Key Spatial Analysis Concepts from Exercise 3

- Contours and Hillshade to visualize topography
Zonal Average of Raster over Subwatershed

Elevation - Raster

Join

Table

Zoneelev

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Subwatershed Precipitation by Thiessen Polygons

- Thiessen Polygons from precip points
- Intersect with Subwatersheds
- Evaluate $A \times P$ Product
- Summarize by subwatershed

\[
P_i = \frac{\sum_k A_{ik} P_k}{\sum_k A_{ik}}
\]
What Is Involved?

Add Field
Field Calculator to Multiply A and P

Field Calculator

Field Calculator

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<th>FID_Thi esse</th>
<th>stname</th>
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Summarize (Sum) for unique subwatersheds (by HydroID)

\[ P_i = \frac{\sum_k A_{ik} P_k}{\sum_k A_{ik}} \]
Now use field calculator to take the ratio:

\[ P_i = \frac{\sum_k A_{ik} P_k}{\sum_k A_{ik}} \]
Subwatershed Precipitation by Interpolation

- Kriging (on Precip field)
- Zonal Statistics (Mean)
- Join
- Export
Runoff Coefficients

- Interpolated precip for each subwatershed
- Convert to volume, P
- Sum over upstream subwatersheds in Excel
- Runoff volume, Q
- Ratio of Q/P

Subwatershed Precip from Thiessen Polygons

<table>
<thead>
<tr>
<th>HydroID</th>
<th>Area (m^2)</th>
<th>Mean Precip (in)</th>
<th>Precip Volume (ft^3)</th>
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<tr>
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Watersheds

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<td>Blanco Rv nr Kyle, TX</td>
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<td>San Marcos Rv at Luling, TX</td>
<td>331, 332, 333, 336</td>
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<tr>
<th>Watershed</th>
<th>Flow (cfs)</th>
<th>Flow Volume (ft^3)</th>
<th>Subwatersheds</th>
<th>Precip volume subwatershed sum</th>
<th>Runoff ratio</th>
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Digital Elevation Model Based Watershed and Stream Network Delineation

Readings

The Terrain Flow Information Model

- Pit removal
- Flow direction field derivation
- Flow Accumulation
- Channels and Watersheds
- Raster to Vector Connection
The terrain flow information model for deriving channels, watersheds, and flow related terrain information.

Watersheds are the most basic hydrologic landscape elements.
The Pit Removal Problem

- DEM creation results in artificial pits in the landscape
- A pit is a set of one or more cells which has no downstream cells around it
- Unless these pits are removed they become sinks and isolate portions of the watershed
- Pit removal is first thing done with a DEM
Increase elevation to the pour point elevation until the pit drains to a neighbor
## Pit Filling

### Original DEM

|    |    |    |    |    |    |    |    | 5  | 7  | 7 |
|----|----|----|----|----|----|----|----|----|----|
| 7  | 7  | 6  | 7  | 7  | 7  | 7  | 7  | 5  | 7  |
| 9  | 9  | 8  | 9  | 9  | 9  | 9  | 7  | 9  | 9  |
| 11 | 11 | 10 | 11 | 11 | 11 | 11 | 9  | 11 | 11 |
| 12 | 12 | 8  | 12 | 12 | 12 | 12 | 10 | 12 | 12 |
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### Pits Filled

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**Pits**

**Pour Points**

---

The diagram illustrates the process of pit filling in a DEM grid, highlighting the original pits and the points where material is added to fill them.
Hydrologic Slope
- Direction of Steepest Descent

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

\[
\frac{67 - 52}{30} = 0.50
\]
Eight Direction (D8) Flow Model
Flow Direction Grid

- Flow Direction:
  - 1
  - 2
  - 4
  - 8
  - 16
  - 32
  - 64
  - 128

- Legend:
  - Dark Red: 1
  - Red: 2
  - Dark Gray: 4
  - Gray: 8
  - Pink: 16
  - Light Pink: 32
  - Light Gray: 64
  - White: 128

- Options:
  - Wshed.shp
  - A Watershed
  - 30097c7.tif
  - Flow Accumulative
  - Filled Auswestdem
  - Mesh30.shp
  - Mesh200.shp
  - Mesh100.shp
Grid Network
Flow Accumulation Grid.
Area draining in to a grid cell

```plaintext
0 0 0 0 0 0
0 2 2 2 0 0
0 0 10 0 1 0
1 0 0 14 0 0
0 4 1 19 1 0
```

Link to Grid calculator

ArcHydro Page 72
Flow Accumulation
> 10 Cell Threshold

Stream Network for
10 cell Threshold
Drainage Area
The area draining each grid cell includes the grid cell itself.
Watershed Draining to Outlet
Vectorized Streams Linked Using Grid Code to Cell Equivalents
DrainageLines are drawn through the centers of cells on the stream links. DrainagePoints are located at the centers of the outlet cells of the catchments.
Catchments

• For every stream segment, there is a corresponding catchment
• Catchments are a tessellation of the landscape through a set of physical rules
Raster Zones and Vector Polygons

One to one connection

DEM GridCode ↔ Catchment GridID

Raster Zones

Vector Polygons
Catchments, DrainageLines and DrainagePoints of the San Marcos basin
Watershed outlet points may lie within the interior of a catchment, e.g. at a USGS stream-gaging site.
Advanced Considerations

- Using vector stream information (DEM reconditioning)
- Enhanced pit removal
- Channelization threshold selection
- Computational considerations
“Burning In” the Streams

- Take a mapped stream network and a DEM
- **Make a grid** of the streams
- **Raise the off-stream DEM cells** by an arbitrary elevation increment
- Produces "burned in" DEM streams = mapped streams
AGREE Elevation Grid Modification Methodology – DEM Reconditioning
Carving

Lower elevation of neighbor along a predefined drainage path until the pit drains to the outlet point
### Carving

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- **Pits**
- **Carve outlets**
Optimal removal of spurious pits in grid digital elevation models

Filling

Carving

Minimizing Alterations
Minimizing DEM Alterations

Original DEM

Optimally adjusted

Carved

Filled

Pits
How to decide on stream delineation threshold?

Drainage density (total channel length divided by drainage area) as a function of drainage area support threshold used to define channels for the three study watersheds.

Why is it important?
Hydrologic processes are different on hillslopes and in channels. It is important to recognize this and account for this in models.

Drainage area can be concentrated (channel) or dispersed (catchment area) representing concentrated (channel) or dispersed (catchment) flow.
Examples of differently textured topography

Badlands in Death Valley.
from Easterbrook, 1993, p 140.

Coos Bay, Oregon Coast Range.
from W. E. Dietrich
Gently Sloping Convex Landscape

From W. E. Dietrich
Topographic Texture and Drainage Density

Driftwood, PA

Same scale, 20 m contour interval

Sunland, CA

Driftwood, PA

Sunland, CA
“landscape dissection into distinct valleys is limited by a threshold of channelization that sets a finite scale to the landscape.” (Montgomery and Dietrich, 1992, Science, vol. 255 p. 826.)

Suggestion: One contributing area threshold does not fit all watersheds.

Lets look at some geomorphology.

• Drainage Density
• Horton’s Laws
• Slope – Area scaling
• Stream Drops

Different methods To help delineate Streams and catchments
Drainage Density

- \( D_d = \frac{L}{A} \)
- Hillslope length \((B) \approx \frac{1}{2}D_d \)

Hillslope length = \(B\)
\[ A = 2B \cdot L \]
\[ D_d = \frac{L}{A} = \frac{1}{2}B \]
\[ \therefore B = \frac{1}{2}D_d \]
Drainage Density for Different Support Area Thresholds

EPA Reach Files

100 grid cell threshold

1000 grid cell threshold
Drainage Density Versus Contributing Area Threshold

\[ Dd = 0.792 A^{-0.434} \]
Horton's Laws: Strahler system for stream ordering

- The Strahler (1952) stream ordering system designates source streams as first order;
- The confluence of two (or more) first order streams is the beginning of a second order stream;
- The confluence of two (or more) second order streams produces a third order stream and so on.
- When a stream of a given order receives a tributary of lower order, its order does not change.
- A Strahler stream is defined as an entire set of sequential stream segments with the same order
Delineate streams by Stream order and Mean stream length: Length Ratio
Delineate streams by Stream order and Mean stream slope: Slope ratio
Constant Stream Drops Law

By using the smallest weighted support area that produces networks consistent with this property we are extracting the highest resolution drainage network statistically consistent with geomorphological laws.
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’.

- Look for statistically significant break in constant stream drop property as stream delineation threshold is reduced
- Break in slope versus contributing area relationship
- Physical basis in the form instability theory of Smith and Bretherton (1972), see Tarboton et al. 1992
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

200 grid cell
18 x 10E4 m^2
The challenge of increasing Digital Elevation Model (DEM) resolution

1980’s DMA 90 m
$10^2$ cells/km$^2$

1990’s USGS DEM 30 m
$10^3$ cells/km$^2$

2000’s NED 10-30 m
$10^4$ cells/km$^2$

2010’s LIDAR ~1 m
$10^6$ cells/km$^2$
Summary of Key Processing Steps

- [DEM Reconditioning]
- Pit Removal (Fill Sinks)
- Flow Direction
- Flow Accumulation
- Stream Definition
- Stream Segmentation
- Catchment Grid Delineation
- Raster to Vector Conversion (Catchment Polygon, Drainage Line, Catchment Outlet Points)
Summary Concepts

• The eight direction pour point model approximates the surface flow using eight discrete grid directions

• The elevation surface represented by a grid digital elevation model is used to derive surfaces representing other hydrologic variables of interest such as
  – Slope
  – Flow direction
  – Drainage area
  – Catchments, watersheds and channel networks
Summary Concepts (2)

• Hydrologic processes are different between hillslopes and channels
• Drainage density defines the average spacing between streams and the representative length of hillslopes
• The constant drop property provides a basis for selecting channel delineation criteria to preserve the natural drainage density of the topography