Surface and Field Analysis

Part 2: Drainage Modeling

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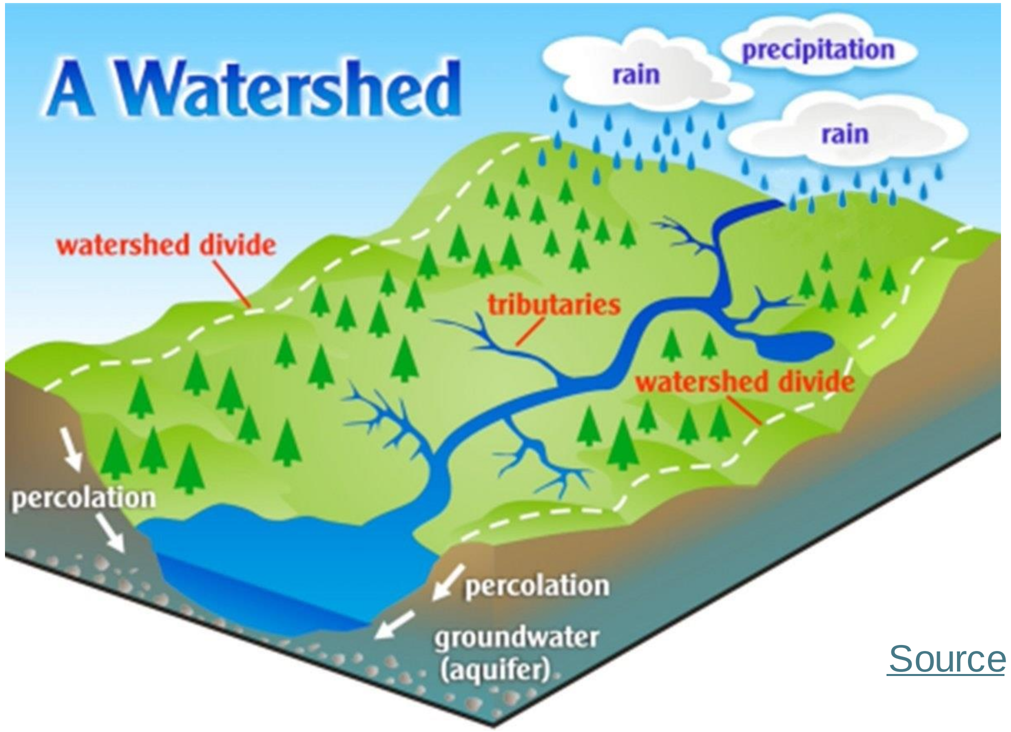
Watershed / Basin / Delta

What is watershed?

- A watershed is an area of land that collects and directs all rainfall and surface water to a specific point, like a river or lake.
- It is defined by natural features, such as hills and valleys, which form its boundaries.
- When rain falls, all the water within a watershed flows downhill, following the terrain, until it reaches a common outlet.
- Understanding watersheds helps us manage water flow, predict flooding, and plan land use efficiently.

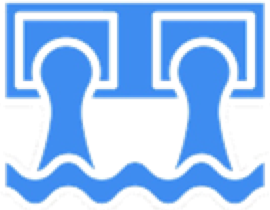


Source

Why watershed is important?

Flood Risk
Assessment

Agricultural
Planning



Stormwater
Management

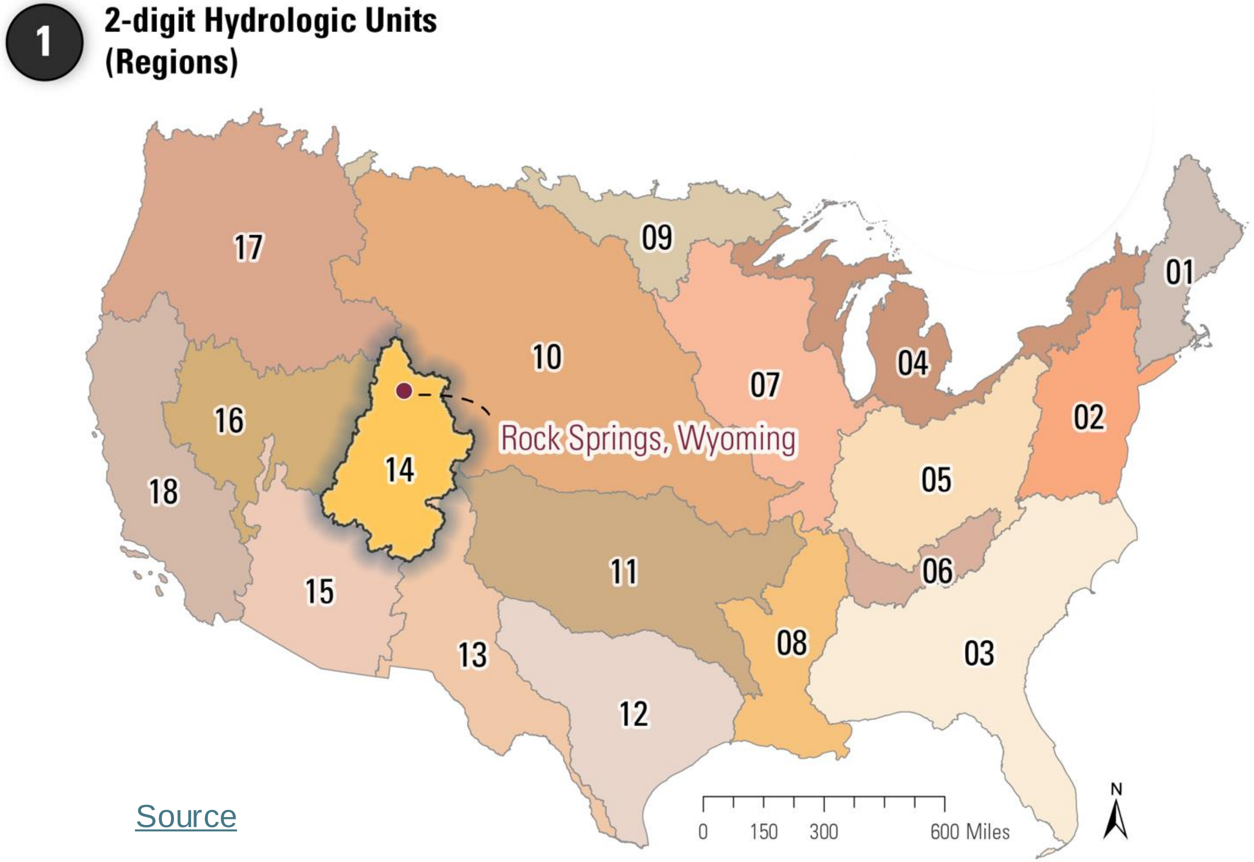
Water Quality
Monitoring

Erosion
Control

Conservation
and Habitat
Restoration

Hydropower
Planning

Watershed can be formed at different scales



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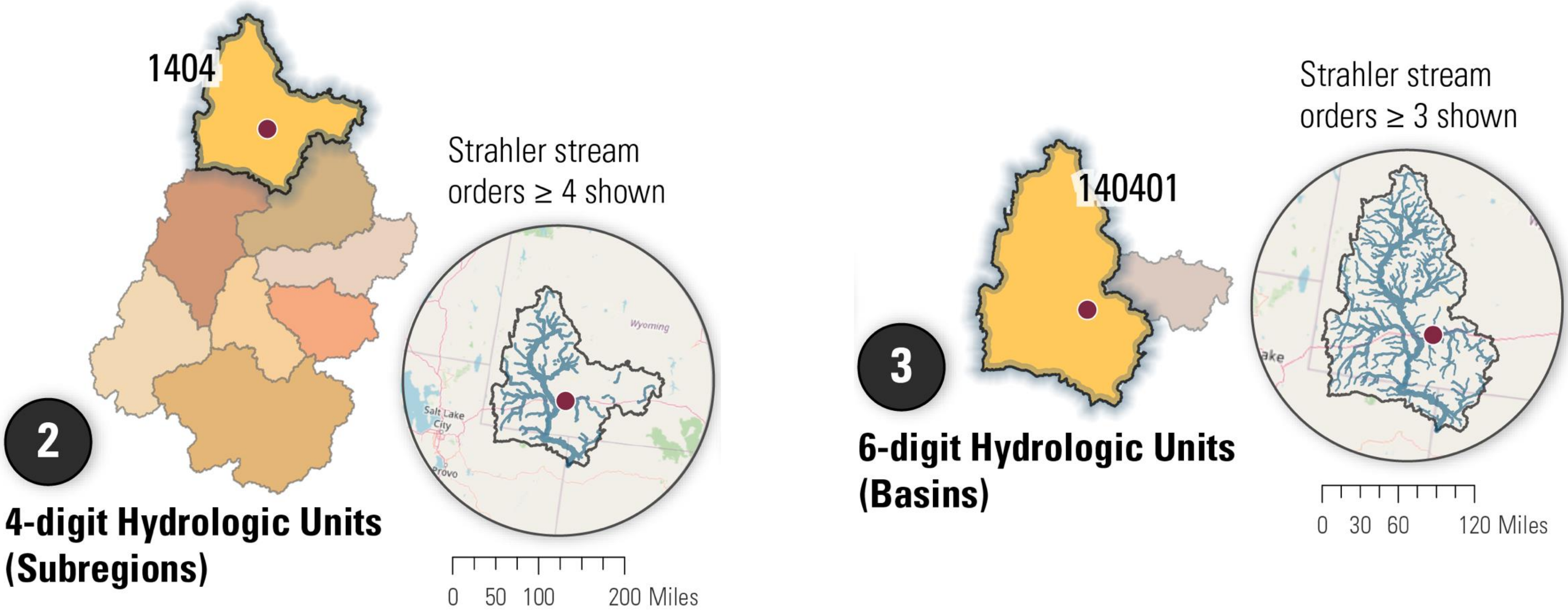
Watershed can be formed at different scales



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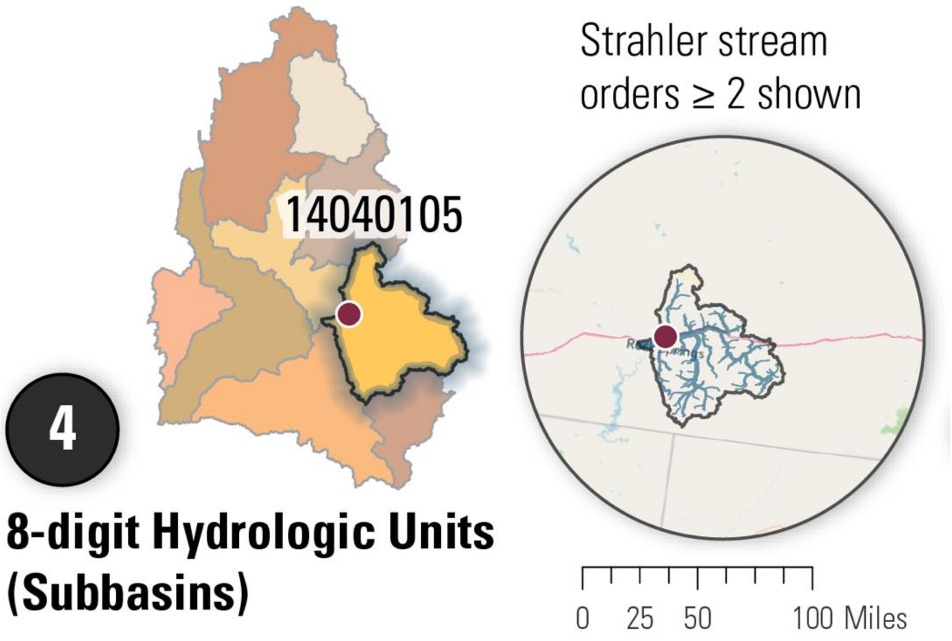
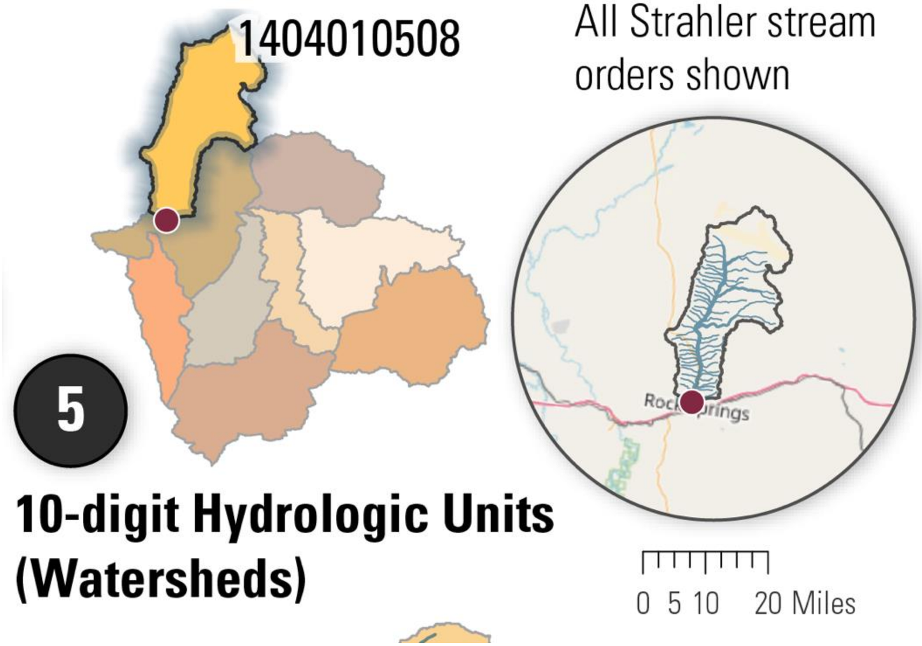
Watershed can be formed at different scales





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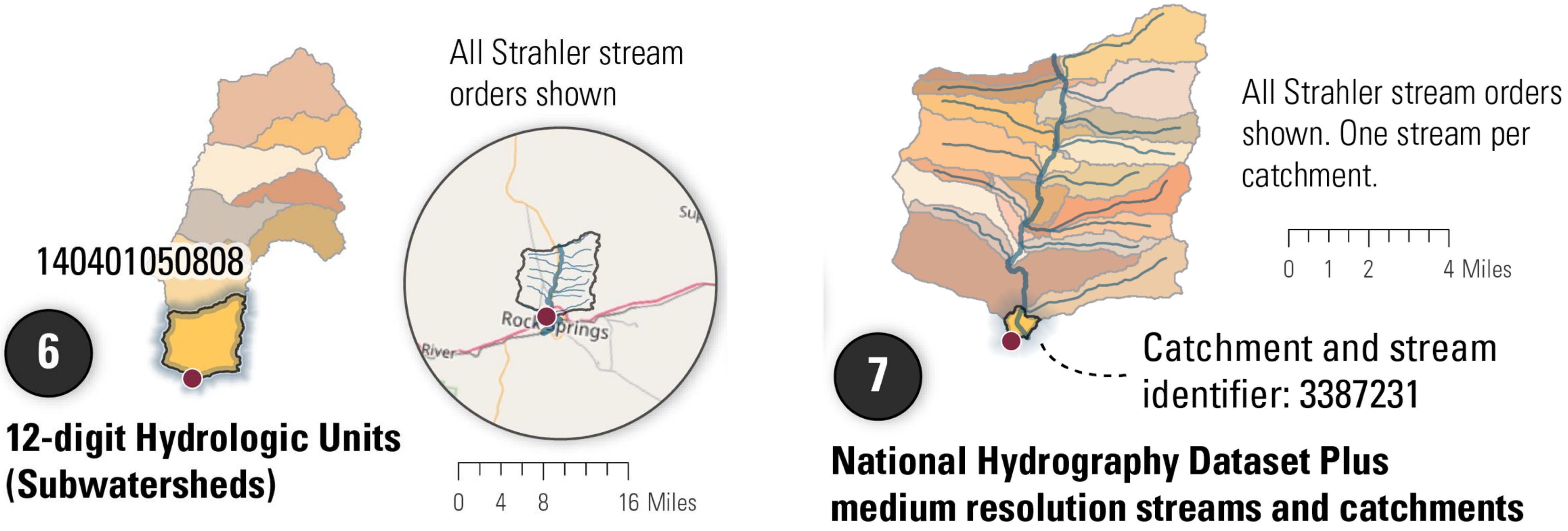
Watershed can be formed at different scales



Source

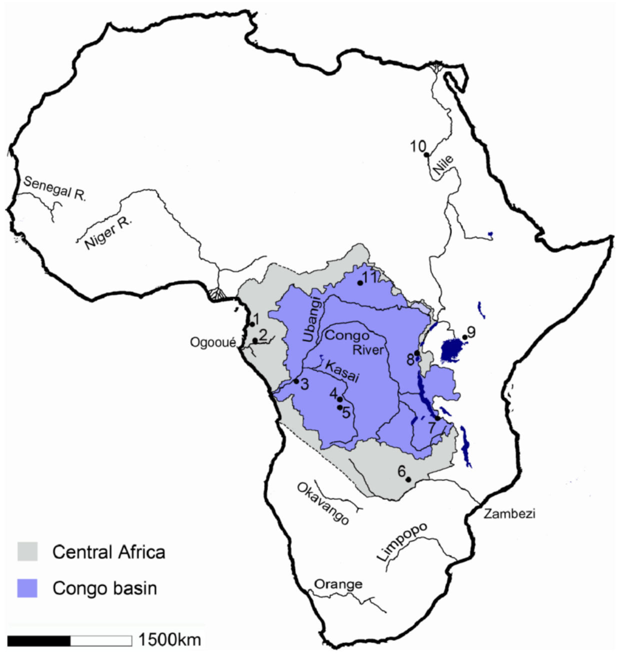
Some of the largest watersheds in the world

Amazon Basin
800 Million Hectares

[Source](#)

Some of the largest watersheds in the world

Congo Basin
300 Million Hectares



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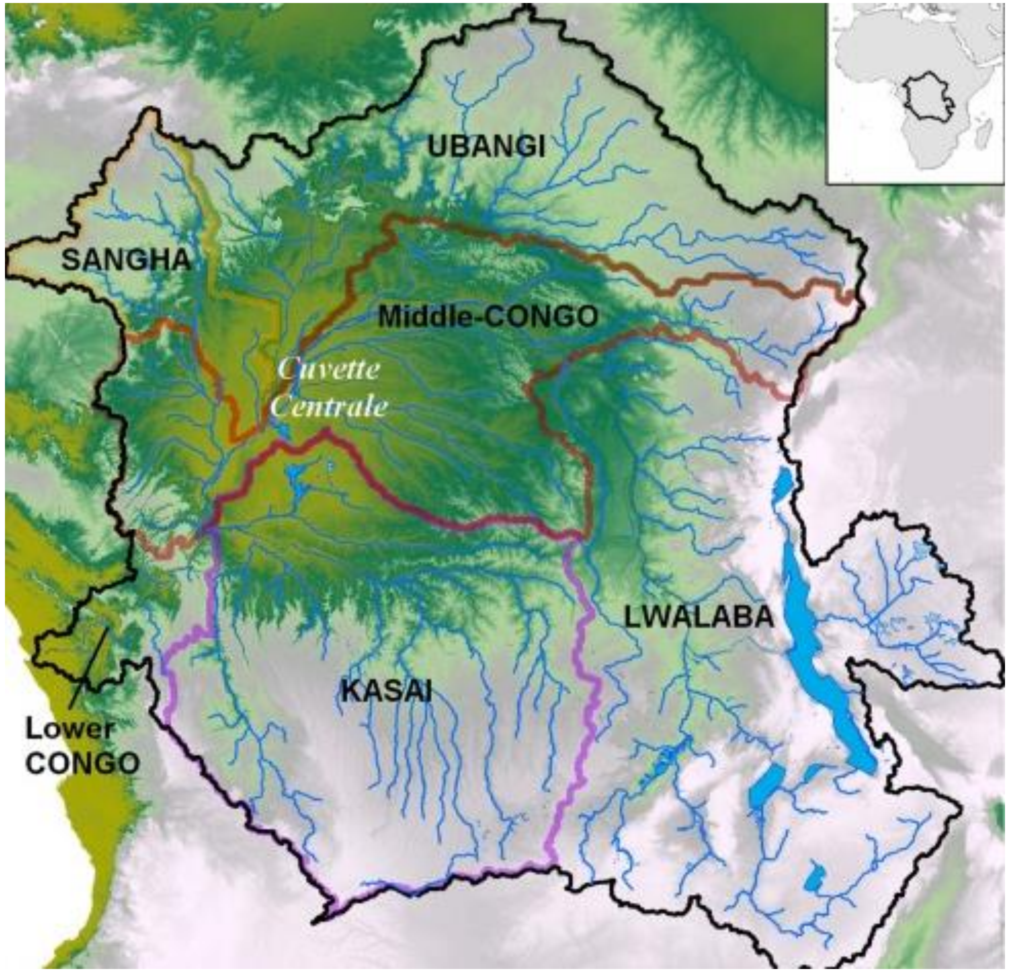


Source

Some of the largest watersheds in the world

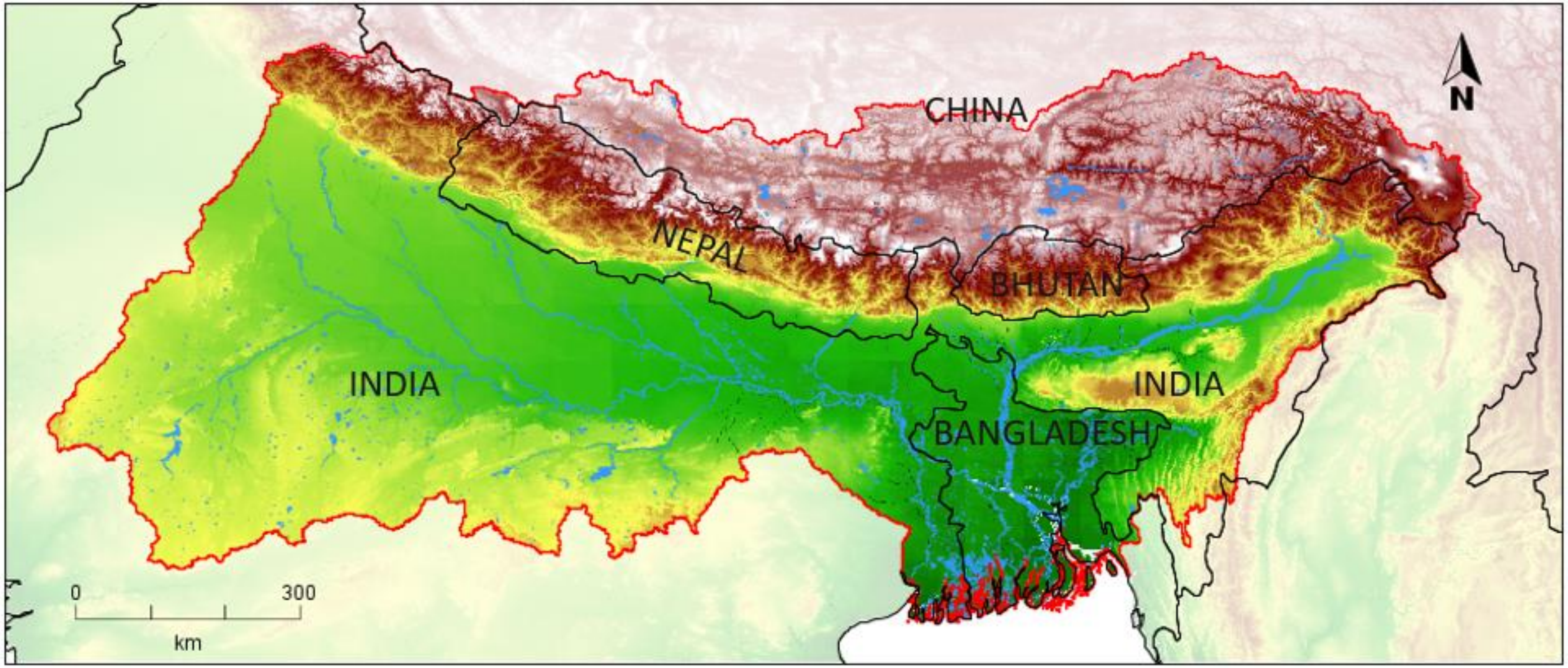
Mississippi Basin
300 Million Hectares

Lake Itasca, MN

Source

Some of the largest watersheds in the world

Mississippi Basin (150 Million Hectares)

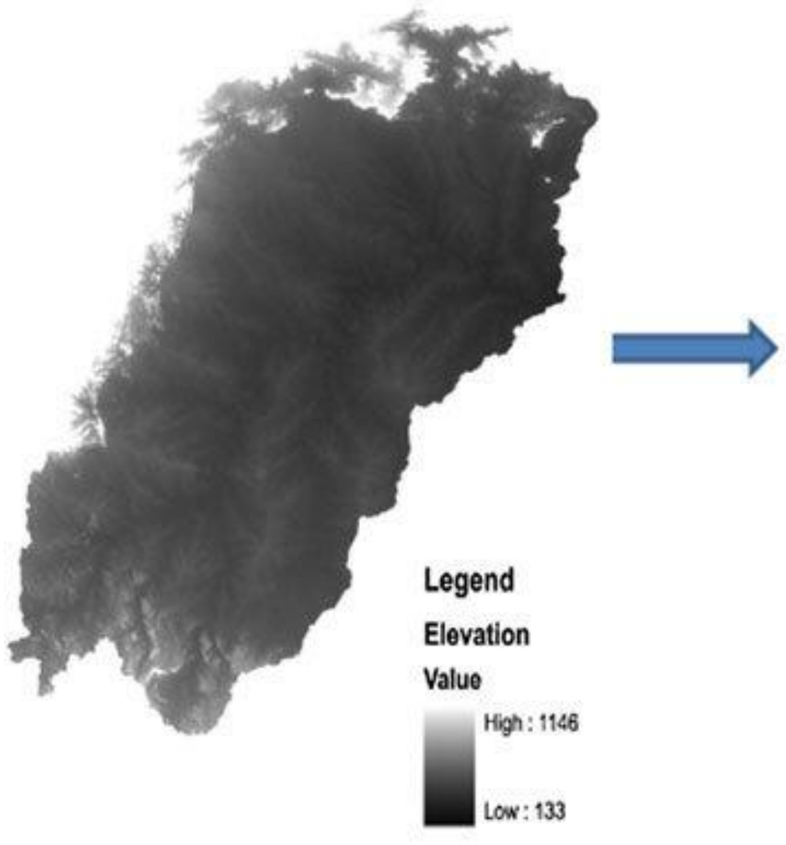


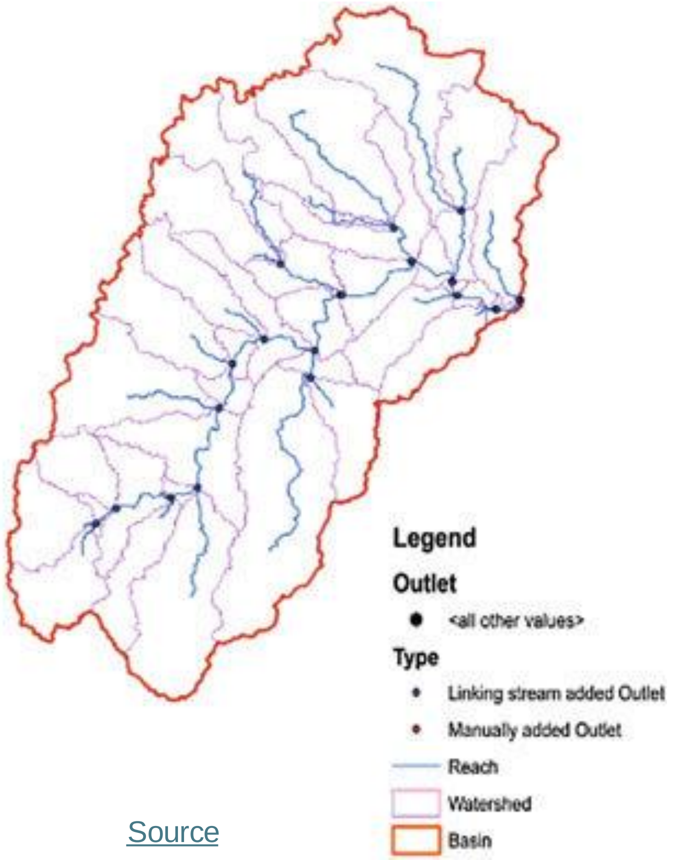
Source

Drainage Delineation from DEM

How do we calculate watershed?

- DEMs are the primary source of information to generate watershed boundary and overall drainage modeling.
- The principle is simple:
  “Water always flows downhill, or downstream, following the path of least resistance.”





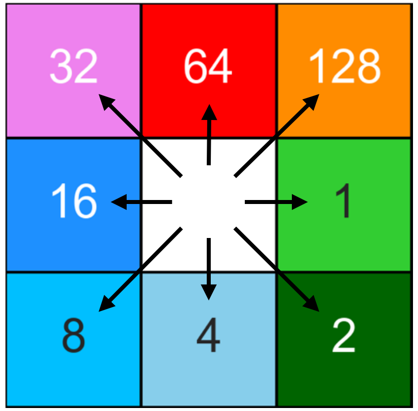
Source

The fundamental concept behind drainage

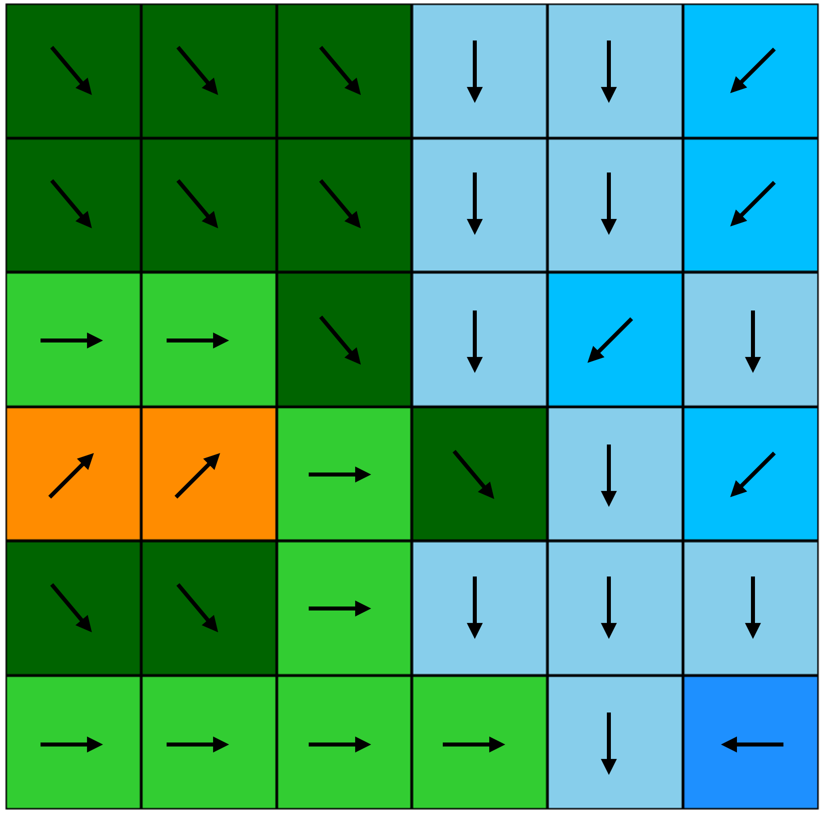
Elevation Surface

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

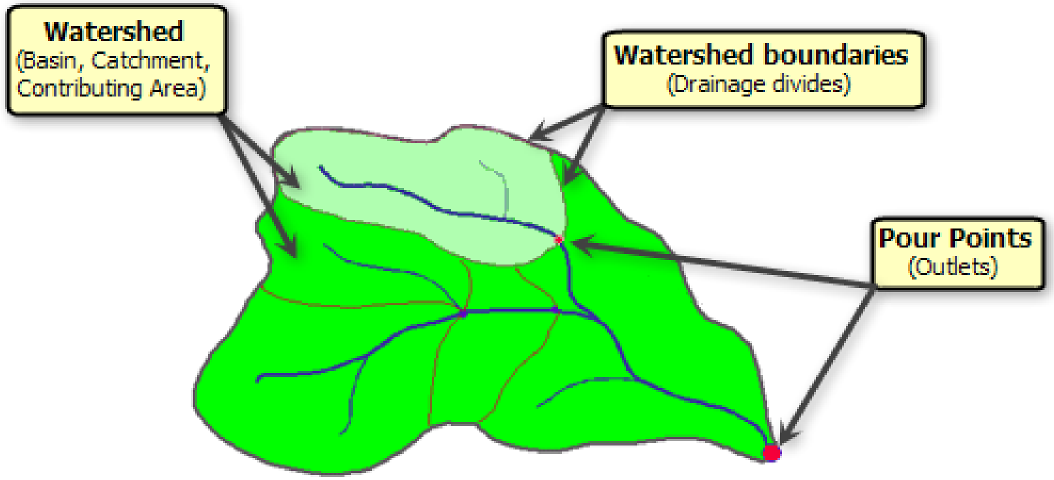
Directional Encoder



Flow Direction Surface



Steps involved in drainage modeling

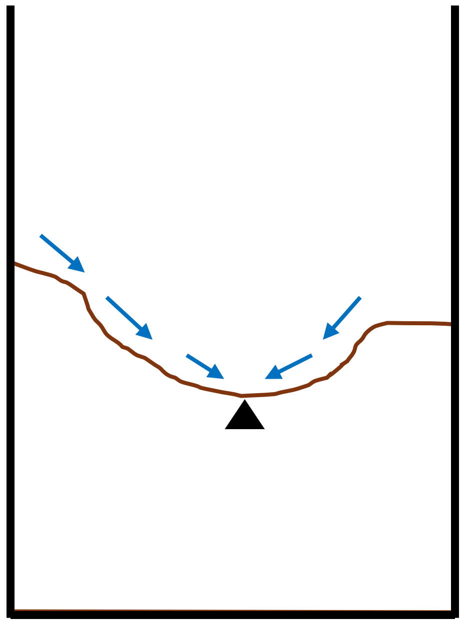


DEM → Hydrologic Conditioning → Flow Direction → Flow Accumulation

- Flow Accumulation → Snap Pour Point → Watershed
- Flow Accumulation → Thresholding → Streamlines

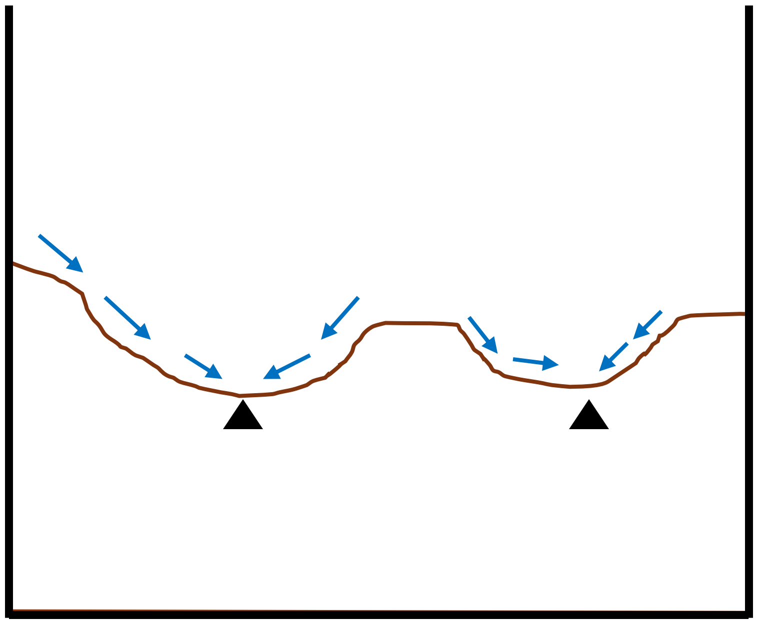
Hydrologic conditioning of DEM

Global minima is easy to detect



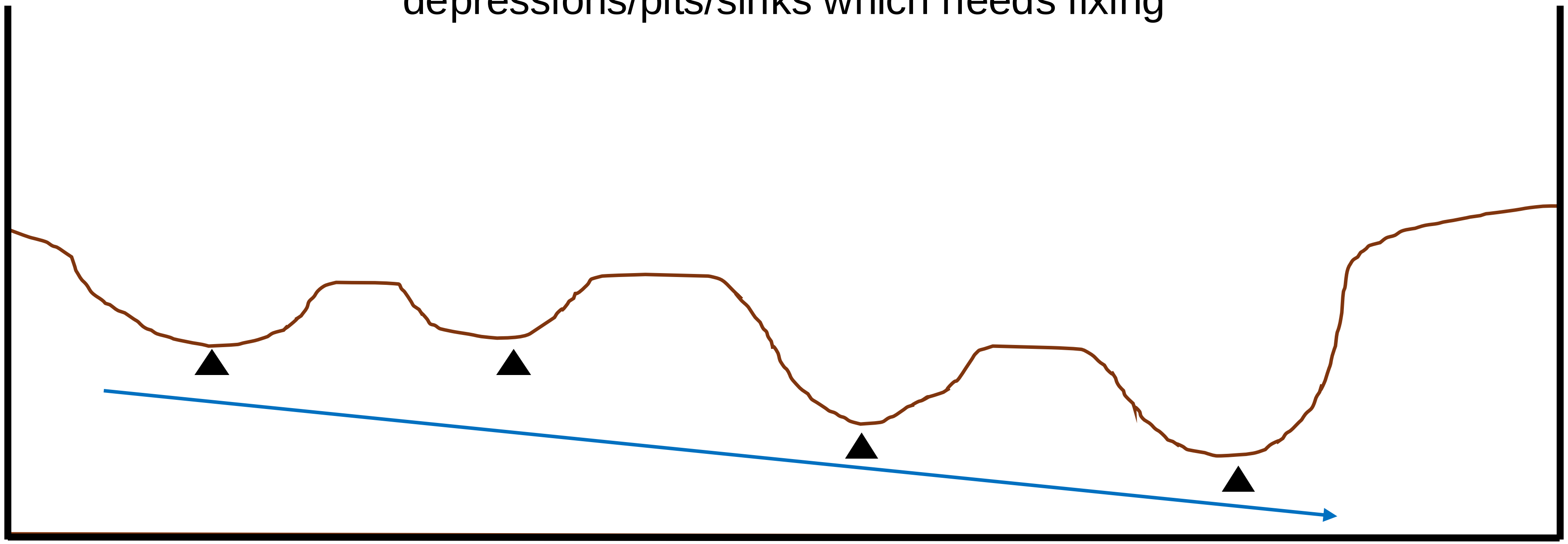
Hydrologic conditioning of DEM

Local minima is tricky



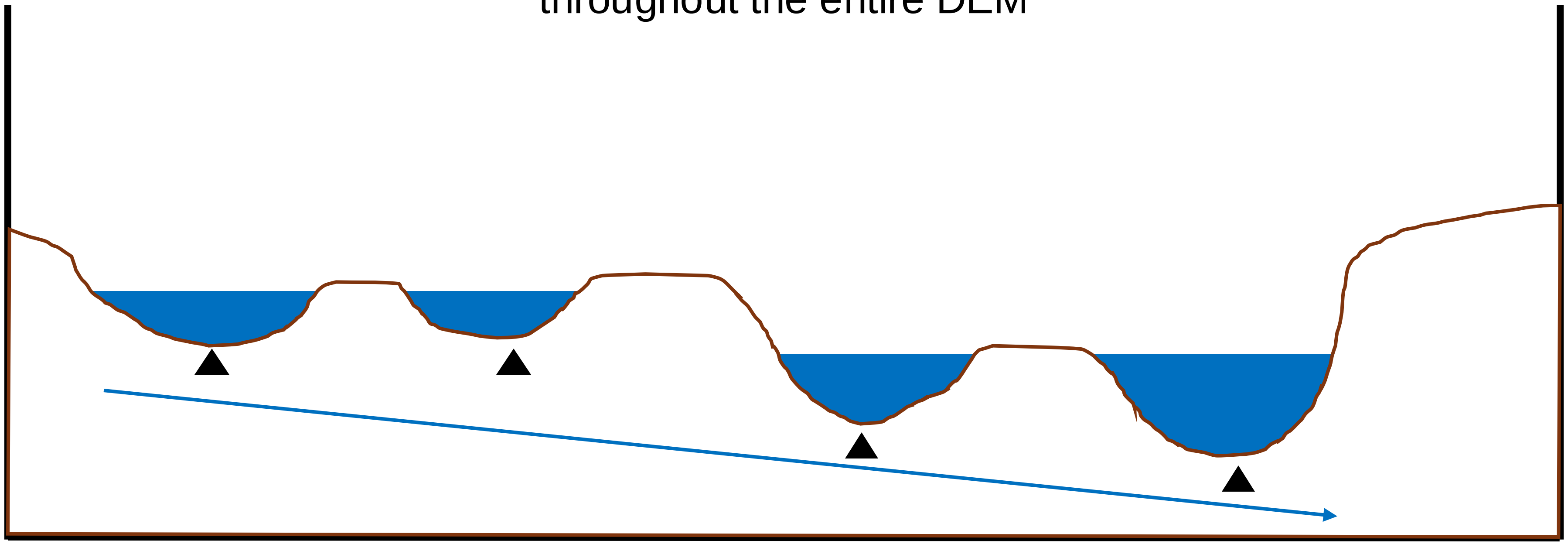
Hydrologic conditioning of DEM

Multiple local minima create the problem of depressions/pits/sinks which needs fixing



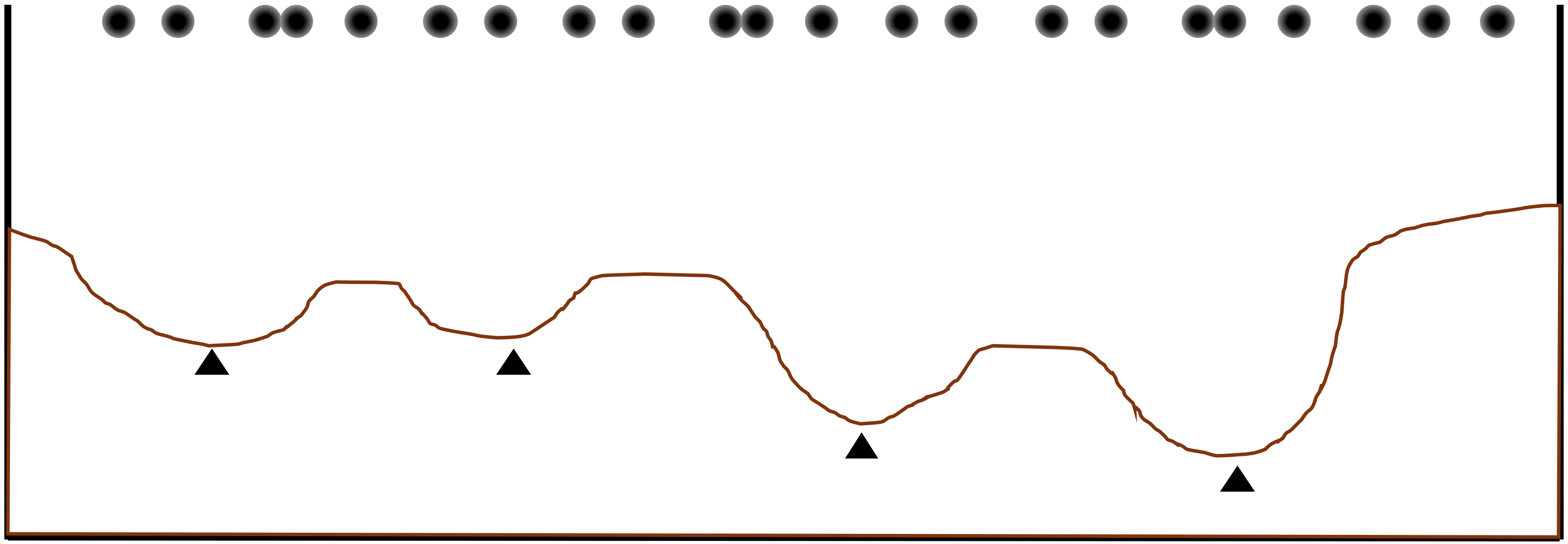
Hydrologic conditioning of DEM

The pits need to be filled up to smoother flow of water throughout the entire DEM

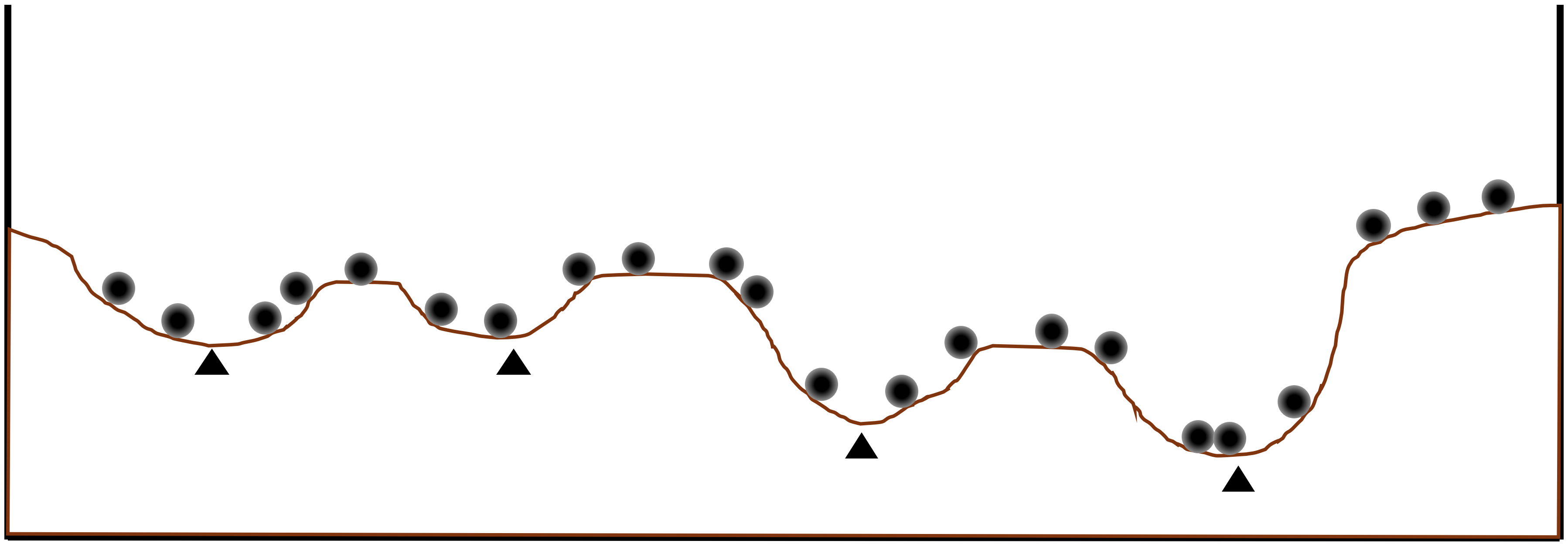


Hydrologic conditioning of DEM

Local minima can be found by multiple methods. One method is to use derivative calculus.

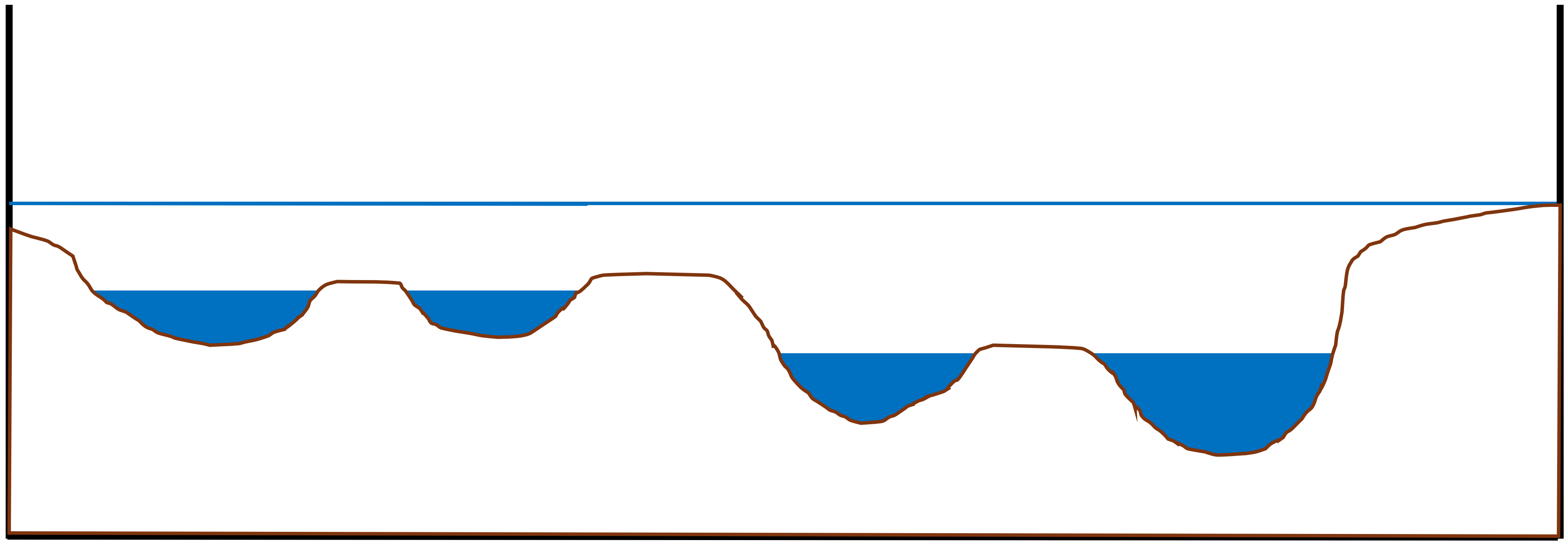


Hydrologic conditioning of DEM



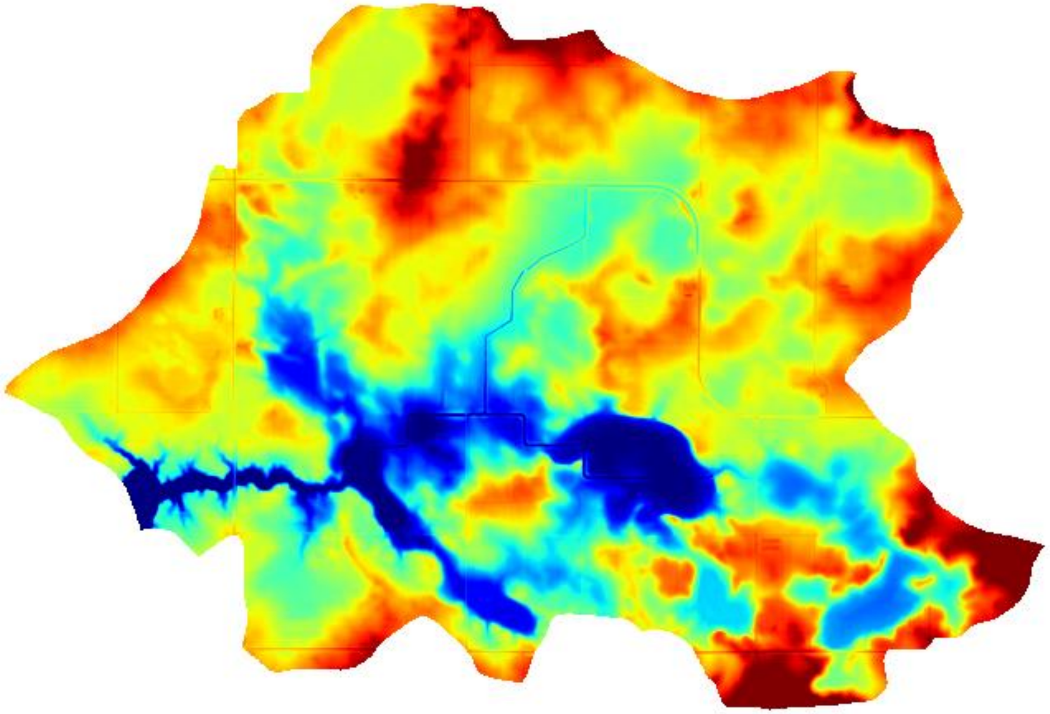
Hydrologic conditioning of DEM

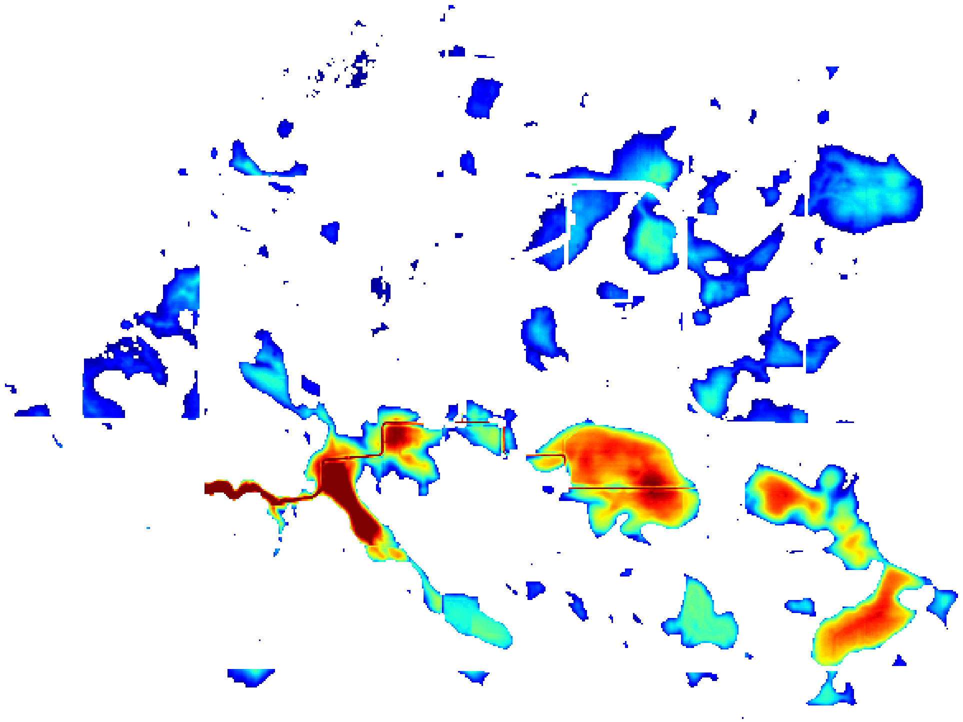
Recently an efficient pit removal algorithm has been developed that fits a plane over the DEM and iteratively reduces its depth until it covers the pits.



Pit Filling in the context of a DEM

Similar principal can be applied to a 2D DEM





Flow Direction encodes the depression less DEM into directional component

- Flow direction is the direction that water would naturally flow from each point on a terrain, based on the steepest downhill slope.
- For each cell, look at the eight surrounding neighbors to determine where water would flow.
- Calculate how steep the slope is from the center cell to each neighbor.
- Identify the direction with the steepest slope; this is where the water flows.

D-8

D-Infinity

MFD

D-8 Flow Direction is the simplest method

Elevation Surface

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

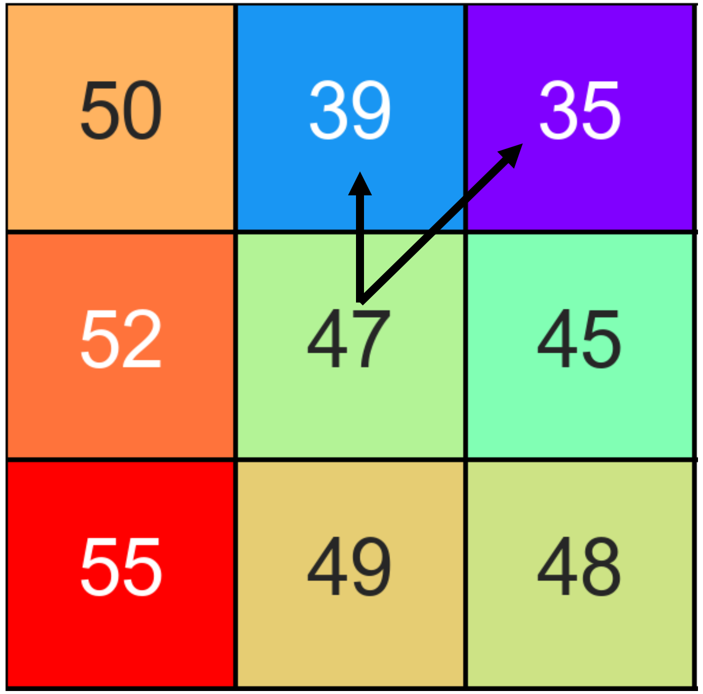
Directional Encoder

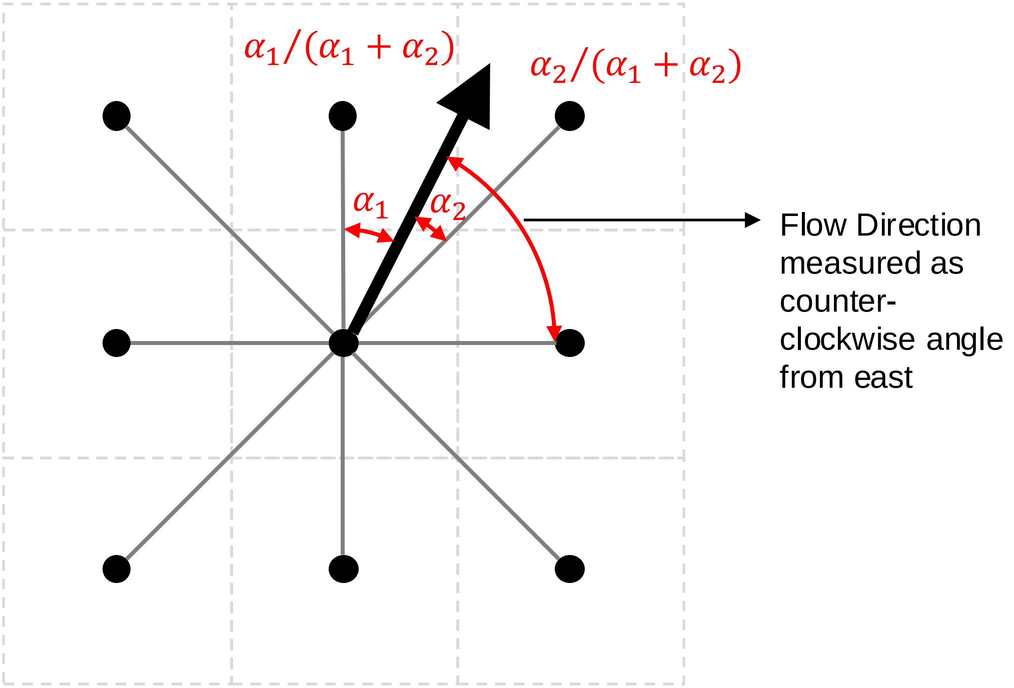
32	64	128
16		1
8	4	2

Flow Direction Surface

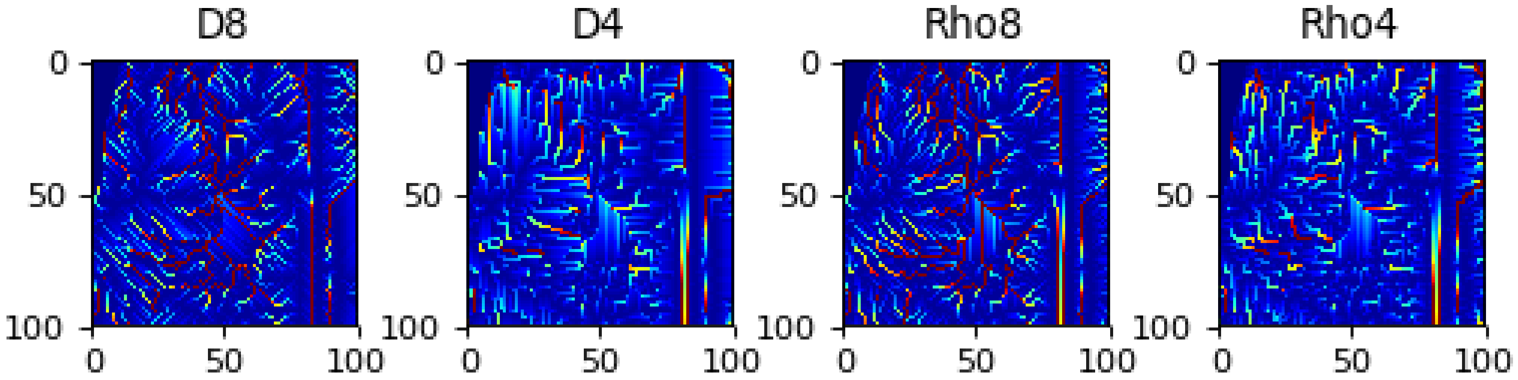
2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

D-Infinity Flow Direction can output angular value

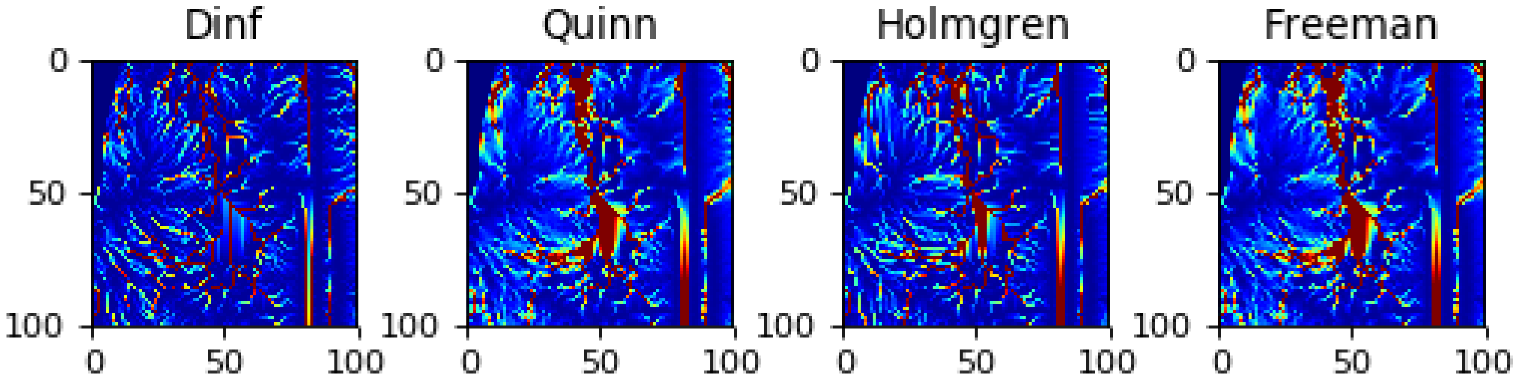




There are many flow direction algorithms out there



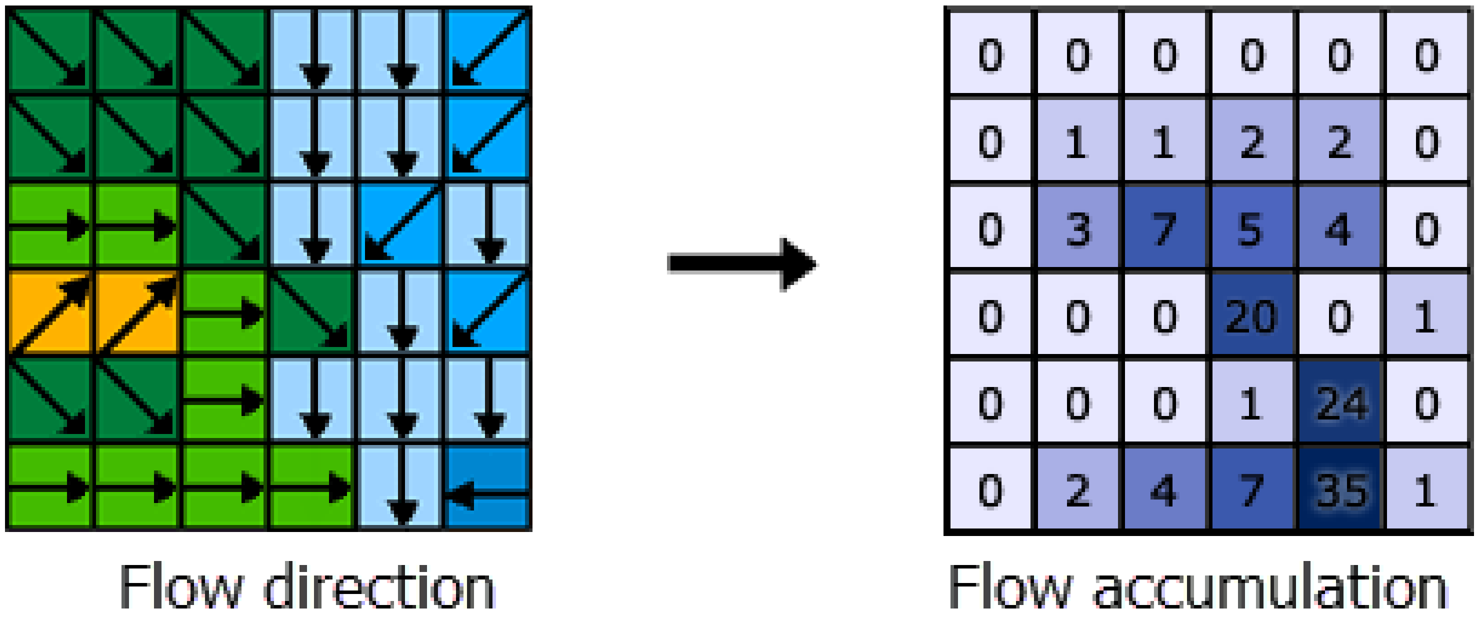
O'Callaghan & Mark, (1984) | O'Callaghan & Mark, (1984) | Fairfield and Leymarie, (1991) | Fairfield and Leymarie, (1991)



Tarboton, (1997) | Quinn (1991) | Holmgren (1994) | Freeman (1991)

Flow Accumulation

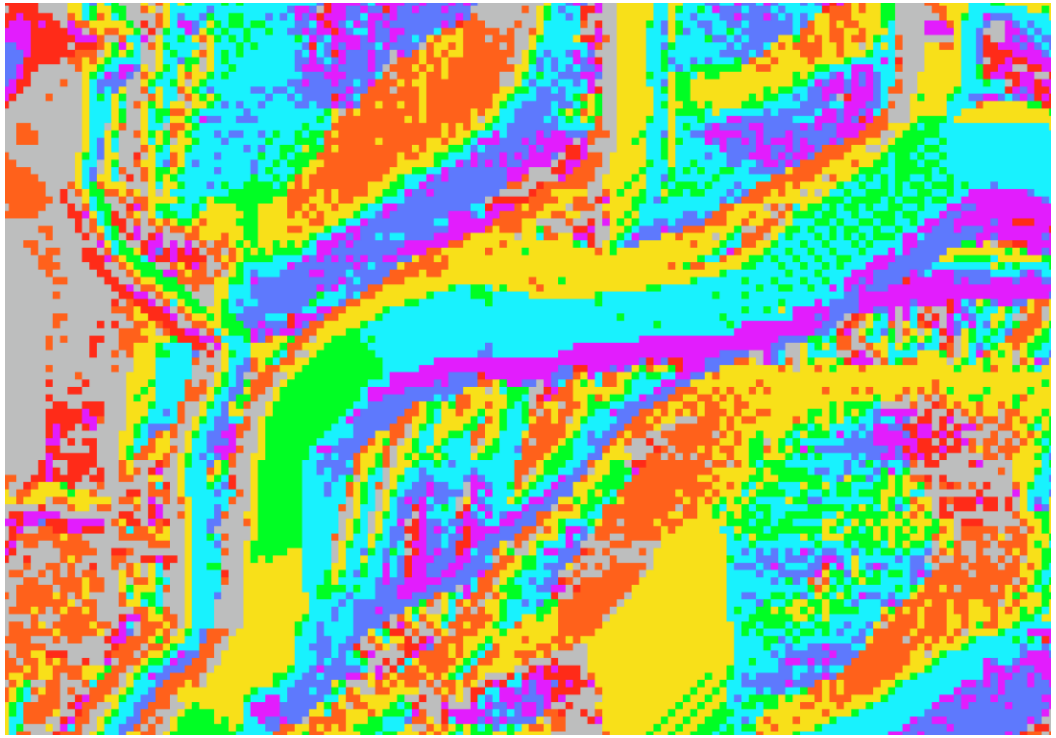
Flow accumulation is the total amount of water that flows into each cell in a terrain, based on how water flows from higher ground to lower ground. It shows how much water accumulates at different points, helping identify areas that collect the most water, like streams or valleys.



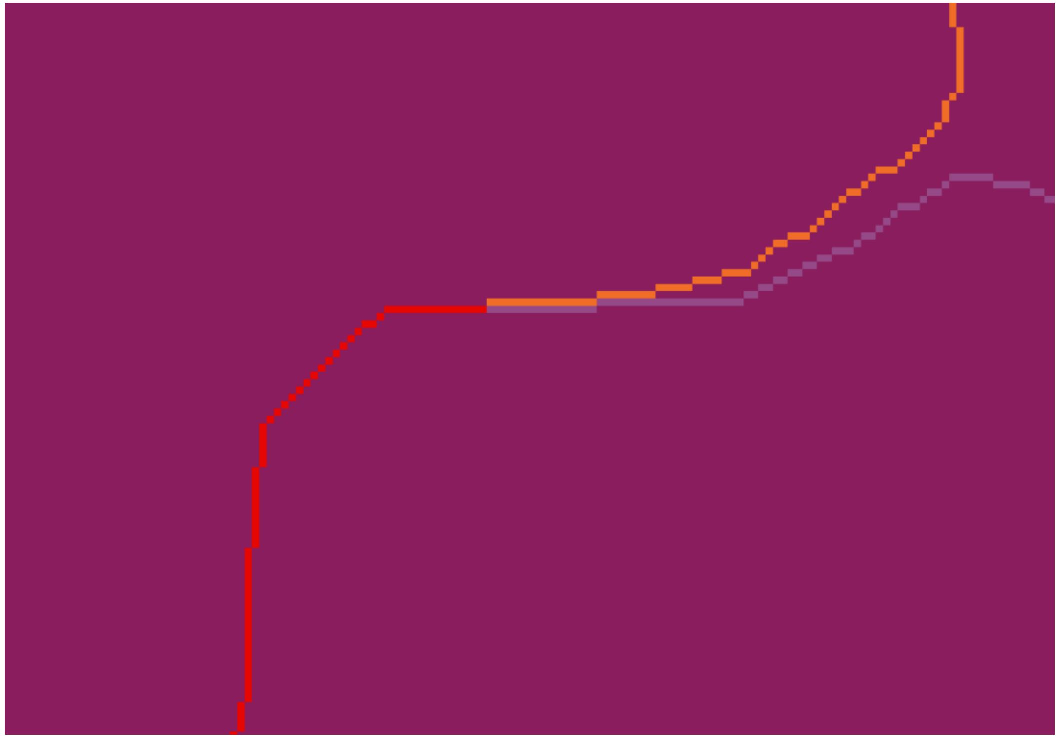
Source

Flow Accumulation

Flow Direction Raster



Flow Accumulation Raster

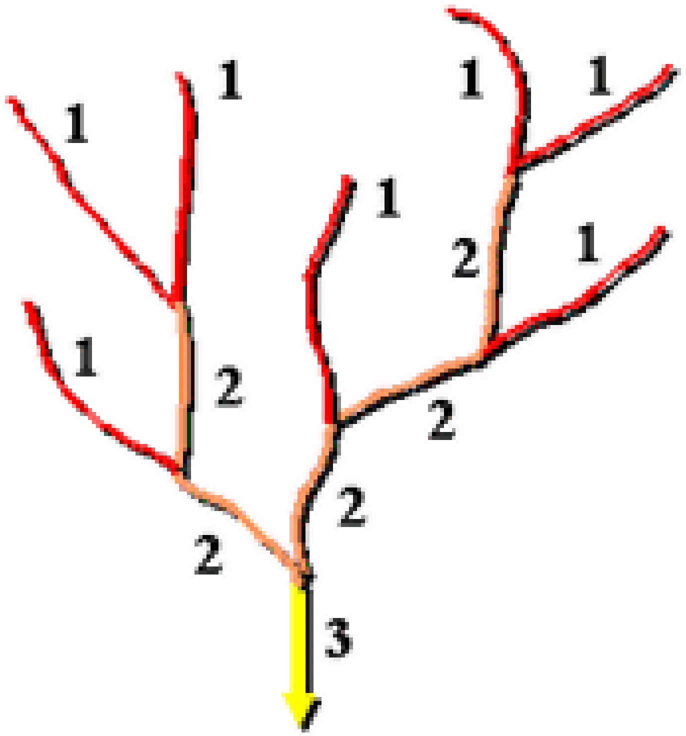


Stream Delineation

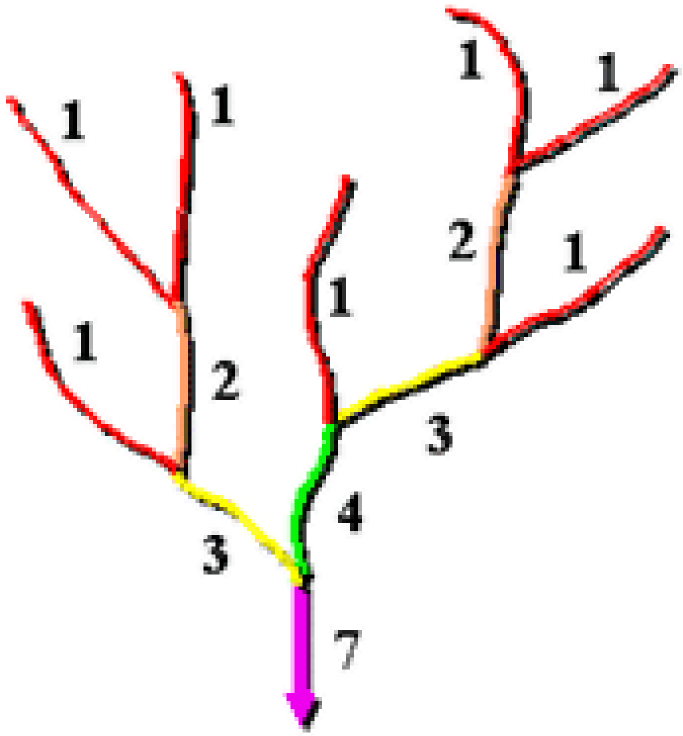
- Flow accumulation raster represents the cells which has the potential to be a stream.
- Stream cells can be defined by a simple threshold value.
- Peukar Douglas method is a semi-automated solution to find the threshold.

Stream Order is the classification of the stream hierarchy in a river system

Strahler Method



Shreve Method

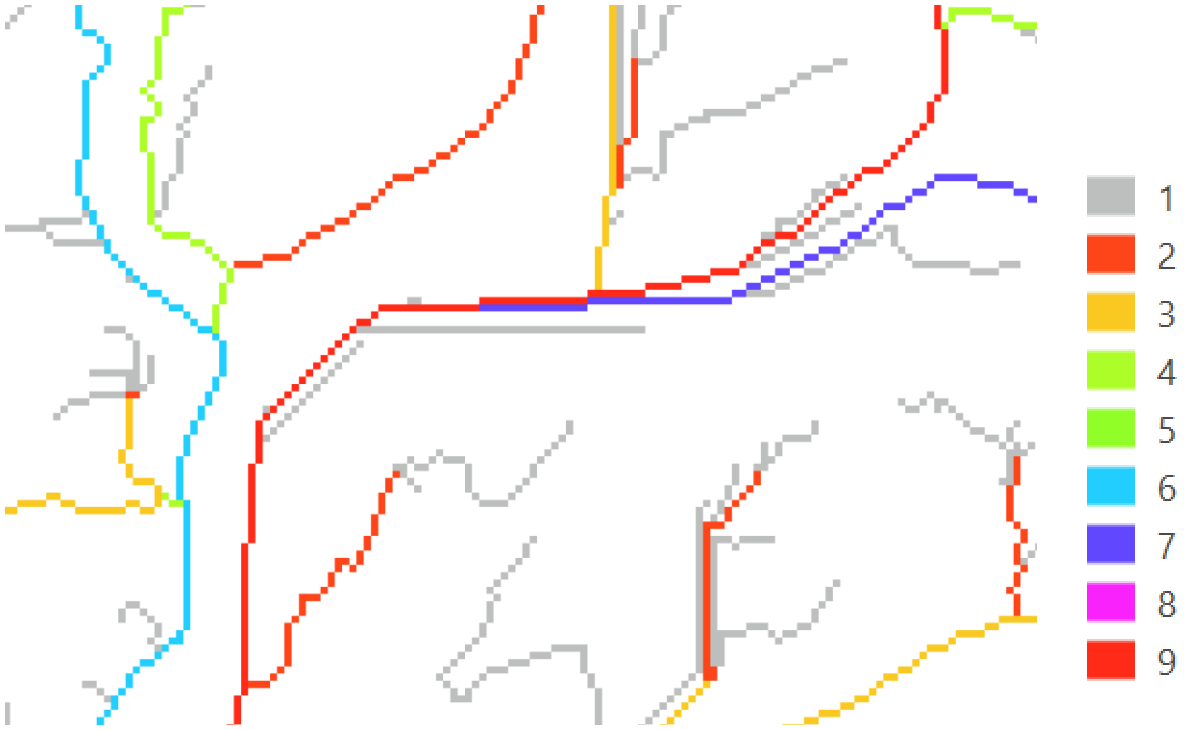


Source

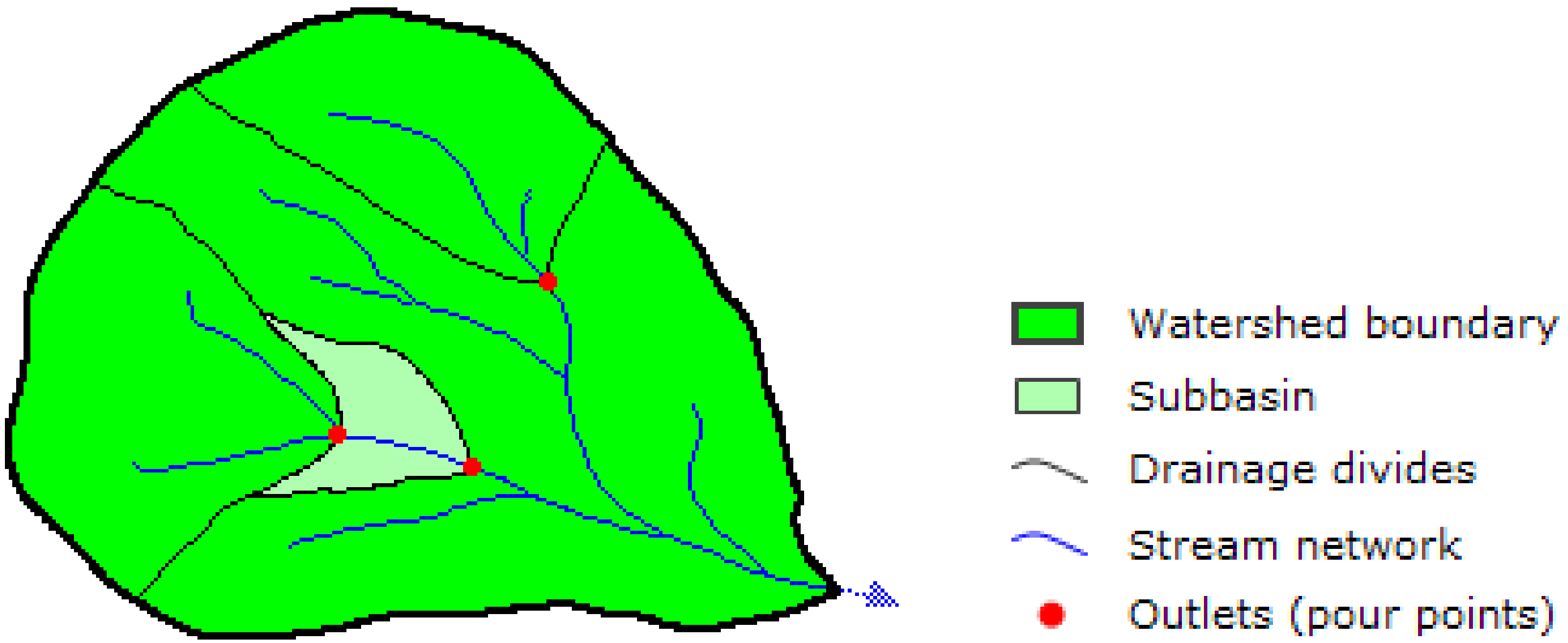
Stream Order is the classification of the stream hierarchy in a river system

Stream Raster

Stream Order Raster



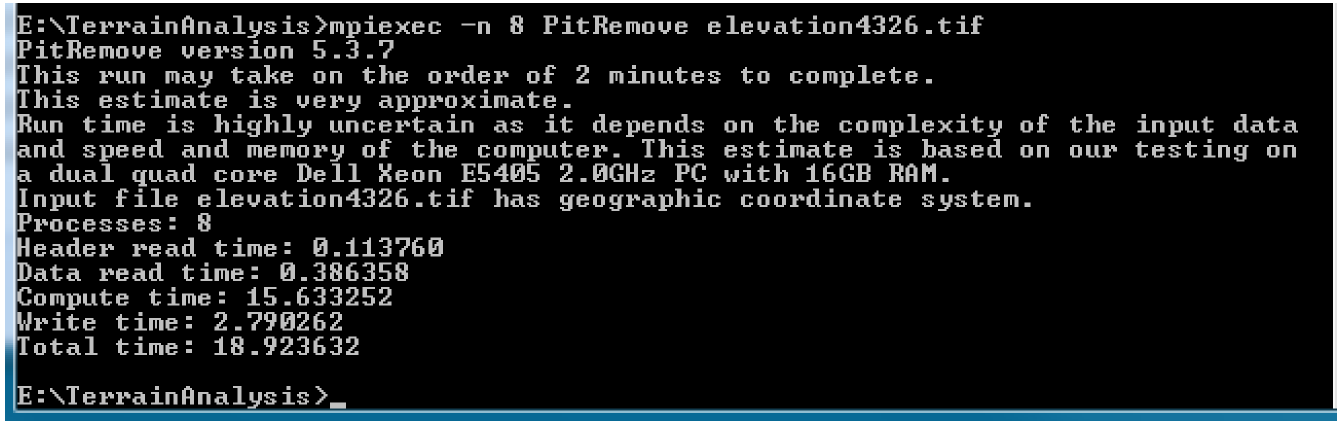
Watershed is delineated by flow direction raster and outlet location as raster or point



Source

Software solutions for hydrologic modeling

- **TauDEM** (Terrain Analysis Using Digital Elevation Models)
- Particularly developed for working in High-performance computers (HPC)
- Open source


```
E:\TerrainAnalysis>mpiexec -n 8 PitRemove elevation4326.tif
PitRemove version 5.3.7
This run may take on the order of 2 minutes to complete.
This estimate is very approximate.
Run time is highly uncertain as it depends on the complexity of the input data
and speed and memory of the computer. This estimate is based on our testing on
a dual quad core Dell Xeon E5405 2.0GHz PC with 16GB RAM.
Input file elevation4326.tif has geographic coordinate system.
Processes: 8
Header read time: 0.113760
Data read time: 0.386358
Compute time: 15.633252
Write time: 2.790262
Total time: 18.923632

E:\TerrainAnalysis>_
```

https://hydrology.usu.edu/taudem/taudem5/

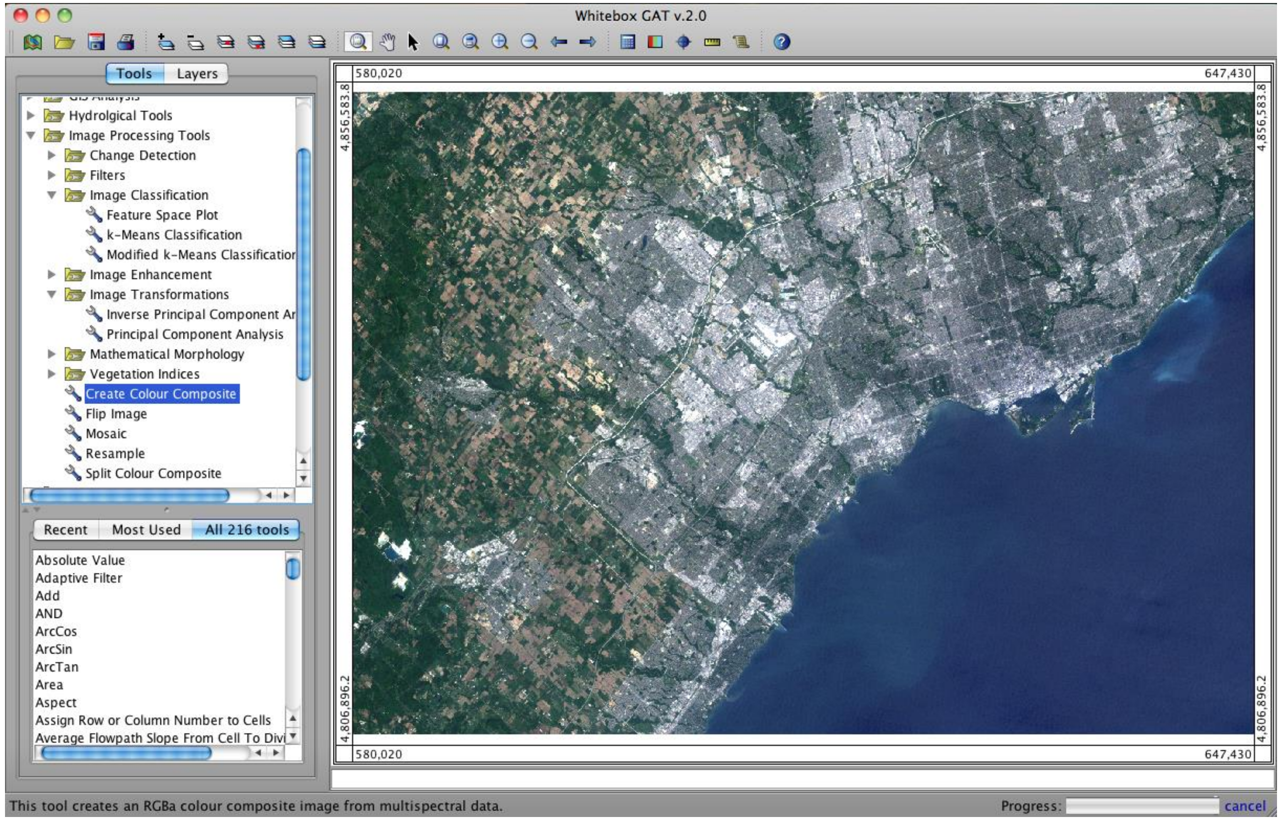
Software solutions for hydrologic modeling

- **Whitebox GAT**

Whitebox

Geospatial Analysis Tools

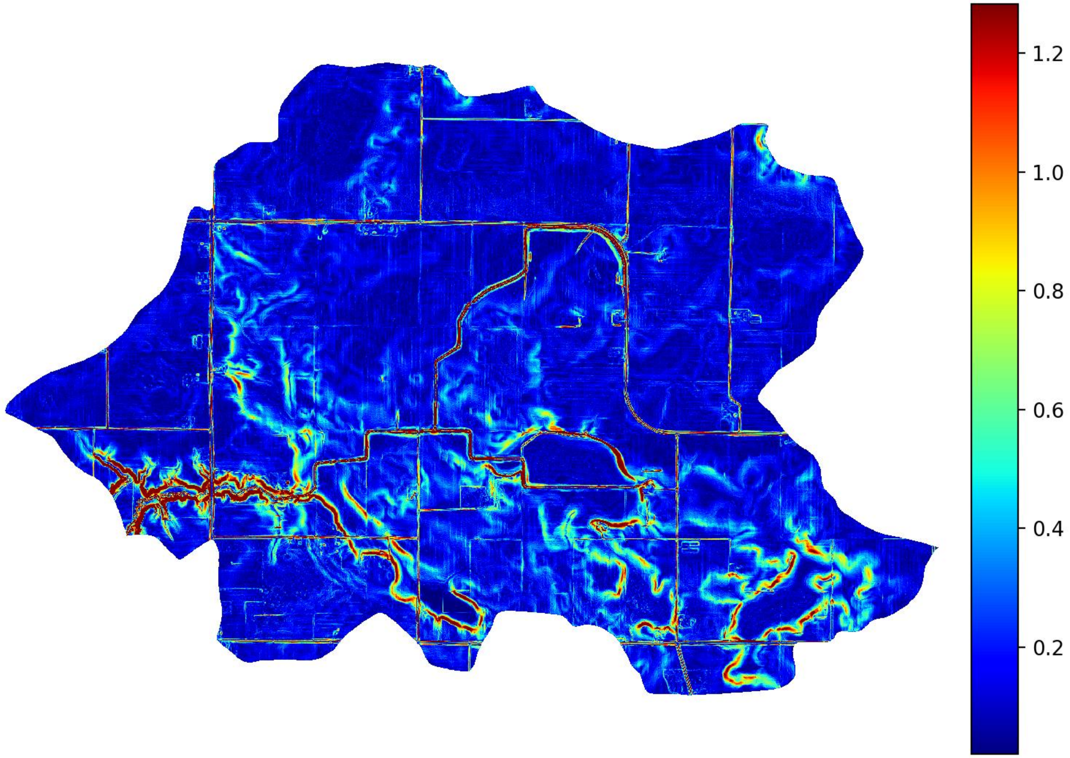
- Open source, GUI
- Many other specialized algorithms like breaching, burning etc.



https://www.whiteboxgeo.com/

Software solutions for hydrologic modeling

- **RichDEM**
- Open source, Python module
- Works well with GDAL based datasets
- Good for building workflows
- Options for many different algorithms



https://richdem.readthedocs.io/en/latest/

In summary

- DEM is the starting point
- Workflow is fill > flow direction > flow accumulation > stream or watershed delineation
- ArcGIS is good for handling smaller dataset
- Other dedicated software available for different use cases

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Thank You