Improving Upland Drainage Representation using LiDAR

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Introduction

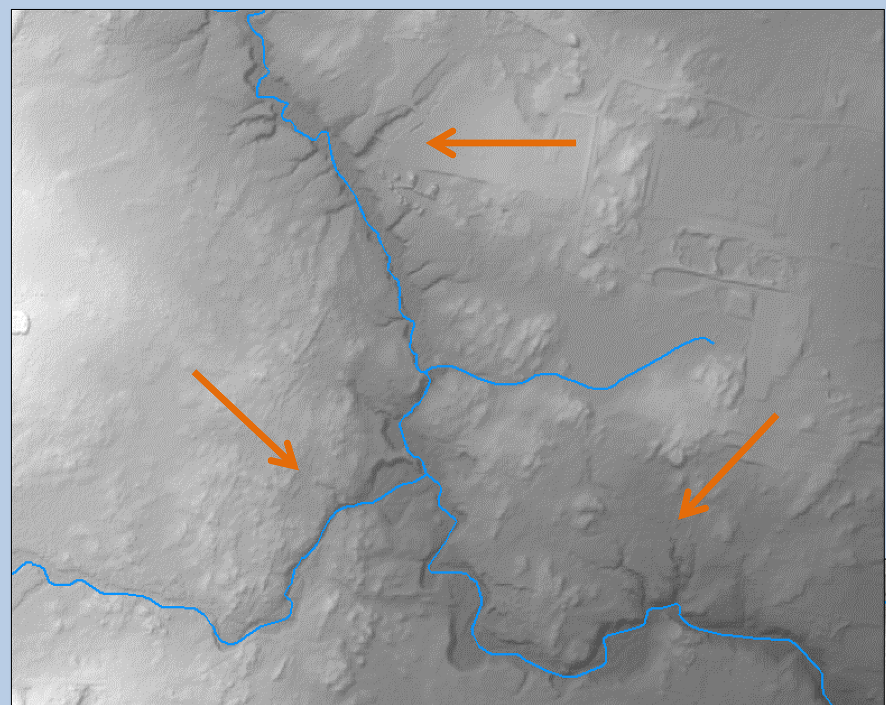

Figure 1. Partial elevation model of Webhannet River watershed in Wells, ME

Understanding surface runoff patterns is fundamental to evaluating the transport of water and materials through a landscape.

These patterns are strongly controlled by the density of upland flow paths, which are often underrepresented in published drainage network data (e.g. National Hydrography Dataset). However, high resolution elevation datasets are increasingly becoming available and present an opportunity to better quantify the extent and patterns of these first order networks.

LiDAR elevation models from low-relief Webhannet River watershed in Wells, ME (above) and high-relief Cromwell Brook watershed in Bar Harbor, ME (right) show that published NHD hydrology datasets are often incomplete, underrepresenting upland drainage networks.

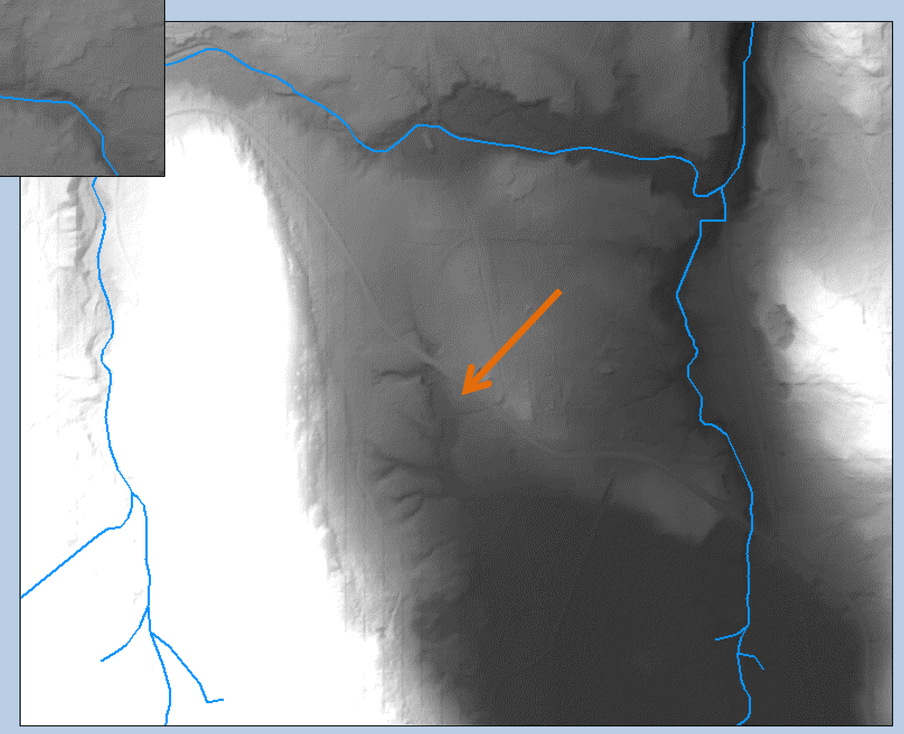

Figure 2. Partial elevation model of Cromwell Brook watershed in Bar Harbor, ME

LiDAR Data

- LiDAR point cloud and two meter resolution elevation model raster now available for all of coastal Maine extending inland to the head of tide of major rivers.
- Data of this resolution make it possible to remotely map upland drainage networks using direct detection methods that analyze small topographic variations in digital elevation models

Topographic Setting

- Uplands: a watershed's hill slopes (Fig. 3) and external links – swales and first-order streams (Fig. 4) – essentially all watershed area outside of fluvial channels, floodplains, and ponds
- Upland travel times (pre-channel flow) are an important factor in determining time of concentration for a watershed
- Our field sites:

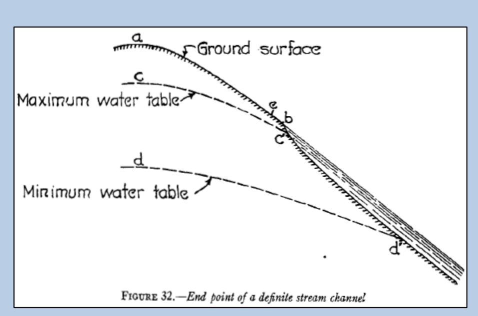

Figure 3. Idealized hill slope and channel head.[1]

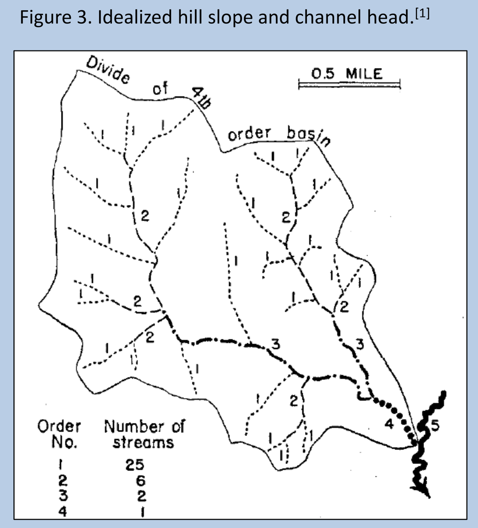

Figure 4. Stream orders within a generic watershed.[5]

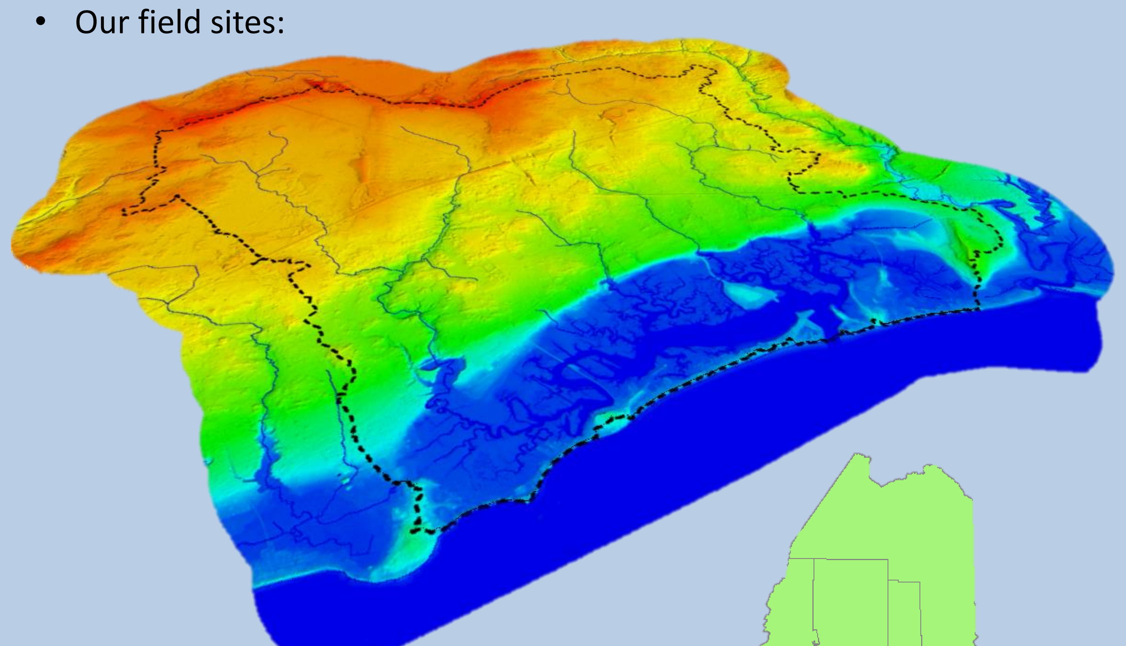

Figure 5. Webhannet River watershed in Wells, ME

Webhannet: Area 37.9 sq km
Max elevation 74m
Uplands dominated by low relief mixed forest and woody wetlands

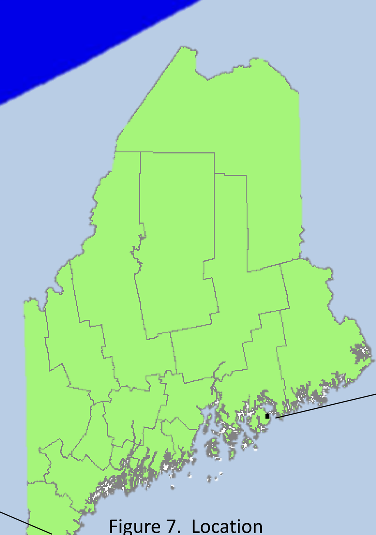

Figure 7. Location diagram (State of Maine)

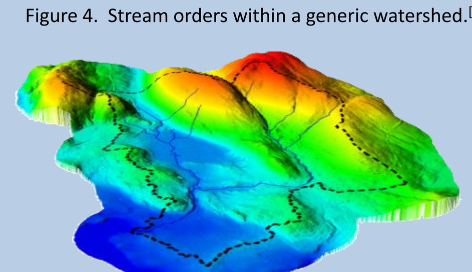

Figure 6. Cromwell Brook watershed in Bar Harbor, ME

Cromwell: Area 8.25 sq km
Max elevation 466m
Steep, high-relief uplands; main branch fed by Tarn Lake, passes through large wetland

Topographic Openness

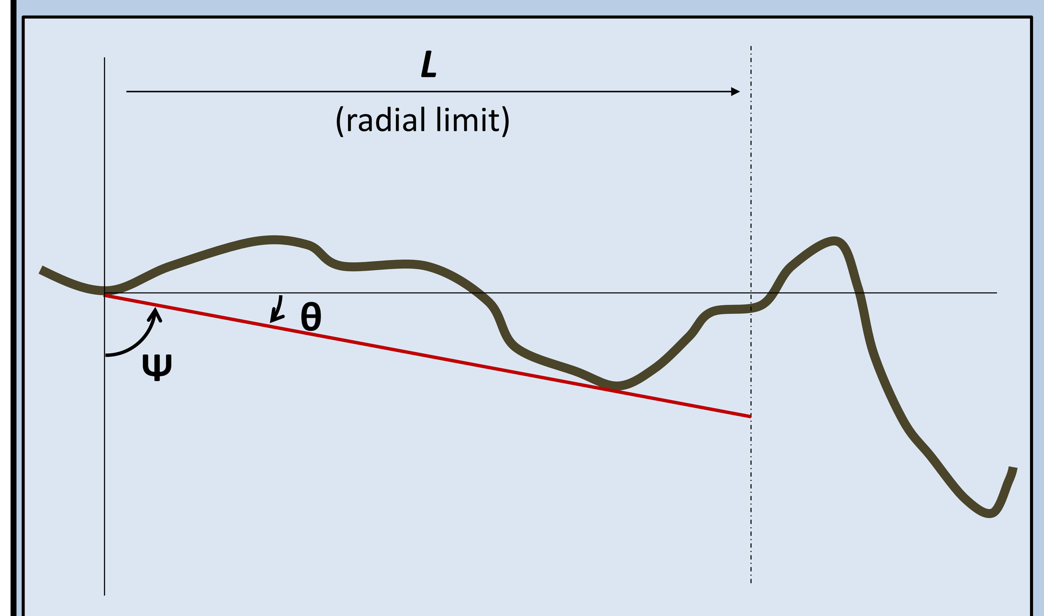

Figure 8. Diagram of negative topographic openness measurement in one direction. Adapted from Yokoyama et al, 2002

- A measure of relative prominence of a point in a landscape
- For finding depressed areas such as stream channels, negative topographic openness (Ψ) is used[5] (Fig 8)
- Because this method does not rely on initiation process relationships to estimate locations of channel heads, it has been used to map channels in terrains that are not purely fluvially shaped, including ancient channels on the surface of Mars in areas that have since been affected by cratering[3]
- Also recently used in Maryland, where it outperformed a statistical NHD densification routine and area to initiation methods at capturing channel heads in watersheds undergoing human development[2]

Calculation of Negative Topographic Openness

- For each point in a regular grid of elevation values, minimum elevation angle θ within user-selected radius L is determined (Fig 8) in each of the eight cardinal and ordinal directions.
- The negative openness angle Ψ for each direction is 90 + θ
- The eight directional openness angles are averaged to arrive at a single negative openness angle for the cell.

Python Code

- Inputs are a space-delimited text file of elevations and a user-chosen sweep radius, which is converted from map units (e.g. meters) L to number of cells R
- Calculations are performed on a moving block of (2R+1) by (2R+1), centered on the cell being calculated for
- Slope from the center cell is calculated for each cell using relative elevation and distance, then minimum slope is calculated for each direction and converted to an openness angle.
- Output is an ASCII grid of openness values

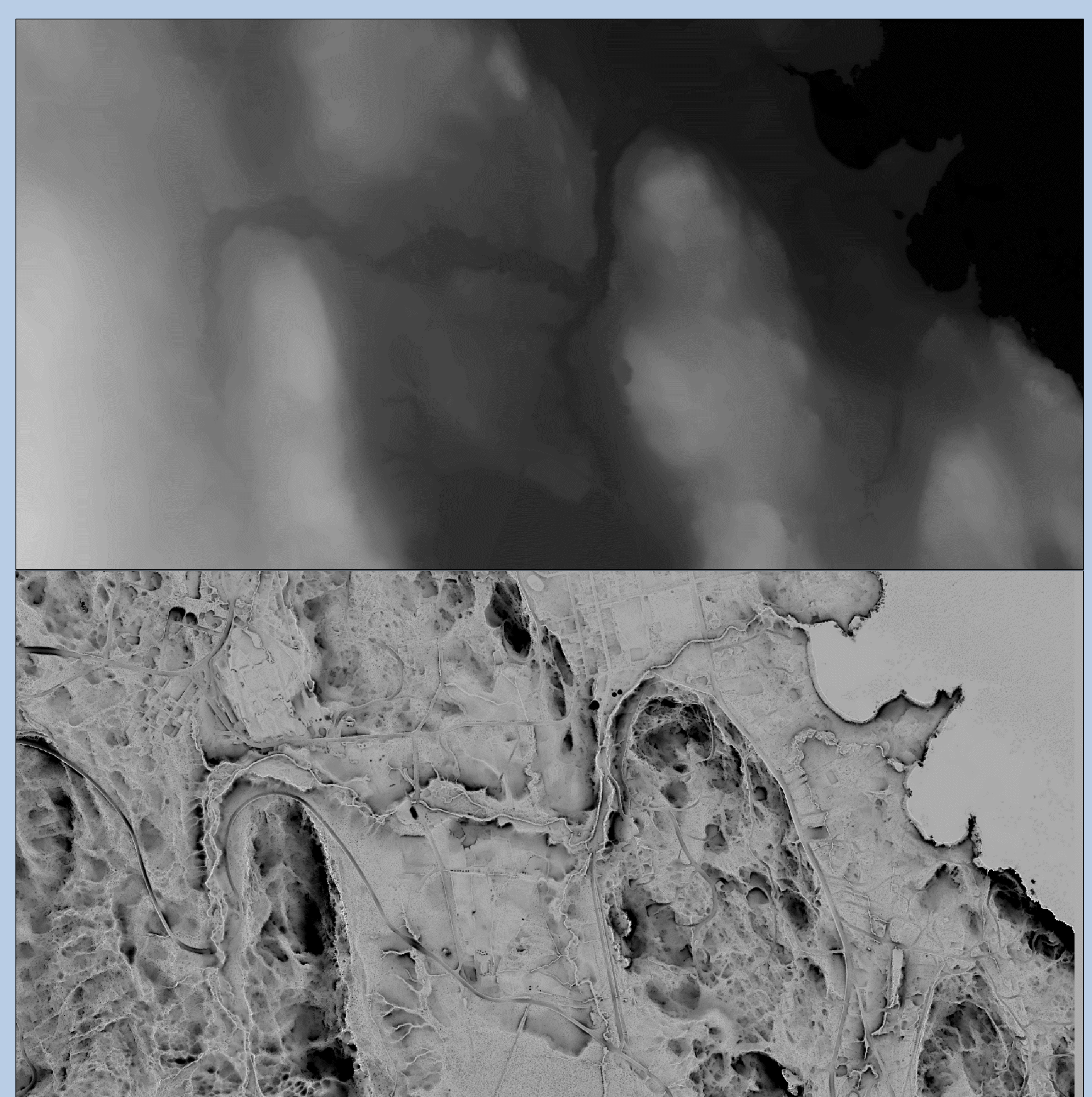

Figure 9. 2m DEM of portion of Cromwell Brook watershed (top) and negative openness grid using 100m sweep radius

Output

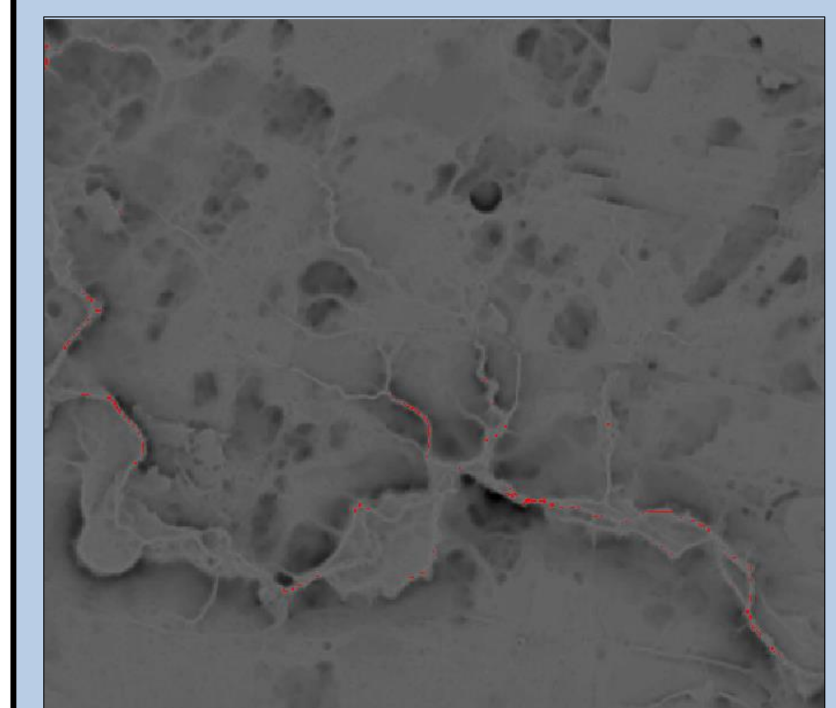

Figure 10. Cells with negative openness angles ≥ 91.5°, Webhannet River watershed.

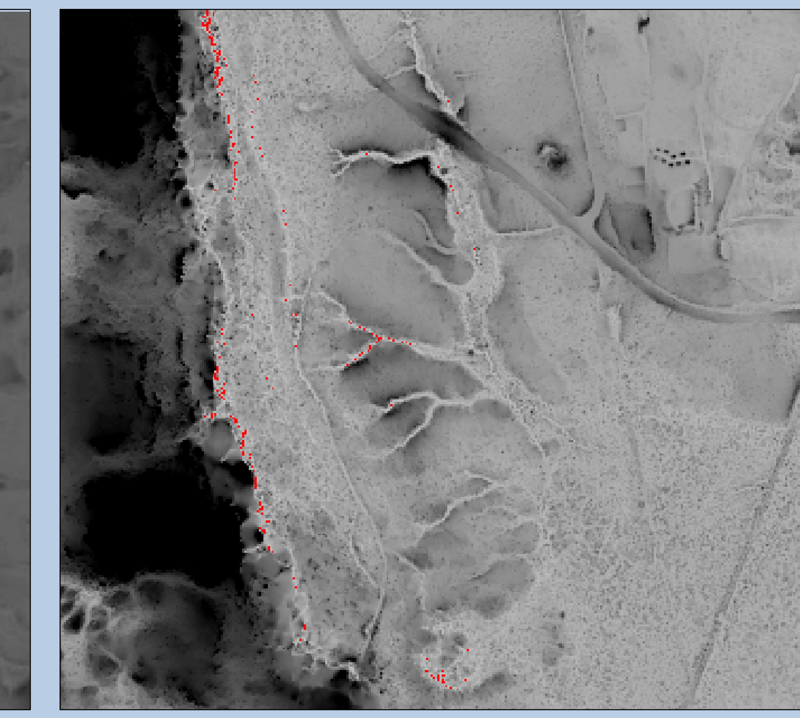

Figure 11. Cells with negative openness angles ≥ 91.5°, Cromwell Brook watershed.

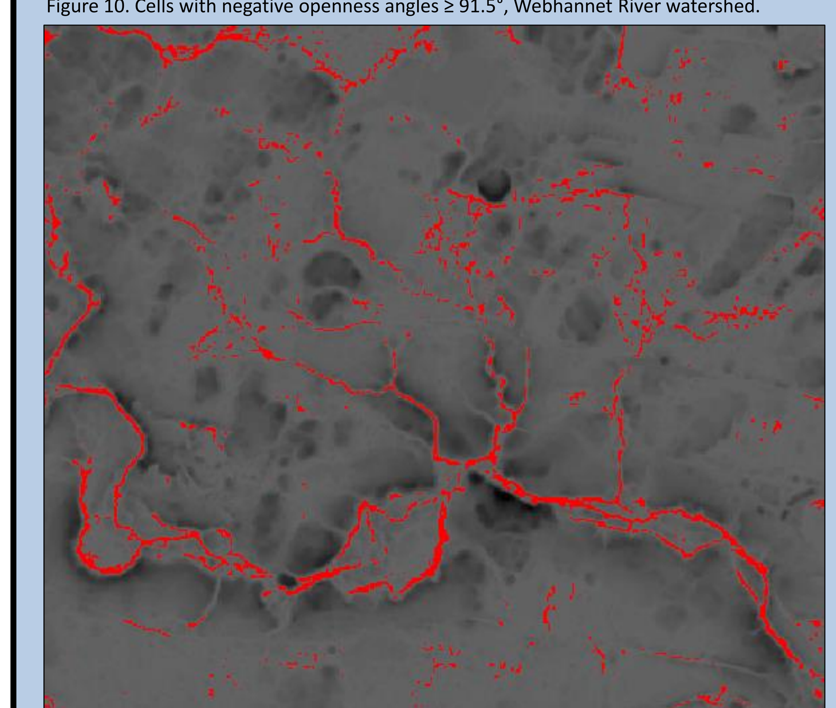

Figure 12. Cells with negative openness angles ≥ 90.0°, Webhannet River watershed.

- Jones (2013) found in Maryland that openness angles ≥ 91.5° were characteristic of in-channel pixels. Unfortunately, these parameters cannot simply be applied to our watersheds
- Using a threshold of 91.5° (Figs 10, 11) results in most in-channel pixels not being captured
- Dropping the threshold to 90.0° (Fig 12) captures channels, but also results in non-channel pixels being included
- More detailed analysis will be undertaken to fine-tune threshold for each watershed and to determine suitability of single threshold across disparate regions of Maine.

Discussion

- While it would have been convenient to discover a threshold of 91.5° was appropriate for our watersheds as well, the initial results above were not surprising
- Possible factors behind the differing results include thickness of the soil layer, climate / rainfall differences, and the glacial carving that shaped Maine's landscape
- Additionally, the effect of the length of the sweep radius must be considered. 100m was used in Maryland; in our watersheds, it is not uncommon for channel heads to fall within that distance of each other
- Still, overall performance of the python openness code is very satisfactory, and the method is able to locate modified conveyances (Fig 13)
- Future work will focus on the use of direct detection-derived drainage networks to investigate changes in upland surface drainage patterns with urbanization

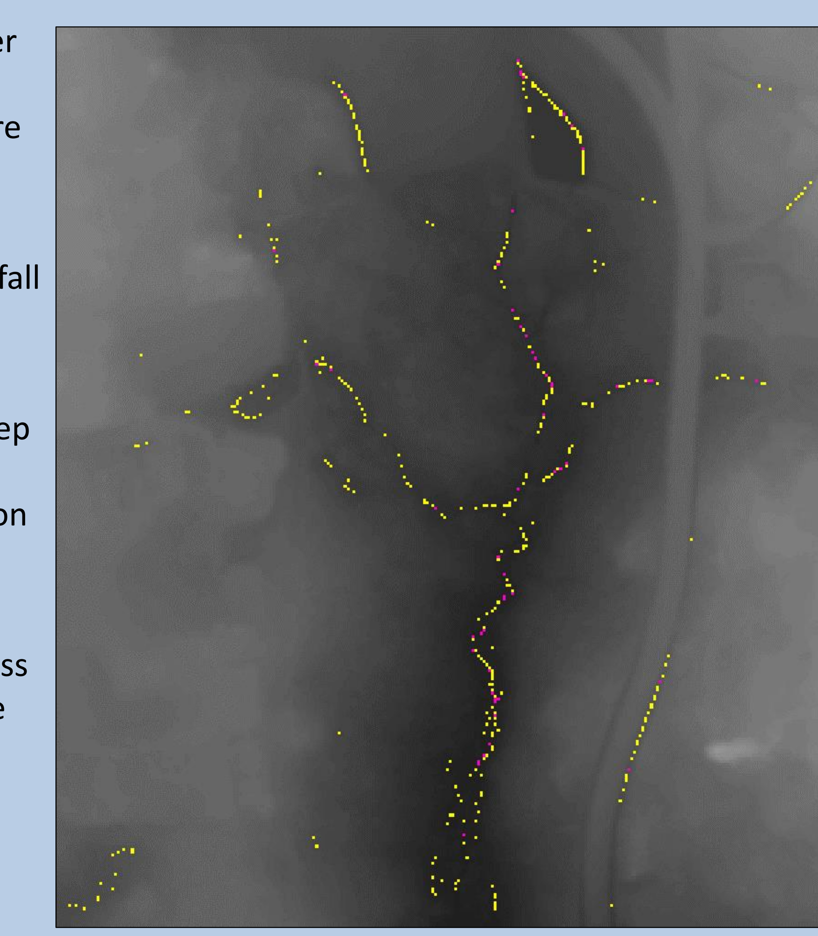

Figure 13. Openness output for human-altered conveyance on University of Maine campus, Orono, ME. All three branches begin with pipe outlets.

References: [1] Horton (1945); [2] Jones (2013); [3] Molloy & Stepinski (2007); [4] Strahler (1957); [5] Yokoyama et al. (2002)

Acknowledgements:
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