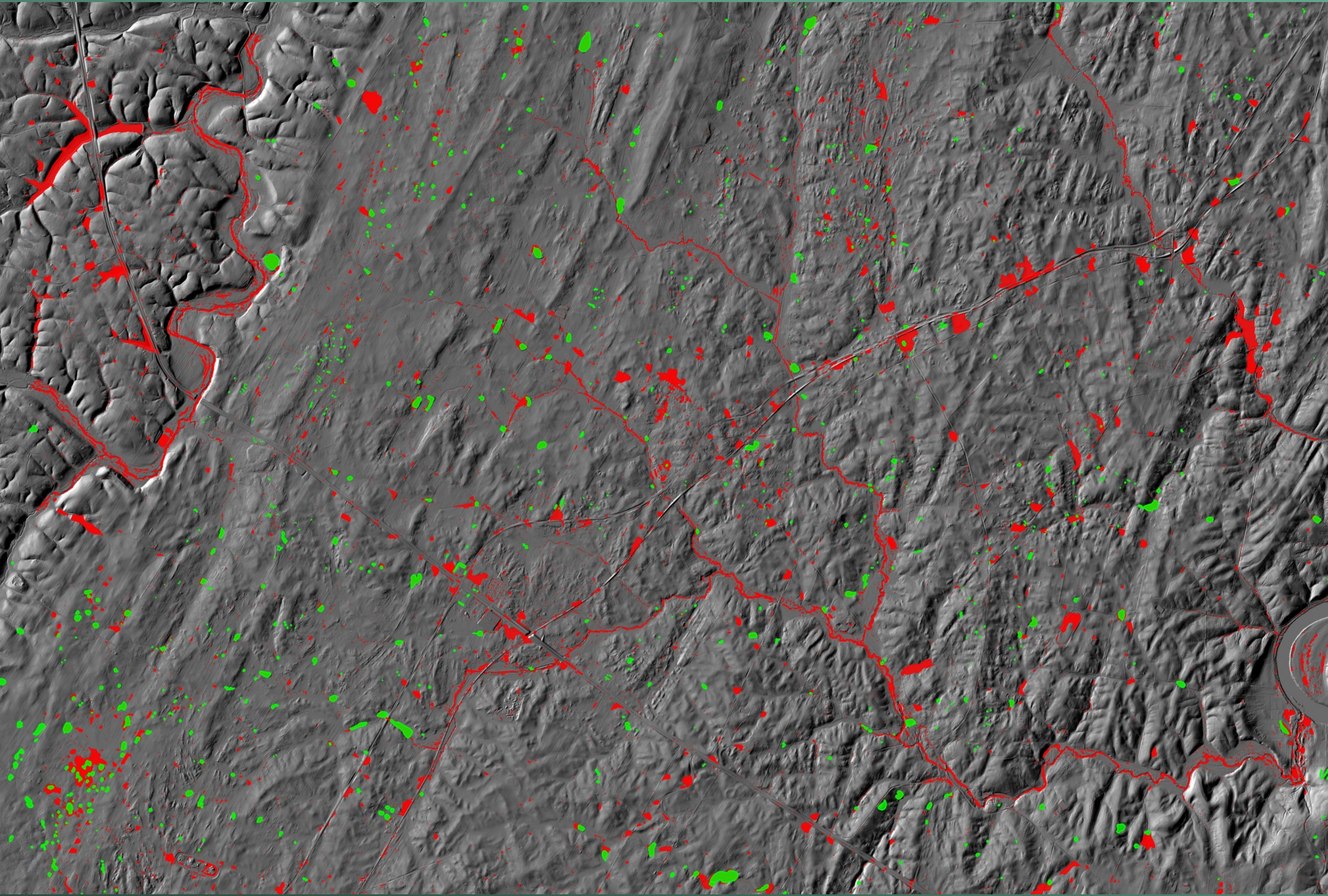


CULVERTS: Need to be mapped along roads and driveways

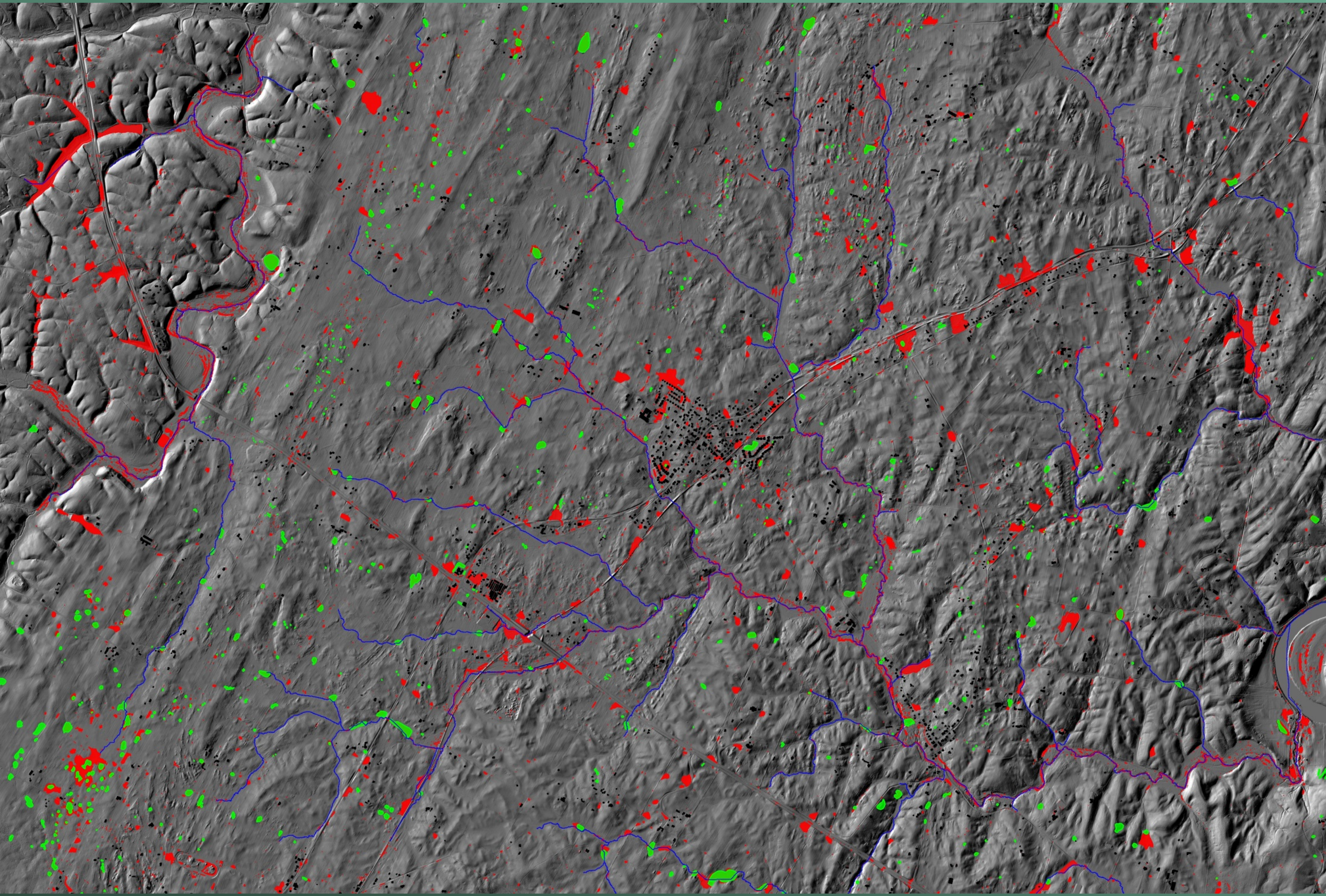
“Filled” LIDAR DEM in red, manual sinks in green, culverts in pink



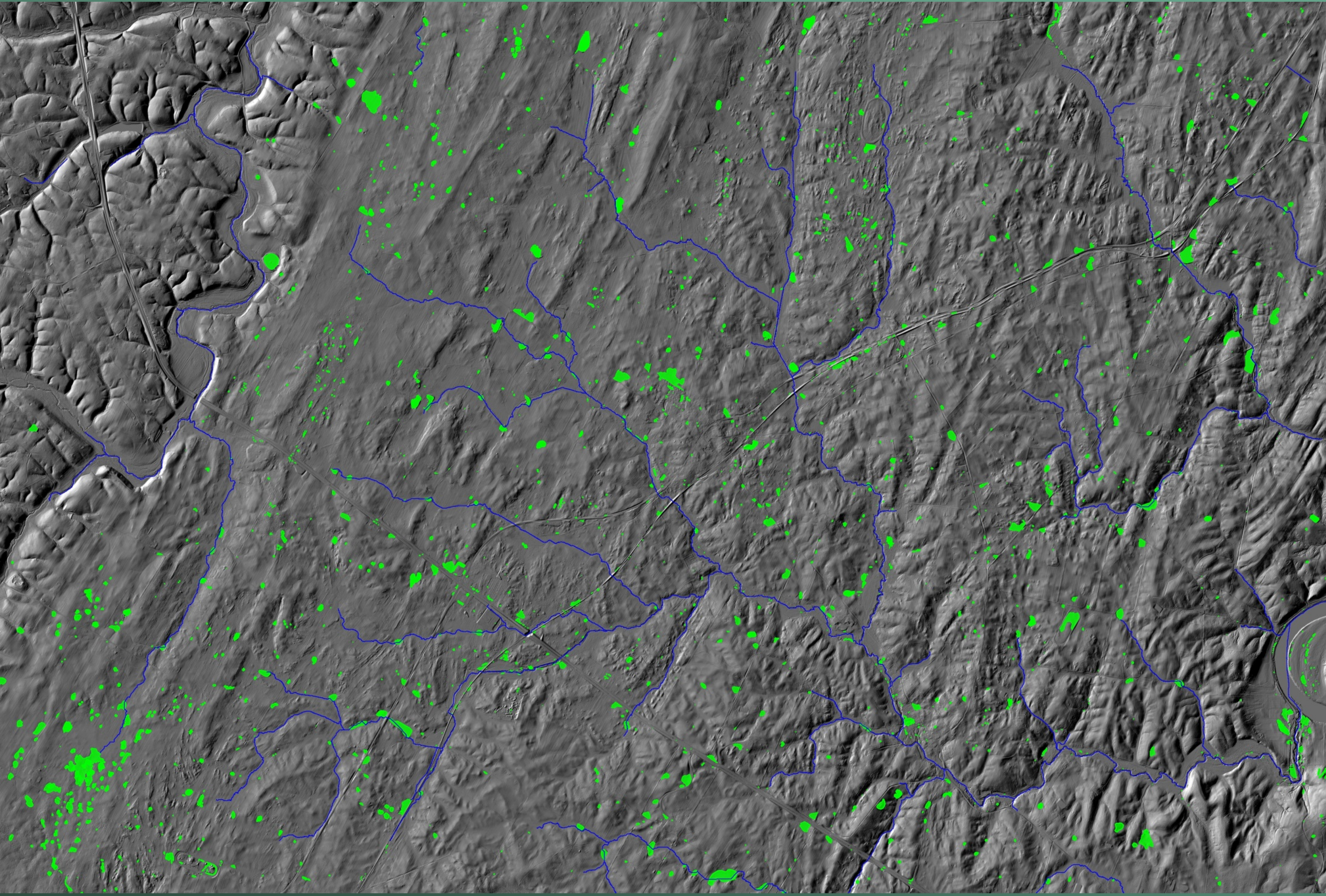
"Filled" sinks after draining, with depth, area and shape thresholds applied



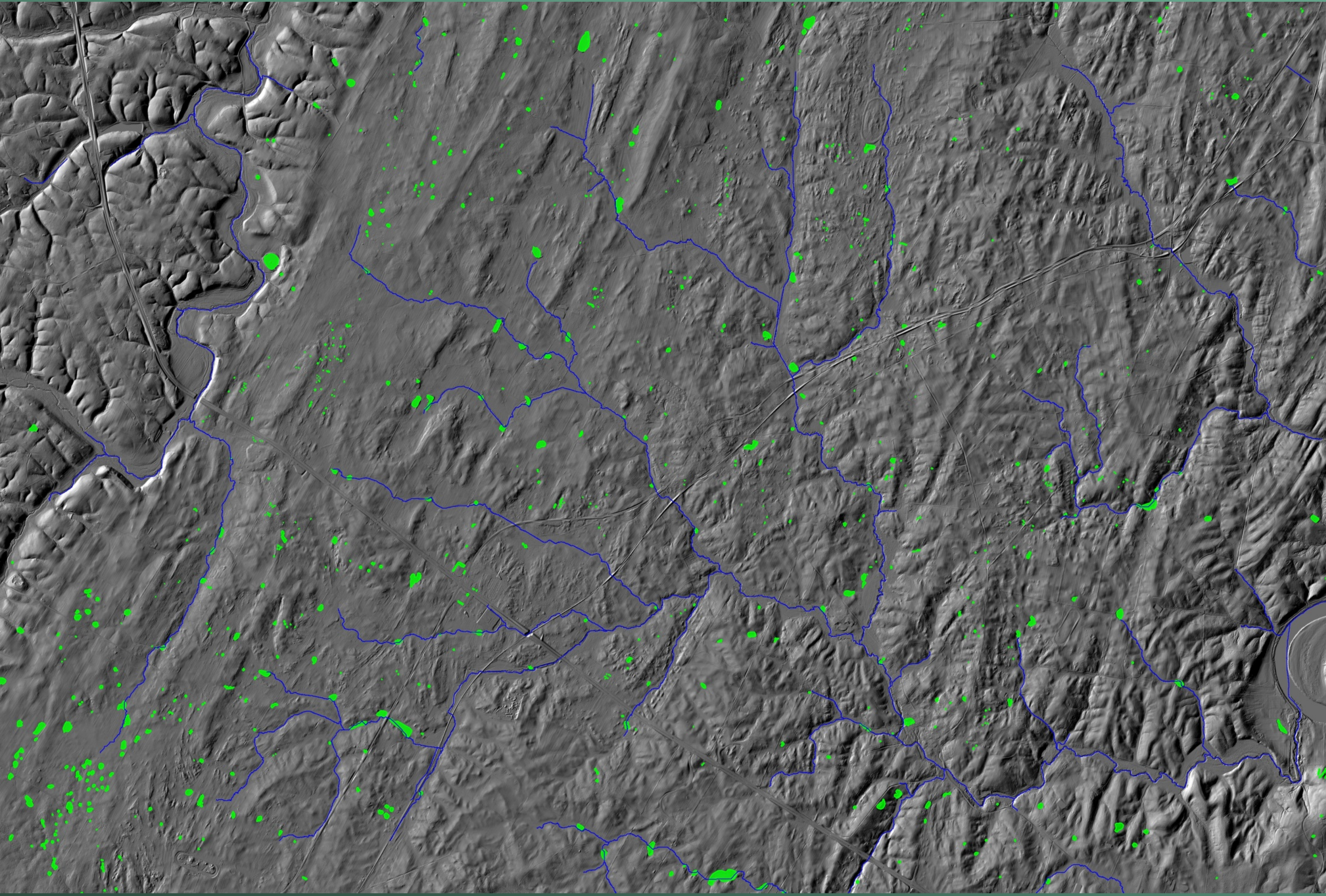
Filter out additional sinks using 2 m buffer distance from streams and structures



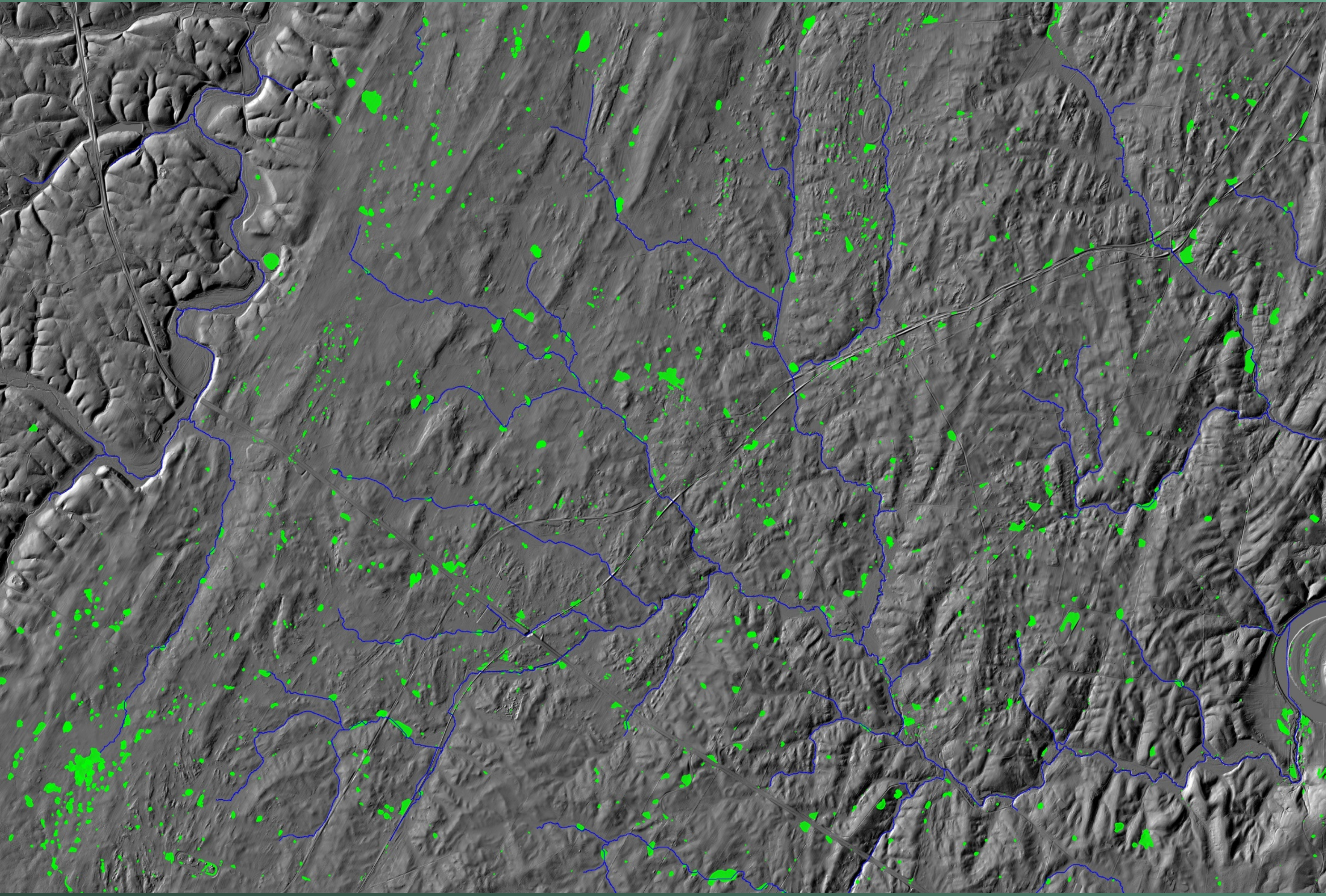
Final dataset for carbonate regions (depressions in western shales removed)



Initial manually digitized data



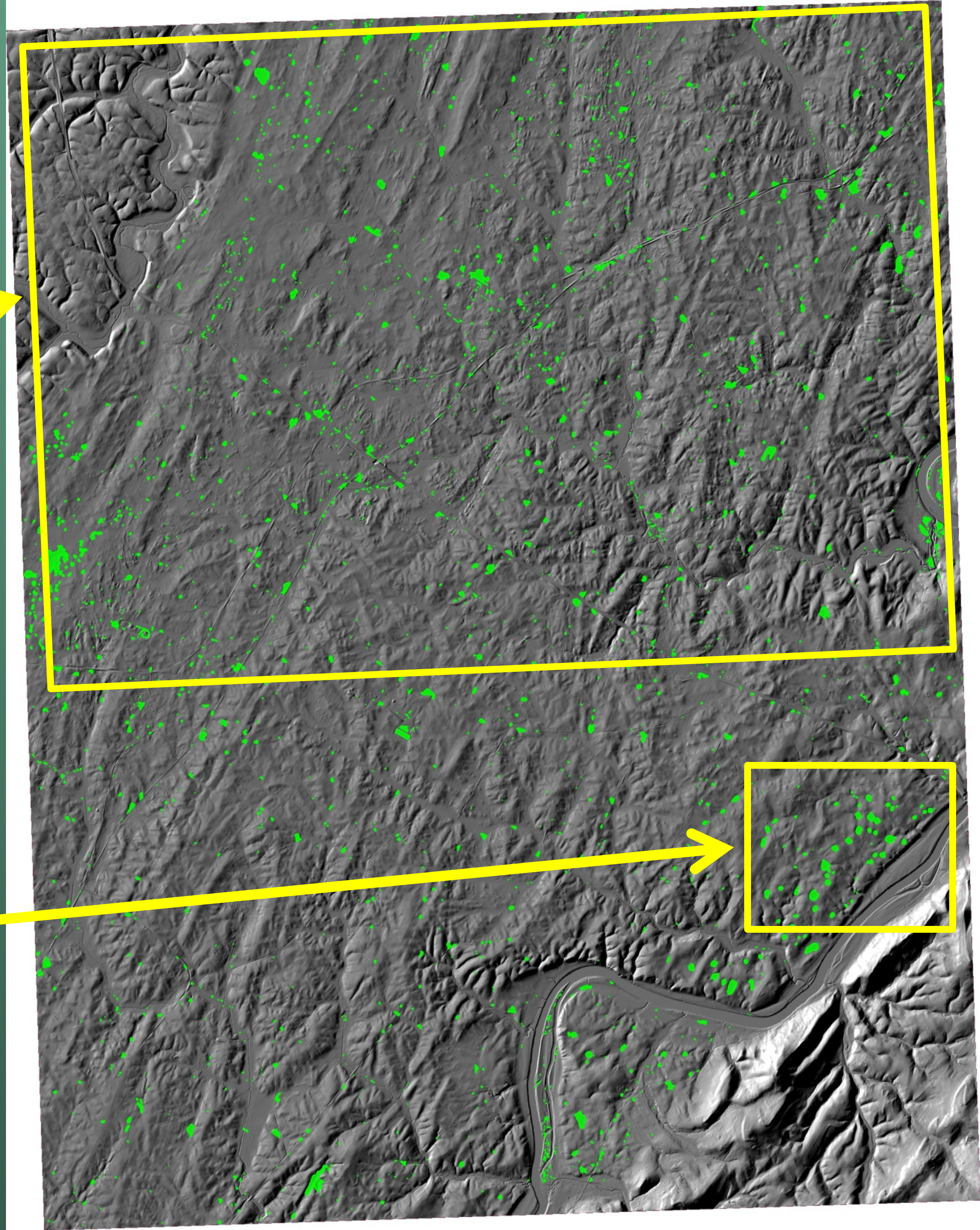
Final dataset: approximately twice as many depressions as manually outlined



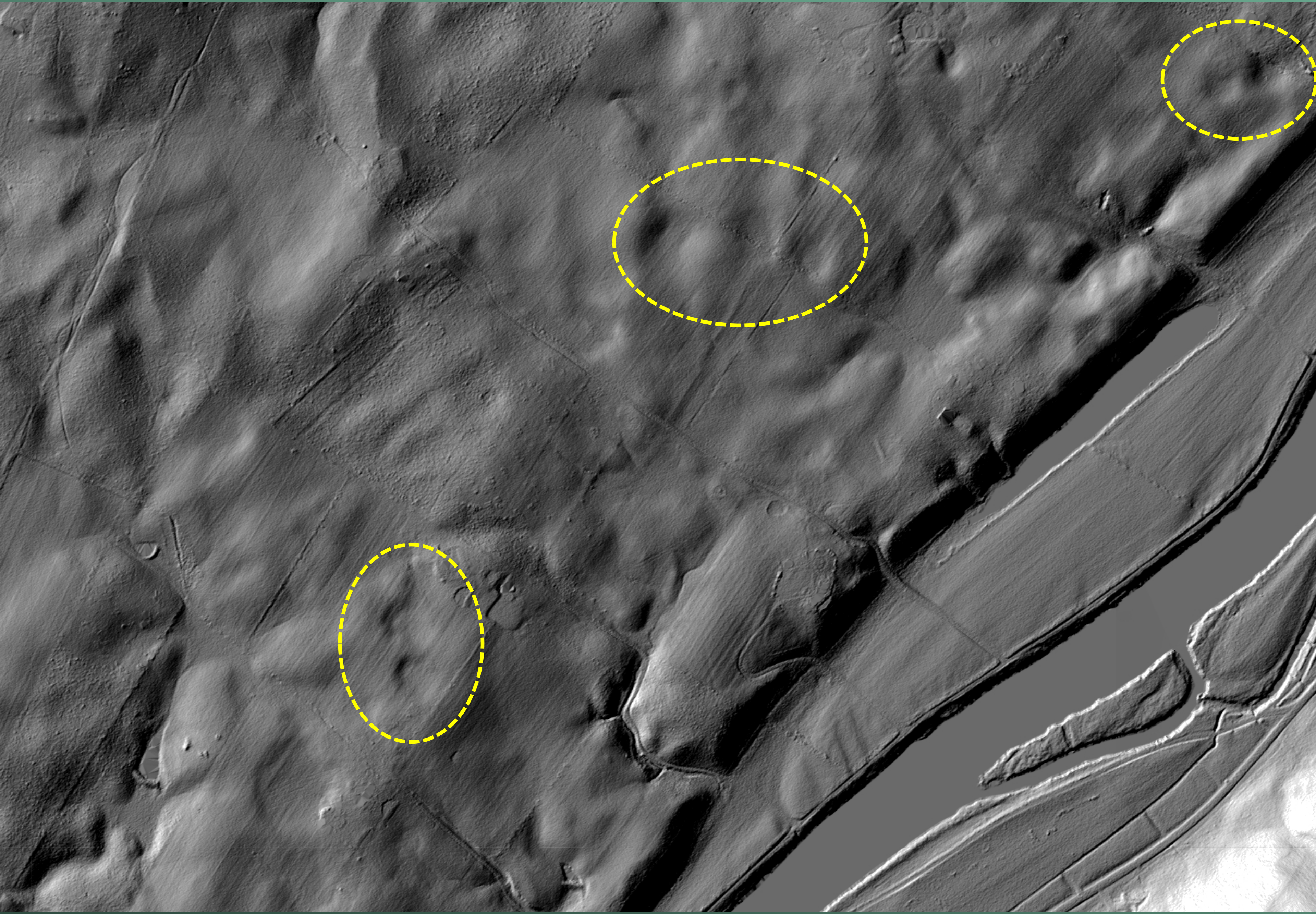
DATA VALIDATION:

Region used for analysis

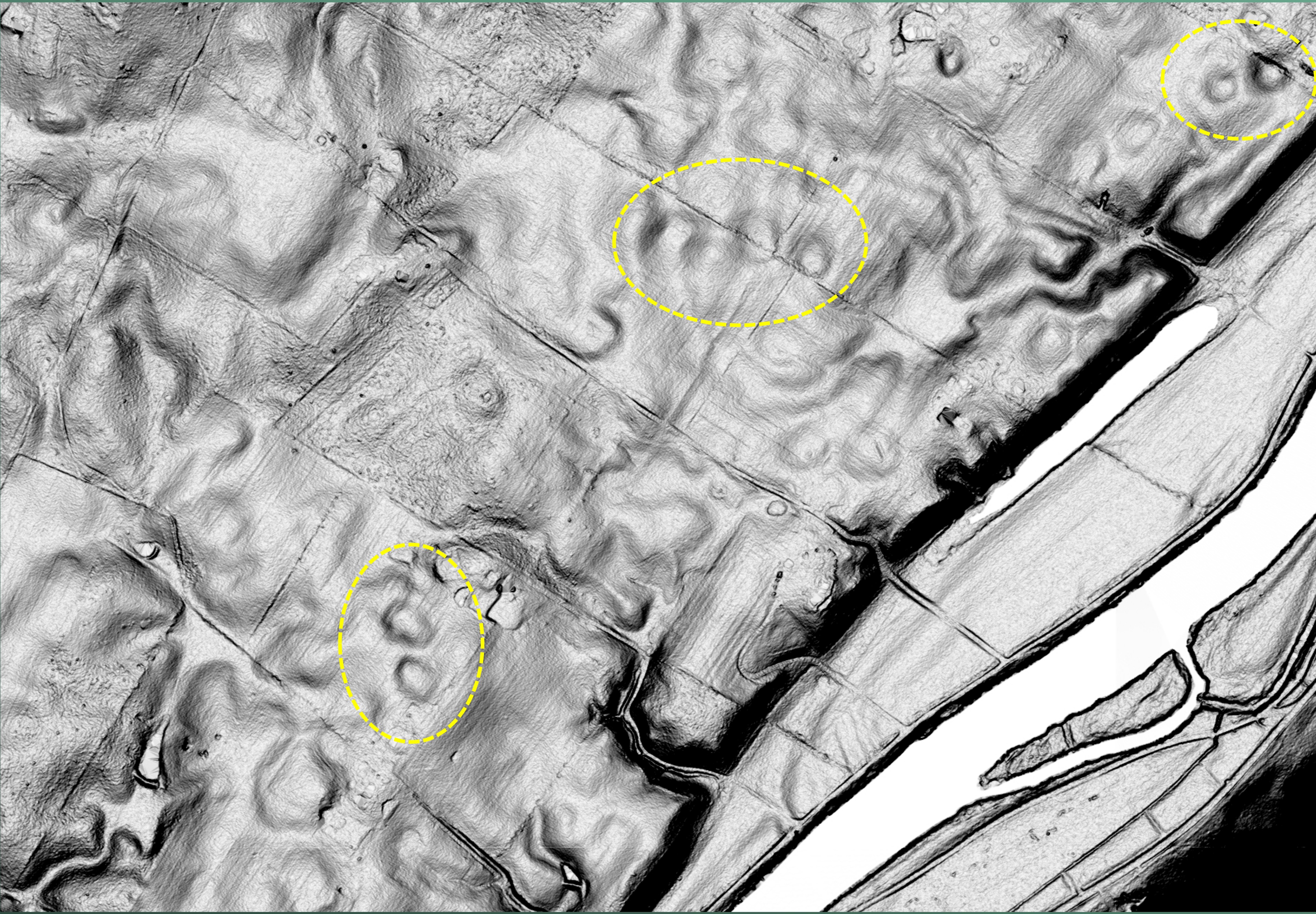
Region shown in following slides



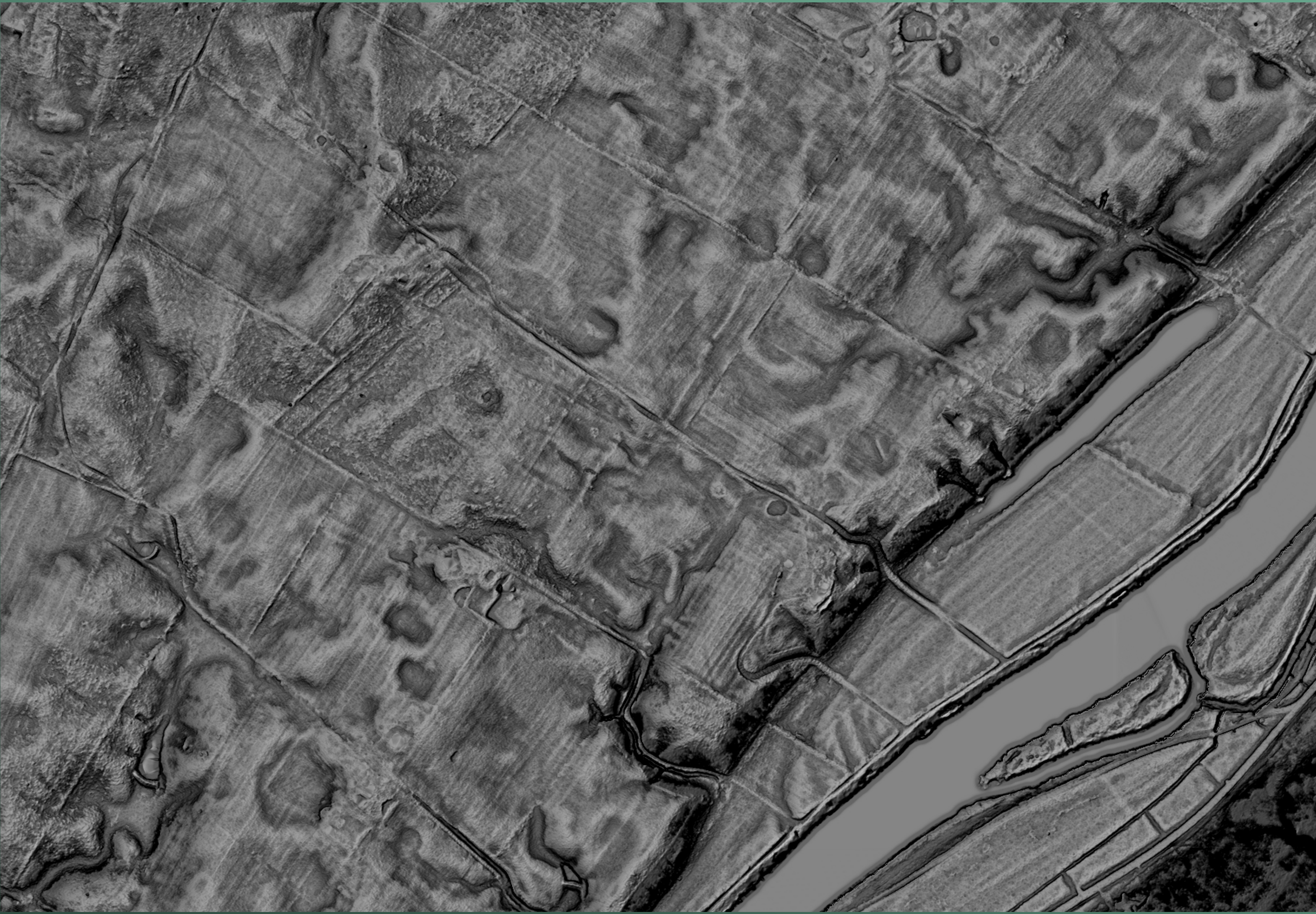
Hillshade of LIDAR



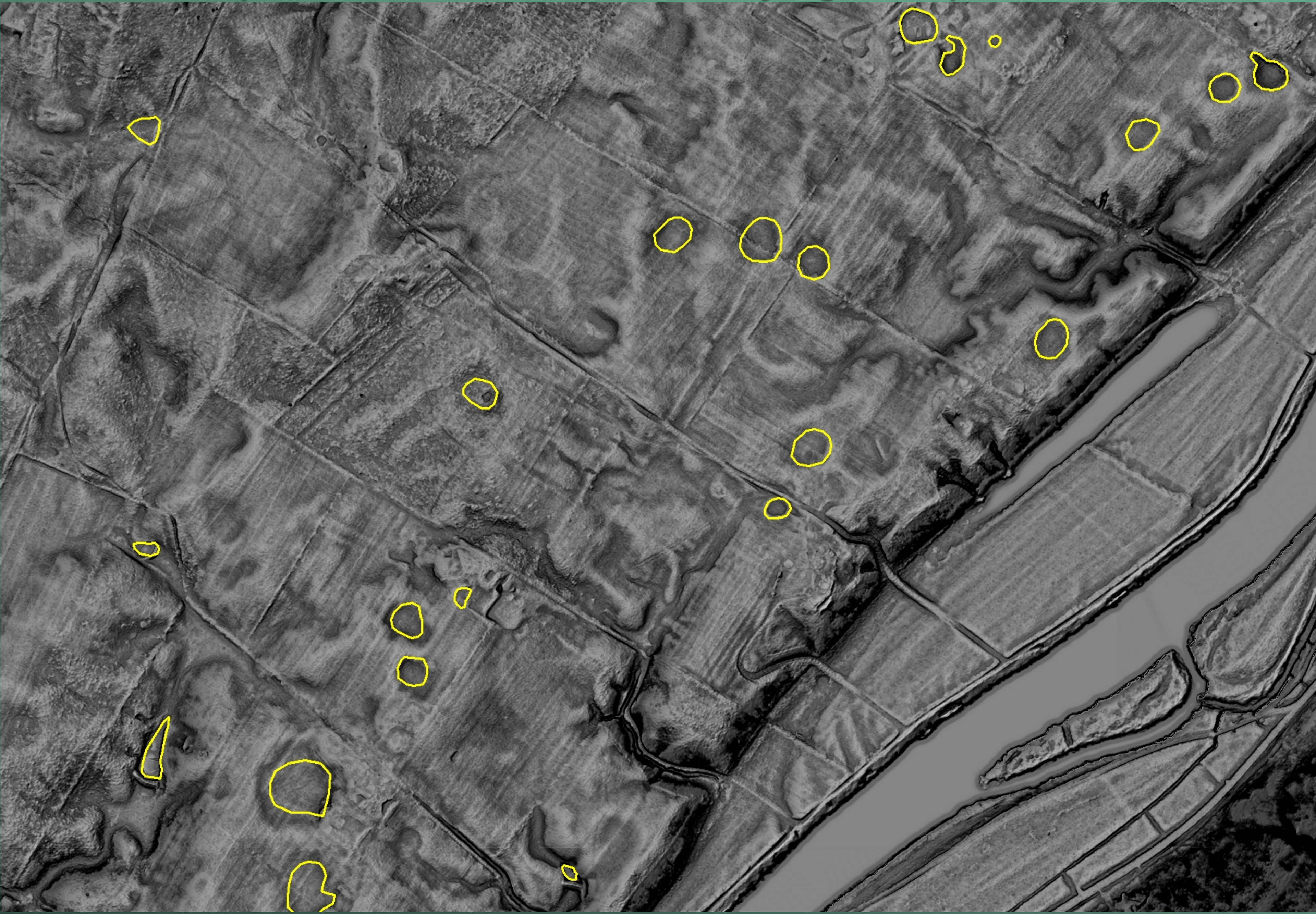
Slopeshade of LIDAR



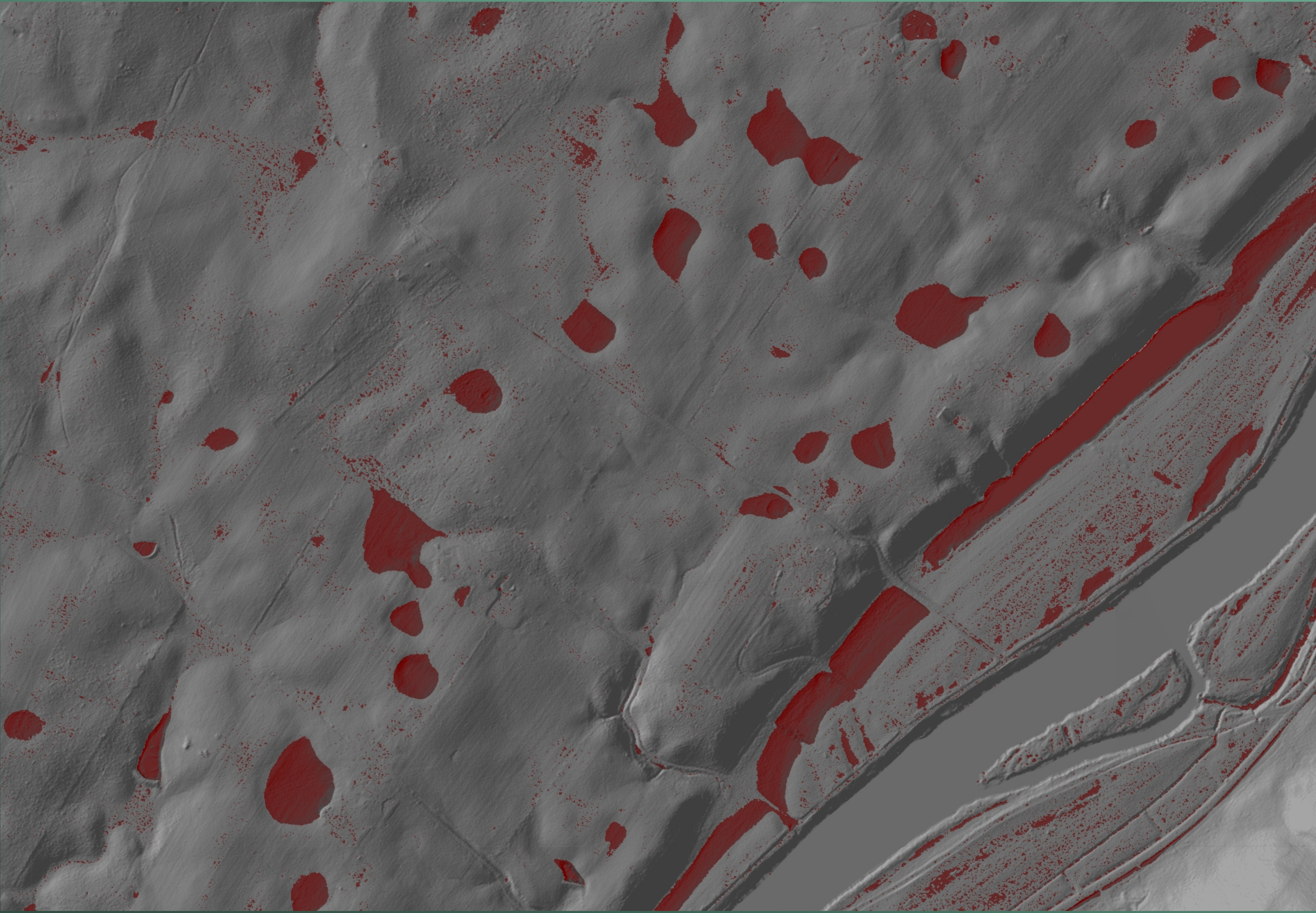
Combined slopeshade and TPI (2m inner, 10 m outer radius) of LIDAR DEM



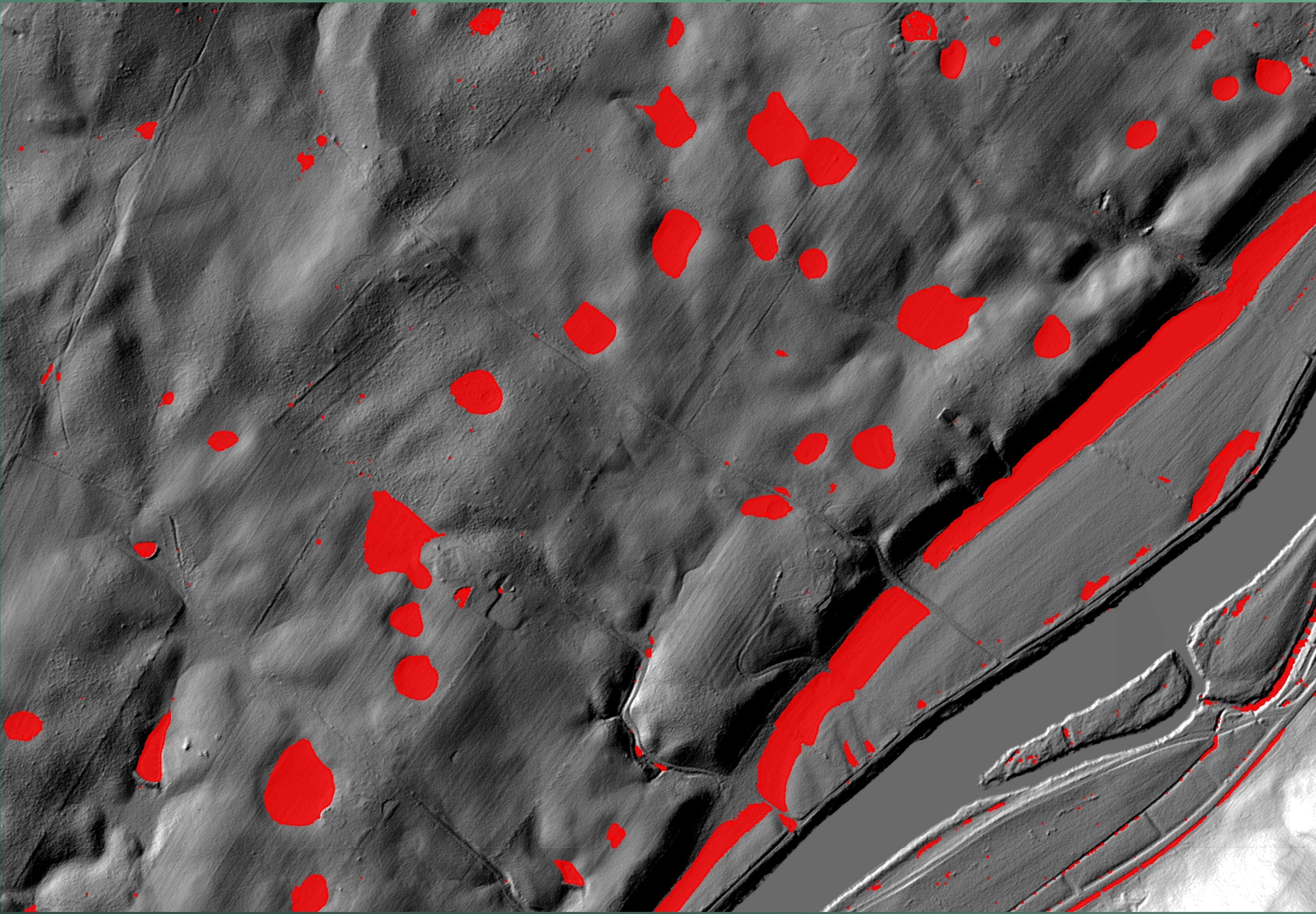
Combined slopeshade and TPI used to manually digitize depressions



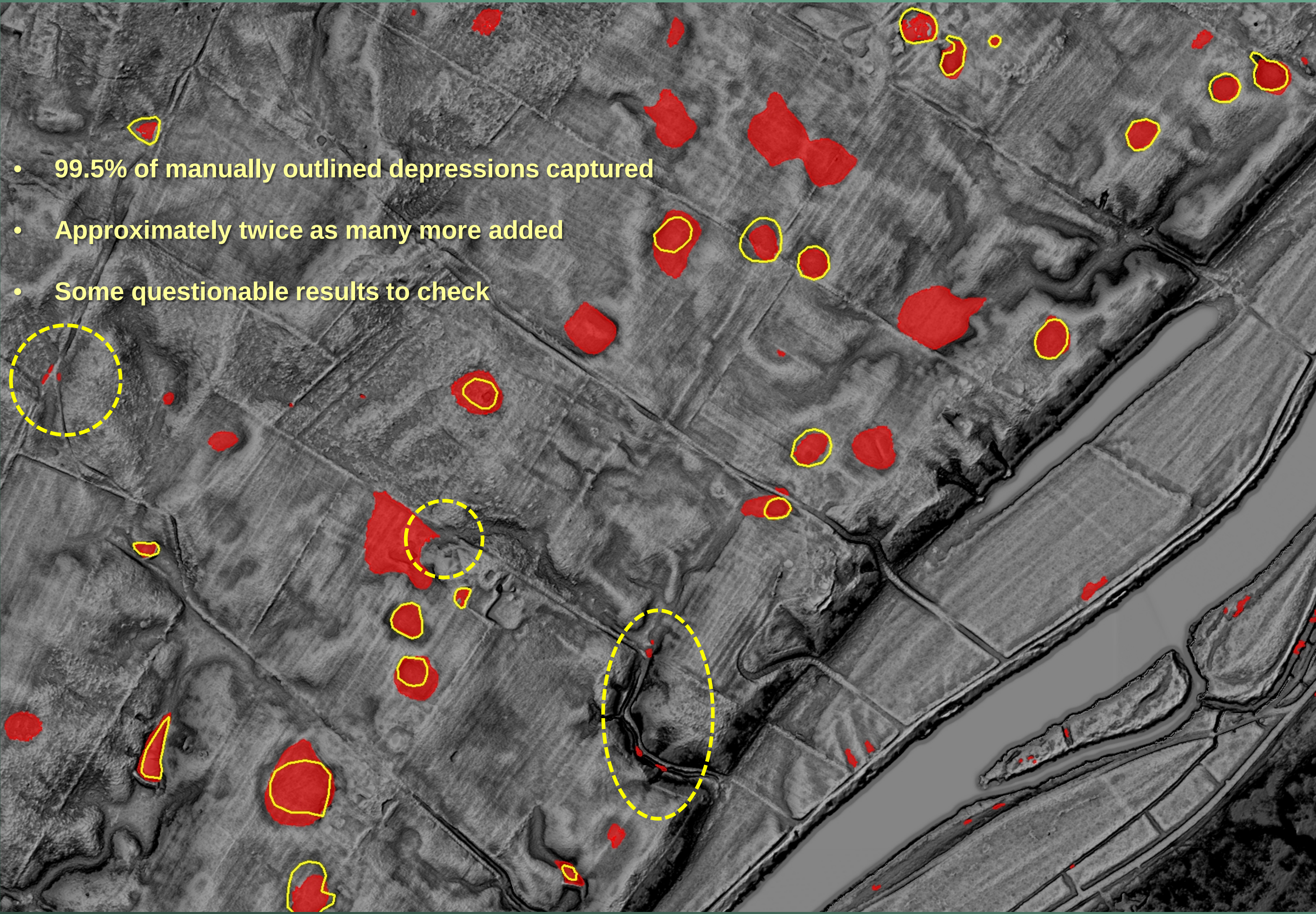
“Filled” LIDAR DEM



Polygons extracted from 'filled' DEM, with depth and area thresholds applied



Final polygons, with shape thresholds, stream and structure buffers applied



- 99.5% of manually outlined depressions captured
- Approximately twice as many more added
- Some questionable results to check

CONCLUSIONS:

- Automated detection of closed depressions is possible, but not perfect!
- Reconditioning of DEM is necessary to obtain valid results
- Mapping of culverts for appropriate flow routing is very important
- Field-checking and some manual revisions of final data is still necessary