Watershed Sciences 4930 & 6920
GEOGRAPHIC INFORMATION SYSTEMS

WEEK EIGHT– Lecture

MORPHOMETRIC ANALYSES

Joe Wheaton

HOUSEKEEPING - AFTER

- Lab
  - DEM wrap up
  - Lab 7

- Pushing buttons…
- Think about what you're doing…

Assignments > Labs >

Lab 07 - Morphometric Analyses

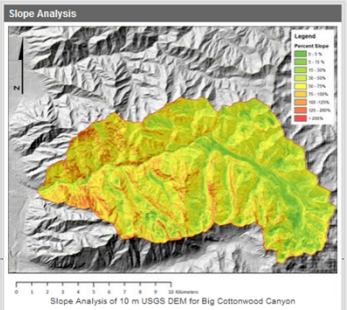
Lab Objectives

The primary purpose of this lab is to show you how to do more with DEMs then just make pretty maps. Upon completion of the workshop exercise, you will have done at **least two** of the following:

1. Delineated a watershed from a DEM
2. Derived a drainage network
3. Apply some common morphometric analyses to DEMs

Meets Course Learning Outcomes 2 & 4.

Slope Analysis



Slope Analysis of 10 m USGS DEM for Big Cottonwood Canyon

Lab Tasks

This week, you are still working for the same old 'Big Cheese' environmental consulting firm who specializes in watershed management (congratulations, you were not fired last week). Your boss has reviewed the work you did comparing and analyzing resolution differences for DEMs in Big Cottonwood Canyon and has come back with some further instructions. For the purposes of this assignment, you should work with the 10 m DEM you used in Lab 6 - Task 1. He would like you to:

- Task 1
  - Delineate the watershed for Big Cottonwood Creek
  - Calculate the size (in km^2) of the Big Cottonwood Creek watershed
- Task 2
  - Perform a Strahler stream order classification of the entire Big Cottonwood Creek watershed
  - Report the total length of streams (in km) of each stream order
- Task 3
  - Calculate slope, plan-form curvature, and profile curvature for the watershed
  - Make maps illustrating slope, plan-form curvature, and profile curvature analysis
  - Provide a brief description about the differences between slope, plan-form curvature, and profile curvature and how the results from your watershed analysis might be used to

What you have to do (IMPORTANT)

Given that Spring Break is coming up and how hard you all worked on Lab 6, you only need to do two of the three tasks. If you are an undergraduate who has just completed WATS 2930, you have already done a watershed delineation. Therefore, you might choose to skip Task 1 and just do Task 2 & 3 (see extra credit options below). Focus on the two tasks that are of most interest to you (and/or relevance to your project). They are all a similar amount of work.

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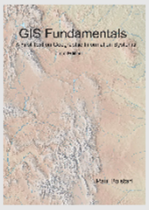
READING FOR TODAY

Assignments > Reading Assignments >

Reading for Tuesday, March 1st

posted 2 minutes ago by Joseph Wheaton



Read Chapter 11 on Terrain Analysis from Bolstad (2008).

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TODAY'S PLAN

I. **Is it *just* a DEM?**

II. Morphometric Analyses
   I. Slope
   II. Aspect
   III. Curvature

III. Combined for Landform Classification

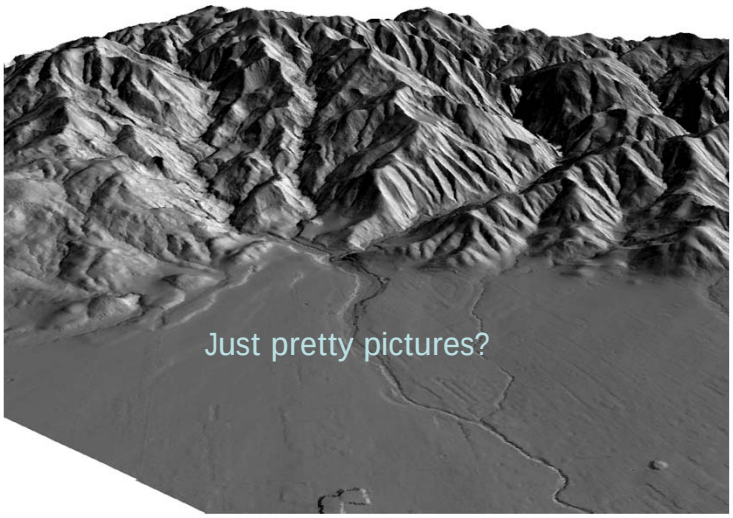
IV. Watershed Delineation

WHAT'S THIS? WHERE'S THIS?

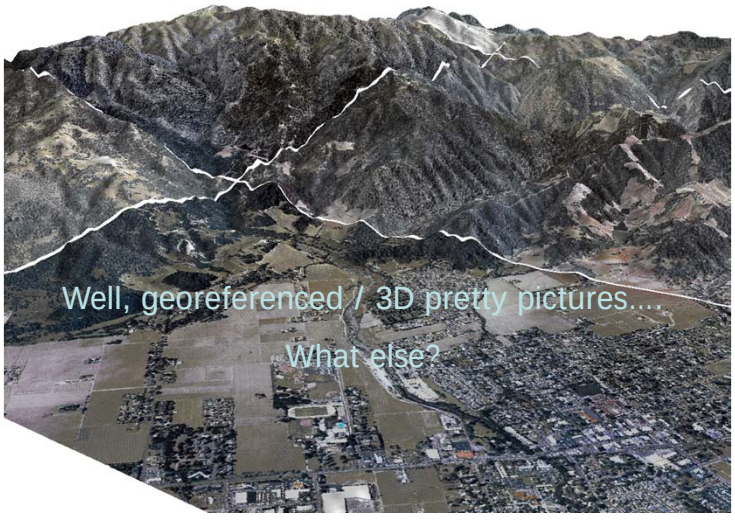
- A hillshade is a morphometric analysis...
- Metrics (measurement) of morphology (i.e. topography)

WHAT CAN YOU DO WITH A DEM?

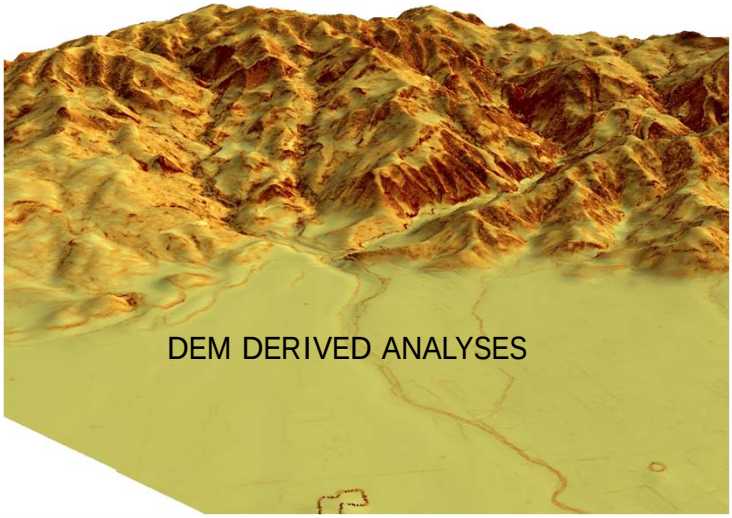
LiDaR-DERIVED HILLSHADE



AERIAL PHOTOGRAPH (LiDaR DRAPING)



LiDaR-DERIVED SLOPE ANALYSIS



DEM MORPHOMETRIC ANALYSES

- Hillshade
- Slope Analysis (affects the overall rate of movement down-slope)
- Aspect (defines direction of flow)
- Profile Curvature (acceleration and deceleration of flow)
- Planform Curvature (convergence and divergence of flow)
- Landform Classification
- Watershed/ Catchment Hydrology
- Slope Stability
- Viewshed Analysis
- DEM Difference

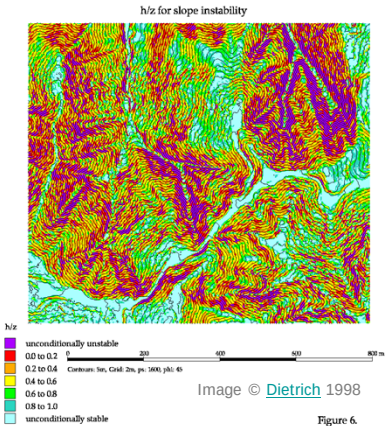
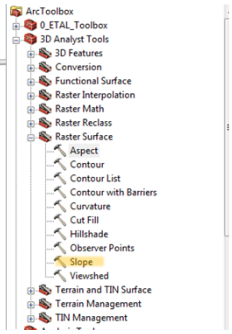


Image © Dietrich 1998

Images © James Barringer & Peter Newsome

TODAY'S PLAN



I. Is it *just* a DEM?

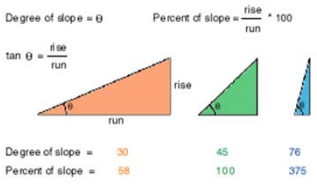
II. Morphometric Analyses
   - **I. Slope**
   - II. Aspect
   - III. Curvature

III. Combined for Landform Classification

IV. Watershed Delineation

CALCULATING SLOPE – 1D

- The slope affects the overall rate of movement downslope
- Proxy for energy grade line in hydrology



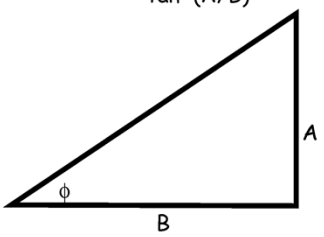
$$\tan\theta = \frac{\partial z}{\partial x} = \frac{rise}{run}$$

Slope as percent = $\frac{rise}{run} * 100$

= A/B * 100

Slope as degrees = ϕ

= $\tan^{-1}(A/B)$



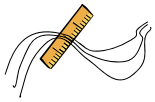
To convert from percent slope to degrees apply formula,
e.g. 3% = how many degrees?

A/B * 100 = 3, then A/B = 3/100 = 0.03

= $\tan^{-1}$ (0.03) = 1.72 degrees

CALCULATING SLOPE – 2D (VECTOR BASED)

- Distance between contours
  - Close together = steep
  - Far apart = shallow



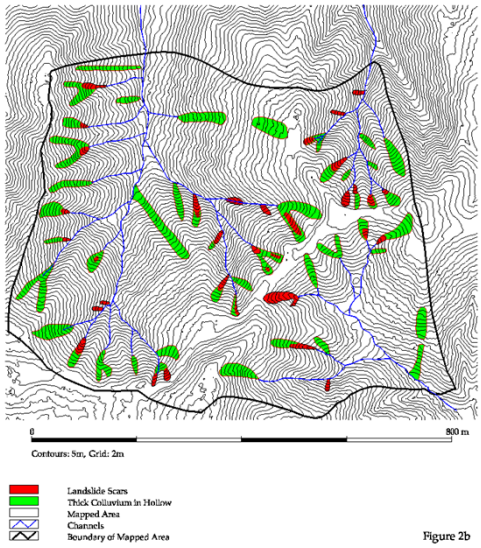


Figure 2b

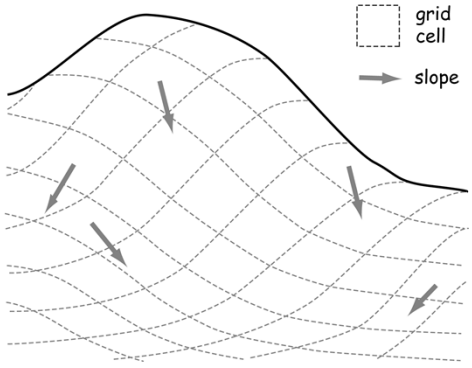
CALCULATING SLOPE – 2D (RASTER BASED)

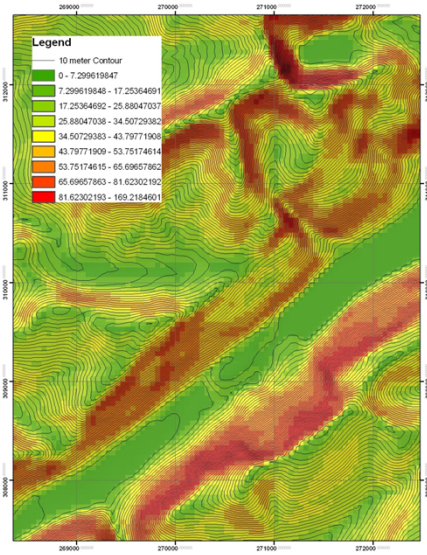
- How do you do that?

42	45	47
40	44	49
44	48	52

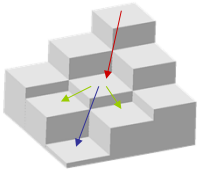
grid cell

slope





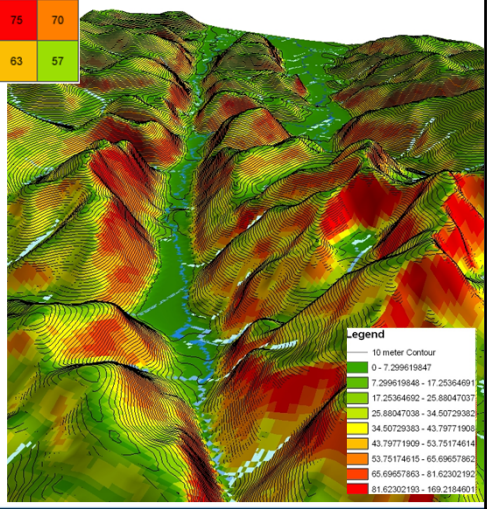
CALCULATING SLOPE – 2D (RASTER BASED)



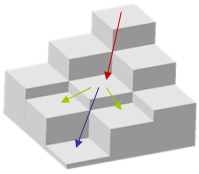
50	45	50
30	30	30
8	10	10

59	56	59
71	75	70
60	63	57

- What do I need to know to calculate
  - An elevation difference (I've got 8 or maybe 12)
  - A distance (I've got 2 or maybe 3)
- Then what?



CALCULATING SLOPE – 2D (RASTER BASED)



50	45	50
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71	75	70
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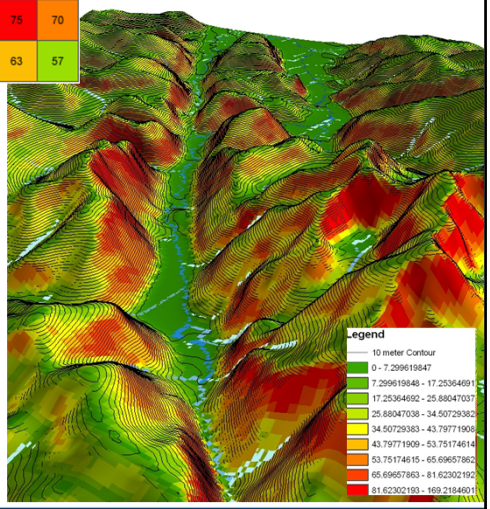
- Absolute Maximum slope
- Maximum of +ve slope
- Average of +ve sloeps
- Minimum of +ve slopes
- Slope entering (-ve) vs. exiting (+ve)
- Hydraulic vs. Sediment (energy grade line, water surface slope, bed slope)



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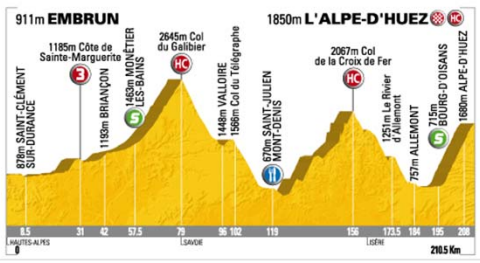
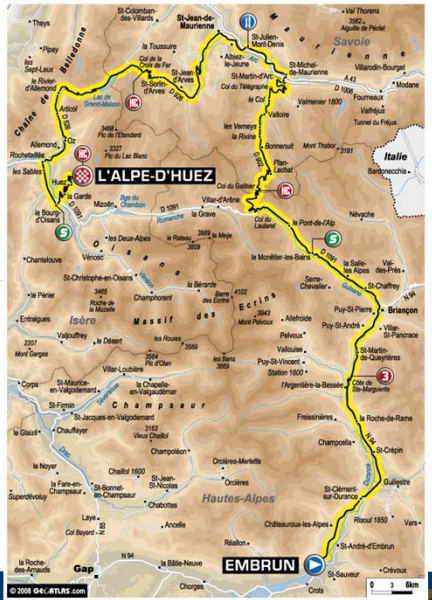
WHO CARES ABOUT SLOPE?

- Measure of potential energy (for going down)
- Indicator of energy expenditure required (for going up)

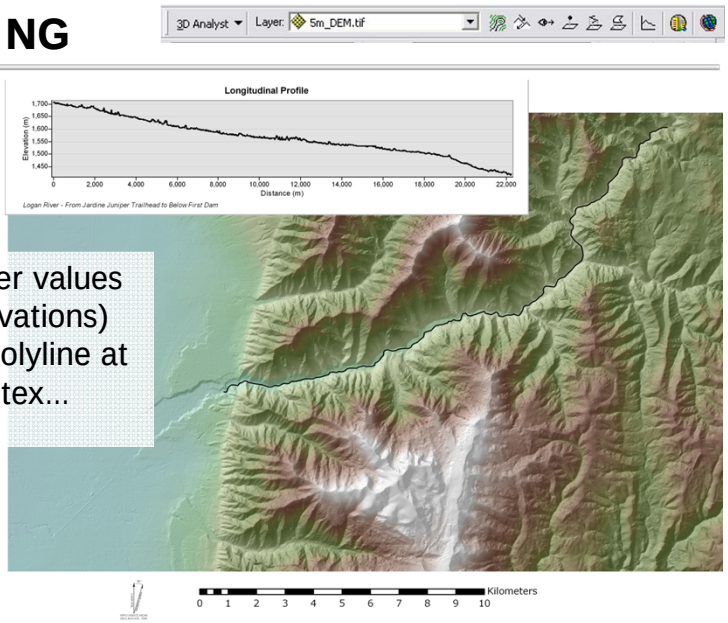
HOW DID THEY GET THAT?



Well... they had a DEM, they had a route... extracted a profile and calculated a derivative over some *dx*



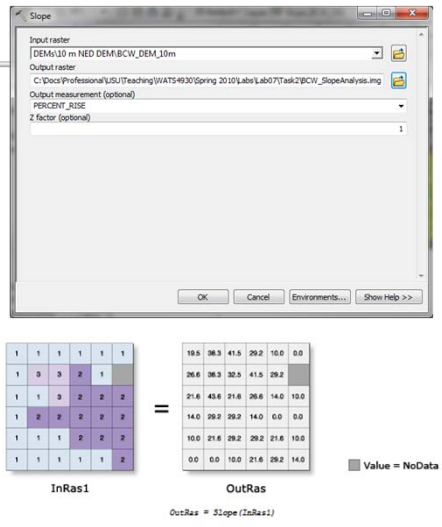
PROFILING



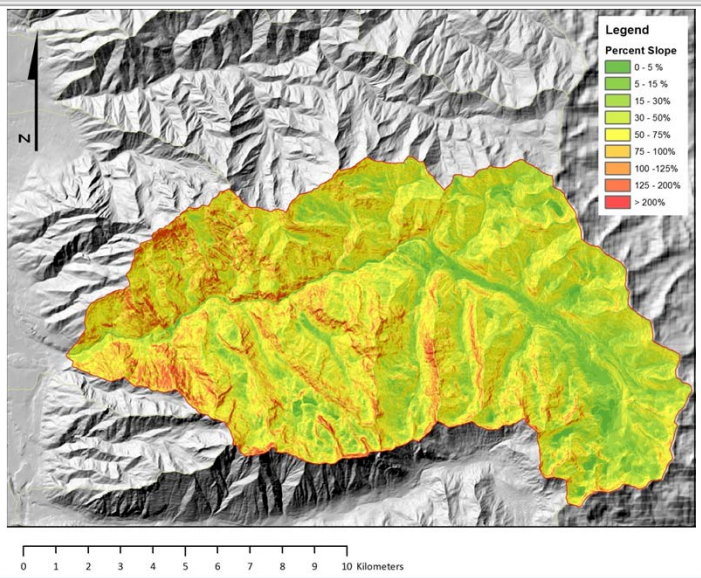
Extract raster values (DEM elevations) along a polyline at every vertex...

IN ARCGIS

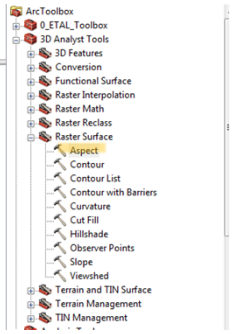
- Slope is the rate of maximum change in z-value from each cell.
- The use of a z-factor is essential for when surface z units are expressed in units different from ground x,y units
- The range of slope values in degrees is 0 to 90. For percent rise, the range is 0 for near infinity. A flat surface is 0 percent, a 45 degree surface is 100 percent



YOU'LL DO THIS FOR BIG COTTONWOOD CANYON



TODAY'S PLAN



I. Is it *just* a DEM?

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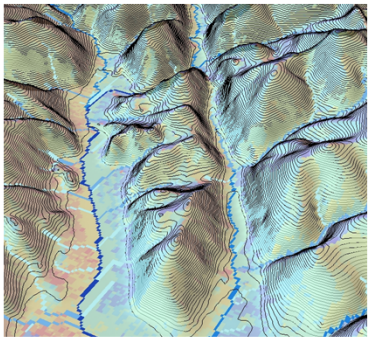
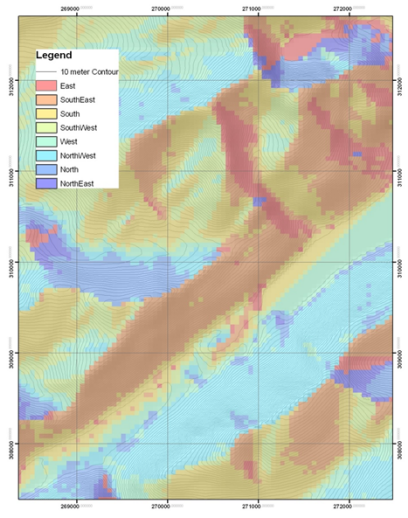
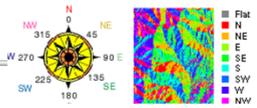
ASPECT – WHAT IS IT?

- Steepest downslope direction from each cell to its neighbours
- The direction slope faces



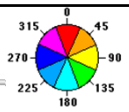




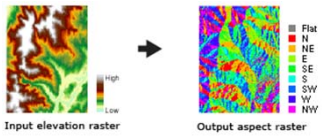
ASPECT – WHO CARES?

- Determines exposure to insolation (sol = sun) and winds…

ASPECT IN ARCGIS

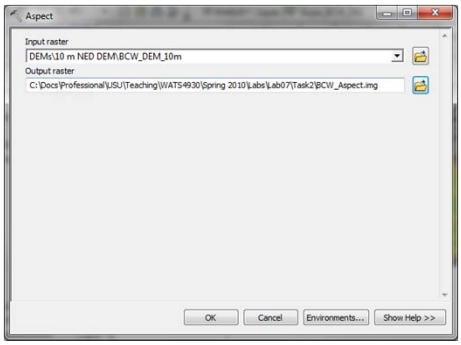


- Aspect is the direction of the maximum rate of change in the z-value from each cell in a raster surface.
- Aspect is expressed in positive degrees from 0 to 359.9, measured clockwise from north.
- Cells in the input raster that are flat—with zero slope—are assigned an aspect of -1.

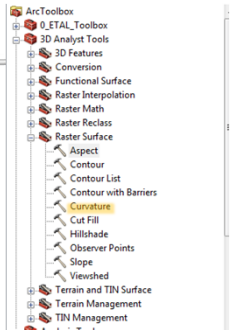


Input elevation raster

Output aspect raster



TODAY'S PLAN



I. Is it *just* a DEM?

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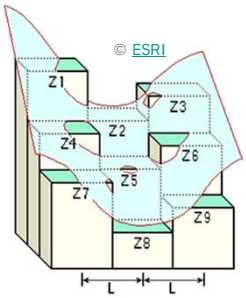
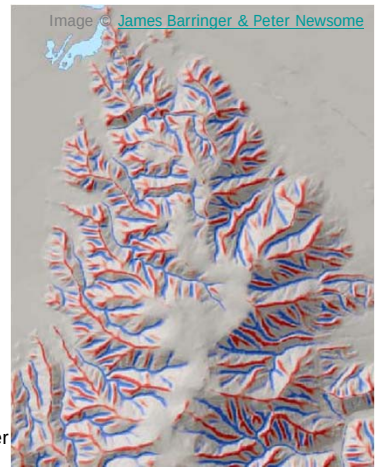
CURVATURE

- Second derivative of elevation
- Derivative of slope (i.e. the rate of change of slope)



$$\frac{\partial^2 z}{\partial S} = \frac{\partial}{\partial z}\left(\frac{\partial z}{\partial x}\right)$$



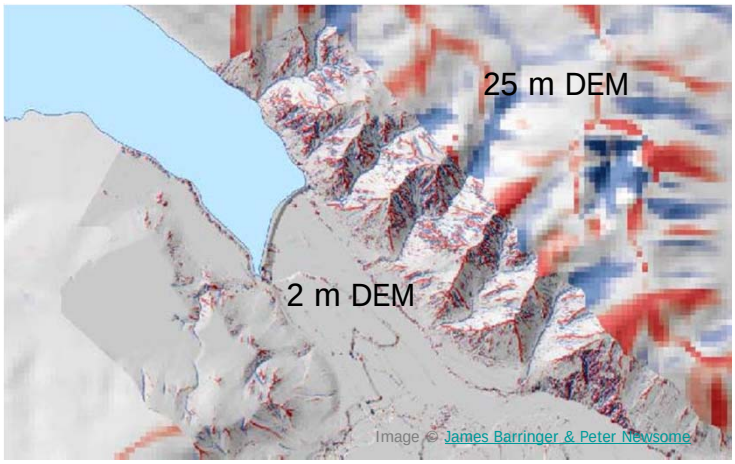
Calculated on a cell-by-cell basis. For each cell, a fourth-order polynomial of the form:

$Z = Ax^2y^2 + Bx^2y + Cxy^2 + Dx^2 + Ey^2 + Fxy + Gx + Hy + I$

is fit to a surface composed of a 3 x 3 window.

GRID RESOLUTION DEPENDENCE!

- 2 m LiDAR DEM vs. 25 m DEM



CURVATURE CAN BE BROKEN DOWN

- Component parts are profile (slopes) and planform (contours) curvature

Z_1	Z_2	Z_3
Z_4	Z_0	Z_5
Z_6	Z_7	Z_8

← C →

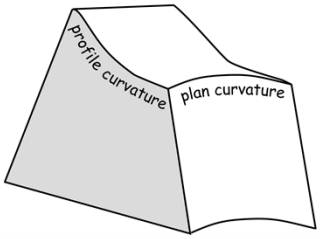
$D = [(Z_4 + Z_5)/2 - Z_0] / C^2$

$E = [(Z_2 + Z_7)/2 - Z_0] / C^2$

$F = (Z_3 - Z_1 + Z_6 - Z_8) / 4C^2$

$G = (Z_5 - Z_4) / 2C$

$H = (Z_2 - Z_7) / 2C$



plan curvature

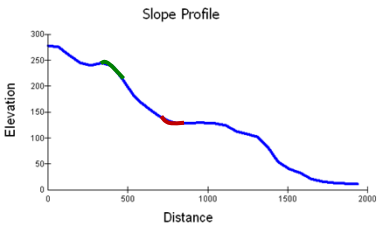
$$\frac{2 (DH^2 + EG^2 - FGH)}{G^2 + H^2}$$

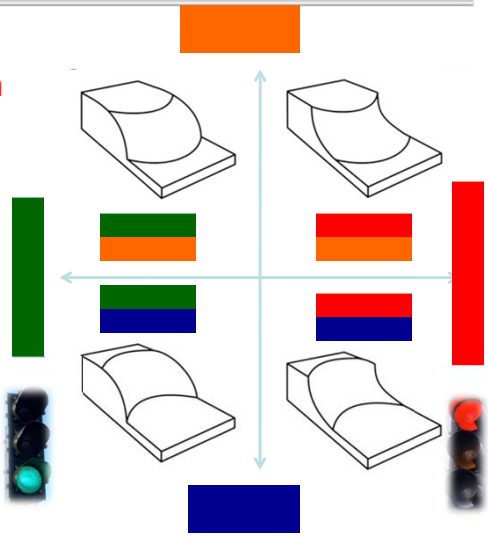
profile curvature

$$\frac{-2 (DG^2 + EH^2 + FGH)}{G^2 + H^2}$$

PROFILE CURVATURE

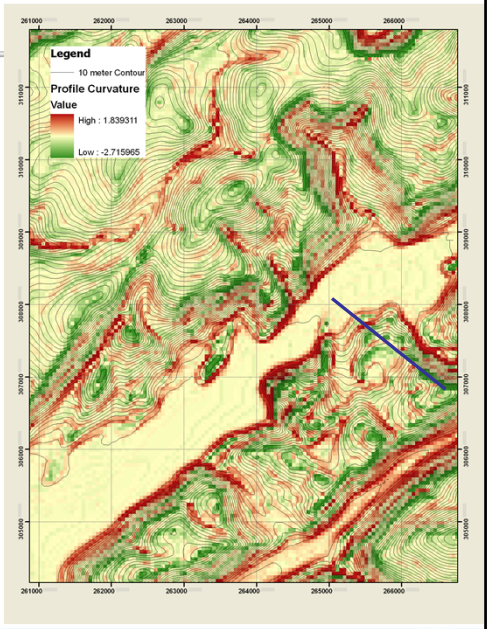
- - Curvature = Acceleration
- + Curvature = Deceleration
- - Convex Slope
- + Concave Slope



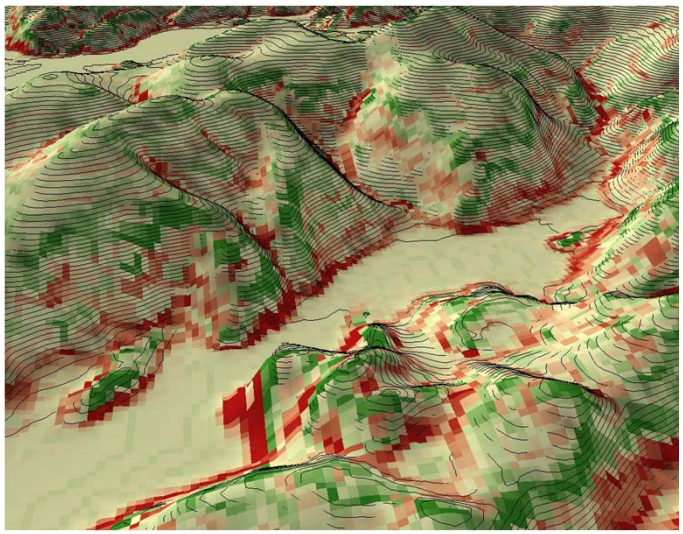


PROFILE CURVATURE

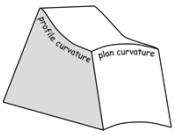
- - Curvature = Acceleration
- + Curvature = Deceleration
- - Convex Slope
- + Concave Slope

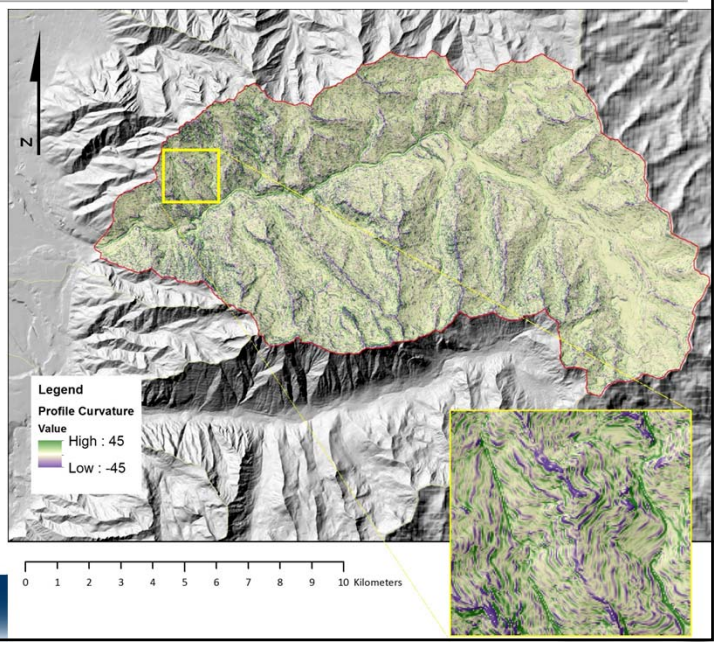


PROFILE CURVATURE



BIG COTTONWOOD PROFILE CURVATURE





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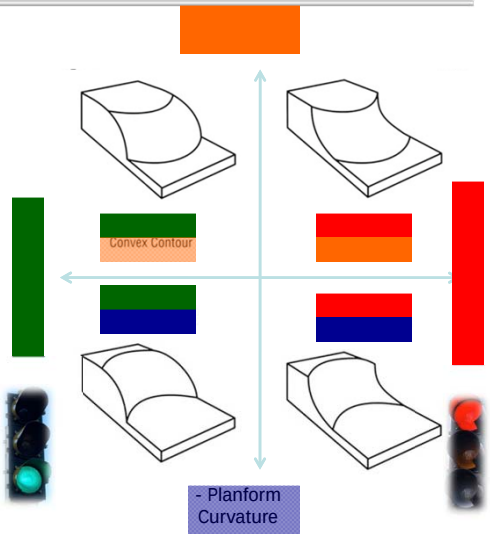
PLANFORM CURVATURE

- + Curvature = Divergent Slope
- - Curvature = Convergent Slope
- 0 = Planar Slope
- + Dry (ridges)
- - Wet (hollows)



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PLANFORM CURVATURE

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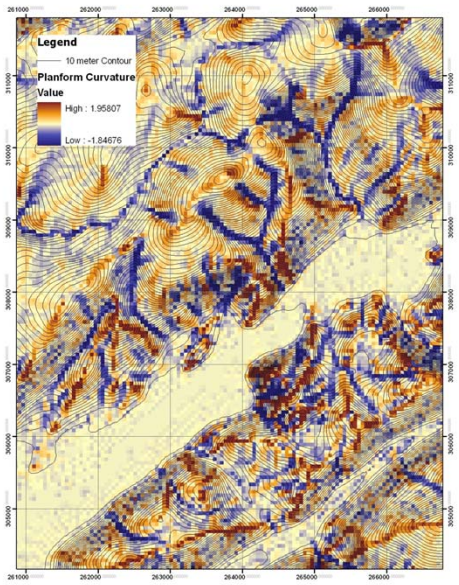
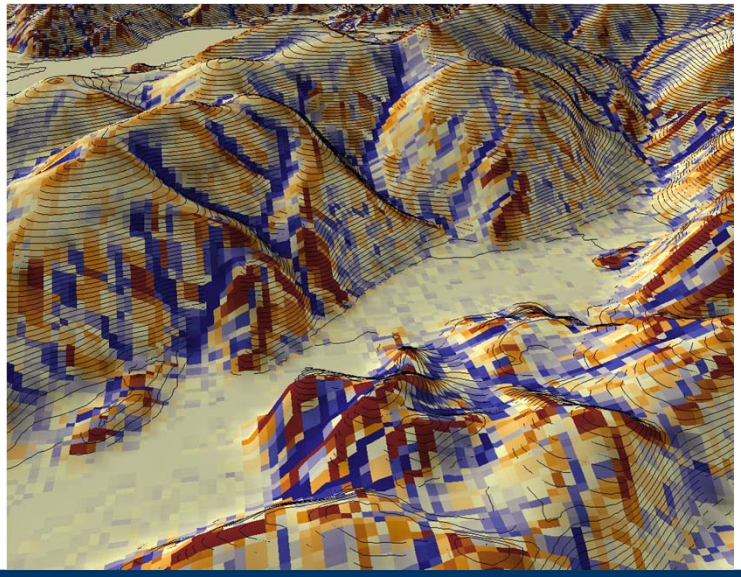
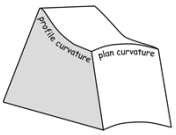
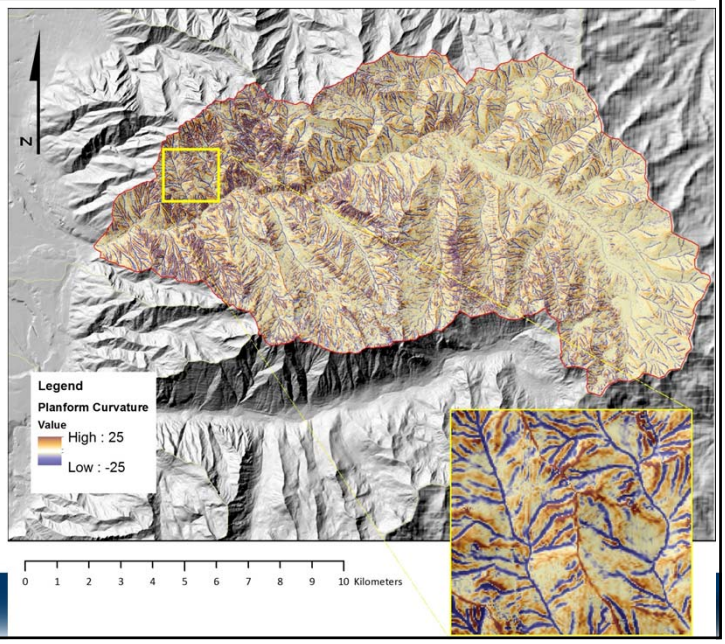


PLANFORM CURVATURE



BIG COTTONWOOD PLANFROM CURVATURE





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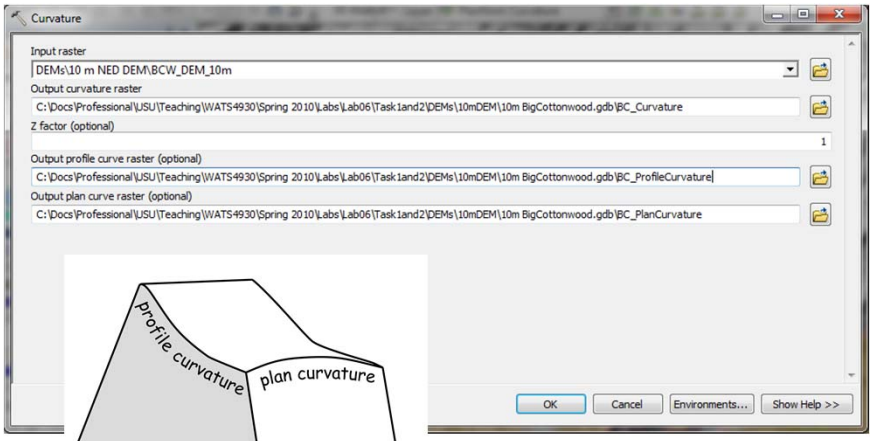
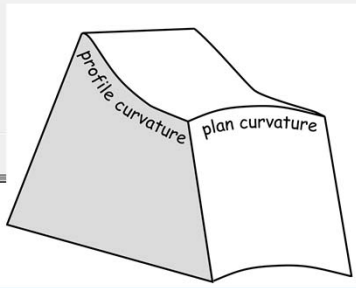
CURVATURE IN ARCGIS





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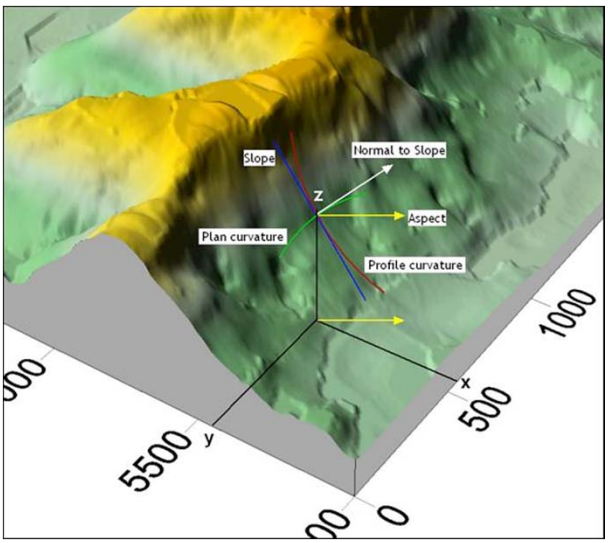
TODAY'S PLAN

I. Is it *just* a DEM?
II. Morphometric Analyses
    I. Slope
    II. Aspect
    III. Curvature
III. Combined for Landform Classification
IV. Watershed Delineation
V. DEM Differencing

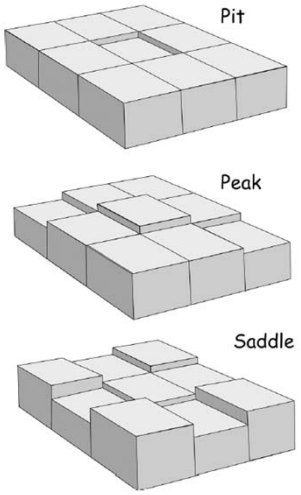
ALL IN ONE…

- So what could one do with slope, curvature and aspect?



LANDFORM CLASSIFCATION

- Based on these definitions



LANDFORMS CLASSIFICATION

- Fuzzy landform classification
- Degree of membership in each class as opposed to crisp classification... (LANDSERF)

Spurs

Hollows

Ridges

Images © James Barringer & Peter Newsome

TODAY'S PLAN

I. Is it *just* a DEM?

II. Morphometric Analyses

  I. Slope

  II. Aspect

  III. Curvature

III. Combined for Landform Classification

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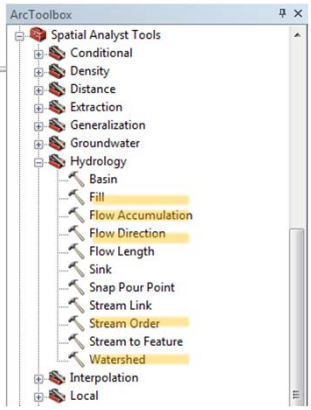
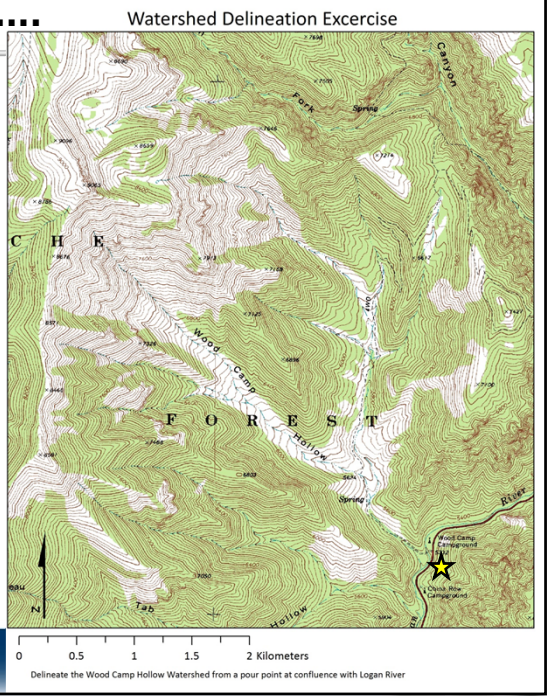
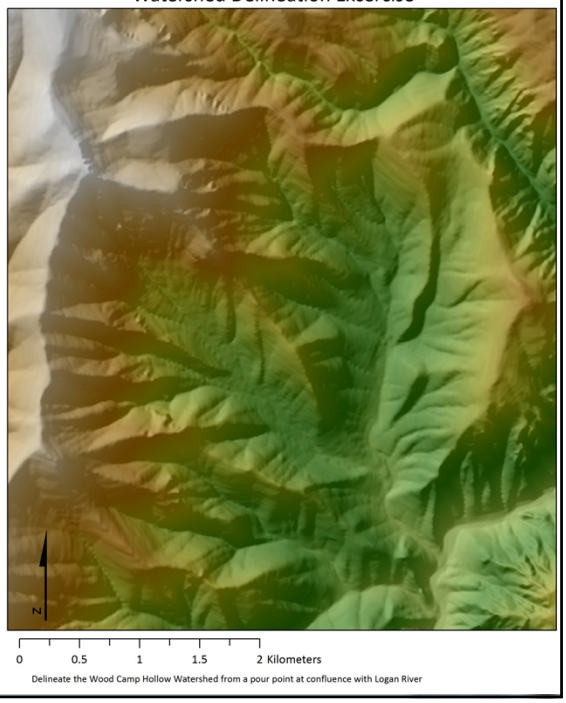


DERIVE WATERSHED….

- Use confluence with Logan River as pour point
- Play the raindrop game…
  - I fall where I fall, but can only flow downhill (i.e. perpendicular to contours)
  - I shed away from ridges and collect in hollows…



JUST DEM…



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DEM & BNDY

- Watershed in Red….

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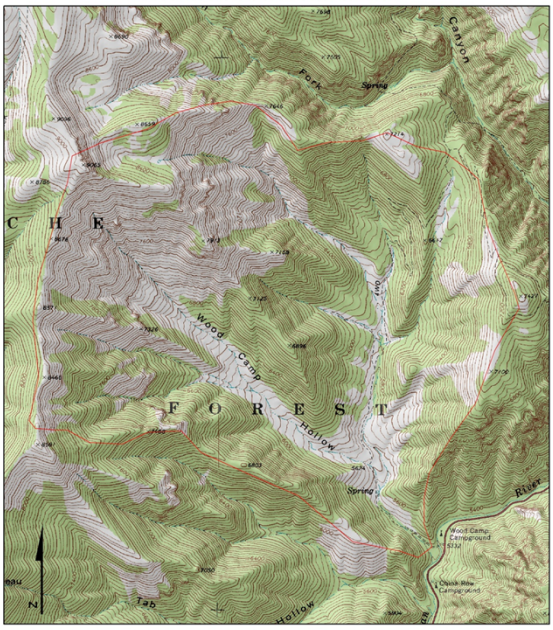
ON USGS MAP

Watershed Delineation Excercise



Delineate the Wood Camp Hollow Watershed from a pour point at confluence with Logan River

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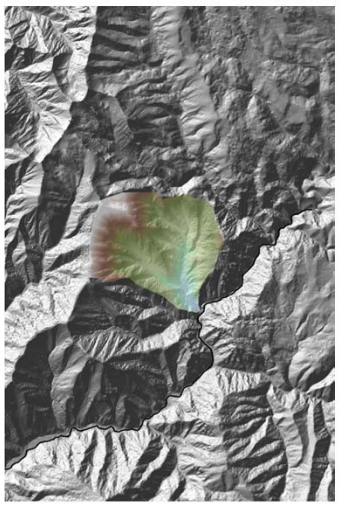
DELINEATION EXCERCISE



0 1 2 3 4 5 6 7 8 9 10 Kilometers

GIS Data from: http://gis.utah.gov/

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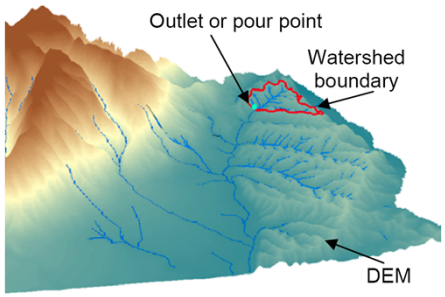
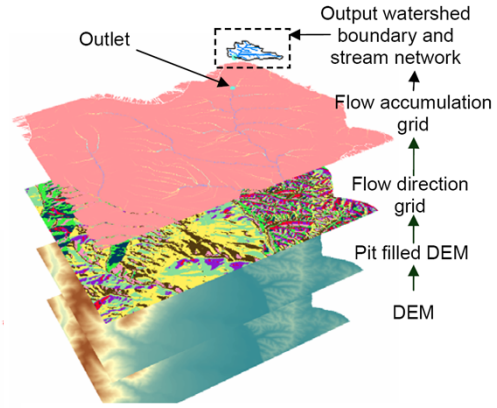
WATERSHED DELINEATION

- 4 Basic Steps
- Assumes gravity is dominant factor influencing flow direction





Images from Multi-Watershed Delineation Tool Manual

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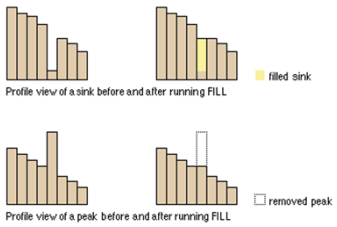
1. PIT-FILLING

- Sinks should be filled to ensure proper delineation of basins and streams.
- If the sinks are not filled, a derived drainage network may be discontinuous.



2. FLOW DIRECTION

- What do we call this?

a)

4	3	2
5		1
6	7	8

1 - East
2 - North East
3 - North
4 - North West
5 - West
6 - South West
7 - South
8 - South East

b)

8	8	7	7	6
1	8	7	6	7
2	1	8	7	6
8	1	7	7	7
1	1	1	8	5

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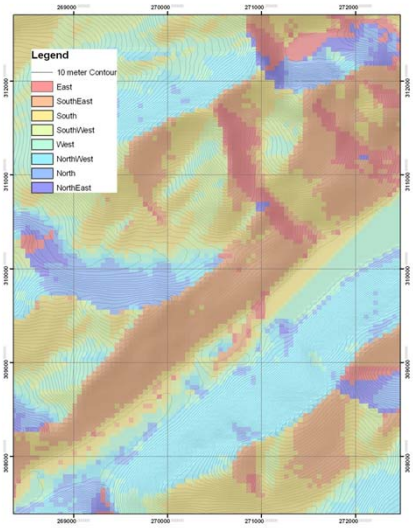

3. FLOW ACCUMULATION

- Count of number of cells upstream (based on flow direction)
- High values indicate greater accumulation

1	1	1	1	1
1	4	3	3	1
1	1	12	1	2
1	1	2	1	1
1	3	6	25	2

Image from Multi-Watershed Delineation Tool Manual

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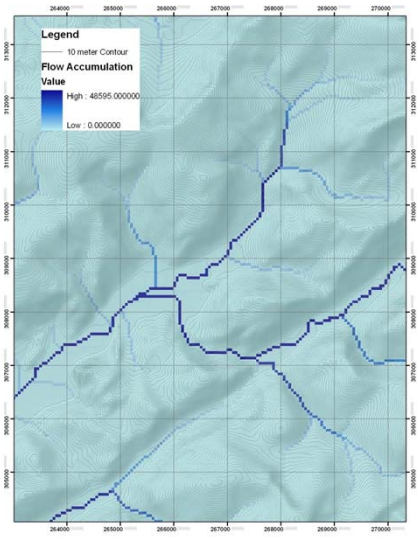
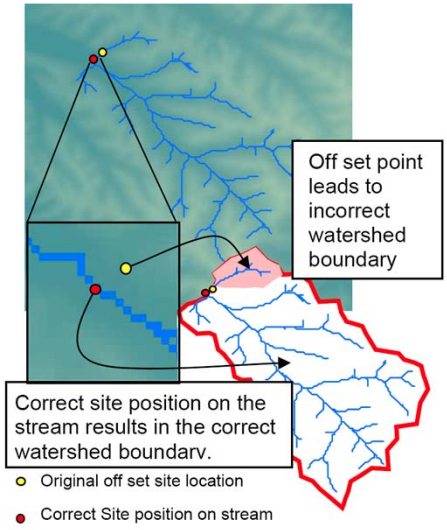


4. DEFINE POUR POINTS

- AKA Basin Outlets
- Very sensitive to DEM grid resolution!



Images from Multi-Watershed Delineation Tool Manual

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5. WATRSHED DELINEATED!

- A catchment boundary defined
- numerous scales (e.g. hydrologic units)
- Helpful as input into hydrologic models

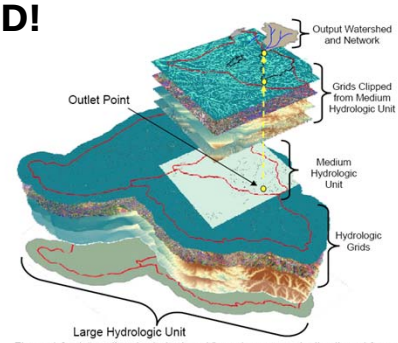
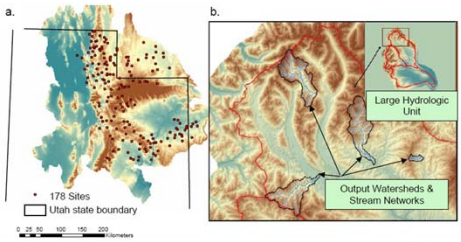


Figure 1.9. A "medium hydrologic unit" can be automatically clipped from a "large hydrologic unit" for easier delineation of individual watersheds.



Images from Multi-Watershed Delineation Tool Manual

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FLOW ACCUMULATION: CAN ALSO BE USED FOR…

- Stream channel network delineation
  - Threshold at some arbitrary resolution-dependent value

1	1	1	1	1
1	4	3	3	1
1	1	12	1	2
1	1	2	1	1
1	3	6	25	2

Image from Multi-Watershed Delineation Tool Manual

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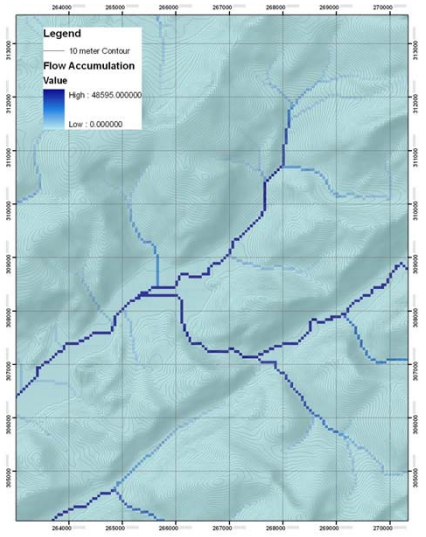
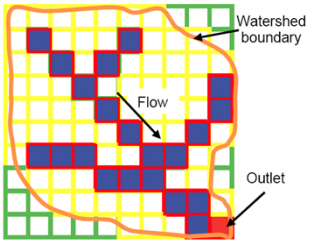
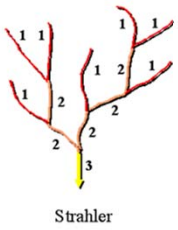


DRAINAGE NETWORK DEFINED

- Connect cells above threshold
- Stream Order





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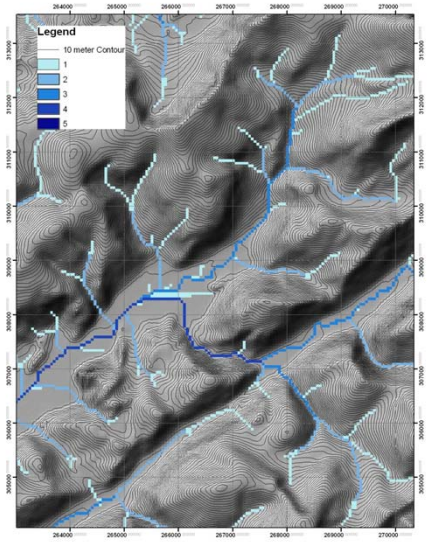

SUMMARY

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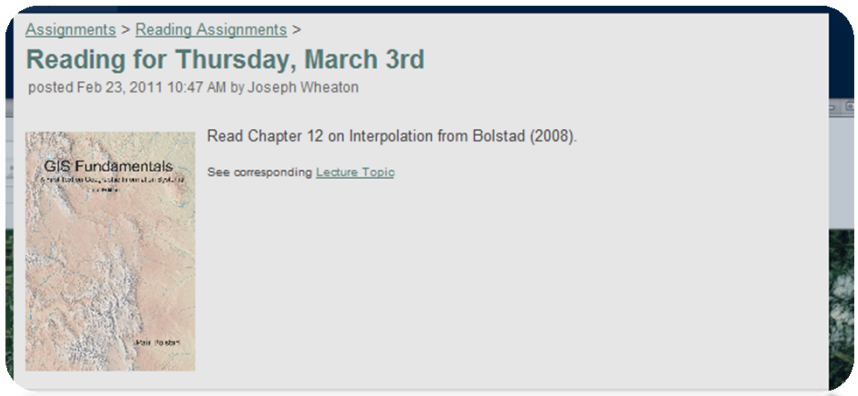
READING FOR THURSDAY