Terrain Analysis Using Digital Elevation Models

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http://www.engineering.usu.edu/dtarb
Outline

- Primary Digital Elevation Model (DEM) analysis
  - Flow Directions
  - Drainage Area
  - Slope
  - Channel network and watershed delineation

- Secondary DEM analysis
  - (Terrain stability mapping)
  - Weighted drainage area accumulation (equivalent clearcut analysis)

- Software
Related activities

- Distributed hydrologic modeling.
- Channel network geomorphology and mapping using digital elevation models.
- Terrain stability mapping and GIS use in hydrologic modeling. (SINMAP)
- Snowmelt processes and models.
- GIS in Water Resources Online Course (with David Maidment, U. of Texas)

For more detail, papers and software see http://www.engineering.usu.edu/dtarb/
SINMAP

Terrain Stability Mapping

\[ \theta = \tan^{-1} S \]

\[ D = h - h_w \]

\[ FS = \frac{C + \cos \theta \left[ 1 - wr \right] \tan \phi}{\sin \theta} \]
Elevation Surface — the ground surface elevation at each point

Digital Elevation Model — A digital representation of an elevation surface. Examples include a (square) digital elevation grid, triangular irregular network, set of digital line graph contours or random points.
The USGS National Elevation Dataset (NED)  
http://edcmts12.cr.usgs.gov/ned/  
Highest-resolution, best-quality elevation data available across the United States merged into a seamless raster format. 1 arc-second cells (1:24,000 scale).

National Hydrography Dataset (NHD)  
http://nhd.usgs.gov/  
The stream network and water bodies of the United States organized by 8-digit hydrologic cataloging units.
Digital Elevation Grid — a grid of cells (square or rectangular) in some coordinate system having land surface elevation as the value stored in each cell.

Square Digital Elevation Grid — a common special case of the digital elevation grid
### Direction of Steepest Descent

<table>
<thead>
<tr>
<th></th>
<th>67</th>
<th>56</th>
<th>49</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>52</td>
<td>48</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>58</td>
<td>55</td>
<td>22</td>
</tr>
</tbody>
</table>

Slope: \[
\frac{67 - 48}{30 \sqrt{2}} = 0.45
\]

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Slope: \[
\frac{67 - 52}{30} = 0.50
\]
Digital Elevation Model Based Channel Network Delineation

Eight direction pour point model D8

Grid network

Drainage Area
Watershed Draining to This Outlet
Streams from 1:250,000 blue lines
100 grid cell constant support area threshold stream delineation

Constant support area threshold
100 grid cell
9 x 10E4 m^2
200 grid cell constant support area based stream delineation

constant support area threshold
200 grid cell
18 x 10E4 m^2
Delineation of Channel Networks and Subwatersheds

500 cell threshold

1000 cell threshold
How to decide on support area threshold?
Curvature based stream delineation
Topographic Texture and Drainage Density

Sunland, CA

Same scale, 20 m contour interval

Driftwood, PA

Sunland, CA

0 1 Kilometers

0 1 Kilometers
Canyon Creek, Trinity Alps, Northern California.
Gently Sloping Convex Landscape

From W. E. Dietrich
Strahler Stream Order

• most upstream is order 1
• when two streams of a order i join, a stream of order i+1 is created
• when a stream of order i joins a stream of order i+1, stream order is unaltered
Slope Law

Rs = 1.7

Order

Mean Stream Slope
Constant Stream Drops Law

\[ \text{Rd} = 0.944 \]
Stream Drop
Elevation difference between ends of stream

Note that a “Strahler stream” comprises a sequence of links (reaches or segments) of the same order.
Suggestion: Map channel networks from the DEM at the finest resolution consistent with observed channel network geomorphology ‘laws’.

- Break in constant stream drop property
- Break in slope versus contributing area relationship
- Physical basis in the form instability theory of Smith and Bretherton (1972), see Tarboton et al. 1992
Statistical Analysis of Stream Drops

Elevation Drop for Streams

Strahler Order vs. Drop (meters)

- Drop
- Mean Drop
### T-Test for Difference in Mean Values

<table>
<thead>
<tr>
<th></th>
<th>Order 1</th>
<th></th>
<th>Order 2-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean X</td>
<td>72.2</td>
<td>Mean Y</td>
<td>130.3</td>
</tr>
<tr>
<td>Std X</td>
<td>68.8</td>
<td>Std Y</td>
<td>120.8</td>
</tr>
<tr>
<td>Var X</td>
<td>4740.0</td>
<td>Var Y</td>
<td>14594.5</td>
</tr>
<tr>
<td>Nx</td>
<td>268</td>
<td>Ny</td>
<td>81</td>
</tr>
</tbody>
</table>

T-test checks whether difference in means is large (> 2) when compared to the spread of the data around the mean values.
Constant Support Area Threshold

Strahler Stream Drop (m) vs Strahler Stream Order

Support Area threshold (30 m grid cells)

<table>
<thead>
<tr>
<th>Drainage Density (km(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3</td>
</tr>
<tr>
<td>2.3</td>
</tr>
<tr>
<td>1.7</td>
</tr>
<tr>
<td>1.4</td>
</tr>
<tr>
<td>1.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>t statistic for difference between lowest order and higher order drops</th>
</tr>
</thead>
<tbody>
<tr>
<td>-8.8</td>
</tr>
<tr>
<td>-5</td>
</tr>
<tr>
<td>-1.8</td>
</tr>
<tr>
<td>-1.1</td>
</tr>
<tr>
<td>-0.72</td>
</tr>
</tbody>
</table>
200 grid cell constant support area based stream delineation

constant support area threshold
200 grid cell
18 x 10E4 m^2
Local Curvature Computation
Contributing area of upwards curved grid cells only
Upward Curved Contributing Area Threshold

<table>
<thead>
<tr>
<th>Upward curved support area threshold (30 m grid cells)</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage Density (km(^{-1}))</td>
<td>2.2</td>
<td>1.8</td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td>t statistic for difference between lowest order and higher order drops</td>
<td>-4.1</td>
<td>-2.2</td>
<td>-1.3</td>
<td>-1.2</td>
</tr>
</tbody>
</table>
Curvature based stream delineation
Equivalent Clearcut Analysis
Software (TauDEM)

Functionality

- Pit removal (standard flooding approach)
- Flow directions and slope
  - D8 (standard)
  - $D_\infty$ (Tarboton, 1997, WRR 33(2):309)
  - Flat routing (Garbrecht and Martz, 1997, JOH 193:204)
- Drainage area ($D_8$ and $D_\infty$)
  - Weighted drainage area accumulation (e.g. for ECA)
- Network and watershed delineation
  - Support area threshold/channel maintenance coefficient (Standard)
  - Combined area-slope threshold (Montgomery and Dietrich, 1992, Science, 255:826)
**TauDEM Software Architecture**

- **ESRI ArcGIS 8.1** (Awaiting release) (under Development using beta)
- **VB GUI applications** (under development)
- **ArcView Extension Avenue Scripts** (SINMAP)
- **Standalone command line applications**
- **C++ COM interface** (under development)
- **DLL interface**
- **TauDEM C++ library**
- **Fortran (legacy) components**
- **Grid read/write interface**
- **ESRI gridio API** (Spatial analyst)
- **Vector shape files**
- **ASCII text grid files**
- **ESRI Binary Grid Files**

Completed software available from [http://www.engineering.usu.edu/dtarb/](http://www.engineering.usu.edu/dtarb/)
Conclusions

- Terrain analysis using digital elevation models provides considerable capability useful in hydrologic analysis.
- In channel network delineation use consistency with geomorphology laws to adapt support area threshold and drainage density to the natural texture of the topography.
- Use curvature based methods to allow channel network drainage density to be spatially variable to adapt to variable topographic texture.
Are there any questions?