Storm Water Damage Risk Assessment along the South Carolina Heritage Trail

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Abstract

Storm water damage in the form of rill formation across the South Carolina Botanic Gardens (SCBG) Heritage Trail has been modelled as a function of contributing area using D8 and D-infinity flow direction algorithms on a preprocessed LiDAR-derived elevation raster grid. D8 was also applied over a set of stochastic Monte Carlo simulations (n=500) representing elevation error. The mean simulated, D8, and D-infinity contributing area was calculated for each 5’×5’ cell along the trail. The receiver operating characteristic (ROC) is compared for each of the three outputs.

Introduction

Since the inception of the SCBG Heritage Trail, storms have caused extensive damages: soil loss, sedimentation, trail washout, death of plant specimens, and destruction of several bridges. Conservation practices such as berms and retention basins have been installed in the immediate vicinity to increase resilience. However, the intensity of storms has been compounded by broad scale management effects which impair the watershed – decreased infiltration and increased connectivity (Calabria, English, and Sawyer 2006).

Since the Trail was opened to the public in spring 2014, two storm events have caused notable damage. The damage is easily observed in the form of rills eroding the Trail. The rills were readily distinguished from surrounding areas of the Trail because they expose distinct layers of gravel and granite fines beneath the compacted surface of Chapel Hill stone.

The goal of this work is to model rill formation risk as a function of contributing area along the Heritage Trail. Contributing area is estimated using flow routing algorithms on high-resolution LiDAR elevation data. Models are validated using ROC analysis by comparison to observed rill formation.

Data Sources

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation</td>
<td>Raster Grid</td>
<td>1 m horizontal accuracy at 95% C.I., RMSE = 39 ft</td>
</tr>
<tr>
<td>Trail, Berms, and Rills</td>
<td>GPS and Photogrammetry</td>
<td>Digitized to Vector, 10 ft expected accuracy</td>
</tr>
<tr>
<td>Culverts</td>
<td>CAD file</td>
<td>Contains layers of underground storm drains</td>
</tr>
</tbody>
</table>

Methods

Pre-Processing the Elevation Grid
- Culverts lowered by 1 ft. This can improve the representation of water flow across roads.
- Streams delineated with contributing area greater than 19,000 cells (4.4ha). Lowered by 3 ft to represent the channel (Saunders 1999).
- Berms were raised by 2 ft.
- Sinks removed by filling (Zandbergen 2010).

D8 Flow Direction Algorithm (Jenson & Domigue 1988)
- Routes surface flow from each cell to the single neighboring cell of steepest downhill slope.
- Simple, widely cited, and readily available in the most commonly used software.
- Fails to represent divergent flow patterns and produces up to 22.5deg error for each cell.

D-infinity Algorithm (Tarboton 1997)
- In a square grid raster with cell width w, the slope across a facet j can be expressed as a vector (s1, s2) where:
  \[ s_1 = (x_0 - x_2) / w \]
  \[ s_2 = (y_0 - y_2) / w \]
- Facet slope direction a and magnitude s are determined:
  - if \( a'^2 < \frac{\pi}{4} \) then \( s = s_1 \)
  - if \( a'^2 > \frac{\pi}{4} \) then \( s = (s_1 - s_2) \sqrt{2w} \)
- Then the D-infinity flow direction is across the downhill facet with the greatest s. The flow is dispersed if \( 0 < a < \frac{\pi}{2} \).

Stochastic Monte Carlo Error Simulations (Zandbergen 2011)
- Spatial Autocorrelation - normally distributed error grids filtered using a moving kernel of 2 cell widths (Figure 7).
- Root Mean Square Error - Error simulations calibrated to a standard deviation equal to the reported RMSE.
- Aggregate Output - Contributing area using the D8 algorithm for each simulation was averaged.

Results & Discussion

The Monte Carlo model performed slightly better than the D-infinity model, and both performed better than D8. Considering the complexity of implementation and the considerable processing time of the Monte Carlo method, the D-infinity model may be more suitable for practical applications. These results indicate that relatively simple storm water damage risk assessments can be performed using flow routing algorithms on LiDAR derived elevation datasets modified with relevant infrastructure. Location and sizing of best management practices can be facilitated by these methods.

Works Cited

\[ p = 1 - 4 \alpha \pi \]

\[ p = 4 \alpha \pi \]

\[ z_0 \]

\[ z_1 \]

\[ z_2 \]

\[ \text{facet I, II, III, IV, V, VI, VII, VIII} \]

\[ r' \]

\[ s = (z_0 - z_1)/w \]

\[ s = (z_0 - z_2)/\sqrt{2w^2} \]

\[ \text{up to 22.5° error} \]

\[ u \text{ up to 22.5° error} \]