CIE5401
GIS and Remote Sensing
Water Resources Management

Lecture 3: Watersheds and QGIS/GRASS
25 February 2018
Susan Steele-Dunne

TU Delft

Course Introduction: Schedule

Lecture Date	Lecture topic	Assignment Due Date
12 February	Introduction to GIS	19 February
19 February	Spatial Analysis in GIS	26 February
26 February	Watershed delineation	5 March
5 March	Visible RS	12 March
12 March	Thermal IR	19 March
19 March	Microwave remote sensing	26 March

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Course Introduction: Schedule

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26 February	**Watershed delineation**	**5 March**
5 March	Visible RS (Vera Hollander & NEO)	12 March
12 March	Thermal IR (eLeaf)	19 March
19 March	Microwave remote sensing (VanderSat)	26 March

Acknowledgements

- GRASS (http://grass.osgeo.org/)
- ESRI: (http://webhelp.esri.com/arcgisdesktop/9.2)
- HydroSHEDS, GMTED2010
- Prof. Nick van de Giesen

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Learning objectives

By the end of this lecture, you will be able to:

1) Explain what a watershed is
2) Explain how graph theory can be used to determine the watershed
3) Use QGIS and GRASS to calculate the watershed from a digital elevation model.

Lecture 3: Watersheds and ArcGIS

- Feedback Assignment 1
- Review Lecture 2/Assignment 2
- What is a watershed?
- Introduction to Graph Theory
- Determining watershed boundaries in QGIS/GRASS
- Group activity

Feedback Assignment 1

- Read the assignment carefully
  (e.g. data needed, what to calculate)
- Projections: Do not re-project data unless you have to.
- No need to clip raster layer with vector layer for zonal statistics
- Map production
  - Careful with color, overlaying color and texture
  - Include land/sea so that Volta does not look like an island?
  - Title should be bigger and clear
  - Edit labels in layer symbology to something human for legend

Review Lecture 2

Main topics discussed:

Projections

Analysis in QGIS for vector and raster data

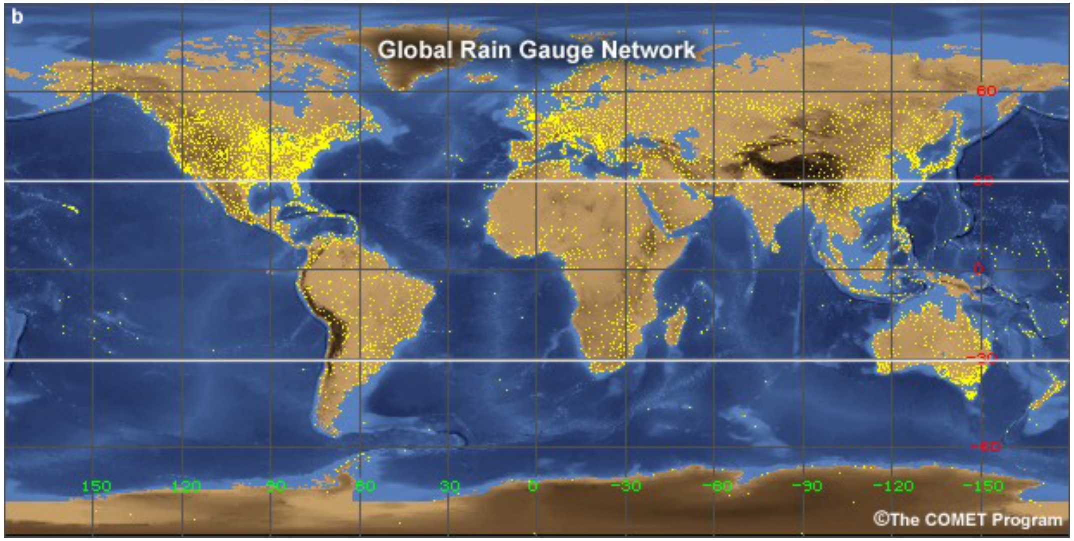
Overlay analysis

…. Any questions?

Review Assignment 2

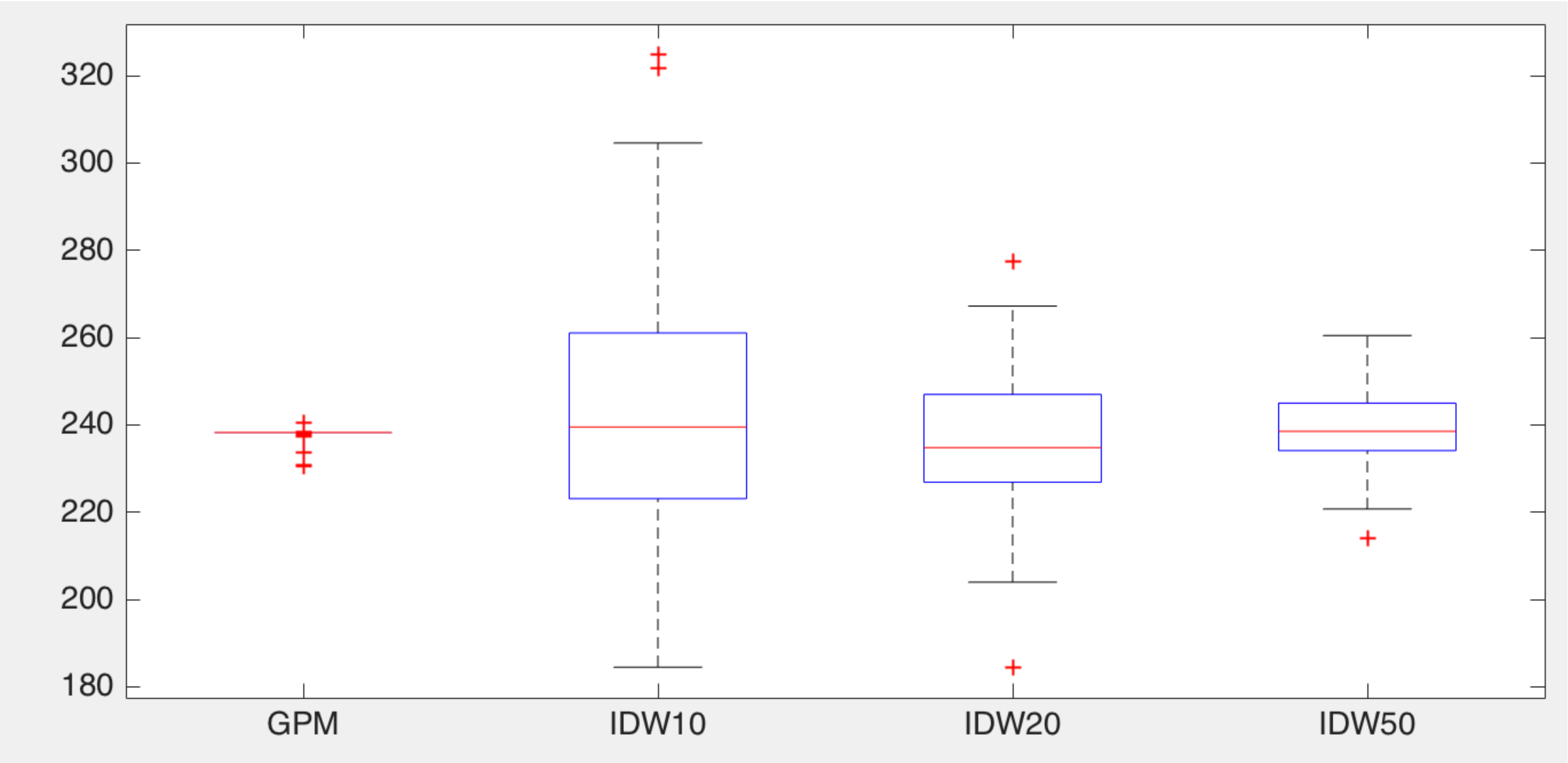
Nice movie:

http://pmm.nasa.gov/education/videos/our-wet-wide-world-gpm-overview



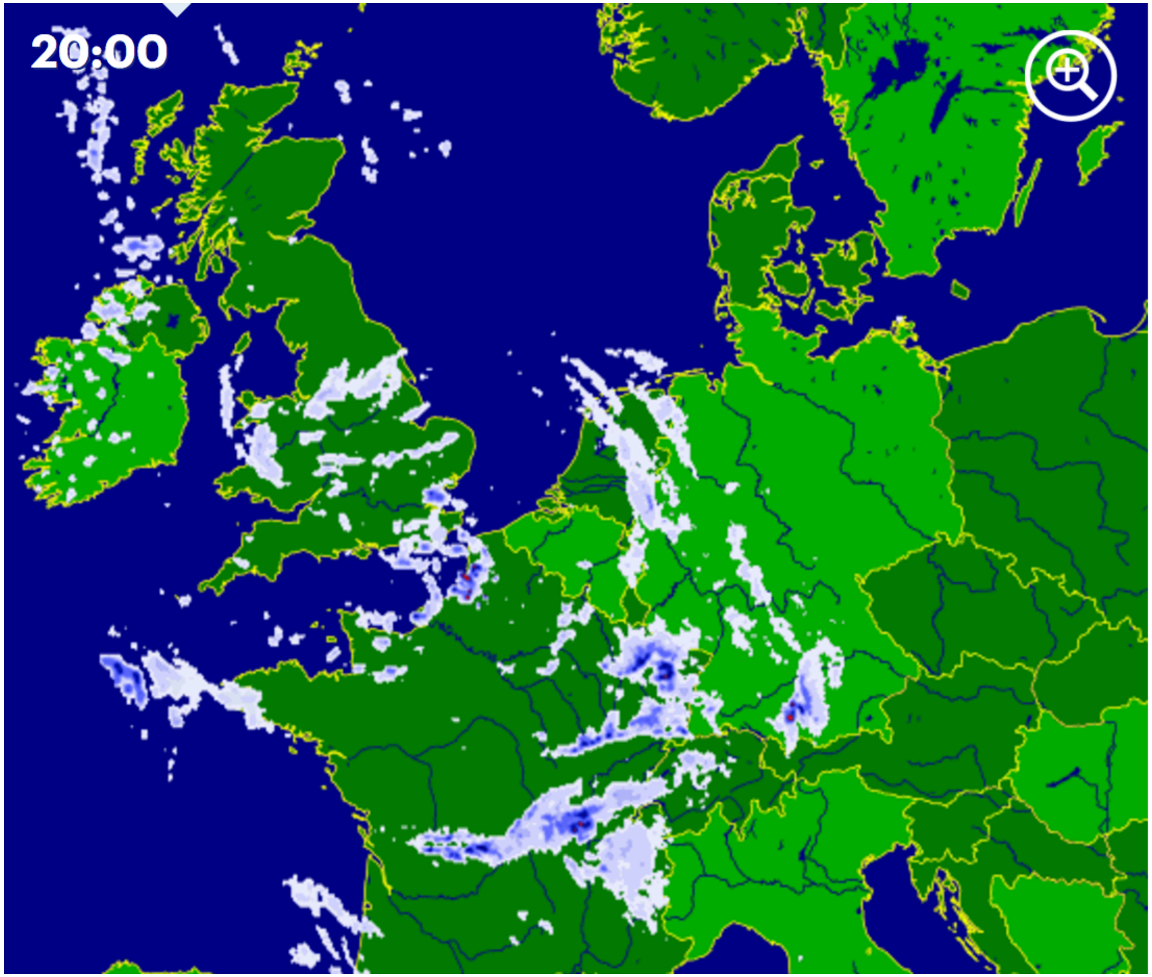
Global Rain Gauge Network ©The COMET Program
http://www.goes-r.gov/users/comet/tropical/textbook_2nd_edition/media/graphics/global_gauges_2.jpg

Review Assignment 2



	Areal mean monthly precipitation (mm)			
	GPM	IDW - 10 points	IDW - 20 points	IDW - 50 points
Average	237.97	242.79	236.81	$\boxed{238.54}$
Standard deviation	1.4274	27.7536	16.0254	8.4429

Review Assignment 2



https://www.buienradar.nl/wereldwijd/europa/buienradar

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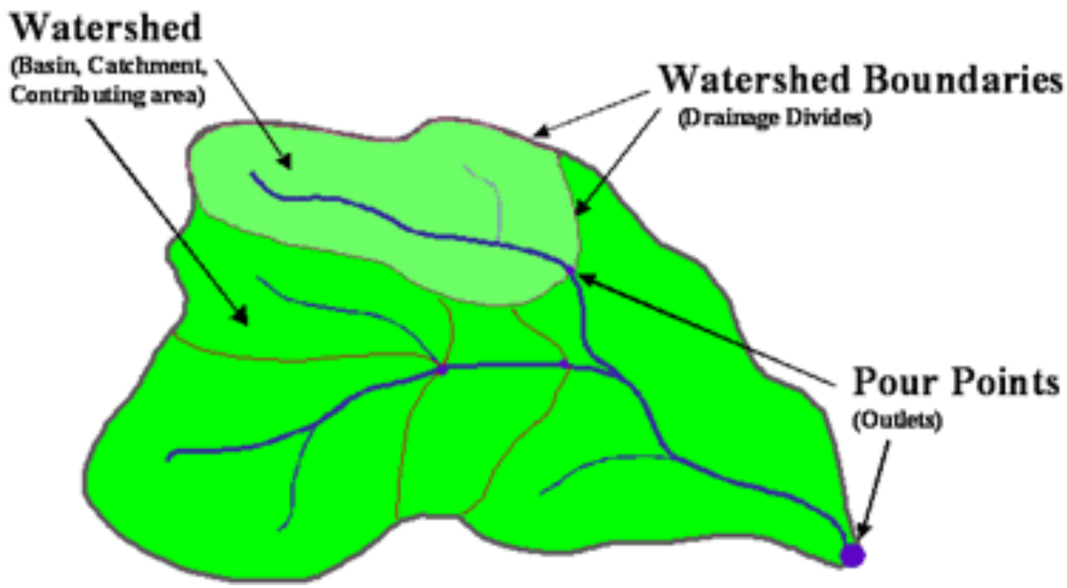
Lecture 3: Watersheds and ArcGIS

- Feedback Assignment 1
- Review Lecture 2/Assignment 2
- **What is a watershed?**
- Introduction to Graph Theory
- Determining watershed boundaries in QGIS/GRASS
- Group Activity

What is a watershed?

The area from which water drains to a common outlet.



A watershed is also known as a drainage basin, basin, catchment, or contributing area.

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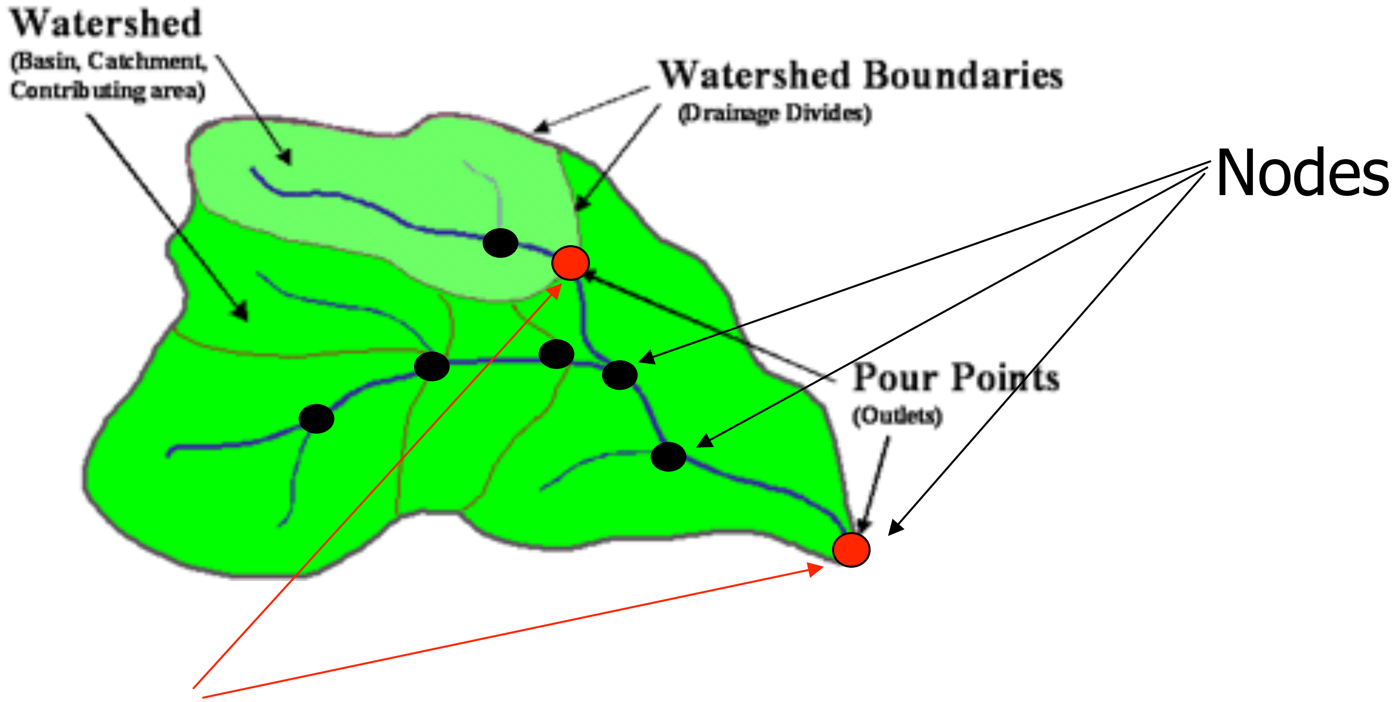
http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Understanding_drainage_systems

What is a watershed?

A stream network is made up of nodes and links

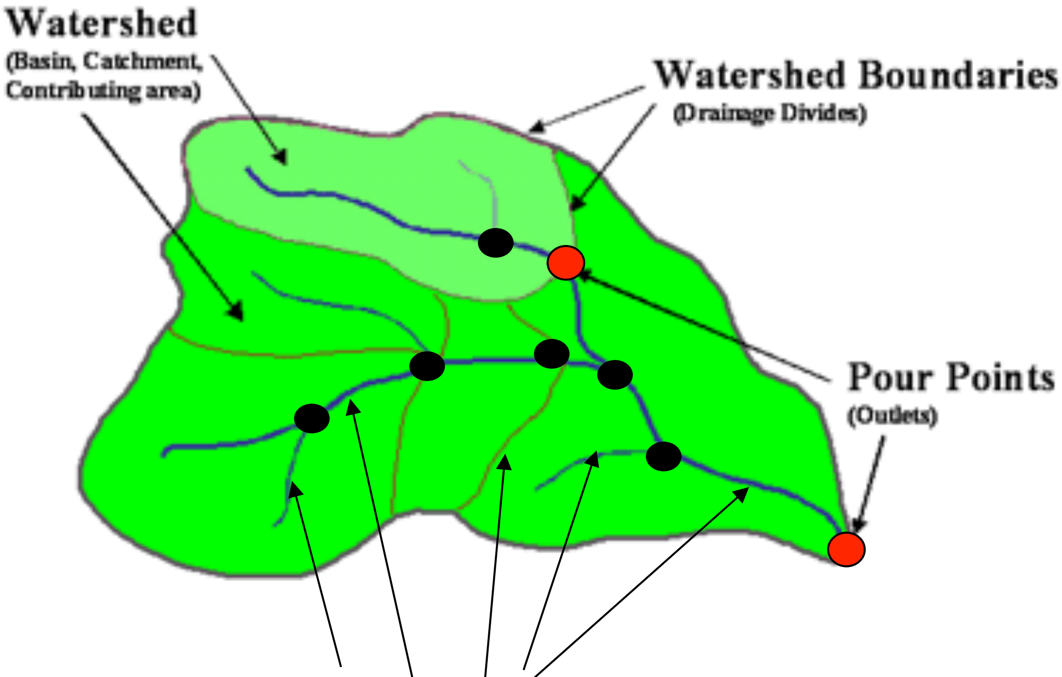


Pour point = outlet

http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Understanding_drainage_systems

What is a watershed?

A stream network is made up of nodes and links



Stream channel = “link”

http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Understanding_drainage_systems

Lecture 3: Watersheds and ArcGIS

- Feedback Assignment 1
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- What is a watershed?
- **Introduction to Graph Theory**
- Determining watershed boundaries in QGIS/GRASS
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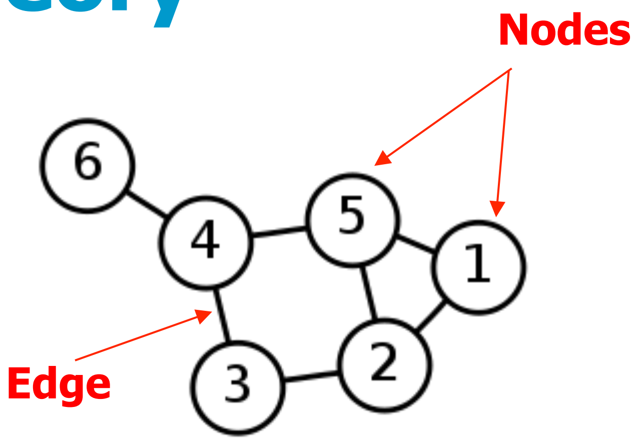
Introduction to Graph theory

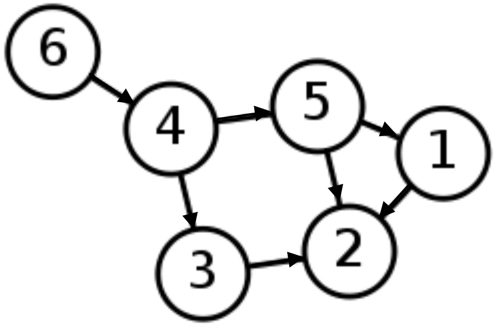
Graph theory = study of graphs

Graph = collection of ***nodes*** (aka vertices)
and ***edges*** (links).

Graphs are used to model pairwise relations between objects



Undirected graph

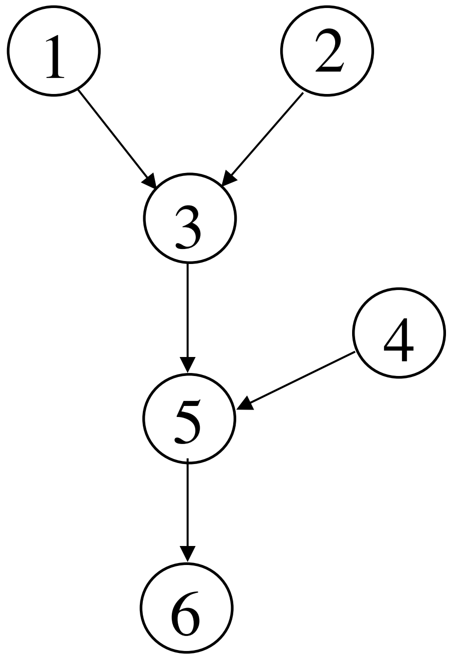


Directed graph aka network

Introduction to Graph theory

Adjacency Matrix

Which nodes are adjacent to which other nodes

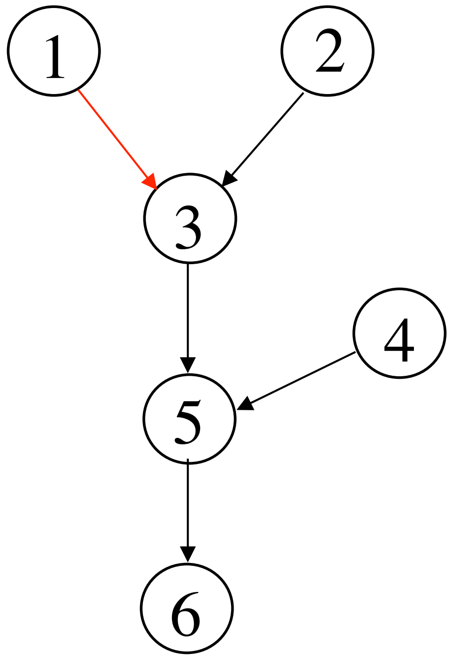


- n x n matrix
- If node i drains into node j, set A(i,j)=1.
- Otherwise, set to zero

Drainage patterns

Adjacency Matrix

Which nodes are adjacent to which other nodes:

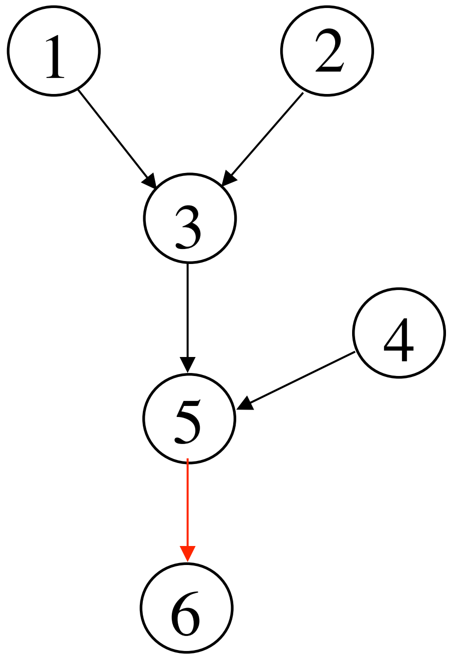


$$A = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Drainage patterns

Adjacency Matrix

Which nodes are adjacent to which other nodes:



$$A = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

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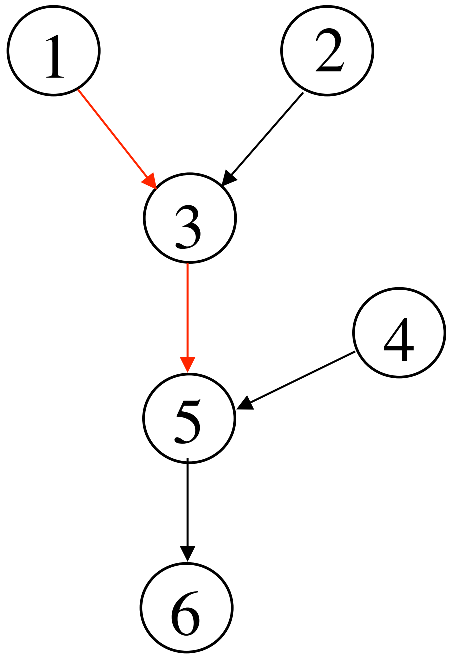
Drainage patterns

Adjacency Matrix²

Which nodes are connected by two steps:

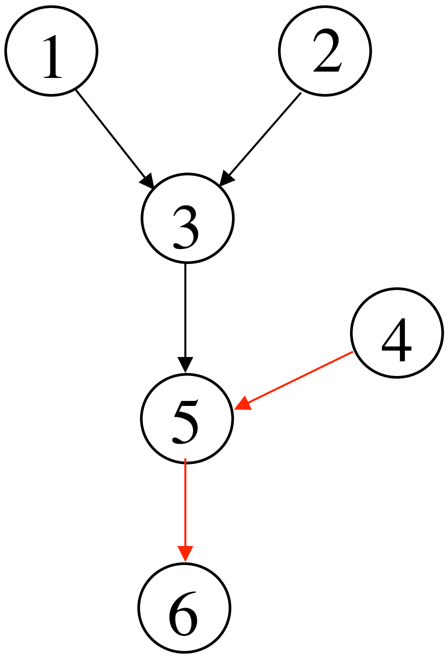


$$A^2 = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Drainage patterns

Adjacency Matrix²

Which nodes are connected by two steps:

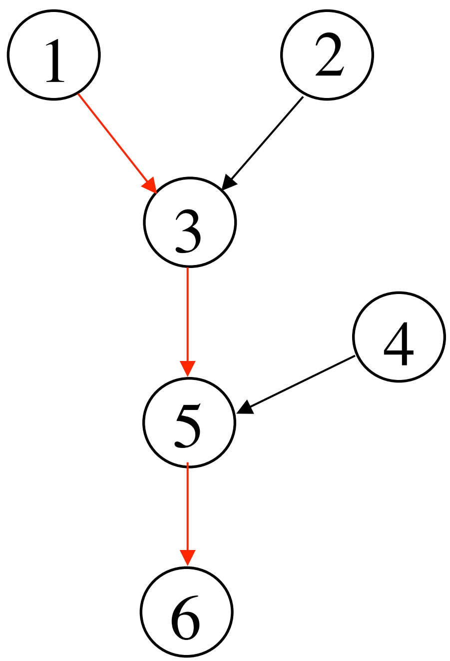


$$A^2 = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Drainage patterns

Adjacency Matrix³

Which nodes are connected by three steps:



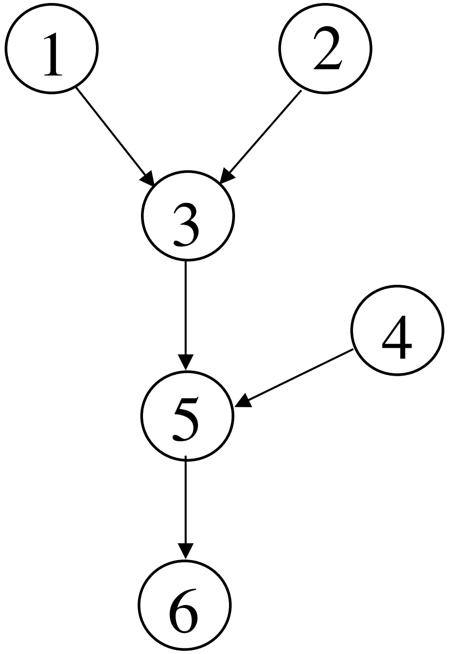
$$A^3 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Drainage patterns

Suppose we add those together:

$$\Sigma = A + A^2 + A^3$$

$$\Sigma = \begin{bmatrix} 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$



What do the rows tell you?

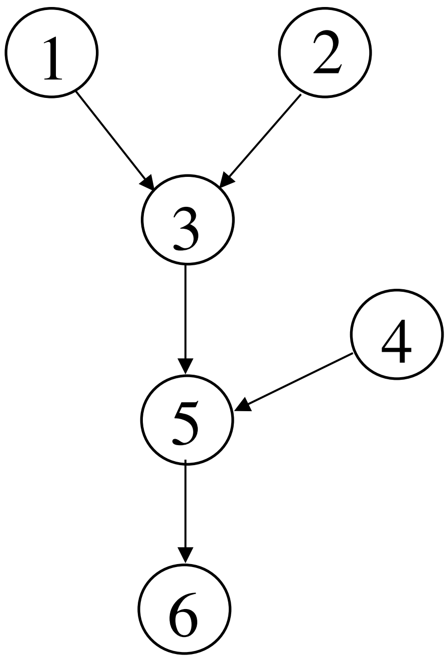
Drainage patterns

"Water availability matrix":

$$\Sigma = A + A^2 + A^3$$

$$\Sigma = \begin{bmatrix} 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Rows show "downstream" nodes!



Which nodes are downstream from node 2? … Nodes 3, 5 and 6.

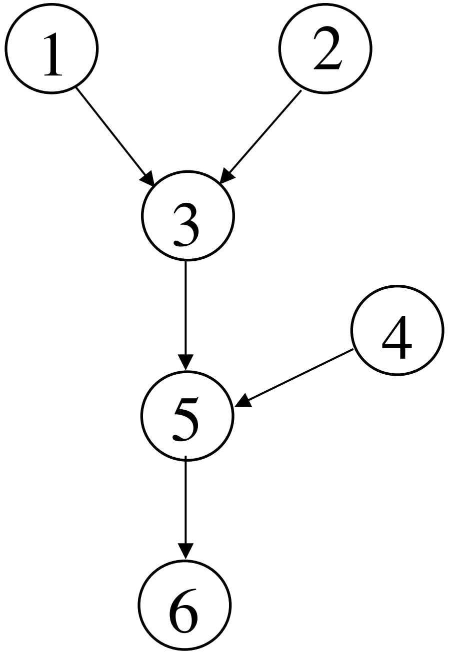
Drainage patterns

"Water availability matrix":

$$\Sigma = A + A^2 + A^3$$

$$\Sigma = \begin{bmatrix} 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

What do the columns tell you?



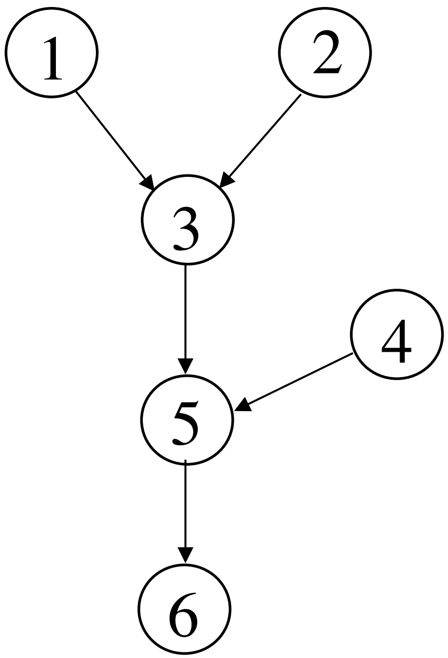
Drainage patterns

"Water availability matrix":

$$\Sigma = A + A^2 + A^3$$

Columns show "upstream" nodes!

$$\Sigma = \begin{bmatrix} 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$



Which nodes are upstream from node 3? Nodes 1 and 2

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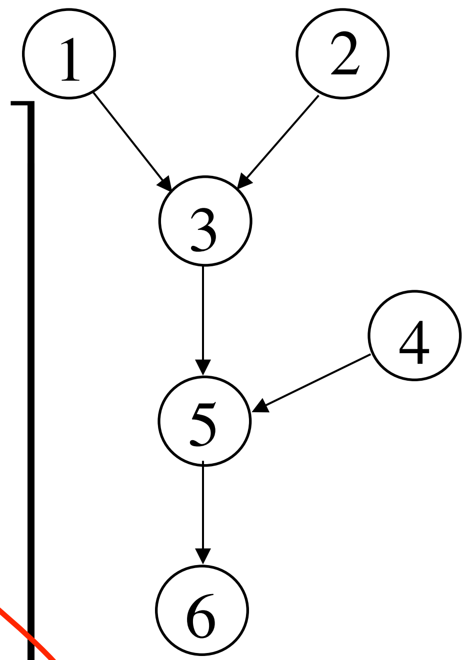
Drainage patterns

"Watershed matrix":

$$\Sigma + I = A + A^2 + A^3 + I$$

$$\Sigma + I = \begin{bmatrix} 1 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$



We want to include the "zero-th" step, i.e. that a node drains itself
=> We get the real watershed matrix!

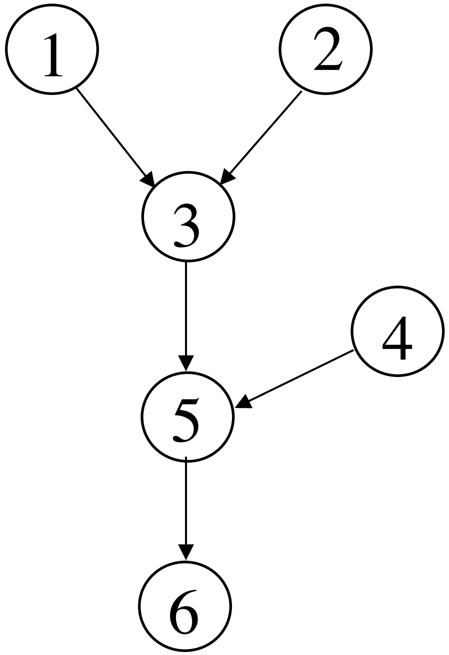
Drainage patterns

"Watershed matrix":

$$\Sigma + I = A + A^2 + A^3 + I$$

$$\Sigma + I = \begin{bmatrix} 1 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\boxed{1 \quad 1 \quad 3 \quad 1 \quad 5 \quad 6}$$



Summing the columns gives the "drainage area" or watershed size for each pixel

Drainage patterns

Adjacency/Watershed Matrix

Interesting property:

$$\underbrace{I + A + A^2 + A^3}_{\text{All the information needed to describe watershed}} = (I - A)^{-1}$$

All the information needed to describe watershed

Adjacency Matrix

i.e. "neighbourhood information"

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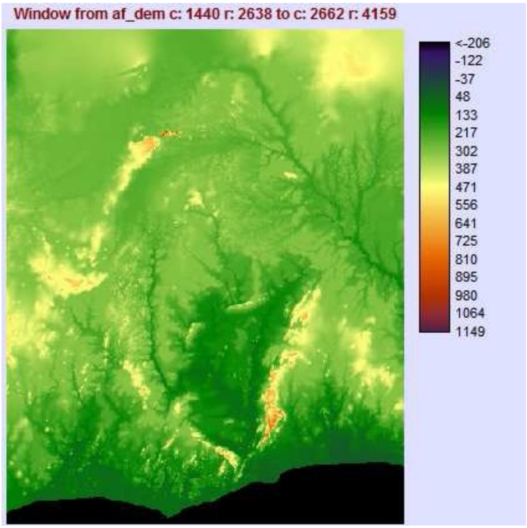
Drainage patterns

Adjacency/Watershed Matrix

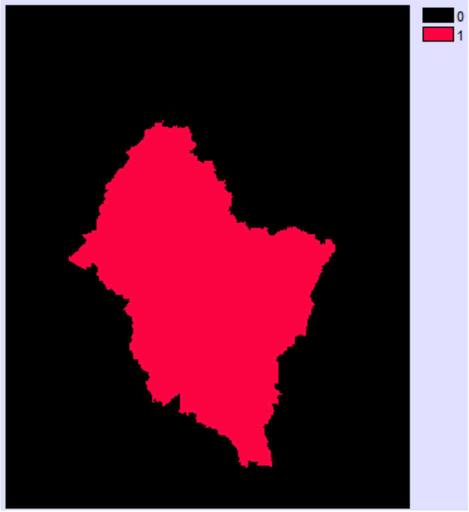
Interesting property:

$$I + A + A^2 + A^3 = (I - A)^{-1}$$

Used in GIS software!



GTOPO30 for the Volta Basin and environs



Watershed of the Akosombo dam.

Coffee

Drainage patterns

Flow accumulation

So far, we assumed all pixels generated same amount of input.

In practice run-off from pixels is variable

Build a row vector Q containing the run-off produced at each node:

$$\Sigma + I = A + A^2 + A^3 + I$$

$$\Sigma + I = \begin{bmatrix} 1 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$Q = \begin{bmatrix} 3.2 & 2.3 & 0 & 0 & 0 & 0 \end{bmatrix}$$

e.g node 1 generates 3.2 units of water, node 2 generates 2.3 units

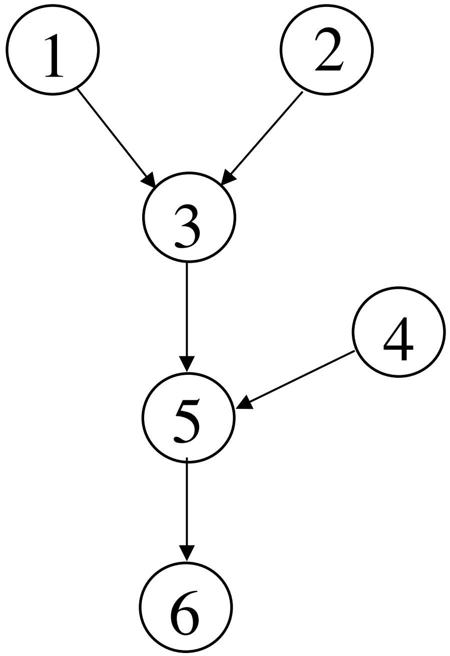
Drainage patterns

Flow accumulation

Build a row vector Q containing the run-off produced at each node:

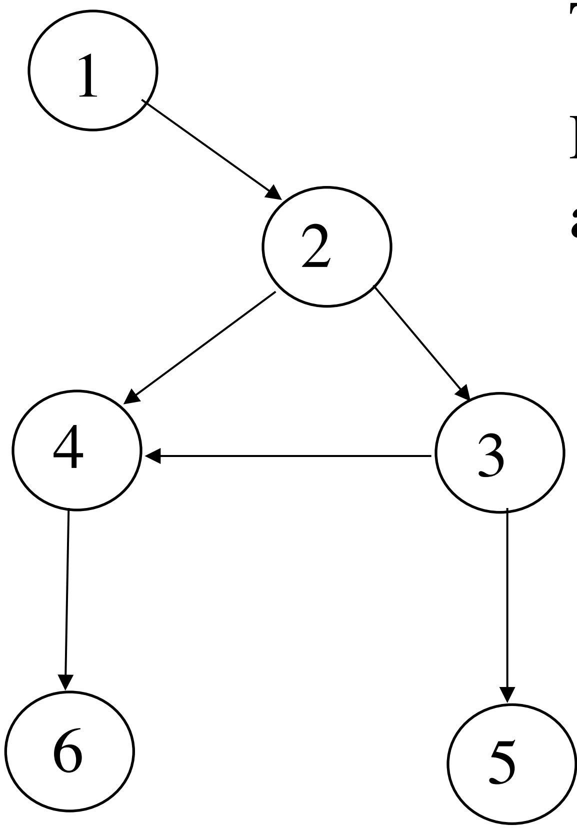
$$Q = \begin{bmatrix} 3.2 & 2.3 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$Q * (\Sigma + I) = \begin{bmatrix} 3.2 & 2.3 & 5.5 & 0 & 5.5 & 5.5 \end{bmatrix}$$



This gives the total flow accumulated in each node

Water use along river network

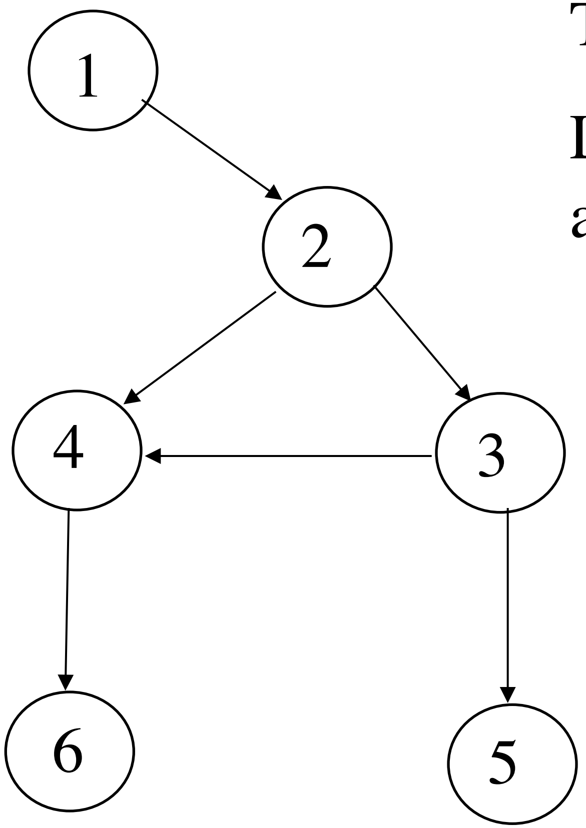


This case will be a bit more complicated.

Let’s start by filling in the regular adjacency matrix ….

$W =$

Water use along river network

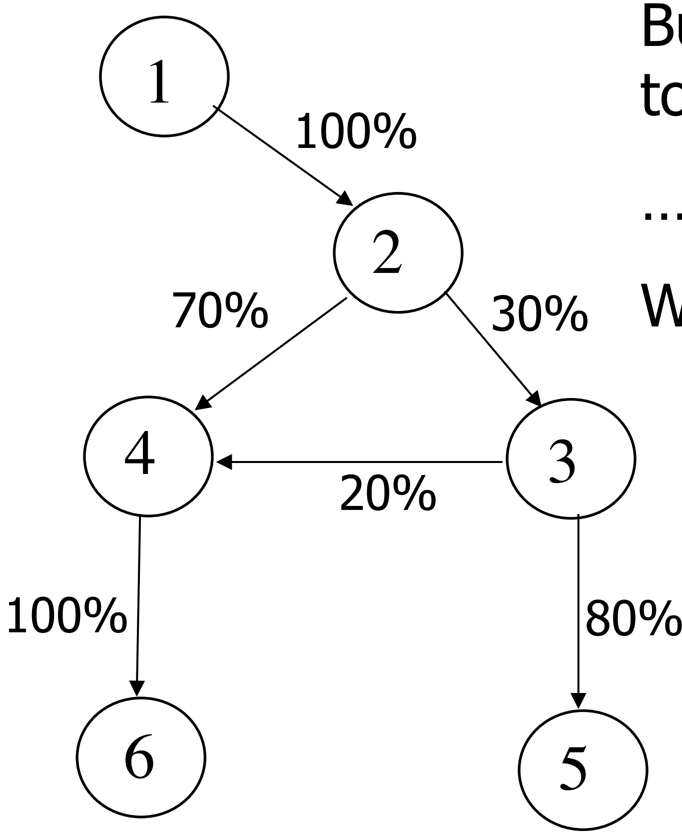


This case will be a bit more complicated.

Let's start by filling in the regular adjacency matrix ….

$$W = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Water use along river network



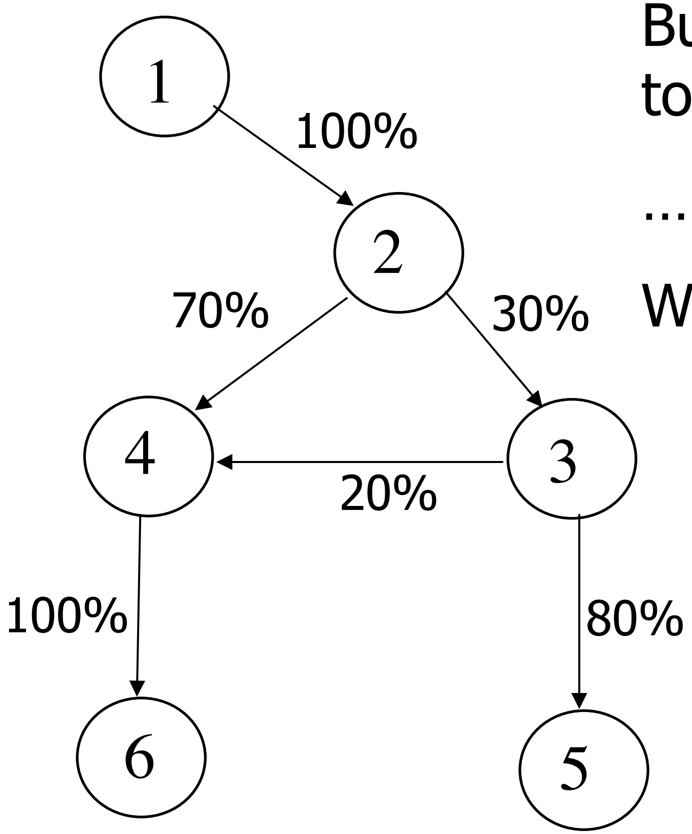
But how can all the water go from node 2 to both nodes 3 and 4?

… It doesn't!

What happens to our adjacency matrix?

$W =$

Water use along river network



But how can all the water go from node 2 to both nodes 3 and 4?

… It doesn't!

What happens to our adjacency matrix?

$$W = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.3 & 0.7 & 0 & 0 \\ 0 & 0 & 0 & 0.2 & 0.8 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

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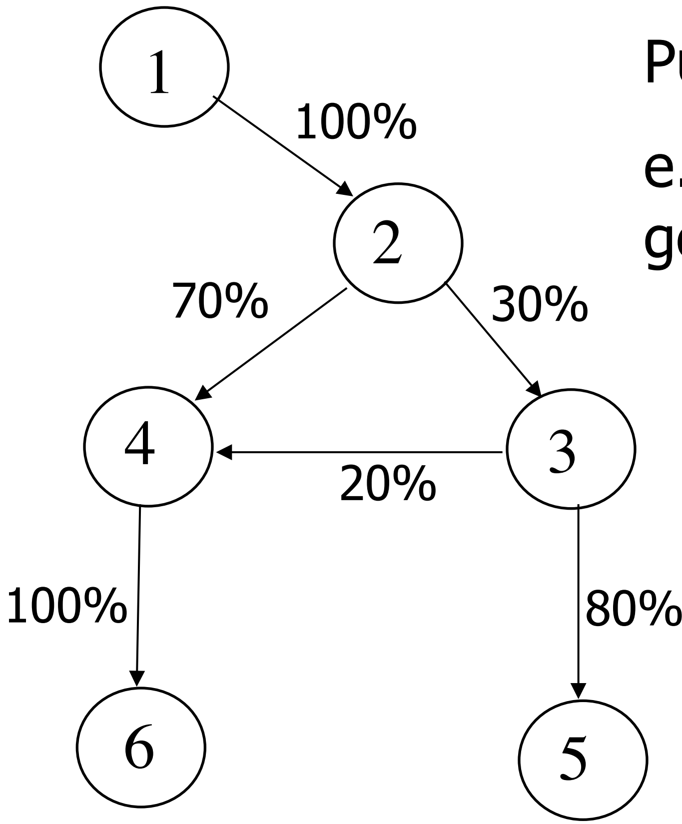
Water use along river network

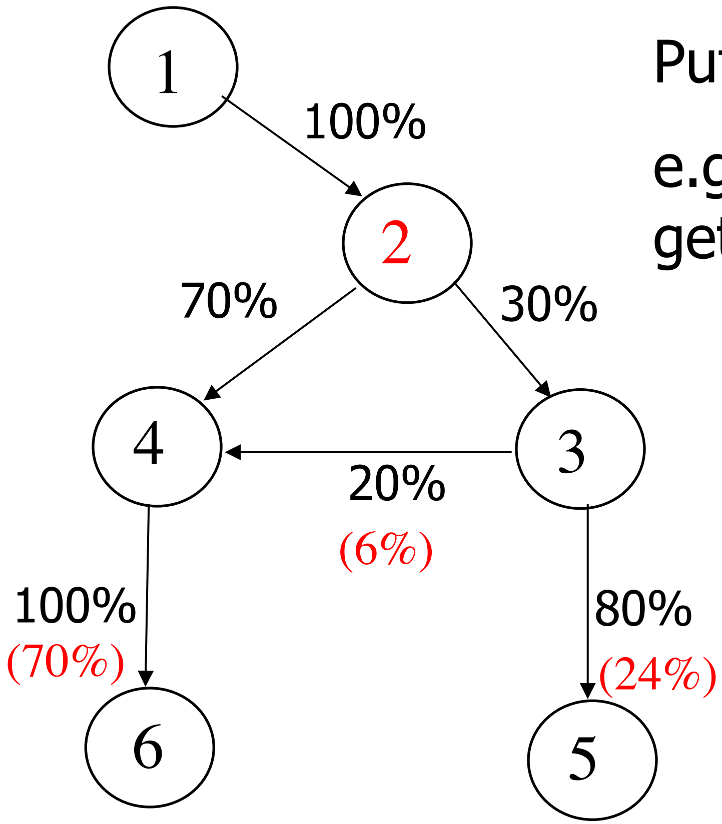


Put W into Matlab/excel and calculate W^2:

e.g. Where does the water from node 2 get to in two steps?

$W^2 =$

Water use along river network

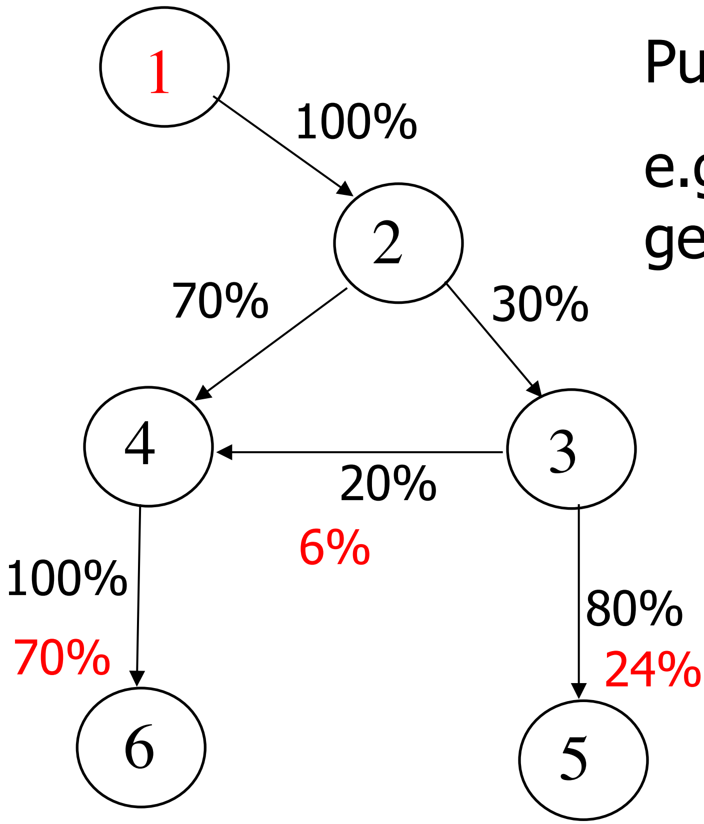


Put W into Matlab/excel and calculate W^2:

e.g. Where does the water from node 2 get to in two steps?

$$W^2 = \begin{bmatrix} 0 & 0 & 0.3 & 0.7 & 0 & 0 \\ 0 & 0 & 0 & 0.06 & 0.24 & 0.7 \\ 0 & 0 & 0 & 0 & 0 & 0.2 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Water use along river network



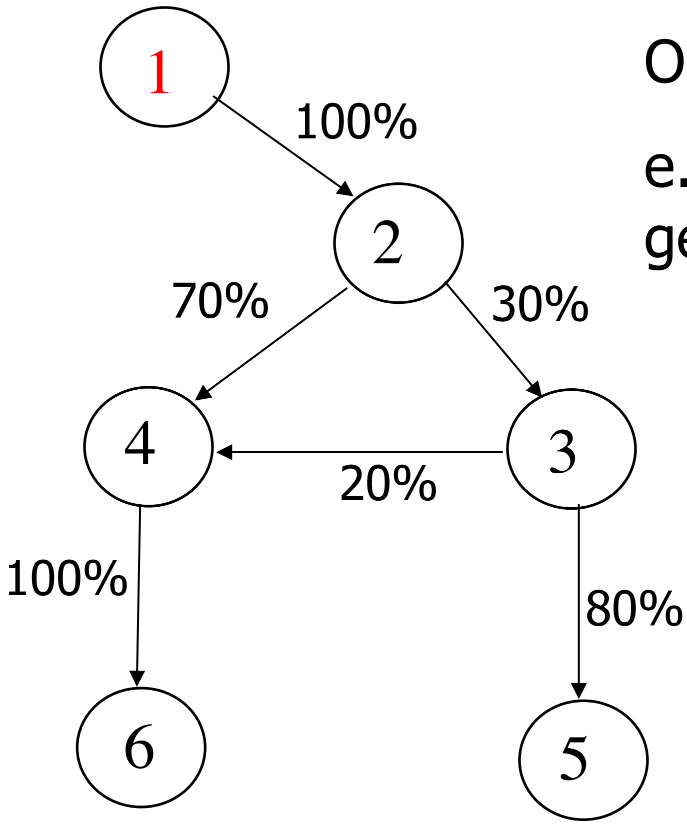
Put W into Matlab/excel and calculate W^3:

e.g. Where does the water from node 1 get to in three steps?

$$W^3 = \begin{bmatrix} 0 & 0 & 0 & 0.06 & 0.24 & 0.7 \\ 0 & 0 & 0 & 0 & 0 & 0.06 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

After 3 steps, 94% of the water from (1) has made it to an outlet, but 6% is just getting to node 4!

Water use along river network

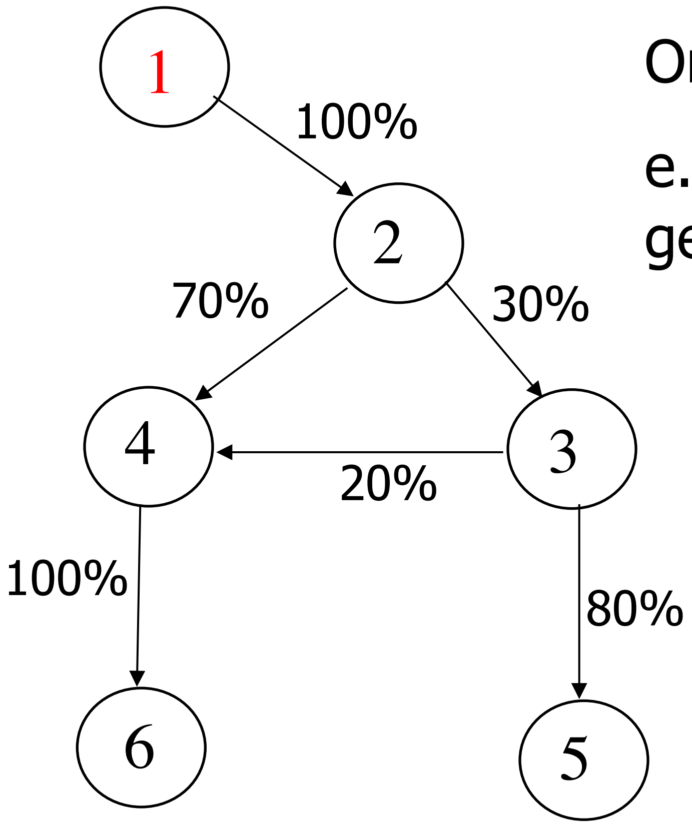


One last time step, let's calculate W^4:

e.g. Where does the water from node 1 get to in four steps?

$W^4 =$

Water use along river network

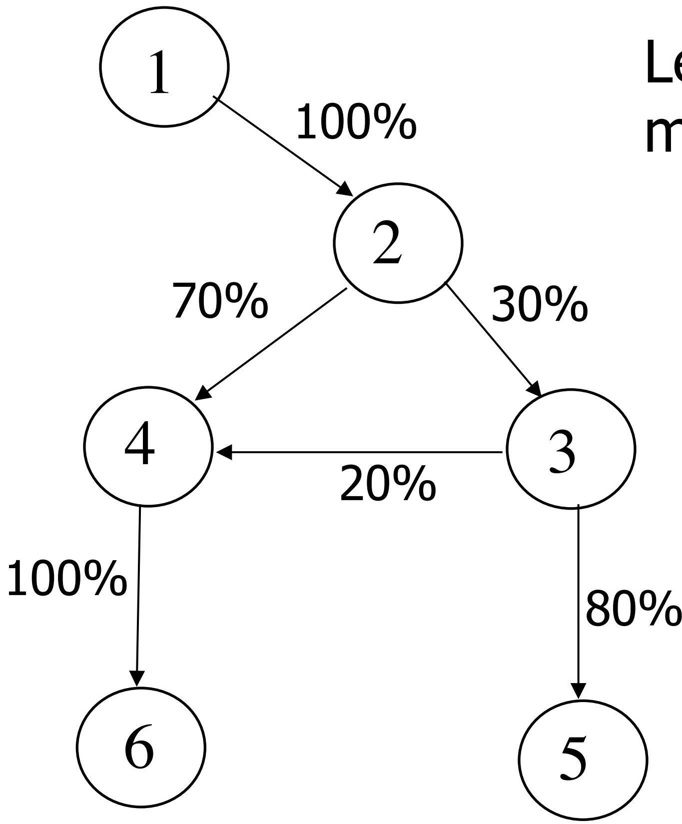


One last time step, let's calculate W^4:

e.g. Where does the water from node 1 get to in four steps?

$$W^4 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0.06 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Water use along river network

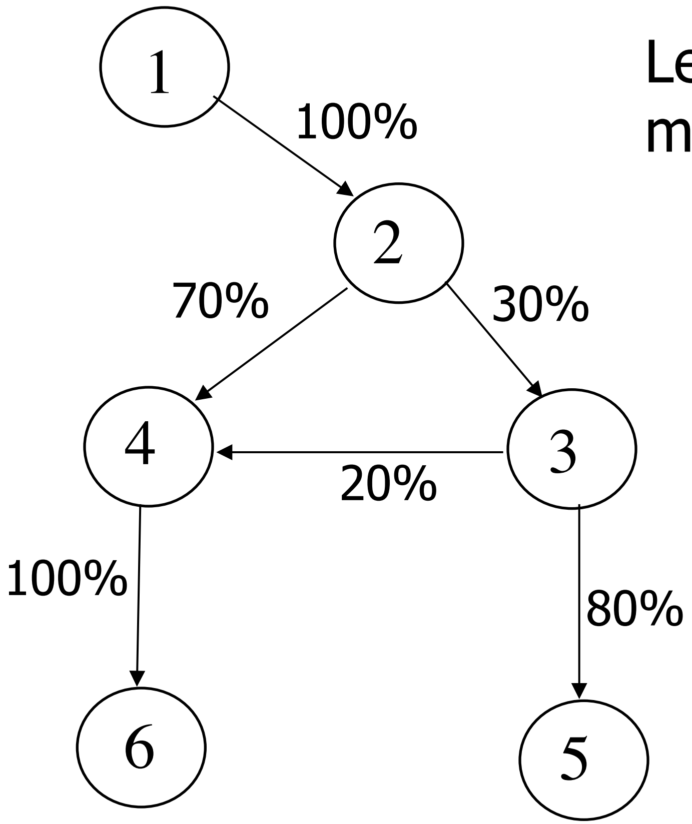


Let's calculate the water availability matrix, Ω, for this case:

$$\Omega = W + W^2 + W^3 + W^4$$

$\Omega =$ 

Water use along river network



Let's calculate the water availability matrix, Ω, for this case:

$$\Omega = W + W^2 + W^3 + W^4$$

$$\Omega = \begin{bmatrix} 0 & 1.0 & 0.3 & 0.76 & 0.24 & 0.76 \\ 0 & 0 & 0.3 & 0.76 & 0.24 & 0.76 \\ 0 & 0 & 0 & 0.2 & 0.8 & 0.2 \\ 0 & 0 & 0 & 0 & 0 & 1.0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

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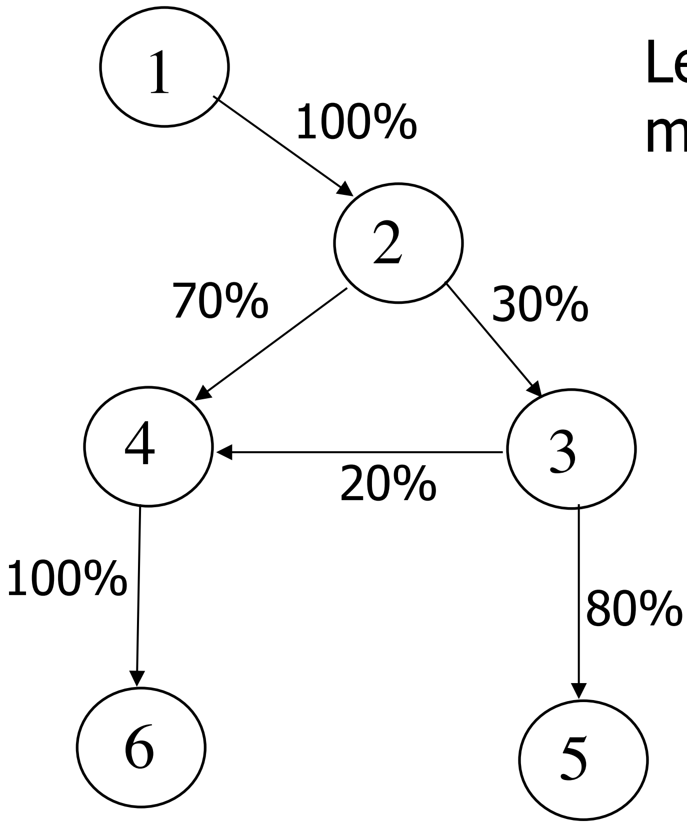
Water use along river network

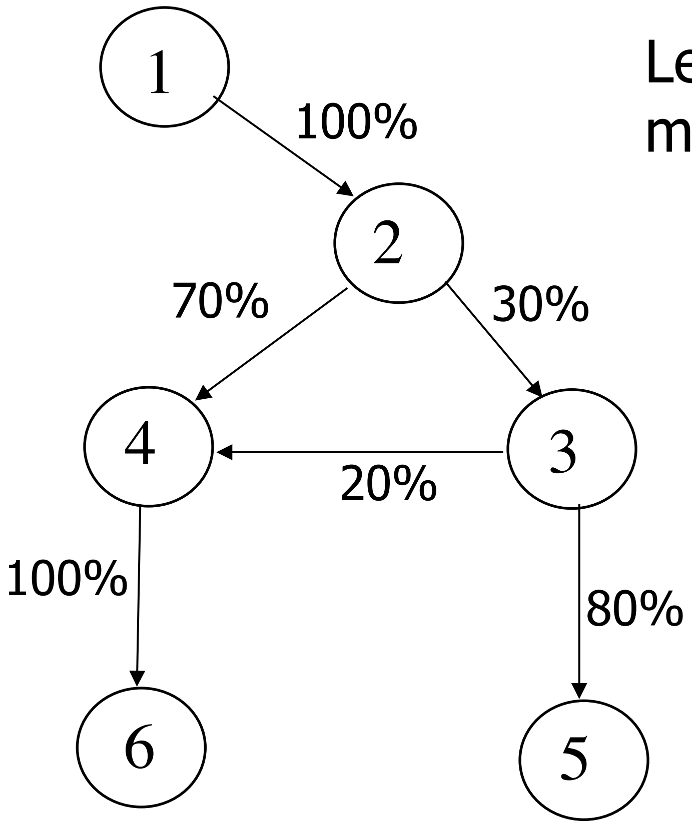


Let’s calculate the water availability matrix, Ω, for this case:

$$\Omega = W + W^2 + W^3 + W^4$$

$$\Omega = \begin{bmatrix} 0 & 1.0 & 0.3 & 0.76 & 0.24 & 0.76 \\ 0 & 0 & 0.3 & 0.76 & 0.24 & 0.76 \\ 0 & 0 & 0 & 0.2 & 0.8 & 0.2 \\ 0 & 0 & 0 & 0 & 0 & 1.0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Water use along river network



Let's calculate the water availability matrix, Ω, for this case:

$$\Omega = W + W^2 + W^3 + W^4$$

$$\Omega = \begin{bmatrix} 0 & 1.0 & 0.3 & 0.76 & 0.24 & 0.76 \\ \boxed{0 & 0 & 0.3 & 0.76 & 0.24 & 0.76} \\ 0 & 0 & 0 & 0.2 & 0.8 & 0.2 \\ 0 & 0 & 0 & 0 & 0 & 1.0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

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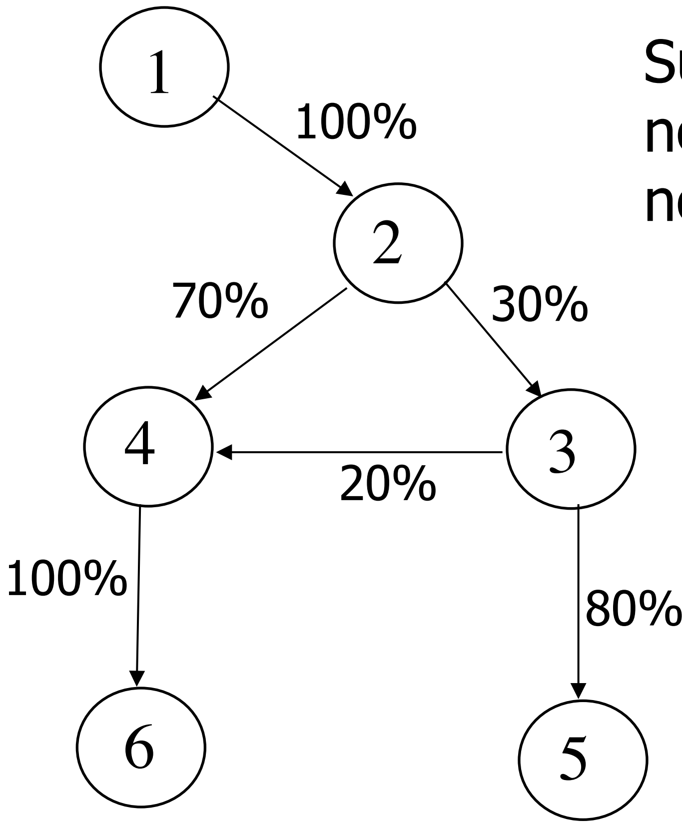
Water use along river network



Suppose we inject 200 units of water at node 1. How much will we see at each node?

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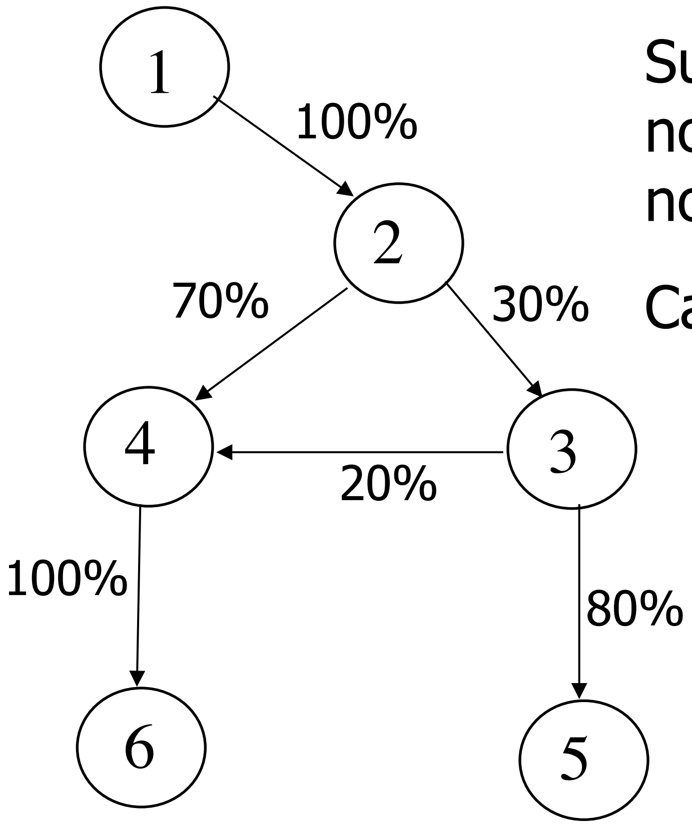
Water use along river network



Suppose we inject 200 units of water at node 1. How much will we see at each node?

Calculate P*Ω where P=[200 0 0 0 0 0]

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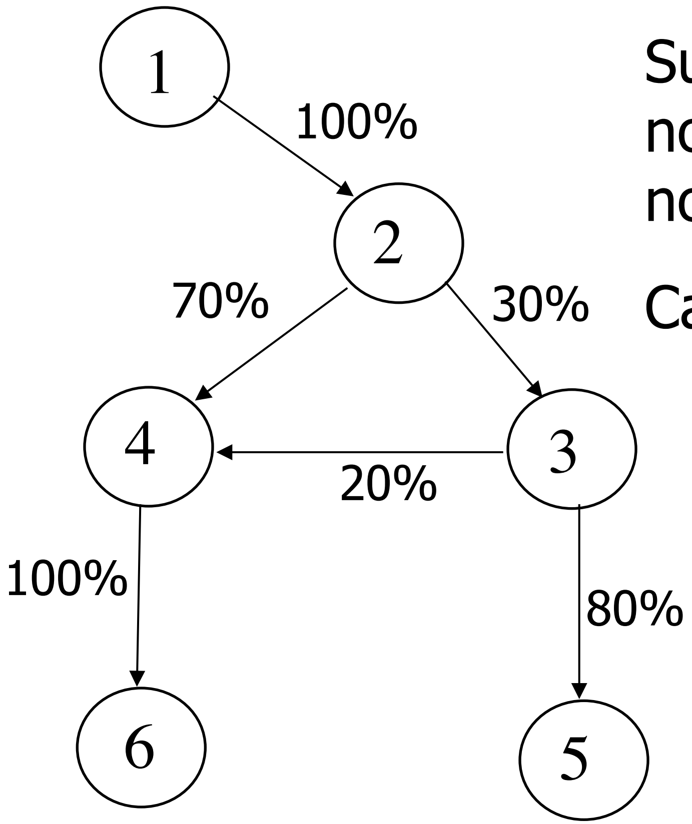
Water use along river network

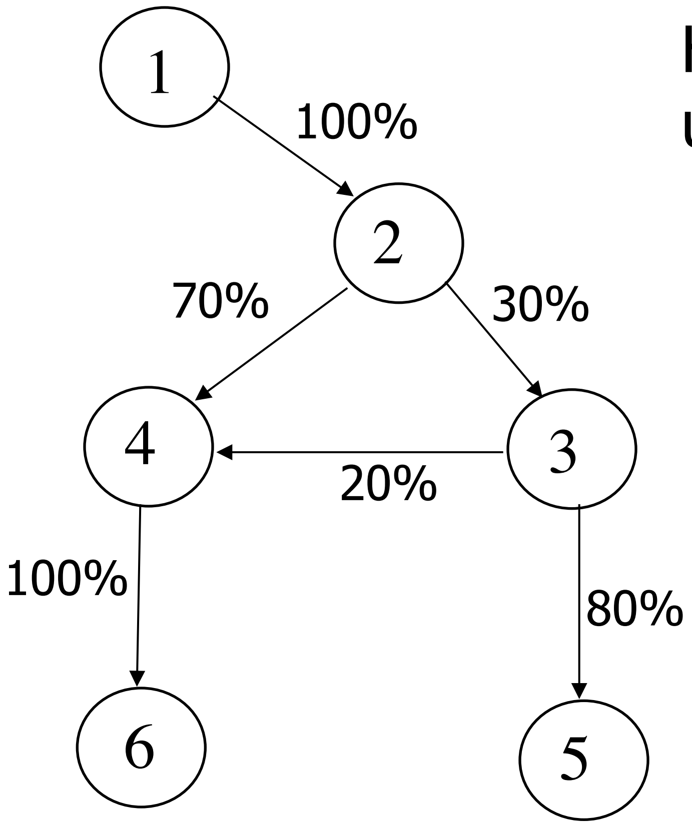


Suppose we inject 200 units of water at node 1. How much will we see at each node?

Calculate Q=P*Ω where P=[200 0 0 0 0 0]

Q=[0 200 60 152 48 152]

Water use along river network



How do you account for water being used at a node?

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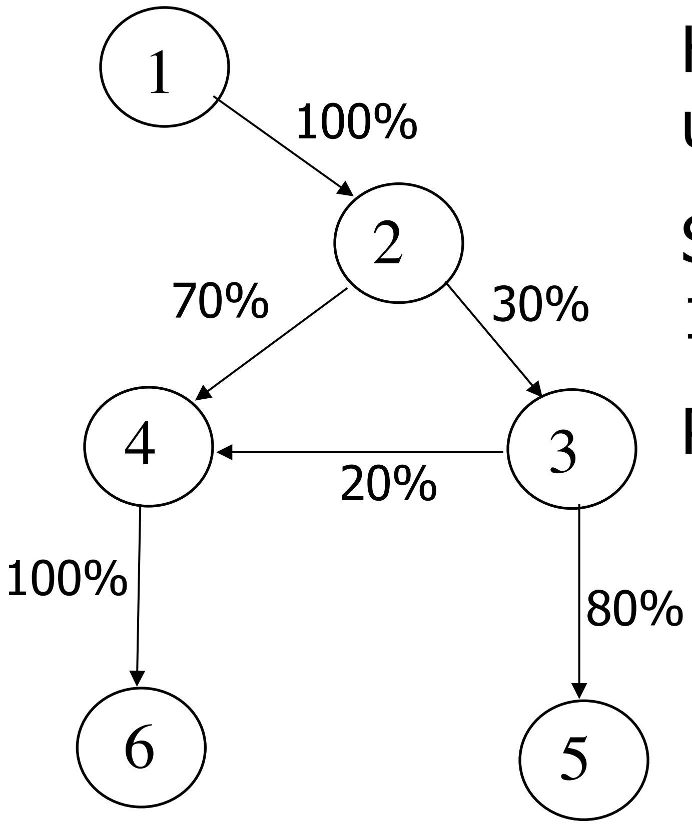
Water use along river network

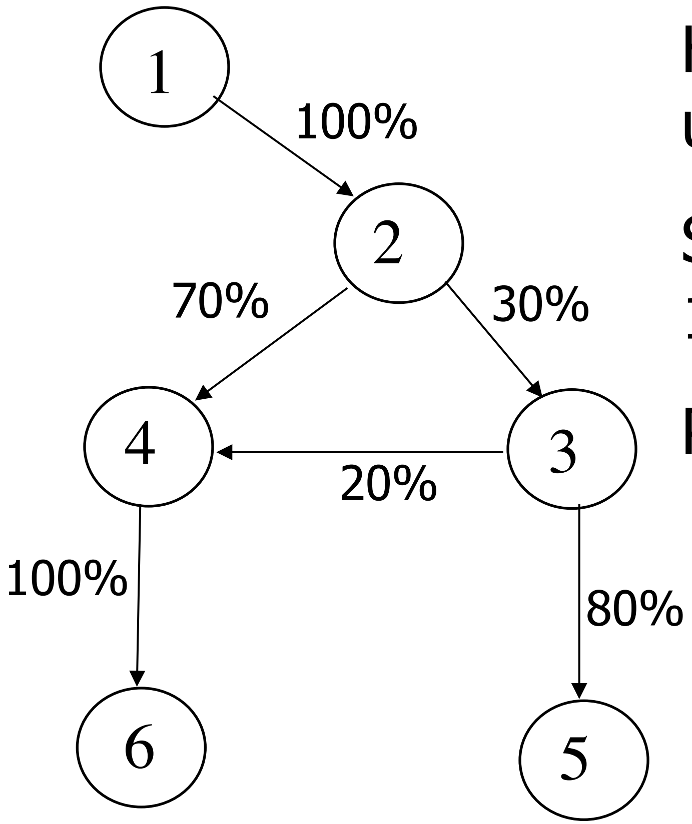


How do you account for water being used at a node?

Suppose we inject 200 units at node 1, but use 100 units at node 2:

P=?

Water use along river network

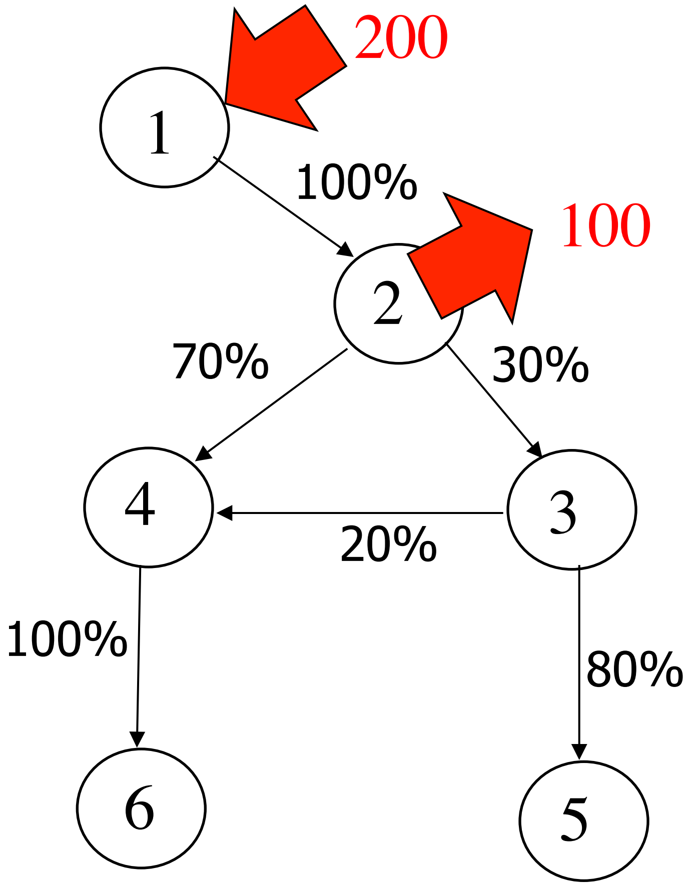


How do you account for water being used at a node?

Suppose we inject 200 units at node 1, but use 100 units at node 2:

P=[200 -100 0 0 0 0]

Water use along river network

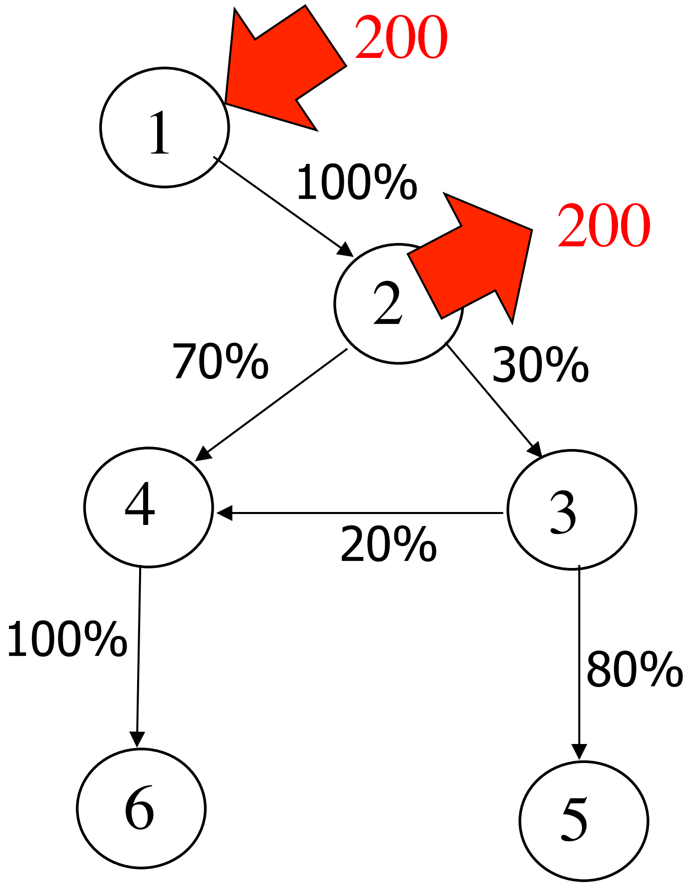


P=[200 -100 0 0 0 0]

Q=P*Ω

Q=[0   200   30   76   24   76]

Water use along river network

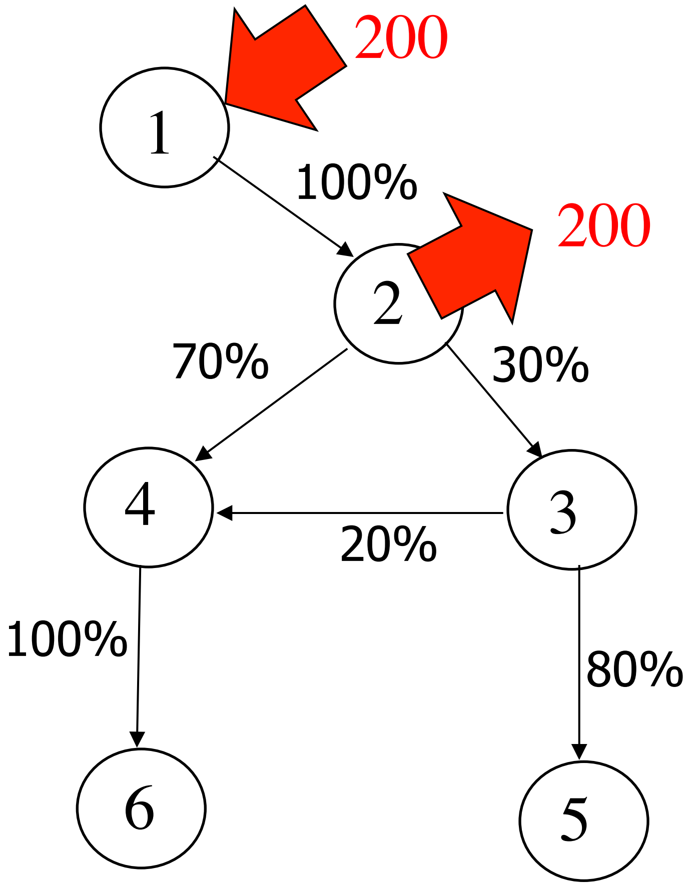


P=[200 -200 0 0 0 0]

Q=P*Ω

Q=??

Water use along river network



P=[200 -200 0 0 0 0]

$Q=P*\Omega$

Q=[0   200   0   0   0   0]

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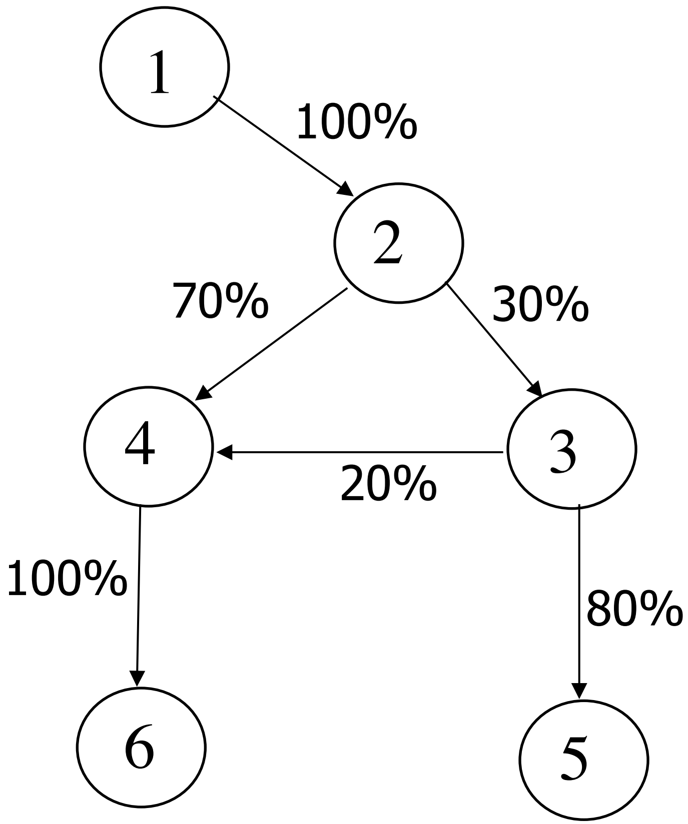
Water use along river network



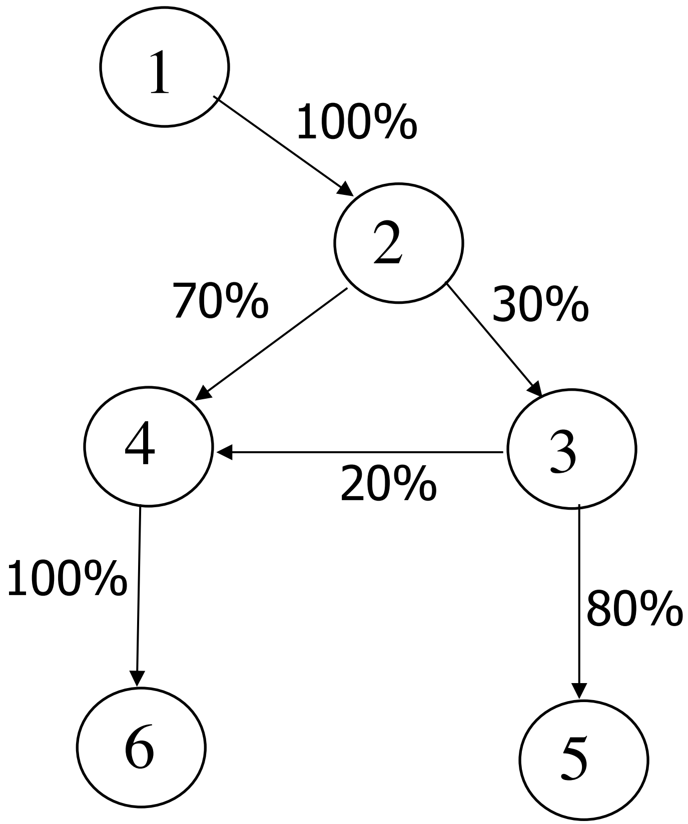
What if you demand too much water??

P=[200 -300 0 0 0 0]

$Q=P*\Omega$

Q=?

Water use along river network



What if you demand too much water??

P=[200 -300 0 0 0 0]

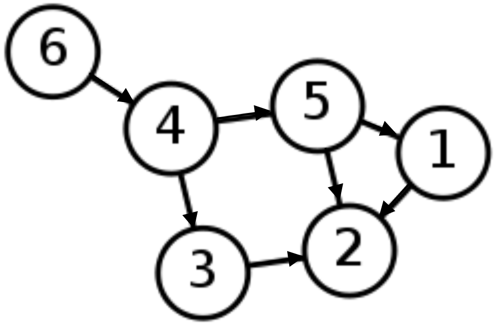
$Q=P*\Omega$

Q=[0 200 -30 -76 -24 -76]

Summary: Graph Theory

Graph = nodes and links

Network = directed graph

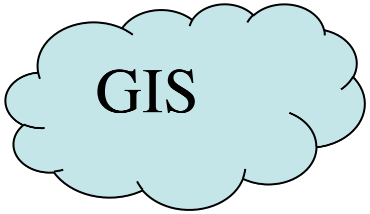


We can use **graph theory** to describe drainage patterns & water use

Adjacency Matrix

Local information

All you need to describe watershed



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Coffee

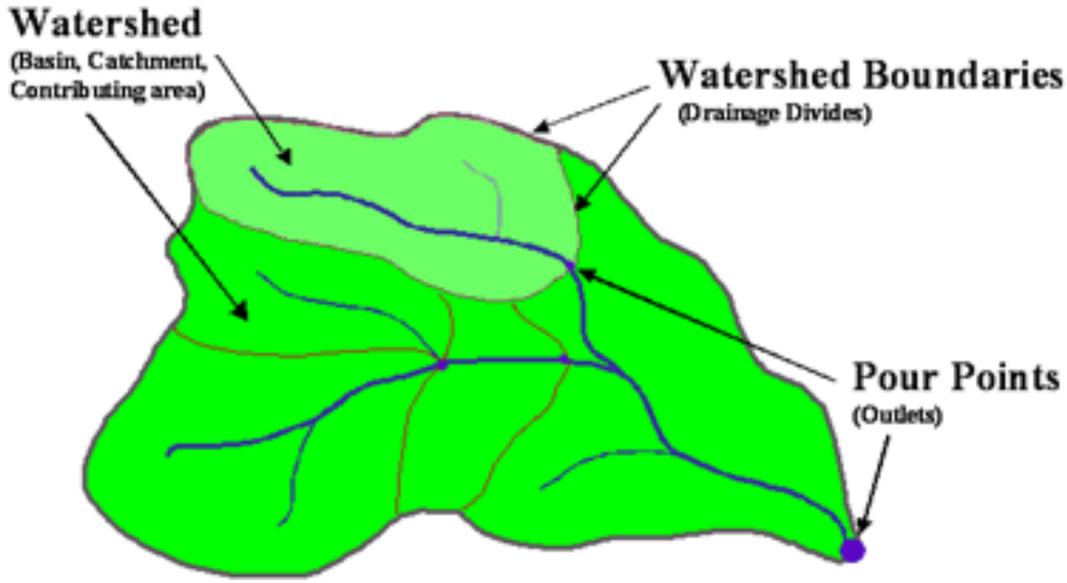
Lecture 3: Watersheds and ArcGIS

- Feedback Assignment 1
- Review Lecture 2/Assignment 2
- What is a watershed?
- Introduction to Graph Theory
- **Determining watershed boundaries in QGIS/ GRASS**
- Group Activity

Watershed delineation

What is a watershed?

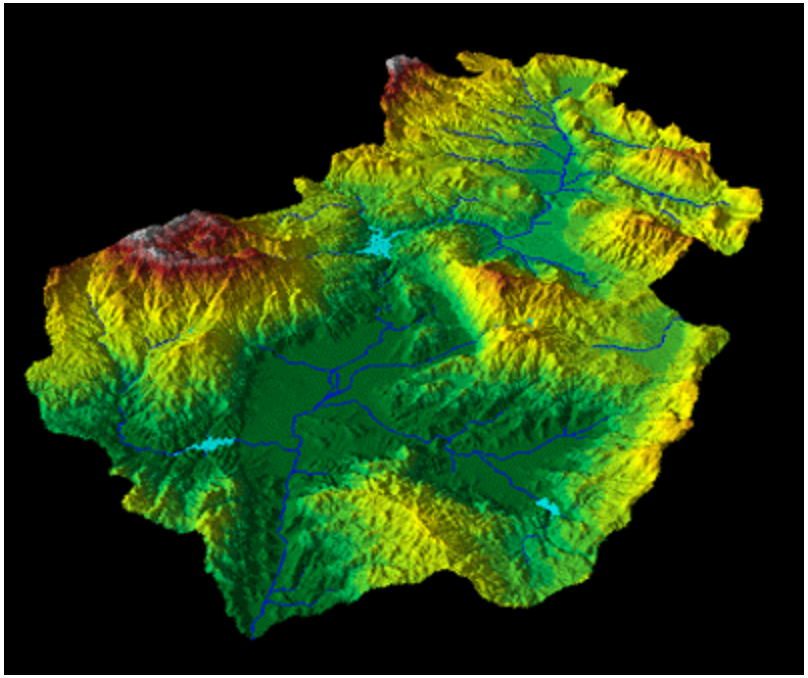
The area from which water drains to a common outlet.



AKA drainage basin, basin, catchment, or contributing area.

Watershed delineation

Digital Elevation Model
Raster data describing surface of earth.



Accuracy depends on:

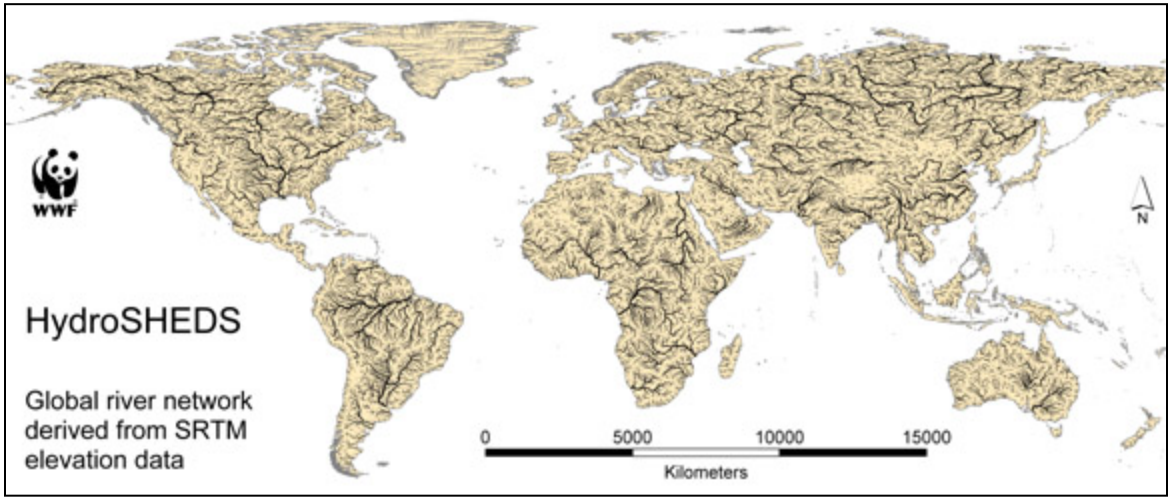
Resolution

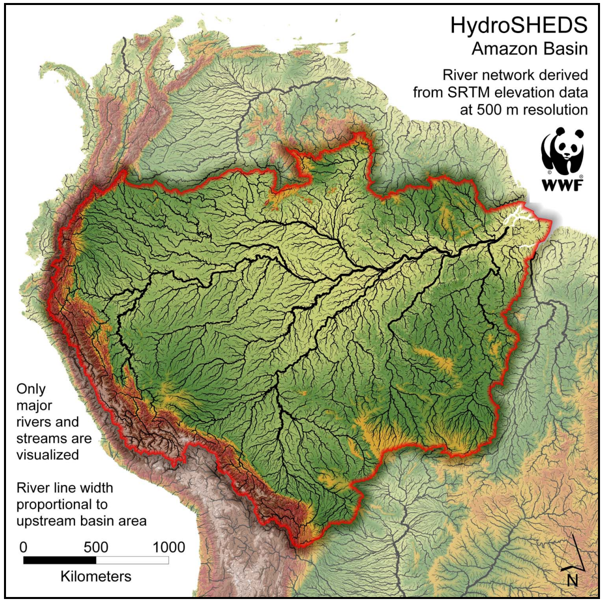
Data type

Observation method

OLD: HydroSHEDS

Hydrological data and maps based on **Sh**uttle **E**levation **D**erivatives at multiple **S**cales)





http://hydrosheds.cr.usgs.gov/

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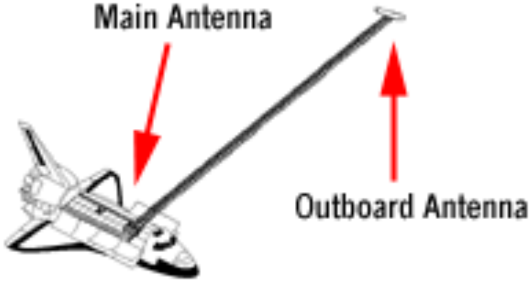
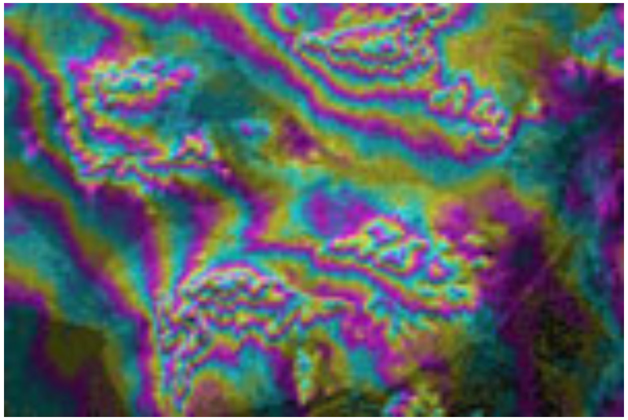
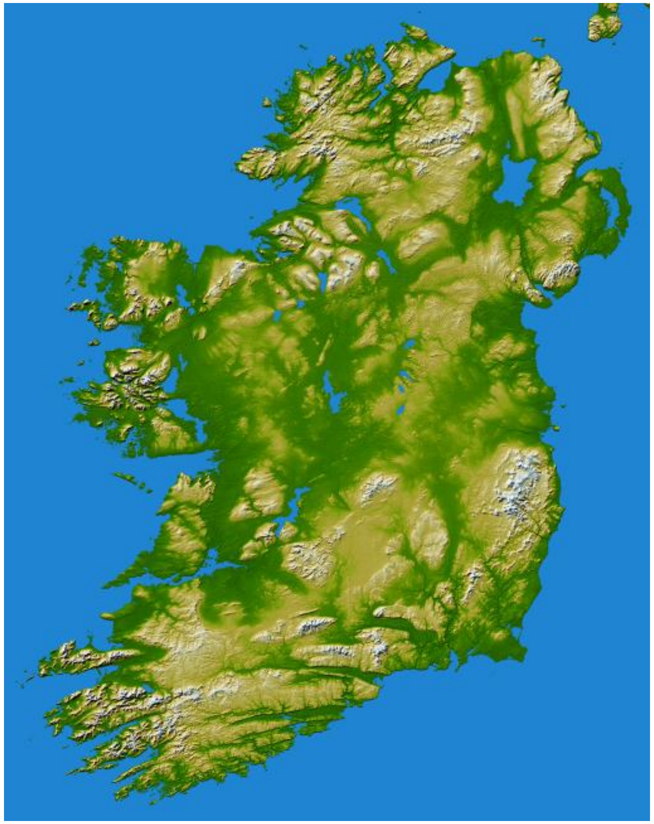
OLD: HydroSHEDS
Shuttle Radar Topography Mission



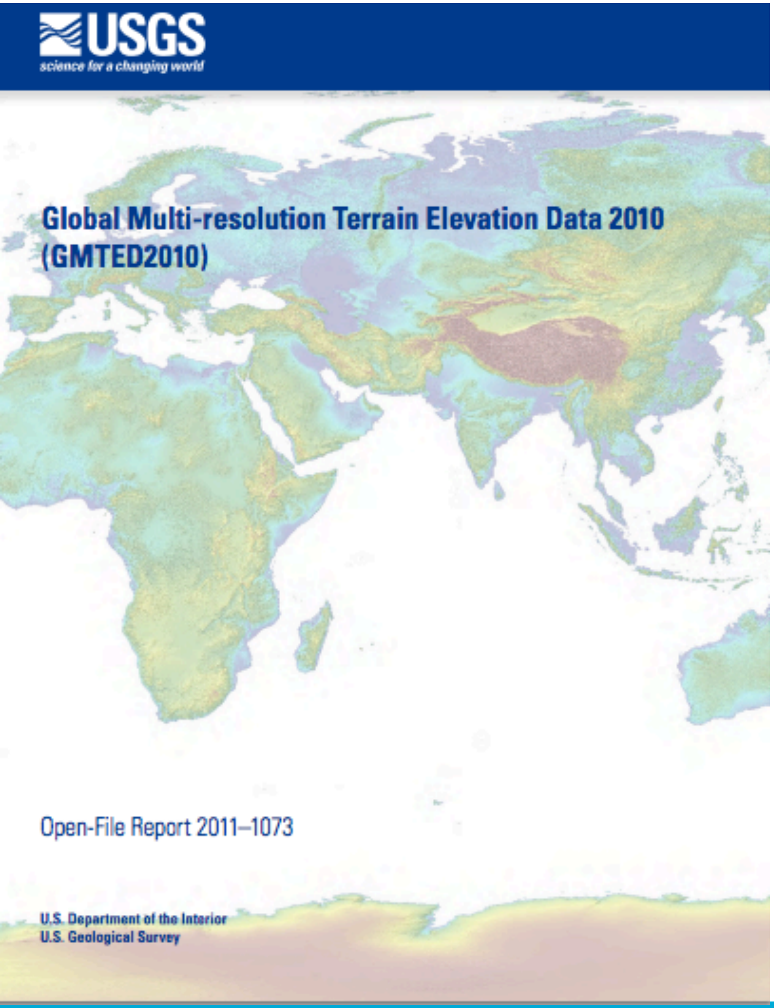
Reflected radar signals collected at two antennas, providing two sets of radar signals separated by a distance.





(http://www2.jpl.nasa.gov/srtm/index.html)

NEW: GMTED2010



New data sources:

Digital Terrain Elevation Data (DTED®) from the Shuttle Radar Topography Mission (SRTM)

Ice, Cloud, and land Elevation Satellite (ICESat).

Canadian elevation data.

http://pubs.usgs.gov/of/2011/1073/pdf/of2011-1073.pdf

NEW: GMTED2010

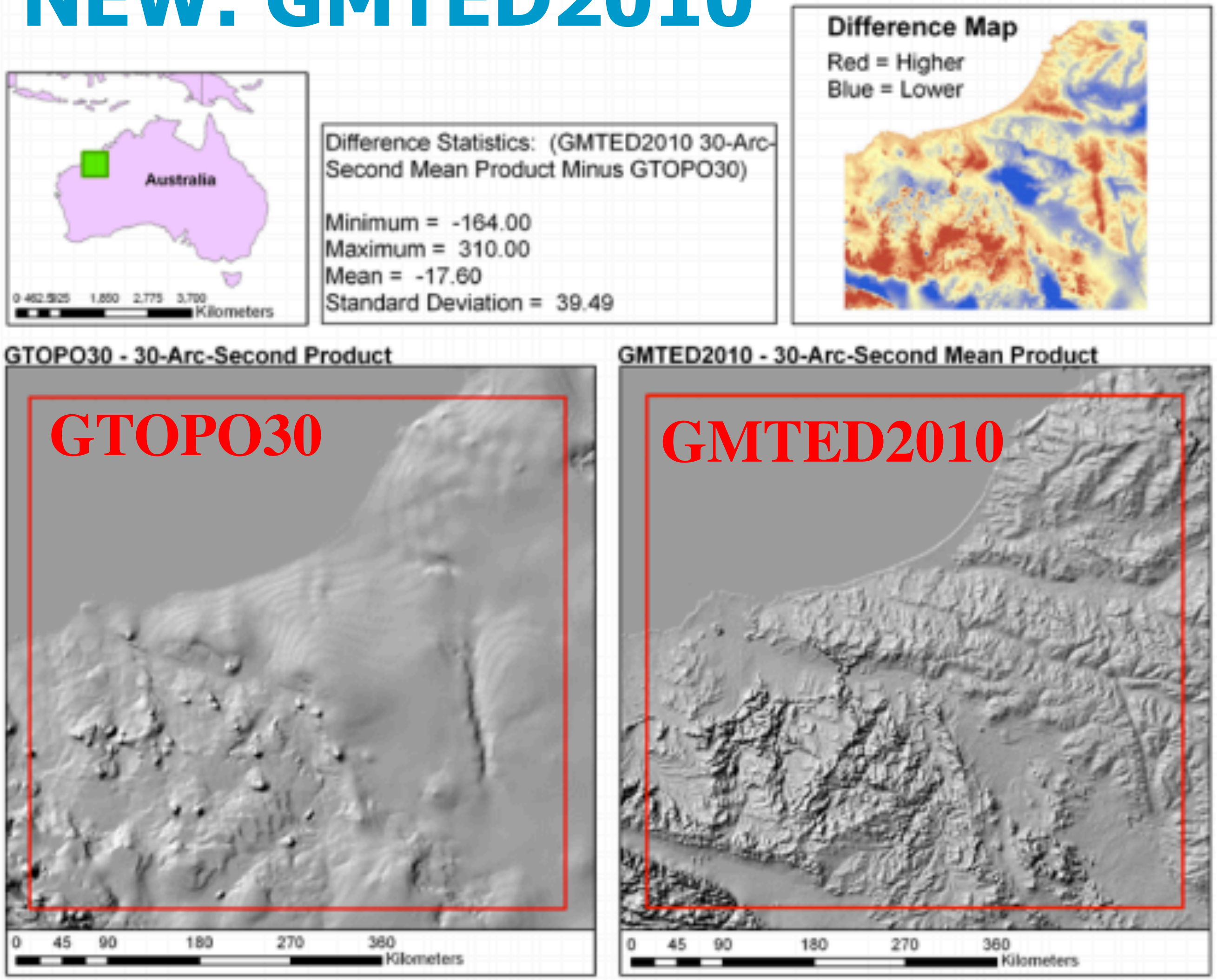


Figure 11. Comparison of the existing GTOPO30 and new GMTED2010 30-arc-second mean elevation product.

http://pubs.usgs.gov/of/2011/1073/pdf/of2011-1073.pdf

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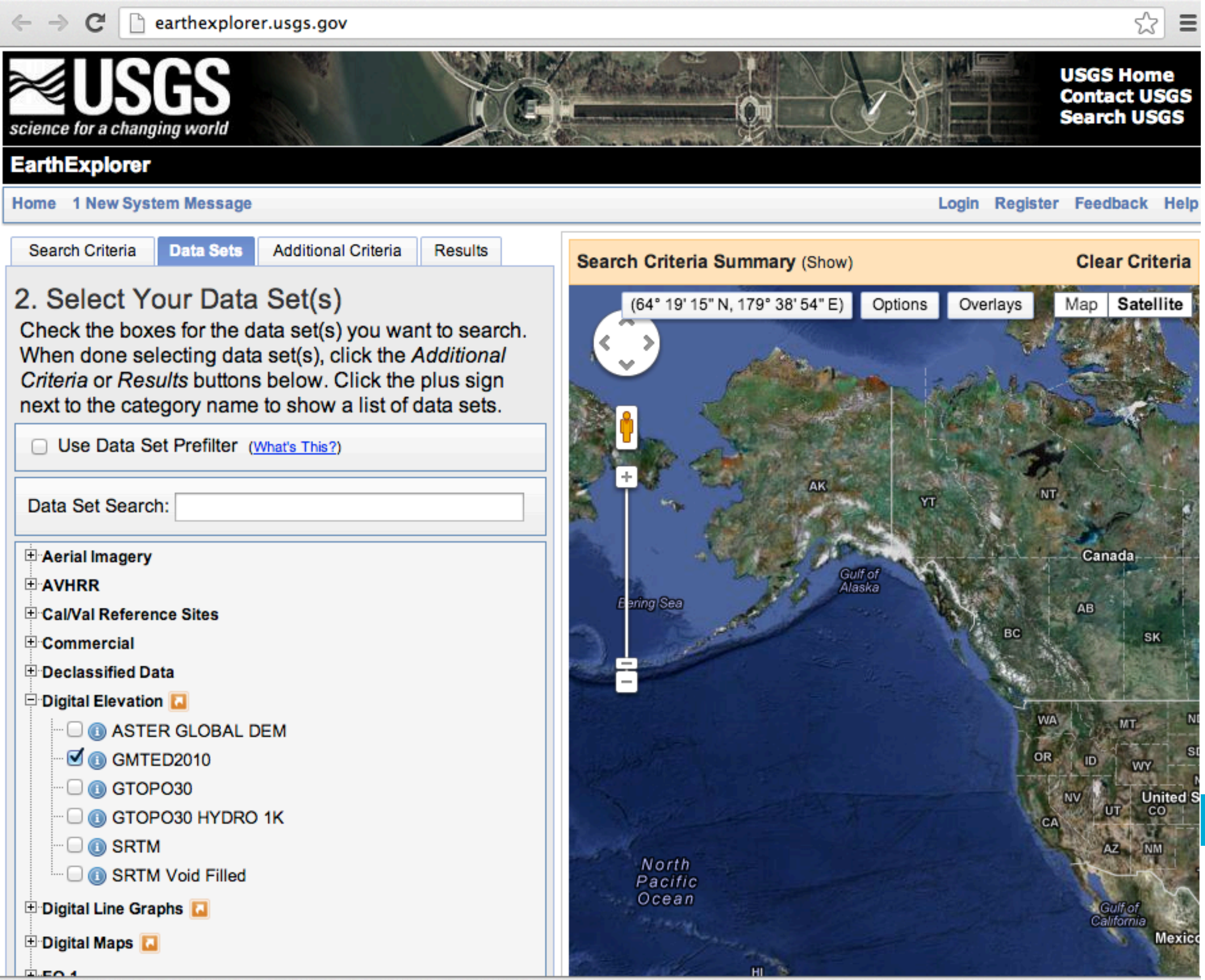
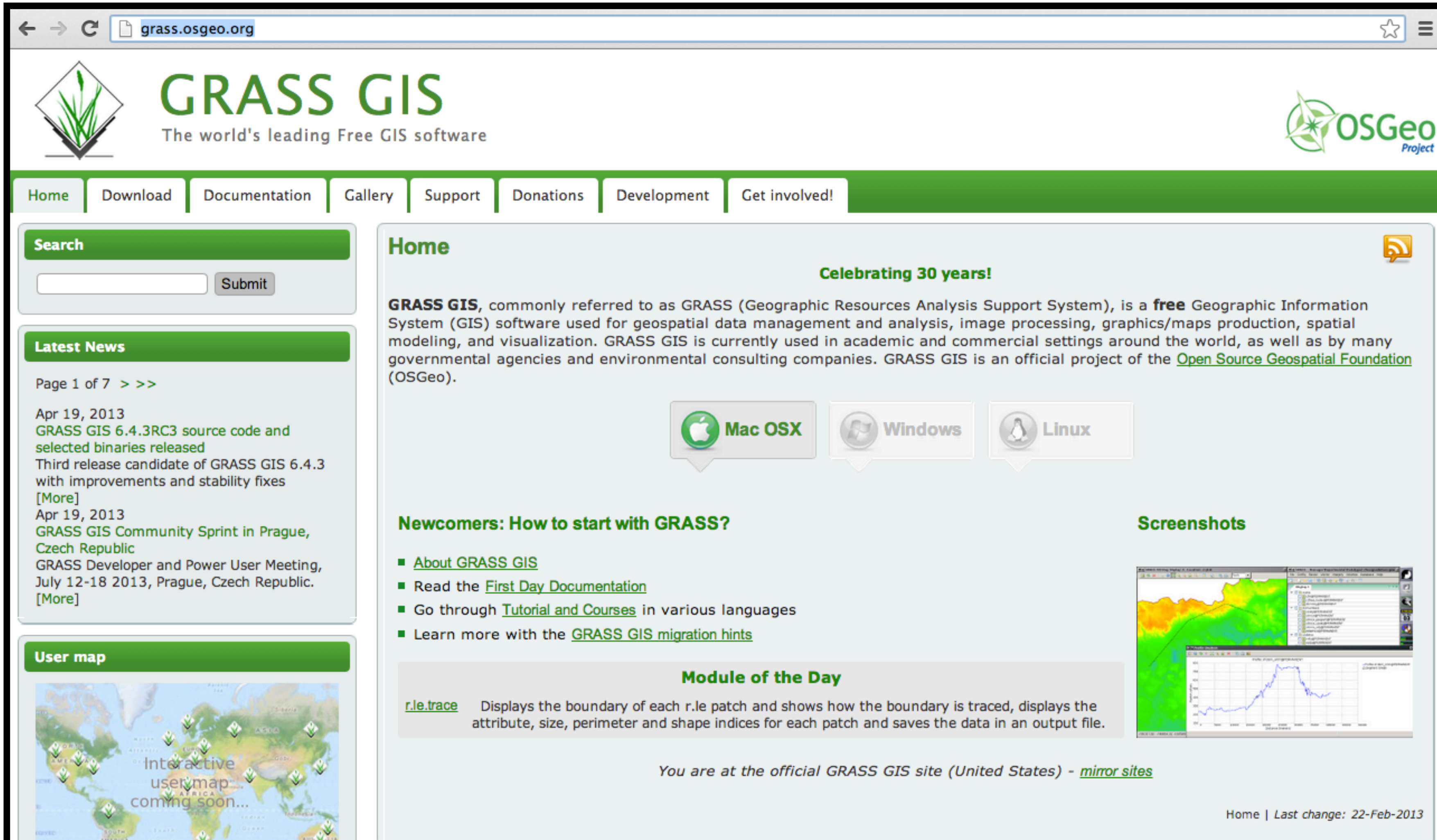
NEW: GMTED2010

Download, free from USGS EarthExplorer:



Watershed delineation using FOSS*?



*Free Open Source Software

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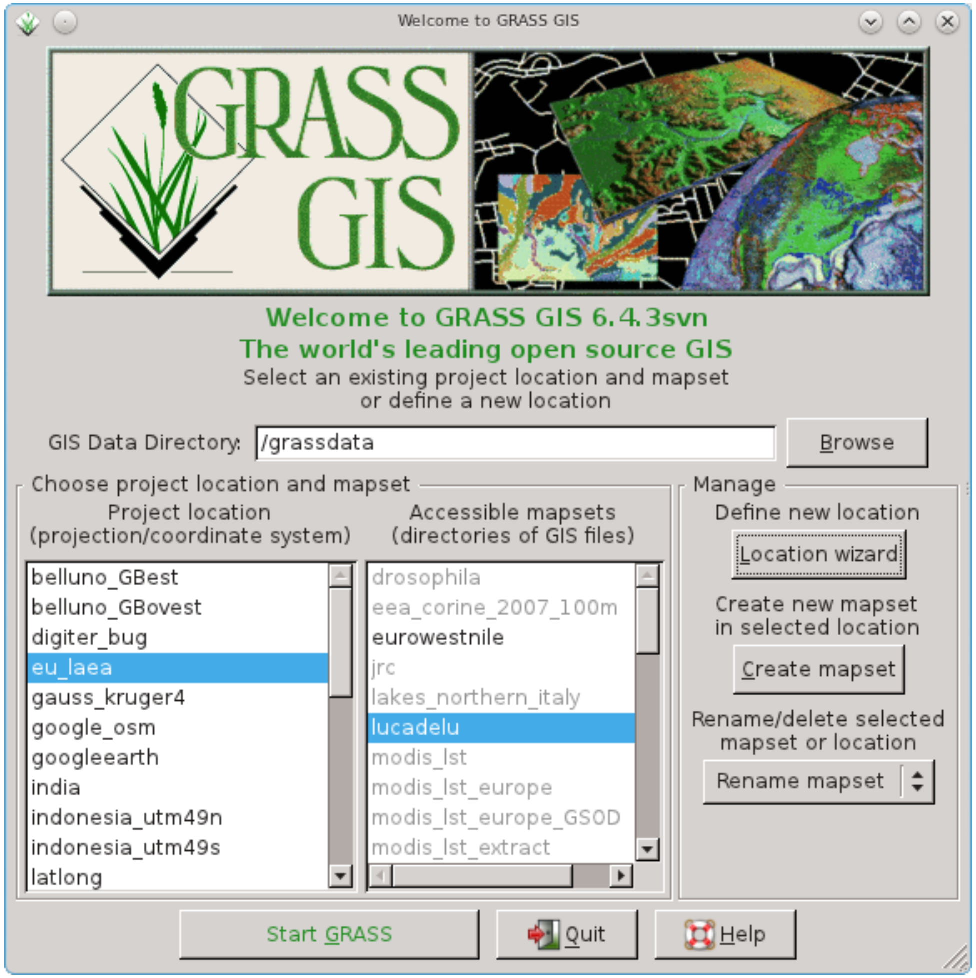
GRASS: Interface



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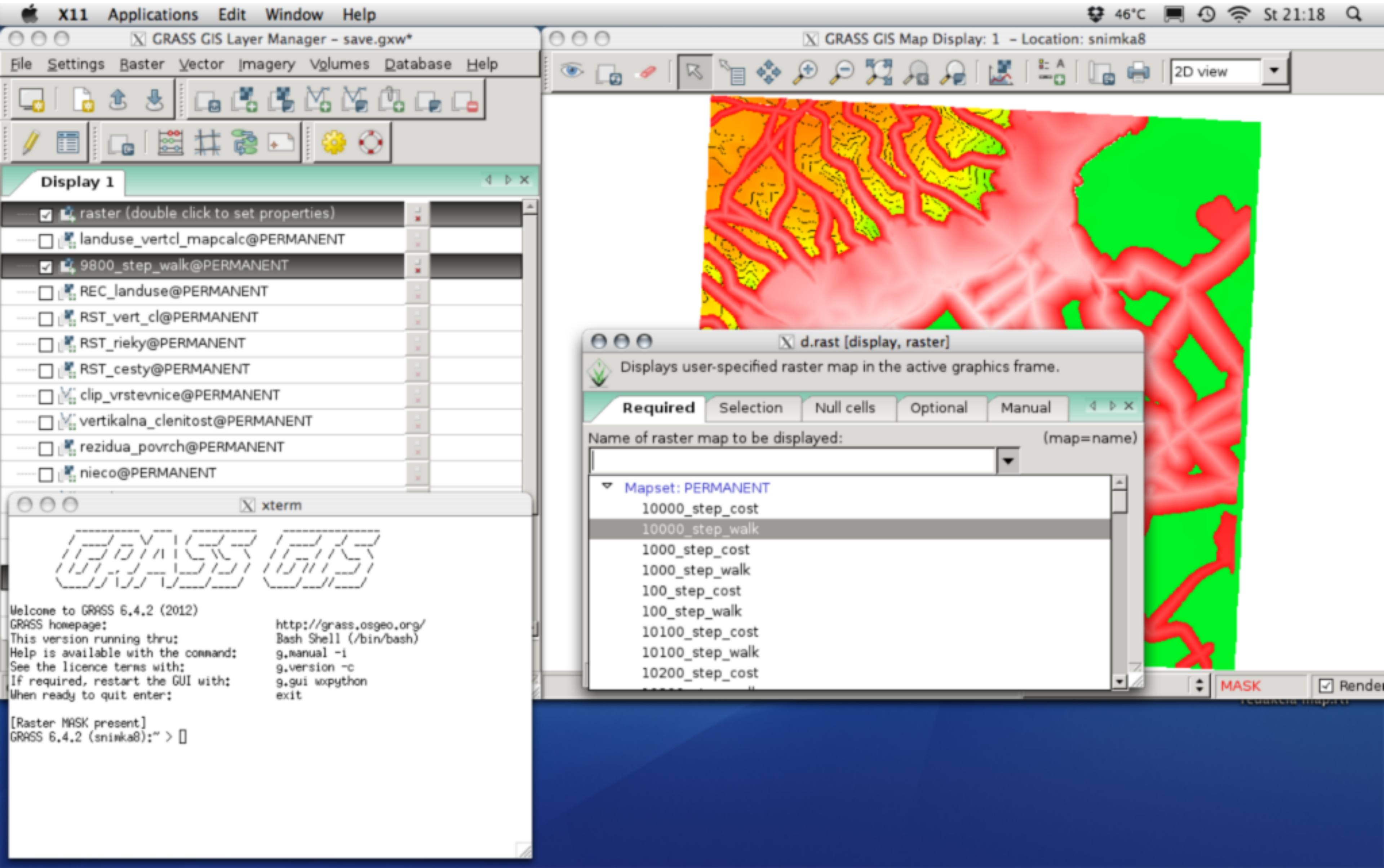
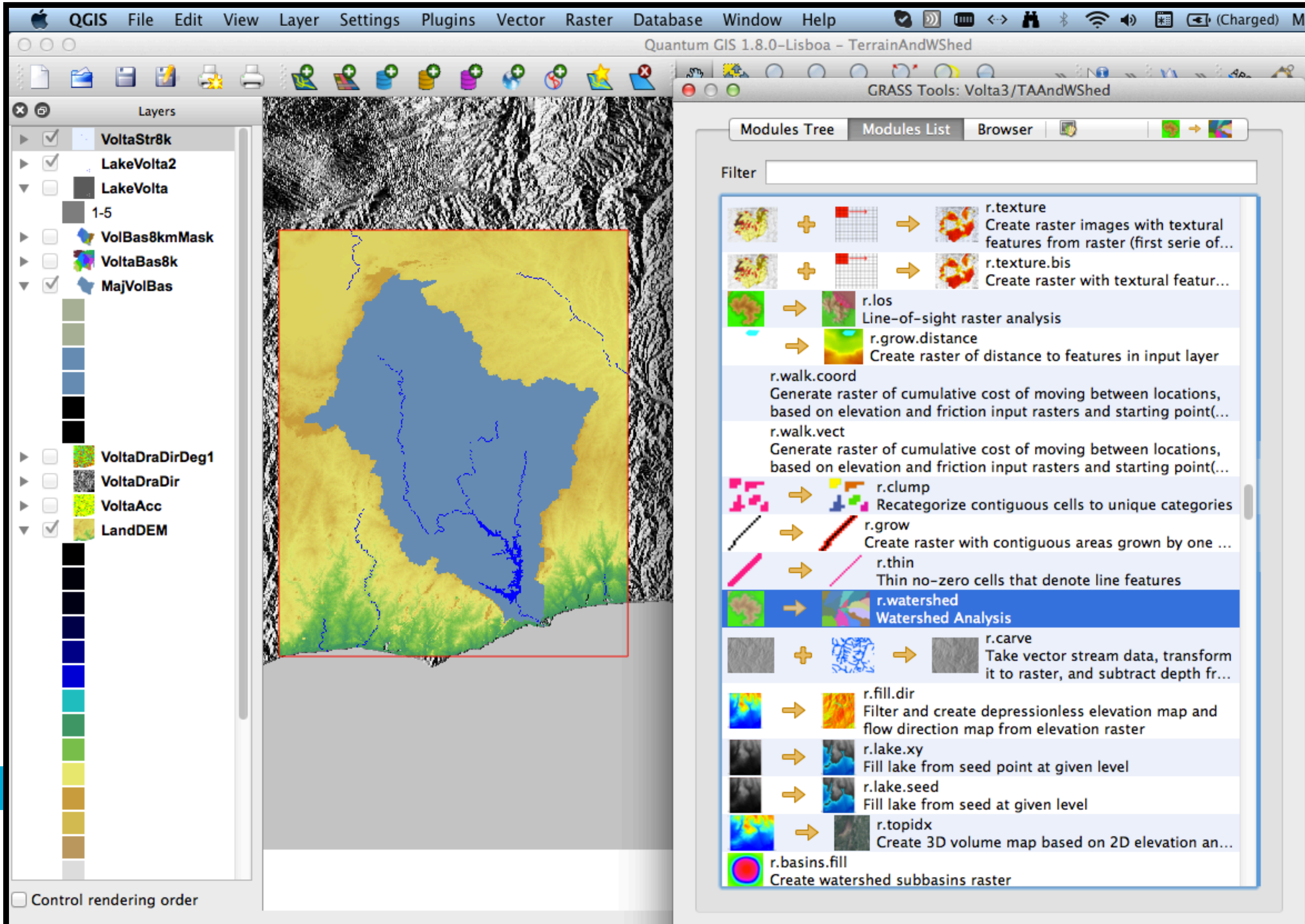
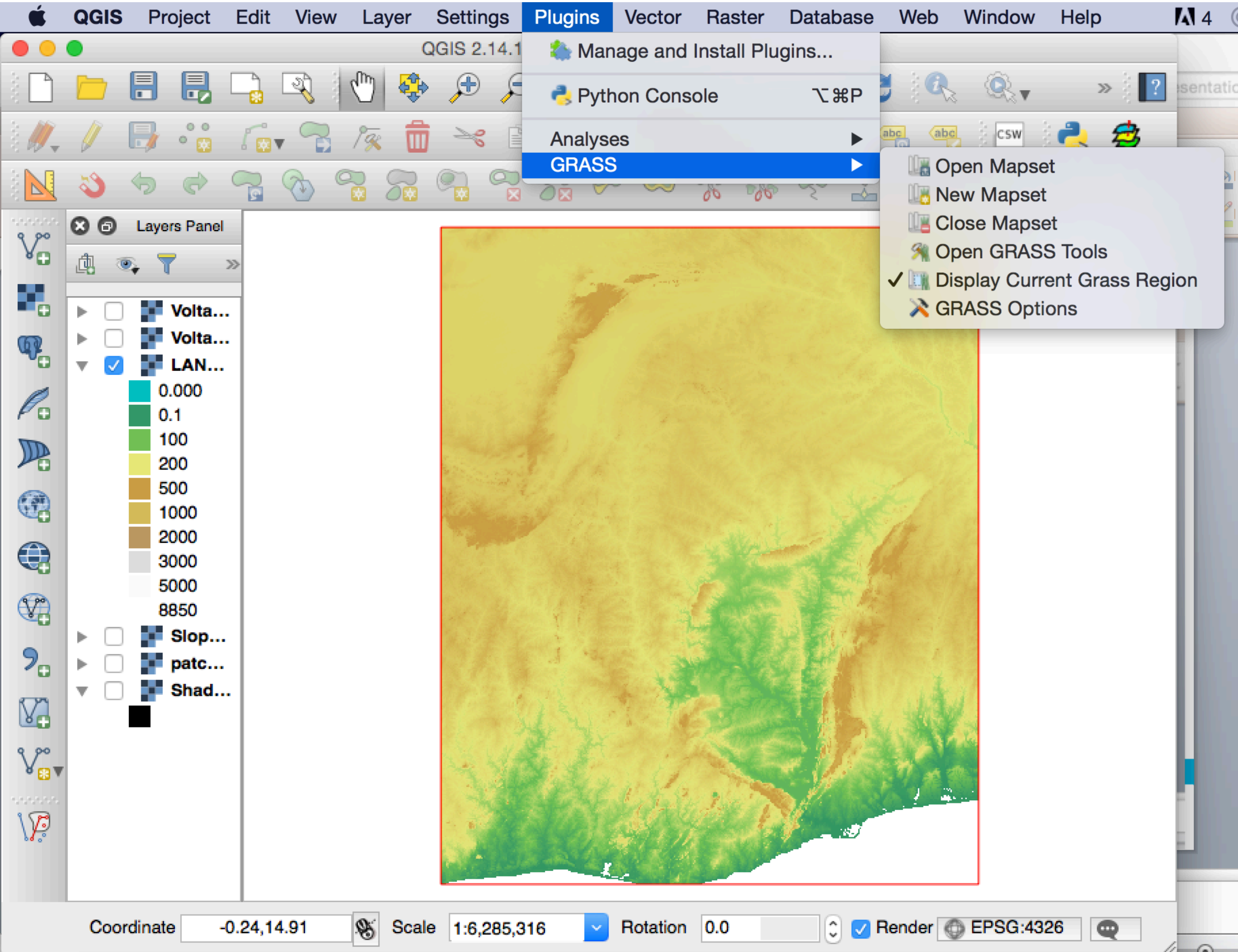
GRASS: Interface



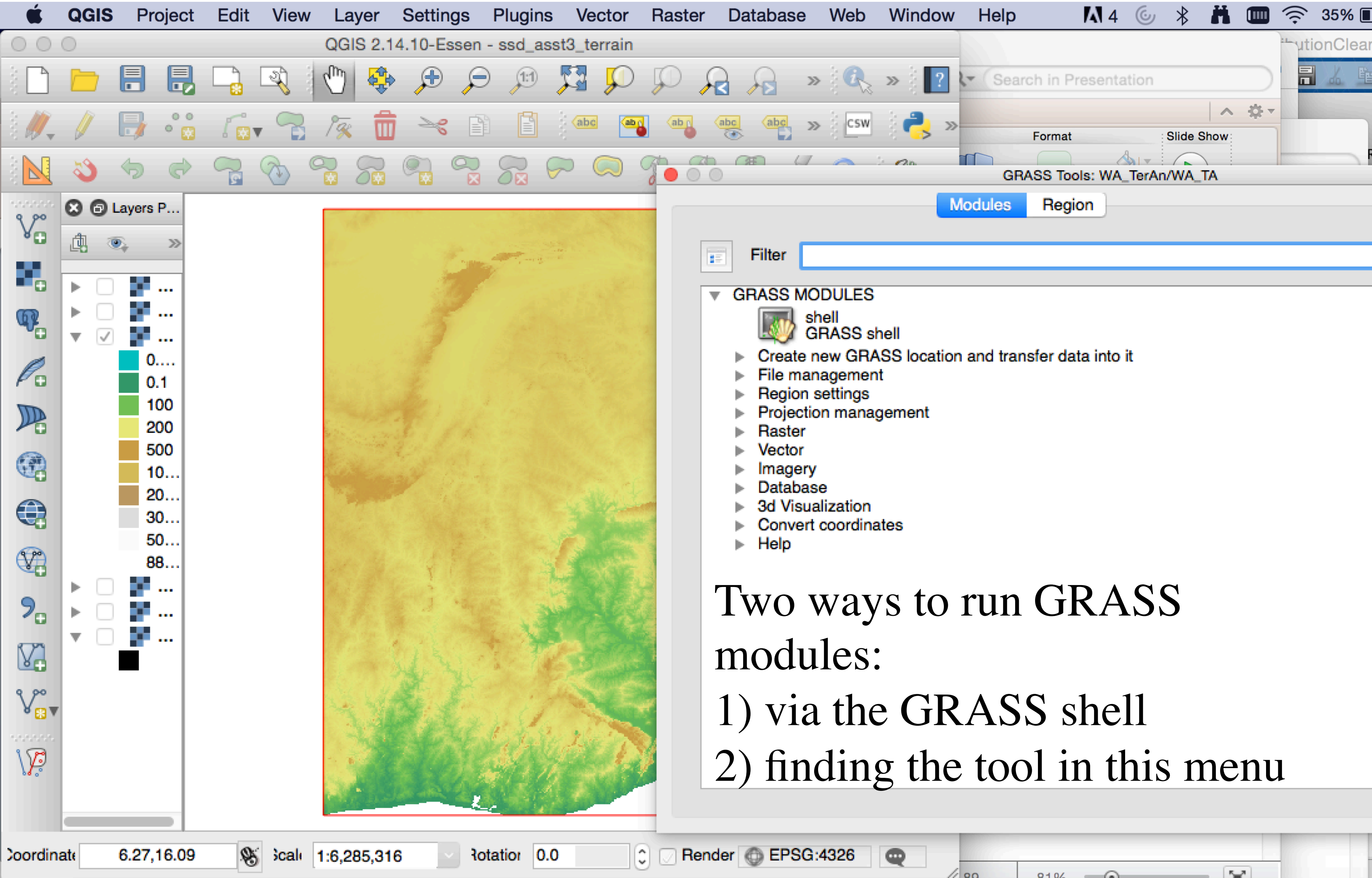
GRASS: QGIS Integration



GRASS overview



GRASS overview



Two ways to run GRASS modules:

1) via the GRASS shell

2) finding the tool in this menu

GRASS modules

- The **g.*** commands are **general** commands (https://grass.osgeo.org/grass64/manuals/general.html)
- The **r.*** commands are **raster** commands (https://grass.osgeo.org/grass64/manuals/raster.html)
- The **v.*** commands are **vector** commands (https://grass.osgeo.org/grass64/manuals/vector.html)

GRASS modules

Secure https://grass.osgeo.org/grass64/manuals/raster.html

r.li.patchdensity	Calculates patch density index on a raster map, using a 4 neighbour algorithm
r.li.patchnum	Calculates patch number index on a raster map, using a 4 neighbour algorithm.
r.li.pielou	Calculates Pielou's diversity index on a raster map
r.li.renyi	Calculates Renyi's diversity index on a raster map
r.li.richness	Calculates richness index on a raster map
r.li.setup	Configuration editor for r.li.'index'
r.li.shannon	Calculates Shannon's diversity index on a raster map
r.li.shape	Calculates shape index on a raster map
r.li.simpson	Calculates Simpson's diversity index on a raster map
r.los	Line-of-sight raster analysis program.
r.mapcalc	Raster map calculator.
r.mapcalculator	Calculate new raster map from a r.mapcalc expression.
r.mask	Creates a MASK for limiting raster operation.
r.median	Finds the median of values in a cover map within areas assigned the same category value in a user-specified base map.
r.mfilter.fp	Raster map matrix filter.
r.mfilter	Performs raster map matrix filter.
r.mode	Finds the mode of values in a cover map within areas assigned the same category value in a user-specified base map.
r.neighbors	Makes each cell category value a function of the category values assigned to the cells around it, and stores new cell values in an output raster map layer.
r.null	Manages NULL-values of given raster map.
r.out.arc	Converts a raster map layer into an ESRI ARCGRID file.
r.out.ascii	Converts a raster map layer into an ASCII text file.
r.out.bin	Exports a GRASS raster map to a binary array.

GRASS modules

Secure https://grass.osgeo.org/grass64/manuals/r.mapcalc.html

NAME

r.mapcalc

DESCRIPTION

r.mapcalc performs arithmetic on raster map layers. New raster map layers can be created which are arithmetic expressions involving existing raster map layers, integer or floating point constants, and functions.

PROGRAM USE

If used without command line arguments, *r.mapcalc* will read its input, one line at a time, from standard input (which is the keyboard, unless redirected from a file or across a pipe). Otherwise, the expression on the command line is evaluated. *r.mapcalc* expects its input to have the form:

result=*expression*

where *result* is the name of a raster map layer to contain the result of the calculation and *expression* is any legal arithmetic expression involving existing raster map layers, integer or floating point constants, and functions known to the calculator. Parentheses are allowed in the expression and may be nested to any depth. *result* will be created in the user's current mapset.

The formula entered to *r.mapcalc* by the user is recorded both in the *result* map title (which appears in the category file for *result*) and in the history file for *result*.

Some characters have special meaning to the command shell. If the user is entering input to *r.mapcalc* on the command line, expressions should be enclosed within single quotes. See NOTES, below.

GRASS modules

Secure https://grass.osgeo.org/grass64/manuals/r.mapcalc.html

The environment variable GRASS_RND_SEED is read to initialise the random number generator.

EXAMPLES

To compute the average of two raster map layers *a* and *b*:

```
ave = (a + b)/2
```

To form a weighted average:

```
ave = (5*a + 3*b)/8.0
```

To produce a binary representation of the raster map layer *a* so that category 0 remains 0 and all other categories become 1:

```
mask = a != 0
```

This could also be accomplished by:

```
mask = if(a)
```

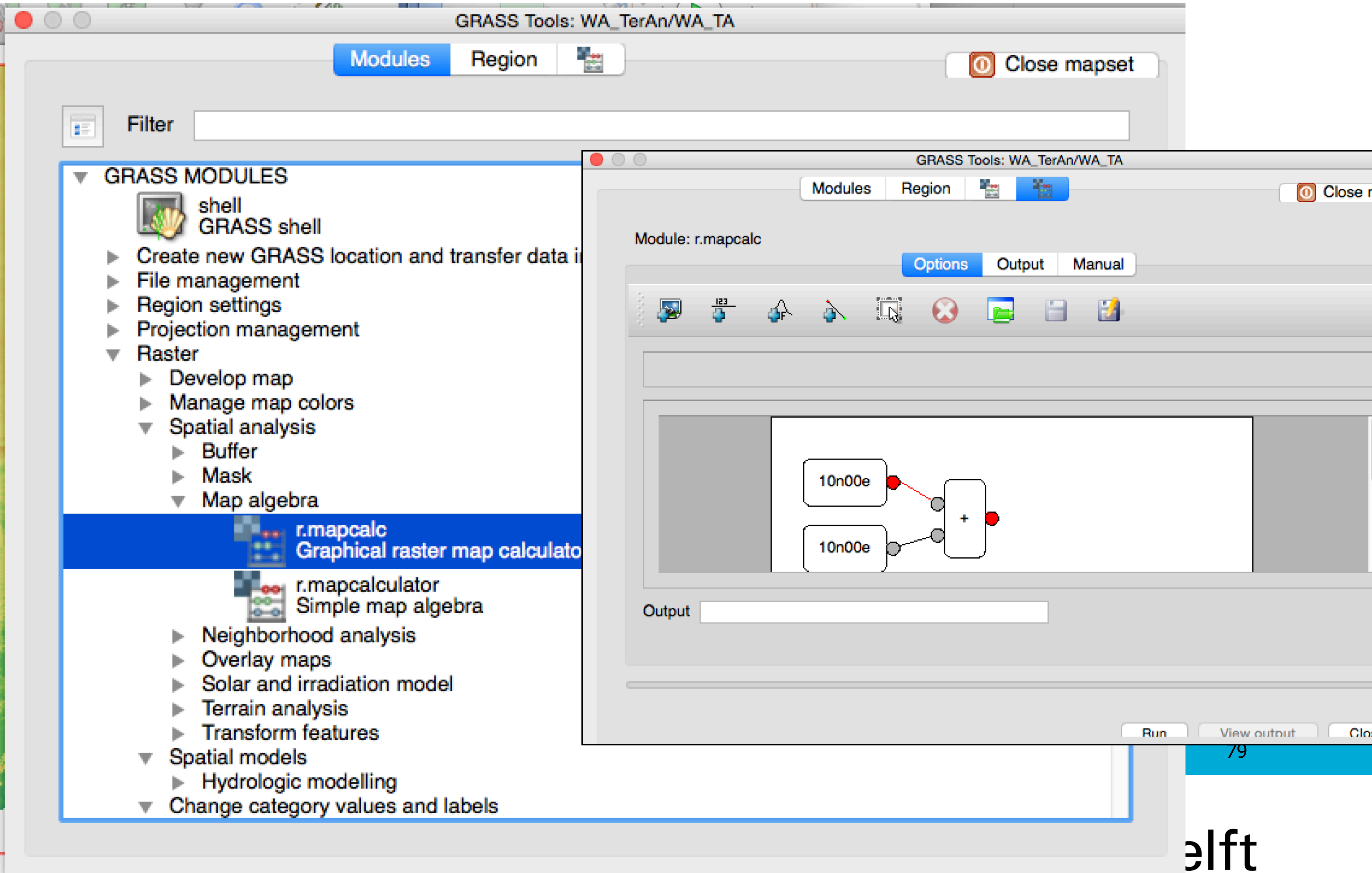
To mask raster map layer *b* by raster map layer *a*:

```
result = if(a,b)
```

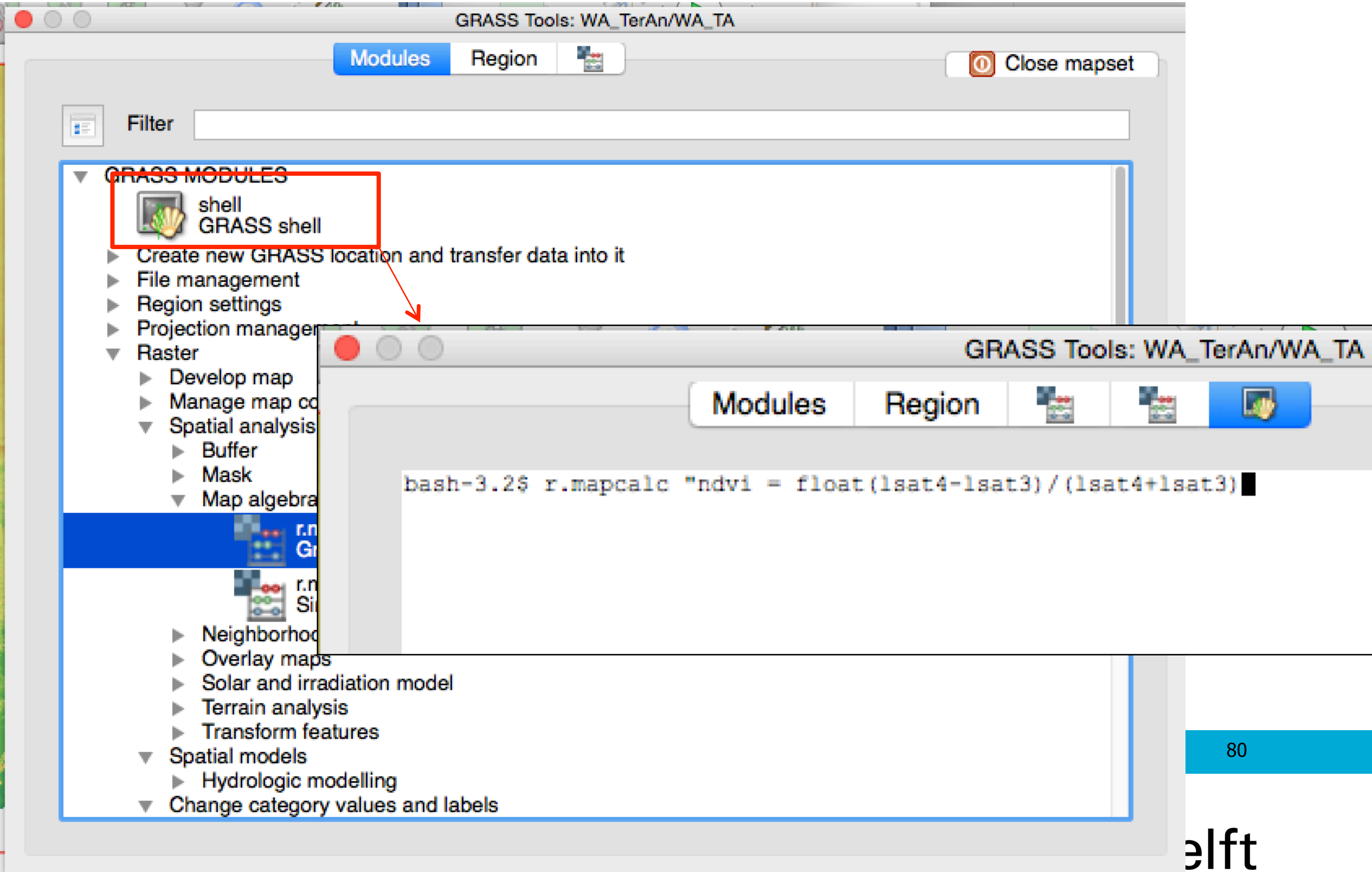
To change all values below 5 to NULL, keep otherwise:

```
newmap = if(map < 5, null(), map)
```

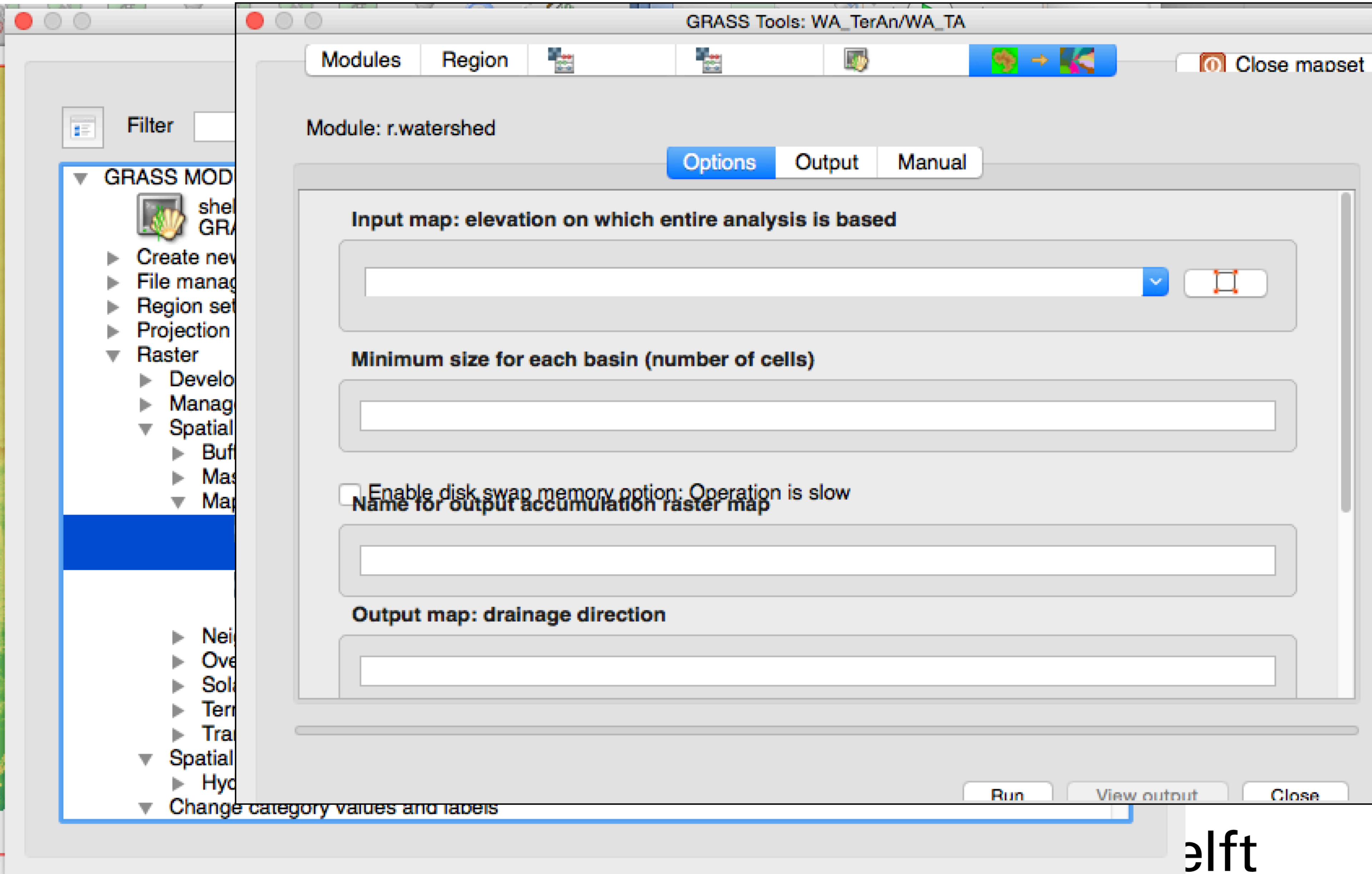
GRASS modules



GRASS modules



GRASS modules



GRASS modules

https://grass.osgeo.org/grass64/manuals/r.watershed.html

NAME

r.watershed - Watershed basin analysis program.

KEYWORDS

raster, hydrology

SYNOPSIS

r.watershed
r.watershed help
r.watershed [-**f4ma**] **elevation**=*name* [**depression**=*name*] [**flow**=*name*] [**disturbed.land**=*string*] [**blocking**=*name*] [**accumulation**=*name*] [**drainage**=*name*] [**basin**=*name*] [**stream**=*name*] [**half.basin**=*name*] [**visual**=*name*] [**length.slope**=*name*] [**slope.steepness**=*name*] [**threshold**=*integer*] [**max.slope.length**=*float*] [**convergence**=*integer*] [**memory**=*integer*] [--**overwrite**] [--**verbose**] [--**quiet**]

Parameters:

elevation=*name*
Input map: elevation on which entire analysis is based
depression=*name*
Input map: locations of real depressions
flow=*name*
Input map: amount of overland flow per cell
disturbed.land=*string*
Input map or value: percent of disturbed land, for USLE

elft

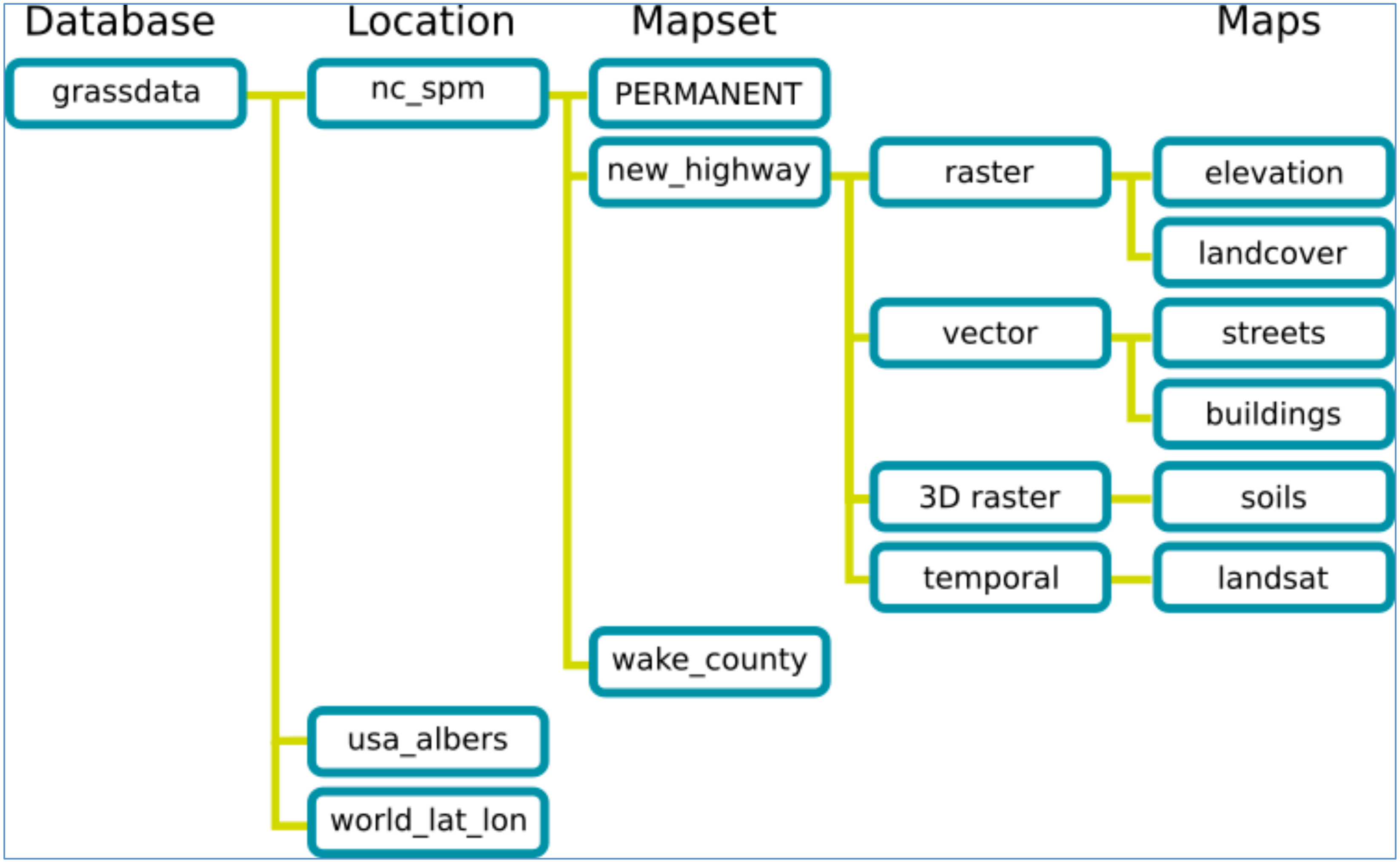
GRASS modules

- The **g.*** commands are **general** commands
  (https://grass.osgeo.org/grass64/manuals/general.html)

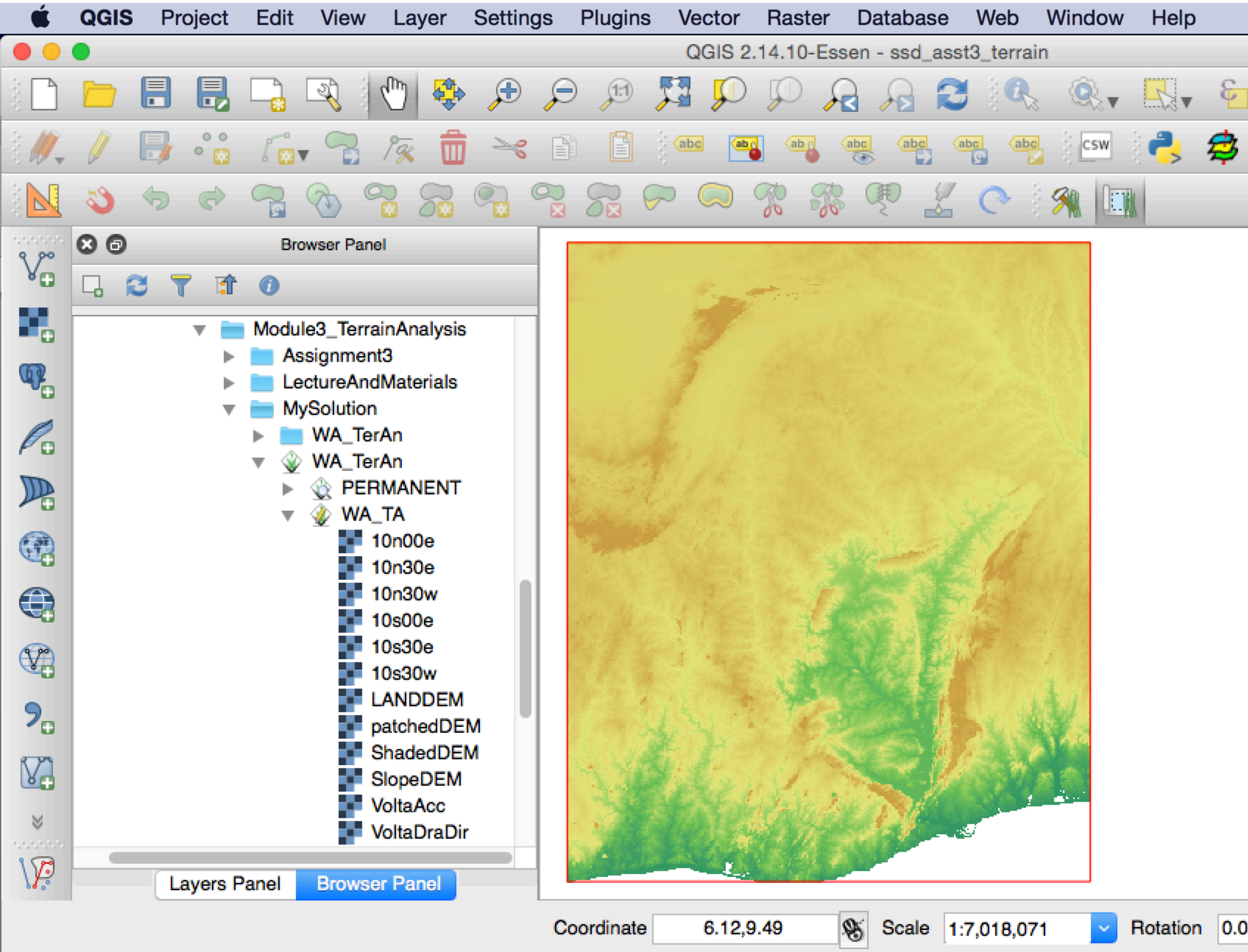
- The **r.*** commands are **raster** commands
  (https://grass.osgeo.org/grass64/manuals/raster.html)

- The **v.*** commands are **vector** commands
  (https://grass.osgeo.org/grass64/manuals/vector.html)

GRASS location structure

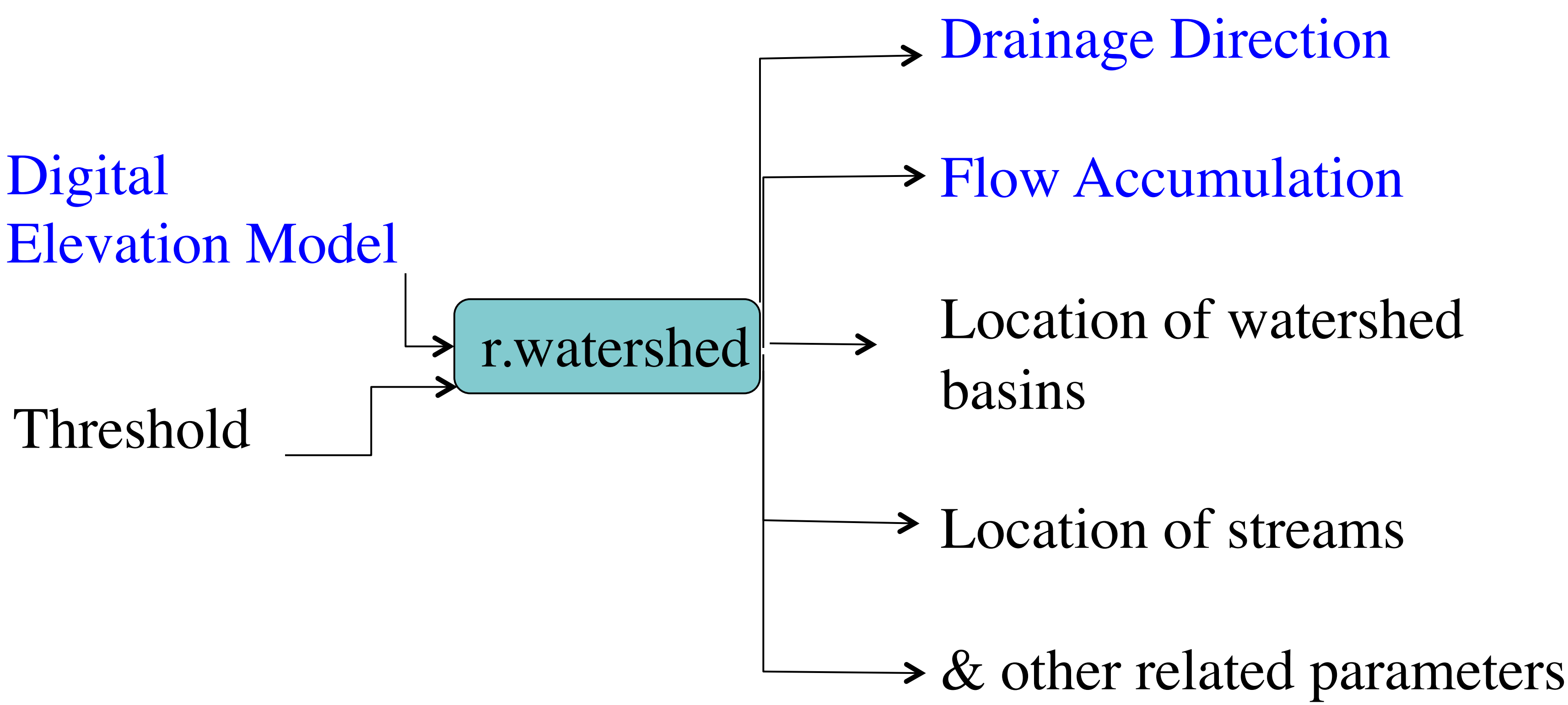


GRASS location structure

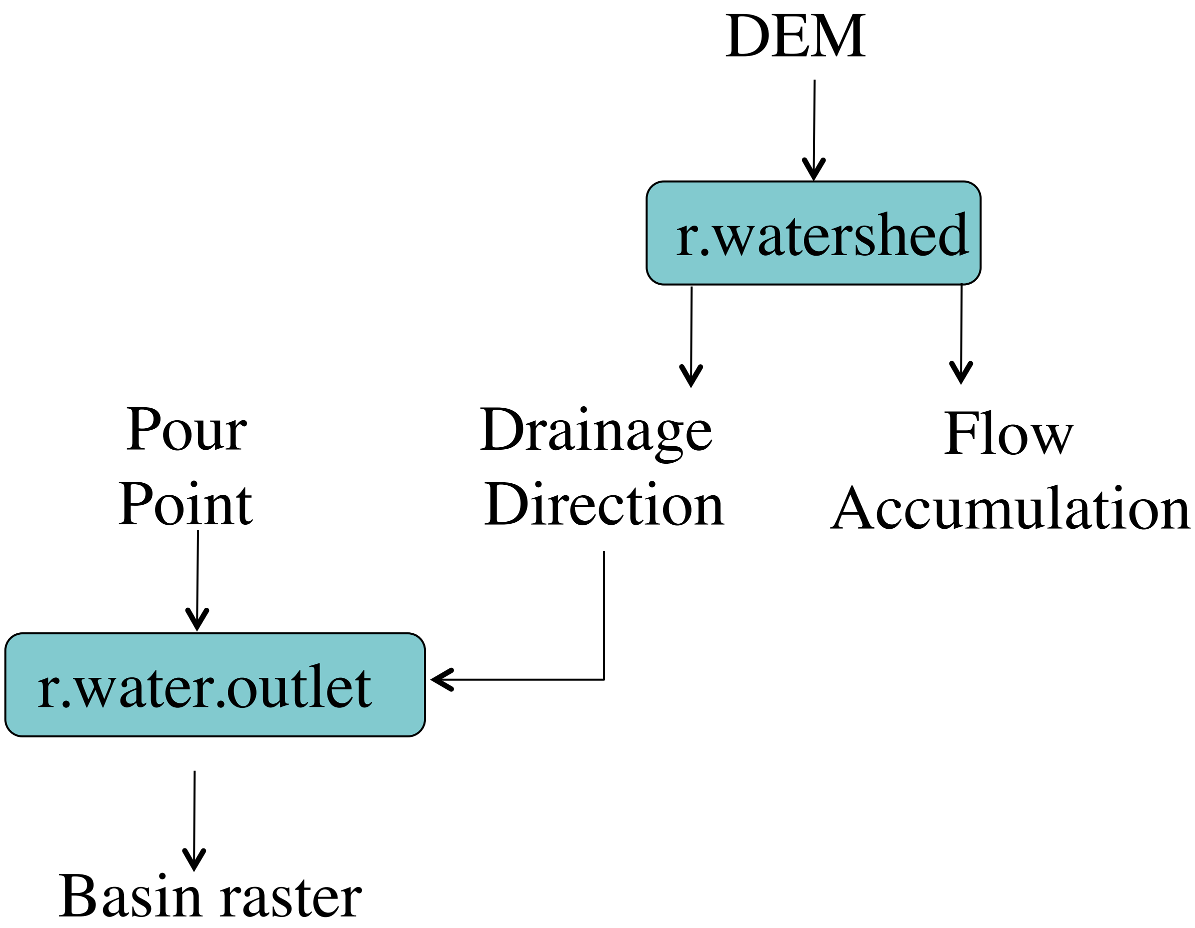


ft

GRASS: Delineating watersheds

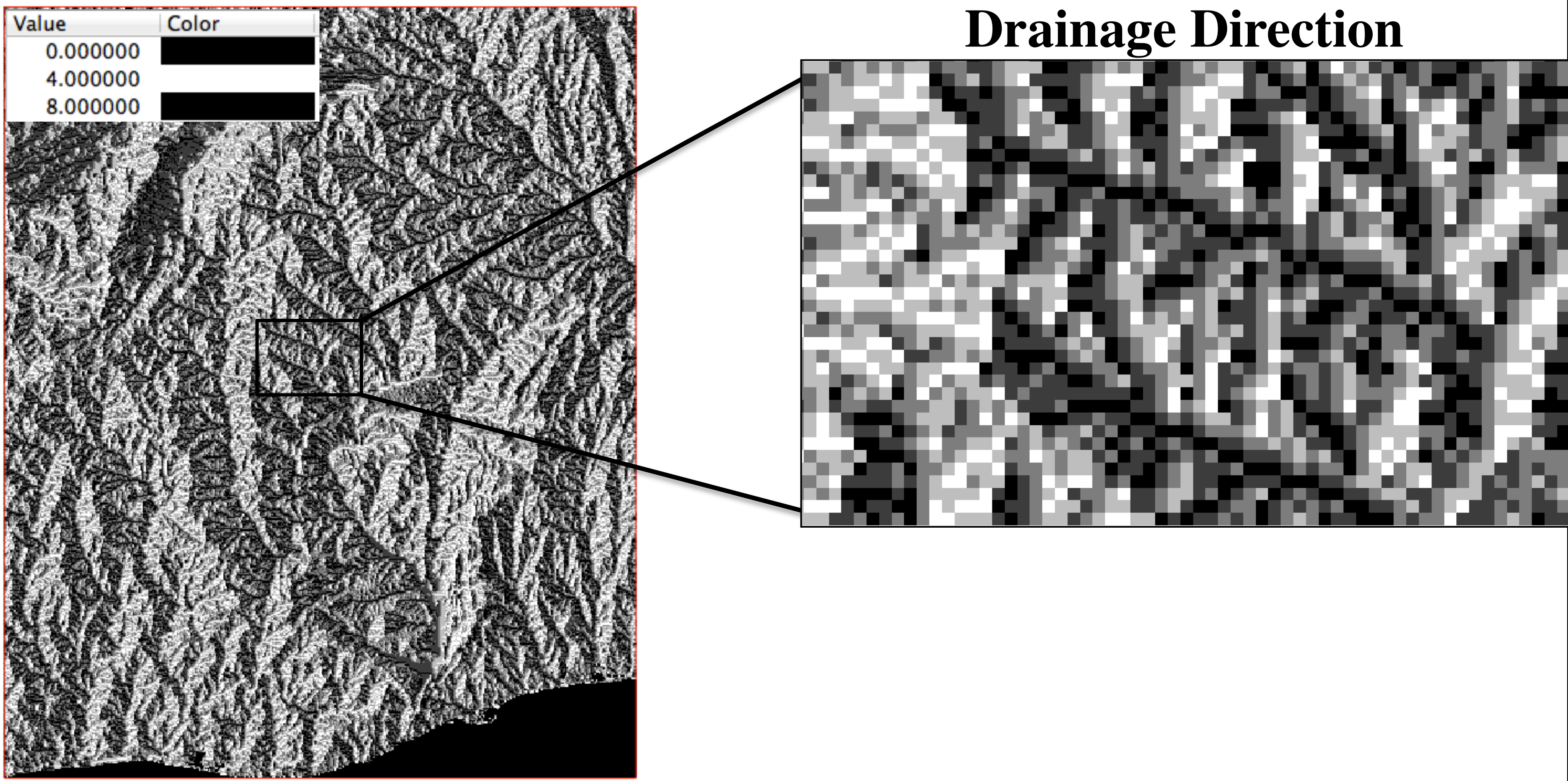


GRASS: Delineating watersheds



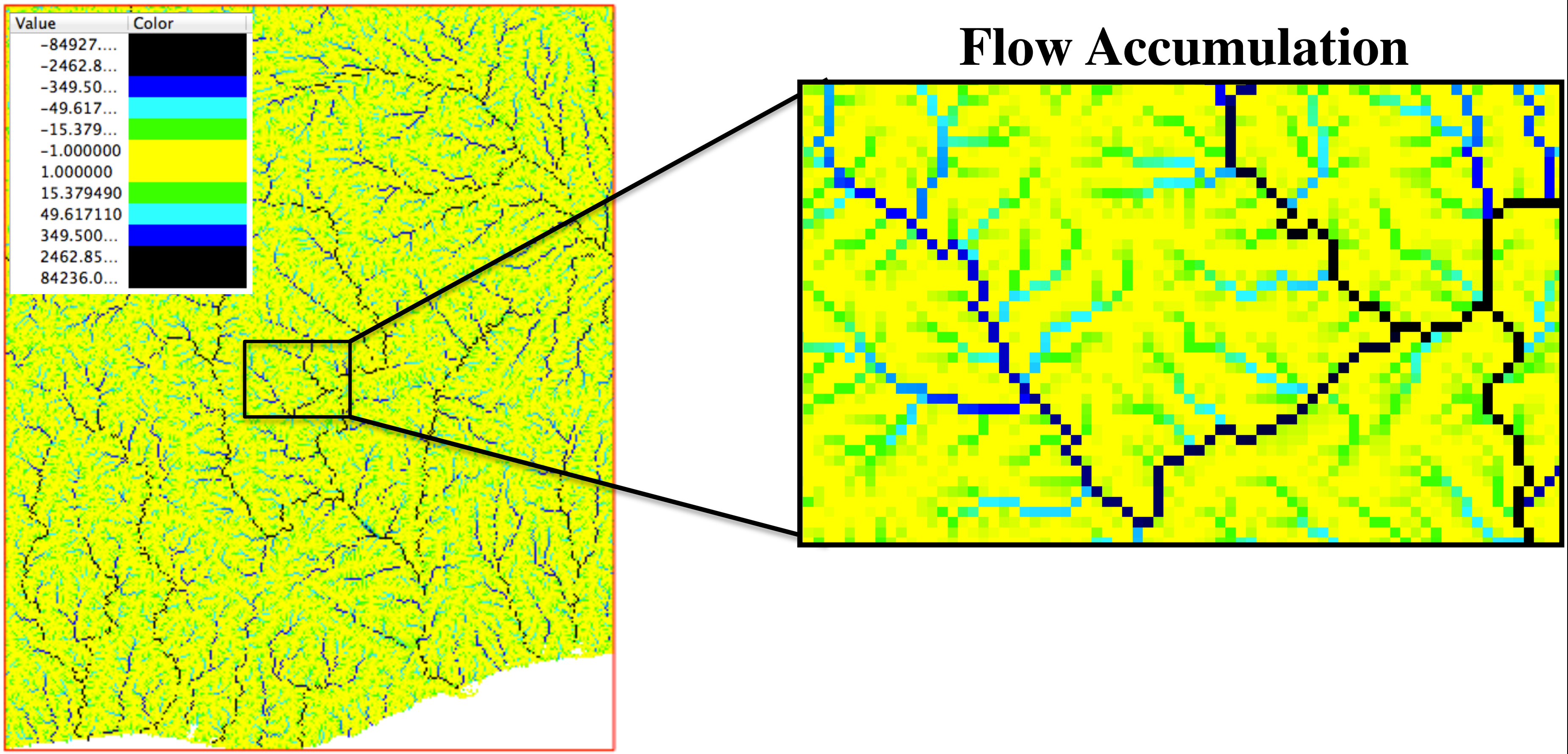
GRASS: Watershed

r.watershed elevation=LandDEM accumulation=VoltaAcc drainage=VoltaDraDir



GRASS: Watershed

r.watershed elevation=LandDEM accumulation=VoltaAcc drainage=VoltaDraDir

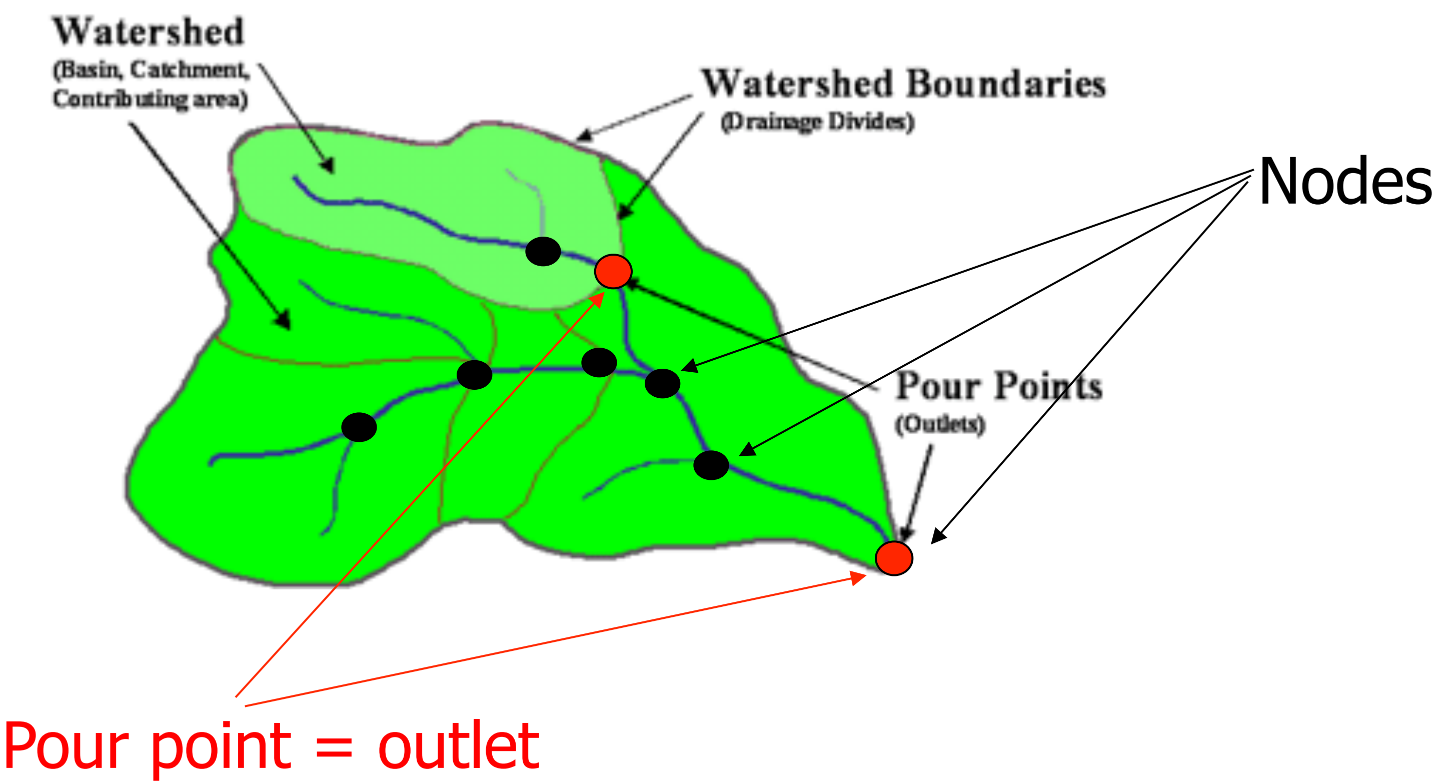


GRASS: Watershed

Better symbology => clearer view of drainage network!

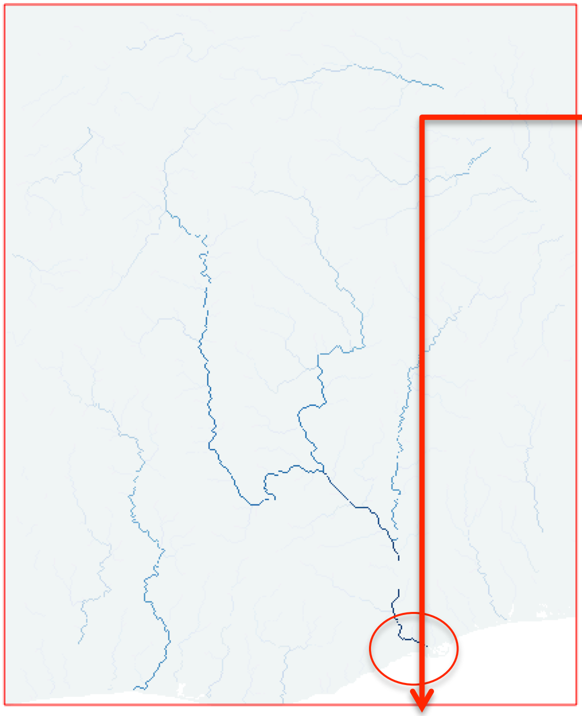
GRASS: Watershed

A stream network is made up of nodes and links

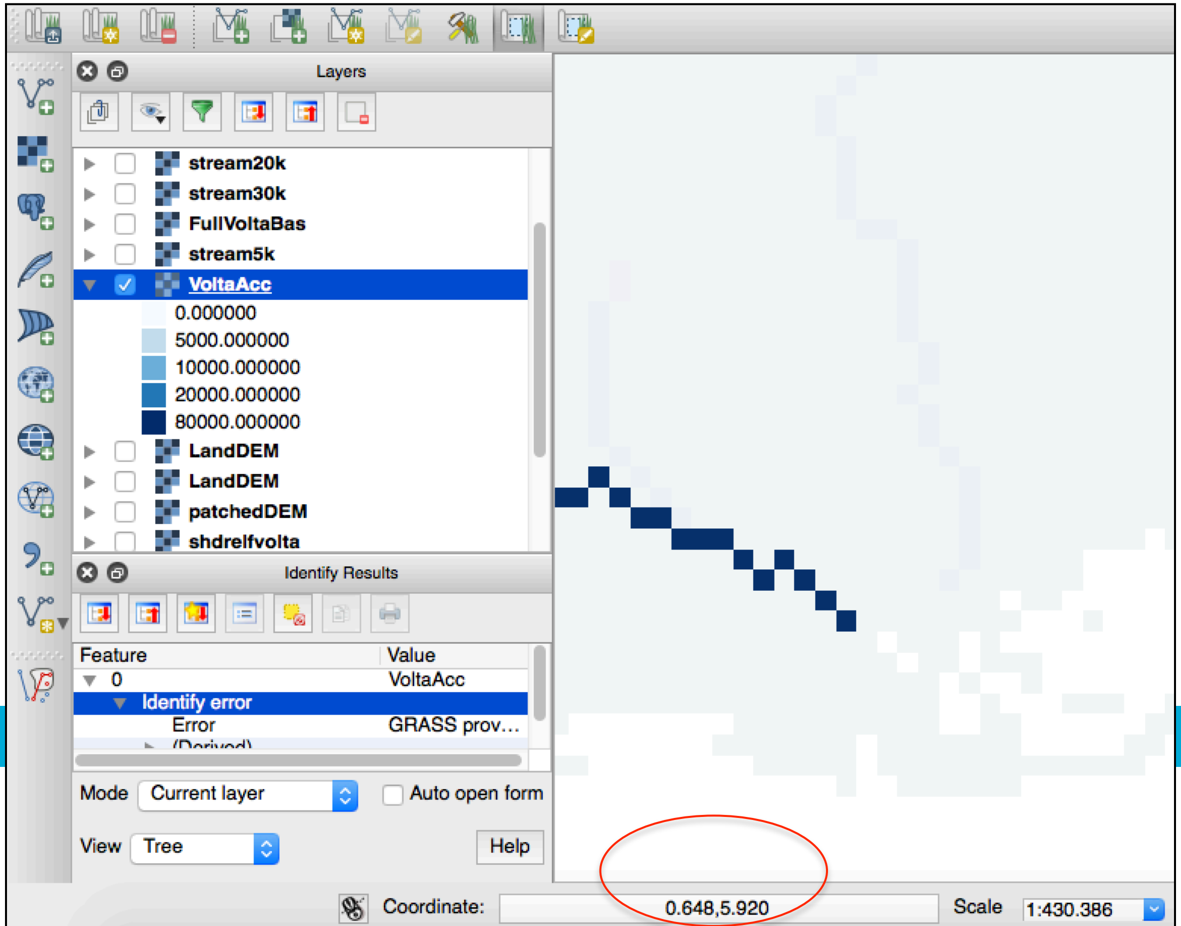


http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Understanding_drainage_systems

GRASS: Watershed



To delineate the watershed, we need **pour points.**



GRASS: Delineating watersheds

DEM

r.watershed

Drainage Direction

Flow Accumulation

Pour Point

r.water.outlet

Basin raster

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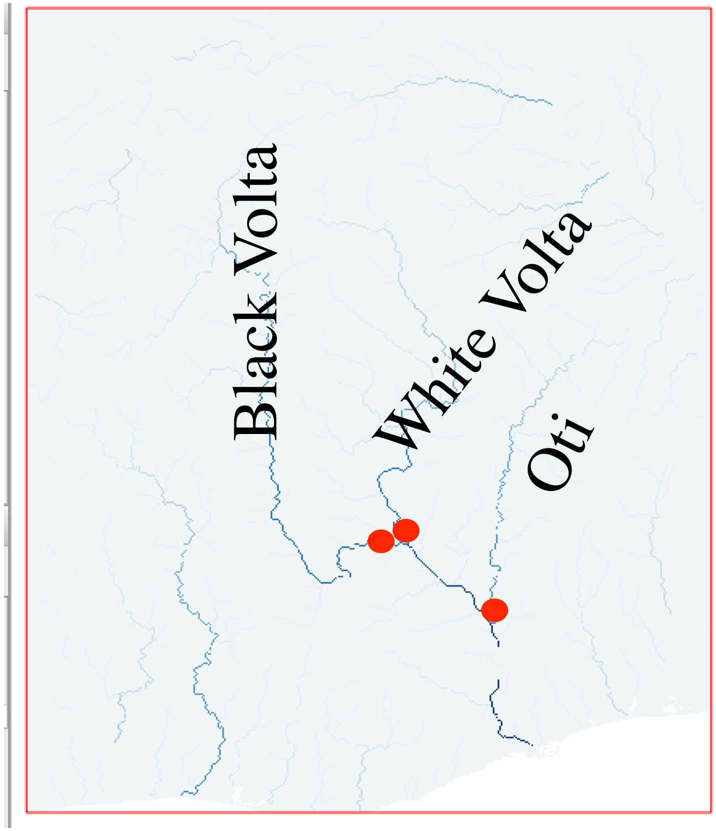
GRASS: r.water.outlet

To delineate the water basin:

Drainage Direction map & Pour point → **r.water.outlet** → Basin raster

GRASS: r.water.outlet



Pour points for sub-basins?

GRASS: Getting Started

CIE5401: GIS and Remote Sensing for
Water Resources Management

Terrain Analysis and Watershed
Delineation using QGIS and GRASS

Susan Steele-Dunne

February 2018

TU Delft Delft University of Technology

See Assignment 3