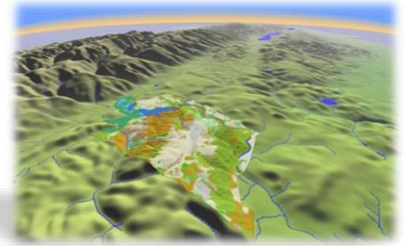




NICHOLAS SCHOOL OF THE
ENVIRONMENT AND EARTH SCIENCES
DUKE UNIVERSITY



ENVIRON 761:

Elevation, Terrain & Ecology

Part 1: Ecohydrology and GIS

Instructor: John Fay

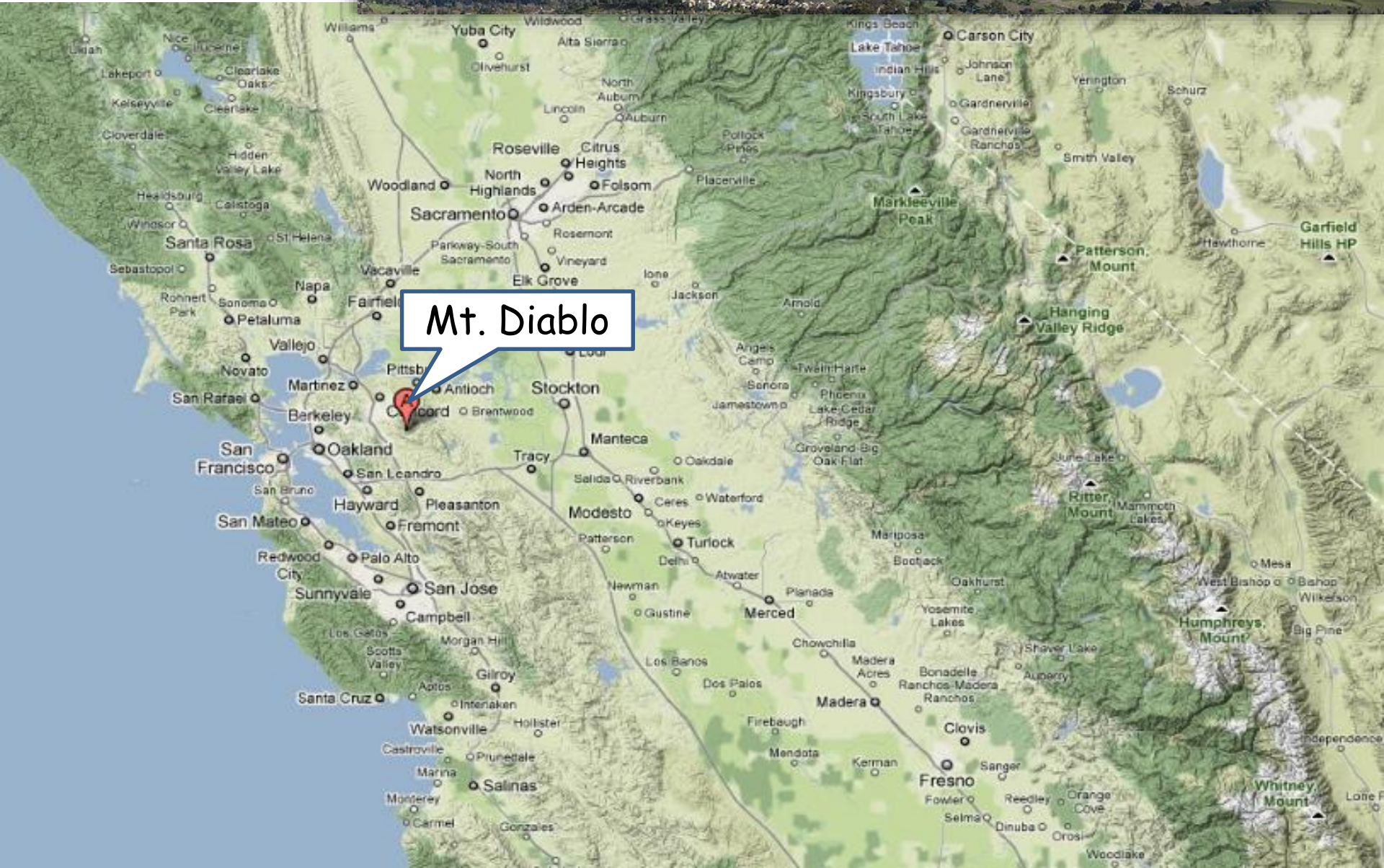
Elevation

Highest Peaks
in California



Rank	Mountain Peak	Elevation
1	Mt. Whitney	14,505 ' / 4421 m
2	Mt. Williamson	14,389 ' / 4386 m
3	White Mt. Peak	14,252 ' / 4344 m
4	North Palisade	14,248 ' / 4343 m
5	Mt. Shasta	14,179 ' / 4322 m
6	Mt. Humphreys	13,992 ' / 4265 m
7	Mt. Keith	13,982 ' / 4262 m
8	Mt. Darwin	13,837 ' / 4218 m
9	Mt. Kaweah	13,807 ' / 4209 m
??	Mt. Diablo	3,864' / 1178 m

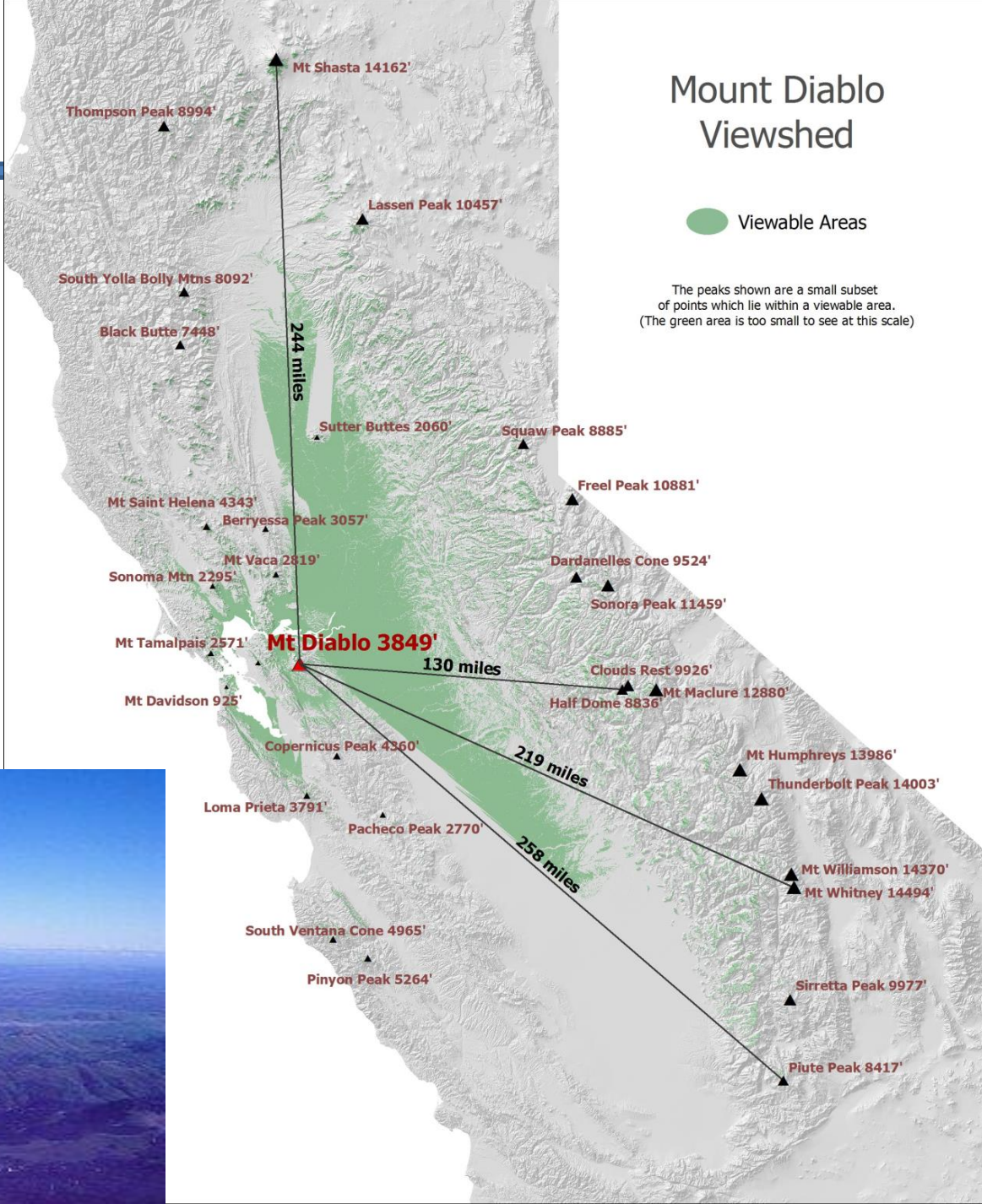
Elevation



Elevation

... is not everything

Even at just 3864 ft., Mt. Diablo has the "second largest viewshed in the world" ...



Elevation vs. Terrain

Elevation:

- height [above sea level] at a given *point*

Terrain:

- the *surface features* of an area of land;
- elevation of a point *in the context* of the elevation of points around it

Looking at changes in elevation across an area (i.e. terrain) gives far more information about a landscape than mere elevation alone



Elevation, terrain & ecology: Overview

- I. Ecohydrology & conservation
 - Surface terrain and the hydrologic cycle
 - GIS techniques for modeling surface flow using a DEM

- II. Vegetation patterns across ecological gradients
 - Properties of a terrain that drive these gradients
 - GIS techniques to derive surface properties from a DEM

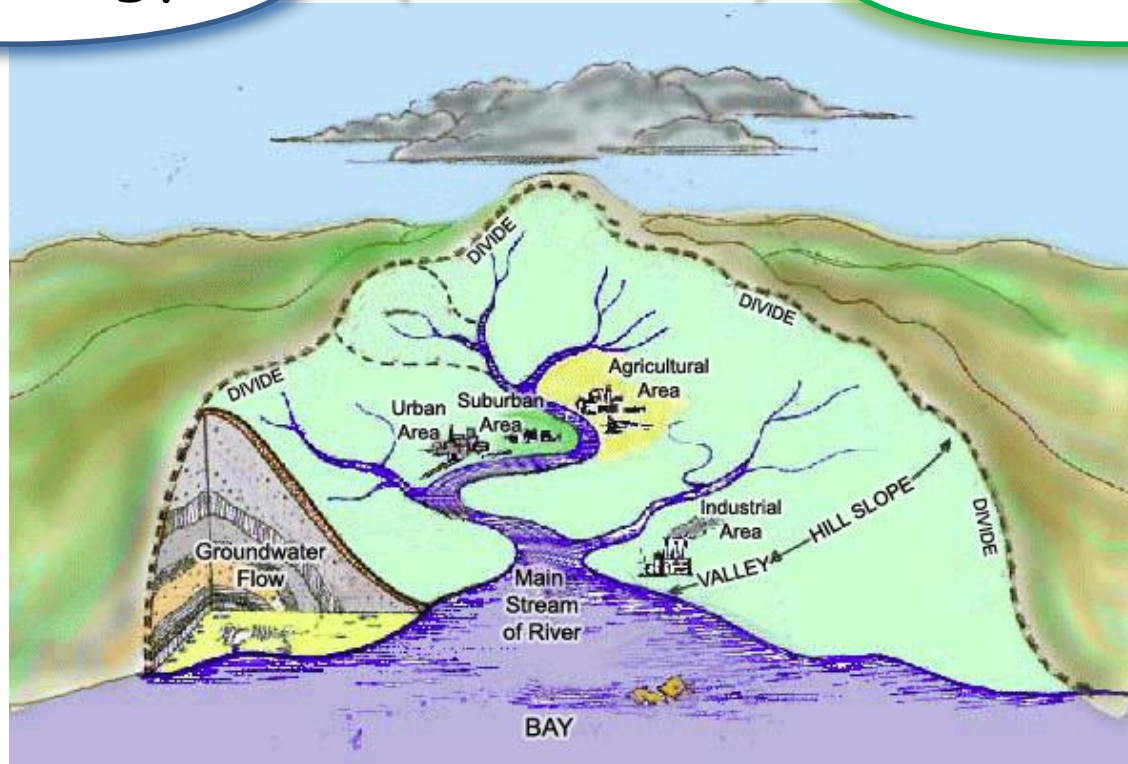
Ecohydrology

Catchment as a "superorganism"
(Lovelock 1995)

Hydrology



Ecology



*Image:
Alice Ferguson
Foundation*

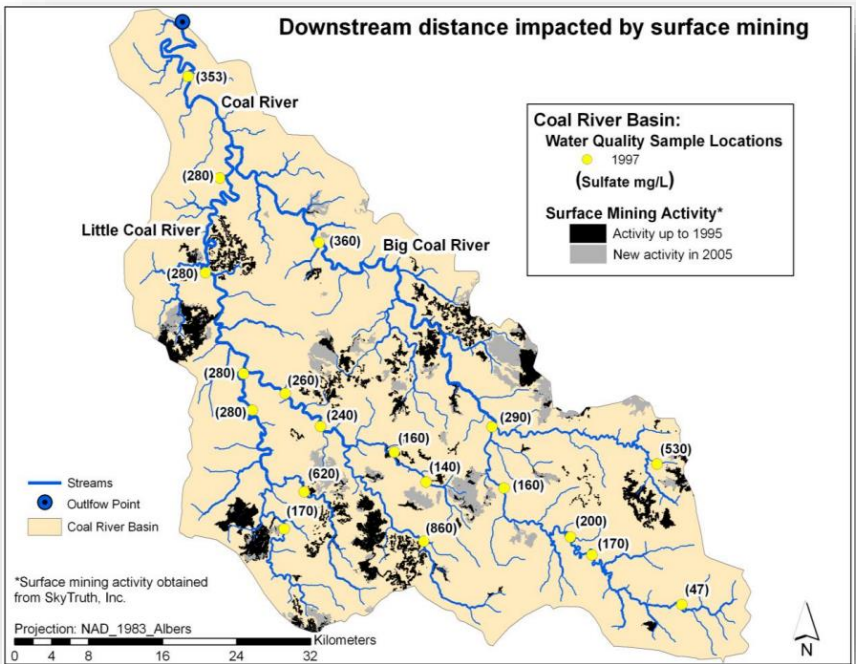
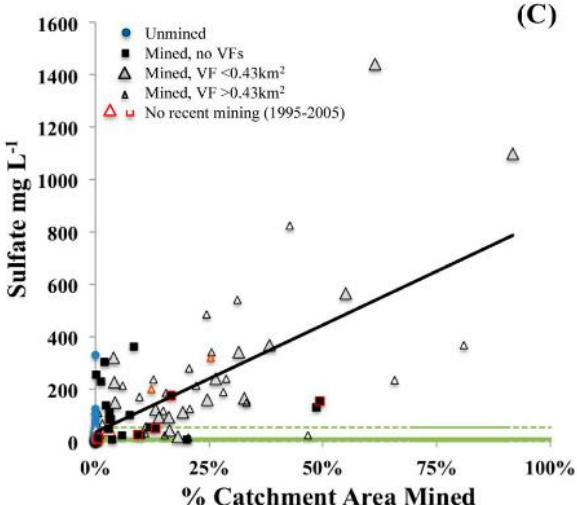
Ecohydrology: Principles

- Drainage systems should be considered as a template for quantifying the *threats* & *opportunities* [to conservation]
- Freshwater ecosystem robustness can be enhanced on the basis of understanding the evolutionary established resistance/resilience of the ecosystem
 - *Hydrology managed by tweaking ecological drivers*
 - *Ecology managed by tweaking hydrologic drivers*

(Zalewski 2002, Wagner & Zalewski 2009)

Ecohydrology: Case Study

Mountaintop mining in WV



Bernhardt et al. (2012)

What is a watershed?

aka: "catchment", "basin", "water divide"...

Simple:

The area of land where surface water converges into a single point.



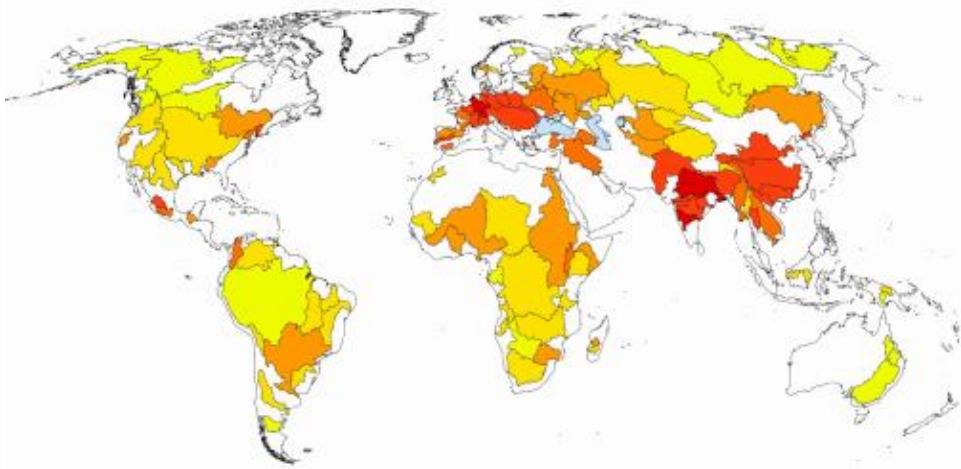
Holistic (and poetic):

"That area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded they become part of a community"

-John Wesley Powell

Watersheds of various scales

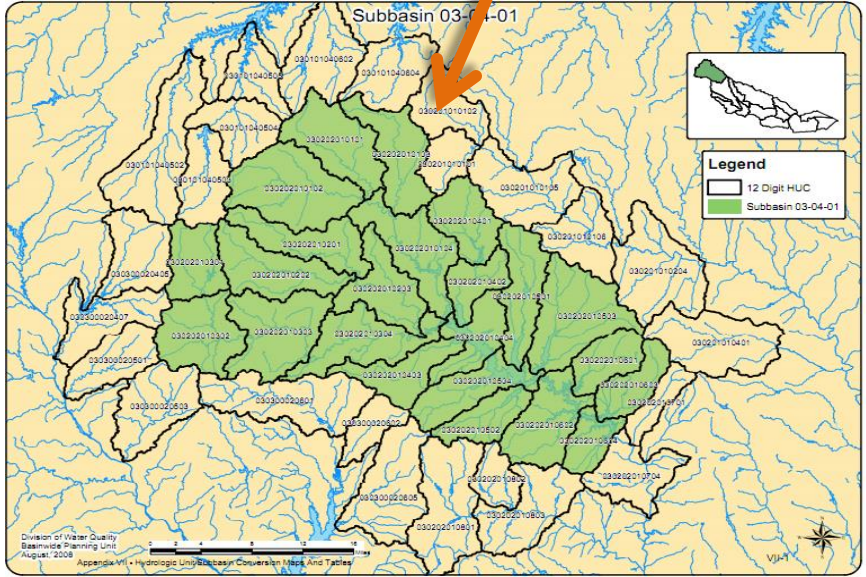
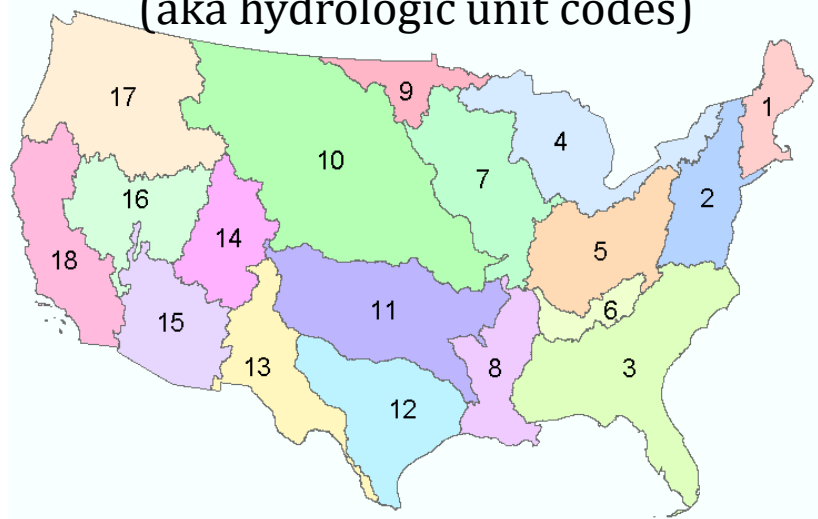
Population by global watersheds (wri.org)



8-digit HUC watersheds of NC



2-digit water resource regions (aka hydrologic unit codes)



12-digit HUCs of Upper Neuse

Spatial scales of drainage systems

Arc Hydro

Basins:

- Administrative/water management units
- Normally named after principal rivers
- Popular data-packaging unit

Watersheds:

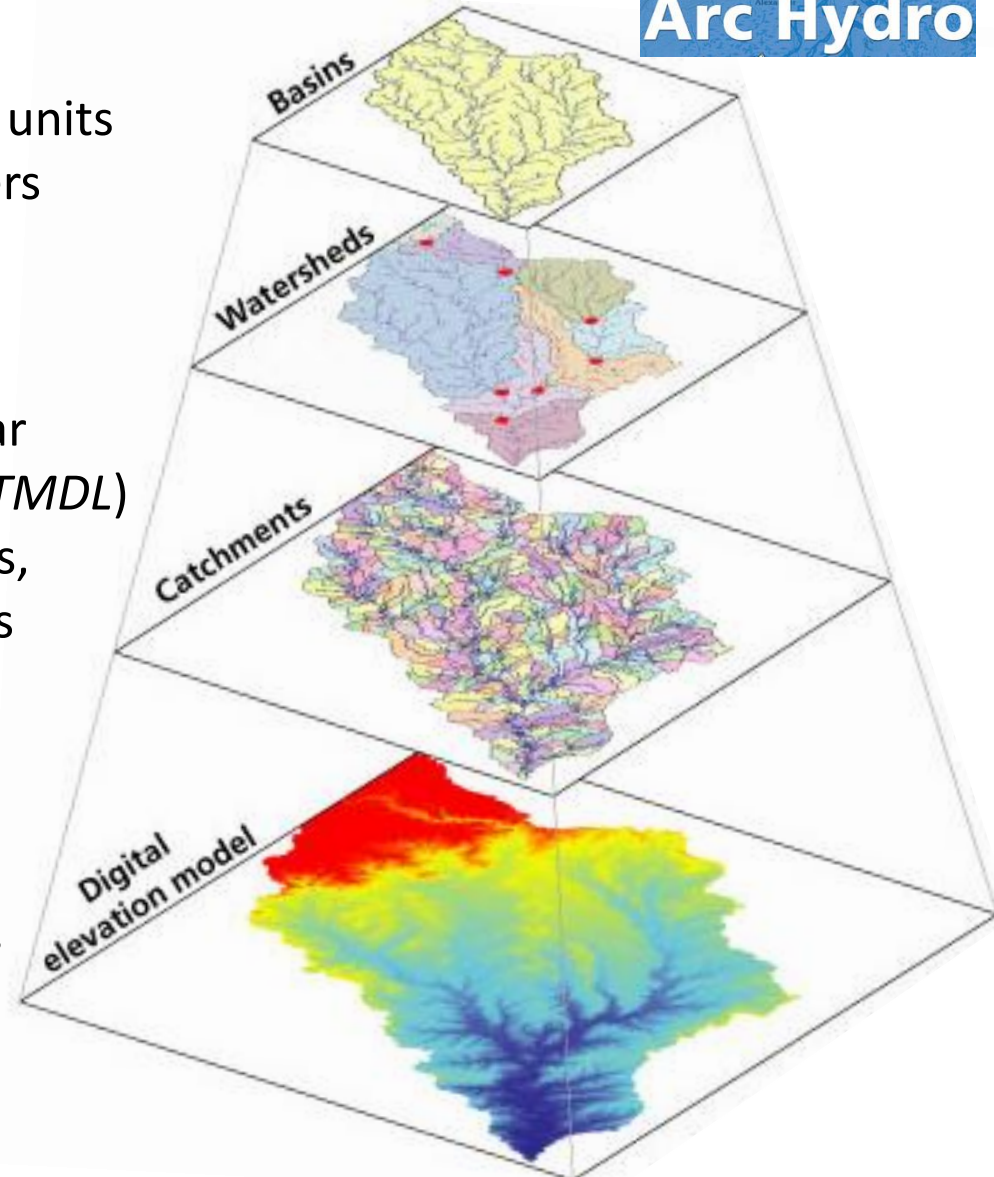
- Subdivisions selected for a particular hydrologic purpose (*e.g. Falls Lake TMDL*)
- Pour points are often river networks, segments, or receiving water bodies

Catchments:

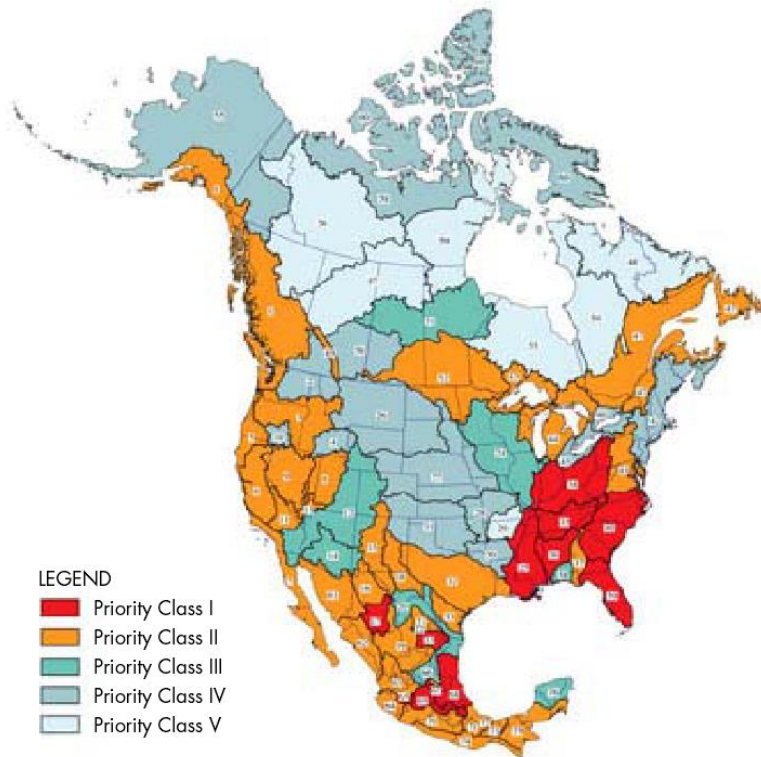
- Subdivisions often defined by a consistent set of physical rules. (*e.g., drainage area, stream nodes*).

Digital elevation model:

- Each cell is an operational unit



Watersheds: A useful ecoregional planning unit



WWF Priority Freshwater Ecoregions

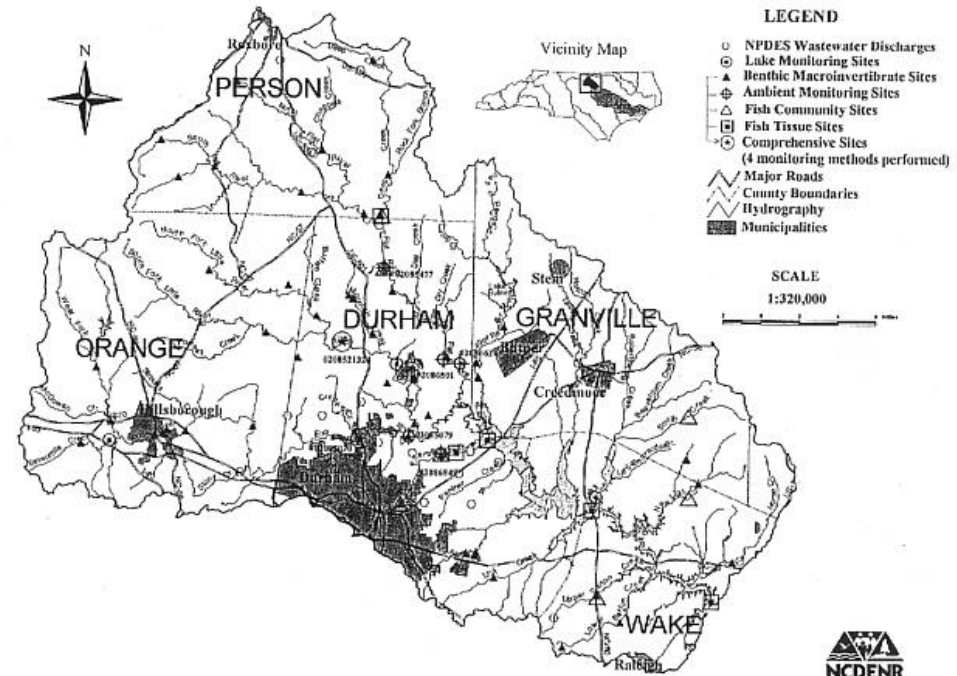


Figure 1.1 Water Quality Monitoring Stations in the Upper Neuse River Basin (Subbasin 01)

- Make sense ecologically (flow of resources)
- But, they often cross political & jurisdictional boundaries

Characterizing drainage areas

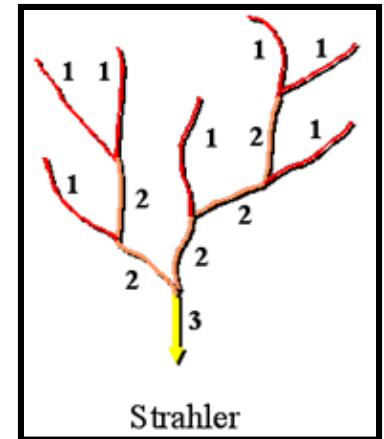
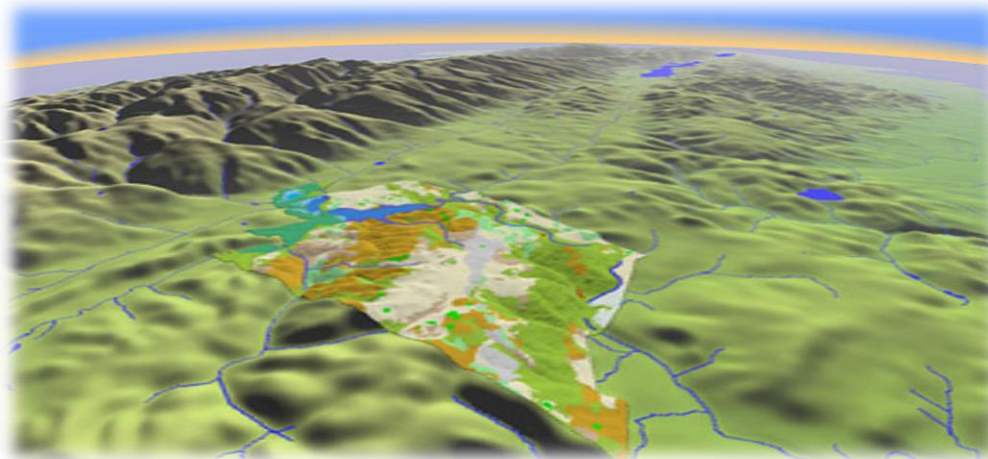
Upstream area & composition

- Area & proportion of a contaminant
- Breakdown of catchment into cover types



Drainage patterns

- Stream channels/stream order
- Upstream accumulation



Determining drainage areas: The old way

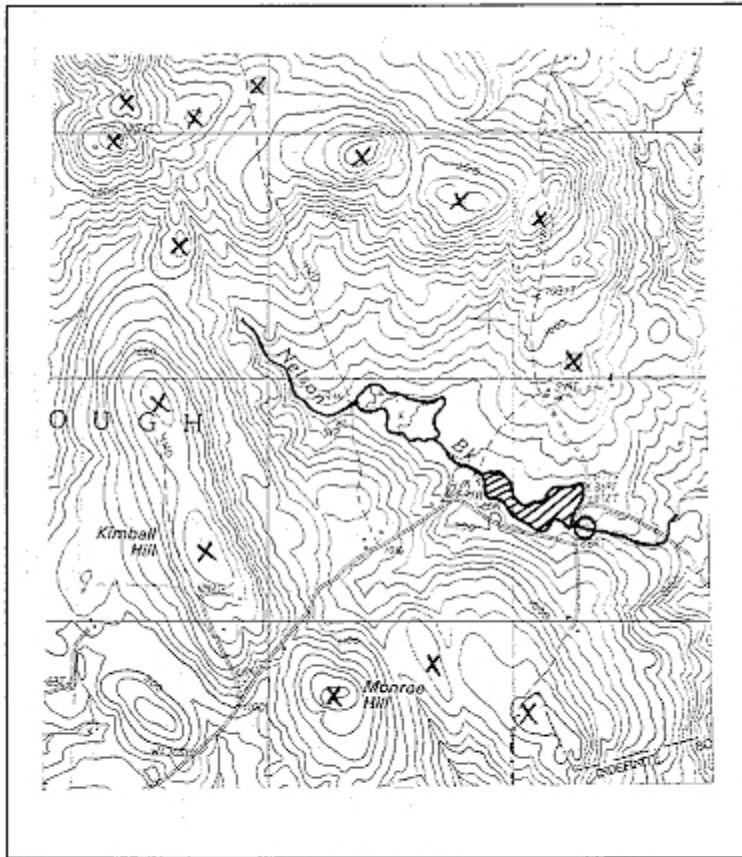


Figure E-4: Delineating a Watershed Boundary - Step 1

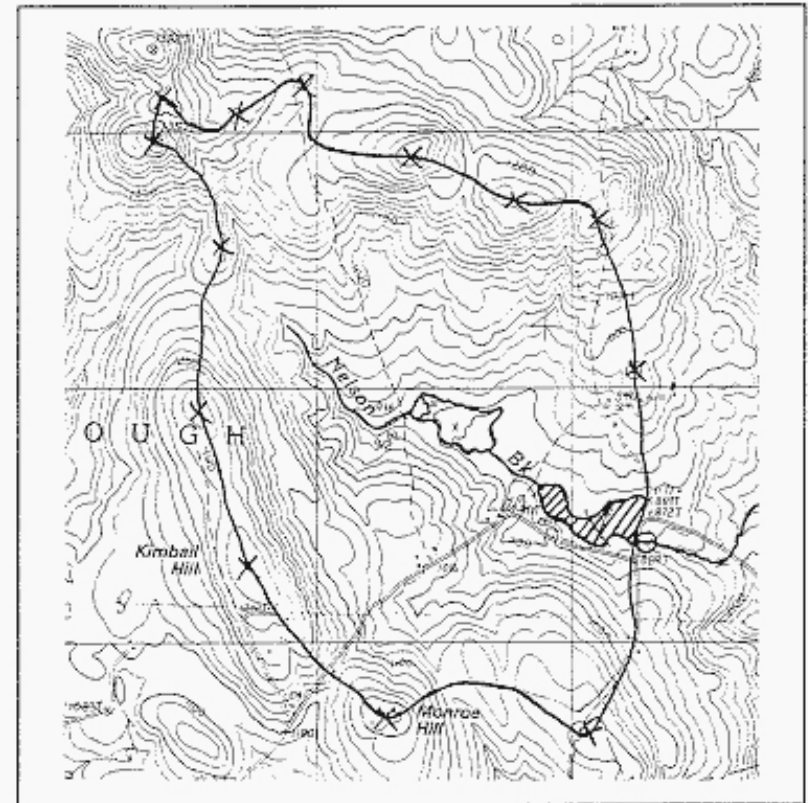
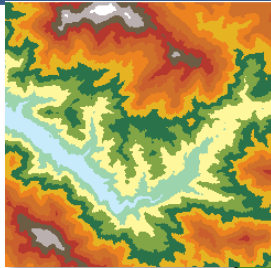


Figure E-5: Delineating a Watershed Boundary - Step 2

Determining drainage area: the new way



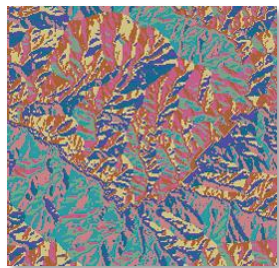
DEM

Flow Direction

Sink

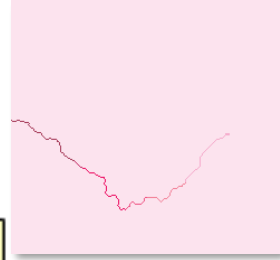
Are there any sinks?

Fill



Depressionless DEM

Flow Accumulation



Stream Order

Stream To Feature

Stream Link

Flow Length

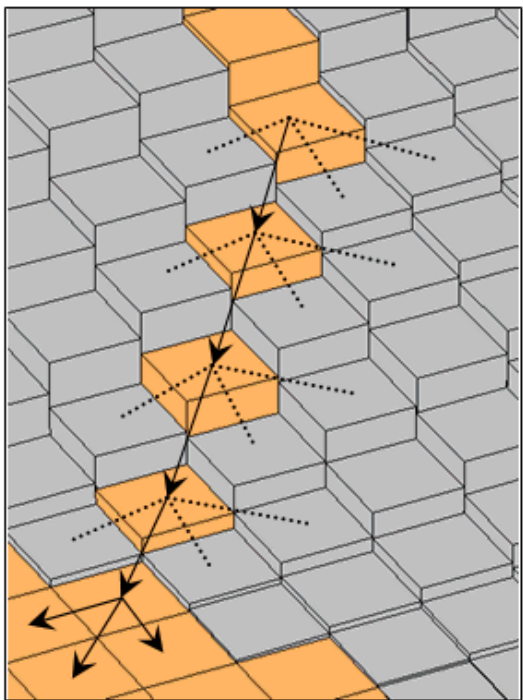
Snap Pour Point

Watershed

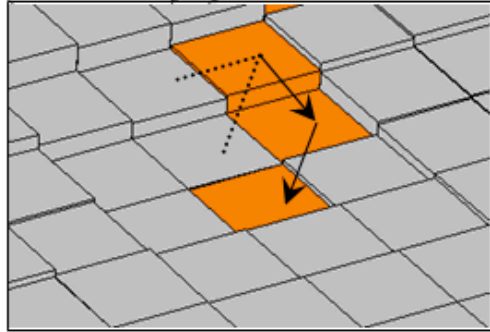
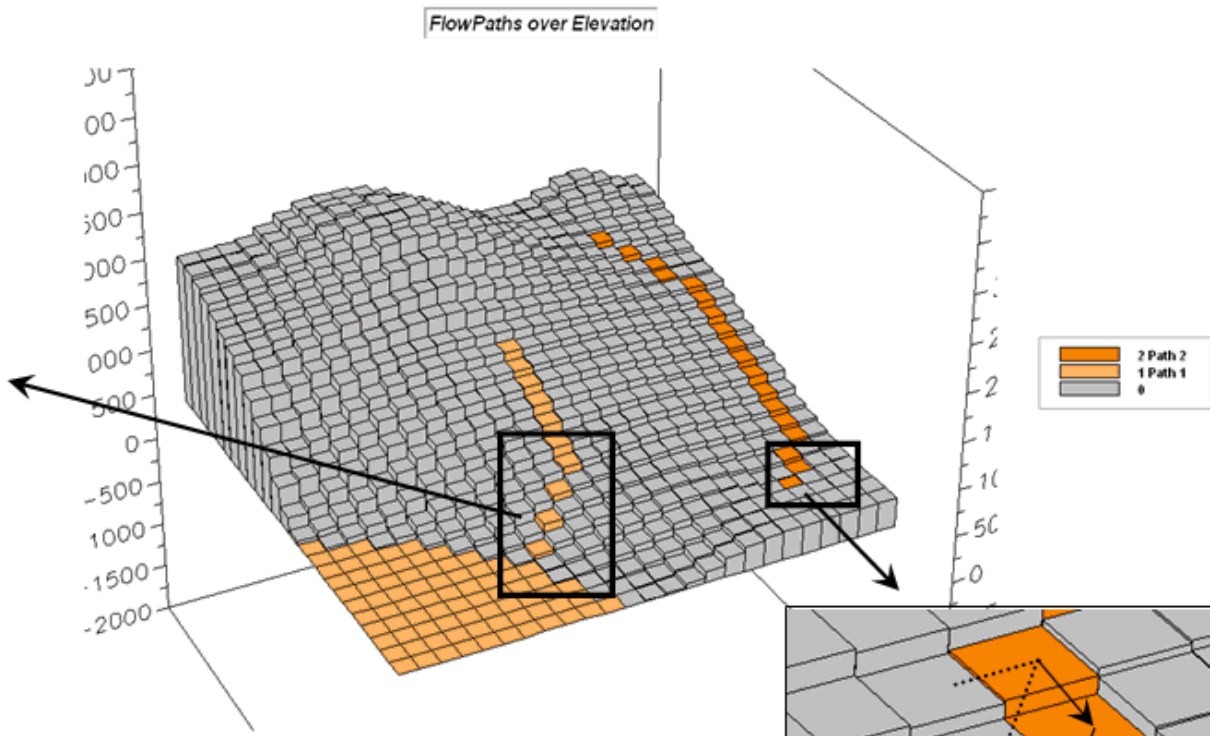


Hydrological modeling flowchart

DEMs and Overland flow



Flat Areas



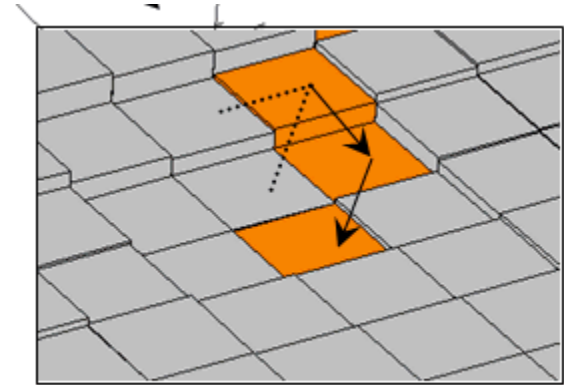
Depression Basin

Overland flow moves downhill by the steepest path...

- *Spreads out across flat areas (cells of equal elevation)*
- *Stops in a depression (all surrounding cells greater)*

Sinks in a DEM

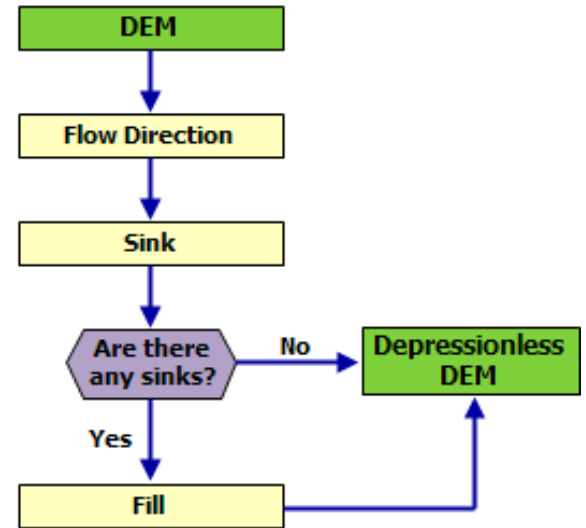
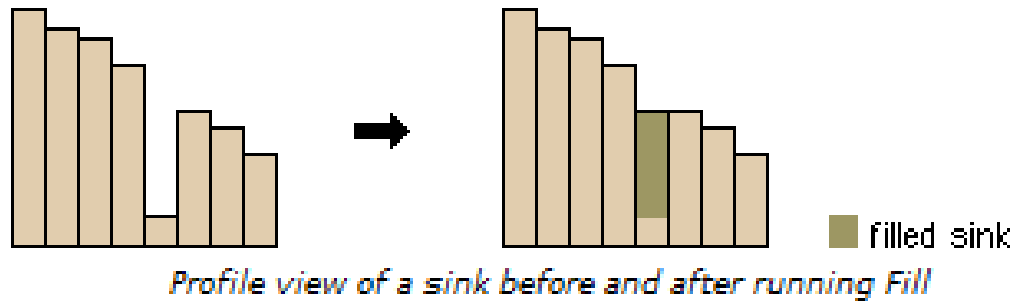
Sinks create havoc in calculating hydrologic flow



Depression Basin

- Sinks are often errors due to the resolution of the data or rounding of elevations to the nearest integer value.
- 0.9 to 4.7% of the cells in a DEM are sinks. The mean adjustment of these sinks ranged from 2.6 to 4.8 m.
- This means that for a 1,000 by 1,000 cell grid (1 million cells), there may be 9,000 to 47,000 sinks to be filled.

Creating a 'depressionless' DEM



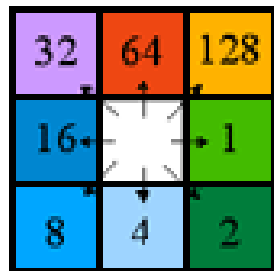
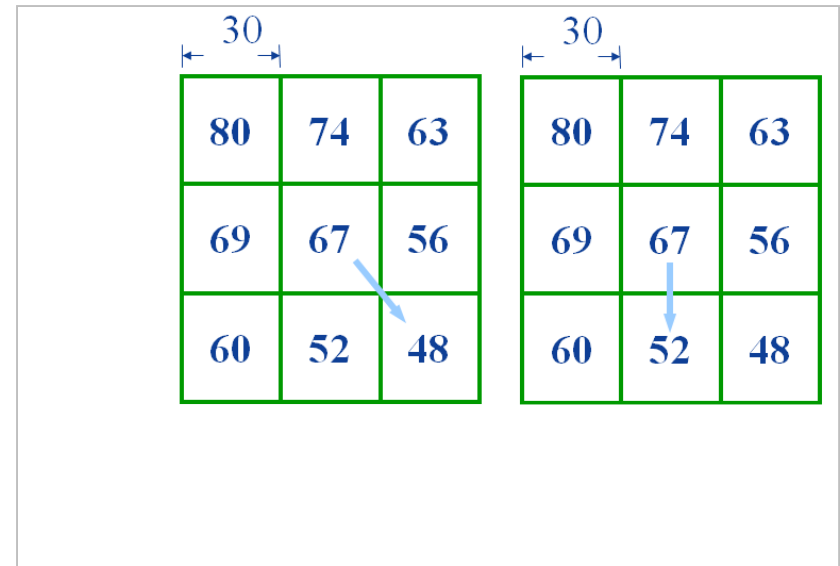
1. Identify sinks:
 - cells that are lower than all neighboring cells or
 - cells that flow into each other
2. Raise sinks to elevation of lowest neighbor
3. Repeat step 1 (in case raising sinks created new sinks)
4. Operation completes when no more sinks are found

Flow Direction

- Find neighboring cell with steepest drop...

$$\text{maximum_drop} = \text{change_in_z-value} / \text{distance} * 100$$

- Assign a value representing that direction...



Direction coding

Any other value than these indicates an improperly filled DEM

Flow Direction

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

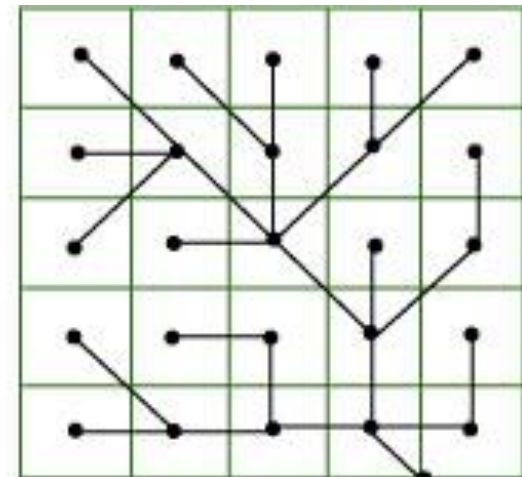
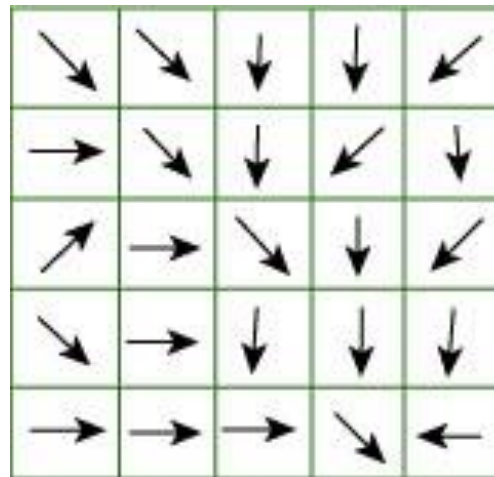
Elevation surface



2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

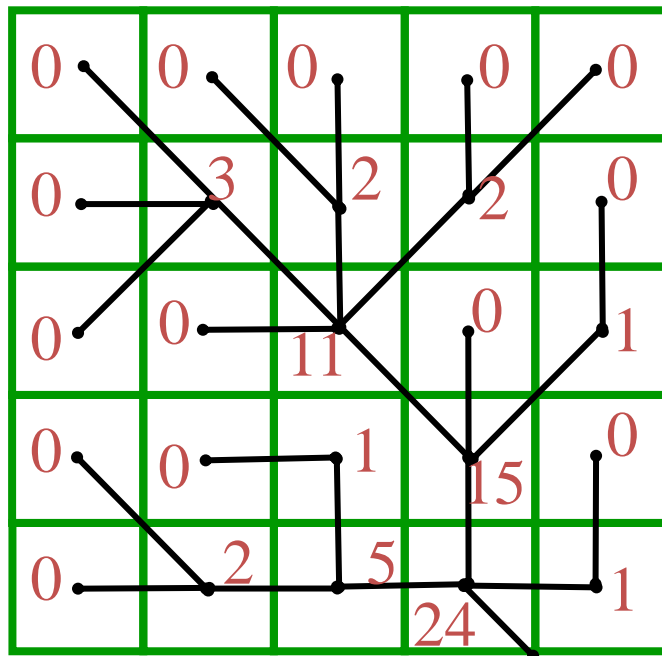
Flow direction

Once established, flow direction allows the creation of a hydrologic flow network

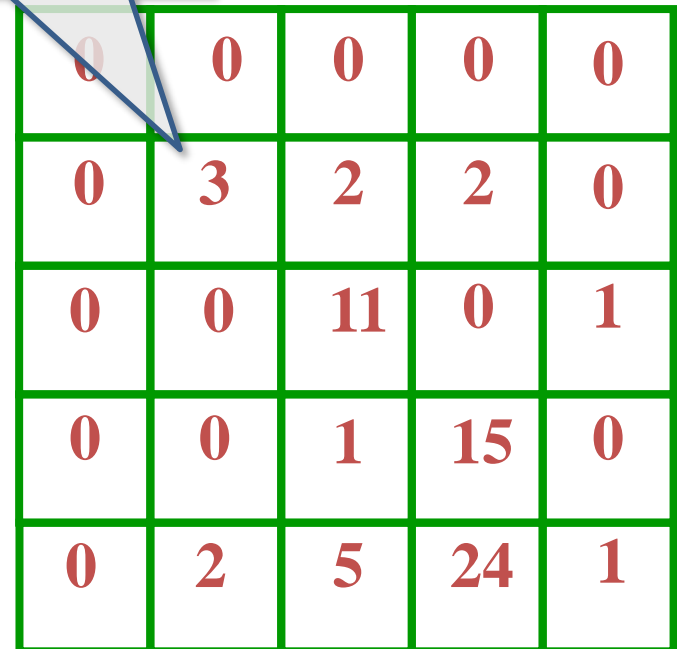


Flow Accumulation

- Calculates the total number of cells upstream of the given cell in the output raster. (*note: it doesn't count the cell itself!*)
- Determined via *network analysis* from the flow direction raster...

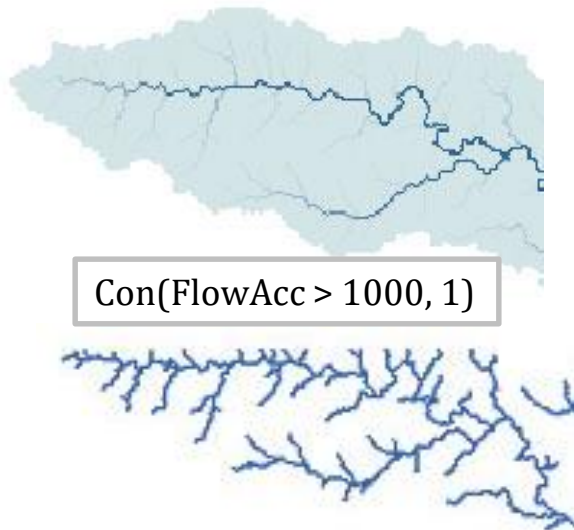
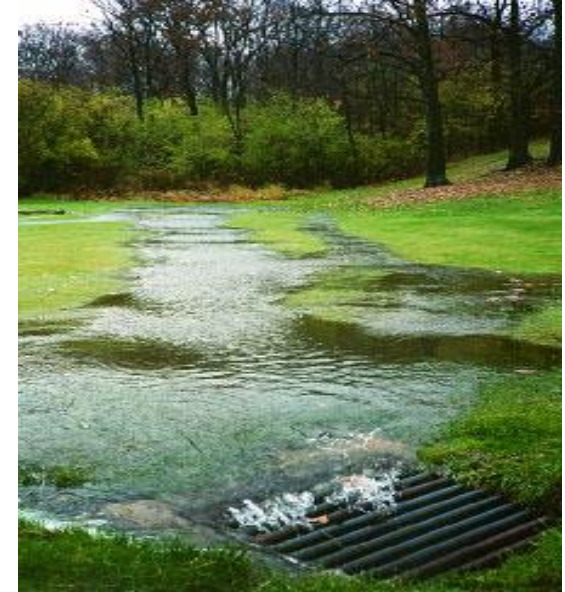


This cell has 3 others that drain into it



Identifying Stream Networks

- When surface runoff gets big enough, we call it a stream.
- "Big enough" can be interpreted as a *flow accumulation threshold*:



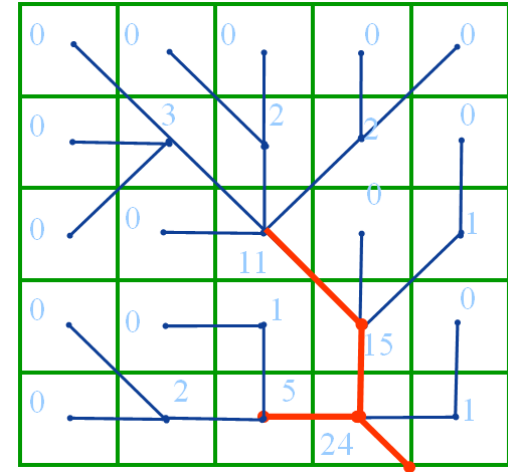
"All cells draining more than, say, 1000 upstream cells is likely to be a stream"

Flow Accumulation Thresholded Streams

- What threshold to use??

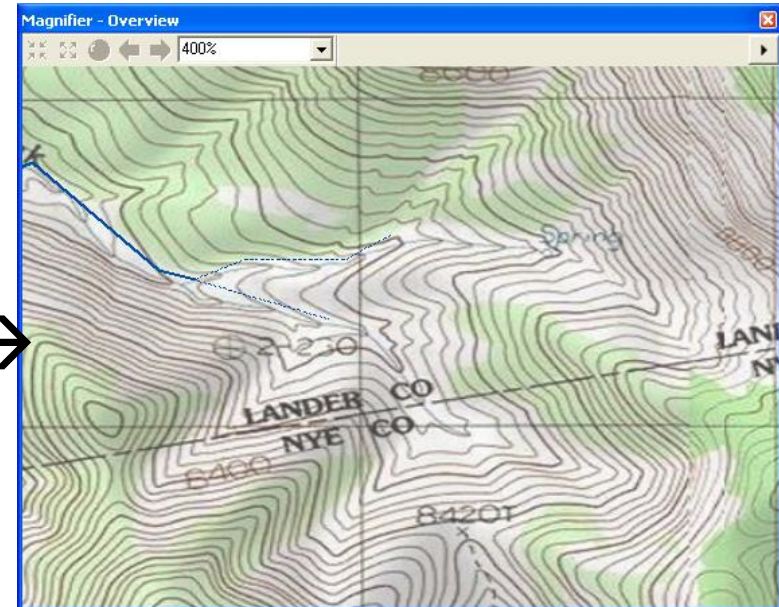
No "correct" answer

- Depends on DEM resolution
- Depends on terrain



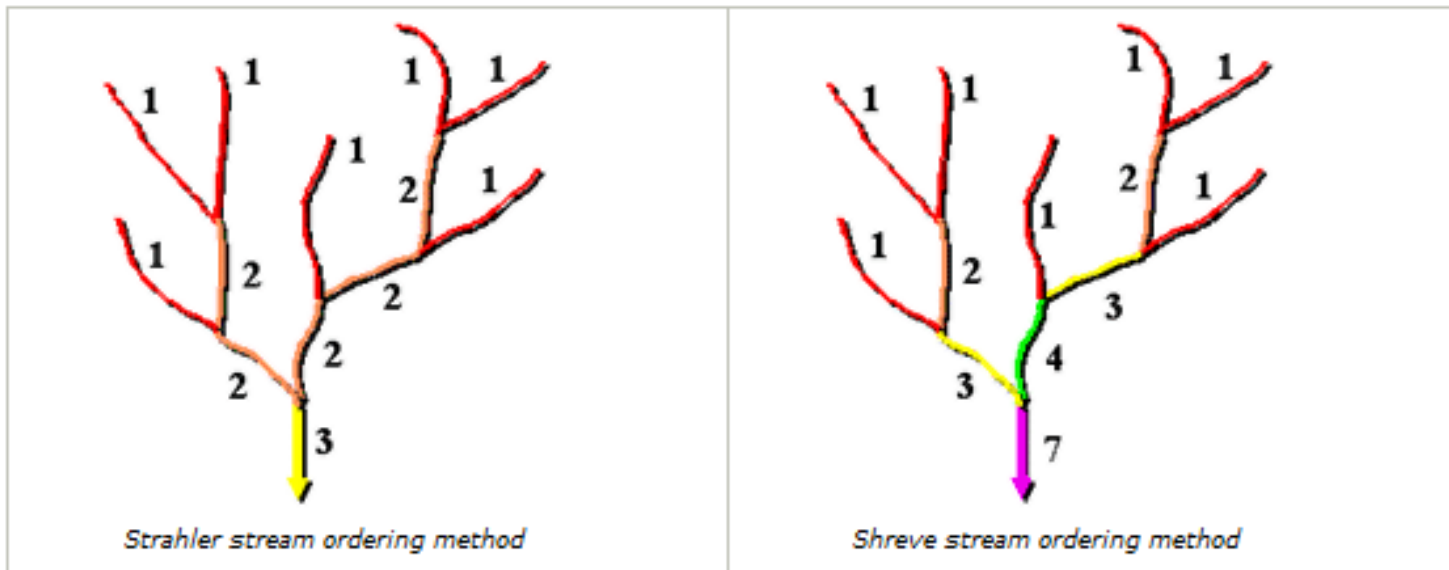
- Document & Validate your selection

- Compare flow accum. streams to those on published maps →



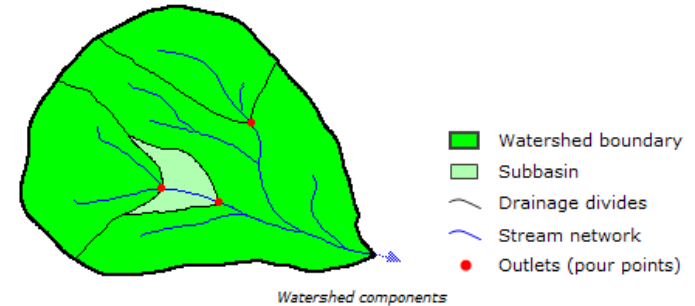
Stream Ordering

- Assigns a numeric order to streams
- Useful for classifying stream based on # tributaries
 - e.g., first order (smallest) streams dominated by overland flow and are more susceptible to non-point source



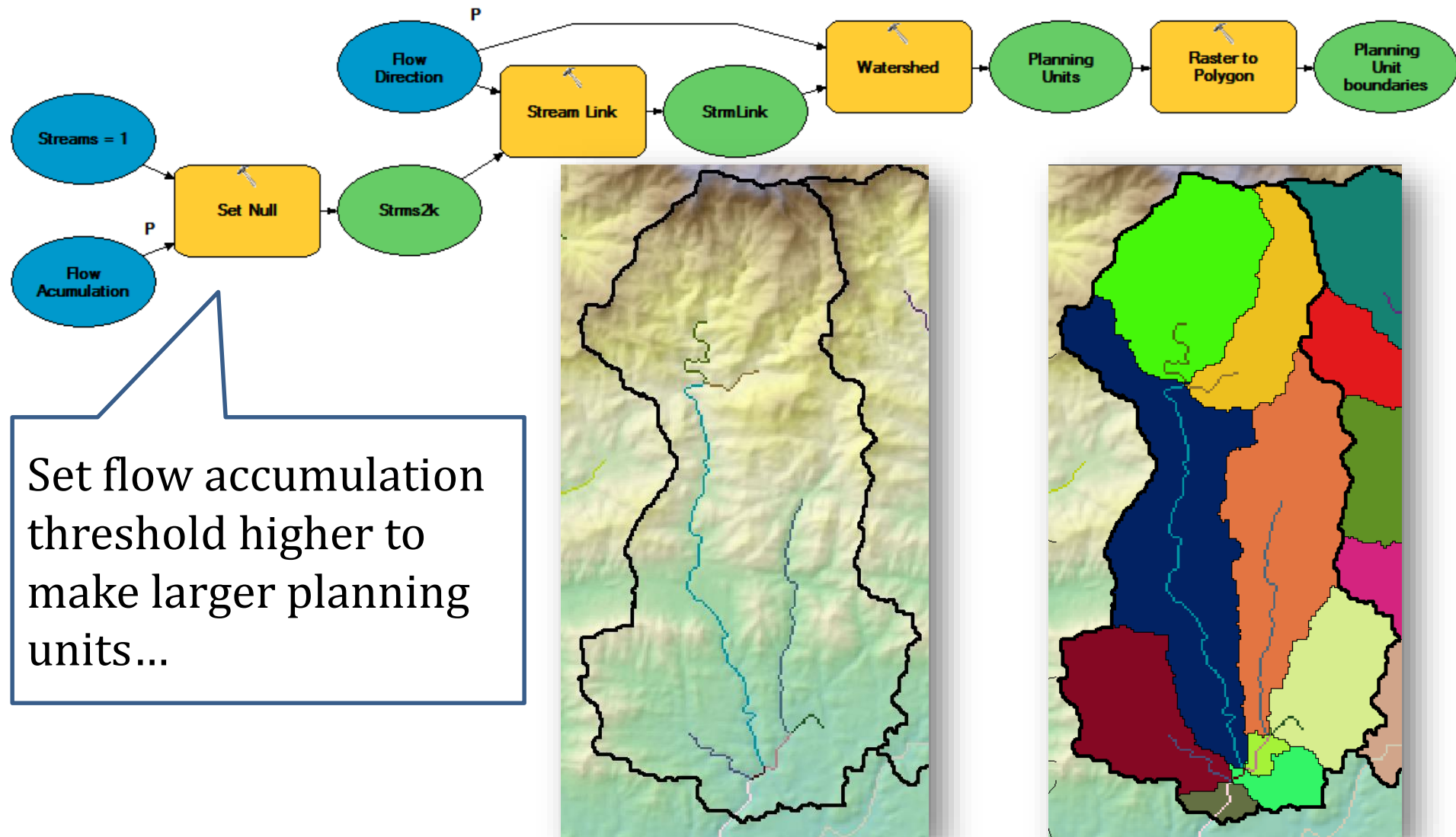
Delineating Watersheds

- Uses flow direction to identify cells upstream of a given pour point and assigns a unique value to those cells.



- Does not nest watersheds; only goes to next pour point.
- Pour points may need to be snapped to ensure that they fall on a stream cell, not near it.

Creating catchment-based planning units



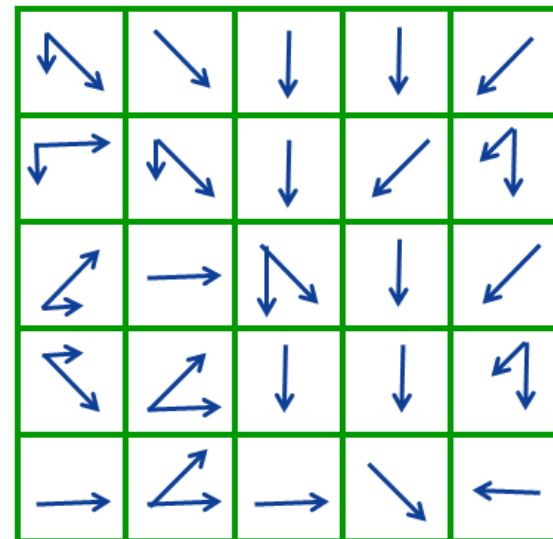
Alternative flow direction algorithms

"D8" - Eight directional flow direction

- All of a cell's contents spill into the most downstream cell
- Simplifies things, but allows for a seamless hydro network

"MDF" – Multi Flow Direction (Qin et al., 2007)

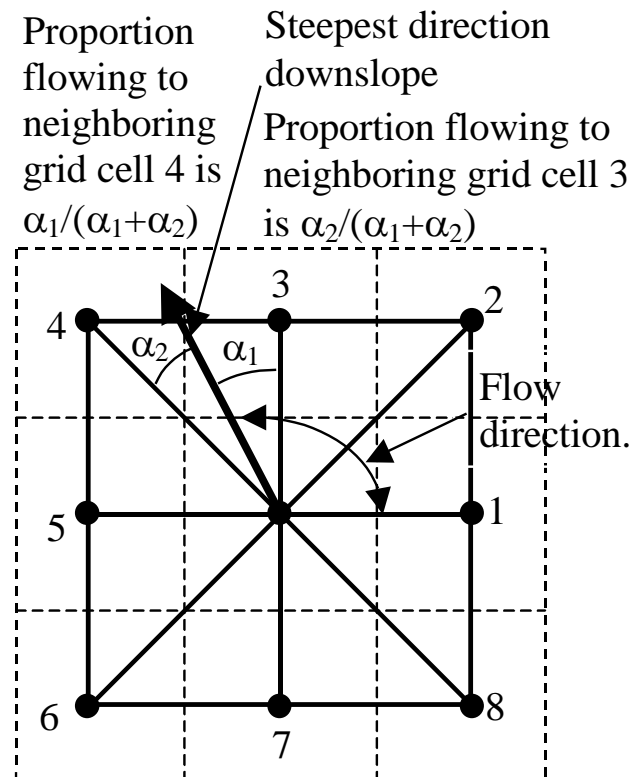
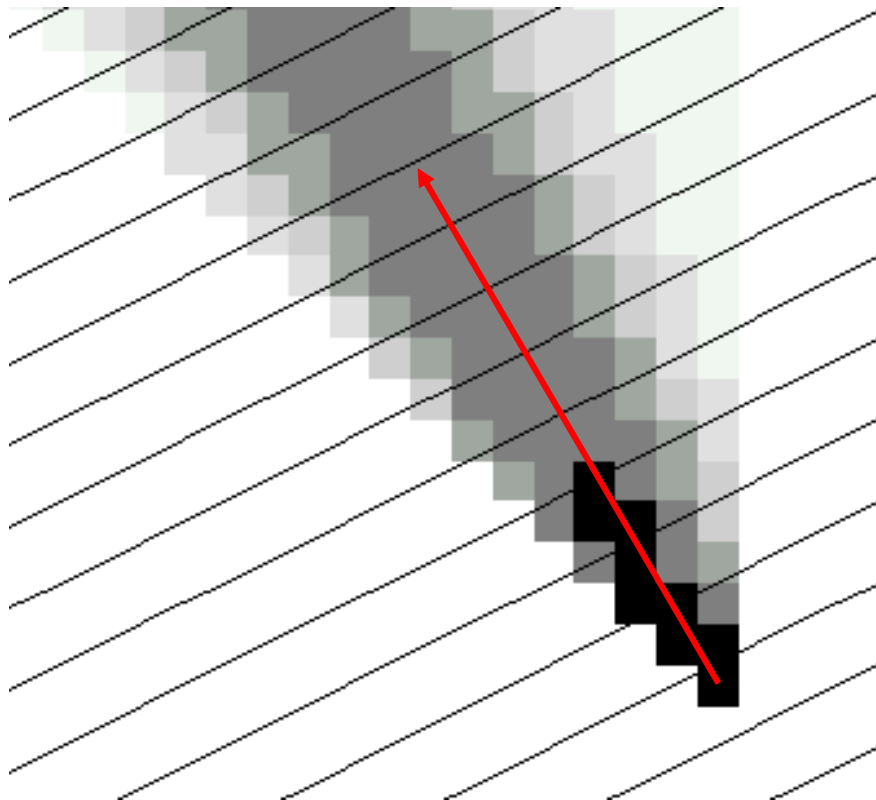
- Flow can go into multiple cells
- More realistic representation of surface flow, but modeling flow gets much more complicated
- Output is Cloud Raster Format; not easily analyzed in ArcGIS...



Alternative flow direction algorithms

"DINF" - Eight directional flow direction (Tarboton 1997)

- Flow follow steepest descent, but not limited to 8 direction.
- Values are 0 -360° (where 0,360 are due east).



The MD- ∞ Algorithm

A new triangular multiple flow direction algorithm for computing upslope areas from gridded digital elevation models

Jan Seibert¹ and Brian L. McGlynn²
WATER RESOURCES RESEARCH, VOL. 43

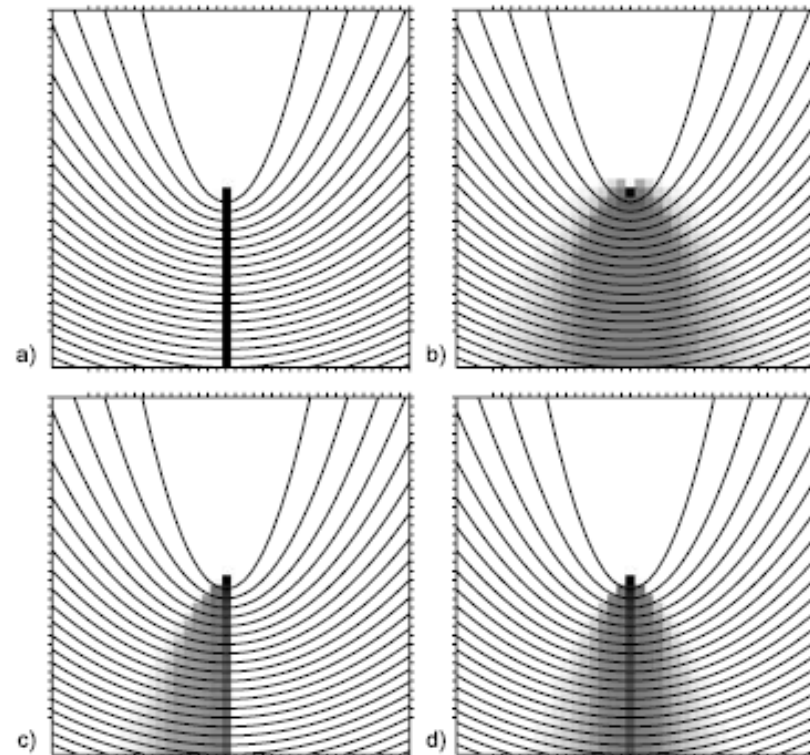
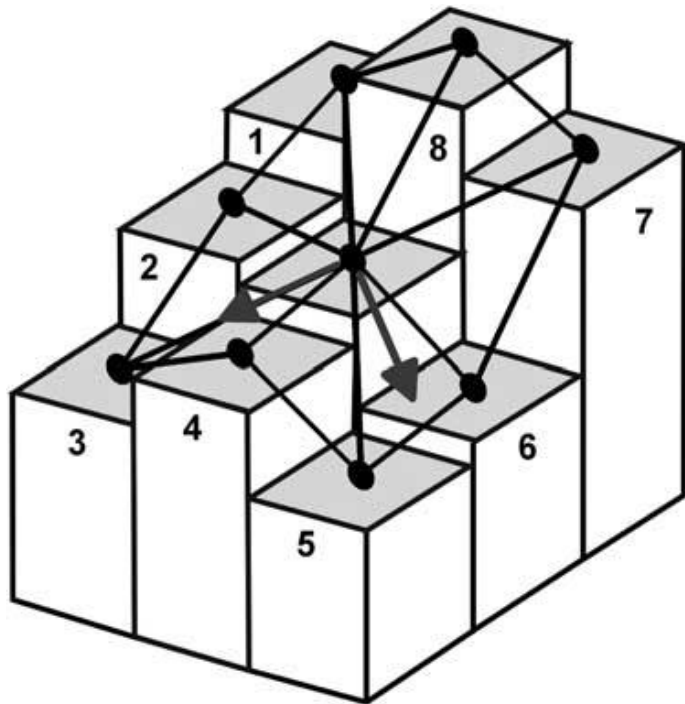
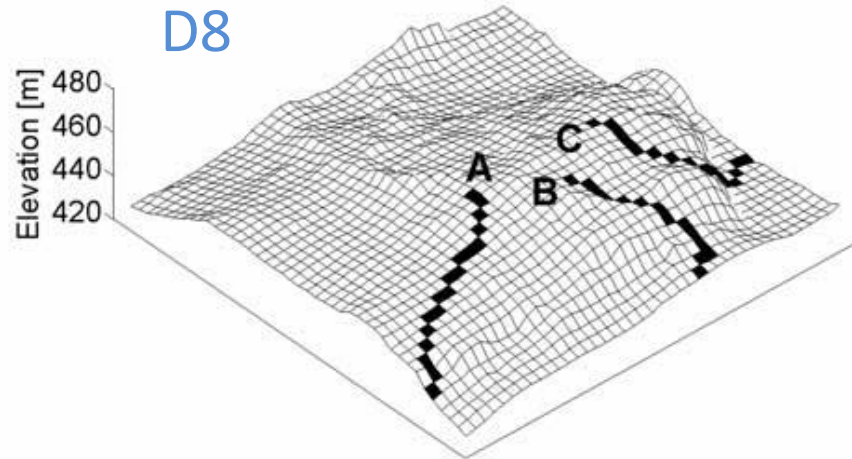
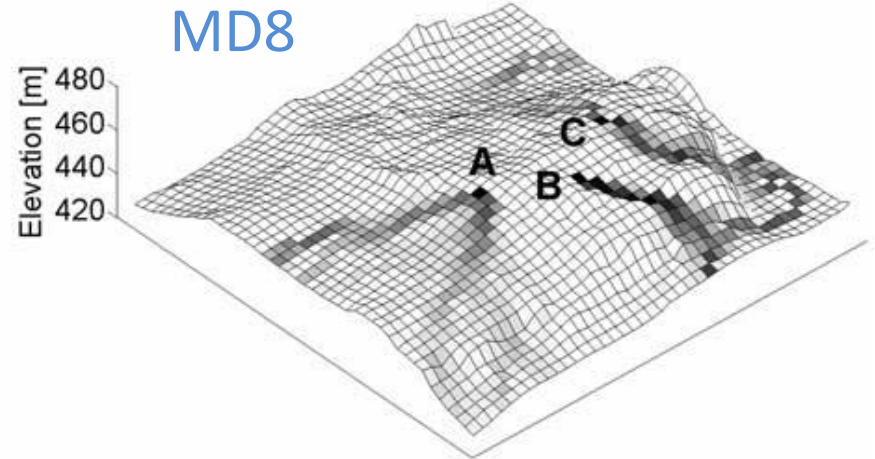


Figure 4. Downslope pattern of area distributed from one cell on a divergent hillslope (synthetic data) for the different algorithms: (a) D8, (b) MD8, (c) D ∞ , and (d) MD ∞ . The portions vary from 0 (white) to 1 (black).

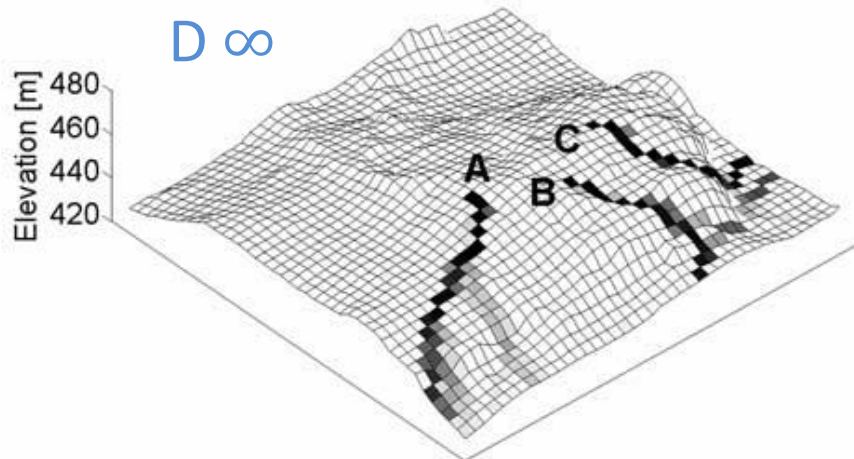
Comparing Algorithms



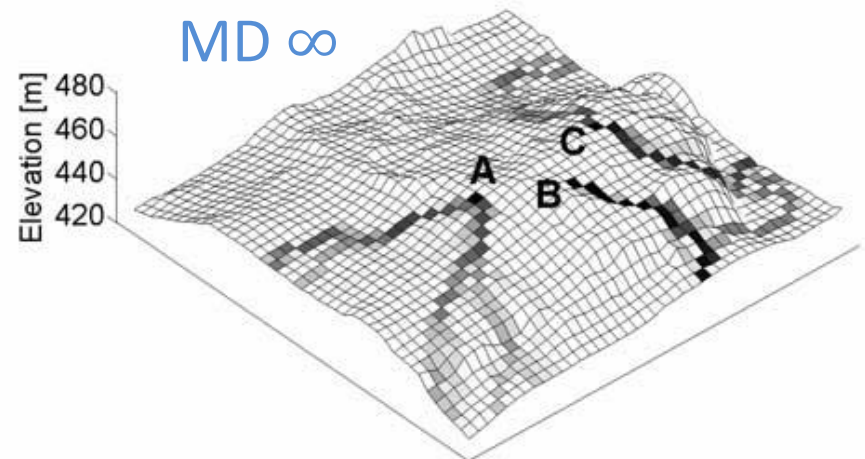
a)



b)



c)



d)

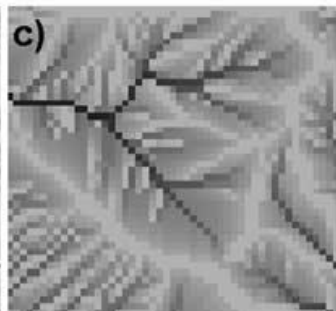
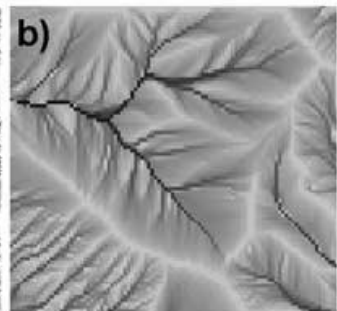
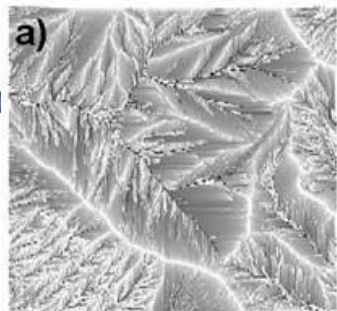
D-8 vs. D-∞

10 m

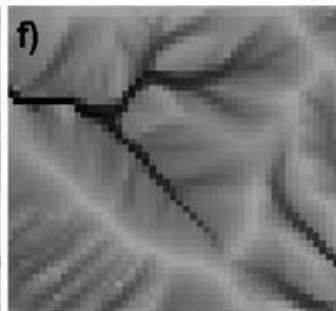
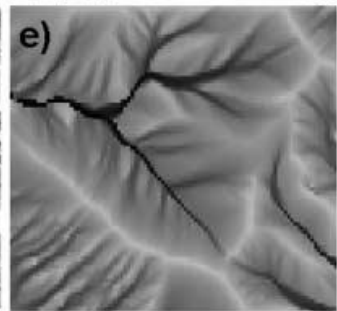
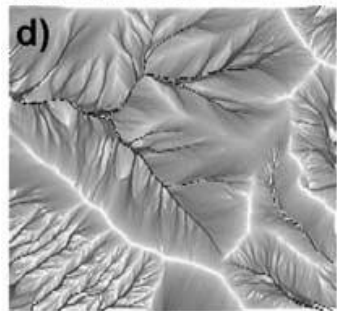
20 m

30 m

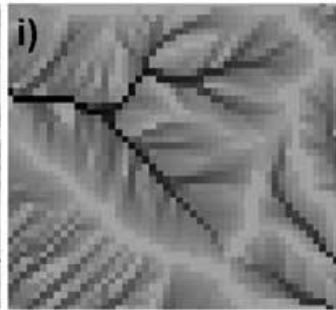
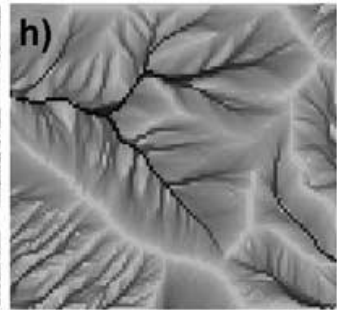
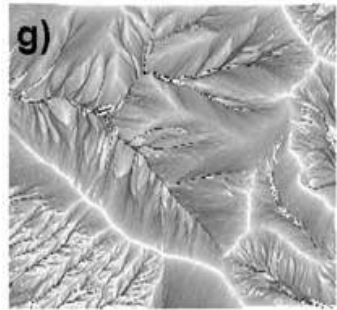
D8



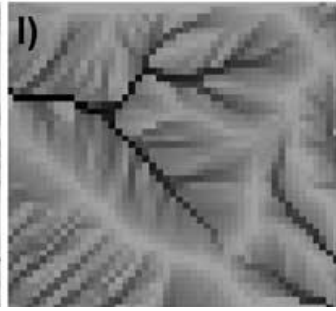
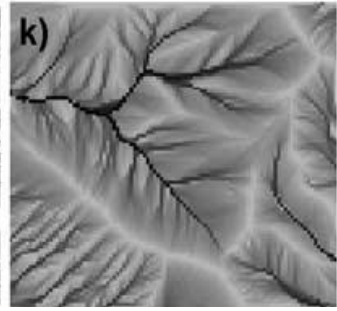
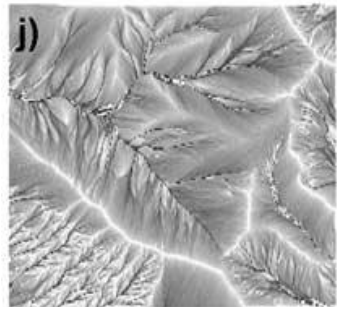
MD8



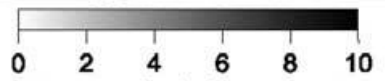
D-∞



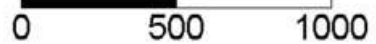
MD-∞



Flow accumulation



$\ln(a)$



Distance in meters

D-8 vs. D-∞: Flow Accumulation

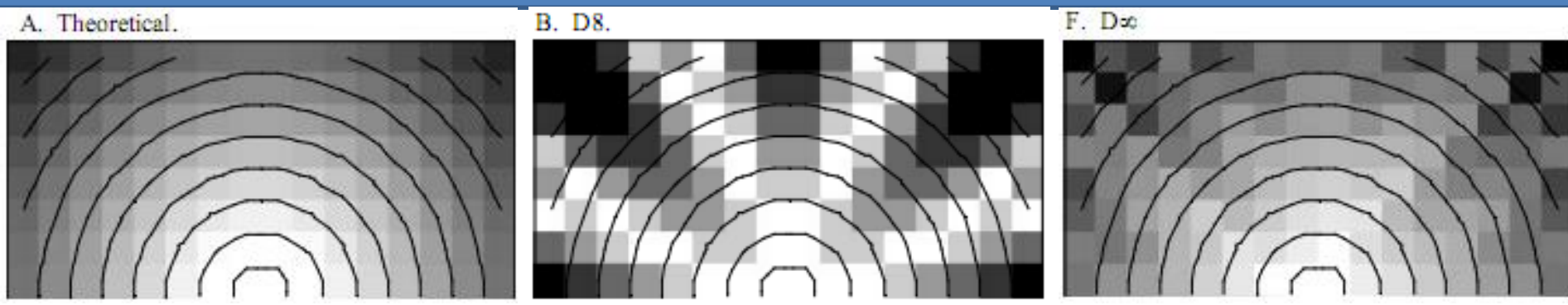


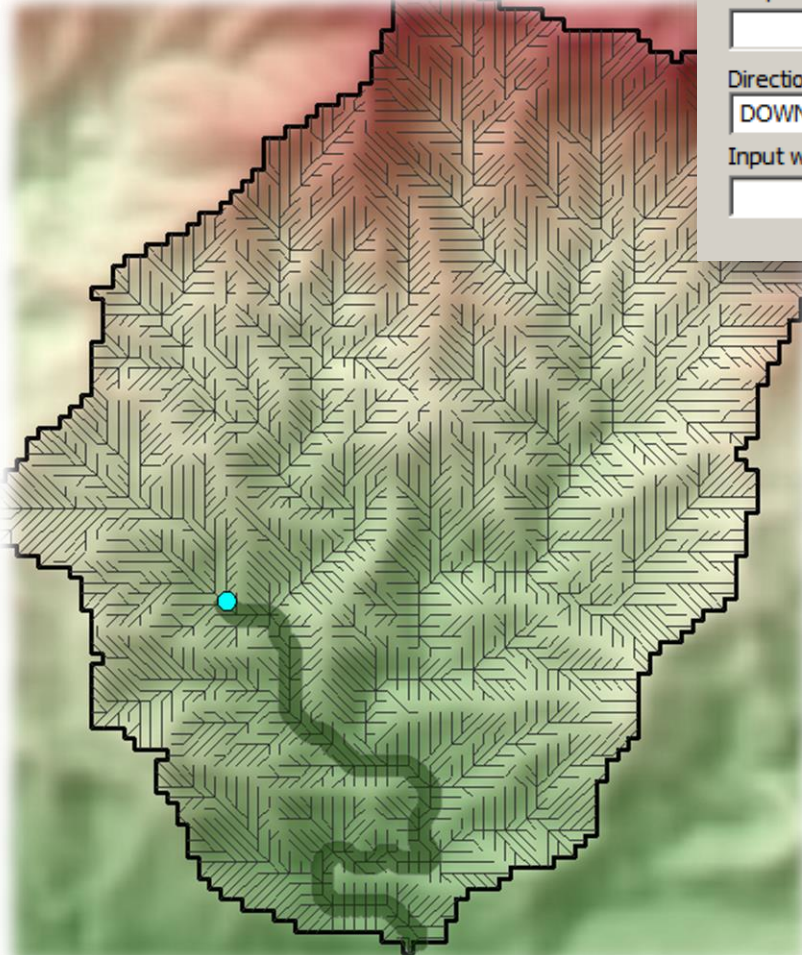
Table 2. Differences between theoretical and DEM computed upslope area for test examples expressed in terms of the mean error (bias) and mean square error (MSE).

	Outward Cone		Inward Cone		Plane	
	bias	MSE	bias	MSE	bias	MSE
	$\text{mean}(A-\hat{A})$	$\text{mean}((A-\hat{A})^2)$	$\text{mean}(A-\hat{A})$	$\text{mean}((A-\hat{A})^2)$	$\text{mean}(A-\hat{A})$	$\text{mean}((A-\hat{A})^2)$
→ D8	-0.13	2.13	1.76	118.88	-0.17	0.065
MS	-0.81	0.69	-1.07	5.70	-1.37	2.065
Lea's method	-1.29	2.41	-4.05	44.00	-2.57	7.912
DEMON	-0.37	0.17	-0.37	19.23	-0.40	0.161
→ D∞	-0.13	0.20	1.87	30.58	-0.17	0.065

<http://www.neng.usu.edu/cee/faculty/dtarb/dinf.pdf>

Flow Length

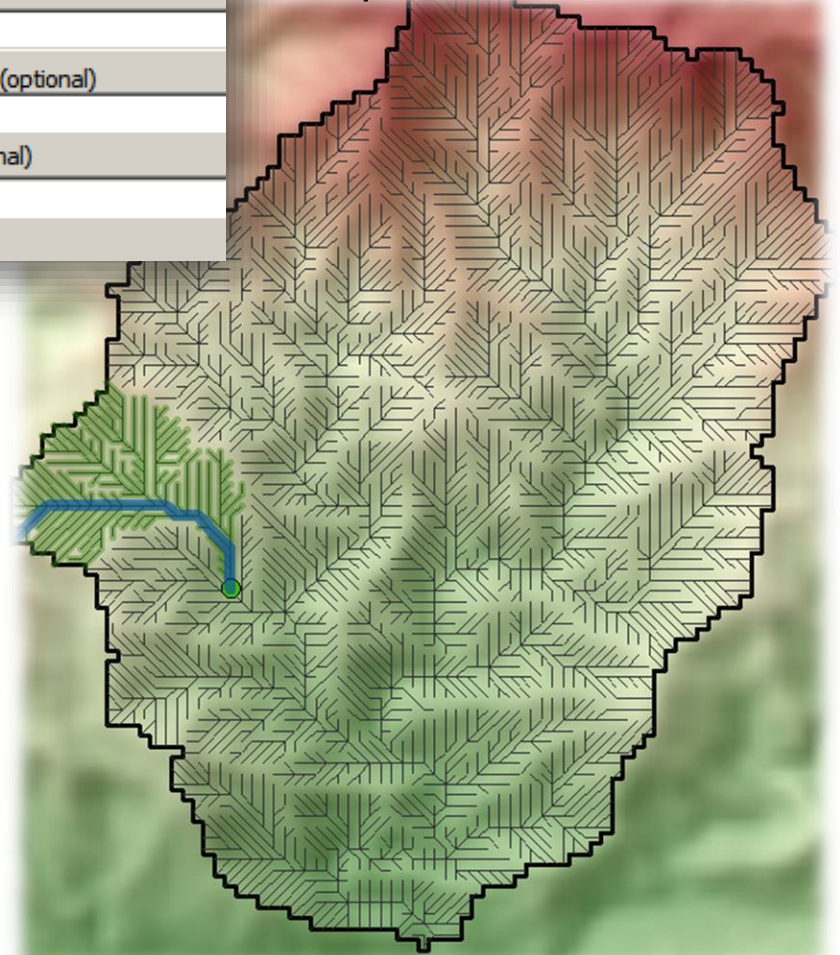
Downstream



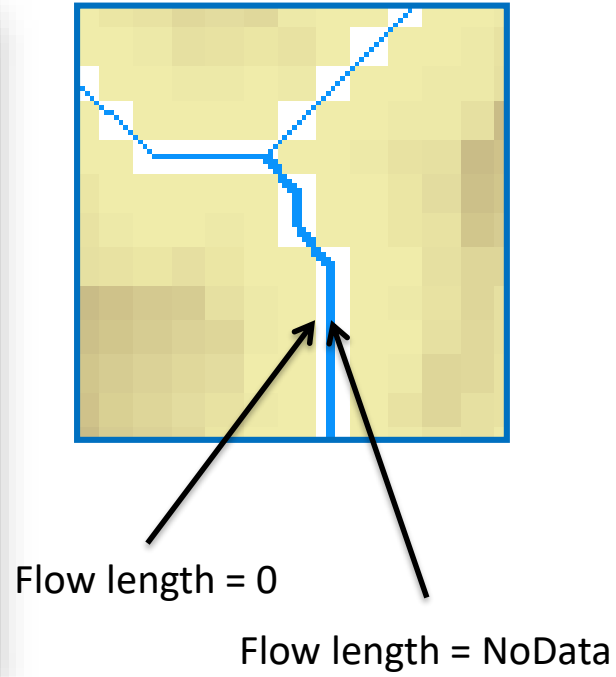
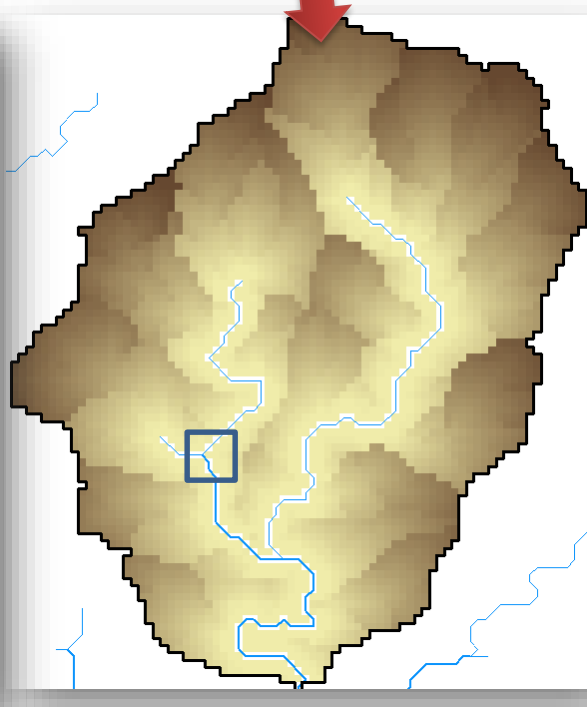
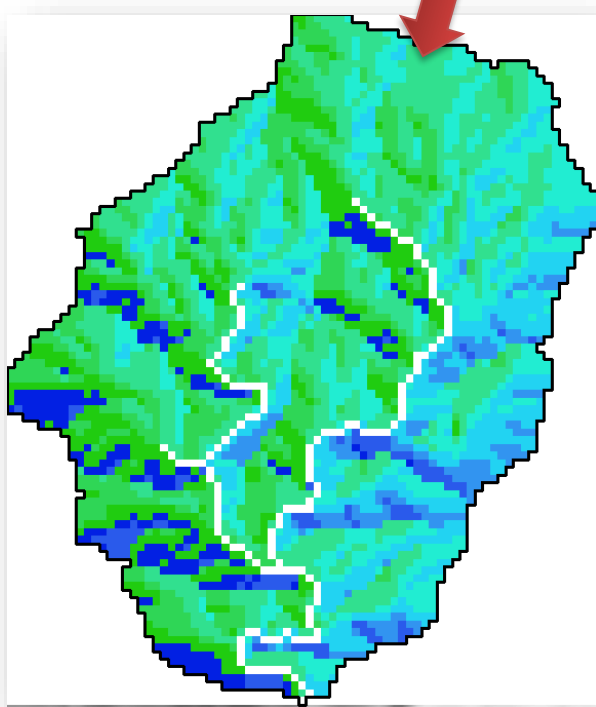
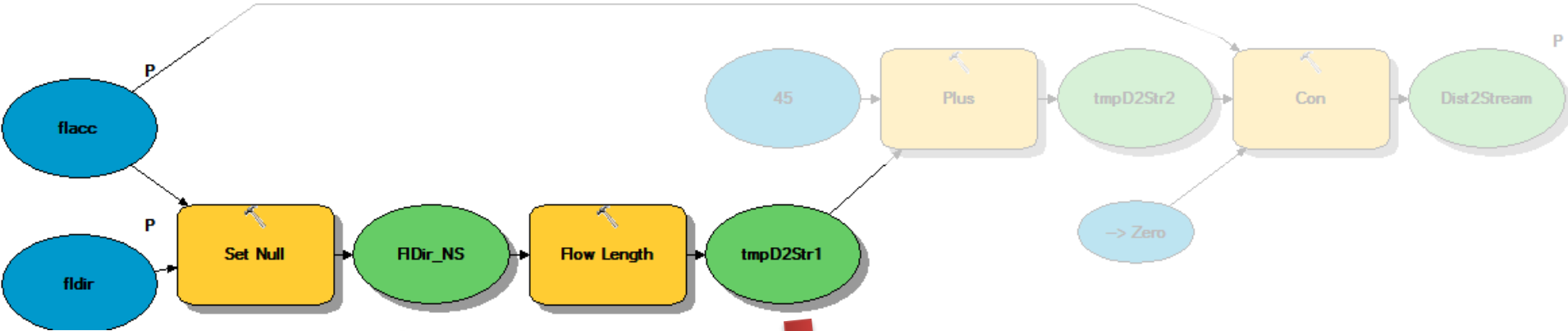
Flow Length

- Input flow direction raster
- Output raster
- Direction of measurement (optional)
DOWNSTREAM
- Input weight raster (optional)

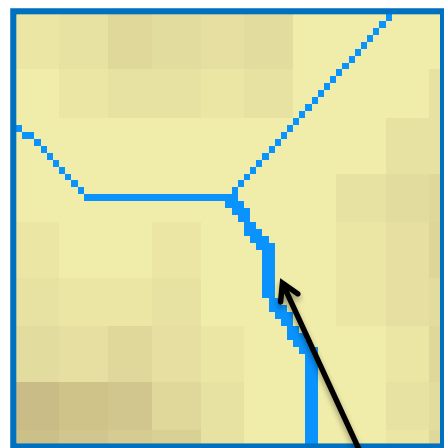
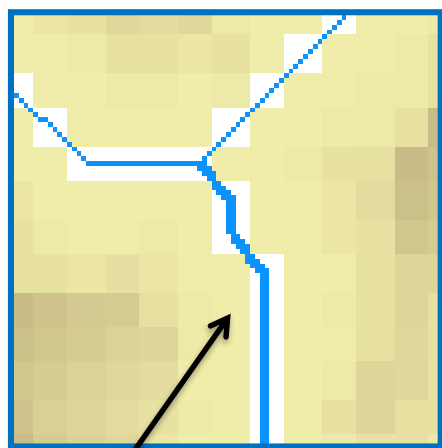
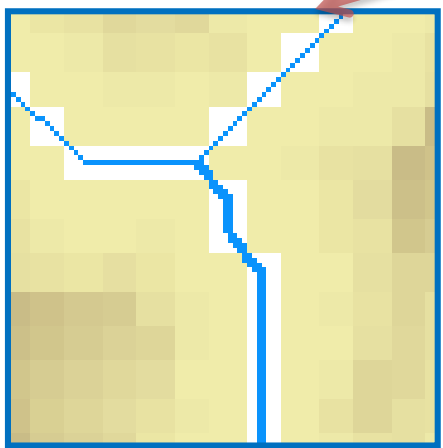
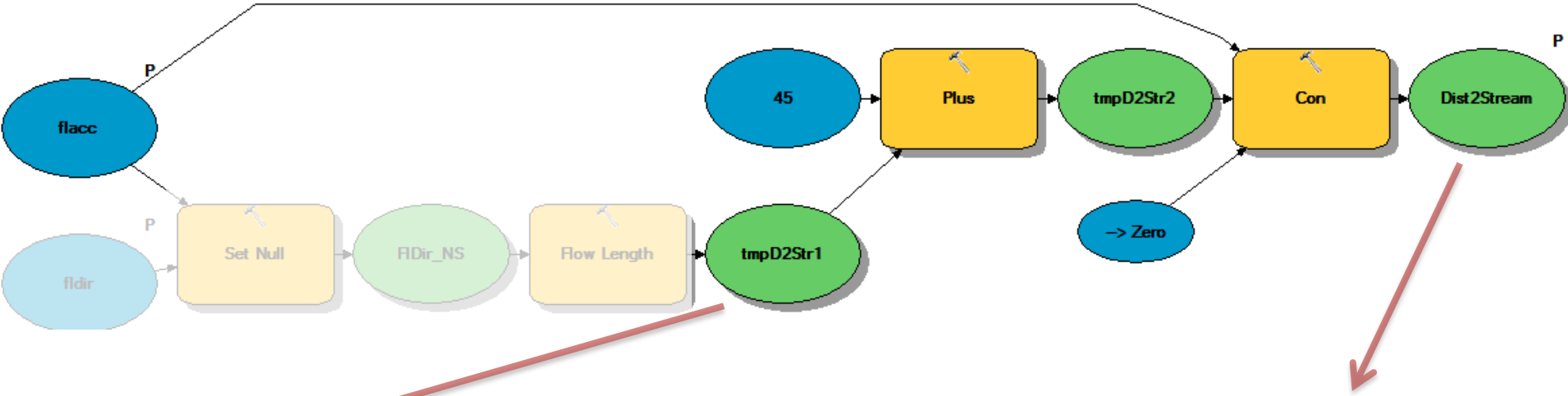
Upstream



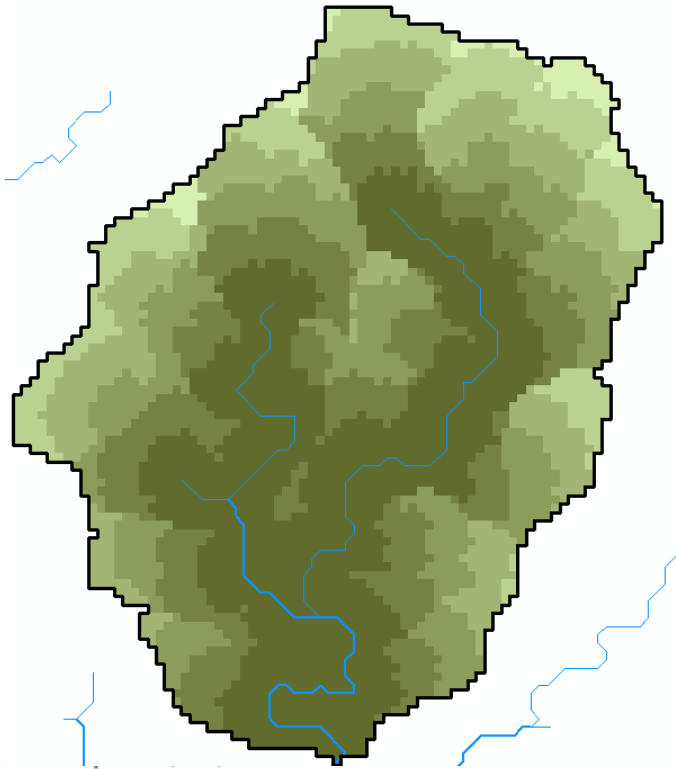
Flow Length (downstream)



Flow Length (downstream)

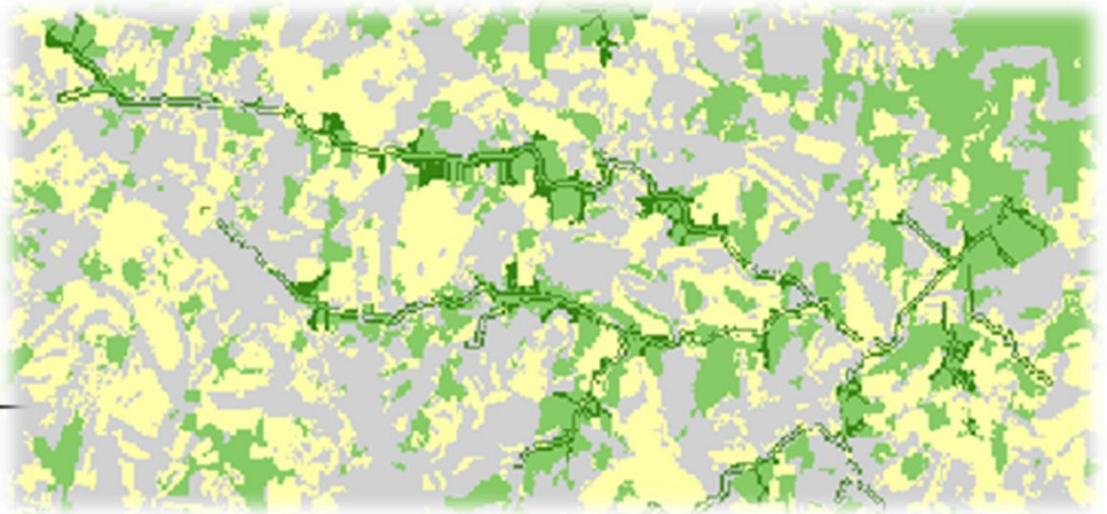


Riparian Areas



DOI 10.1007/s10980-006-0020-0

RESEARCH ARTICLE



Improved methods for quantifying potential nutrient interception by riparian buffers

Matthew E. Baker · Donald E. Weller ·
Thomas E. Jordan

Other topics

- Weighted flow accumulation
- Weighted flow length
- Stream burning

- NHD+ dataset:
<http://www.horizon-systems.com/nhdplus/>
- ArcHydro:
<http://resources.arcgis.com/en/communities/hydro/01vn000000s000000.htm>
- Whitebox:
<http://www.uoguelph.ca/~hydrogeo/Whitebox/>

Ecohydrology: Summary

- Ecohydrology: couples hydrology + ecology
 - Catchment a useful ecological unit
- DEMs & Ecohydrology:
 - DEMs are all you need to roughly approximate:
 1. Drainage area
 2. Accumulated flow (and materials)
 3. Stream courses & stream order

