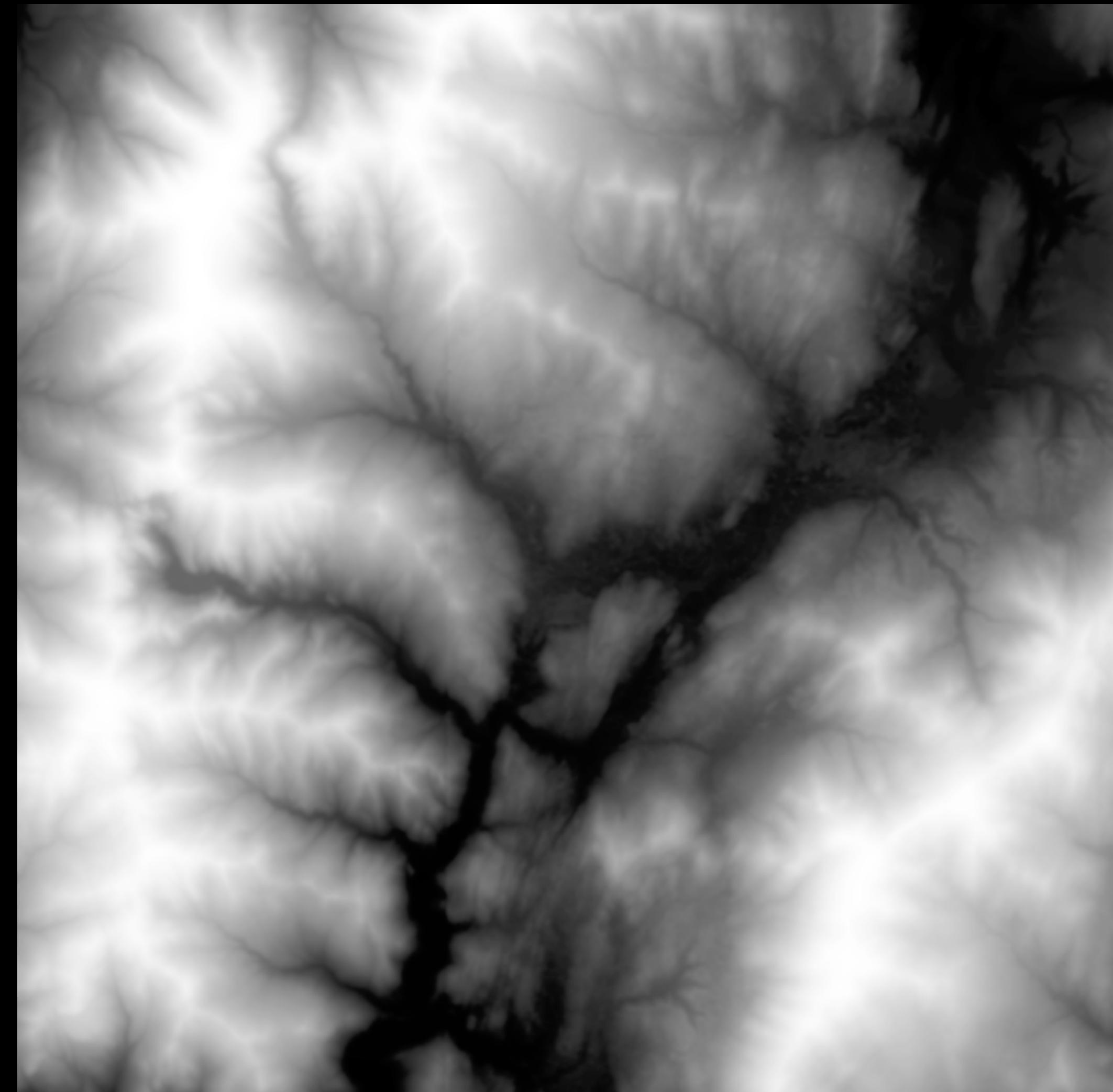


Digital Elevation Model (DEM)

- raster of elevations



Slope

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



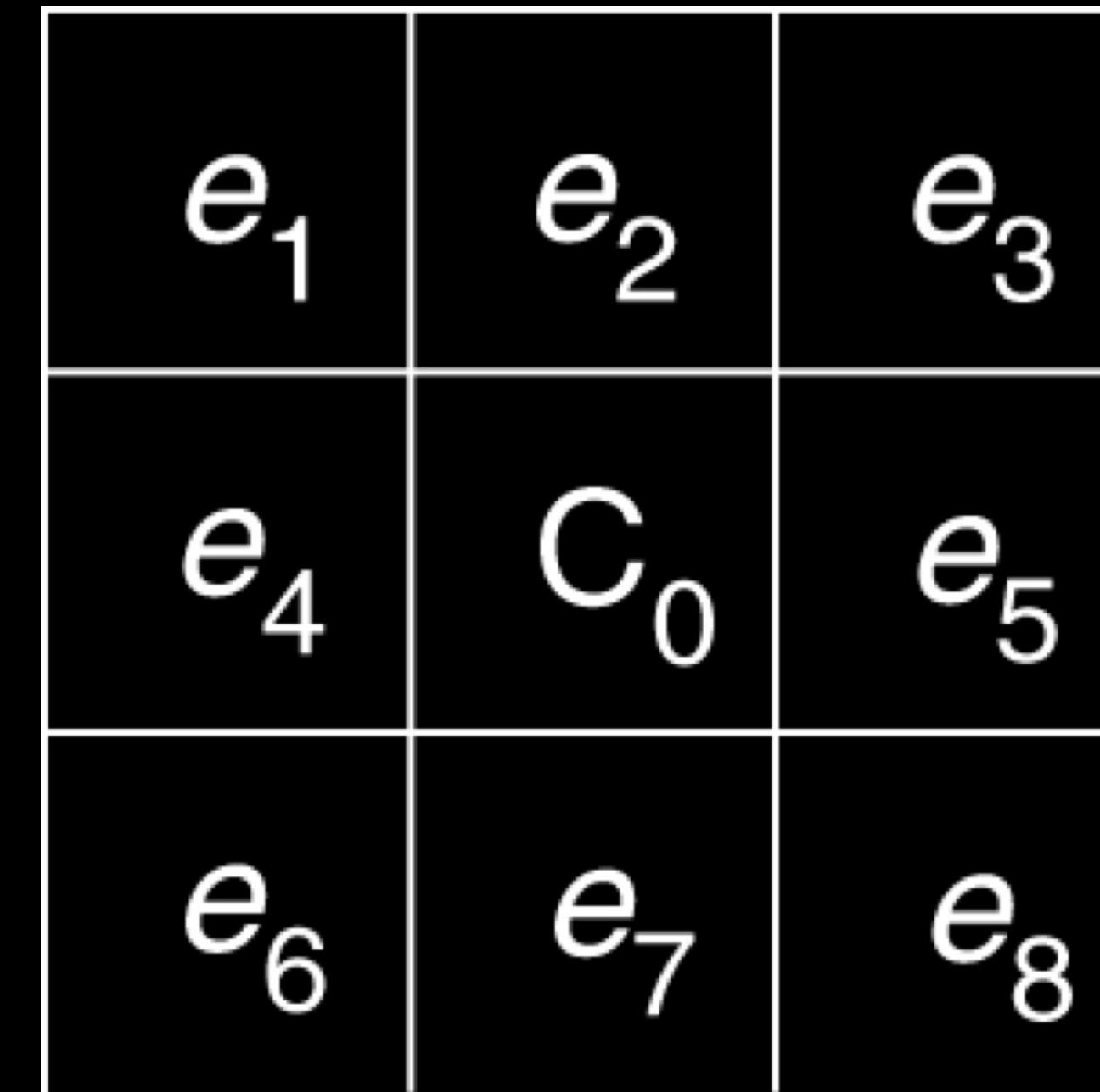
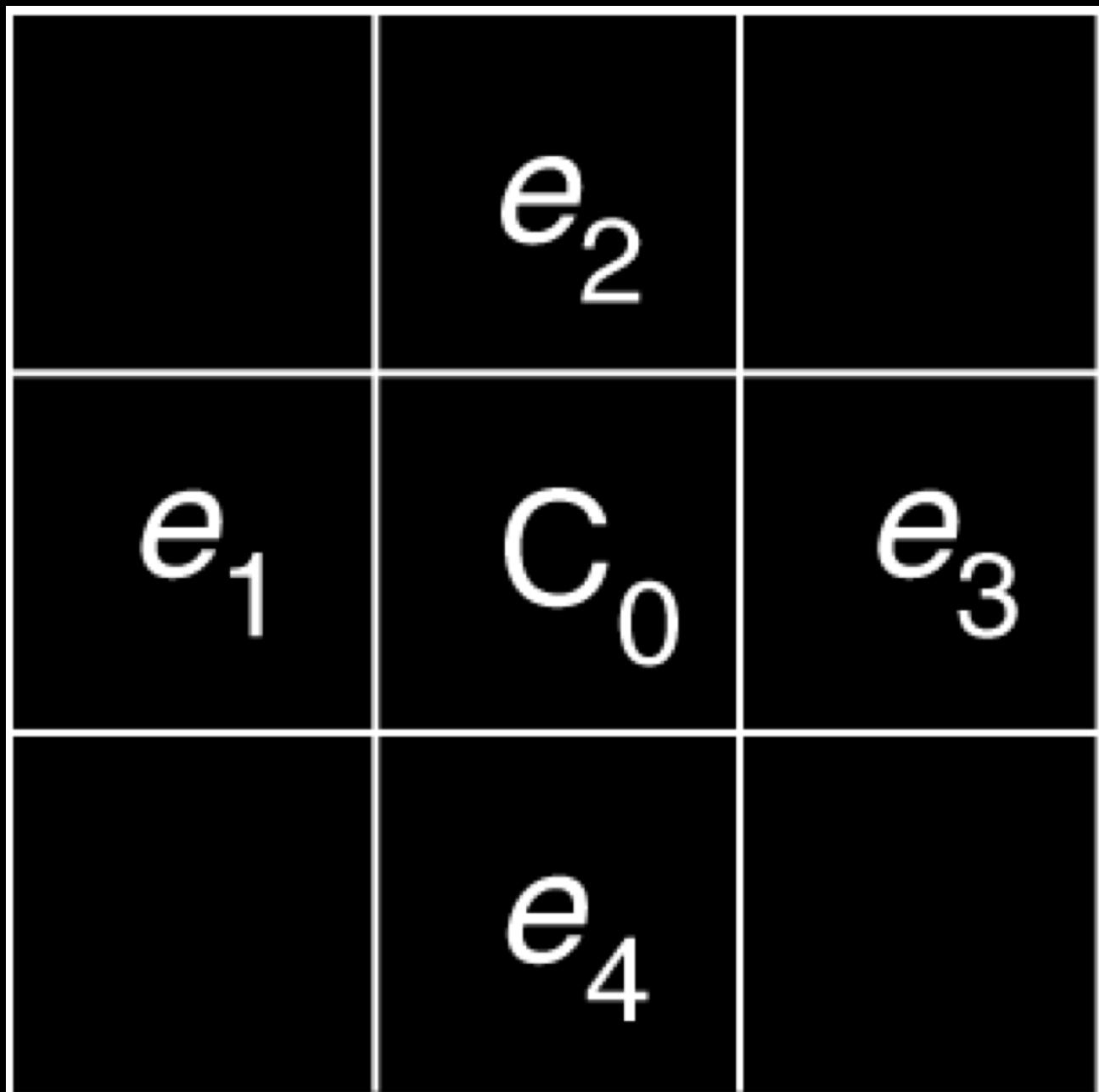
Aspect (aka Exposure)

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



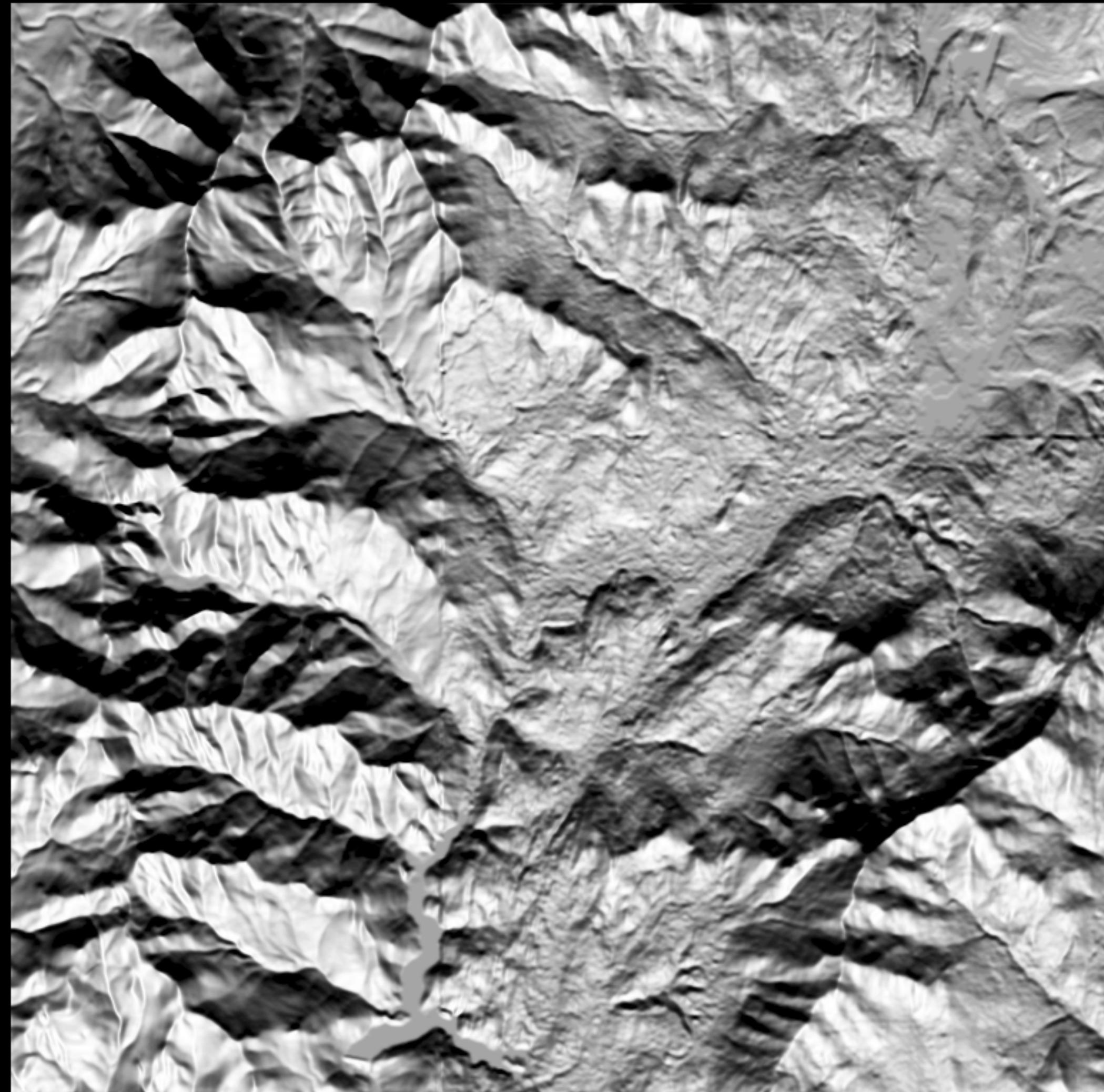
Slope & Aspect: Calculation Neighborhoods

- 4 nearest neighbors
 - "rook's case"
 - GDAL: ZevenbergenThorne
- 8 nearest neighbors
 - "queen's case"
 - diagonal weights = $1 / \sqrt{2}$
 - GDAL: Horn



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



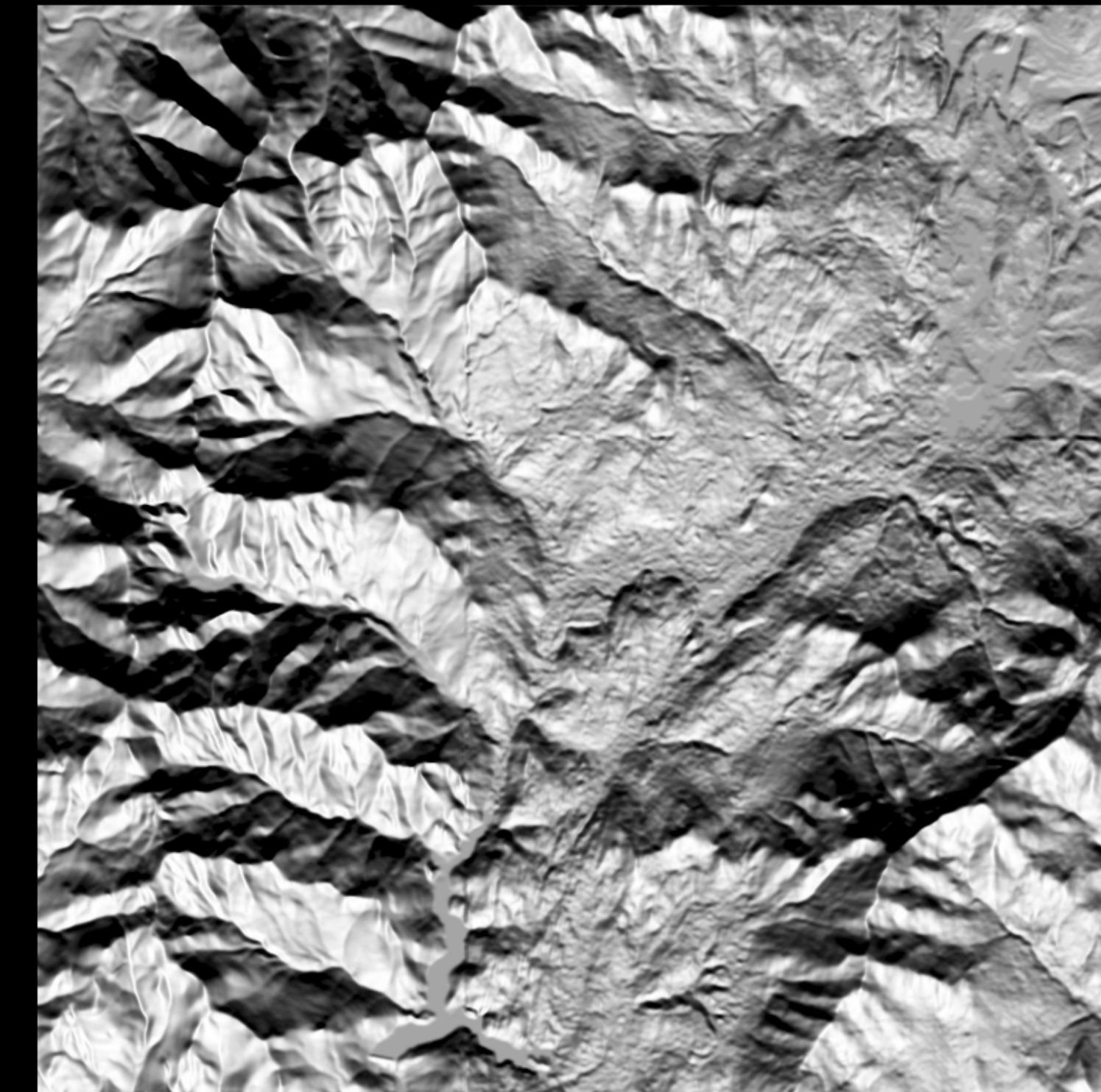
Aspect vs Hillshade

- aspect



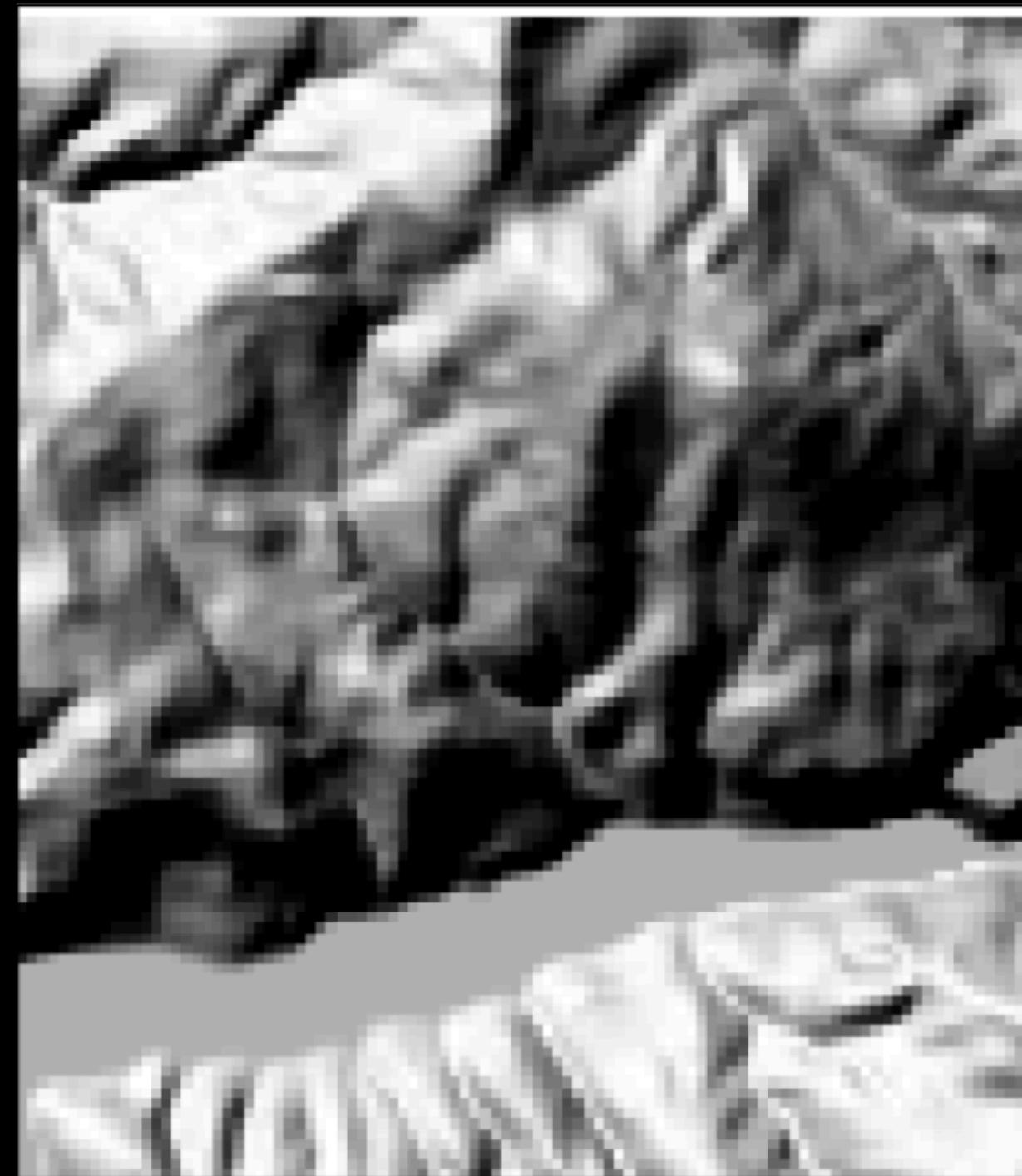
- hillshade

- $Z_{\text{sun}} = 47.5^\circ$
- $A_{\text{sun}} = 180^\circ$

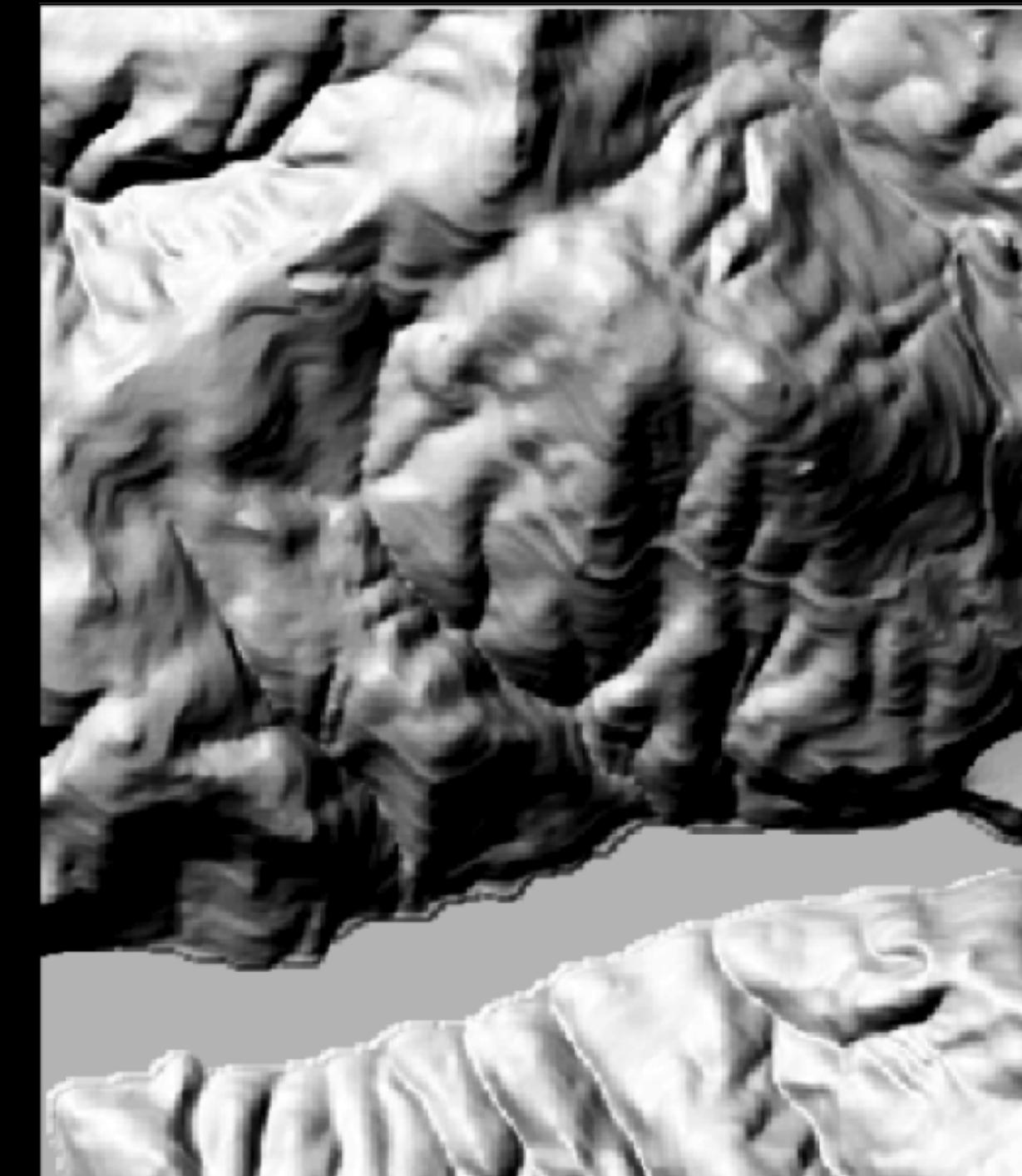


DEM Resolution

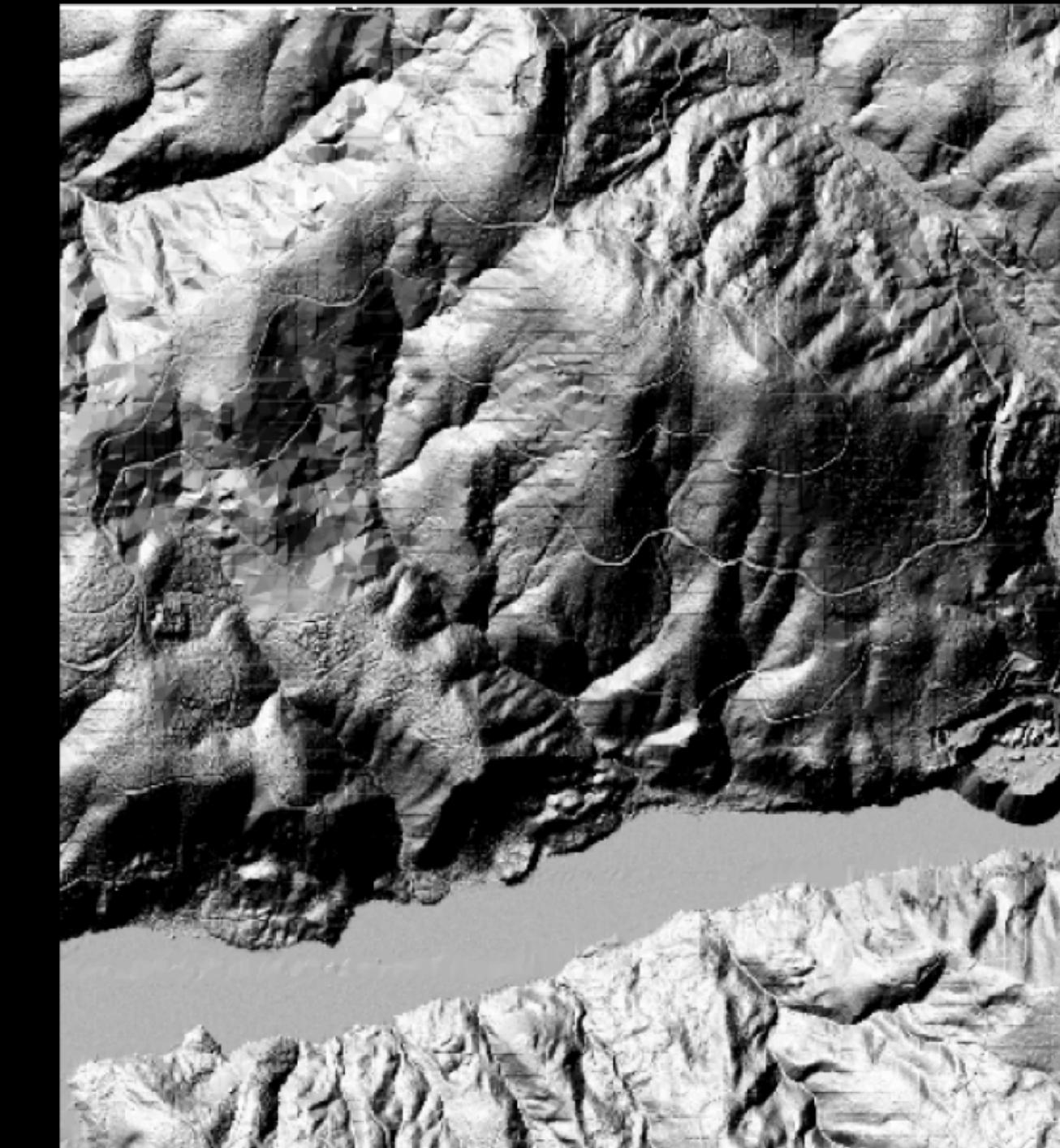
30m (USGS)



10m (USGS)

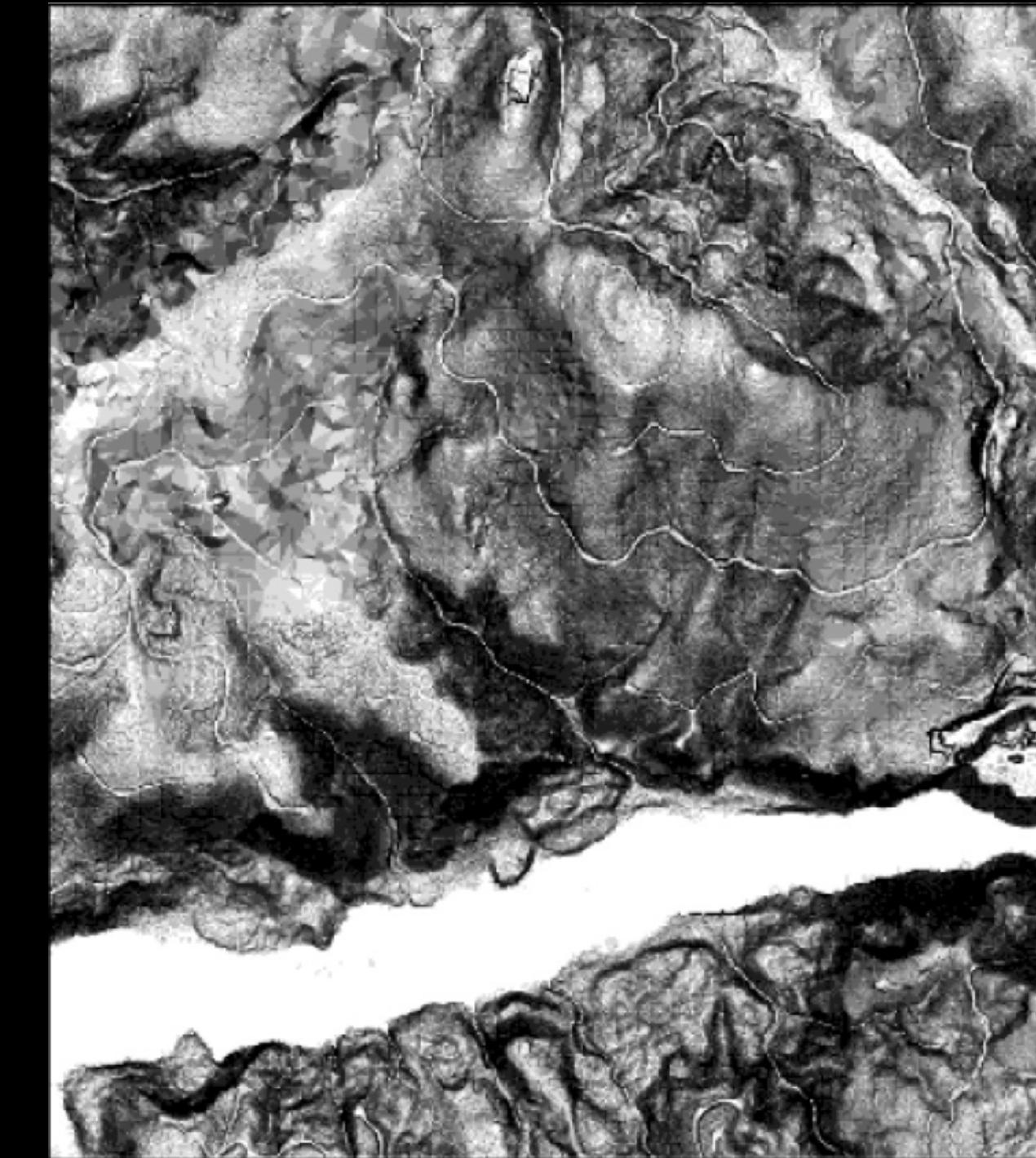
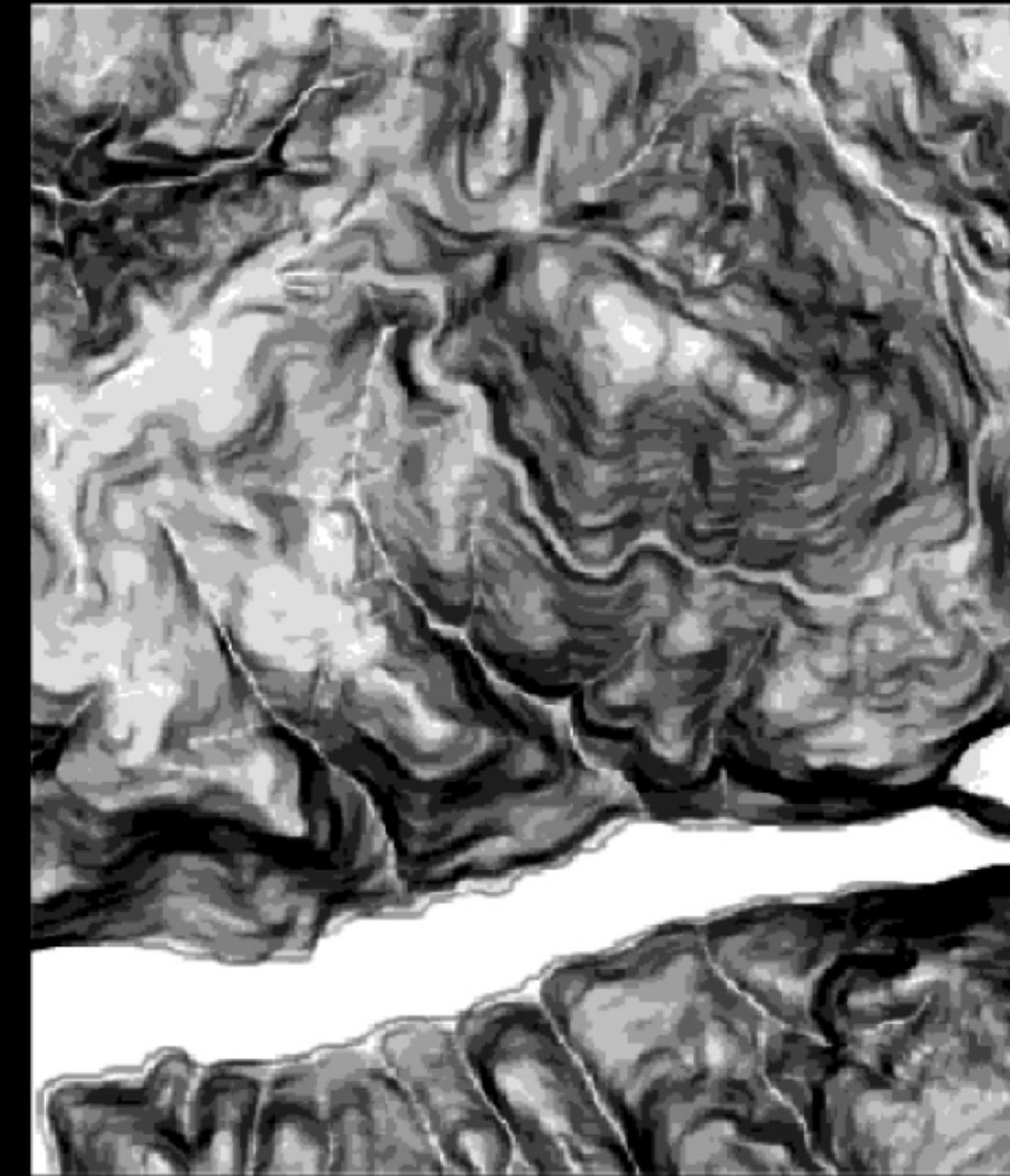
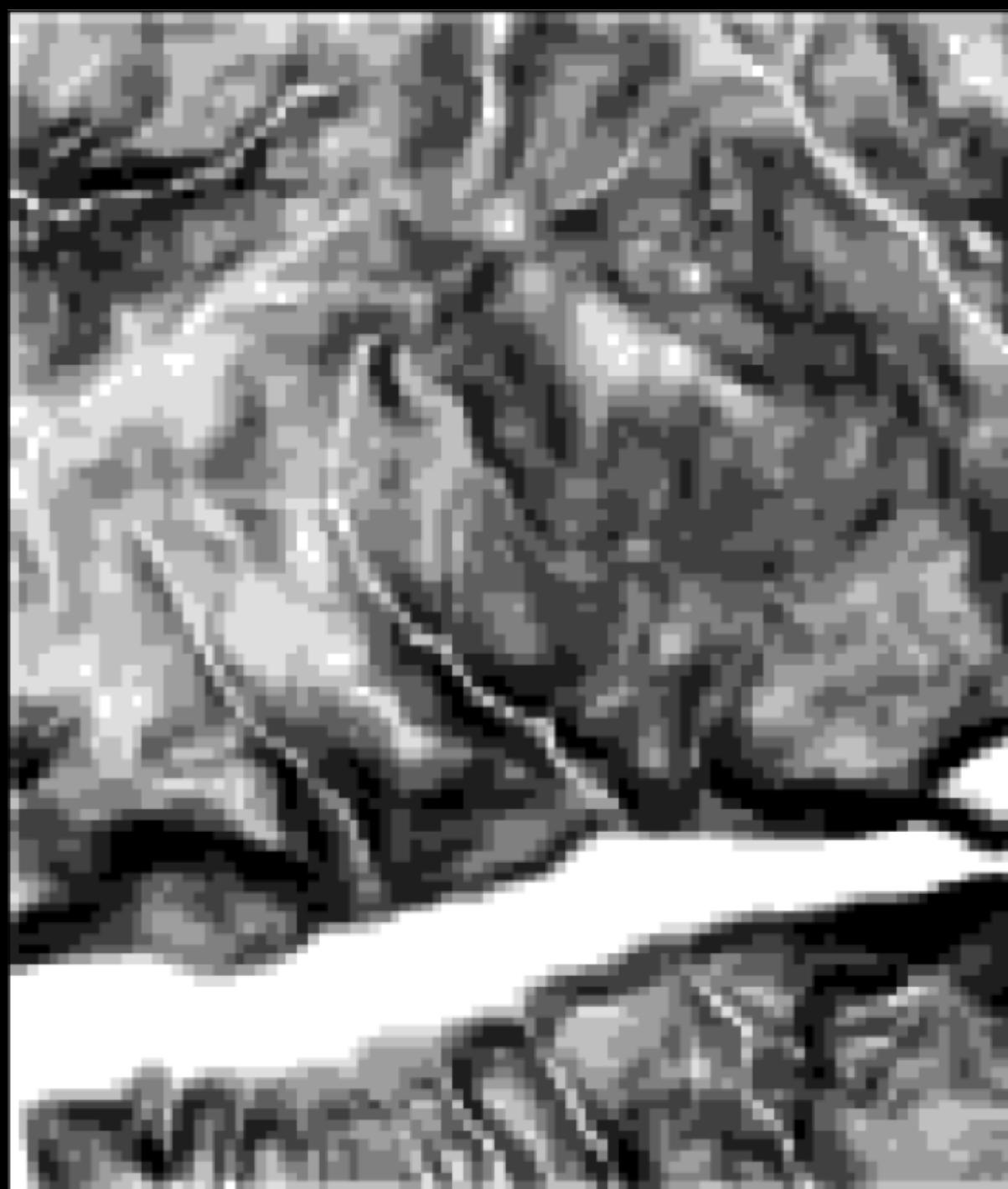


1.83m LIDAR



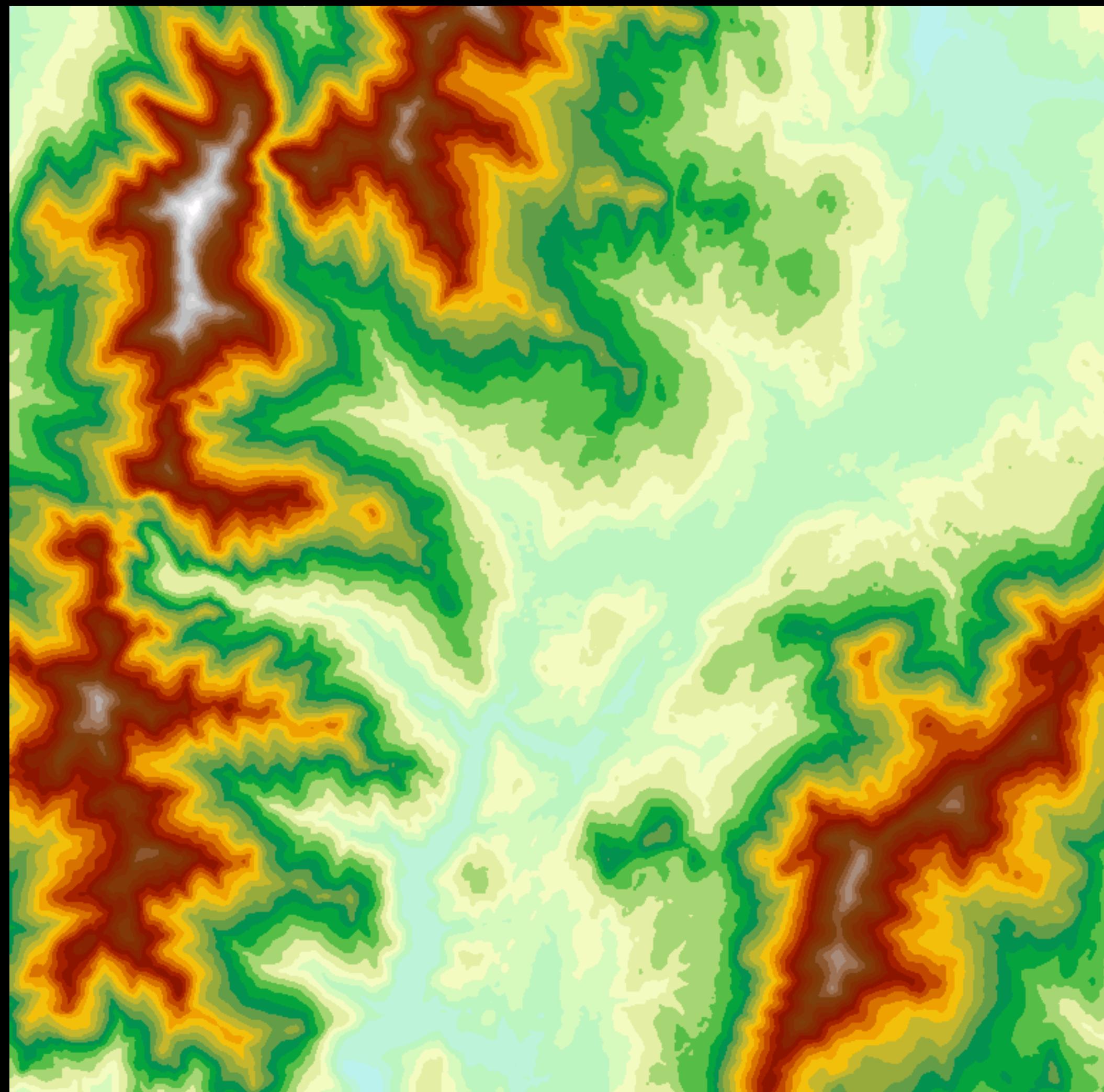
DEM Resolution: Derived Products

Slope layers derived from three previous DEMs



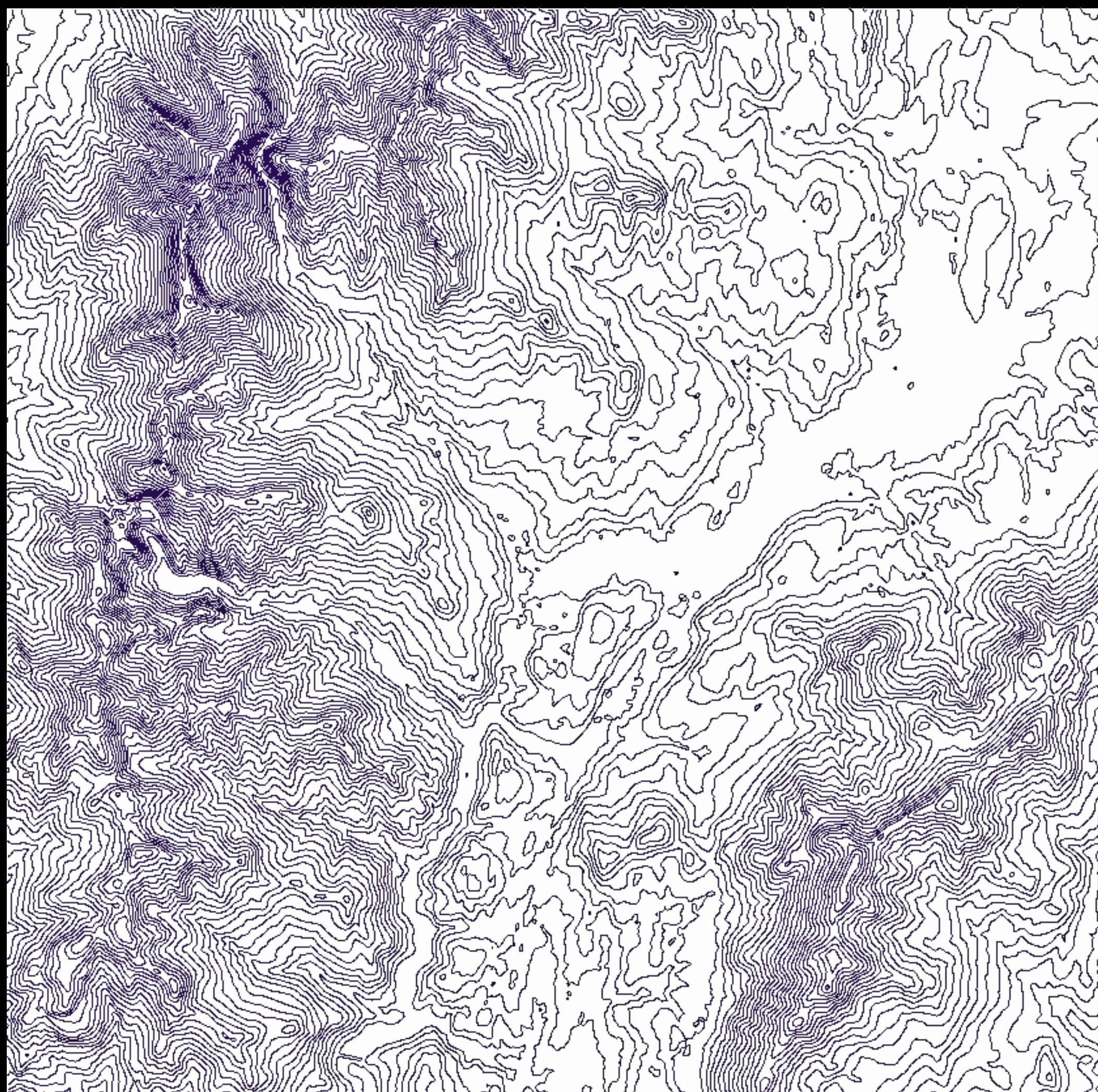
DEM Rendering: Hypsometric Map

- Classified DEM
 - color → elevation “band”
- QGIS:
Setting a Color Ramp



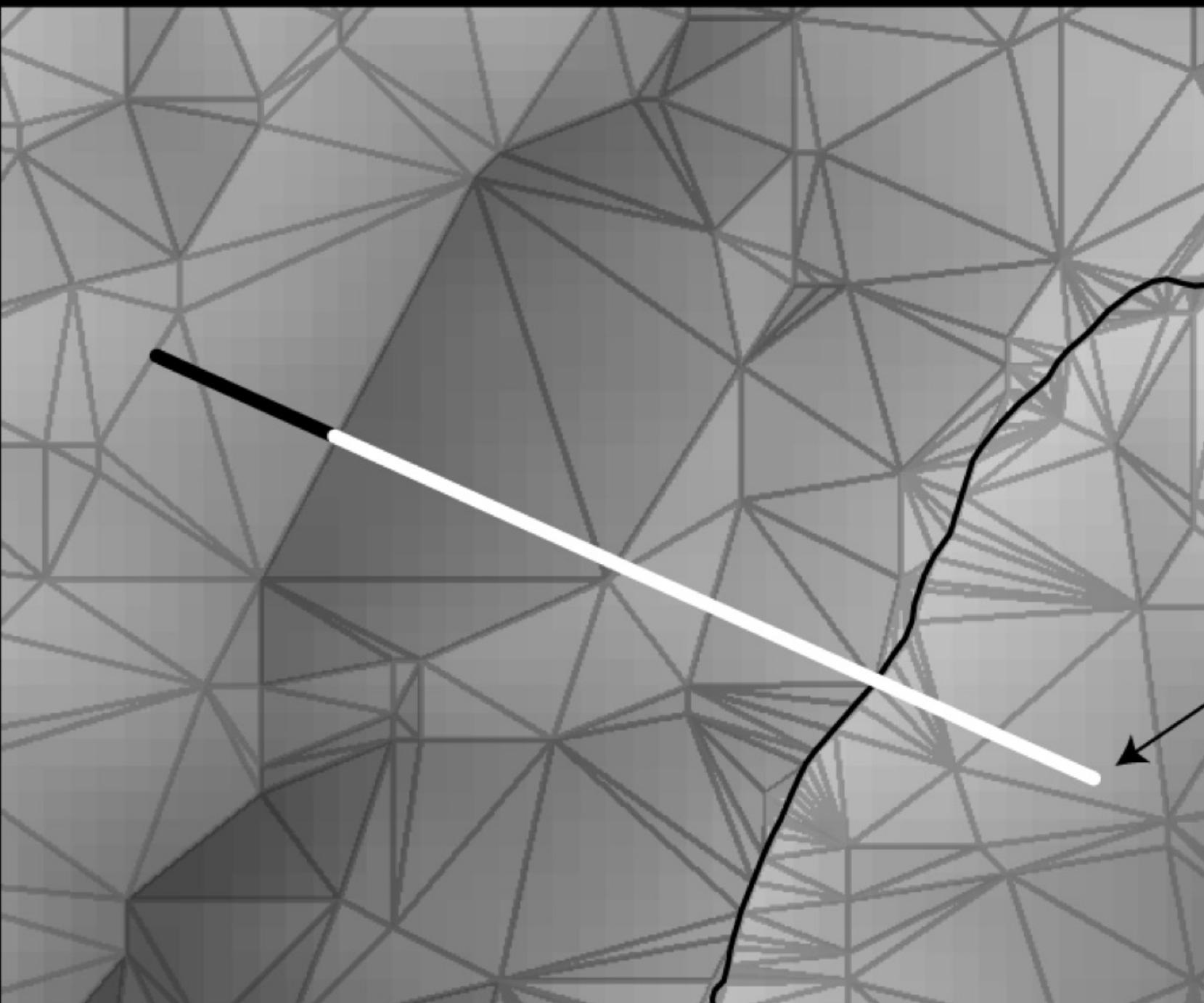
DEM Rendering: Contour Map

- Lines of constant elevation

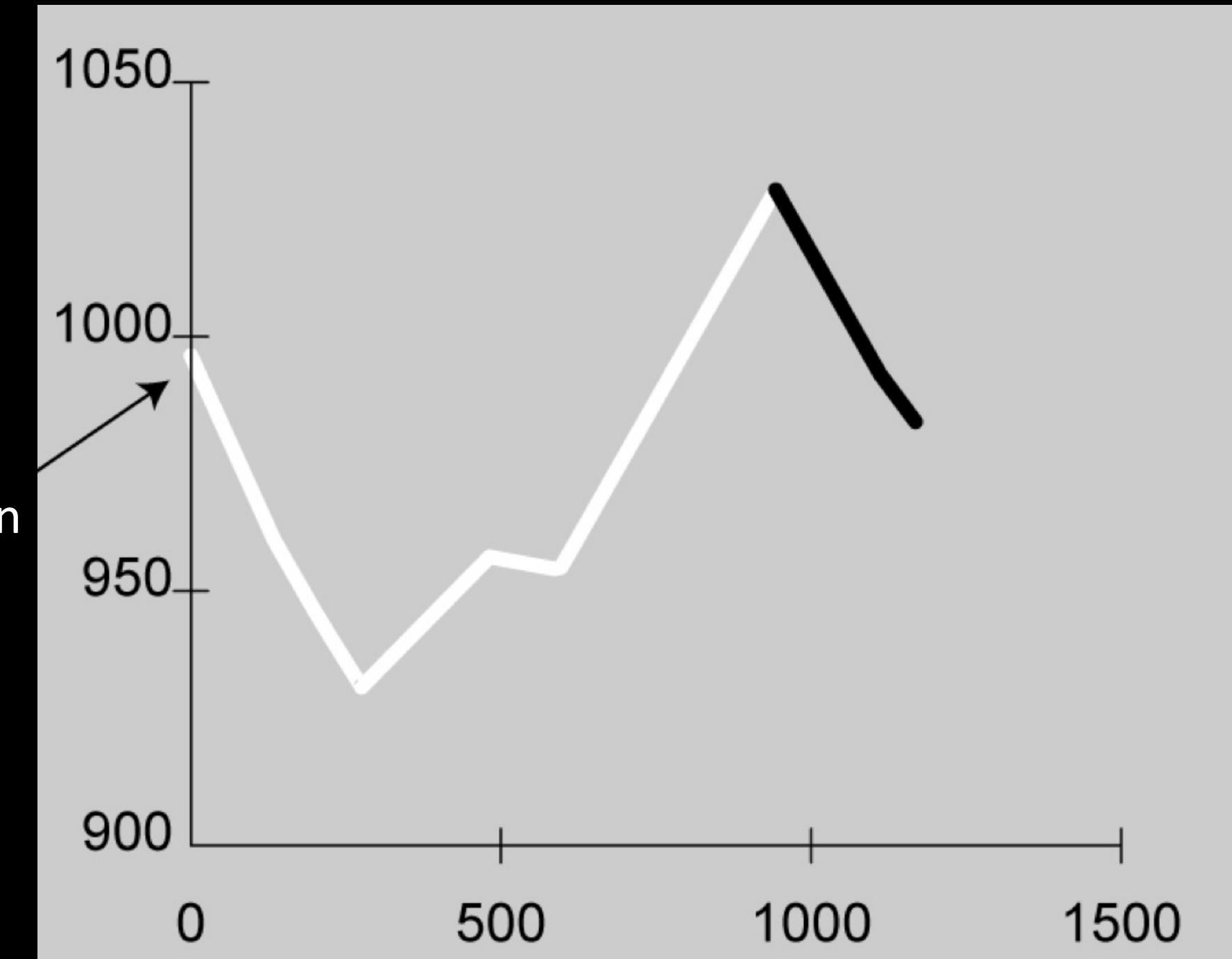


Visibility: Sightlines

- Sightline = visibility between points
 - white: visible
 - black: obscured

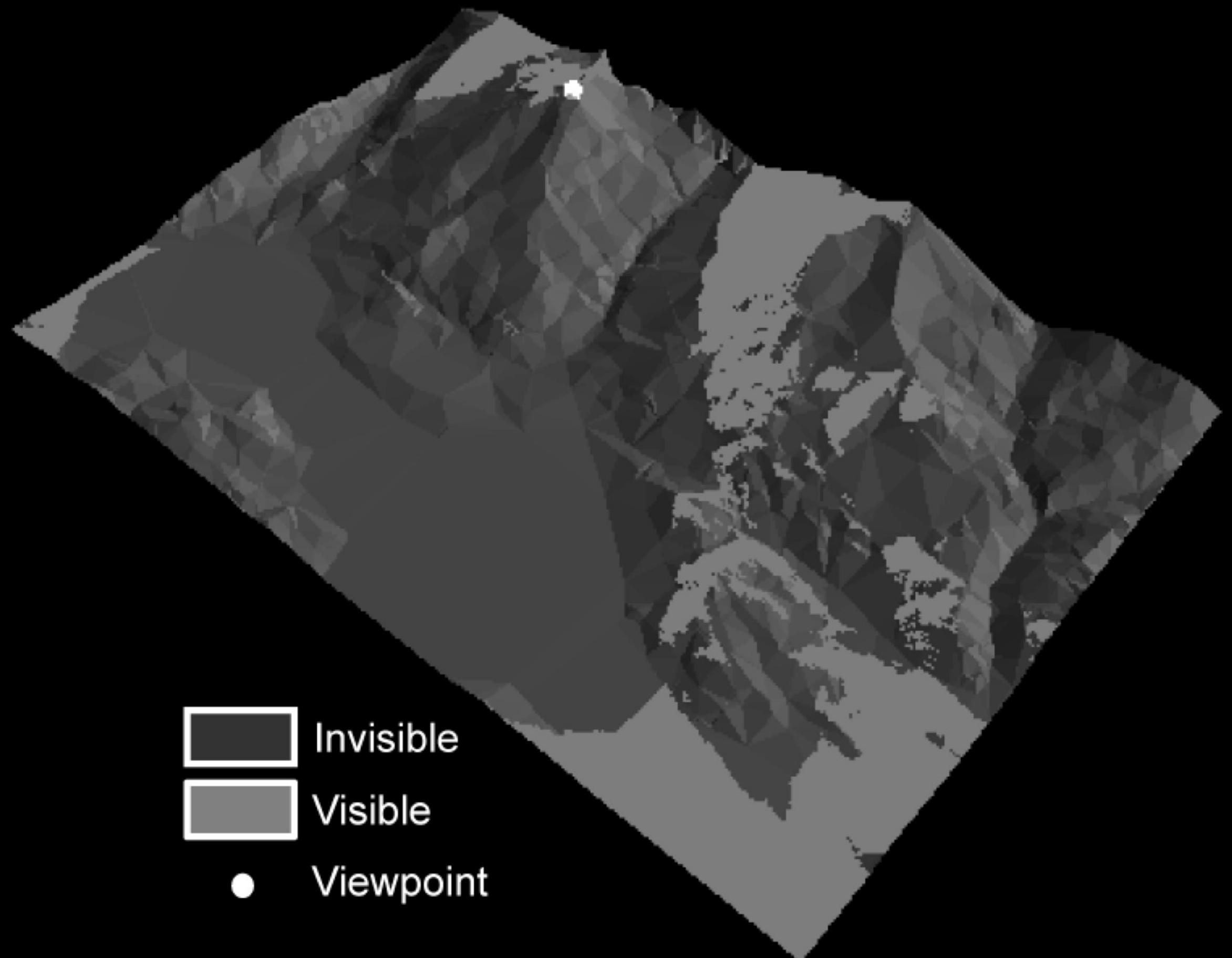


observation
point



Visibility: Viewshed

- Viewshed = area visible from point



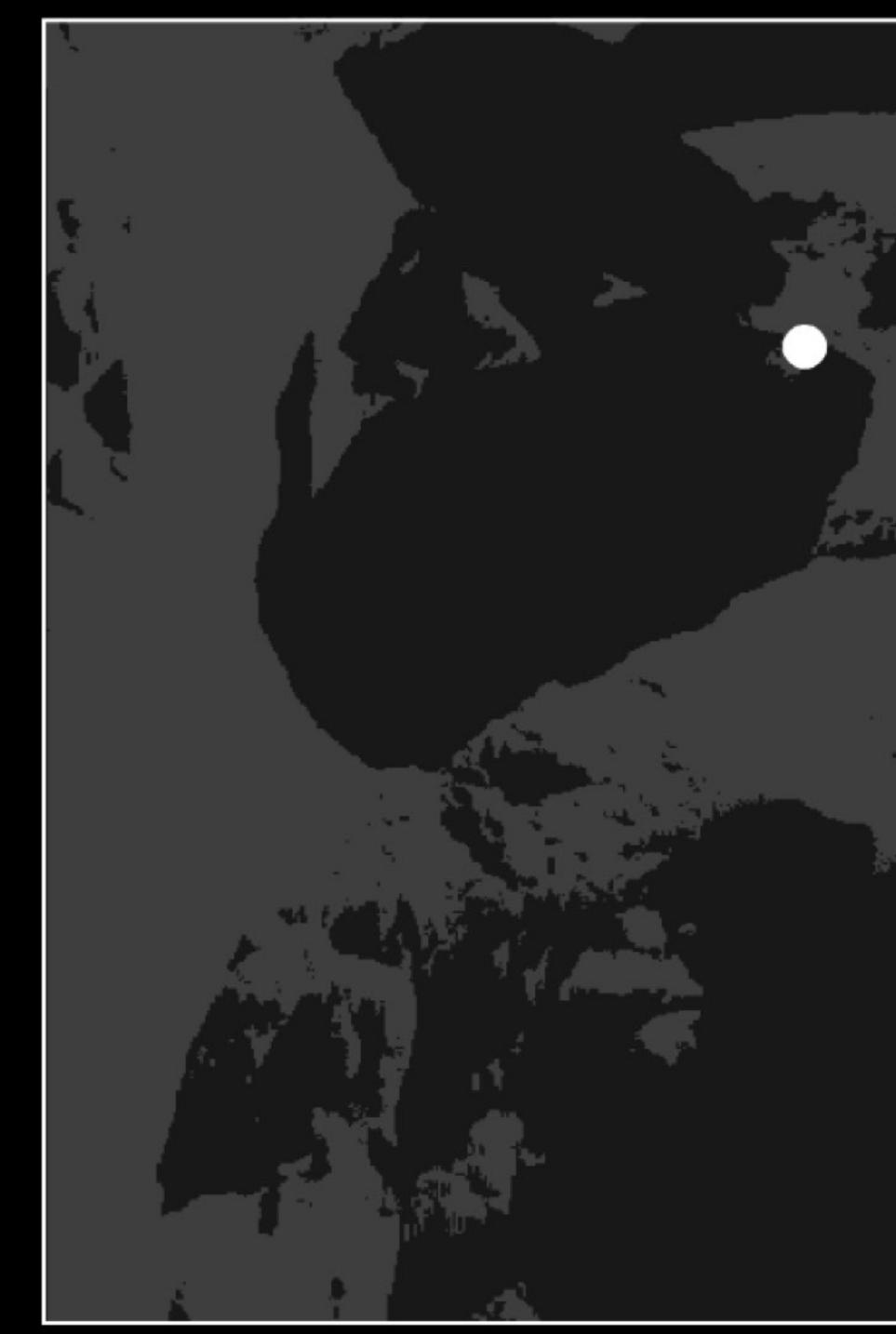
Viewshed = f(Elevation)

- (b) higher than (a) → larger viewshed



(a)

0
1



(b)

Viewshed = f(Search Radius)

- (a) → edge of DEM
- (b) → fixed radius



(a)



(b)

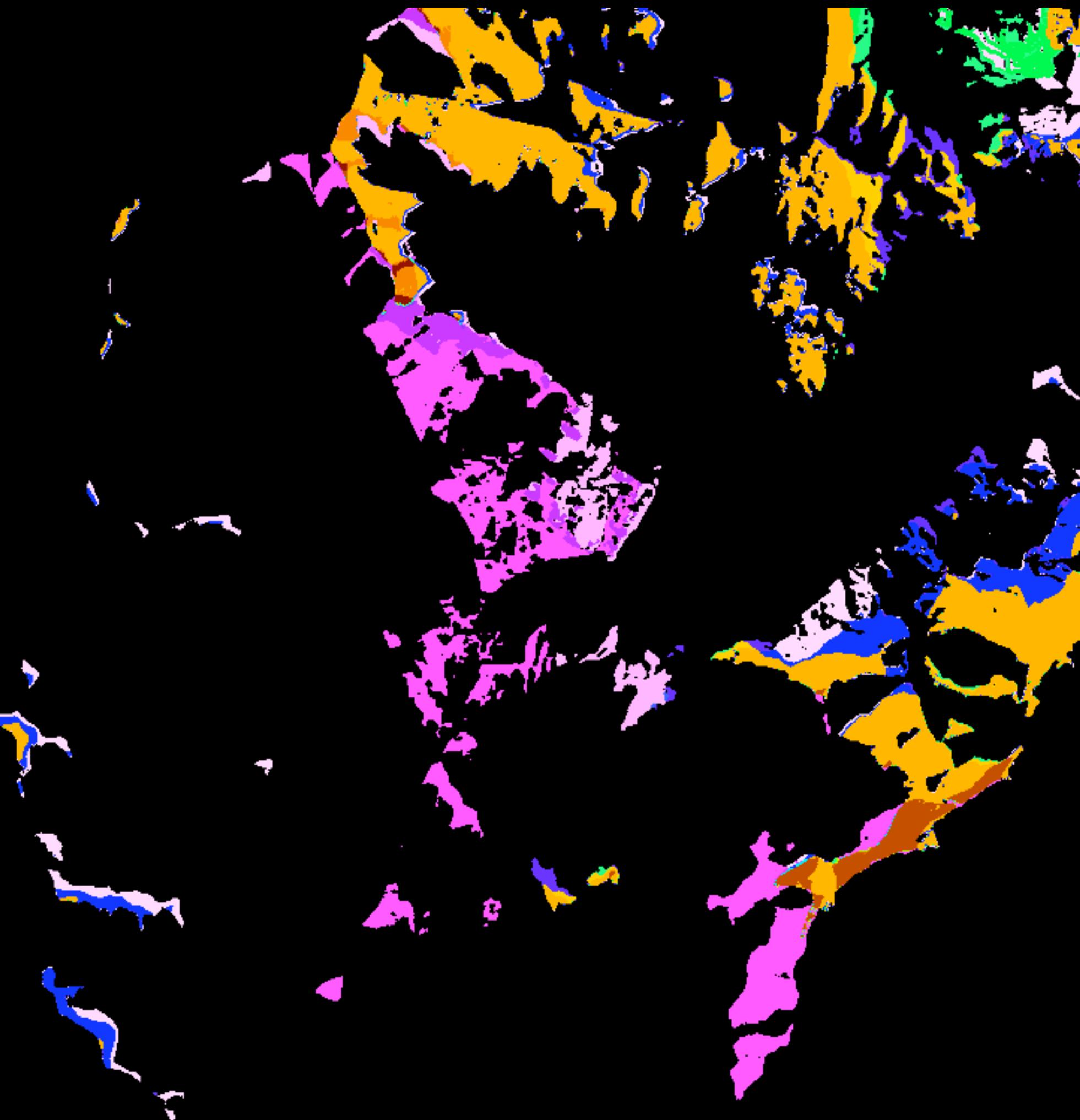
Viewshed: Cumulative

- 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
 $\text{code} = \text{visible from points(code)}$



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
 - direction water will flow out of each cell
3. Derive watershed raster
 - mark all cells that flow towards common outlet

Flow Direction

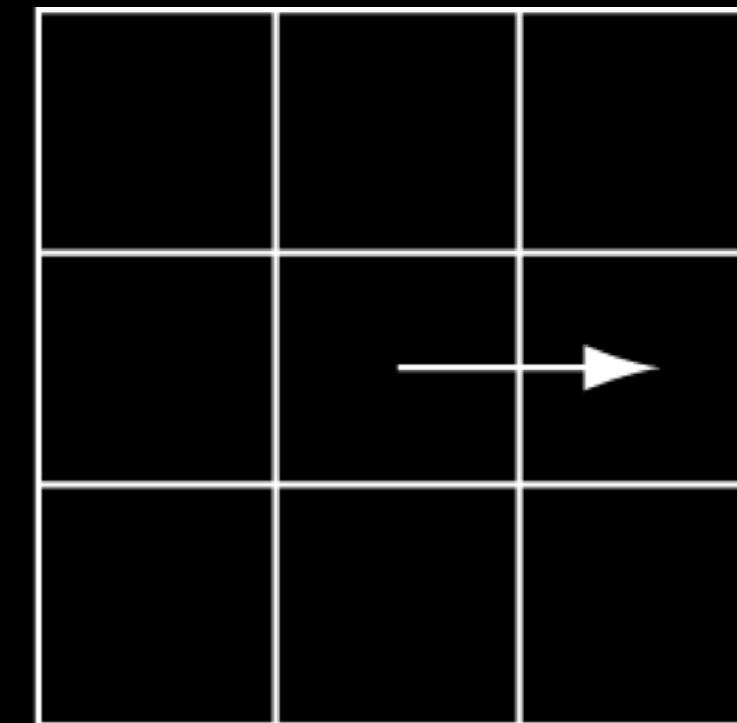
- For 8-neighborhood:
 - calculate distance-weighted drop
 - 4 immediate neighbors: center - neighbor
 - 4 corner neighbors: $(\text{center} - \text{neighbor}) / \sqrt{2}$
 - flow direction = maximum drop

1014	1011	1004
1019	1015	1007
1025	1021	1012

(a)

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

(b)



(c)

Automated Watershed Delineation (fine)

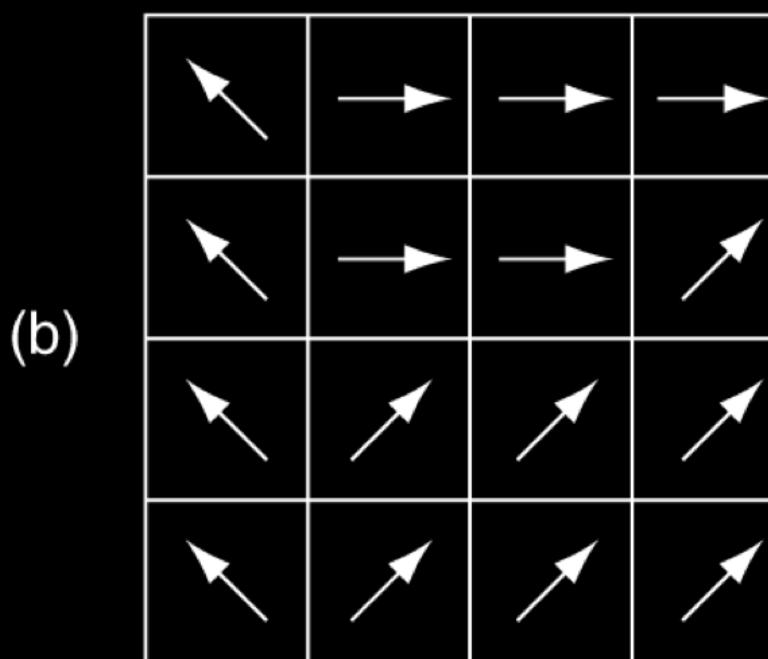
1. Fill sinks (depressions) in DEM
2. Derive catchment areas
 - accumulated water flow through each cell
3. Derive channel network
 - apply threshold value to catchment area
4. Derive watershed basins
 - areas draining into each channels

Flow Accumulation

A. filled elevation raster

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

B. flow direction raster



C. flow accumulation raster

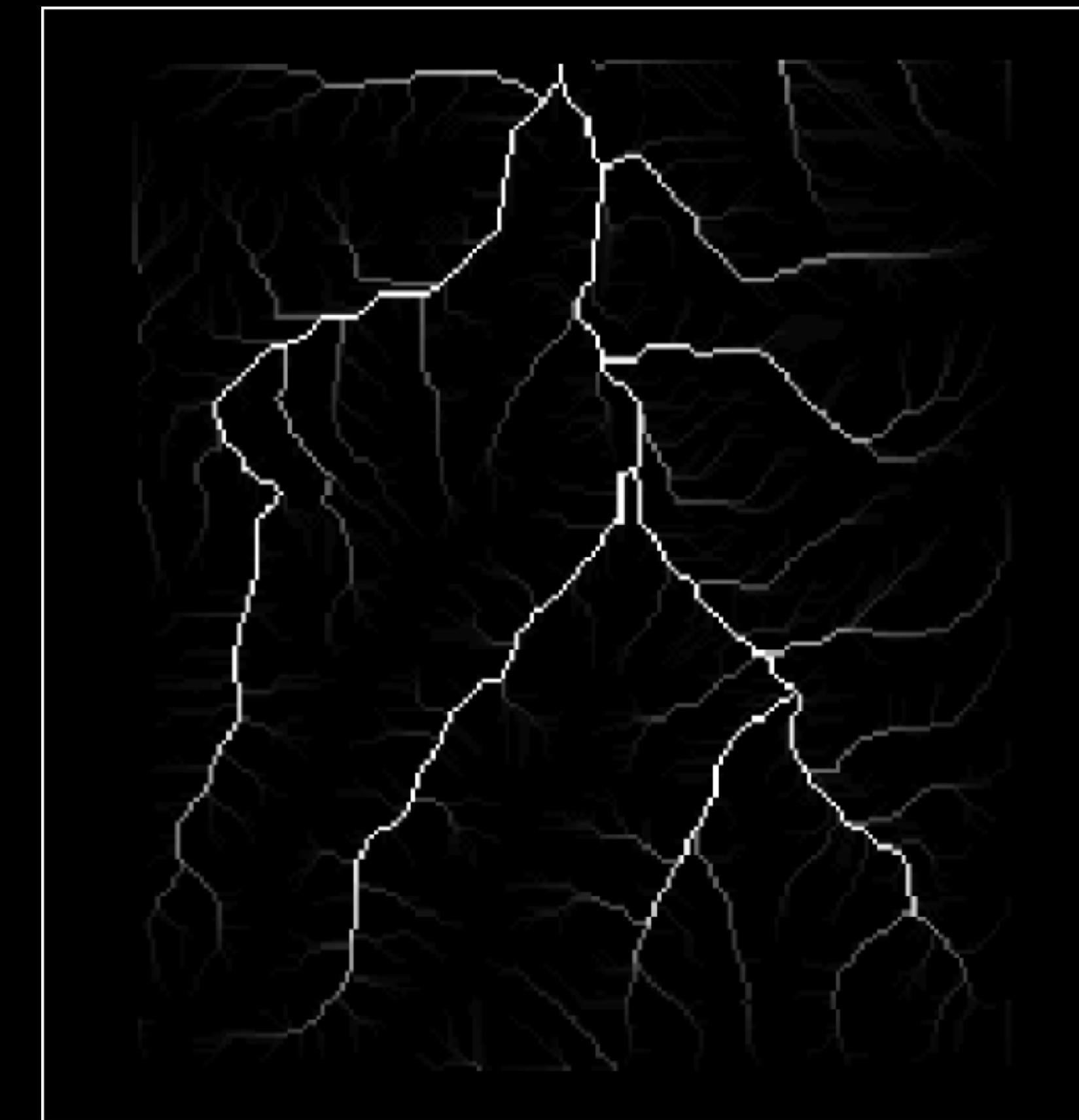
- shaded cells have same accumulation value
 - top cell receives flow from left and lower-left cells
 - bottom cell receives flow from lower-left cell
 - already had accumulation value of 1

(c)

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

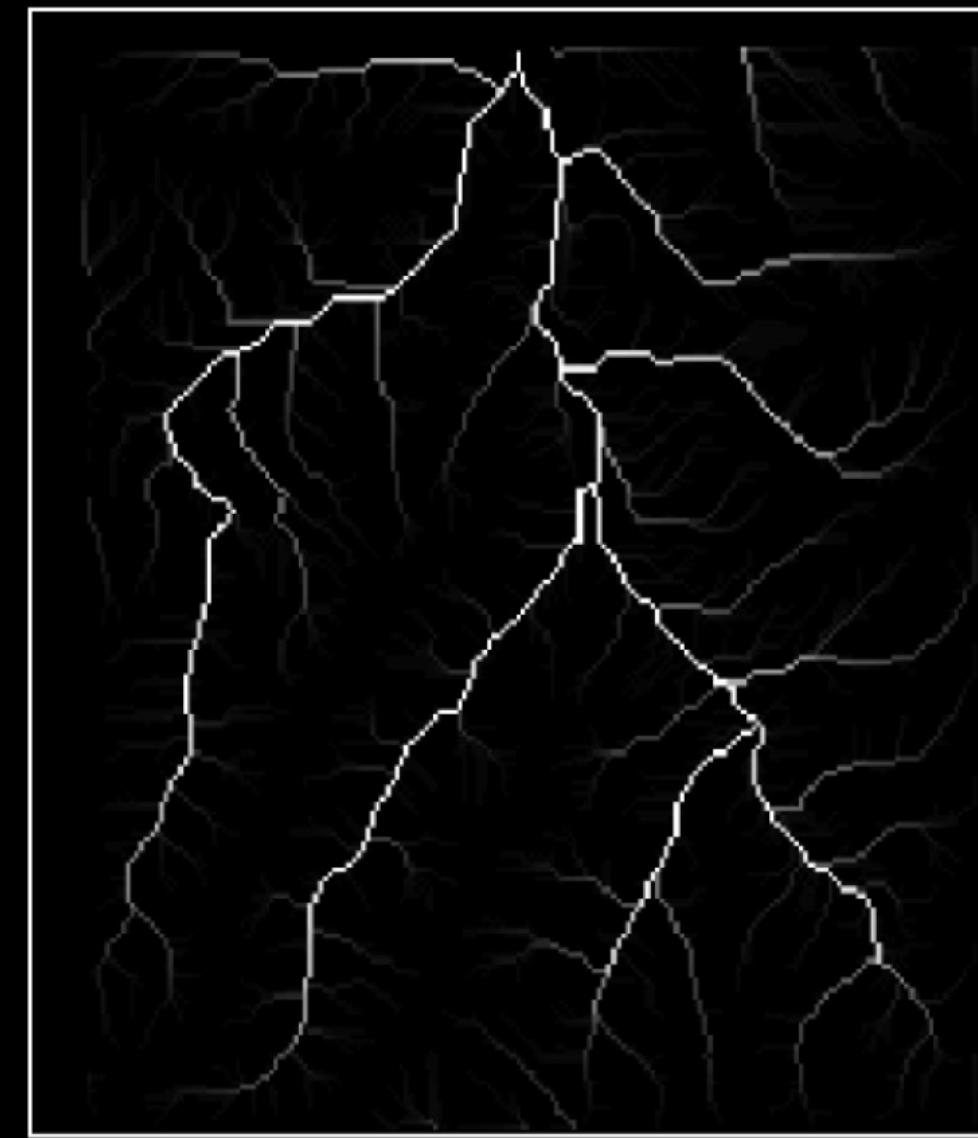
Flow Accumulation

- brighter symbols = higher accumulation values

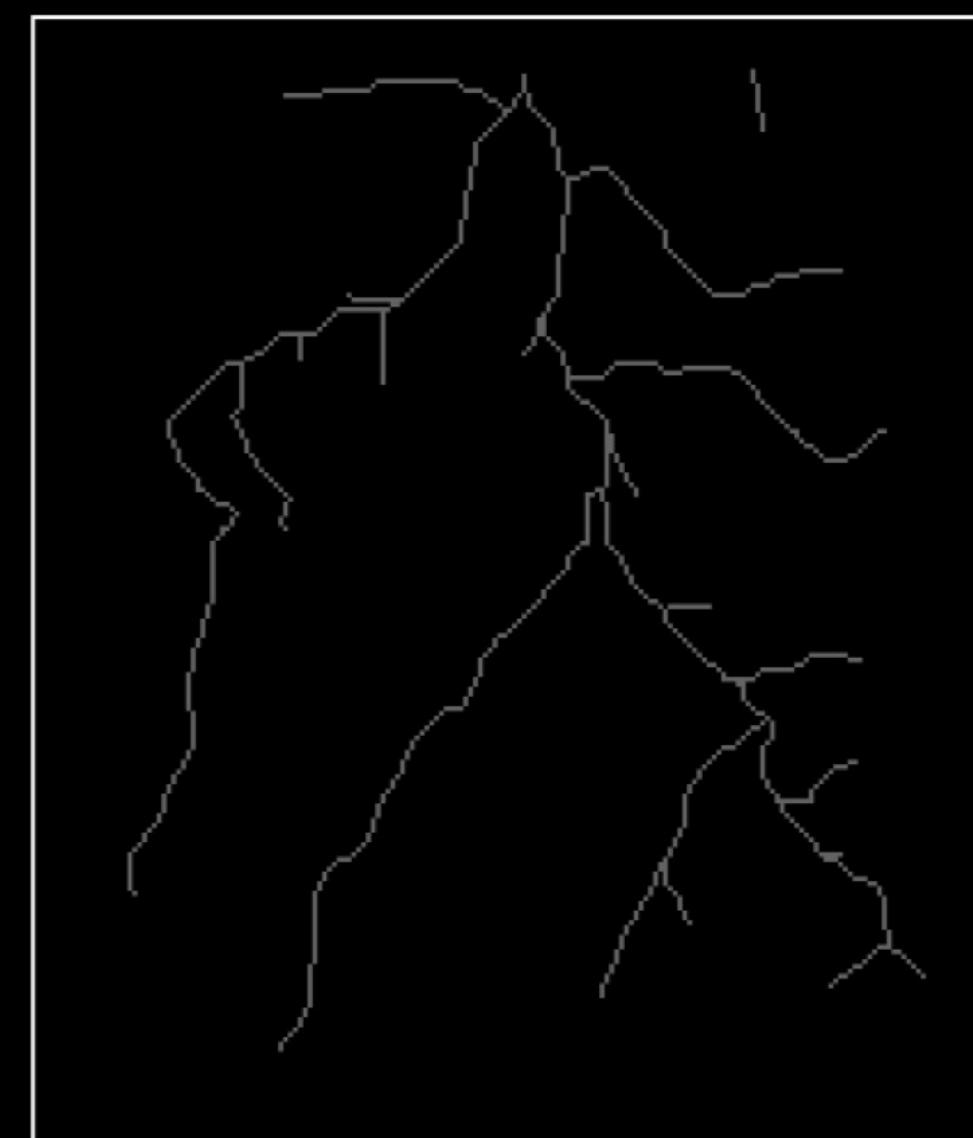


Stream Network

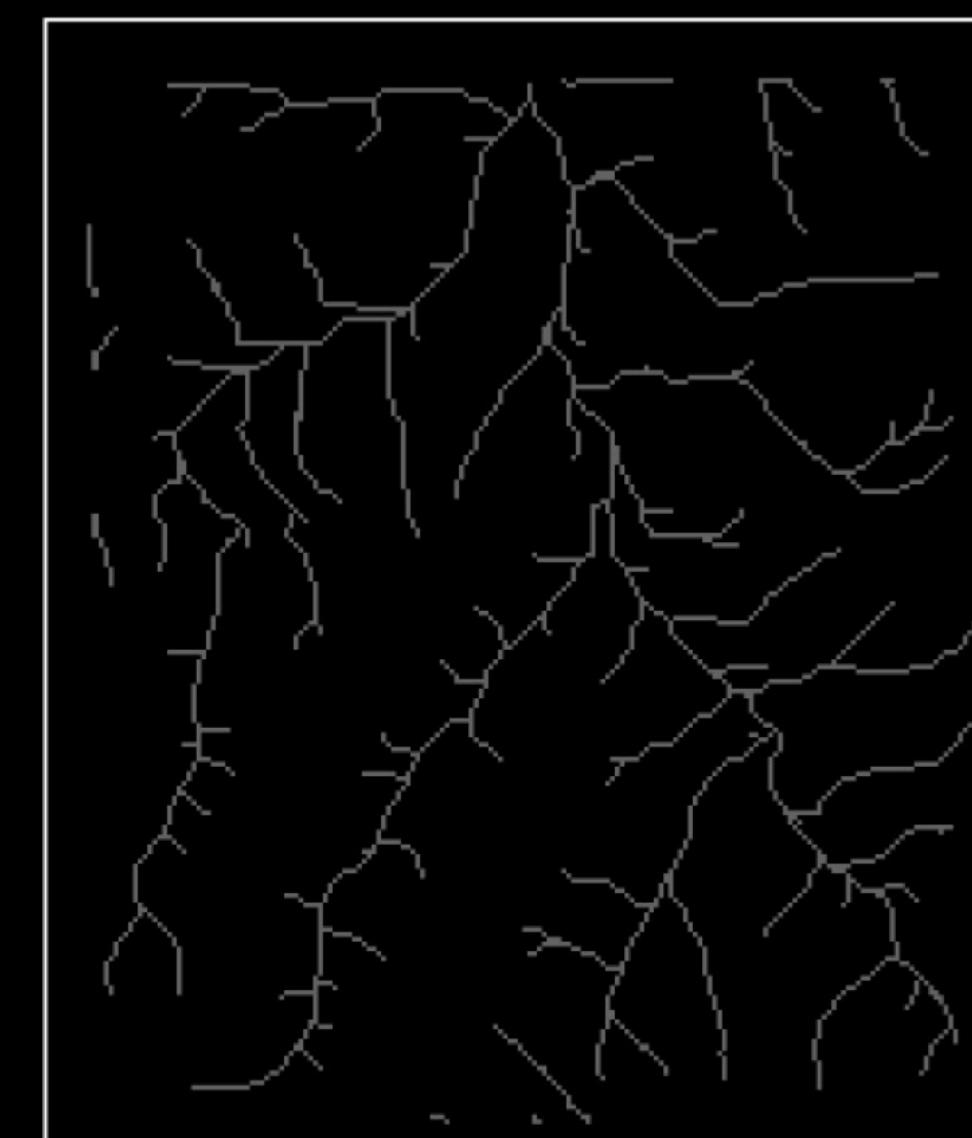
- flow accumulation raster
- stream network (threshold = 500)
- stream network (threshold = 100)



(a)



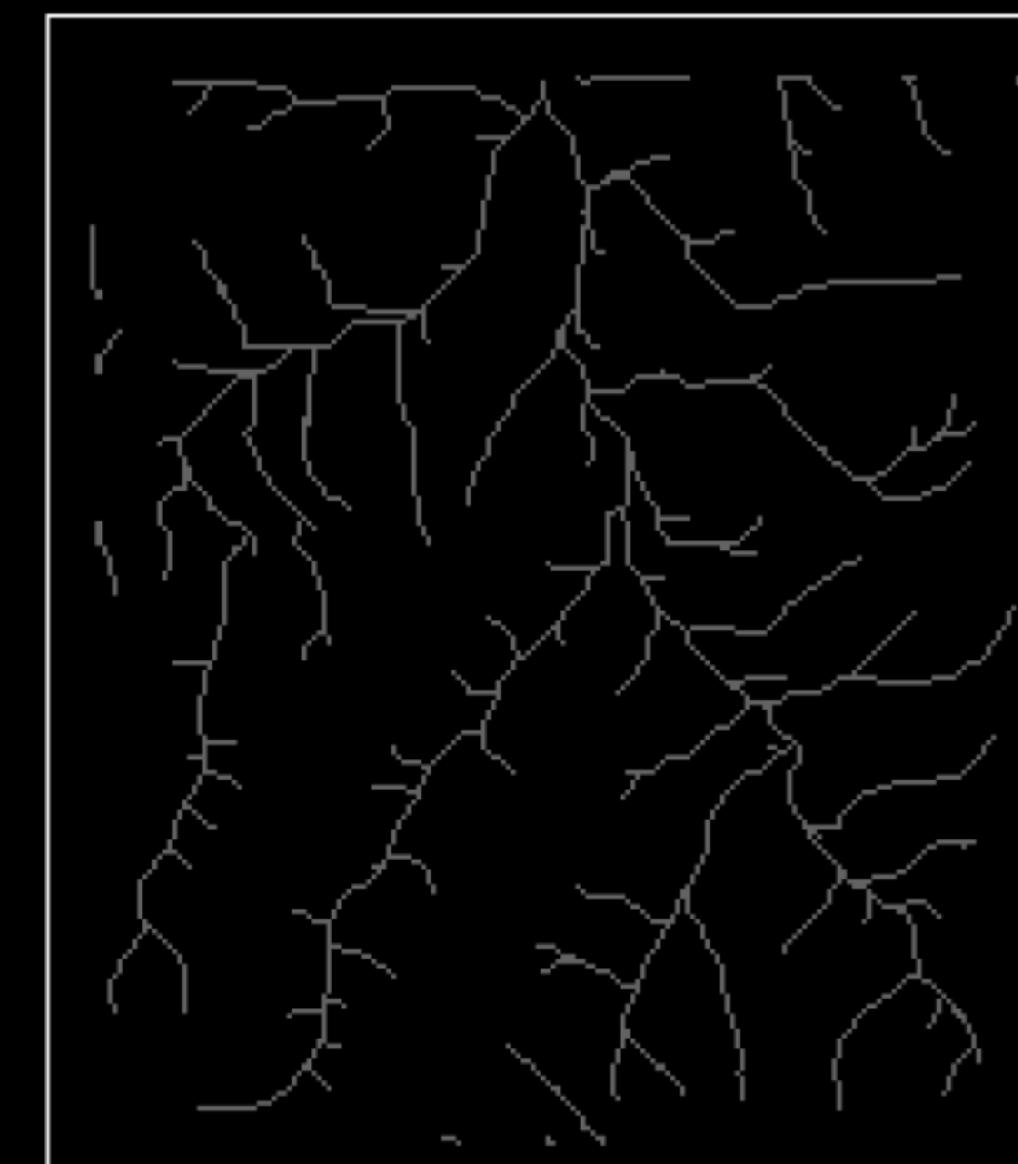
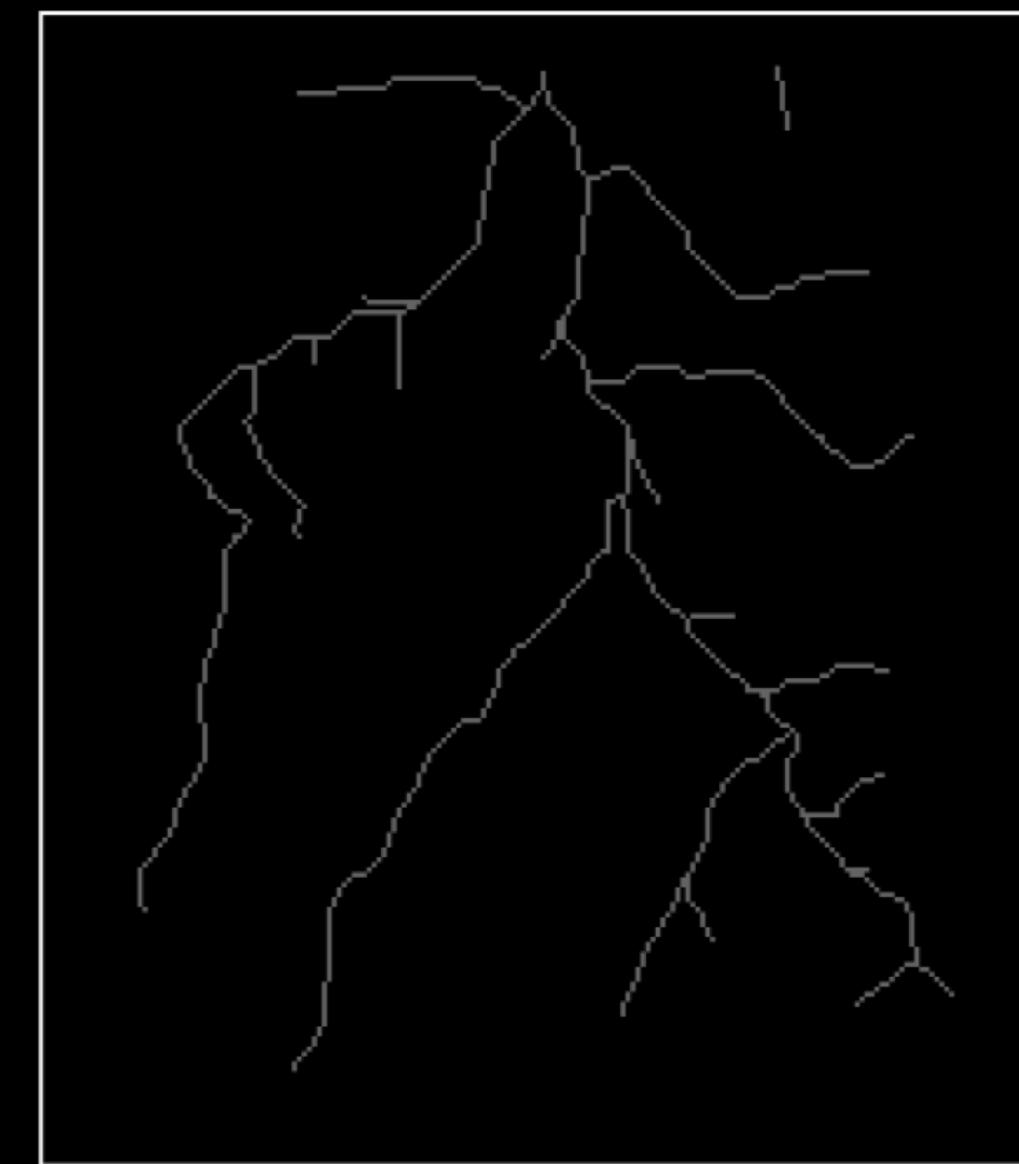
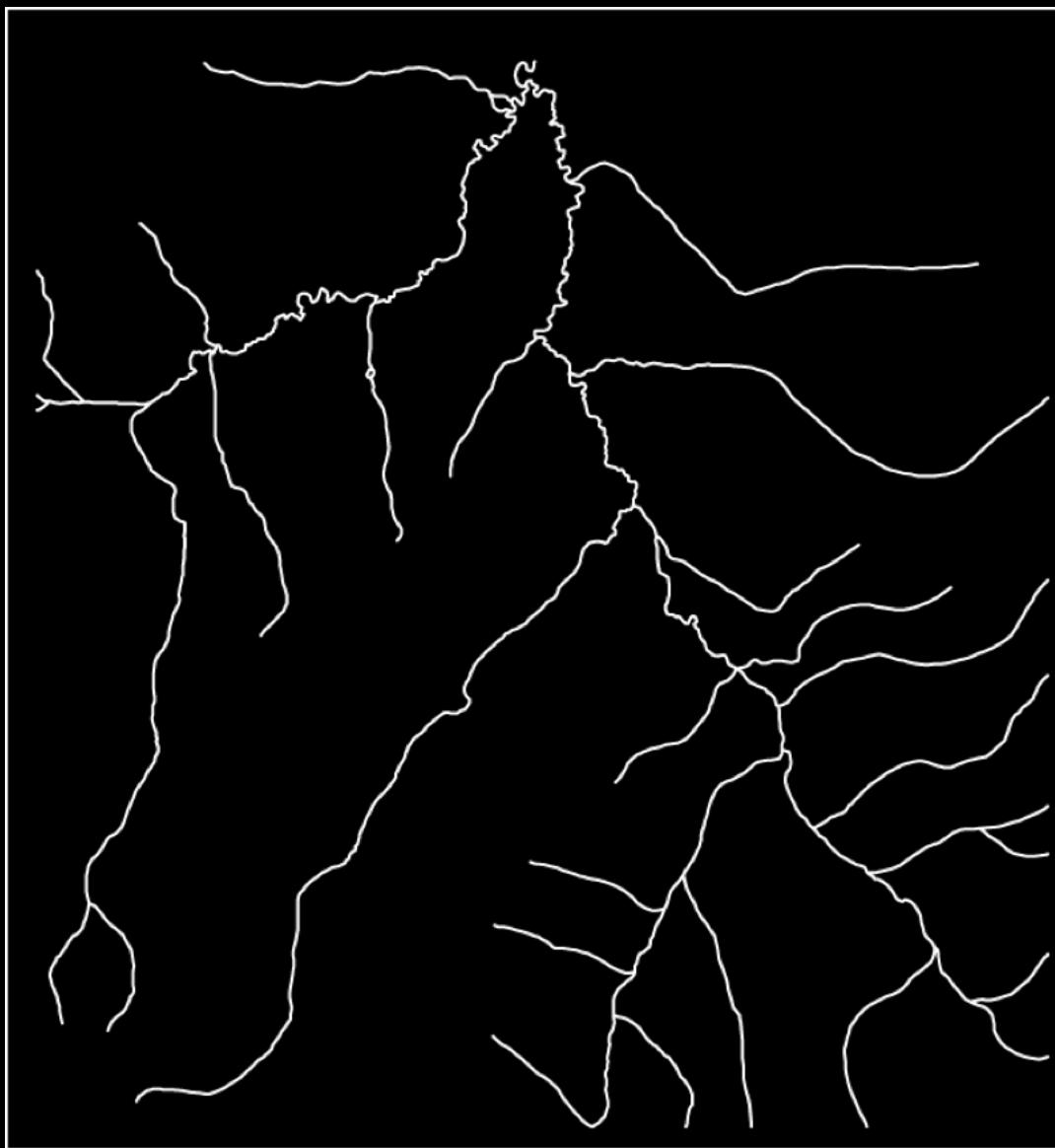
(b)



(c)

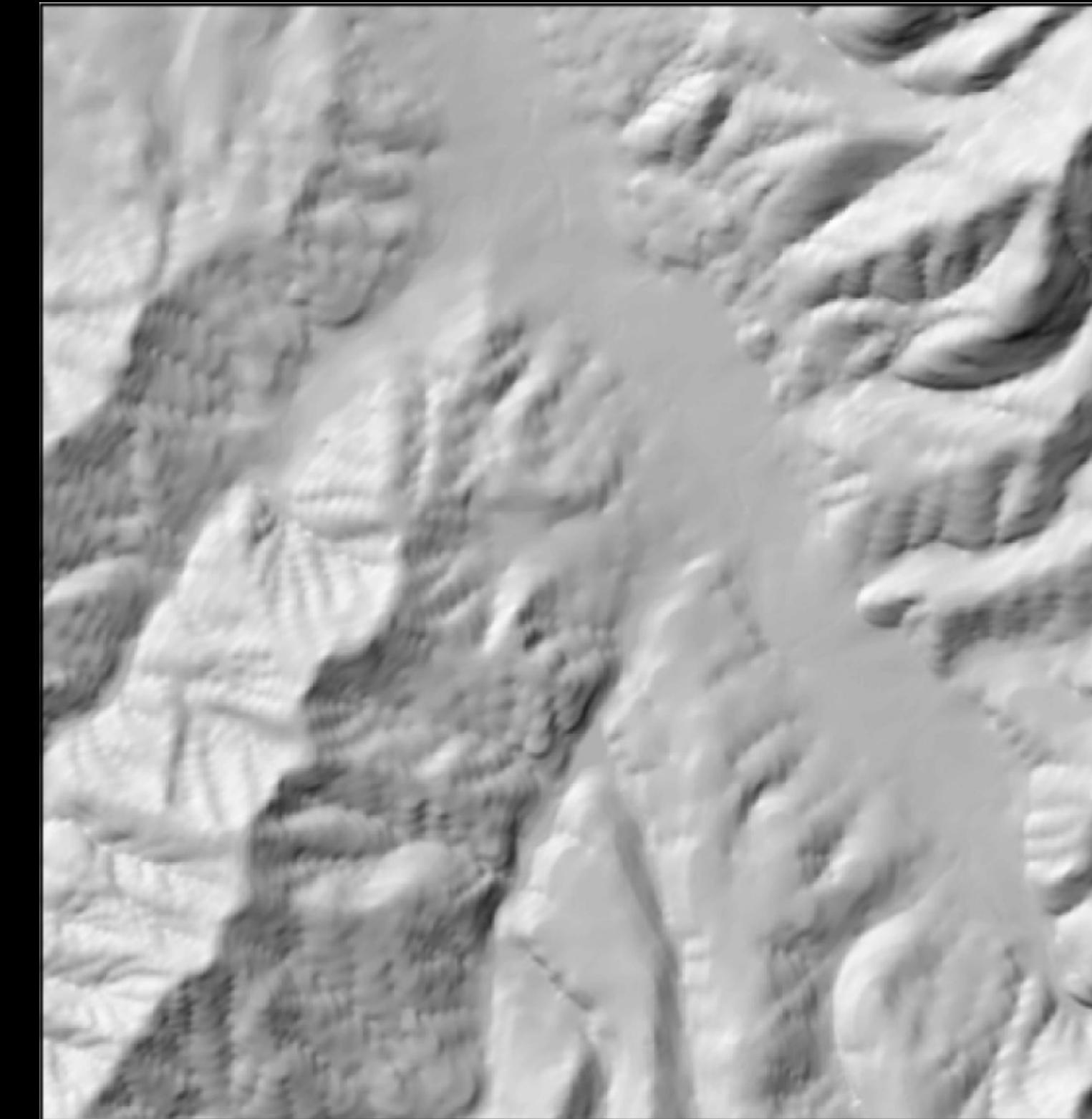
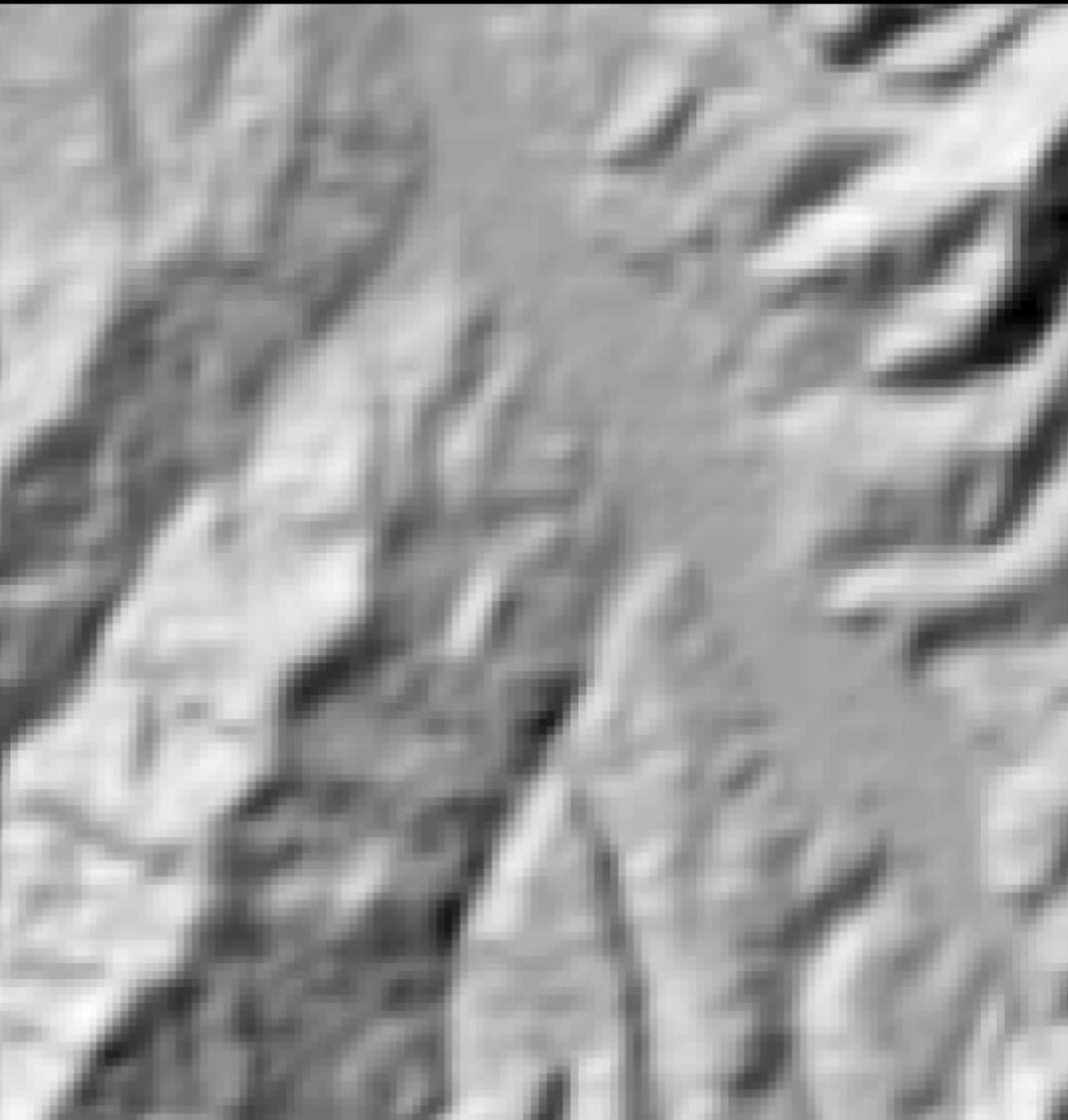
Stream Network

- mapped
(1:24000 DLG)
- calculated
(threshold = 500)
- calculated
(threshold = 100)



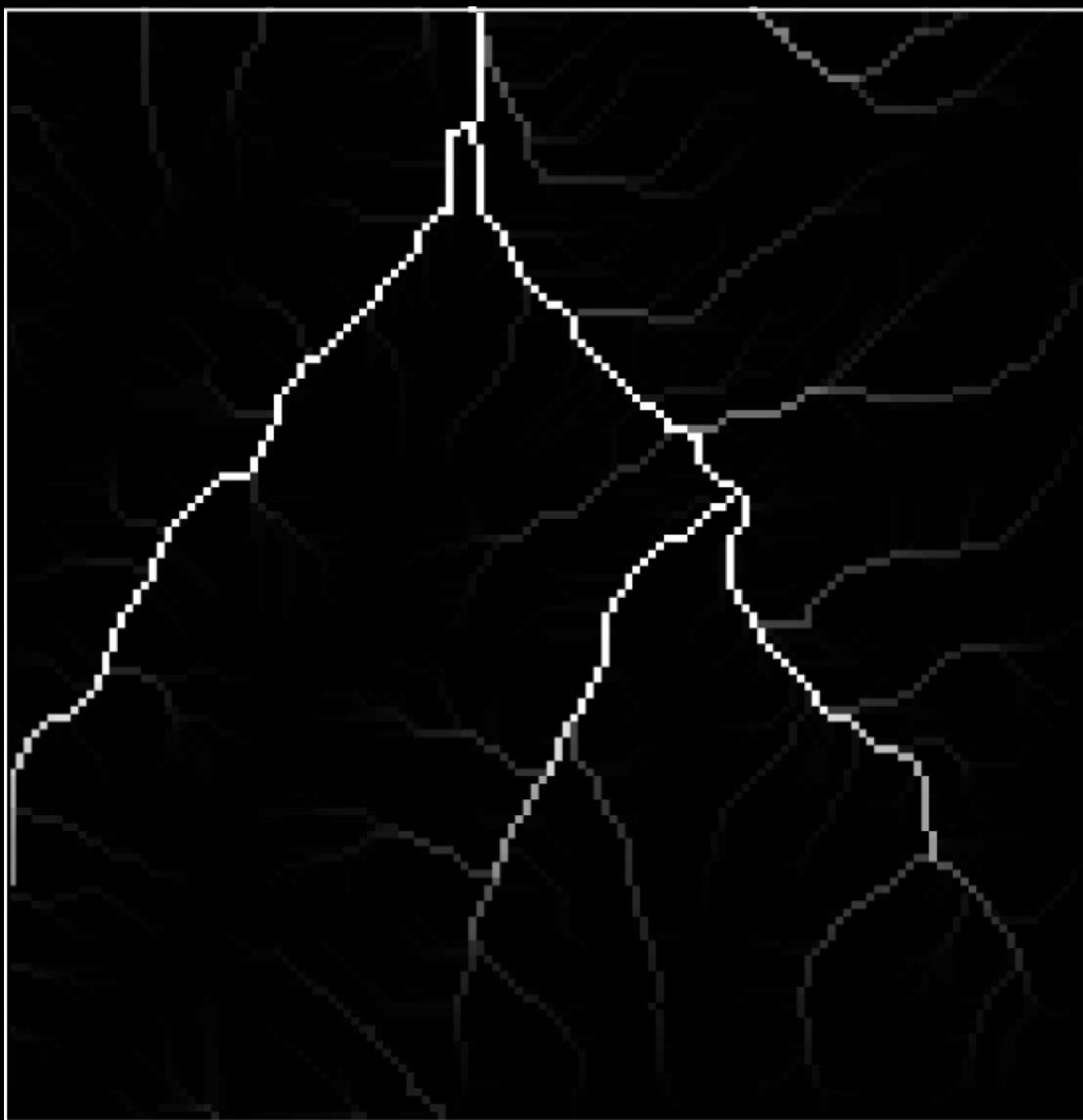
Resolution Affects Watershed Analysis

- 30m DEM
- 10m DEM



Resolution Affects Watershed Analysis

- stream network
from 30m DEM
- stream network
from 10m DEM



(a)



(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

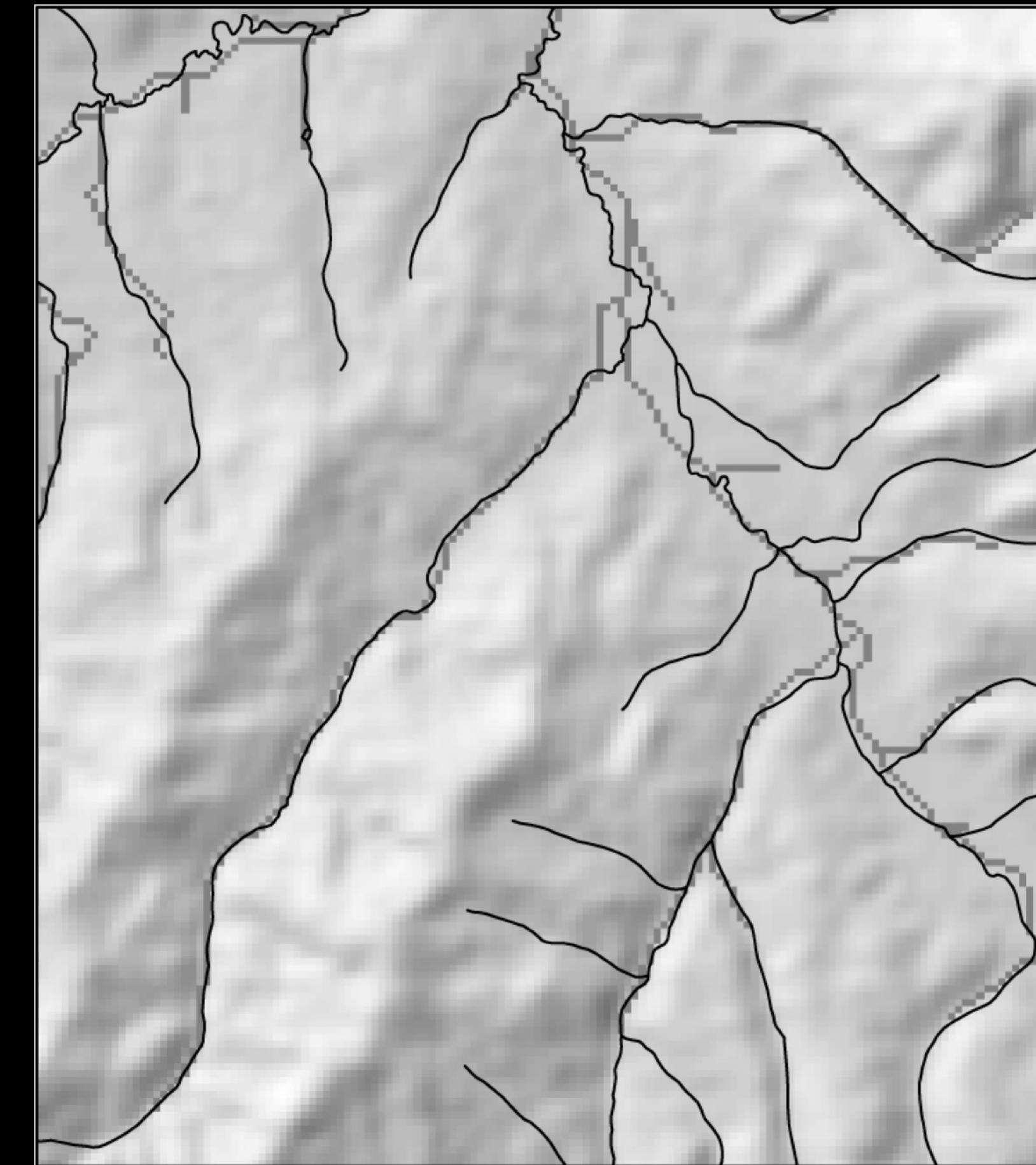


Figure Credits

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