

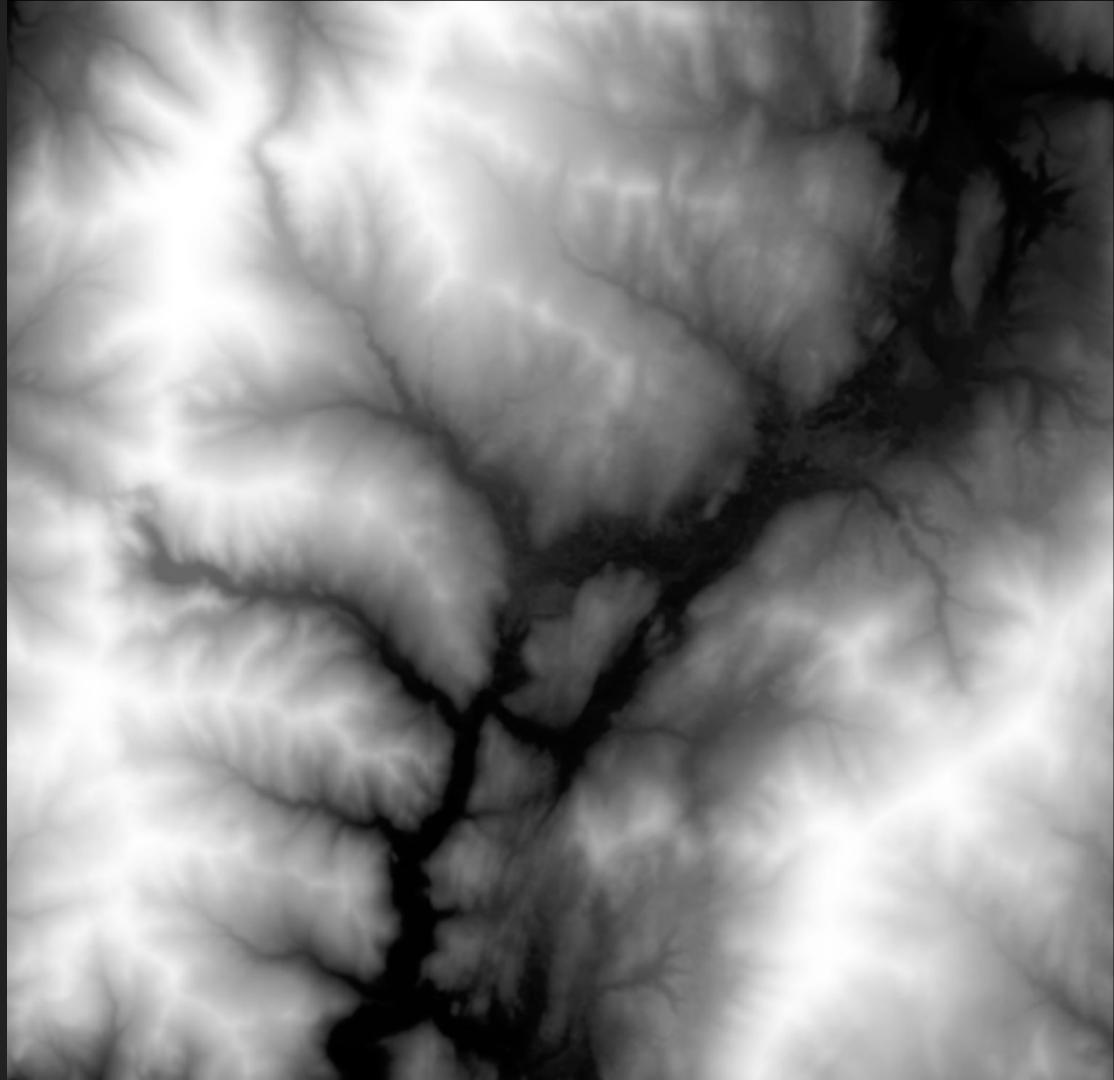
# Geographic Information Systems

ESM 263 - Winter 2023

# Terrain and Watershed Analysis

# Digital Elevation Model (DEM)

raster of elevations



# Slope

- Magnitude of gradient
- $\tan(\text{slope}) = ((\partial z / \partial x)^2 + (\partial z / \partial y)^2)^{1/2}$



# Aspect (aka Exposure)

- Direction of gradient
- $\tan(\text{aspect}) = -(\partial z / \partial y) / (\partial z / \partial x)$
- NB: cyclical
  - wraps around at  $360^\circ$
  - this image →
    - white: south
    - black: north



# Slope & Aspect: Calculation Neighborhoods

4 nearest neighbors

- "rook's case"
- GDAL: ZevenbergenThorne

	$e_2$	
$e_1$	$C_0$	$e_3$
	$e_4$	

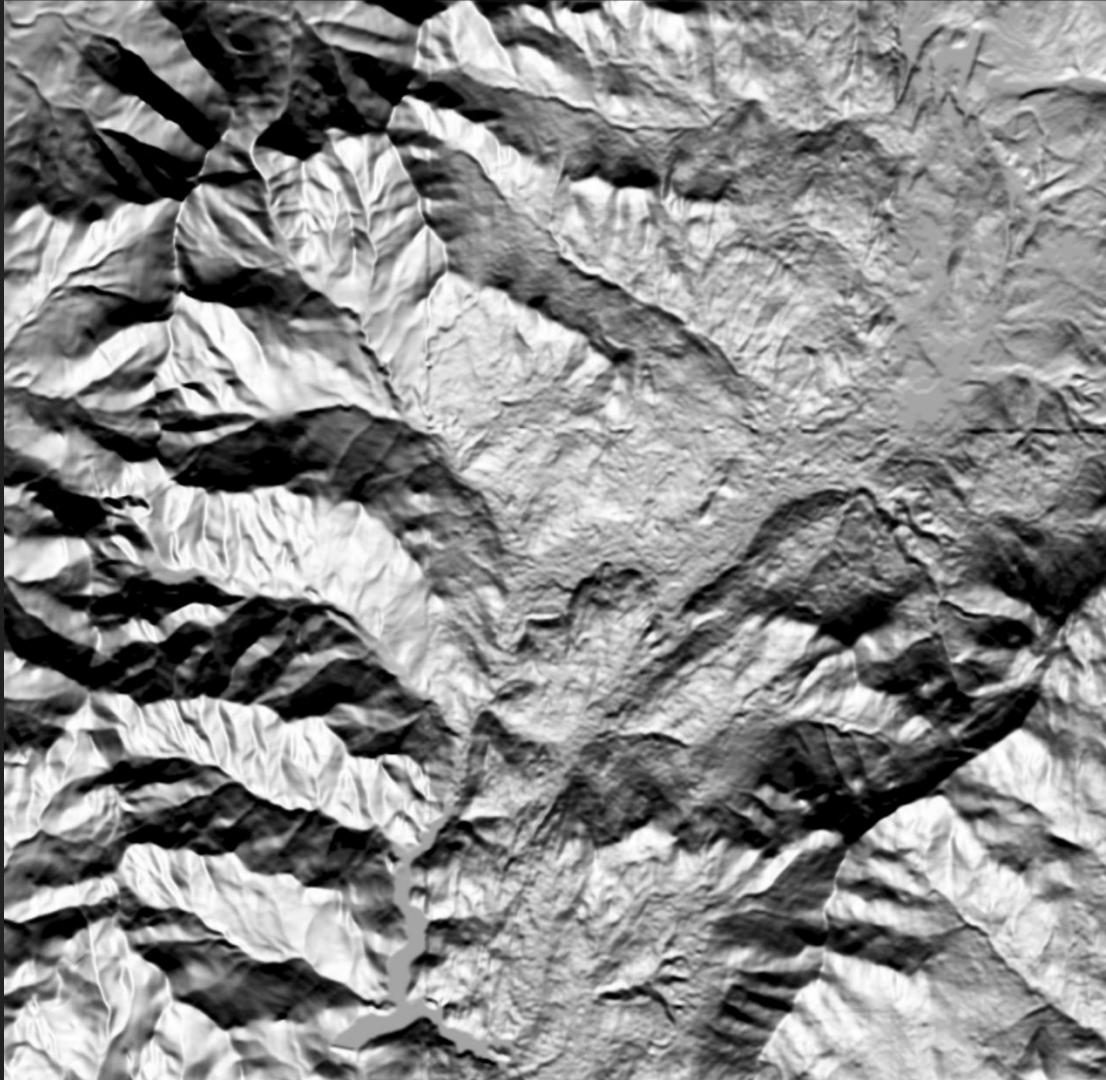
8 nearest neighbors

- "queen's case"
- diagonal weights =  $1 / \sqrt{2}$
- GDAL: Horn

$e_1$	$e_2$	$e_3$
$e_4$	$C_0$	$e_5$
$e_6$	$e_7$	$e_8$

# Hillshade

- local sun angle
- $\cos(Z) =$   
 $\cos(Z_{\text{sun}}) \times \cos(S) +$   
 $\sin(Z_{\text{sun}}) \times \sin(S) \times \cos(A_{\text{sun}} - A)$
- this image →
  - $Z_{\text{sun}} = 47.5^\circ$
  - $A_{\text{sun}} = 180^\circ$



# Hillshade with Shadows

Shadowed pixels → 0



# Aspect vs Hillshade

aspect



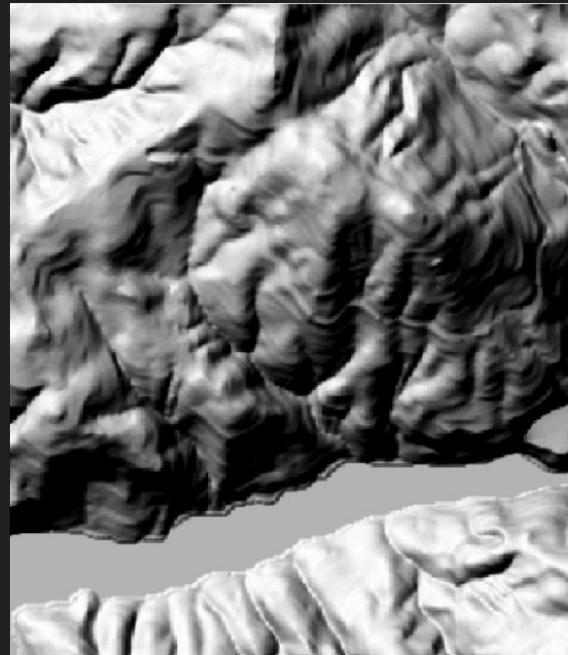
Hillshade ( $Z_{\text{sun}} = 47.5^\circ$ ,  $A_{\text{sun}} = 180^\circ$ )



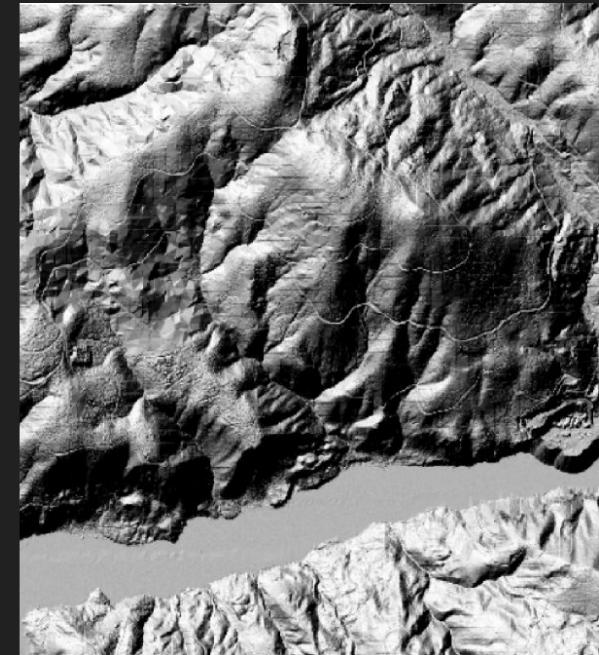
# DEM Resolution



30 m (USGS)

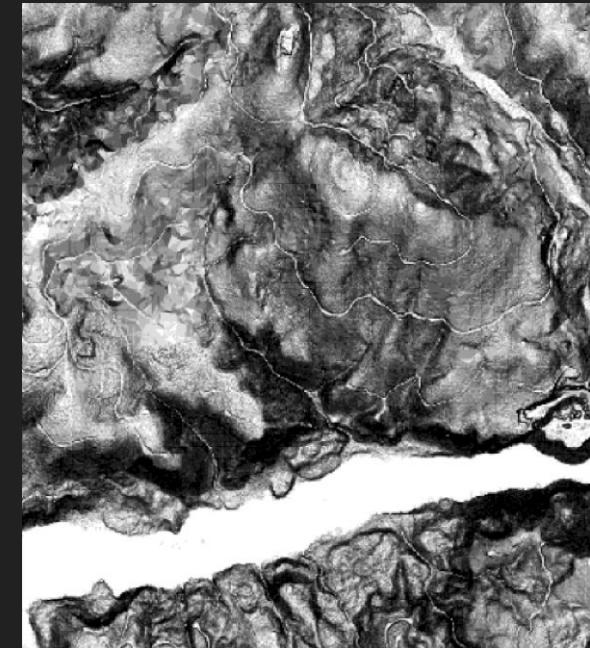
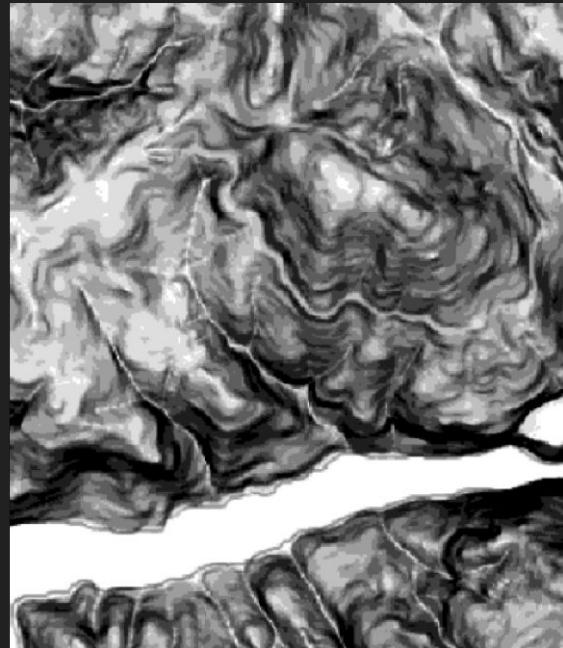
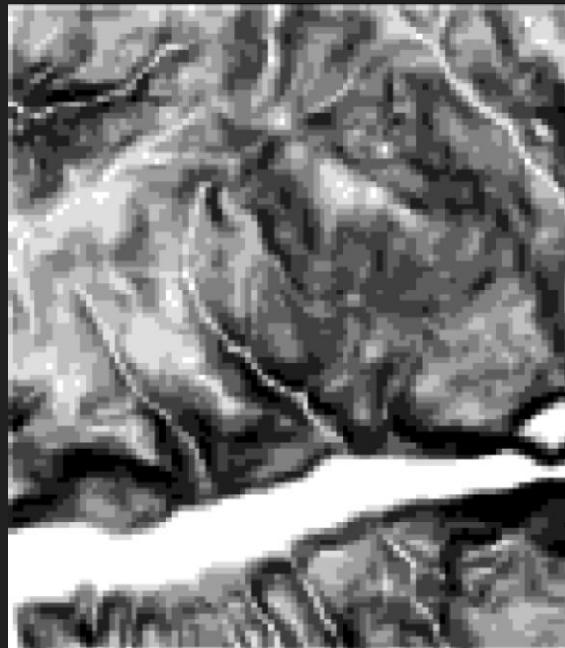


10 m (USGS)



1.830 (LIDAR)

# DEM Resolution: Derived Products



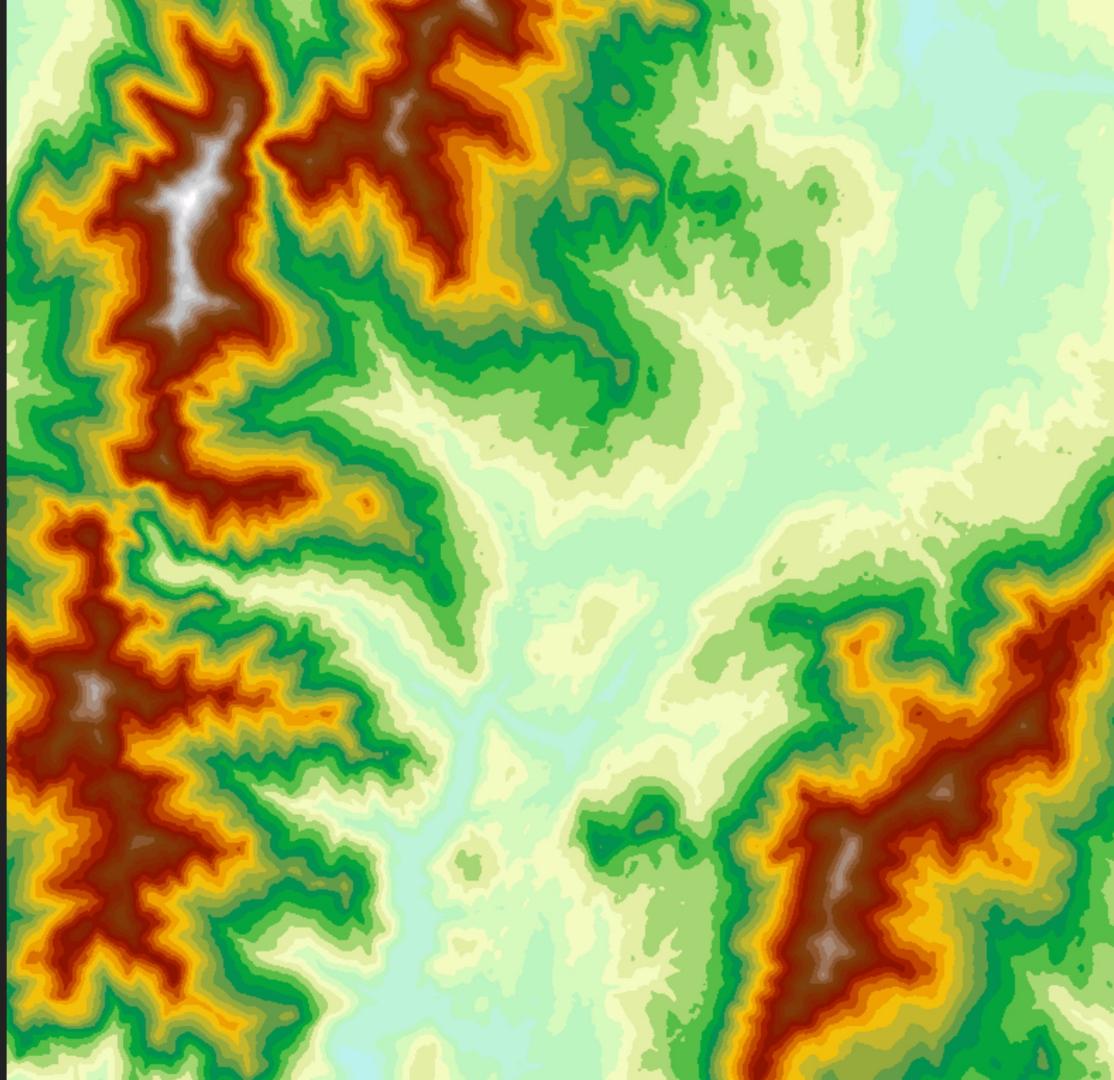
Slope layers derived from three previous DEMs

# DEM Rendering: Hypsometric Map

Classified DEM

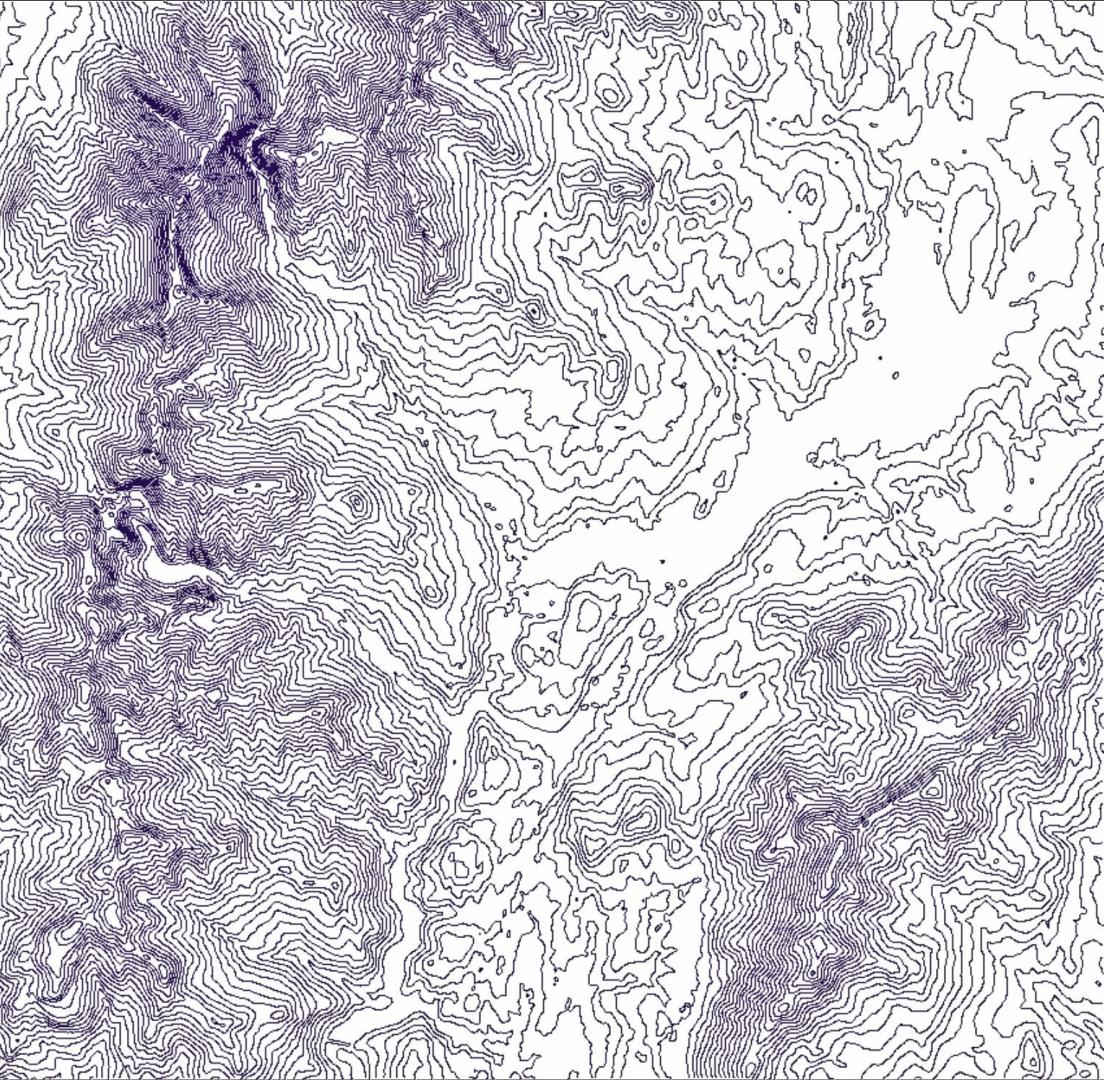
Color: elevation “band”

QGIS: Setting a Color Ramp



# DEM Rendering: Contour Map

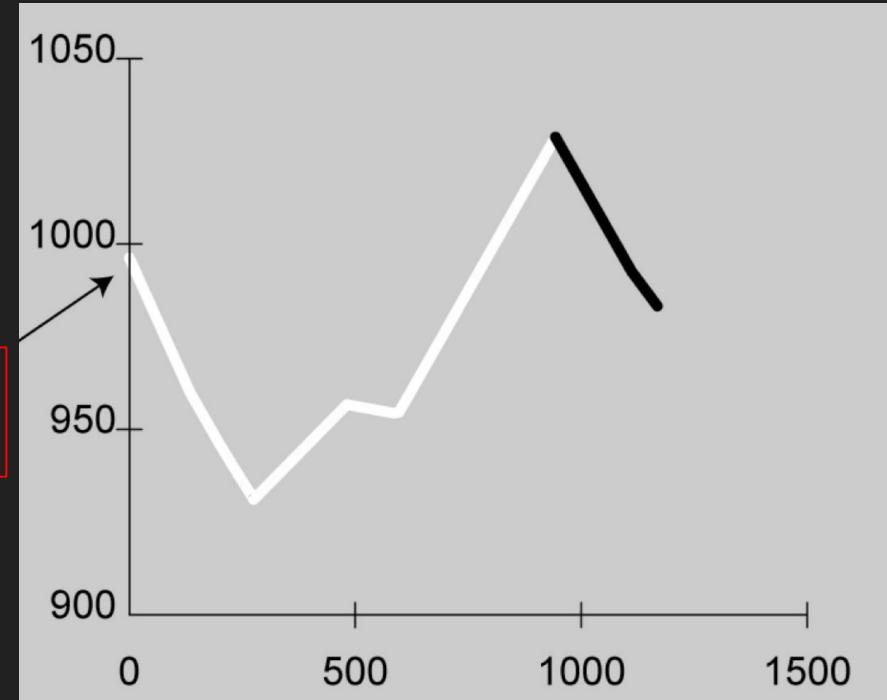
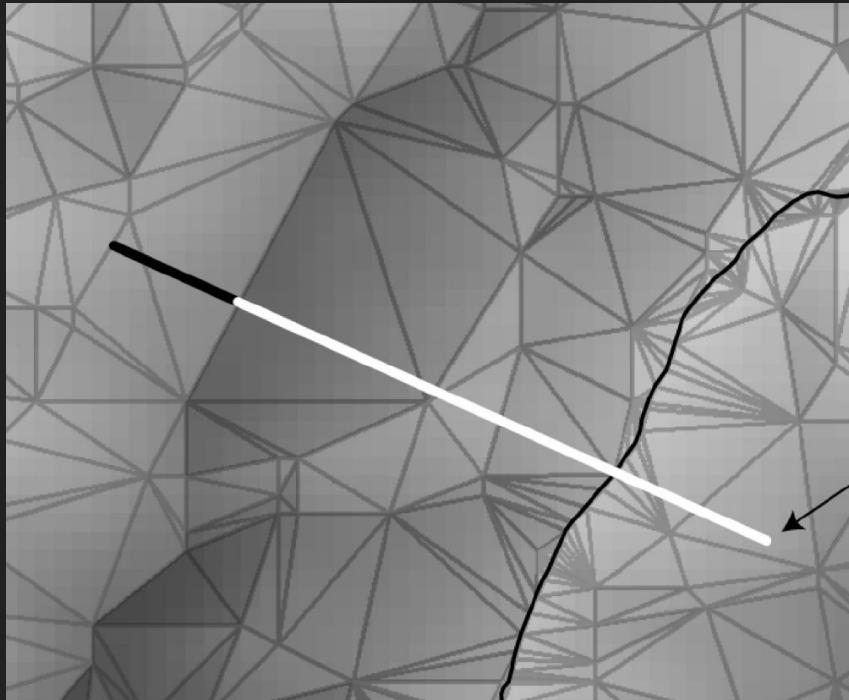
Lines of constant elevation



# Visibility: Sightlines

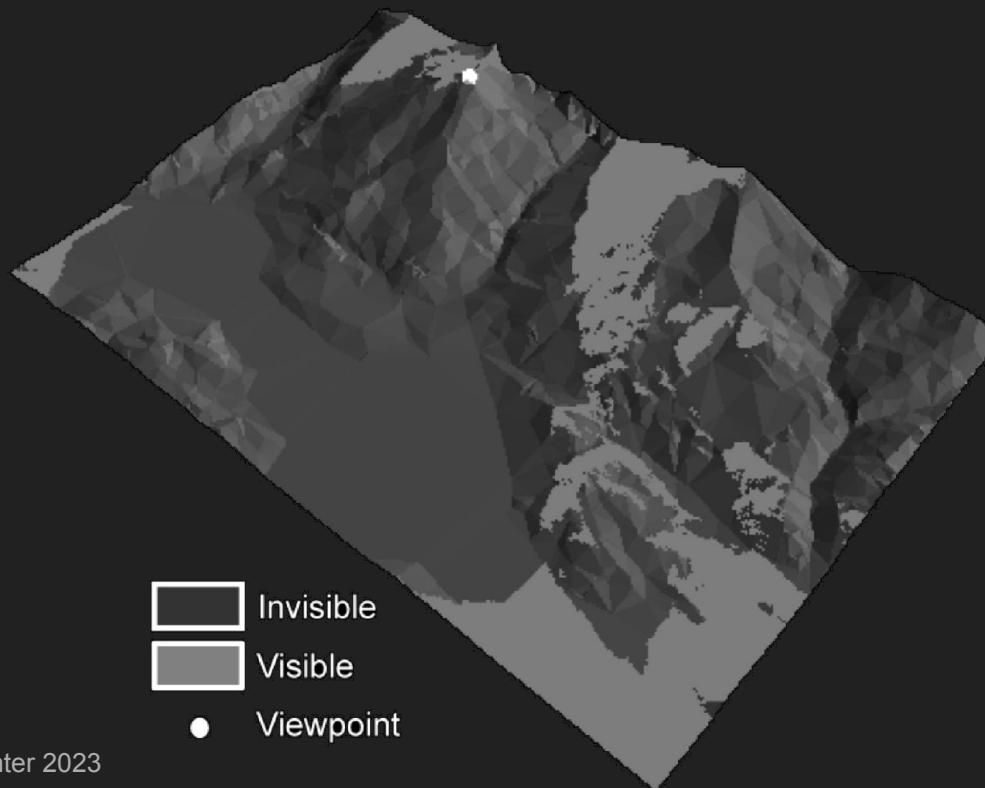
Sightline = visibility between points

- white: visible
- black: obscured



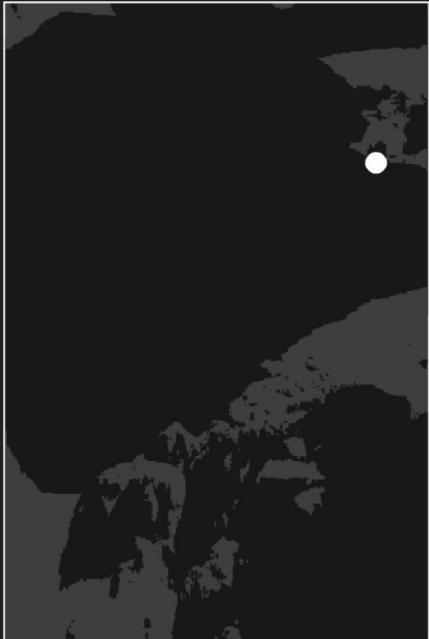
Viewshed = area visible from point

# Visibility: Viewshed

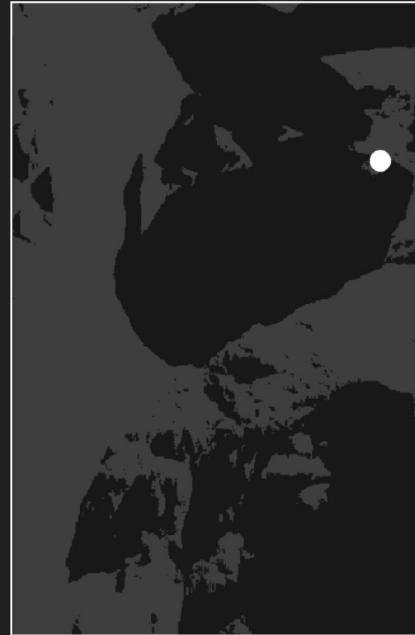


$\text{Viewshed} = f(\text{Elevation})$

(b) higher than (a) → larger viewshed



(a)



(b)

# Viewshed = f(Search Radius)

edge of DEM



(a)

fixed radius



(b)

# Viewshed: Cumulative

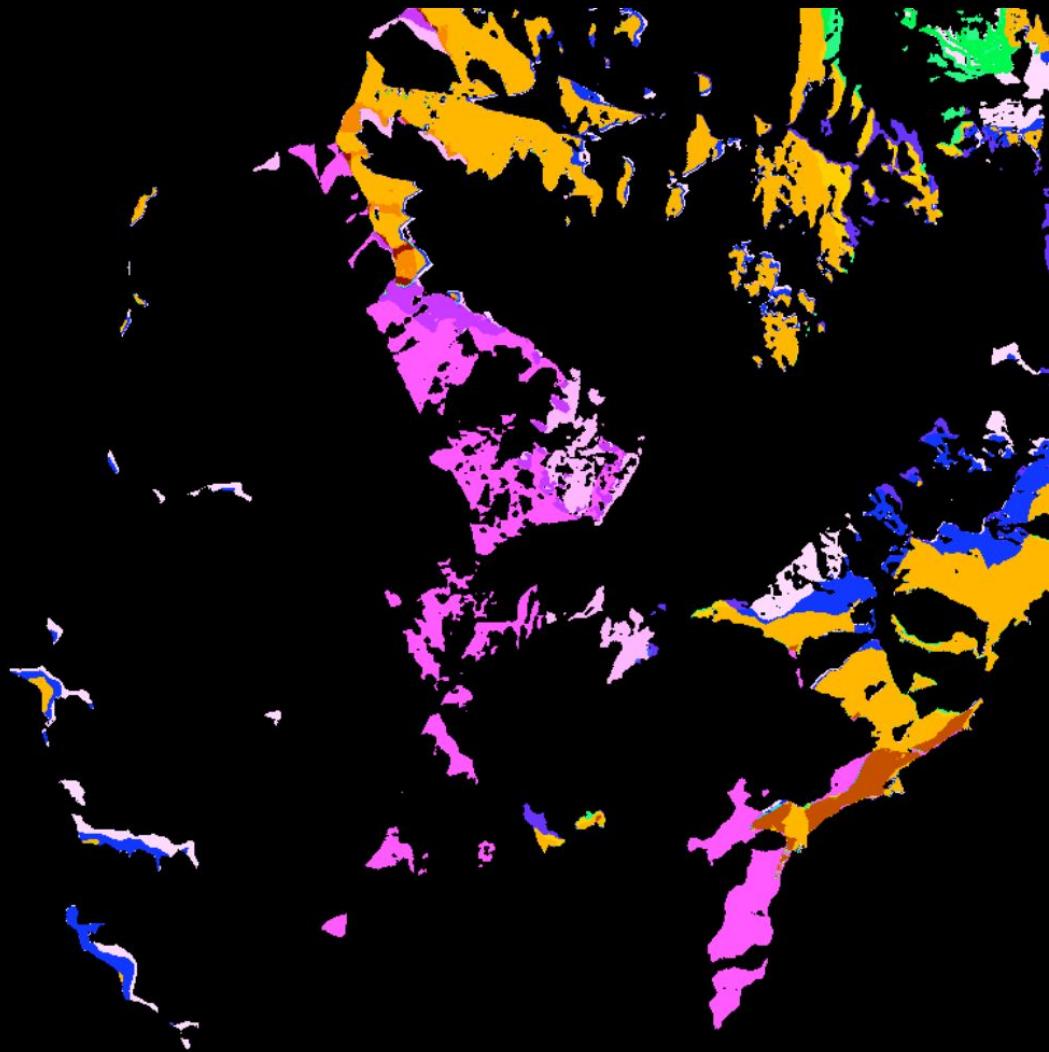
- green areas visible from at least one point
- pink areas invisible from any point



# Viewshed: Specific

Cell values code all possible combinations of search points

code = visible from points(code)



# Watershed Analysis

- **Watershed**
  - area that drains surface water to a common outlet
  - defined by topographic divides
- **Watershed analysis**
  - Use
    - DEMs
    - raster operations
  - To
    - derive topographic features
      - e.g. stream networks
      - delineate watersheds

# Watershed Delineation

- "Coarse"
  - maximal areas that drain off edge of DEM
- "Fine"
  - minimal areas that drain into each stream segment

# Automated Watershed Delineation (coarse)

1. Fill sinks (depressions) in DEM
2. Derive flow direction raster
  - o direction water will flow out of each cell
3. Derive watershed raster
  - o mark all cells that flow towards common outlet

# Flow Direction

For 8-neighborhood:

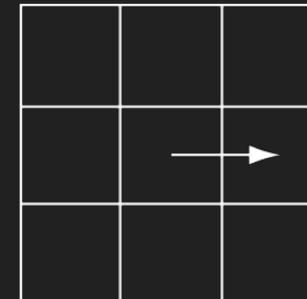
- calculate distance-weighted drop
  - 4 immediate neighbors: center - neighbor
  - 4 corner neighbors:  $(\text{center} - \text{neighbor}) / \sqrt{2}$
- flow direction = maximum drop

1014	1011	1004
1019	1015	1007
1025	1021	1012

(a)

+1	+4	+11
-4		+8
-10	-6	+3

(b)



(c)

# Automated Watershed Delineation (fine)

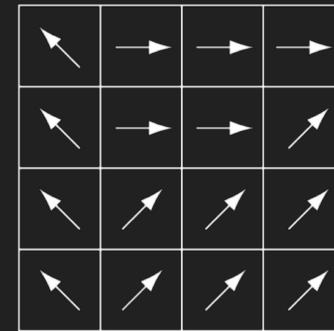
1. Fill sinks (depressions) in DEM
2. Derive catchment areas
  - o accumulated water flow through each cell
3. Derive channel network
  - o apply threshold value to catchment area
4. Derive watershed basins
  - o areas draining into each channels

# Flow Accumulation

1. filled elevation raster
2. flow direction raster
3. flow accumulation raster
  - shaded cells have same accumulation value
    - top cell receives flow from left and lower-left cells
    - bottom cell receives flow from lower-left cell
      - already had accumulation value of 1

1014	1011	1004	996
1019	1015	1007	999
1025	1021	1012	1003
1033	1029	1020	1003

(a)



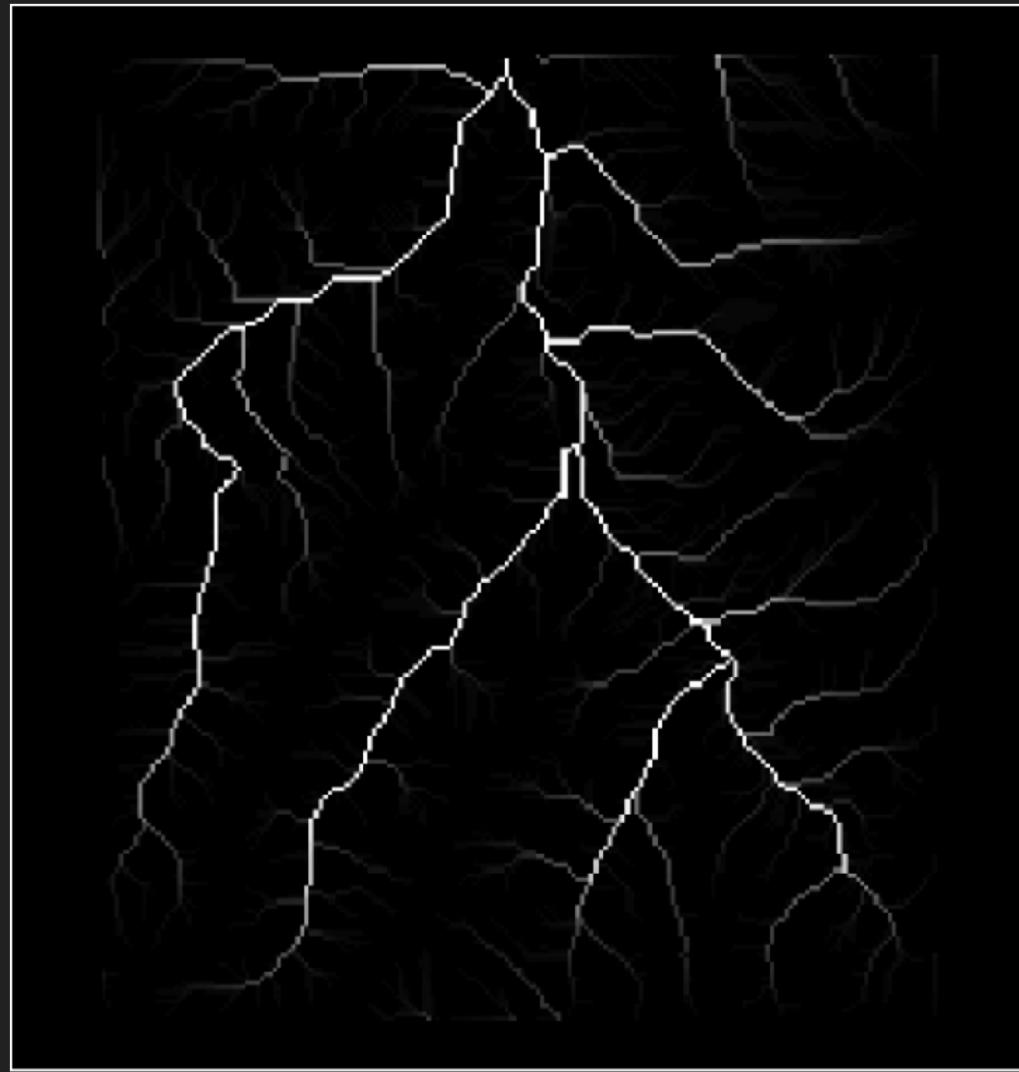
0	0	1	2
0	0	2	6
0	0	2	3
0	1	2	3

(c)

# Flow Accumulation

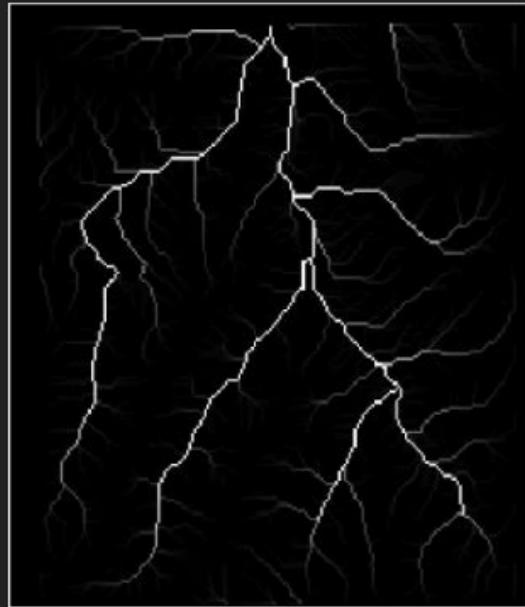
brighter symbols

= higher accumulation values



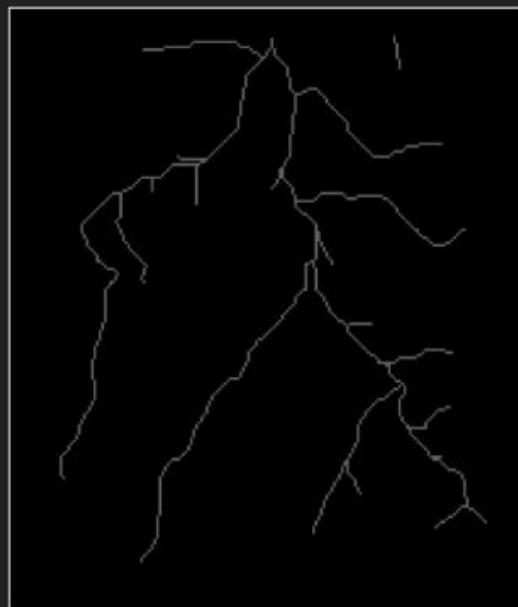
# Stream Network

flow accumulation raster



(a)

stream network (threshold = 500)



(b)

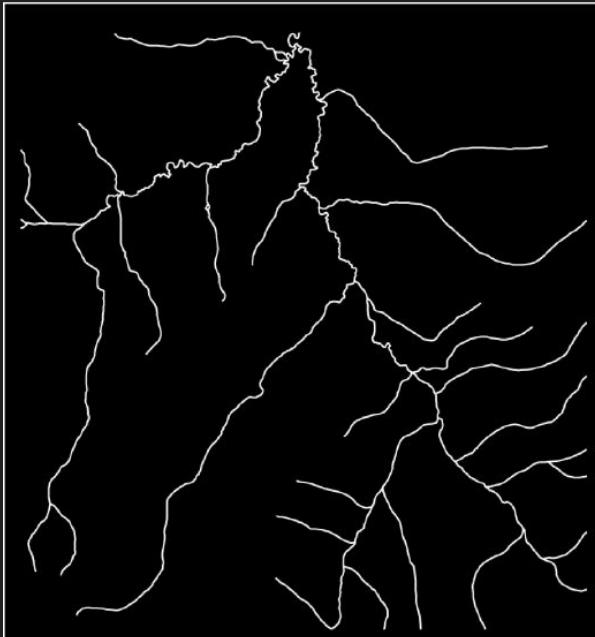
stream network (threshold = 100)



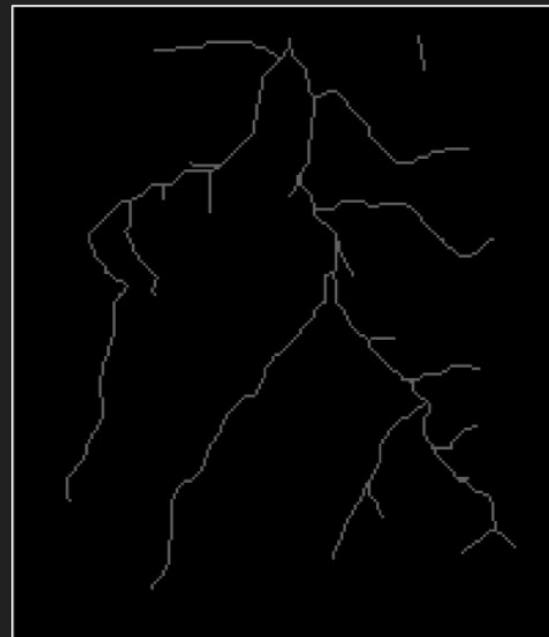
(c)

# Stream Network

mapped (1:24000DLG)



Calculated (threshold = 500)

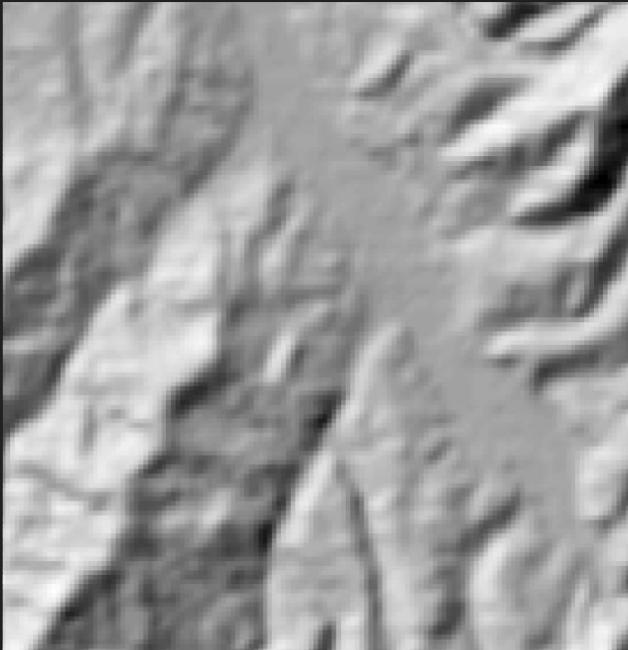


Calculated (threshold = 100)

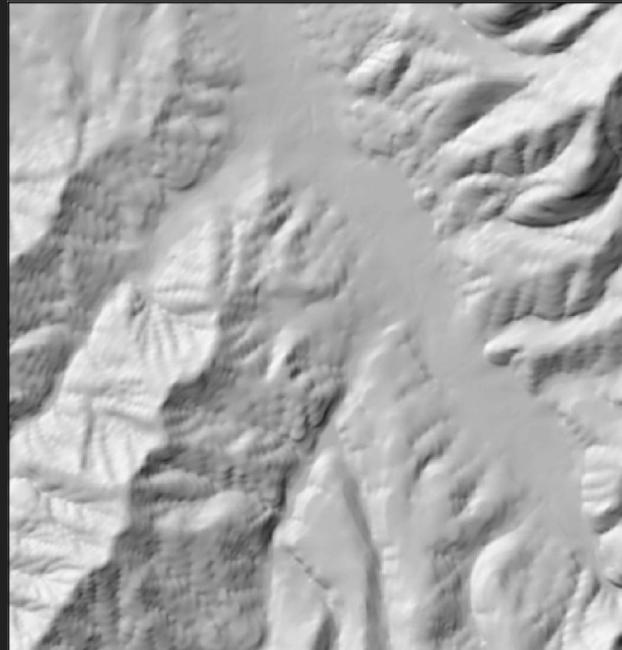


# Resolution Affects Watershed Analysis

30 m DEM

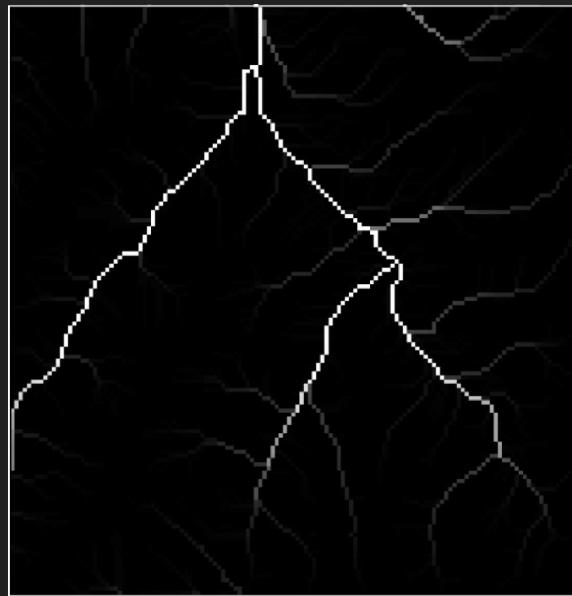


10 m DEM



# Resolution Affects Watershed Analysis

Stream network from  
30 m DEM



(a)

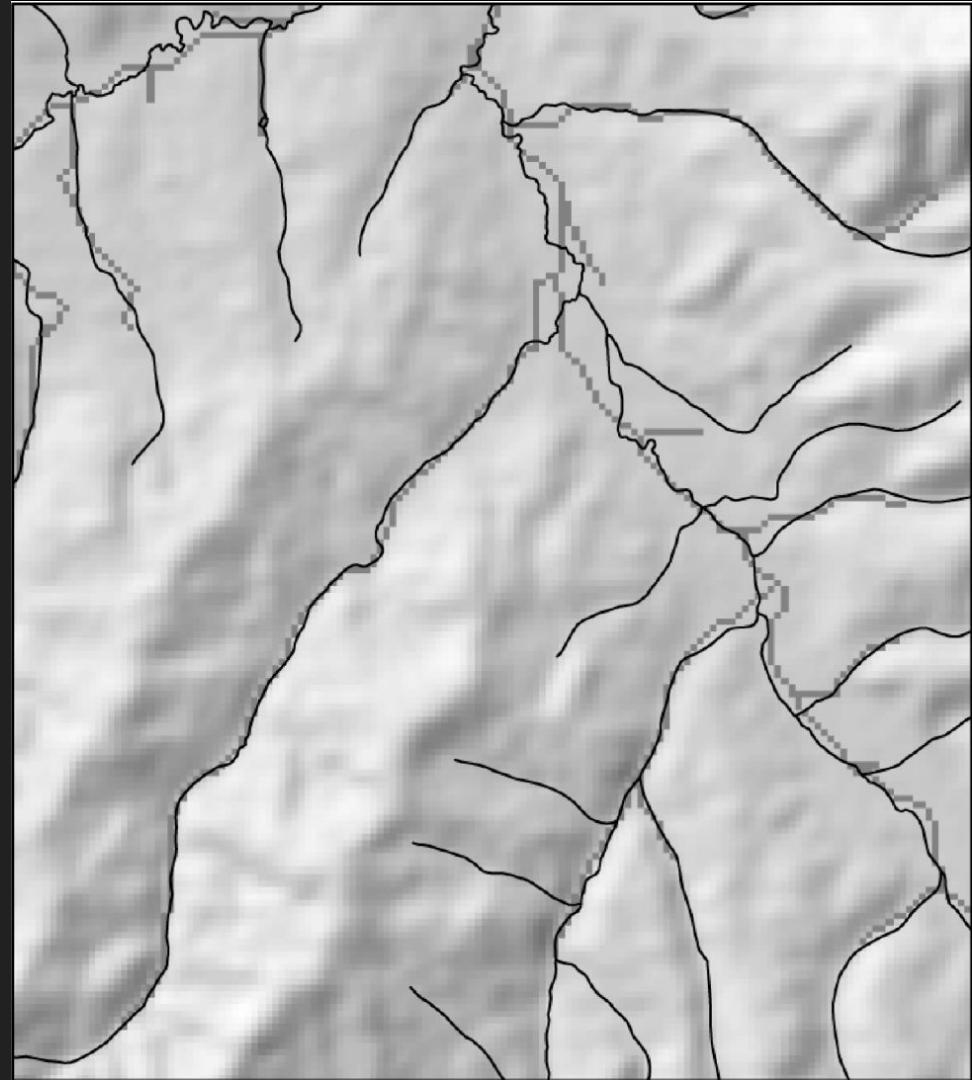
Stream network from  
10 m DEM



(b)

# Relief Affects Watershed Analysis

- gray raster lines  
= stream segments from D8 method
- thin black lines = stream segments from 1:24,000-scale DLG
- Agreement:
  - good in valleys
  - poor in flat areas



# Figure Credits

- Introduction to Geographic Information Systems, 4th ed.
  - ISBN 978-0-07-305115-2
- ArcMap Help