Algorithms for GIS

Flow on terrains (II)

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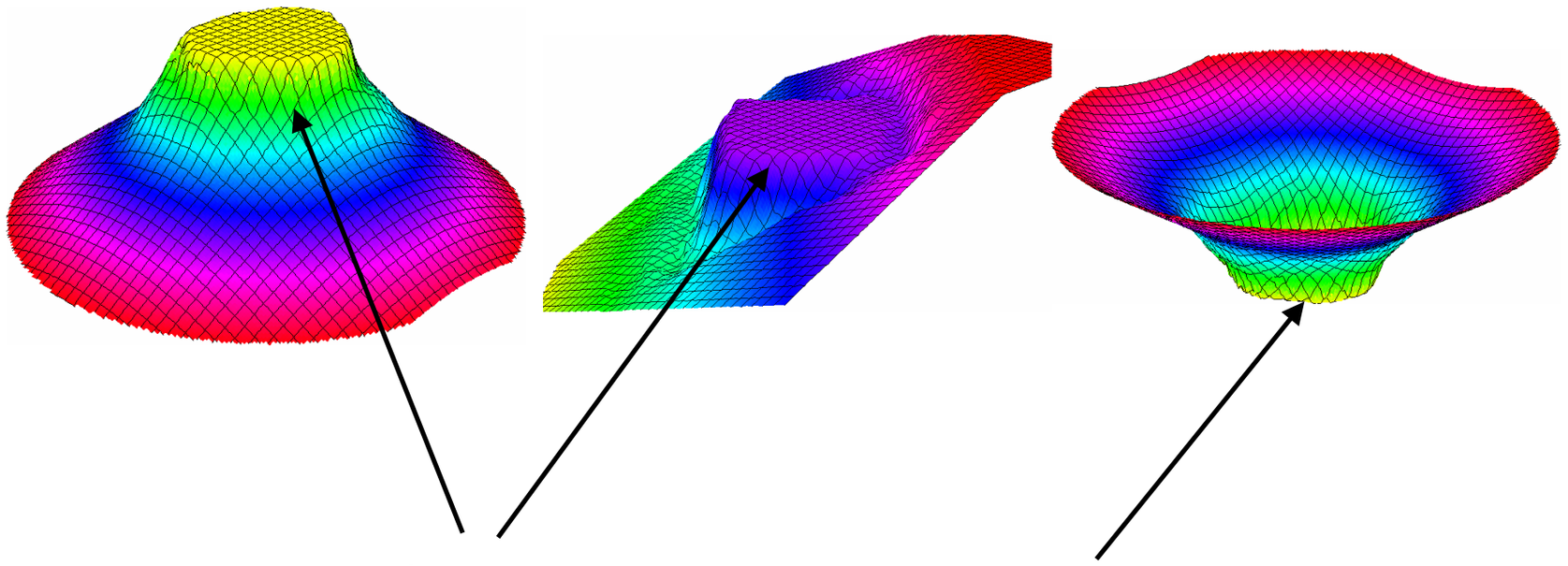
Overview

- Flow on grid terrains
  - Dealing with flat areas
  - From flow accumulation to river network and watersheds
  - Pfafstetter watershed and river hierarchy
  - Sea level rise

Flat areas



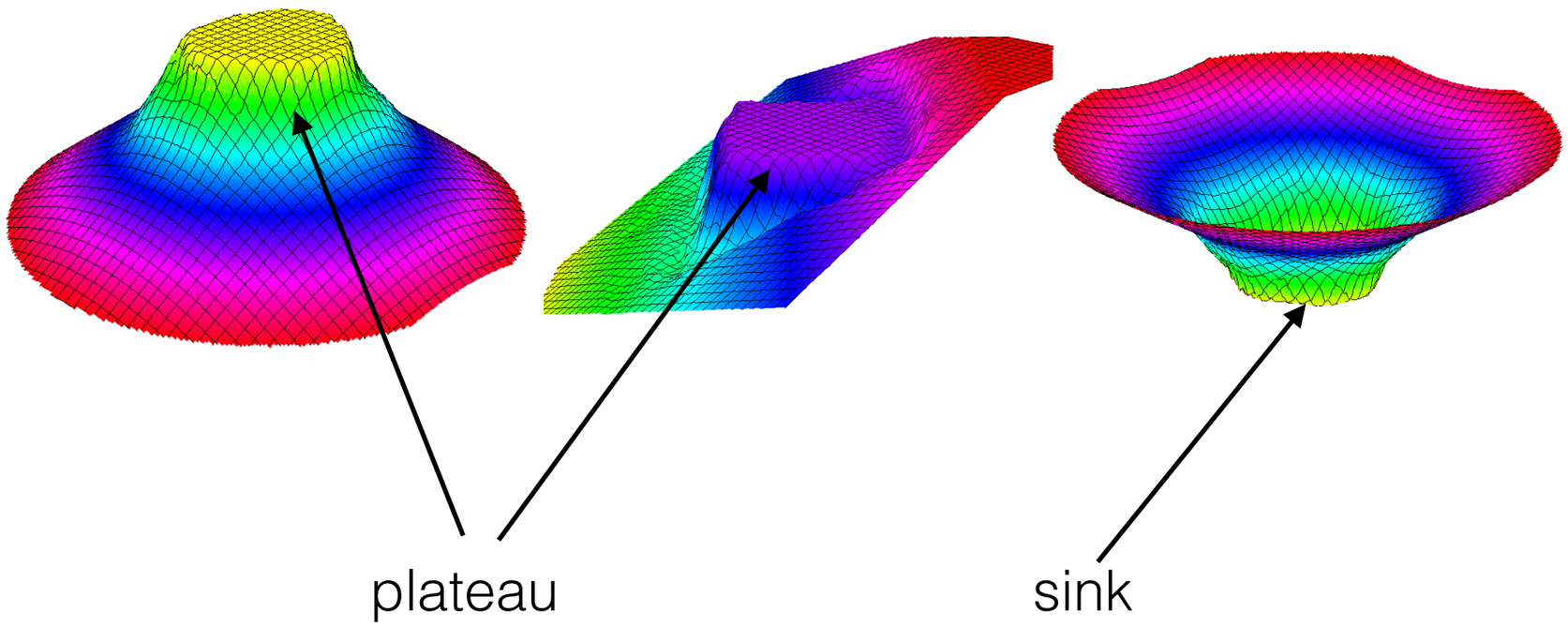
plateau

flat area has at least one spill point from which water flows downhill

sink

flat area surrounded by higher grounds

Flat areas



plateau

flat area has at least one spill point from which water flows downhill

sink

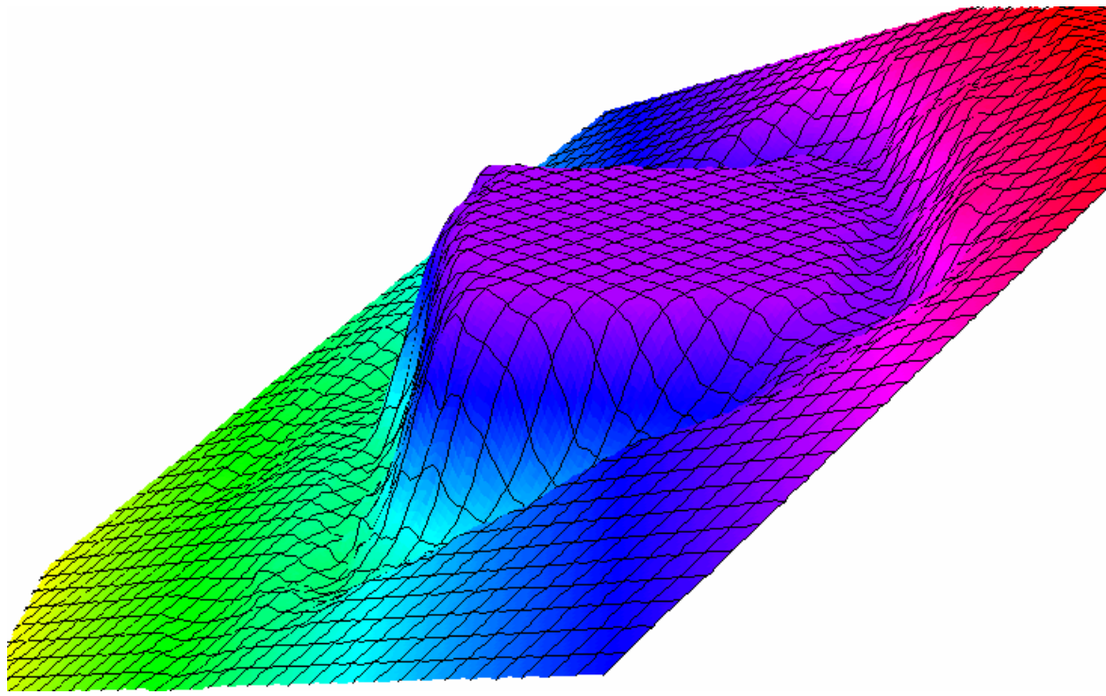
flat area surrounded by higher grounds

- Goal: identify flat areas
  - Label each flat area with its own label
  - Plateau or sink?

How, and how fast?

Plateaus

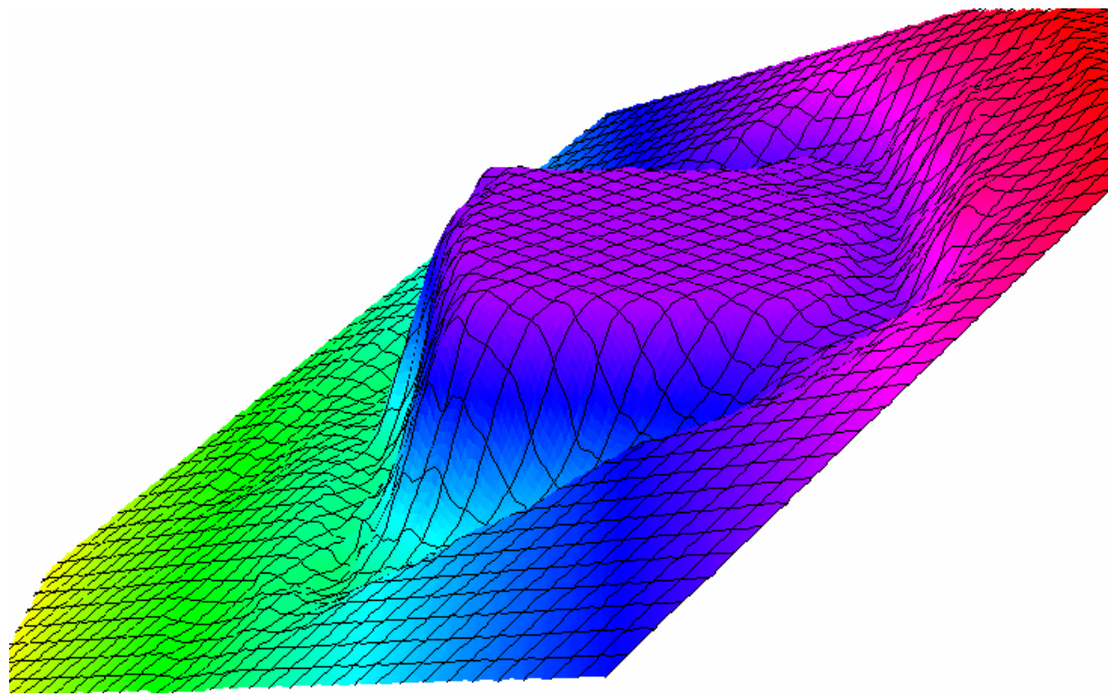
- Water leaves through the spill points —> direct FD towards the spill points



Plateaus

- Water leaves through the spill points —> direct FD towards the spill points

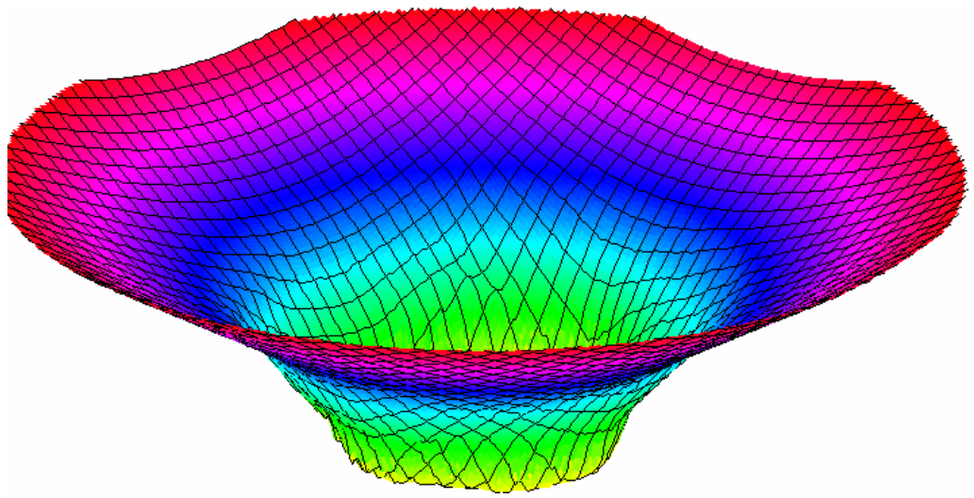
- Idea: multi-source BFS
  - Initialize queue with all spill points.
  - While queue not empty
    - Remove cell p from queue
    - Look at all its neighbors
    - If any neighbor is still white, set its FD towards p; add it to the queue



- BFS computes shortest paths —> water finds its shortest way to the spill point

Sinks

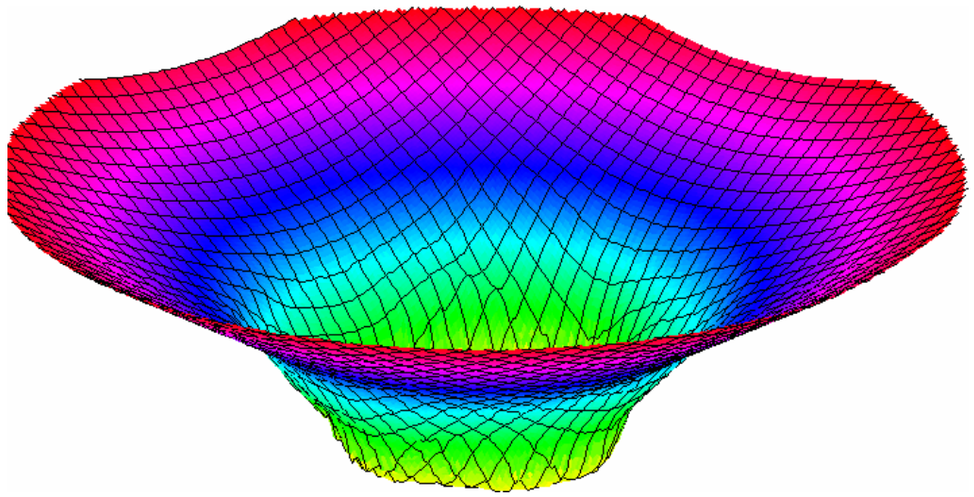
- Water comes into the sink from the surrounding area and cannot escape the sink following downslope paths.



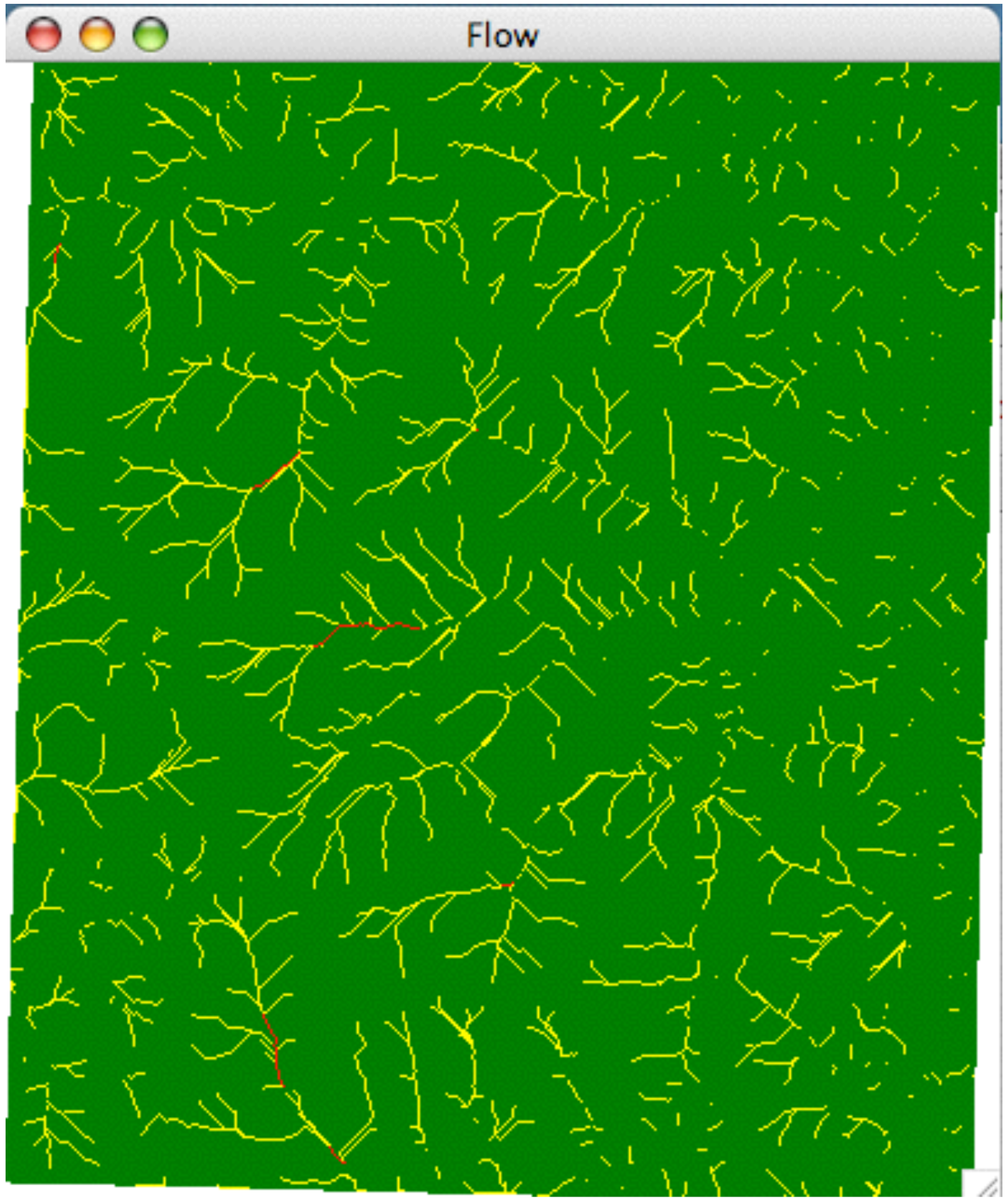
Sinks

- Water comes into the sink from the surrounding area and cannot escape the sink following downslope paths.

- Do not route water out of the sinks (i.e. FD is undefined on sinks).



FA with no FD on sinks

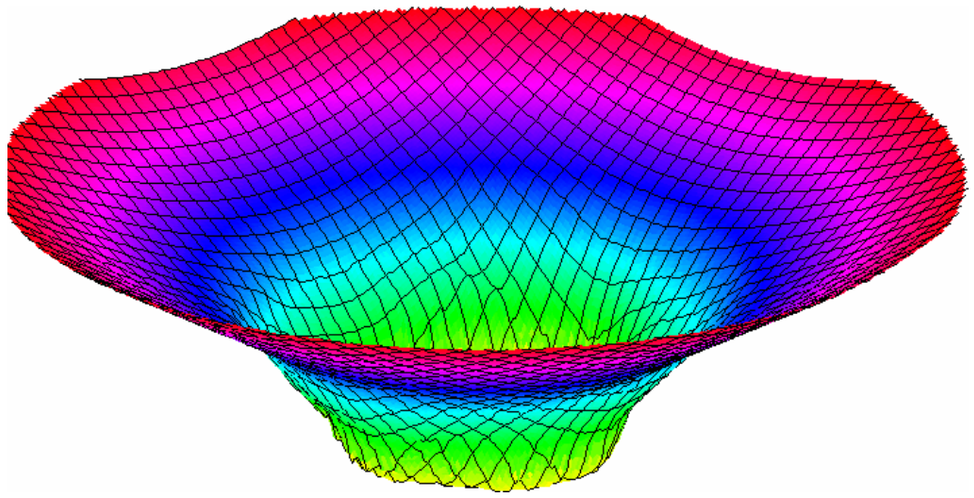


Sinks

- Water comes into the sink from the surrounding area and cannot go “out” following downslope paths.

- Do not route water out of the sinks, (i.e. FD is undefined on sinks).

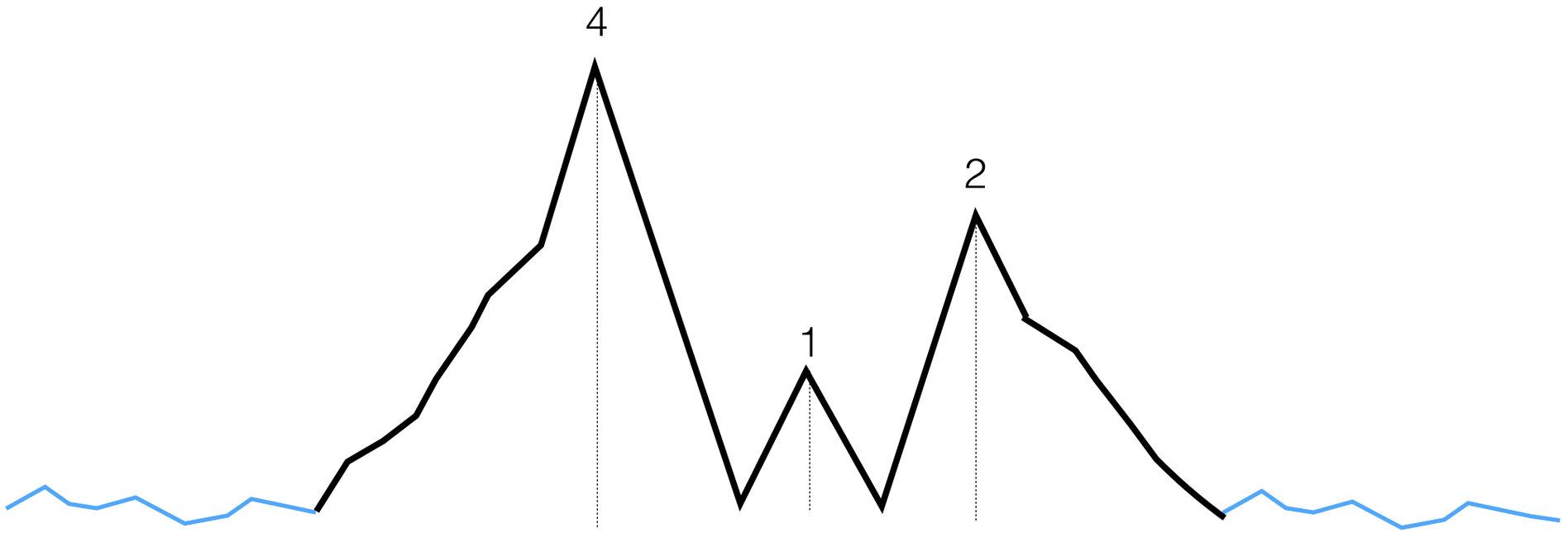
- Or, Route water out of the sink by simulating a process of flooding



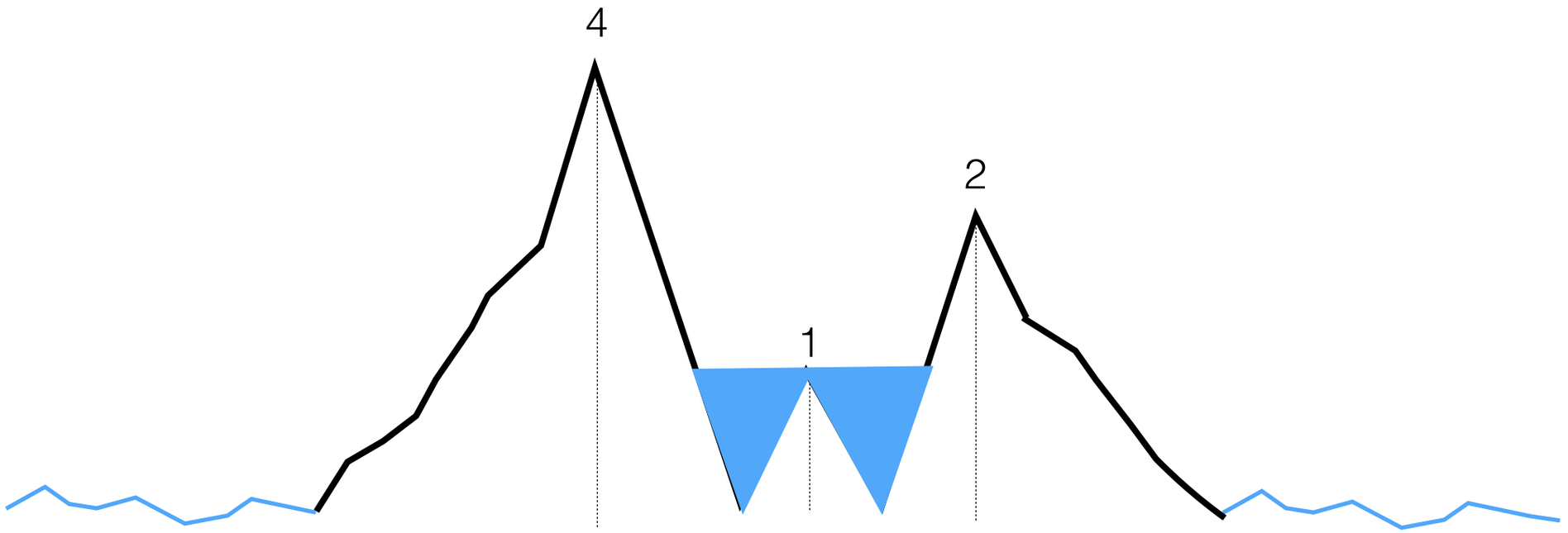
Flooding the sinks

- Flooding simulates steady state when an infinite amount of water (rain) falls uniformly across the terrain, and the terrain is bordered by a giant ocean (and no evaporation, infiltration, etc).
- At steady state all points in the terrain have found a path towards the ocean. More rain does not raise the water level.

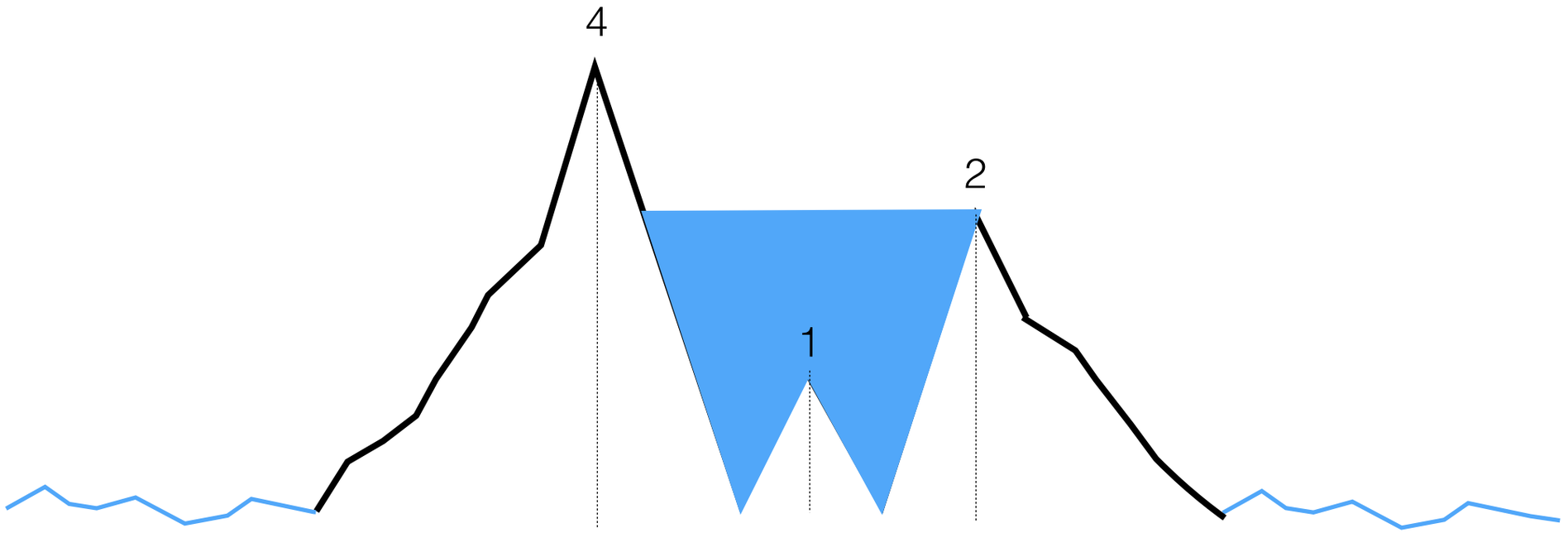
Flooding the sinks



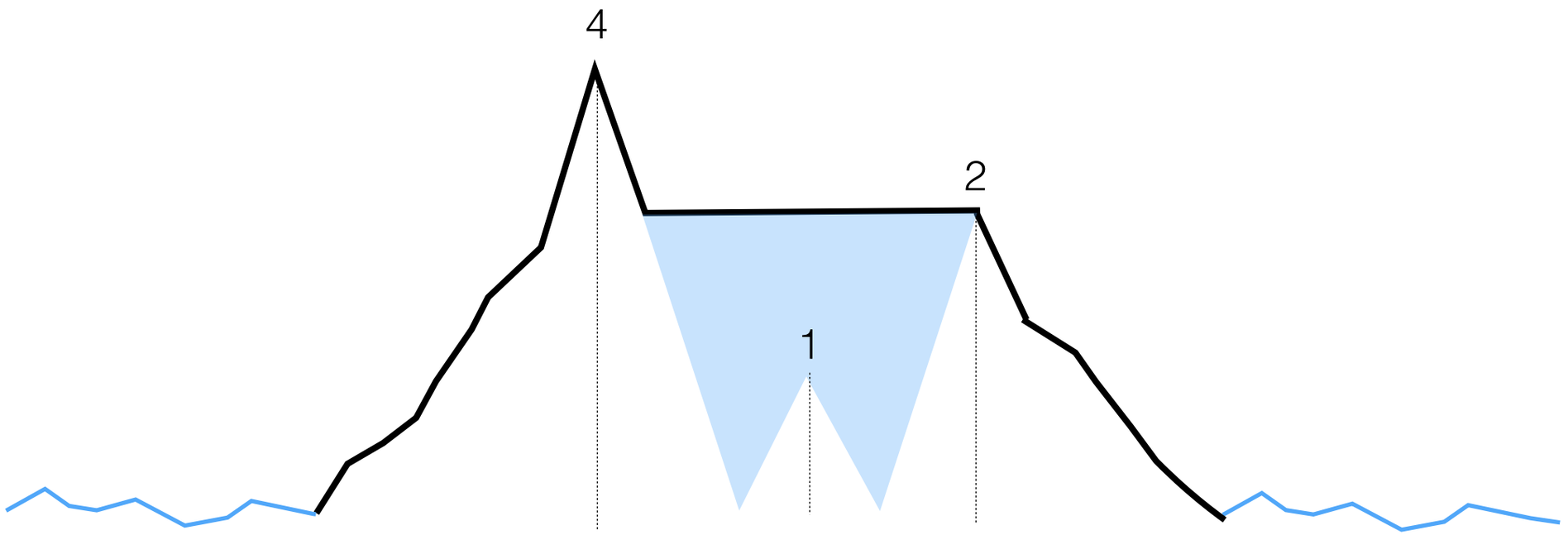
Flooding the sinks



Flooding the sinks

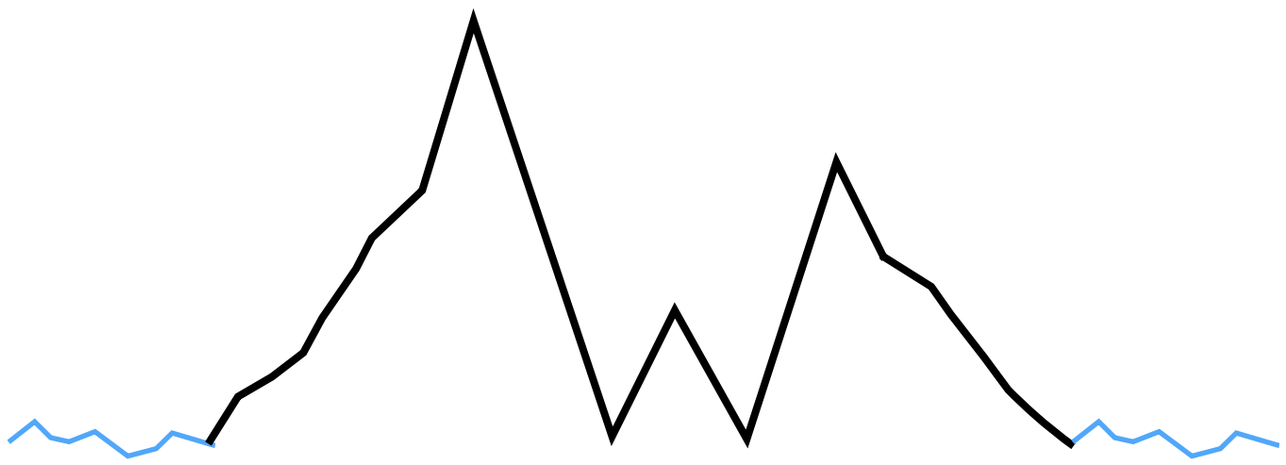


Flooding the sinks

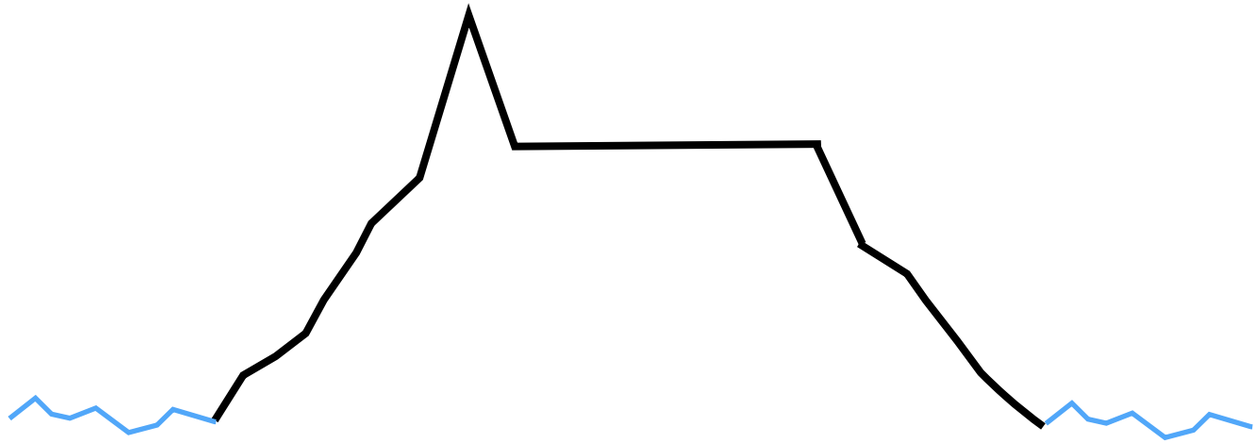


Flooding the sinks

original terrain

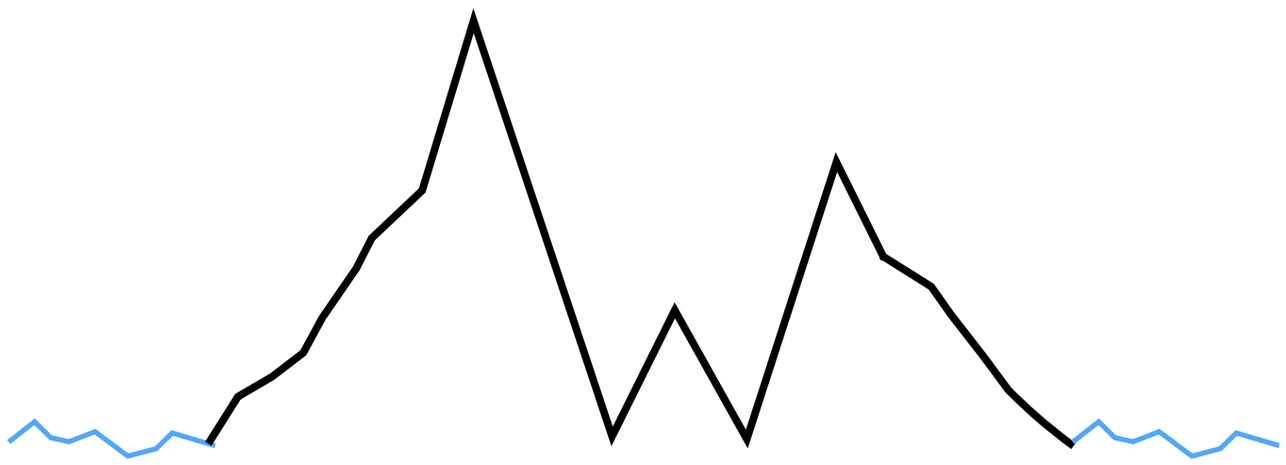


flooded terrain

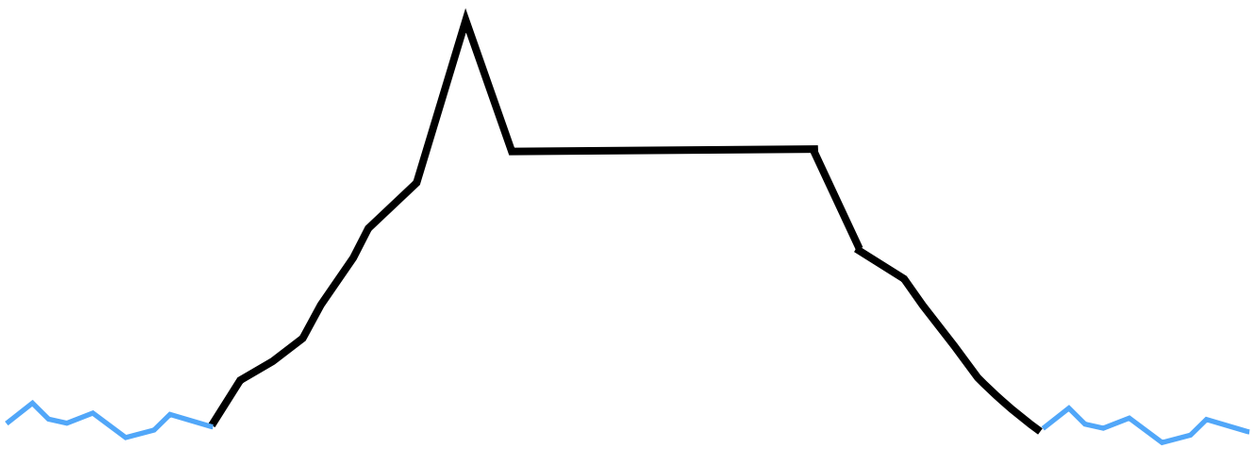


Flooding the sinks

original terrain



flooded terrain



- A flooded terrain has no sinks: All its flat areas are plateaus.
- We can compute FD at every point on the flooded terrain
- Viewing the FD on the original terrain: We are routing water out of the sinks using upslope paths. Every point in the terrain will have a path to the ocean. Claim: it's the lowest path.

FD: The overall process

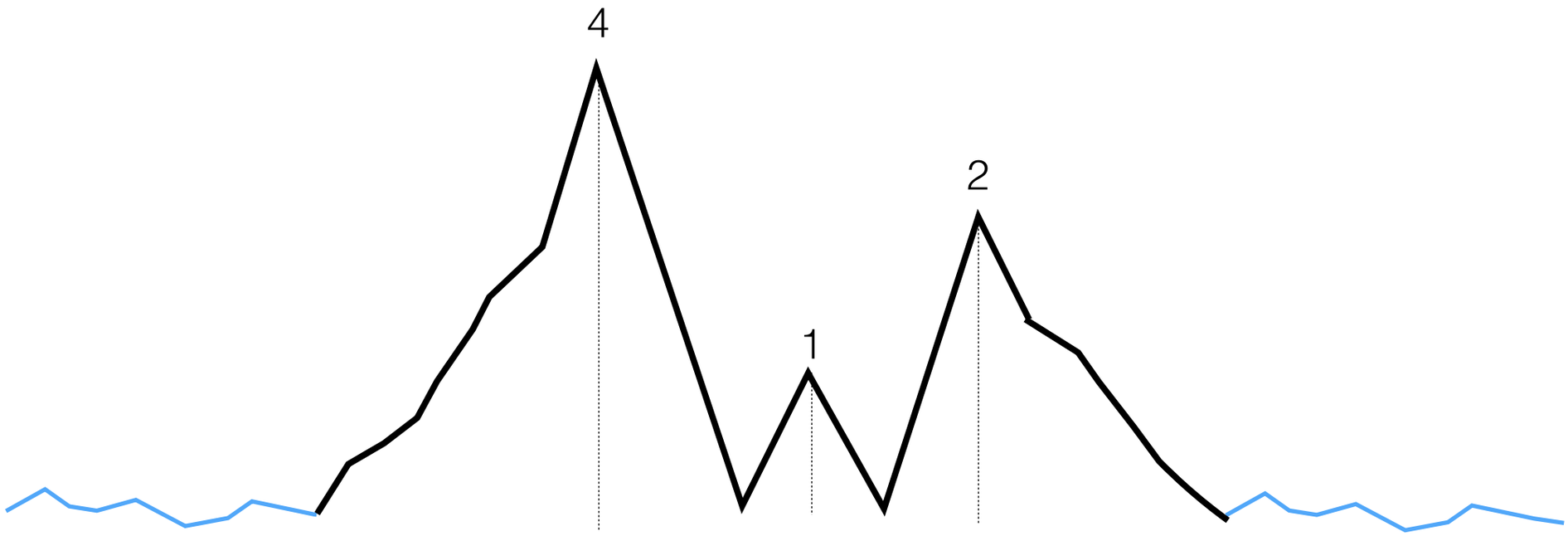
- Compute FD
- Identify plateaus
- Compute FD on plateaus
- Flood the sinks, and, for each sink, record the lowest height at which it merges with the ocean.
- Raise each basin to its flooded height
- Compute FD on flooded terrain

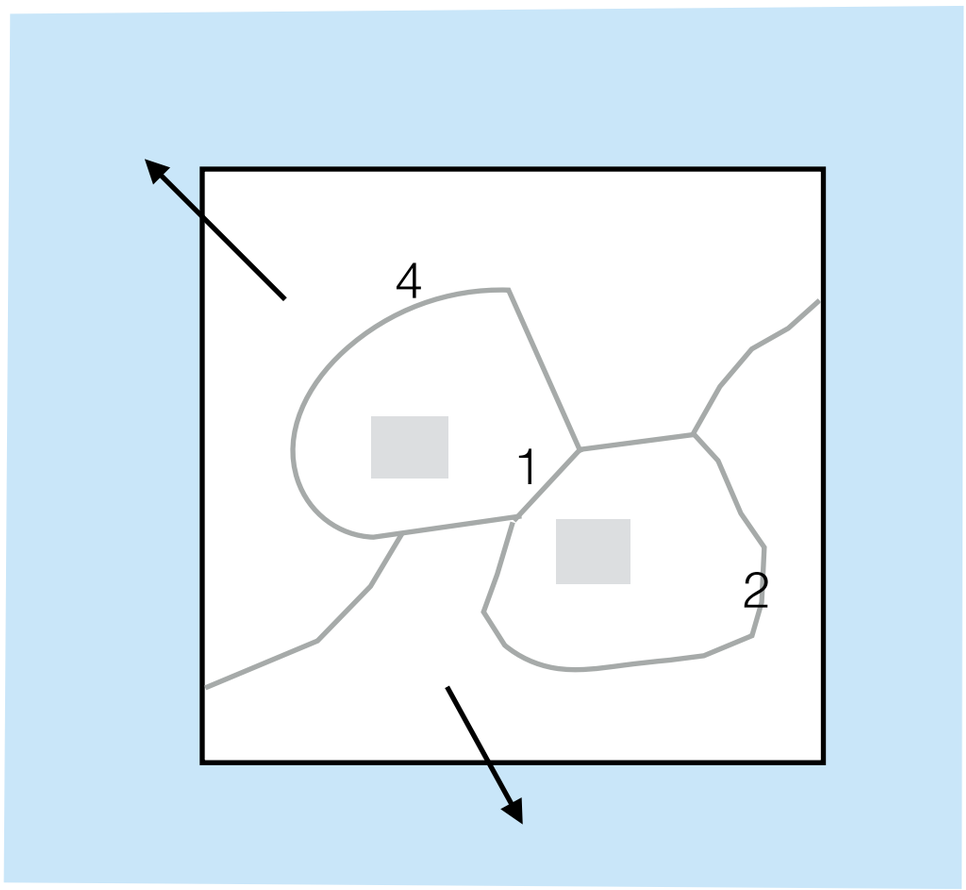
Flooding the sinks

- Find the sinks in the terrain, including the ocean.
- For each sink, compute its basin.
- Find the boundaries between sink-basins.
- Mark each edge between two sink-basins with the elevation of the lowest point along their boundary.
- Label the ocean as DONE.
- Sort the edges in increasing order of height
- For next edge (s,t) at height h
    - If none of s and t are DONE, raise them to height h
    - If one of them is DONE, then the other becomes DONE and it is raised to h
    - merge s,t and update graph

Since every flow path leads to a sink or the ocean, this partitions the terrain into sink-basins.

This represents the height at which s and t will merge


4
2
1


4
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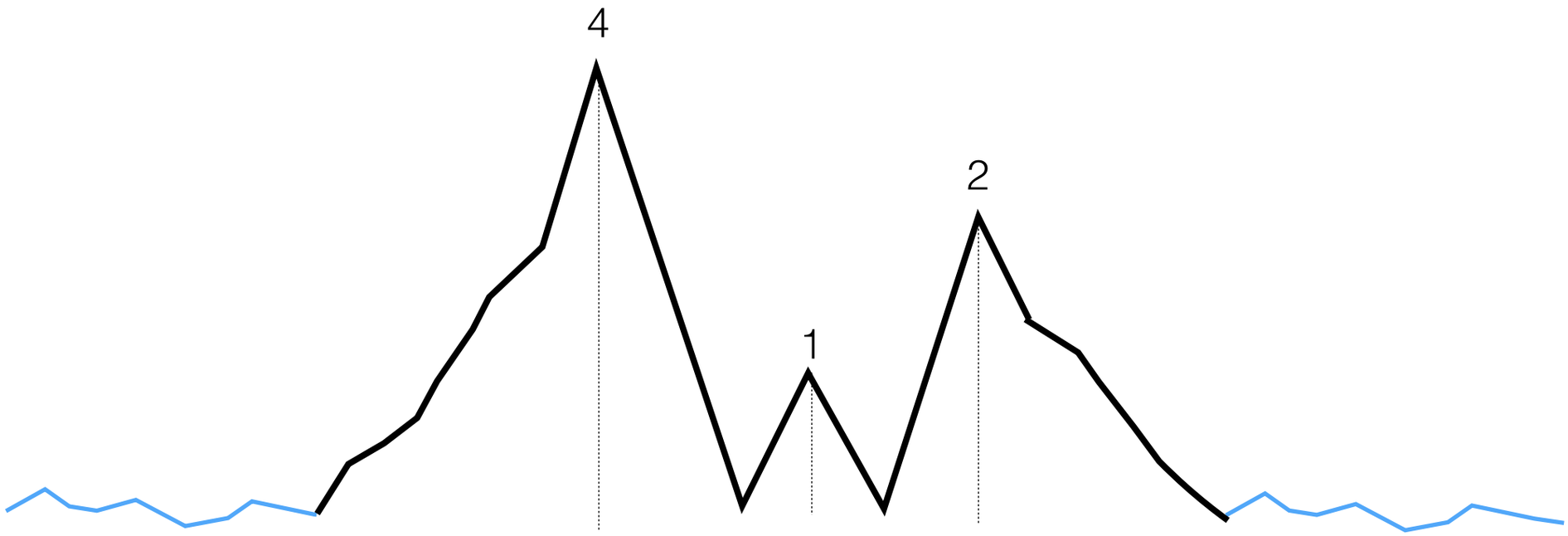
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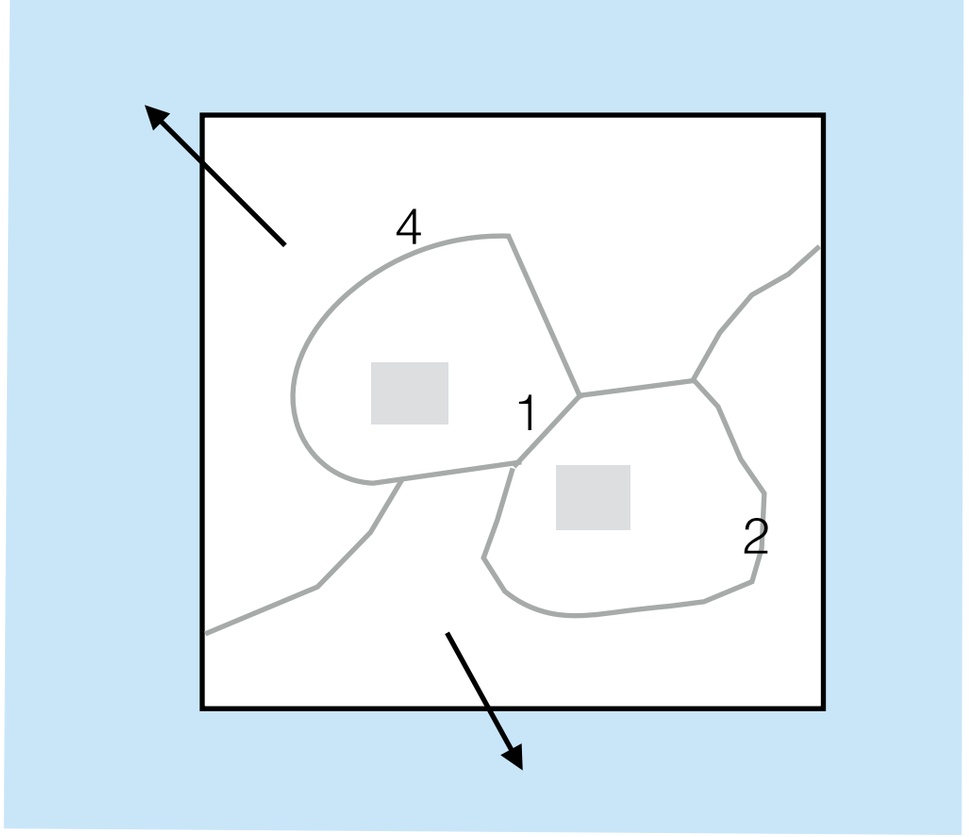
4
1
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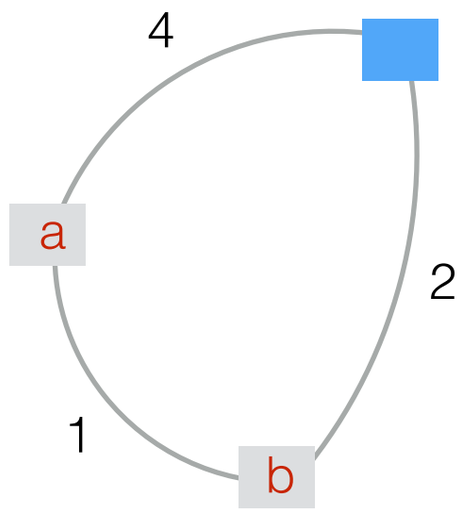
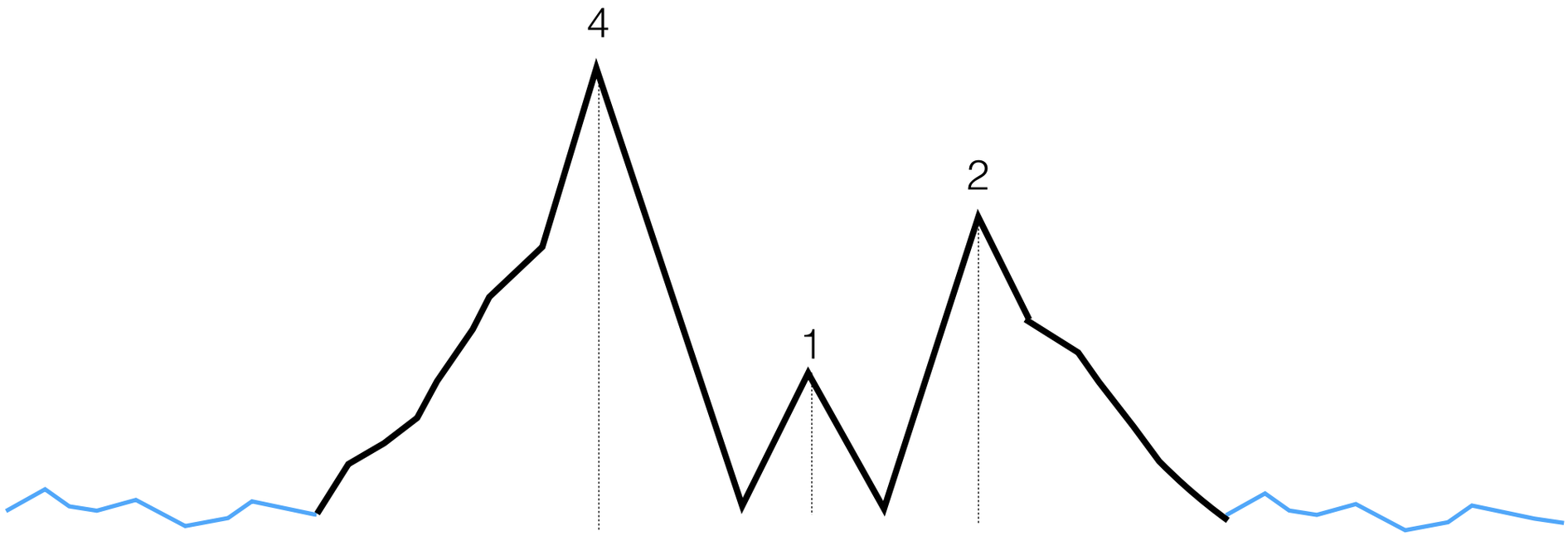
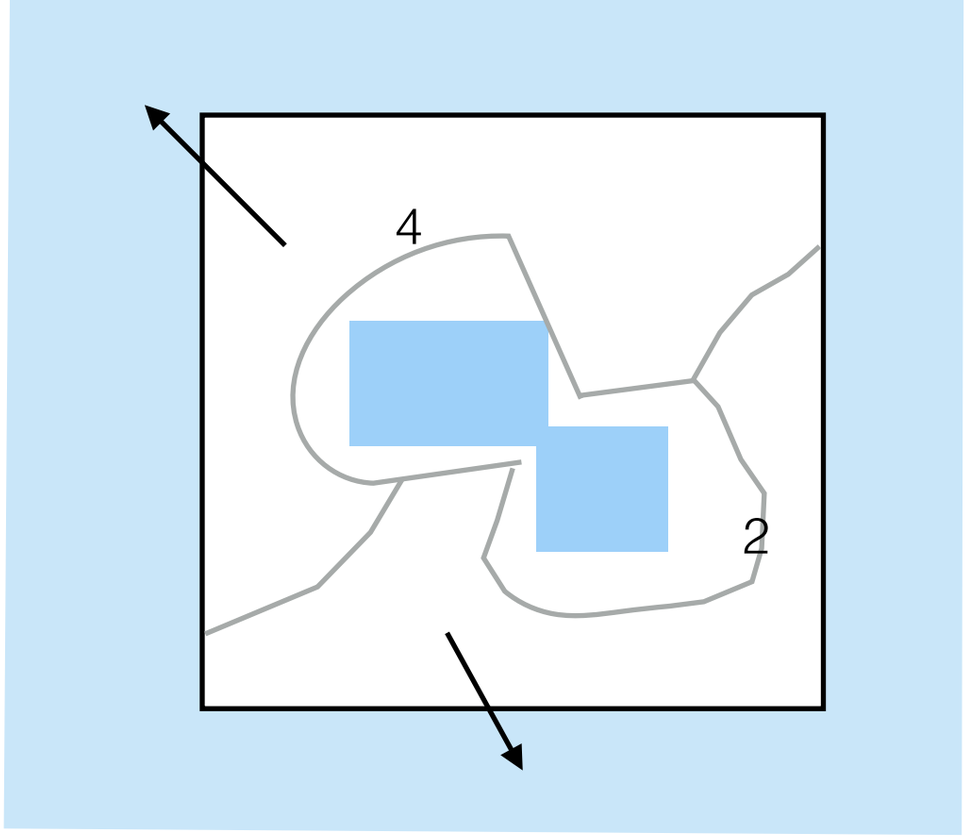
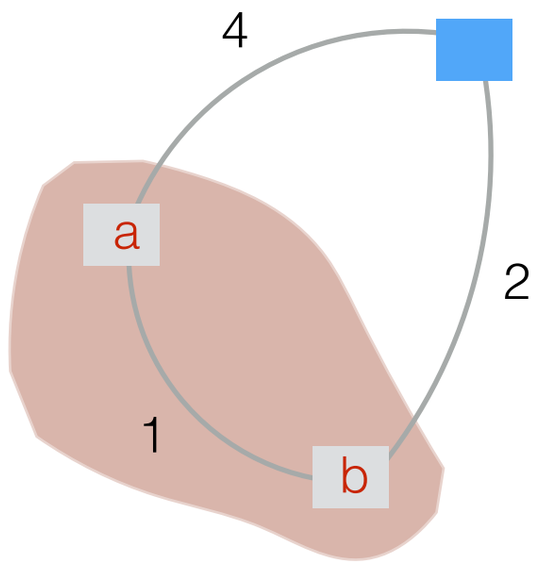
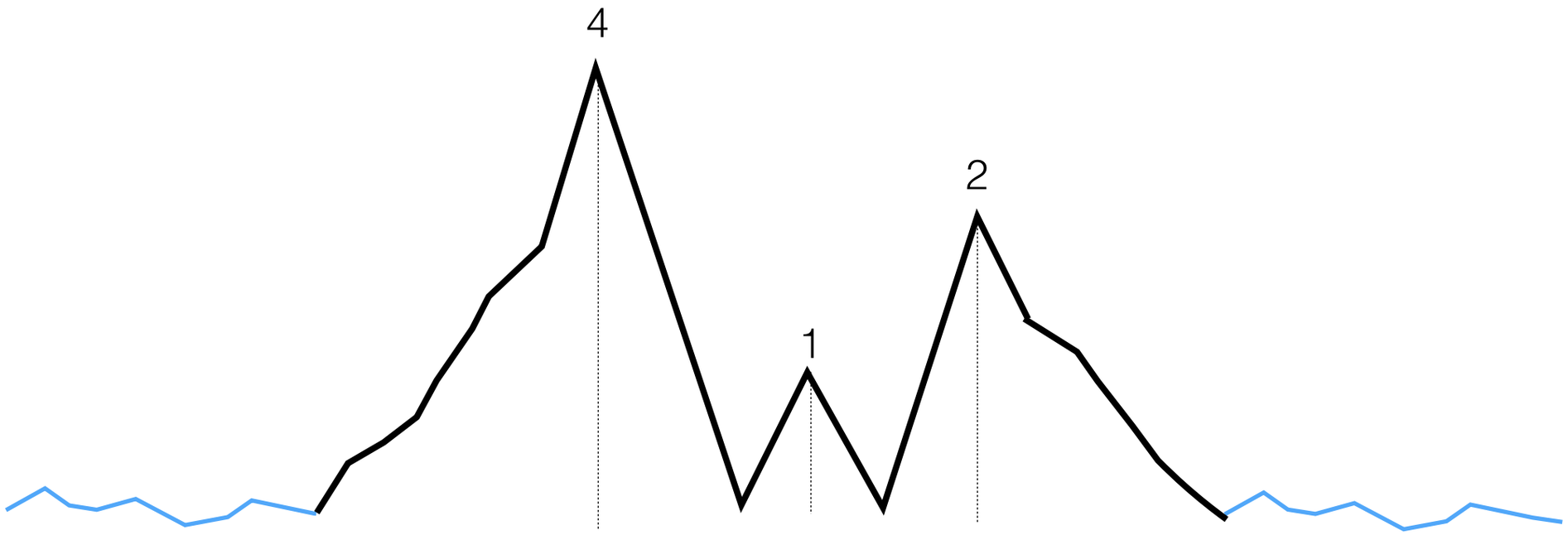

4
a
2
1
b

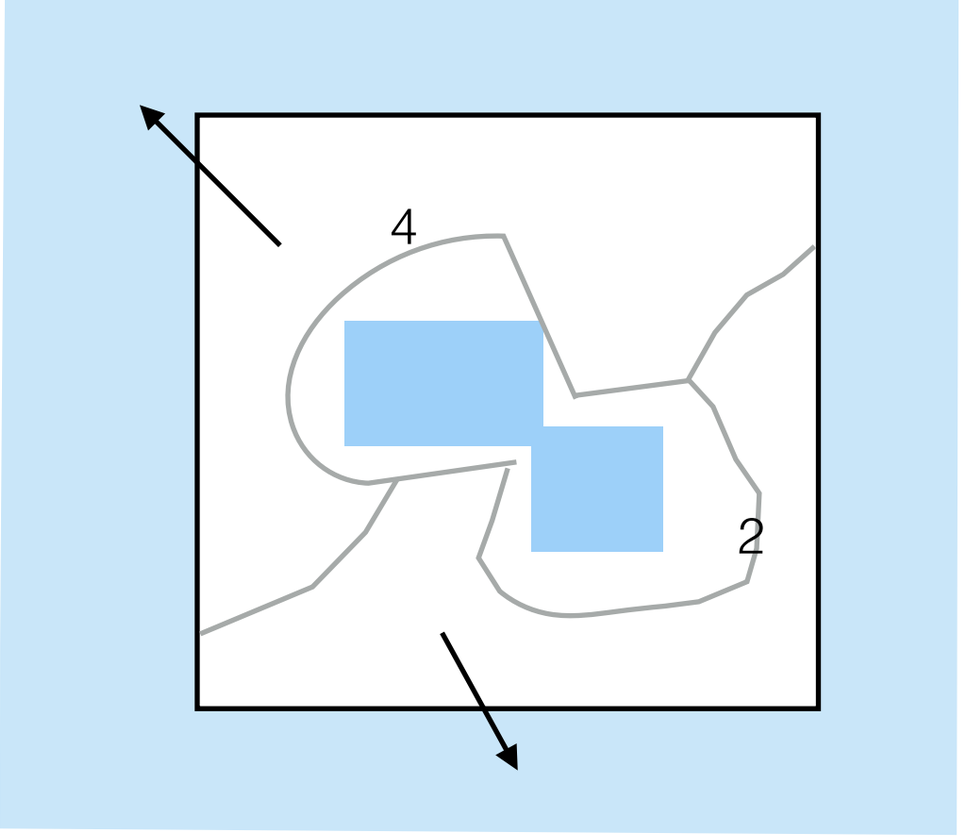


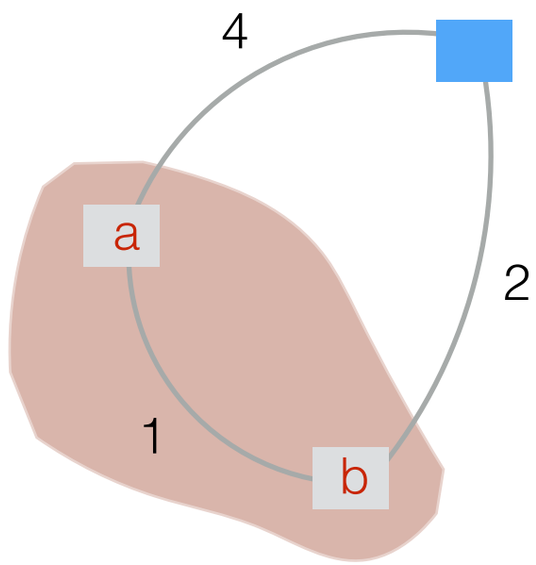




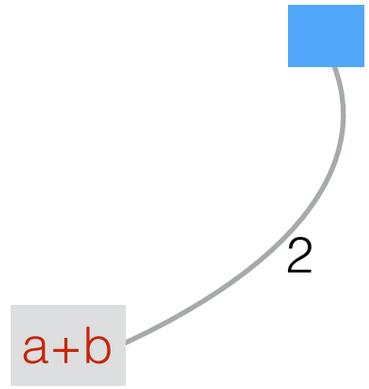
edge 1:
raise(a) = 1
raise(b) = 1
join (a,b)

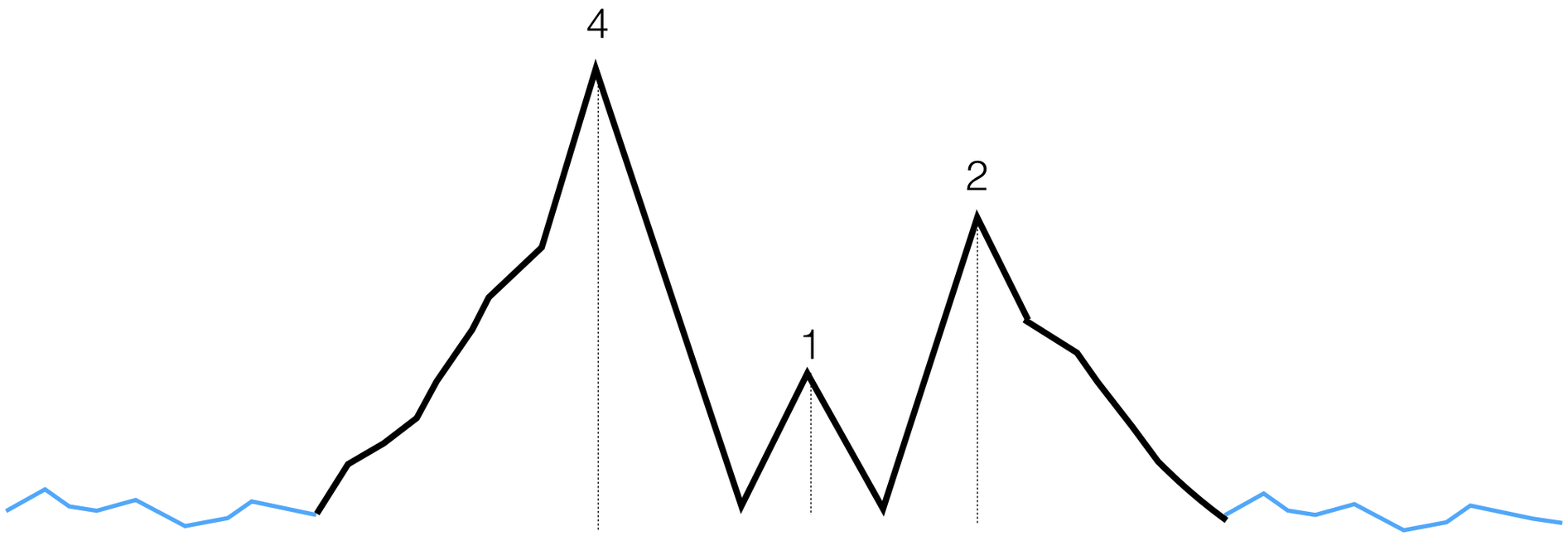


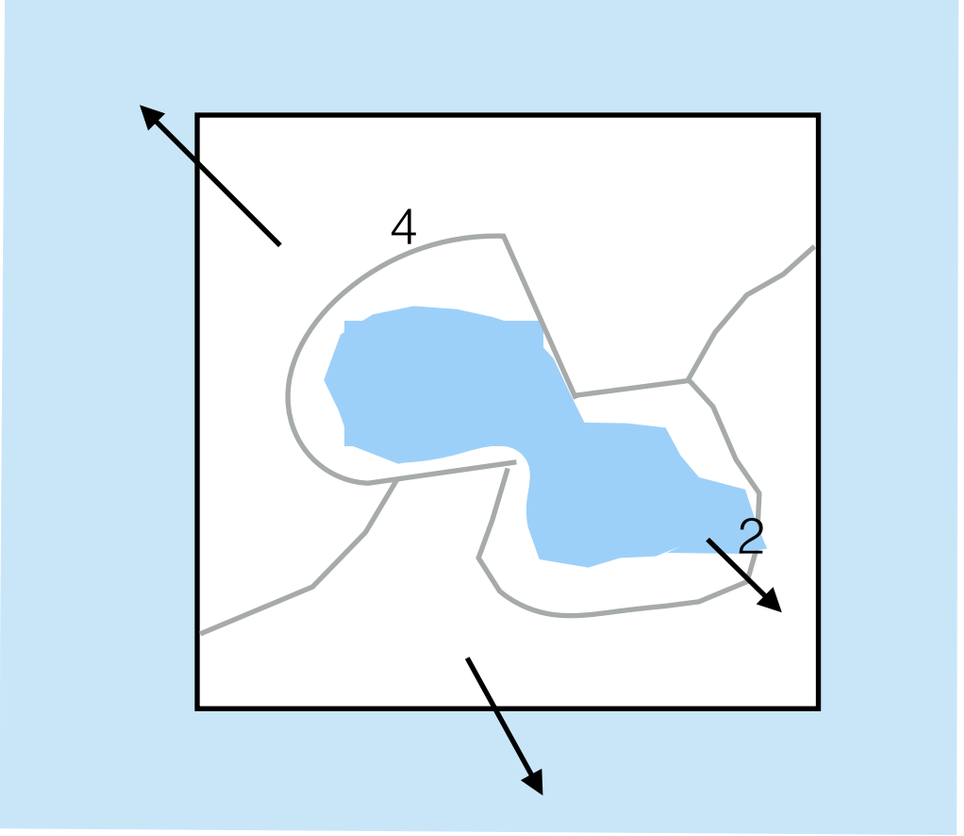


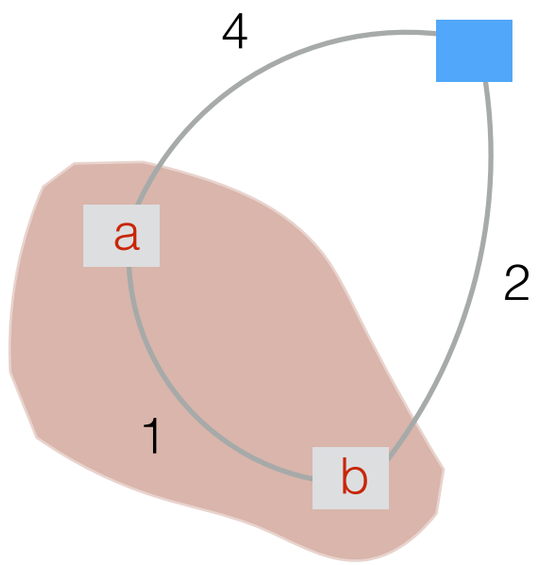


edge 1:
raise(a) = 1
raise(b) = 1
join (a,b)

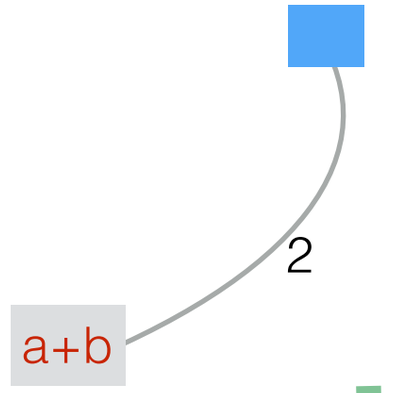








edge 1:
raise(a) = 1
raise(b) = 1
join (a,b)



edge 2:
raise(a,b) = 2
a ,b DONE

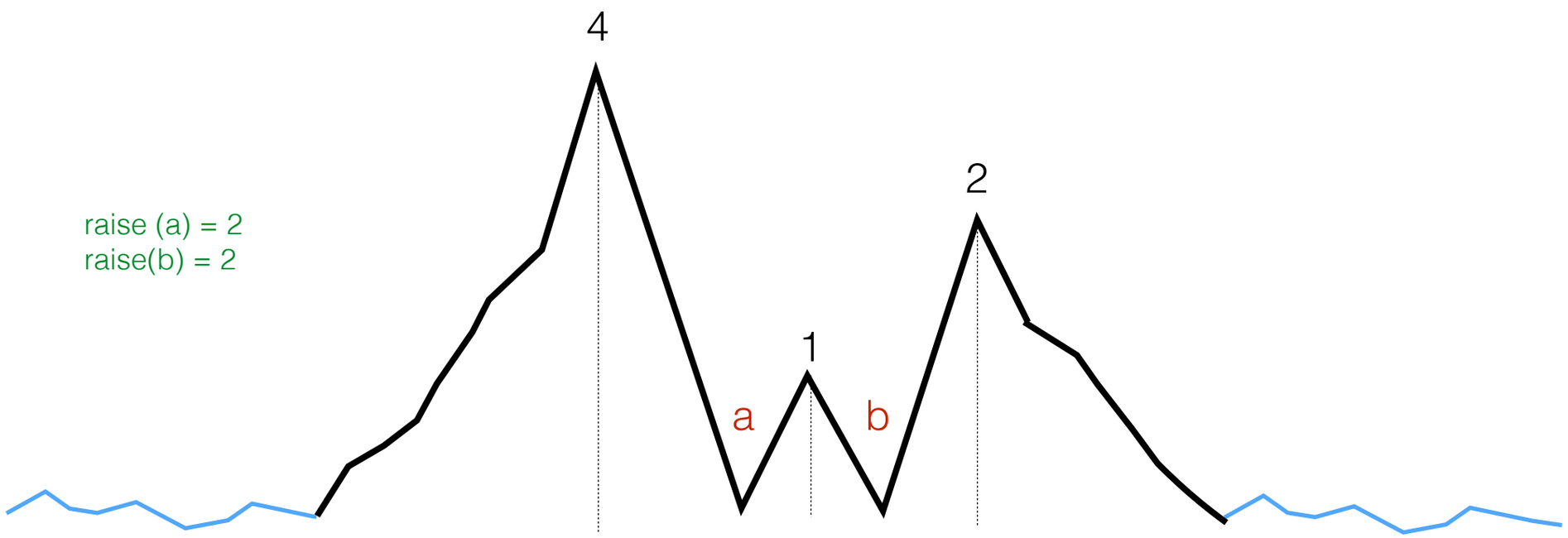
Flooding the sinks

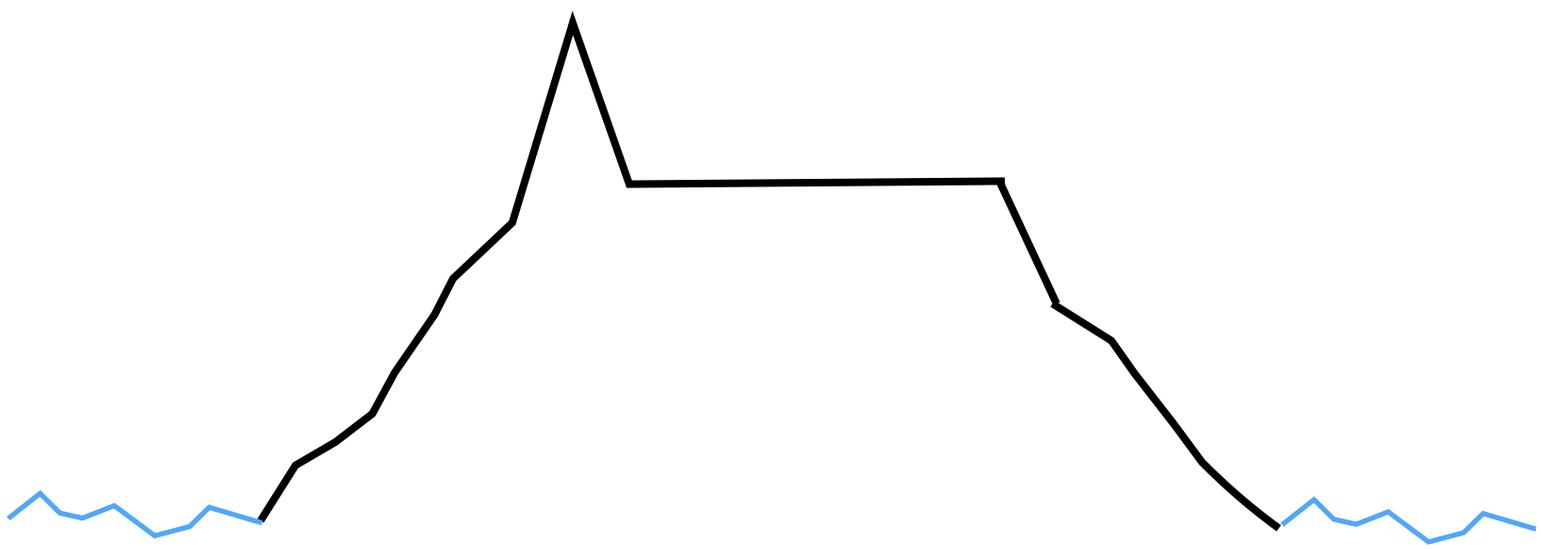
- Find the sinks in the terrain, including the ocean.
- For each sink, compute its basin.
- Find the boundaries between sink-basins.
- Mark each edge between two sink-basins with the elevation of the lowest point along their boundary.
- Label the ocean as DONE.
- Sort the edges in increasing order of height=
- For next edge (s,t) at height h
    - if s,t in the same set, ignore
    - If none of s and t are DONE, raise them to height h
    - If one of them is DONE, then the other becomes DONE and it is raised to h
    - union s and t
- Create the flooded terrain

Flooded terrain:

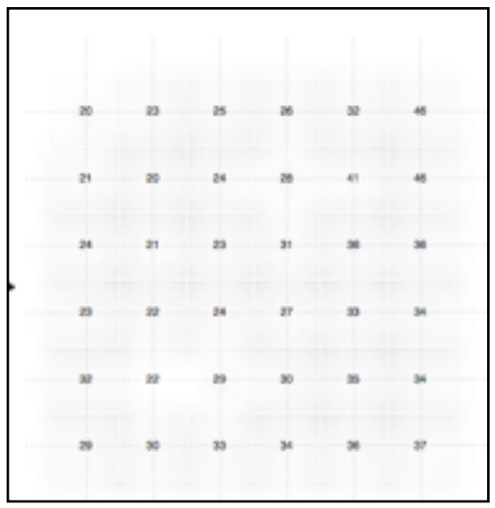
- For each point (i,j) in the terrain: set elevation(i,j) = max (elev(i,j), raise (basin(i,j))

raise (a) = 2
raise(b) = 2

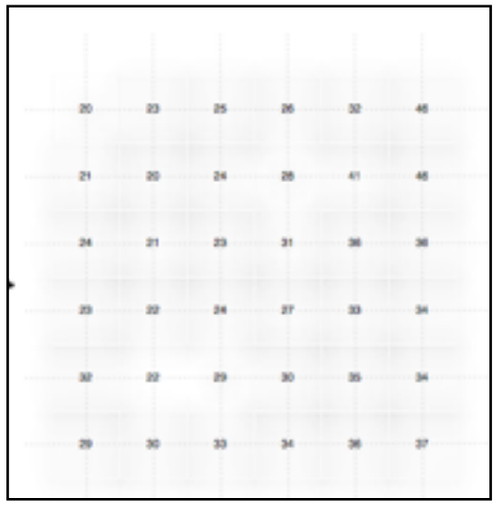




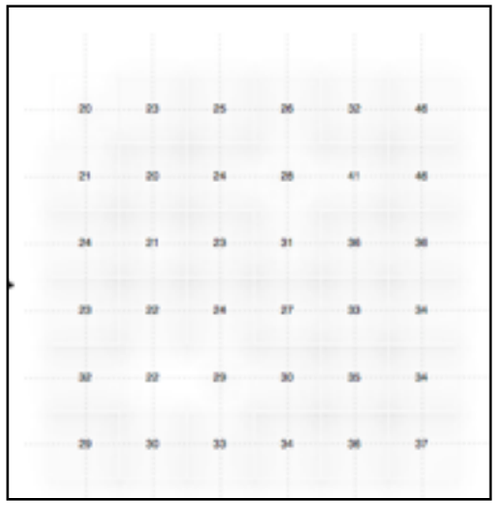
flooded terrain



elevation grid

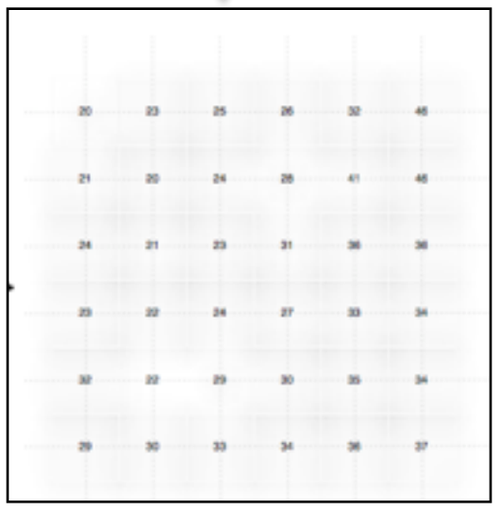


FD grid
(except plateaus and sinks)



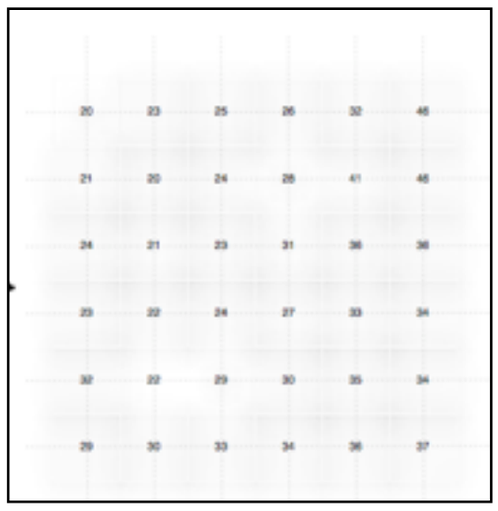
FD grid
(except on sinks)

flood sinks

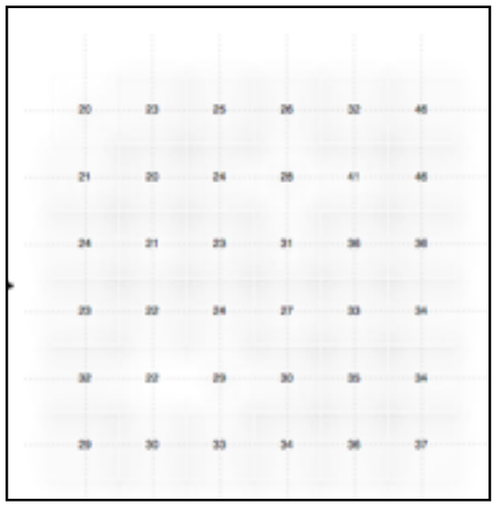


flooded elevation grid

identify plateaus assign FD on plateaus



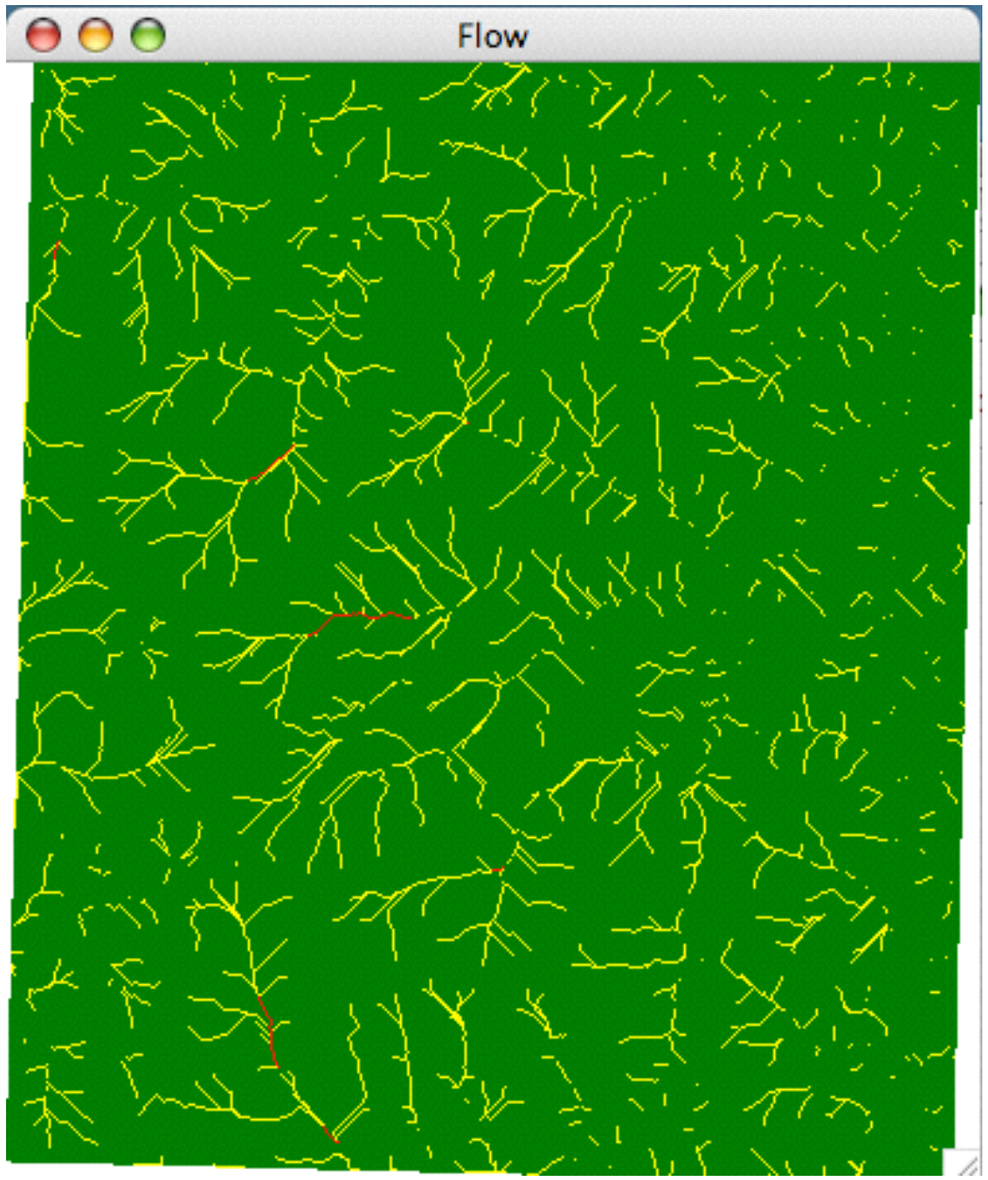
FD of flooded elevation



FA

It’s worth it!

- Flooding creates more realistic, connected river networks.



FA: no FD on sinks

FA with flooding

From FD and FA to rivers and watersheds

Terminology

- Mouth or end of a river
- Source of a river
- Streams
- Tributaries
- Junctions
- Watersheds
- Drainage basins
- Catchments
- Drainage divides

STAR GAZING YOGA SEA CREATURES GARDENING LEGENDS BIRDS MORE

Reference*

GEOGRAPHY BODIES OF WATER

Q: What is a mouth of a river?

A: QUICK ANSWER

The mouth of a river is another name for its terminus, where it meets an ocean, sea or lake. Because rivers generally carry abundant sediment and deposit it at the mouth, they often form deltas, or broad, shallow areas. The opposite enc
headwaters
same genera

Reference*

SCIENCE EARTH SCIENCE

Q: What is a river source?

A: QUICK ANSWER

A river source is the place from which a river begins to flow. Types of sources include lakes, bogs, springs, streams, collections of snow or rainwater, glaciers, swamps and other rivers. CONTINUE READING

KEEP LEARNING

Q: What is the difference between a rive and a stream?

A: QUICK ANSWER

The Minnesota Department of Natural Resources explains that there i official distinction between streams and rivers, but streams are comm held to be smaller bodies of water that feed into larger bodies, namel Both streams and rivers possess currents and are somewhat narrow, are at least constrained between two banks. CONTINUE READING

Reference*

SCIENCE | ENVIRONMENTAL SCIENCE | CONSERVATION

Q: What is a watershed?

A:

QUICK ANSWER

A watershed is any area of land where water falls, flows and drains into a common lower outlet such as a river or lake. It can be as small as a puddle or as large as an area where all the water from the land goes to the same point.

CONTINUE READING ▼

KEEP LEARNING

How does a watershed function?

What are some ways to protect a wildlife habitat?

What is the major river that flows through the Grand Canyon?

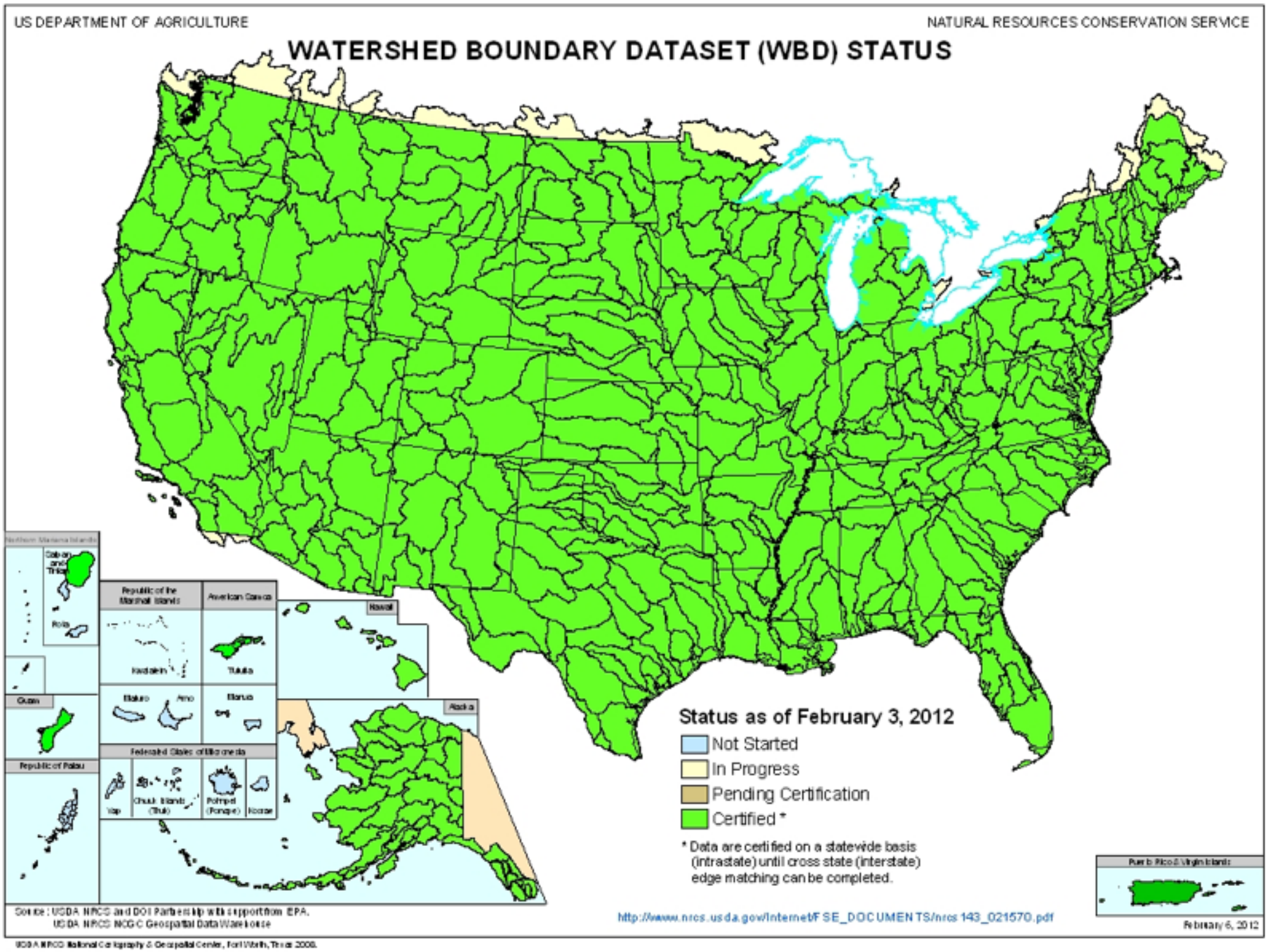
FULL ANSWER

A watershed is commonly known as a rainfall or precipitation collector. It collects water from the highest point, also called the headwater, and delivers the water through tributary streams to a larger water basin or a mouth, such as a river. One of the more well-known watersheds is the Sierra Nevada watershed, which supplies water not only to more than half of California and Northwestern Nevada's population, but also supports and provides premium habitat to the wildlife in the mountain area.

Watersheds, drainage basins, catchments

- Used interchangeably
- Area of land where where all the water that falls on the land flows to a common outlet.
- Every place on Earth is in some watershed
- Separated by ridges and hills (watershed divides)
- Scale: Watersheds are nested inside each other


WYOMING
UTAH
NEVADA
COLORADO
CALIFORNIA
NEW MEXICO
ARIZONA
BAJA CALIFORNIA
SONORA
Green
Big Sandy
Blacks Fork
Rock Springs
Flaming Gorge Reservoir
Little Snake
Yampa
White
Duchesne
Strawberry Reservoir
Green
Colorado
Grand Junction
Gunnison
Blue Mesa Reservoir
San Rafael
Dirty Devil
Fremont
Escalante
Moab
San Miguel
Dolores
Animas
San Juan
Navajo Reservoir
Farmington
Chinle
Chaco
Paria
Lake Powell
Page
Kanab
Virgin
St. George
Muddy
Las Vegas
Henderson
Lake Mead
Lake Mohave
Bullhead City
Oraibi Wash
Flagstaff
Little Colorado
Puerco
Verde
Lake Havasu City
Prescott
Lake Havasu
Bill Williams
Colorado
Hassayampa
Agua Fria
Theodore Roosevelt Lake
Salt
Scottsdale
Phoenix
San Carlos Lake
San Francisco
Gila
Painted Rock Reservoir
Yuma
San Luis Rio Colorado
Santa Cruz
San Pedro
San Simon
Tucson
White



How do you think these maps are created?

FD and FA lead to elegant models of these concepts

A tree in FD graph represents a river and its tributaries.

Root of a river tree: river mouth

Pruning the tree: a river = all points with FA above a given threshold.

River backbone: walk from the mouth up along path with largest FA

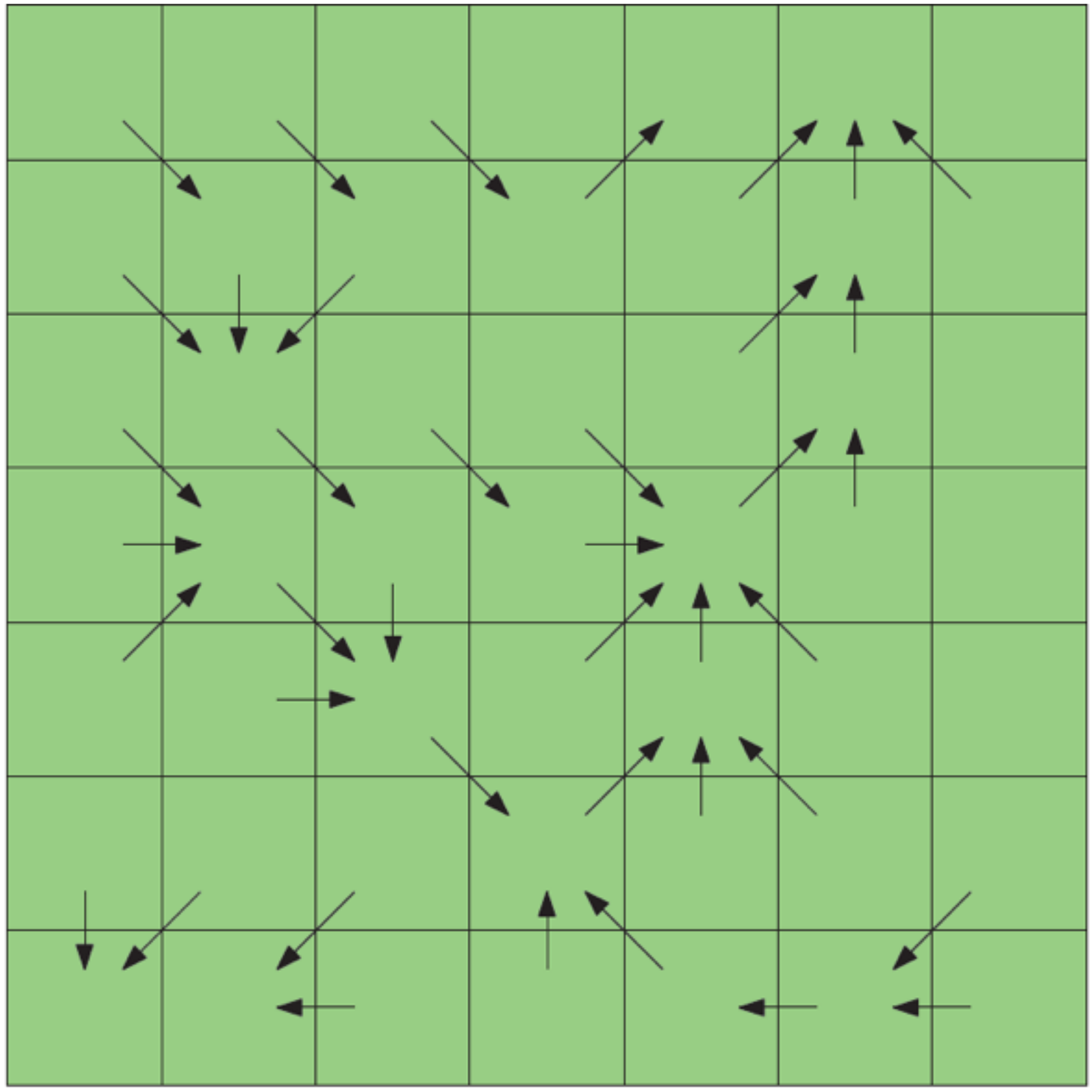
Junctions: points in the river tree with >1 child

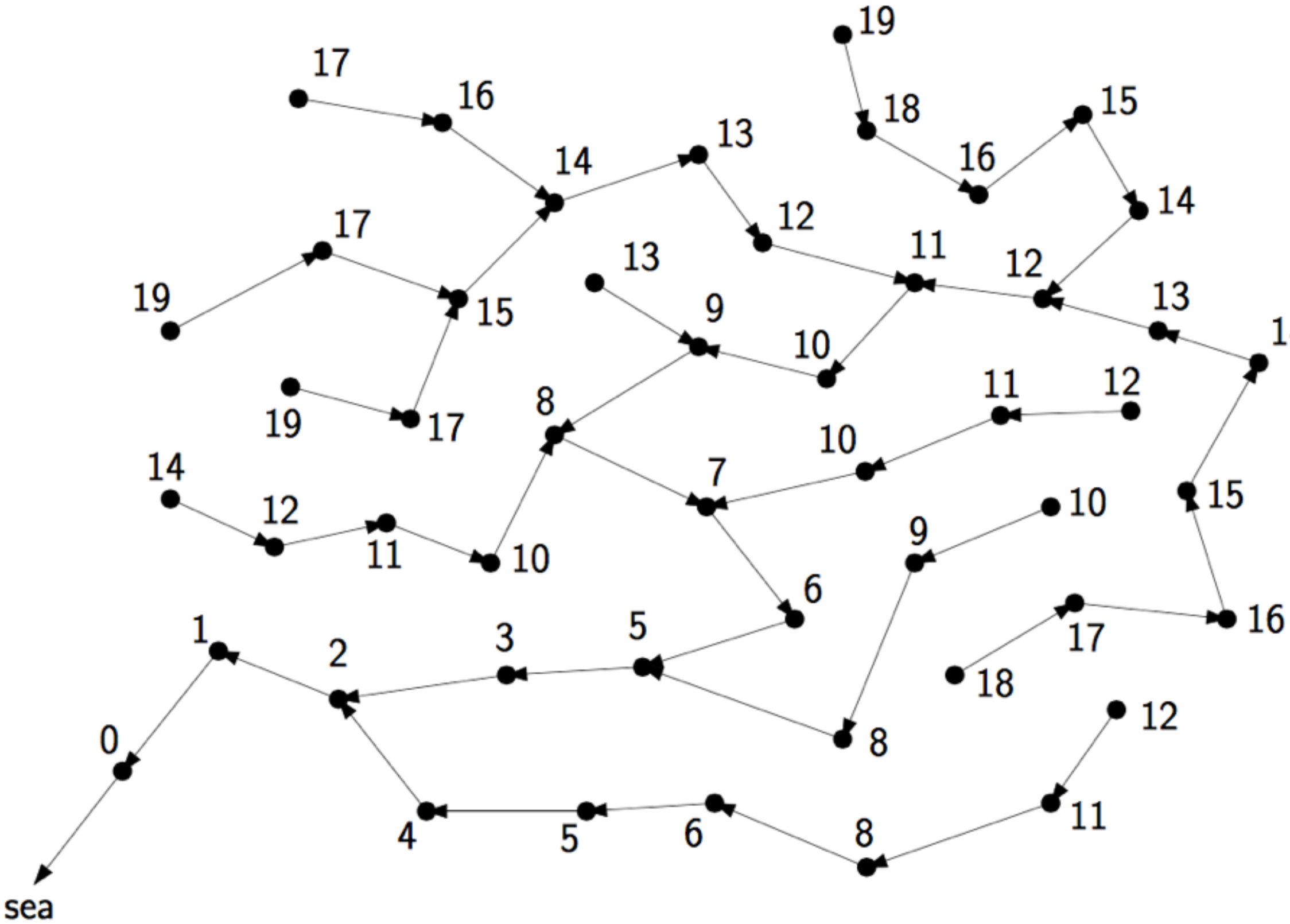
River tributaries: the connected components of the river tree minus the river backbone

Watershed (s): all cells in the terrain that have a flow path into s.

Watershed hierarchy:

- find river backbone
- find largest tributaries and their basins
- find inter-basins
- recurse in each basin

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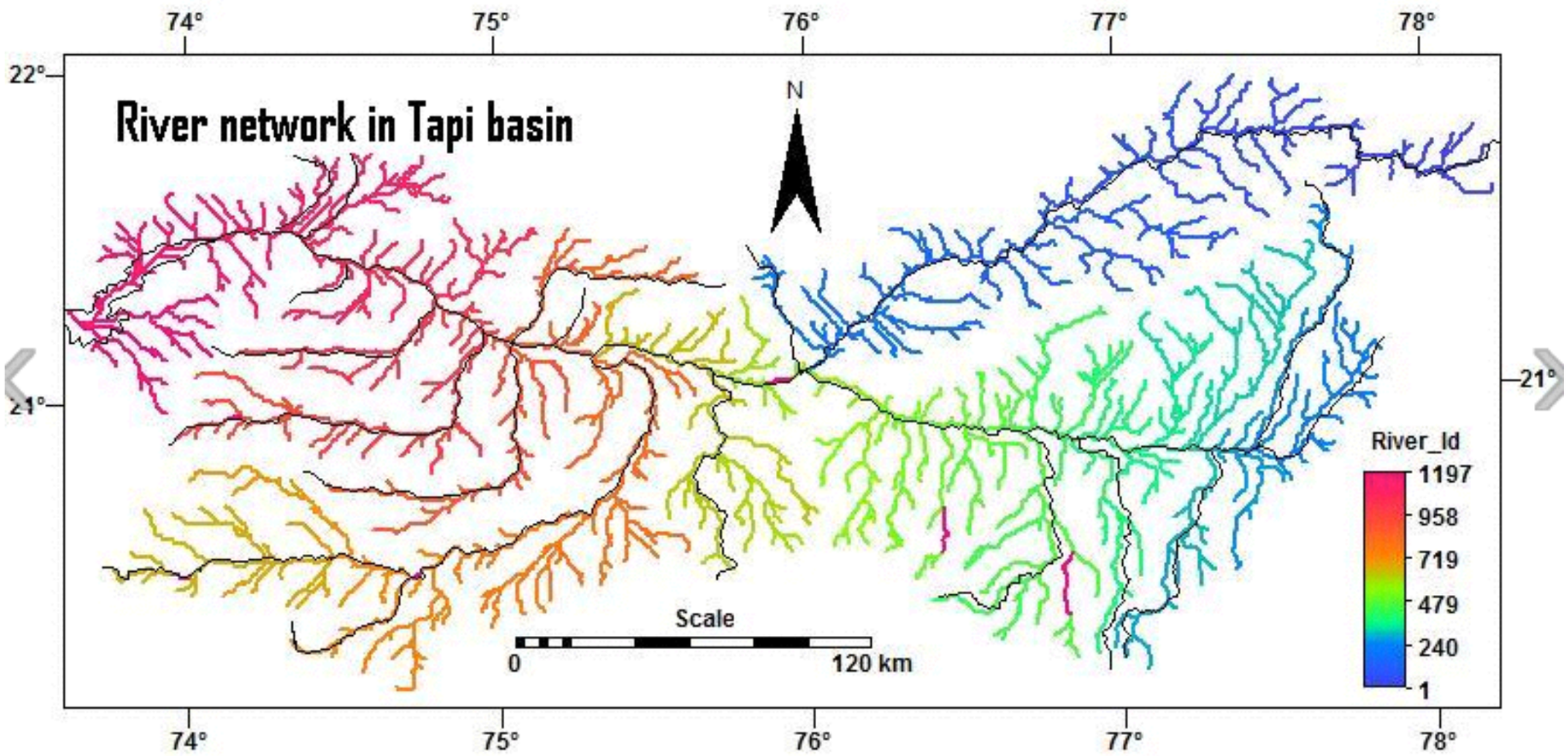
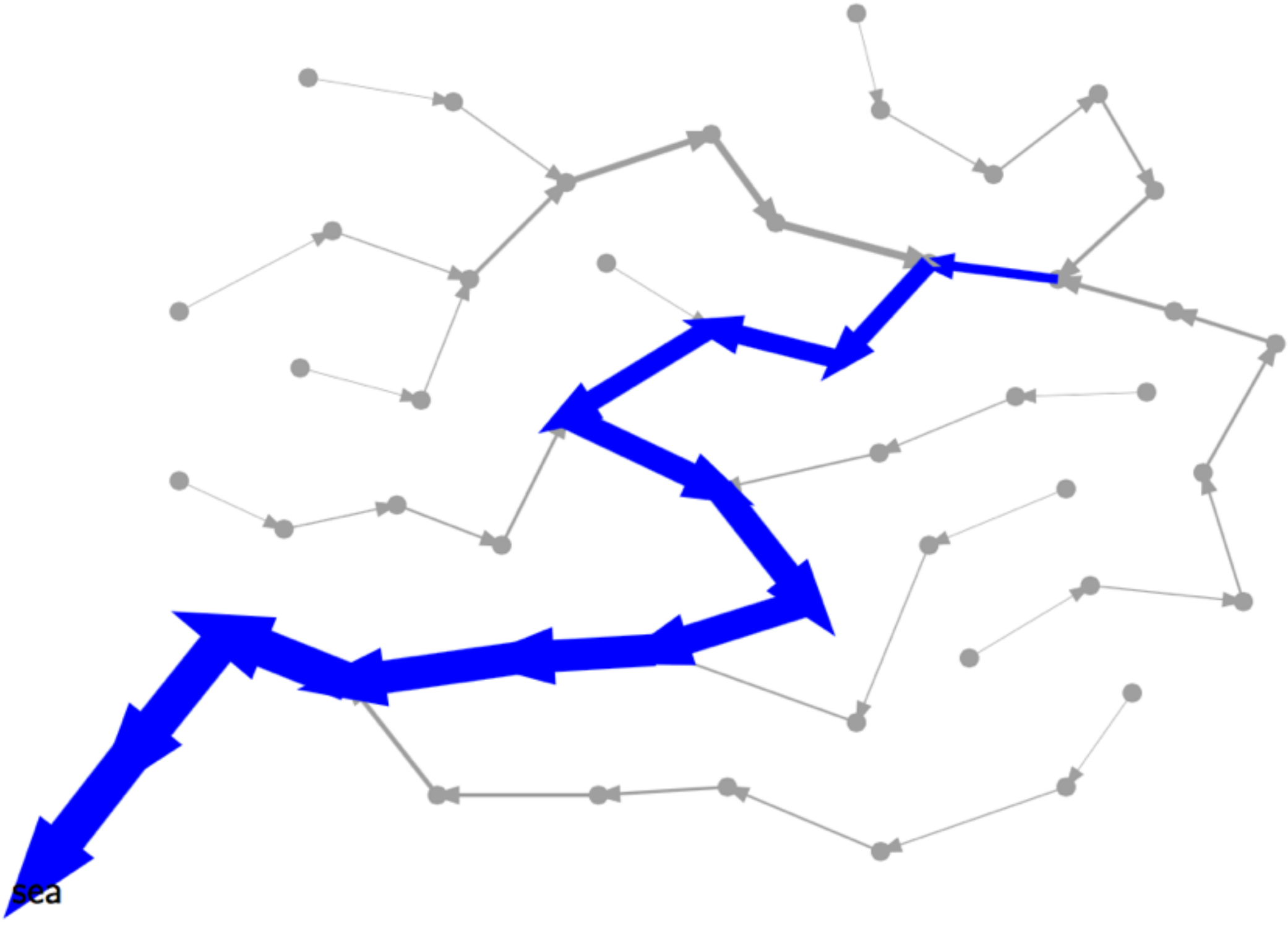
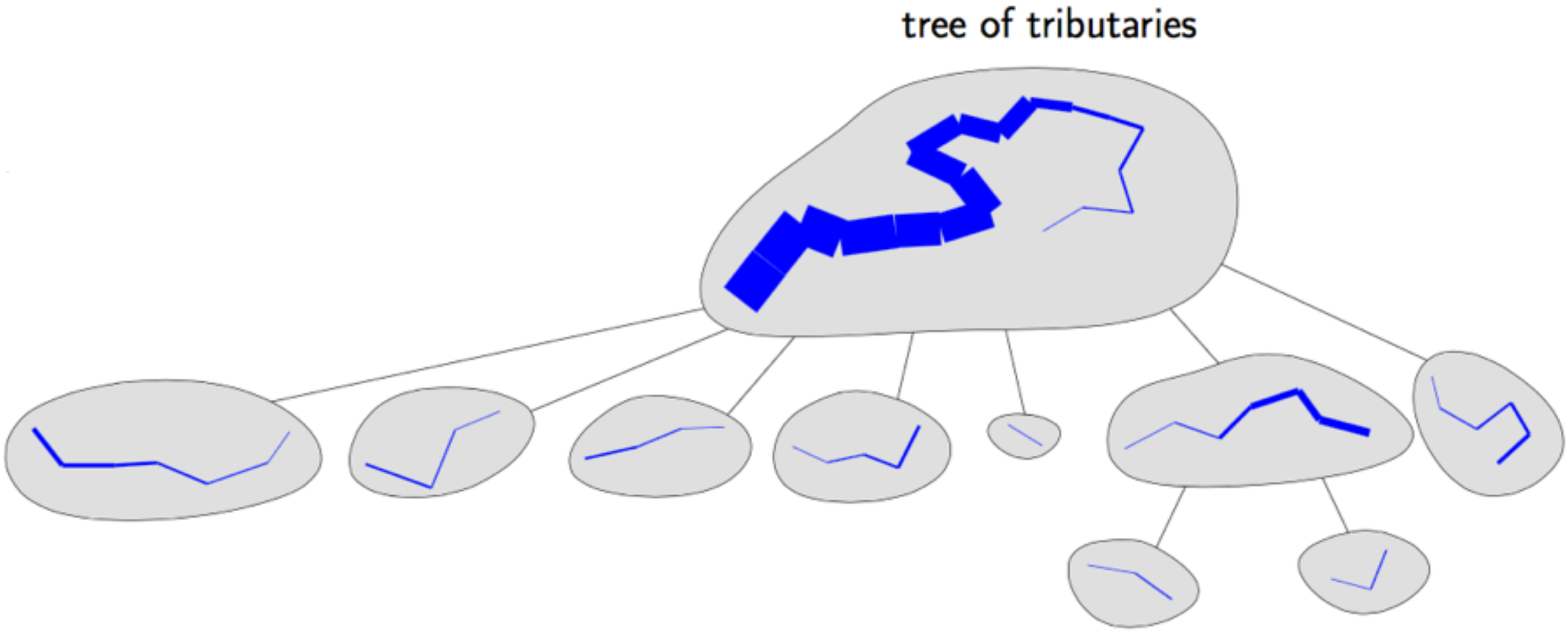
sea

- Rivers = cells with FA > threshold



River: start at mouth, keep going upstream into the stream with biggest drainage area.



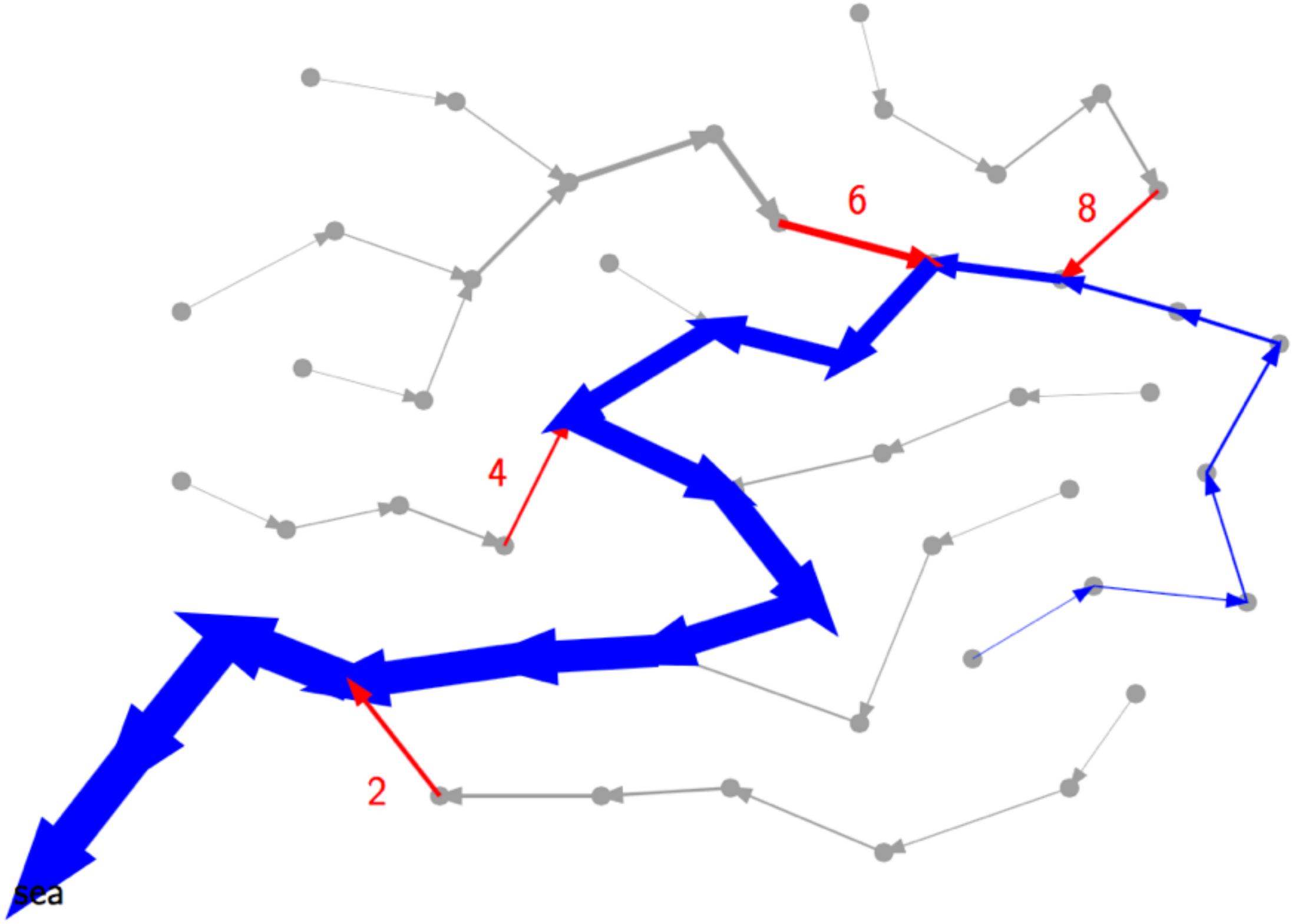

tree of tributaries

FD and FA lead to elegant models of these concepts

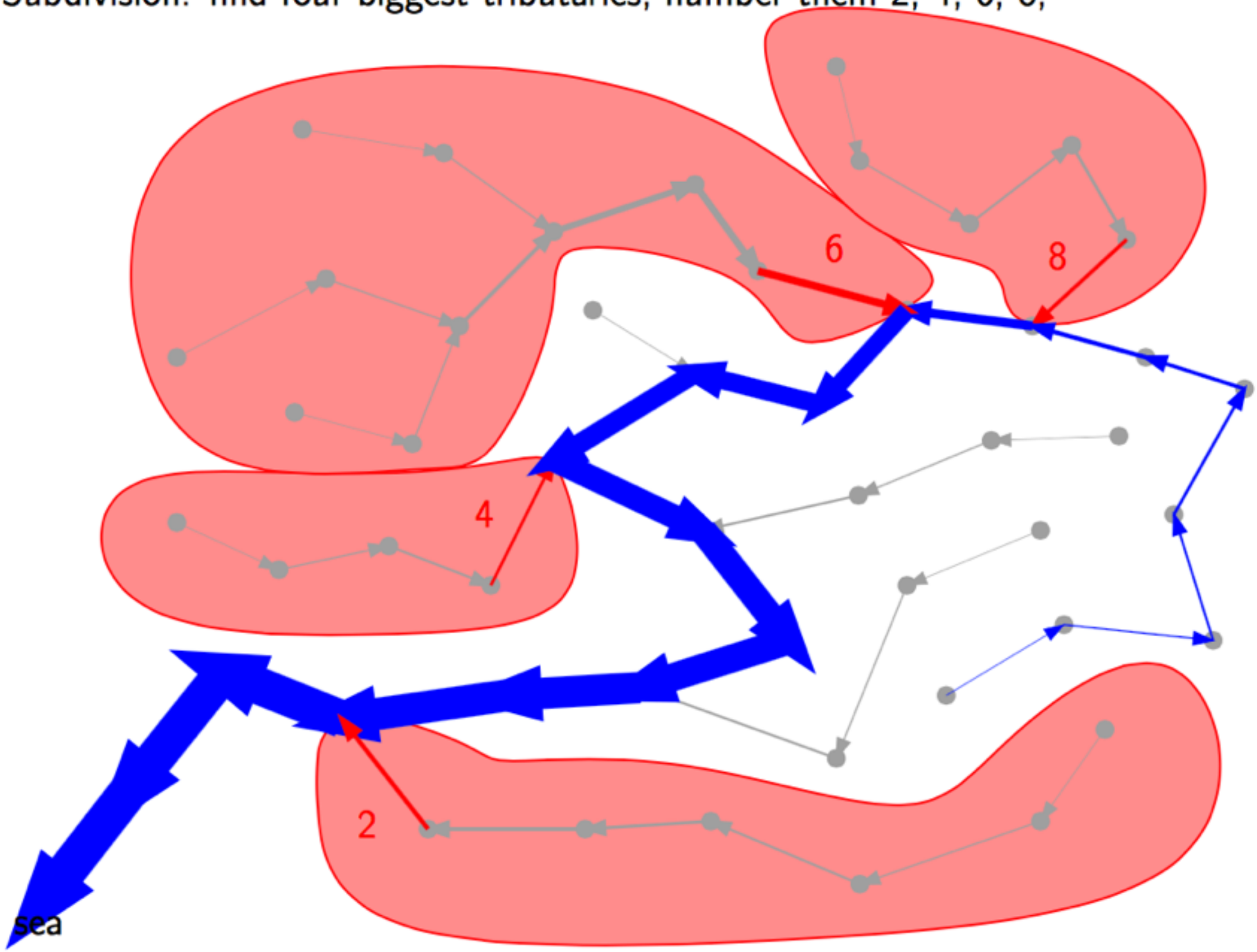
Watershed hierarchy:

- find river backbone
- find largest tributaries and their basins
- find inter-basins
- recurse in each basin

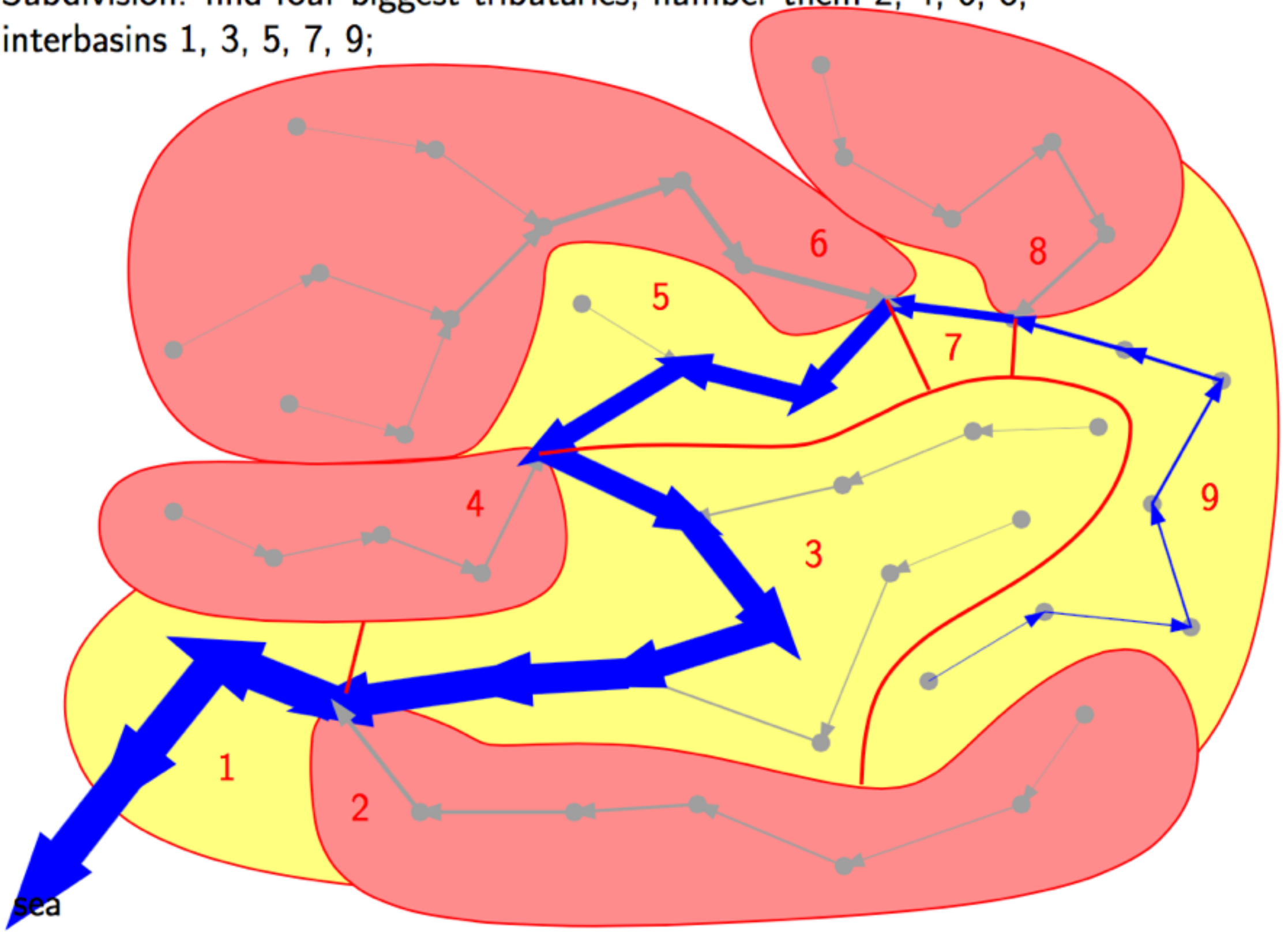
Subdivision: find four biggest tributaries, number them 2, 4, 6, 8;



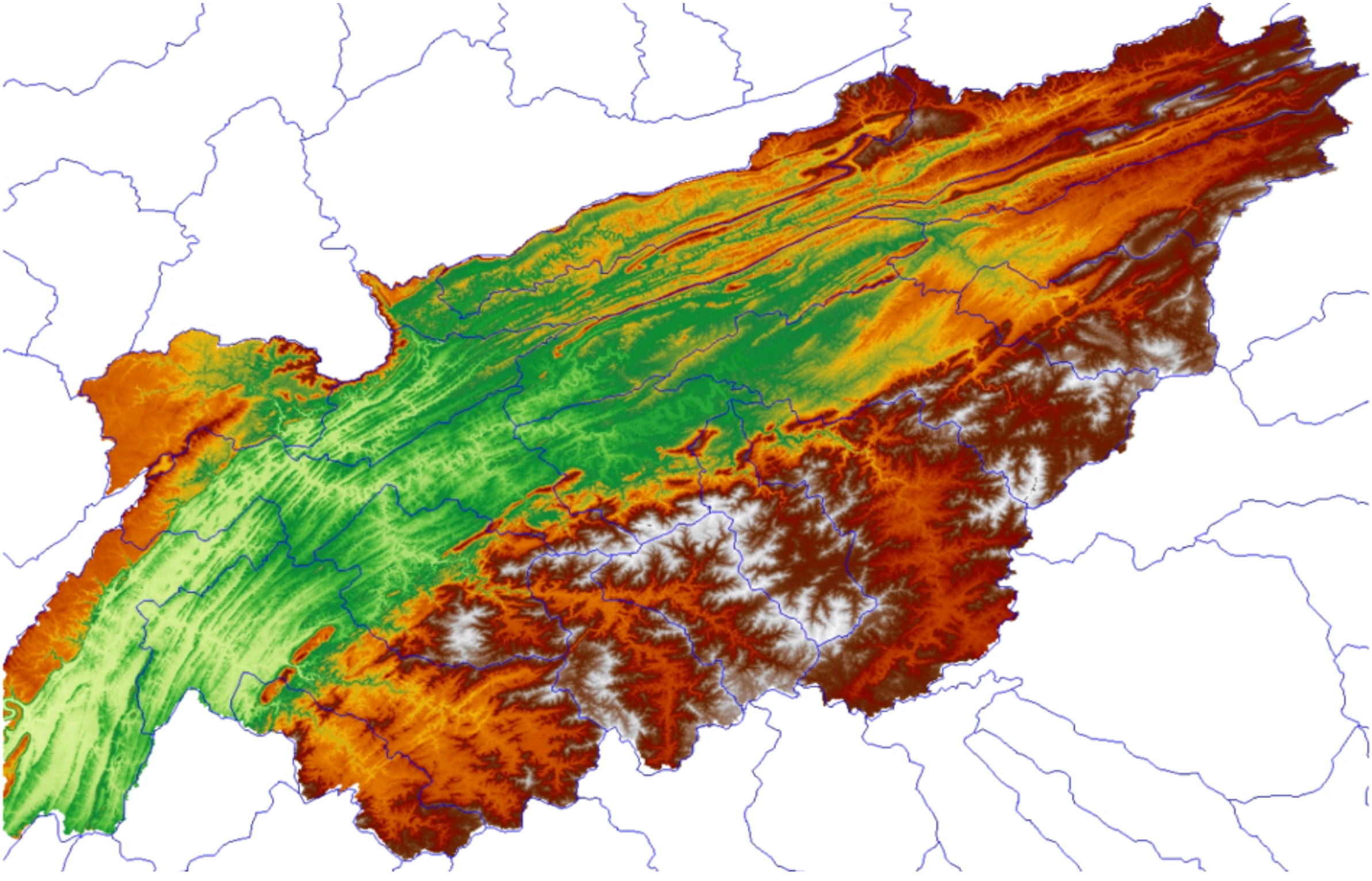
Subdivision: find four biggest tributaries, number them 2, 4, 6, 8;



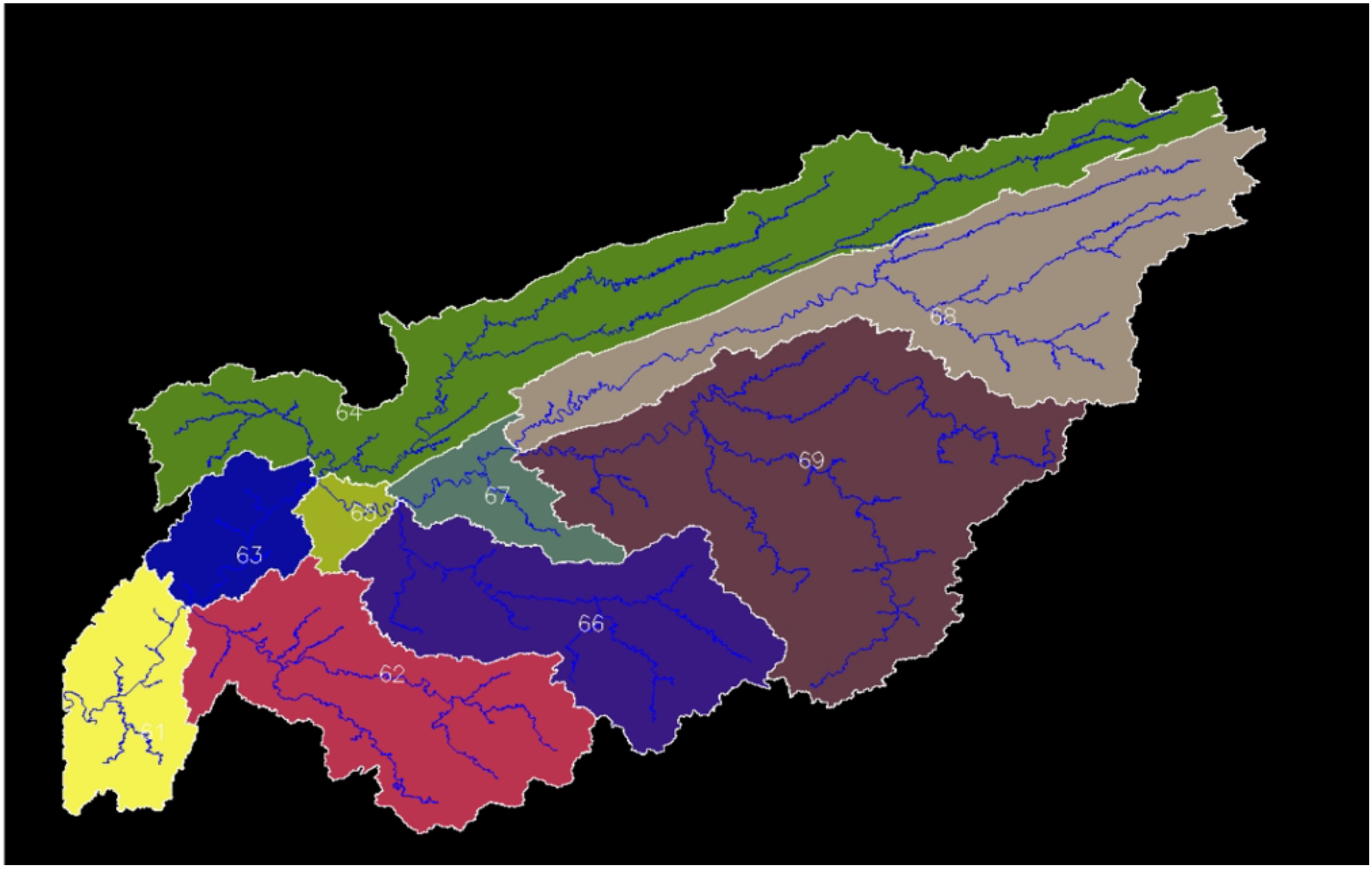
Subdivision: find four biggest tributaries, number them 2, 4, 6, 8;
interbasins 1, 3, 5, 7, 9;



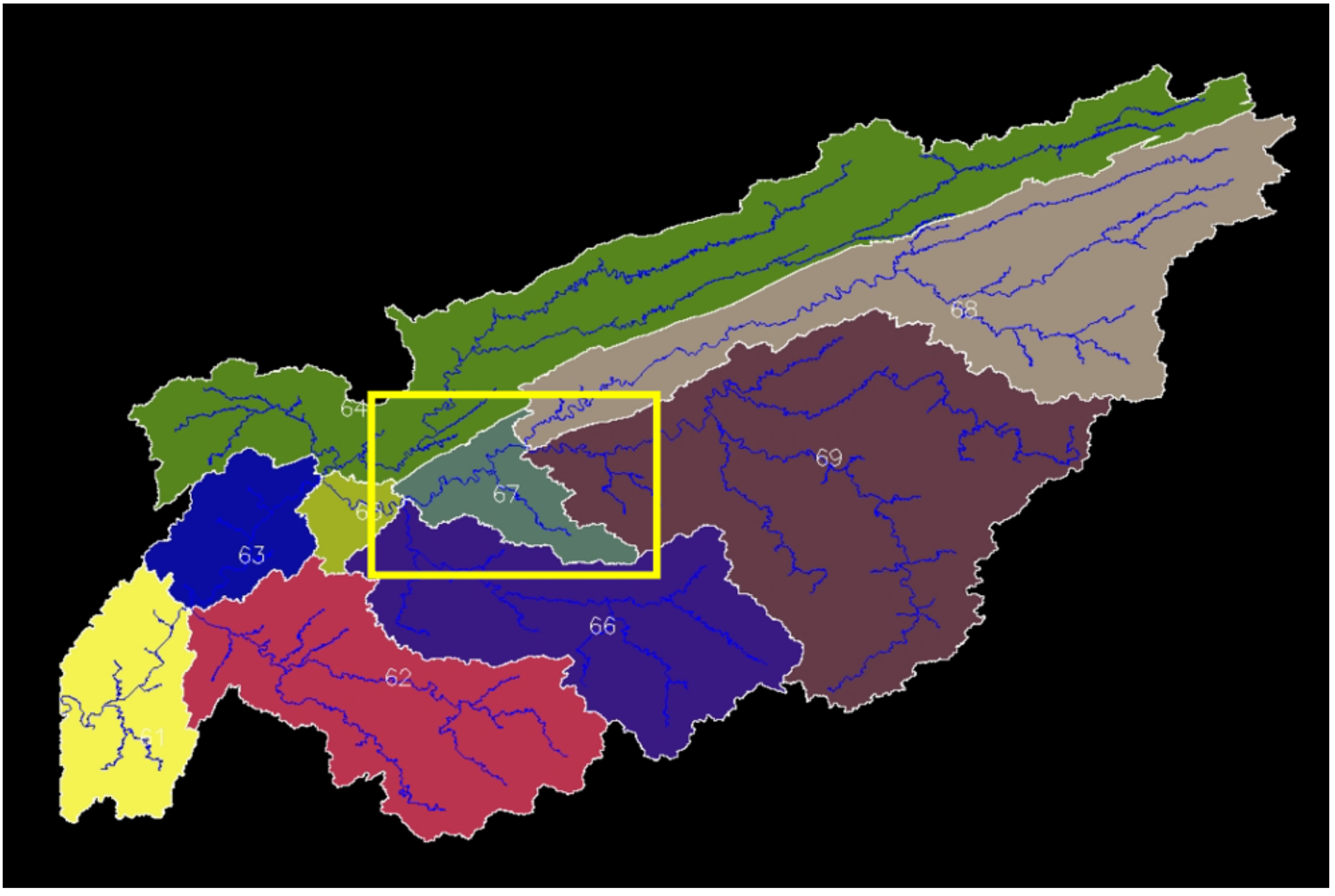
In real life



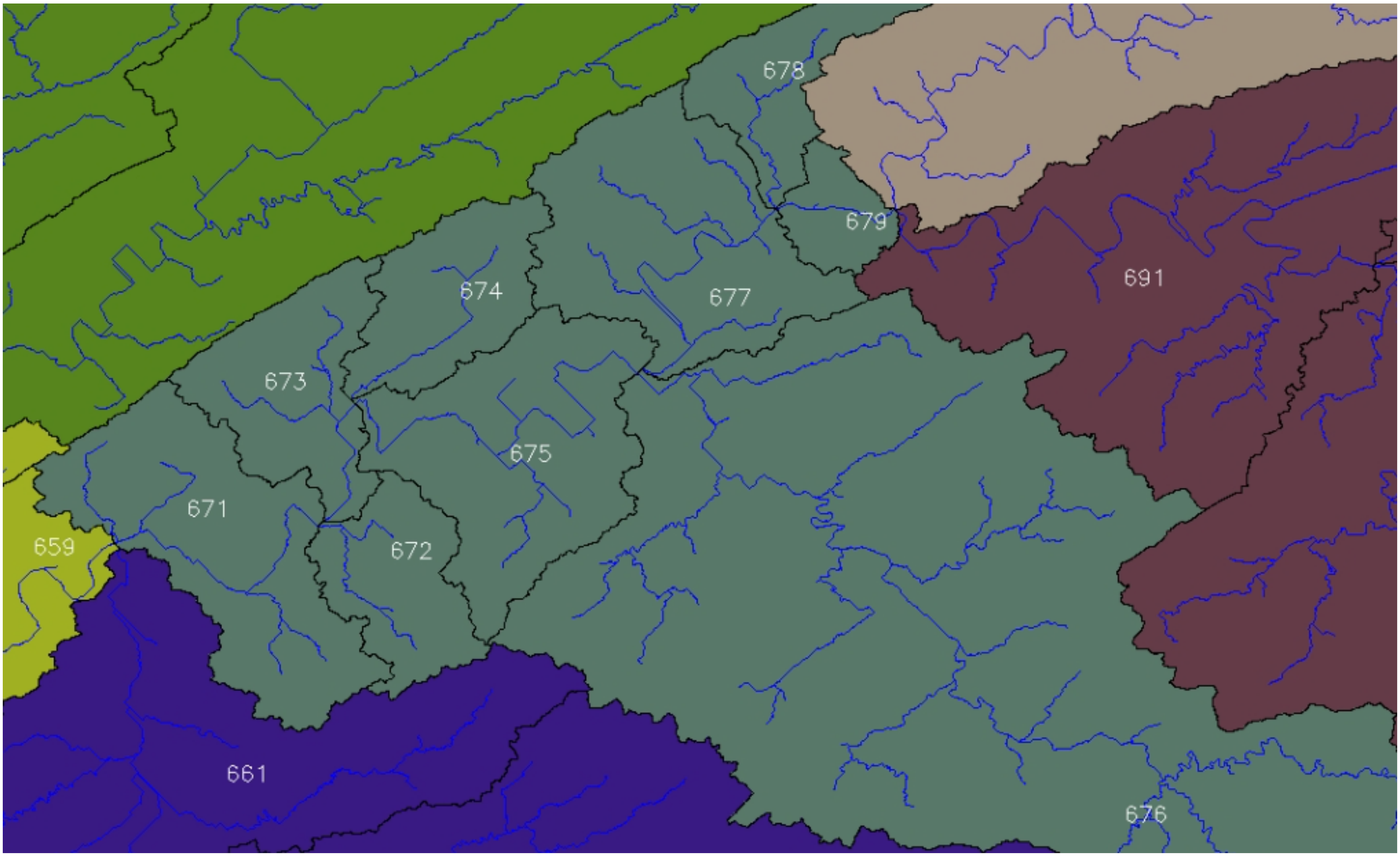
In real life



In real life



In real life



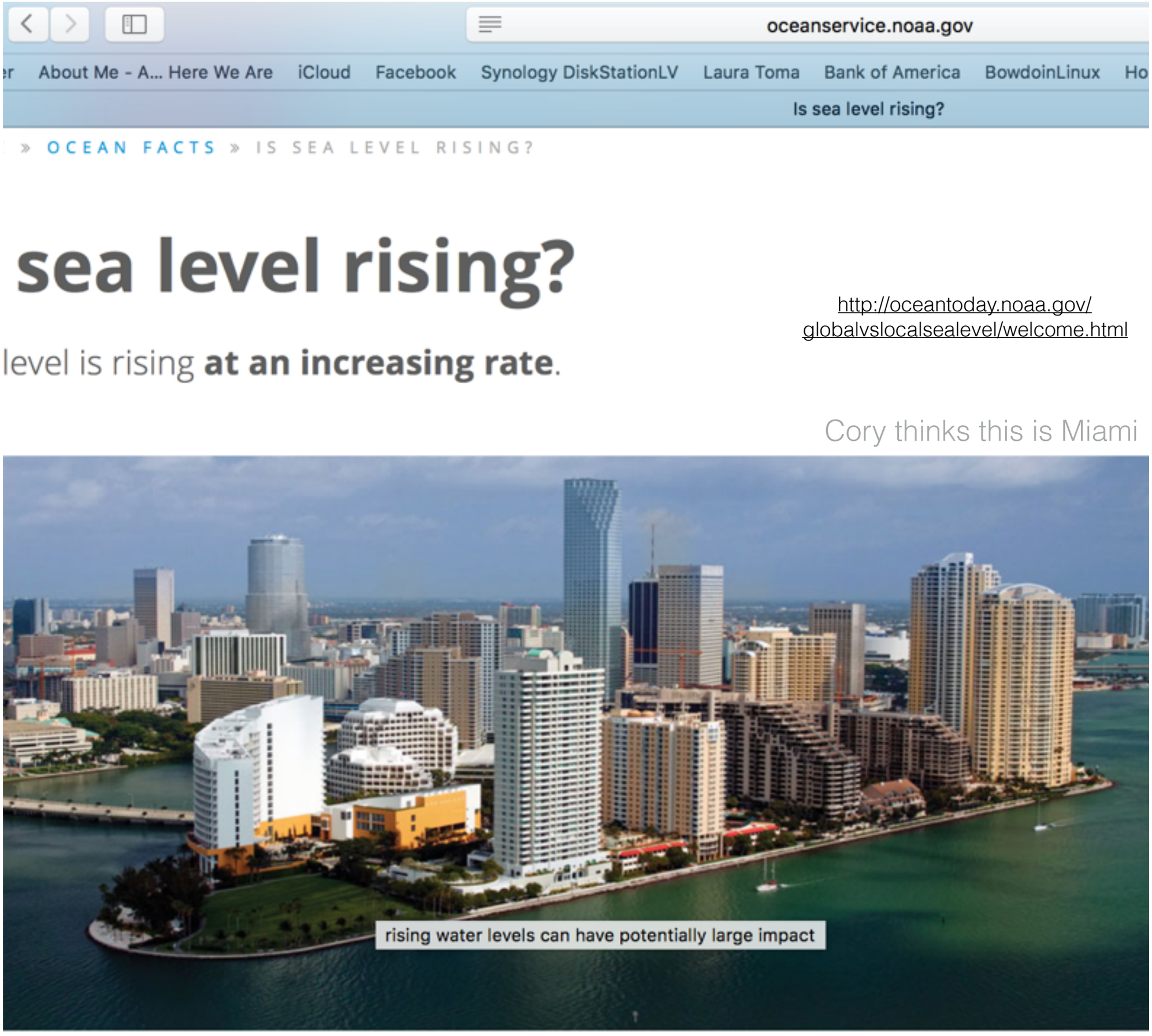
Full animation by

Herman Haverkort

University of Eindhoven

http://www.bowdoin.edu/~ltoma/teaching/cs350/fall14/Lectures/pfafstetter-short.pdf

Sea level rise (SLR)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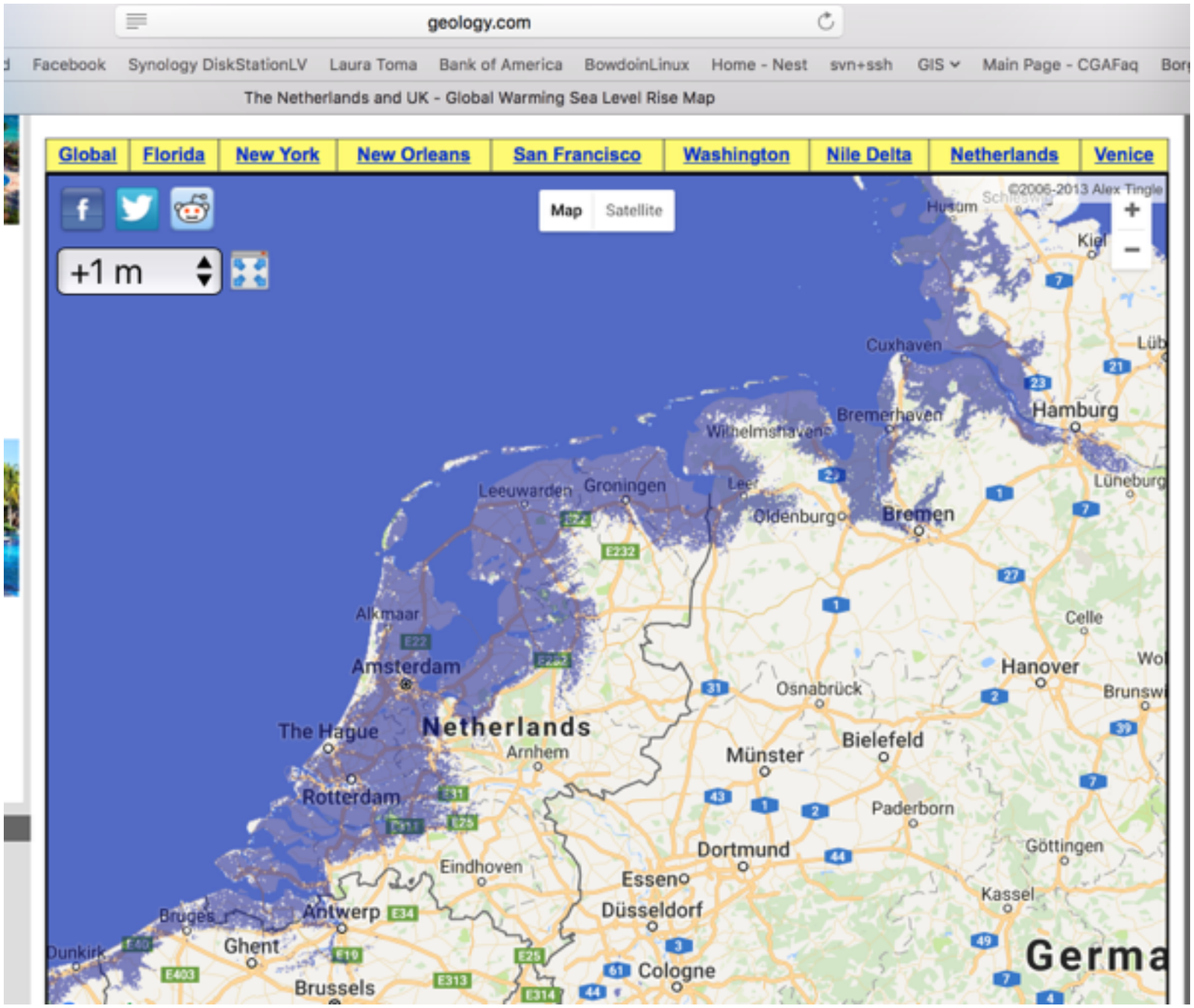
Laura Toma
Bank of America
BowdoinLinux
Is sea level rising?
» OCEAN FACTS » IS SEA LEVEL RISING?
sea level rising?
level is rising at an increasing rate.
http://oceantoday.noaa.gov/globalvslocalsealevel/welcome.html
Cory thinks this is Miami
rising water levels can have potentially large impact
n the majority of Americans living in coastal states, rising water levels can have large impacts.

Sea level rise (SLR)

How will Bowdoin's campus look when water level rises by 3 ft?

At what level of SLR it will be completely under water?



geology.com/sea-level-rise/

Sea level rise (SLR)

Input: a grid terrain which has a coast, i.e. is connected to the ocean.

- Model what happens when the water level in the ocean rises by x ft.

- And one step further:

  For a given point p in the terrain, at what SLR is p flooded?