COA 690/790 GIS in Marine Science

Lecture 11
Terrain Analysis

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Digital Elevation Models

Terrain determines the natural availability and location of surface water, and hence soil moisture and drainage.

Terrain affects water quality through control of sediment generation and transport.

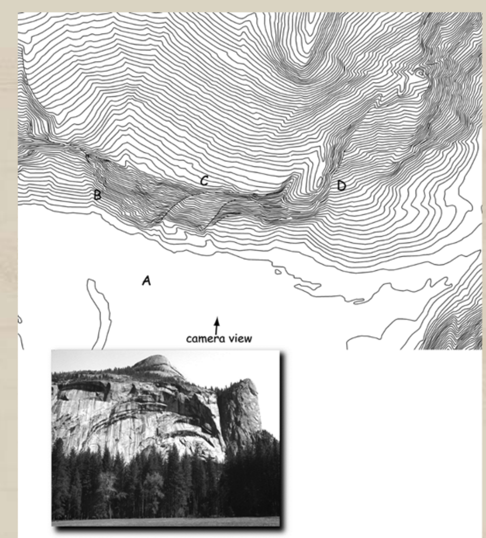
Elevation, slope steepness and direction defines flood zones, watershed boundaries and hydrologic networks.

Terrain also strongly influences location and nature of transportation networks or the cost and methods of house and road construction.

Table 11-1: A subset of commonly used terrain variables. (adapted from Moore et al., 1993).

Variable	Description	Importance
Height	Elevation above base	Temperature, vegetation, visibility
Slope	Rise relative to horizontal distance	Water flow, flooding, erosion, travel cost, construction suitability, geology, insolation, soil depth
Aspect	Downhill direction of steepest slope	Insolation, temperature, vegetation, soil characteristics and moisture, visibility
Upslope area	Watershed area above a point	Soil moisture, water runoff volume and timing, pollution or erosion hazards
Flow length	Longest upstream flow path to a point	Sediment and erosion rates
Upslope length	Mean upstream flow path length to a point	Sediment and erosion rates
Profile curvature	Curvature parallel to slope direction	Erosion, water flow acceleration
Plan curvature	Curvature perpendicular to slope direction	Water flow convergence, soil water, erosion
Visibility	Site obstruction from given viewpoints	Utility location, viewshed preservation

Contour lines (Topographic contours)



Most terrain analysis are performed using a raster data model

Digital Elevation Models

Terrain Analysis - Slope and Aspect

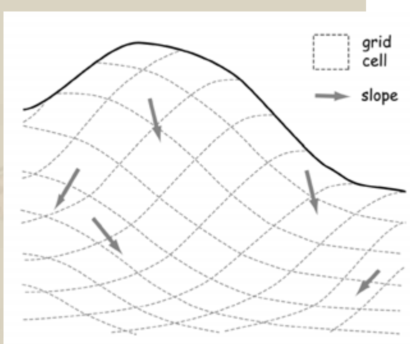
•Used for: hydrology, conservation, site planning, other infrastructure development.

•Watershed boundaries, flowpaths and direction, erosion modeling, and viewshed determination all use slope and/or aspect data as input.

•Slope is defined as the change is elevation *(a rise)* with a change in horizontal position *(a run).*

•Slope is often reported in degrees *(0° is flat, 90° is vertical)*

Slope *(continued)*

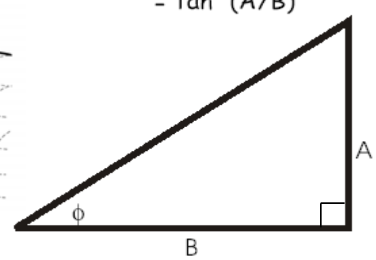


$$\text{Slope as Percent} = \frac{\text{rise}}{\text{run}} * 100$$

$$= A/B * 100$$

$$\text{Slope as Degrees} = \phi$$

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



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

Slope *(continued)*
Measured in the steepest direction of elevation change

Often does not fall parallel to the raster rows or columns

Which cells to use?

Several different methods:

- *Four nearest cells*
- *3rd Order Finite Difference*

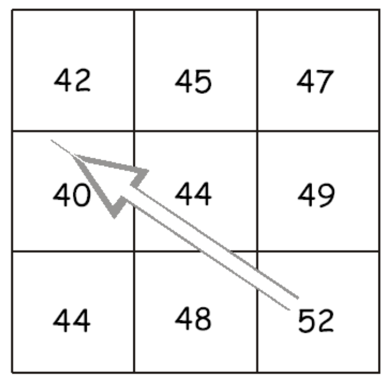


Figure 11-18: Direction of steepest slope.

Slope *(continued)*

Elevation is Z

- Using a 3 by 3 *(or 5 by 5)* moving window
- Each cell is assigned a subscript and the elevation value at that location is referred to by a subscripted Z value

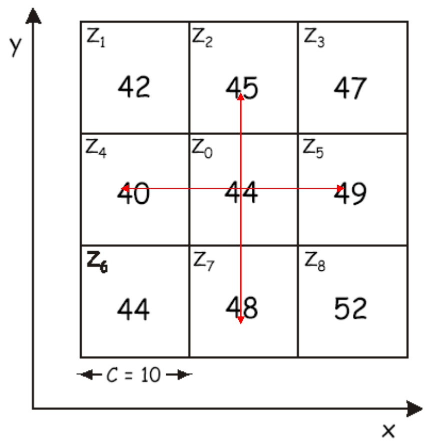
The most common formula:

$$s = \operatorname{atan} \sqrt{\left(\frac{dZ}{dx}\right)^2 + \left(\frac{dZ}{dy}\right)^2}$$

Slope *(continued)*

$$dZ/dx = (Z_5 - Z_4)/(2C)$$

$$dZ/dy = (Z_2 - Z_7)/(2C)$$



for Z_o

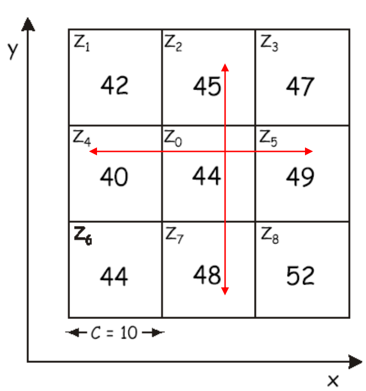
$\Delta Z/\Delta x = (49 - 40)/20 = 0.45$

$\Delta Z/\Delta y = (45 - 48)/20 = -0.15$

$$\text{slope} = \tan^{-1} [(0.45)^2 + (-0.15)^2]^{1/2}$$

$$= 25.3^o$$

Slope *(continued)*



Generalized formula for

$\Delta Z/\Delta x$ and $\Delta Z/\Delta y$

$\Delta Z/\Delta x = (Z_5 - Z_4)2^*$

$\Delta Z/\Delta y = (Z_2 - Z_7)2^*$

* = times cell width

Using the four nearest cells

- Slope calculation base on cells adjacent to the center cell
- The distance is from cell center to cell center

Slope *(continued)*

Multiply *(kernal, cell by cell)*
Add *(results)*
Divide by #cells x cell width
Use slope formula

Four nearest cells
elevation values

42	45	47
40	44	49
44	48	52

← C = 10 →

Kernal for ΔZ/Δx x

Z_1 0	Z_2 0	Z_3 0
Z_4 -1	Z_0 0	Z_5 1
Z_6 0	Z_7 0	Z_8 0

ΔZ/Δx = (49 – 40)/20 = 0.45 5

Kernal for ΔZ/Δy y

Z_1 0	Z_2 1	Z_3 0
Z_4 0	Z_0 0	Z_5 0
Z_6 0	Z_7 -1	Z_8 0

ΔZ/Δy = (45 – 48)/20 = -0.15 5

$$\text{slope} = \tan^{-1}\left[(0.45)^2 + (-0.15)^2\right]^{0.5}$$

$$\text{slope} = 25.3^{\circ}$$

Multiply *(kernal, cell by cell)*
Add *(results)*
Divide by #cells x cell width
Use slope formula

3rd-order Finite Difference

elevation values

42	45	47
40	44	49
44	48	52

← C = 10 →

kernal for dZ/dx

Z_1 -1	Z_2 0	Z_3 1
Z_4 -2	Z_0 0	Z_5 2
Z_6 -1	Z_7 0	Z_8 1

dZ/dx =
[1 * (47 - 42) +
2 *(49 - 40) +
1 * (52 - 44)]/80
= 0.39

kernal for dZ/dy

Z_1 1	Z_2 2	Z_3 1
Z_4 0	Z_0 0	Z_5 0
Z_6 -1	Z_7 -2	Z_8 -1

dZ/dy =
[1 * (47 - 52) +
2 *(45 - 48) +
1 * (42 - 44)]/80
= -0.16

$$\text{slope} = \tan^{-1}\left[(0.39)^2 + (-0.16)^2\right]^{0.5}$$

$$\text{slope} = 22.9^{\circ}$$

Aspect

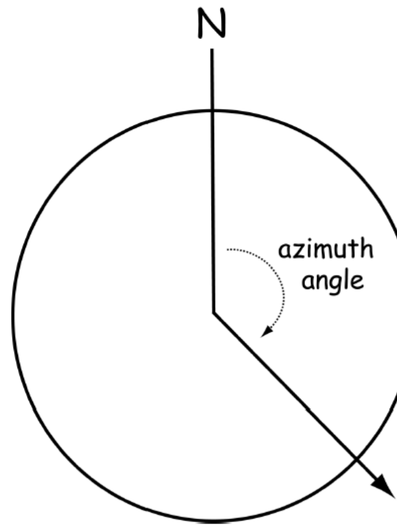


Figure 11-7: Aspect may be reported as an azimuth angle, measured clockwise in degrees from north.

Aspect

The orientation *(in compass angles)* of a slope

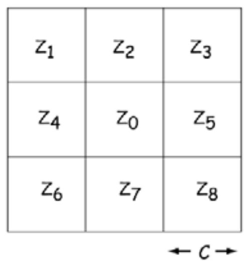
Calculation:

Aspect = $\tan^{-1}[-(\Delta Z/\Delta y)/(\Delta Z/\Delta x)]$

As with slope, estimated aspect varies with the methods used to determine **ΔZ/Δx and ΔZ/Δy**

Aspect calculations also use the four nearest cell or the 3rd-order finite difference methods

Curvature



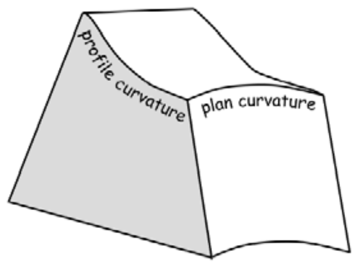
$D = [(Z_4 + Z_5)/2 - Z_0] / C^2$

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

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

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

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



plan curvature

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

profile curvature

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

Flow direction

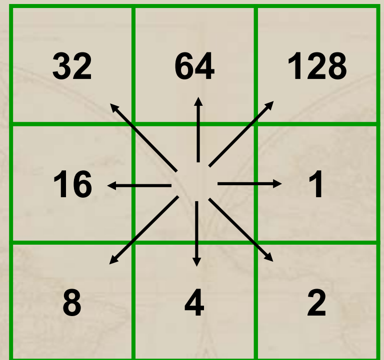
Use in hydrologic analysis

Excess water at a point on the Earth will flow in a given direction

Flow may be either on or below surface but always in the direction of steepest descent (often the same as local aspect)

Directions stored as compass angle is raster data layer

Eight Direction Pour Point Model



ESRI Direction encoding

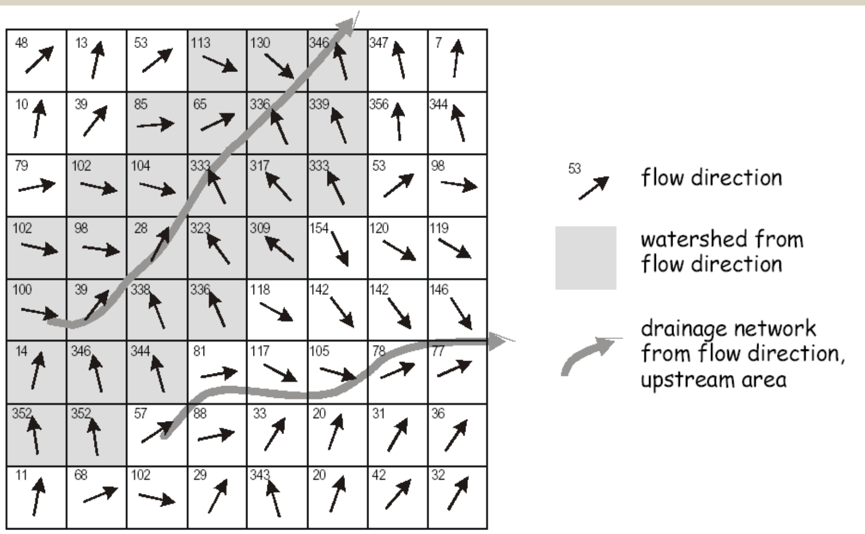


Figure 11-21: Flow direction, watershed, and drainage network shown for a raster grid. Elevation data are used to define the flow direction for each cell. These flow directions are then used to determine a number of important hydrologic functions.

Watershed

- An <u>area</u> that contributes flow to a point on the landscape
  Water falling anywhere in the upstream area of a watershed will pass through that point.
- Many be small or large
- Identified from a flow direction surface

Drainage network

- A <u>set of cells</u> through which surface water flows
- Based on the flow direction surface

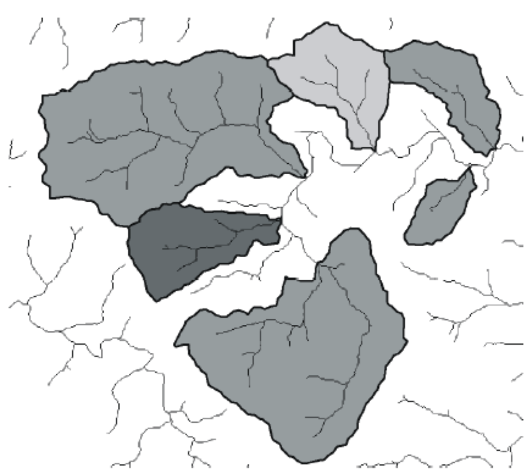


Figure 11-22: Drainage network and watersheds derived from DEM. Flow direction was determined from local aspect. Upstream watersheds and the probably drainage paths were then determined from flow direction.

Viewshed

The *viewshed* for a point is the collection of areas visible from that point.

Views from any non-flat location are blocked by terrain.

Elevations will hide a point if they are higher than the viewing point, or higher than the line of site between the viewing point and target point

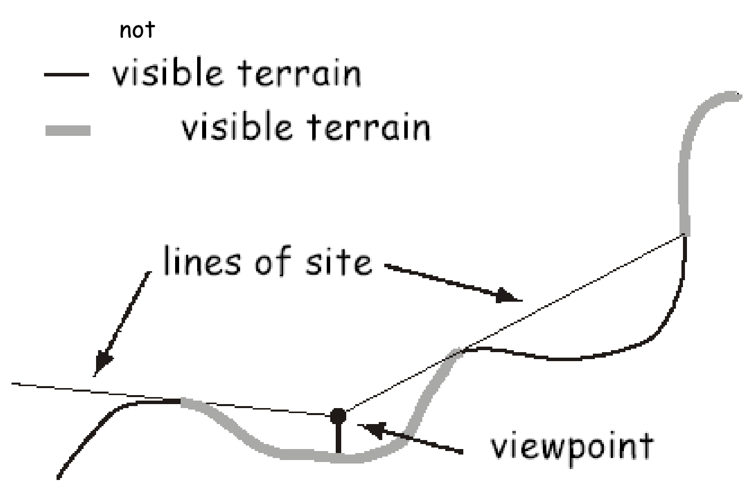


Figure 11-23: Mechanics of defining a viewshed

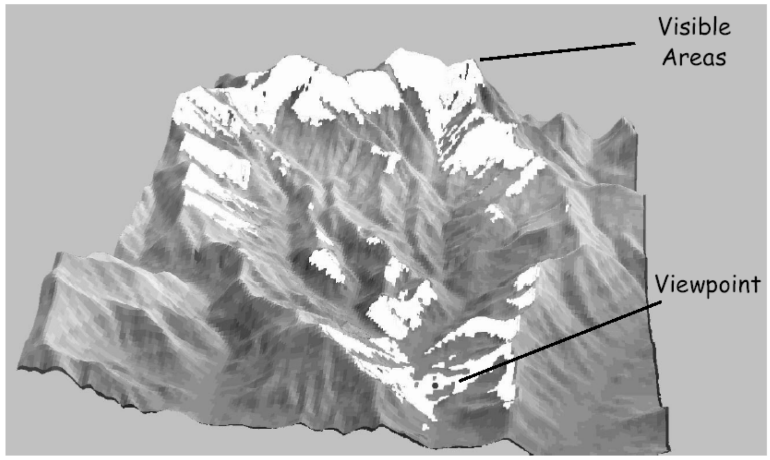
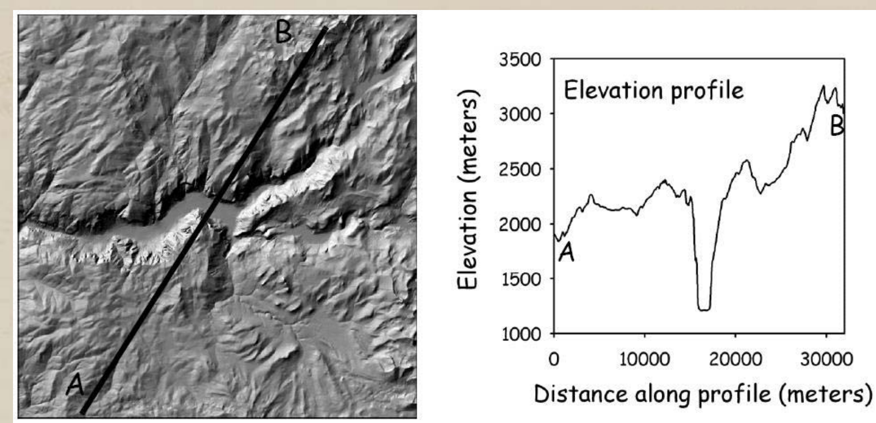


Figure 11-24: An example of a viewpoint, and corresponding viewshed.

Profile plots



Shaded Relief Surfaces