

CIE5401

GIS and Remote Sensing

Water Resources Management

Lecture 3: Watersheds and QGIS/GRASS

25 February 2018

Susan Steele-Dunne

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

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 (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

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

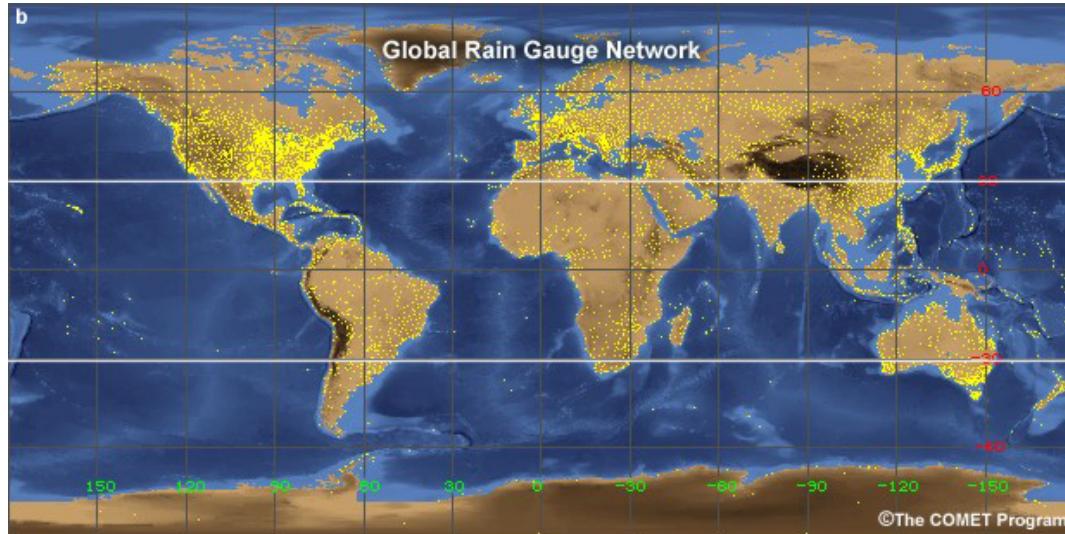
Overlay analysis

.... Any questions?

Review Assignment 2

Nice movie:

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

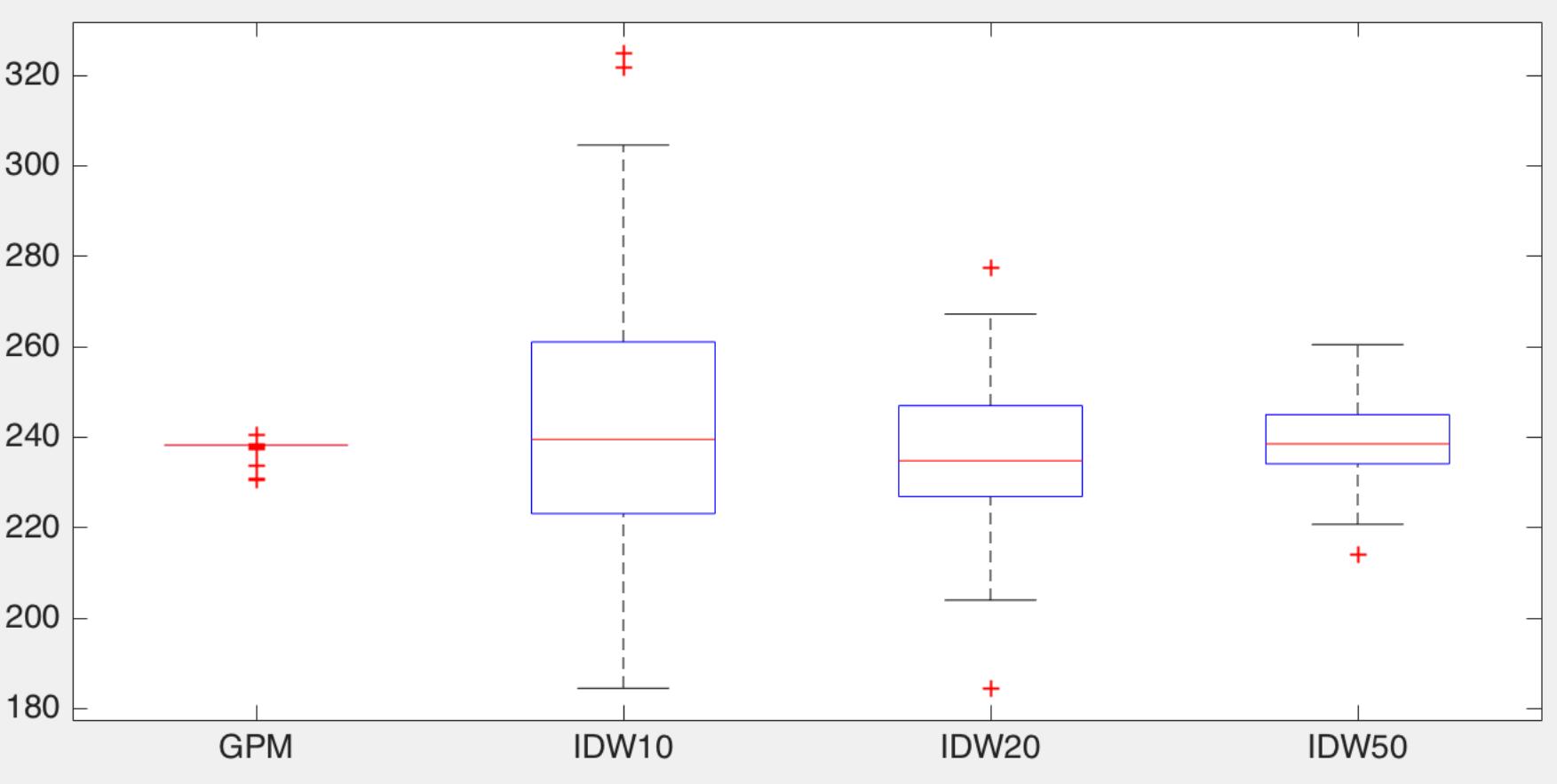


9

Global Rain Gauge Network ©The COMET Program

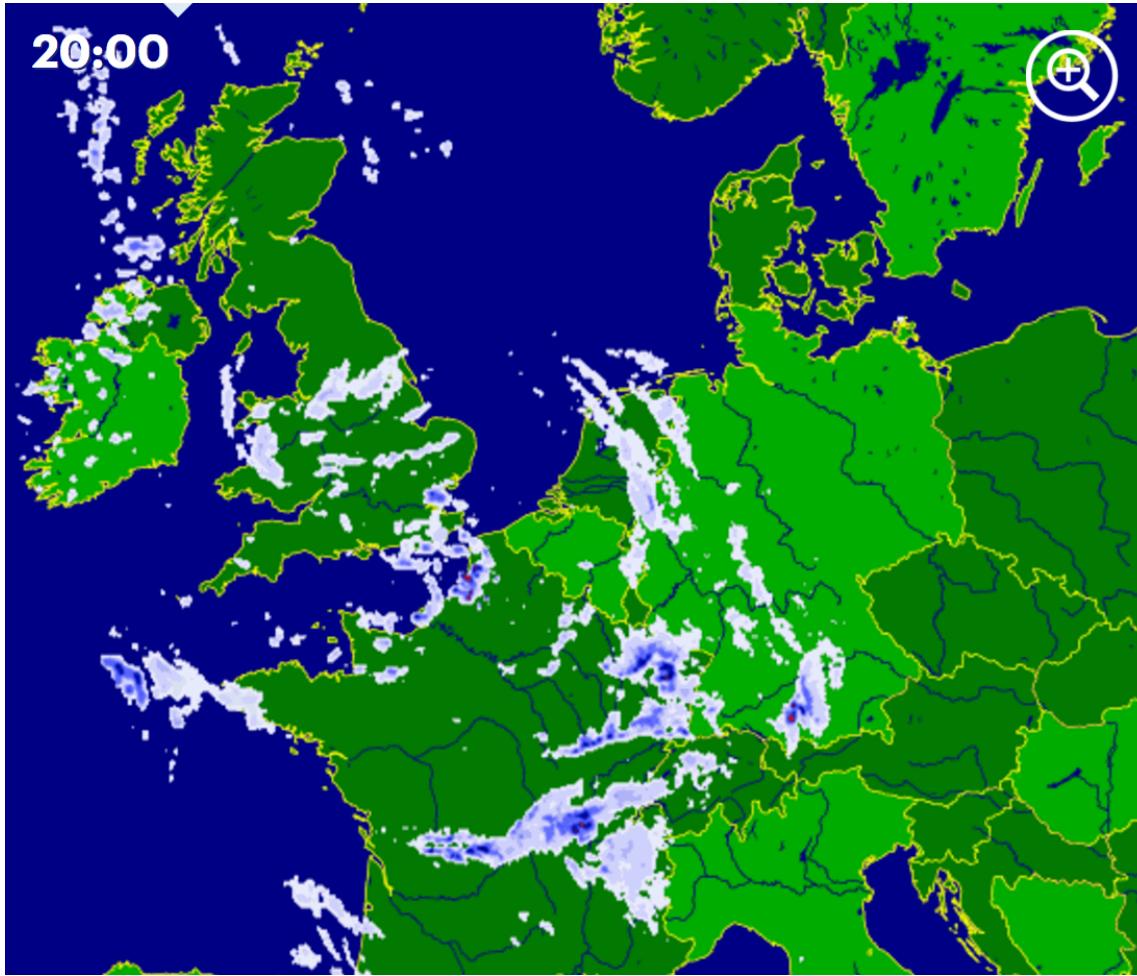
http://www.goes-r.gov/users/comet/tropical/textbook_2nd_edition/media/graphics/global_gauges_2.jpg

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	238.54
Standard deviation	1.4274	27.7536	16.0254	8.4429

Review Assignment 2



11

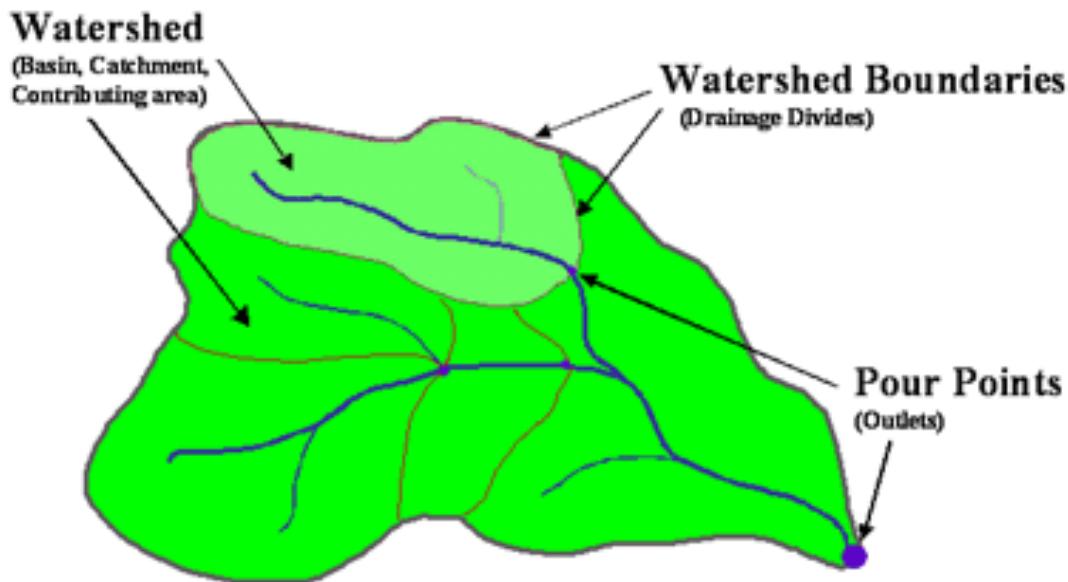
<https://www.buienradar.nl/wereldwijd/europa/buienradar>

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?

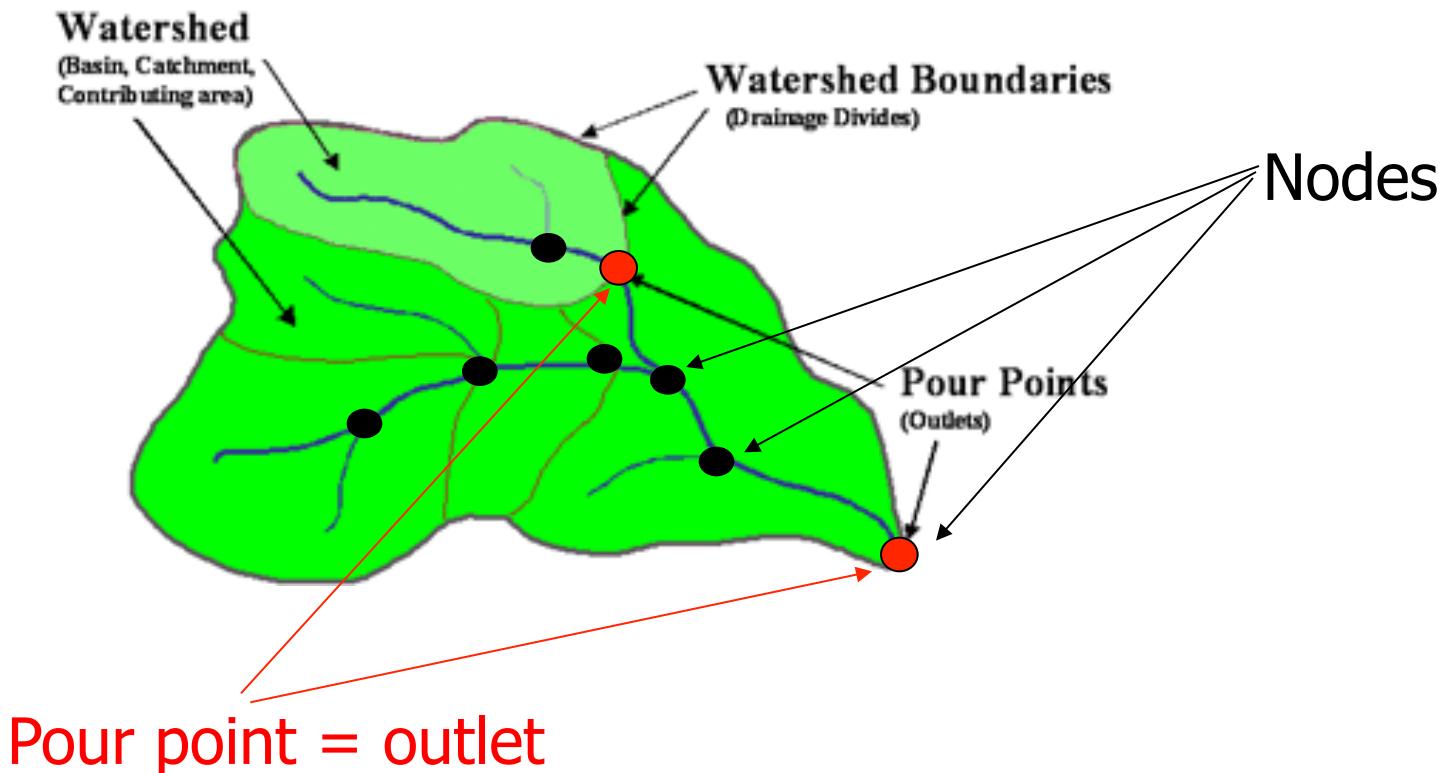
The area from which water drains to a common outlet.



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

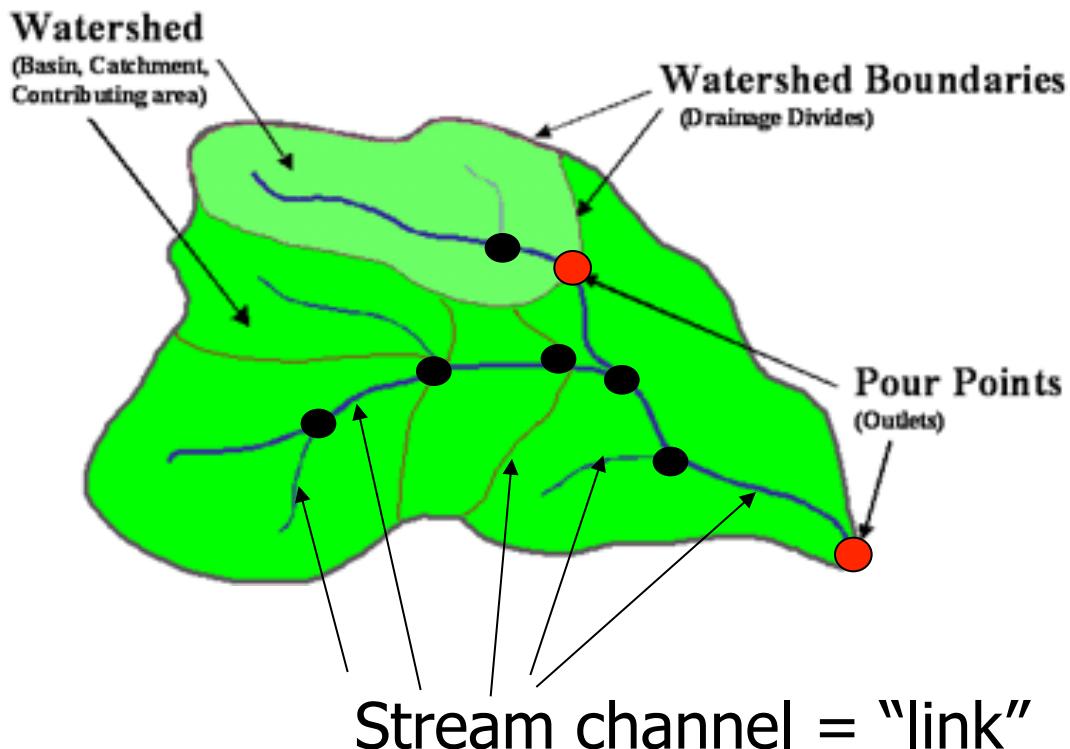
What is a watershed?

A stream network is made up of nodes and links



What is a watershed?

A stream network is made up of nodes and links



Lecture 3: Watersheds and ArcGIS

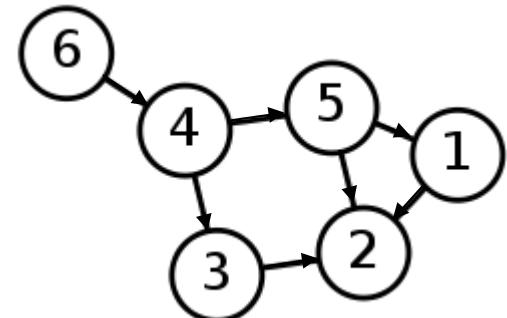
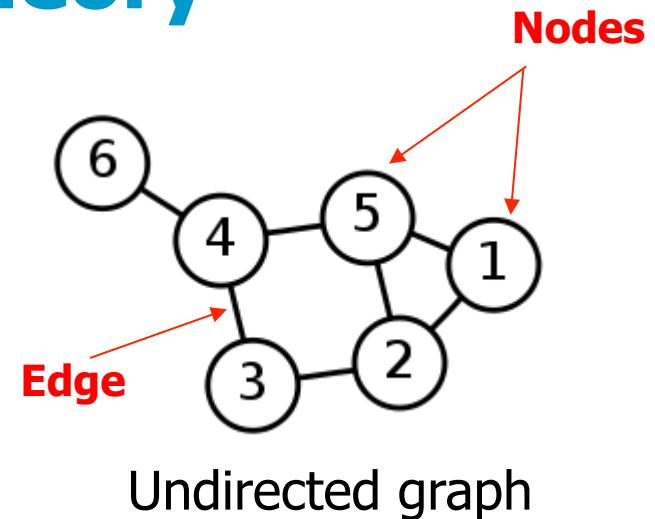
- Feedback Assignment 1
- Review Lecture 2/Assignment 2
- What is a watershed?
- **Introduction to Graph Theory**
- Determining watershed boundaries in QGIS/GRASS
- Group Activity

Introduction to Graph theory

Graph theory = study of graphs

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

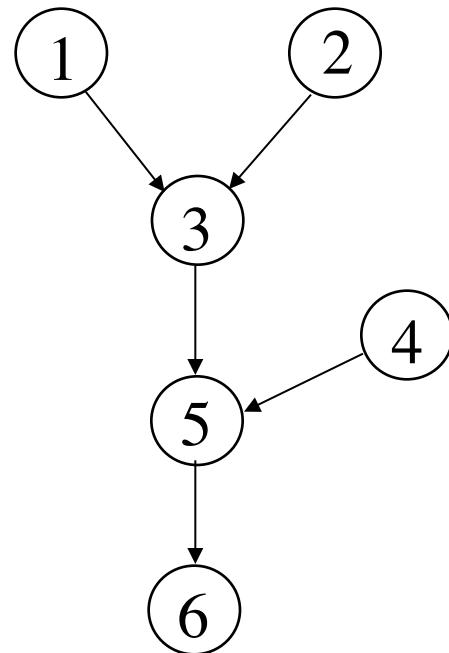
Graphs are used to model pairwise relations between objects



Introduction to Graph theory

Adjacency Matrix

Which nodes are adjacent to which other nodes

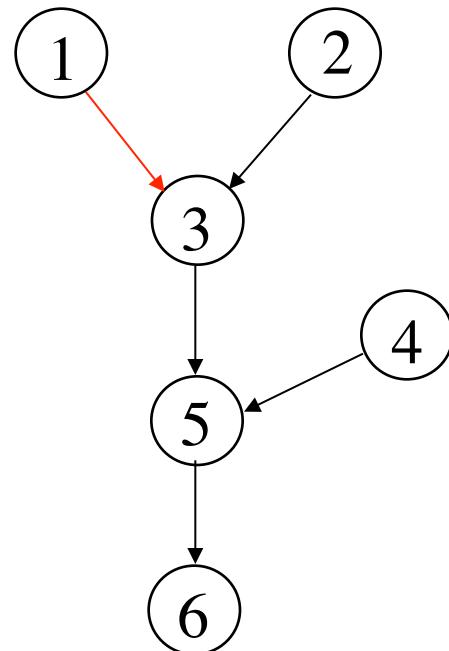


- $n \times n$ matrix
- If node i drains into node j , set $A(i,j)=1$.
- Otherwise, set to zero

Drainage patterns

Adjacency Matrix

Which nodes are adjacent to which other nodes:

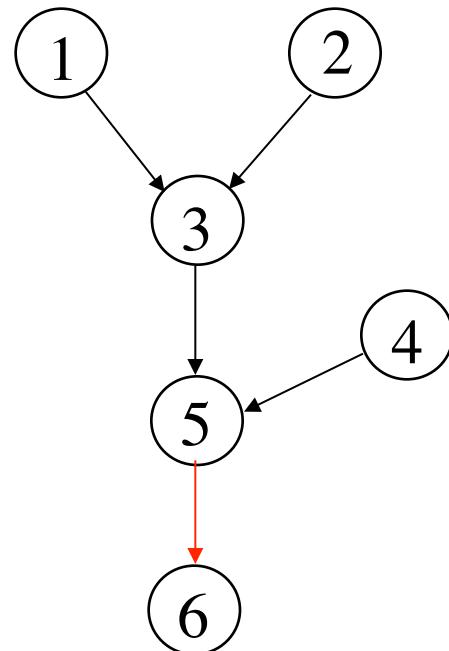


$$A = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Drainage patterns

Adjacency Matrix

Which nodes are adjacent to which other nodes:

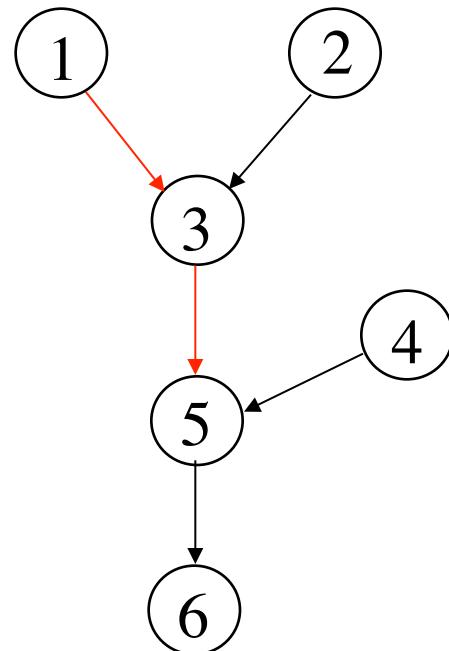


$$A = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Drainage patterns

Adjacency Matrix²

Which nodes are connected by two steps:



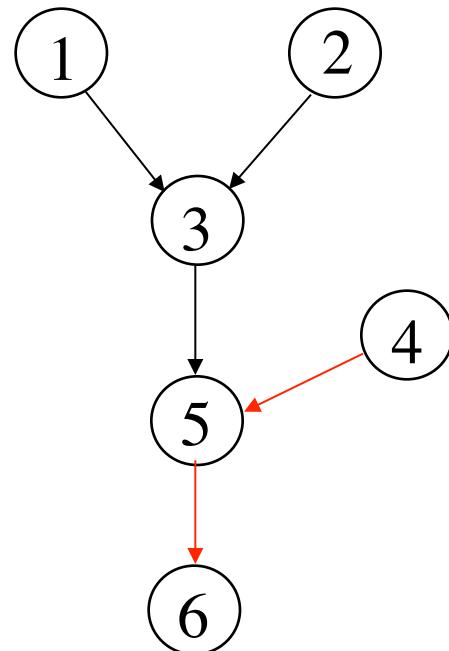
$$A^2 =$$

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

Drainage patterns

Adjacency Matrix²

Which nodes are connected by two steps:

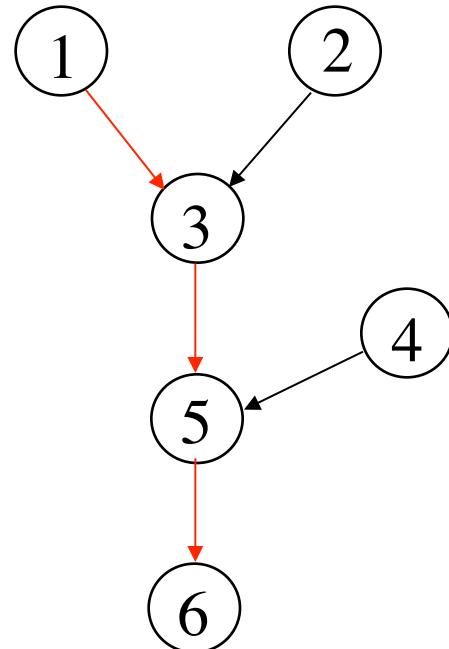


$$A^2 = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Drainage patterns

Adjacency Matrix³

Which nodes are connected by three steps:



$$A^3 =$$

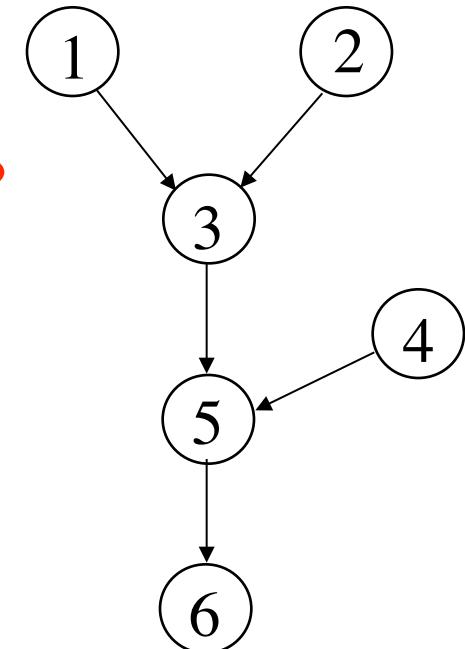
$$A^3 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

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?

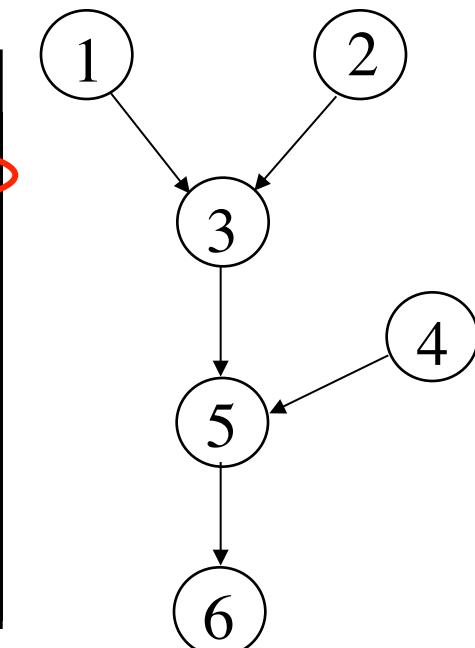
Drainage patterns

“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!

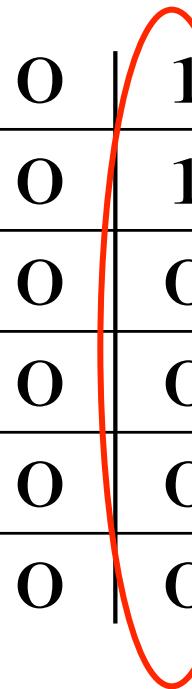


Which nodes are downstream from node 2? ... Nodes 3, 5 and 6.

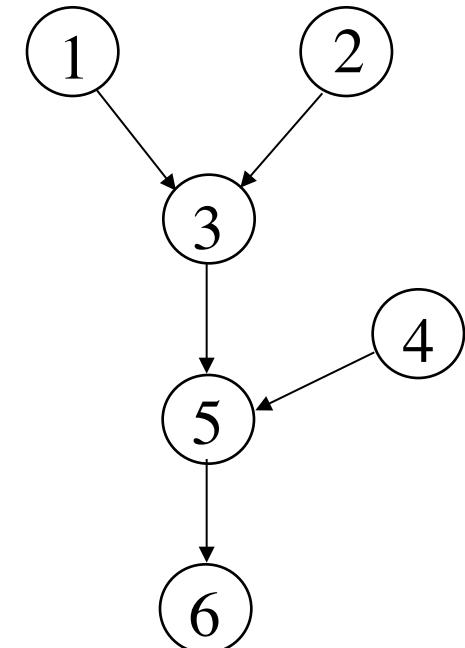
Drainage patterns

“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?



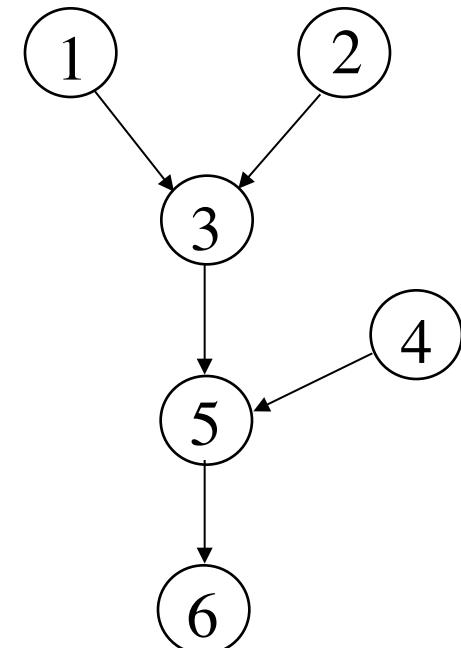
Drainage patterns

“Water availability matrix”:

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

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

Columns show
“upstream” nodes!



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

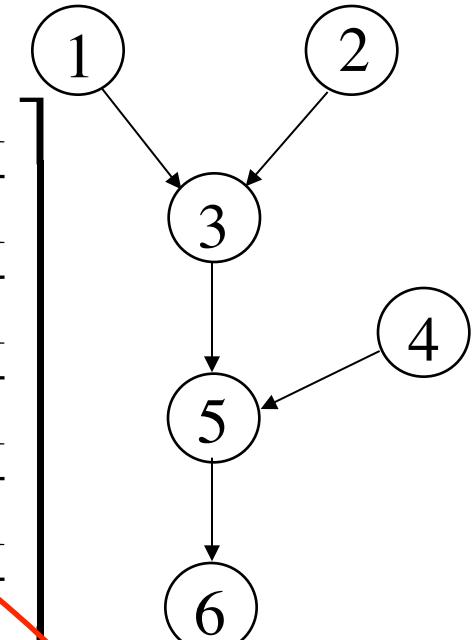
Drainage patterns

“Watershed matrix”:

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

$$\Sigma + I =$$

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



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

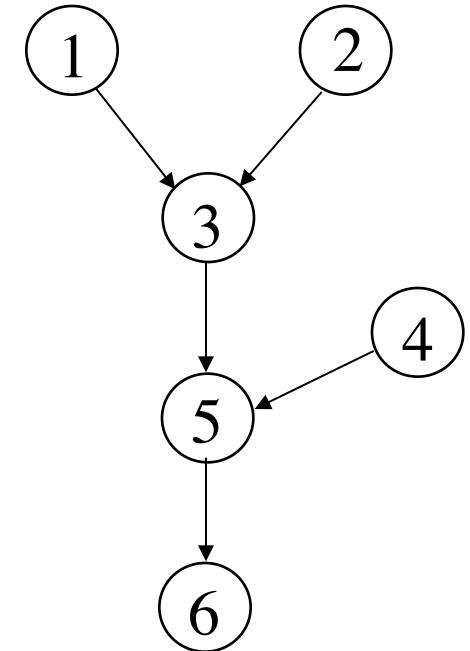
Drainage patterns

“Watershed matrix”:

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

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

1 1 3 1 5 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”

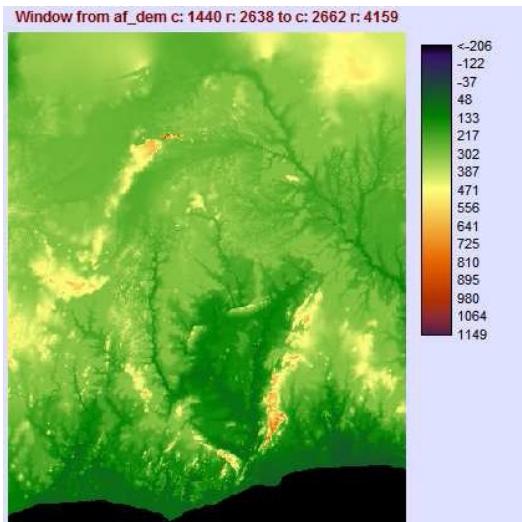
Drainage patterns

Adjacency/Watershed Matrix

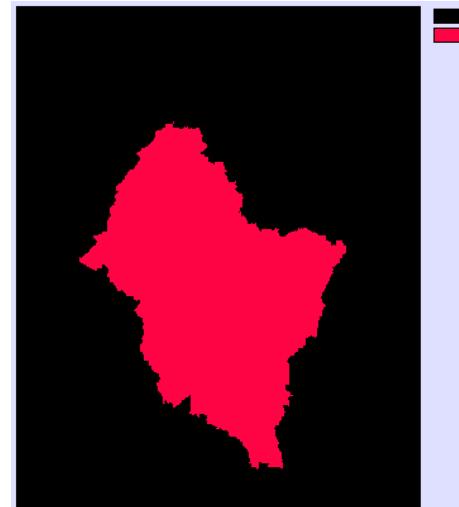
Interesting property:

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

*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:

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

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

$$Q = [3.2 \quad 2.3 \quad 0 \quad 0 \quad 0 \quad 0]$$

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

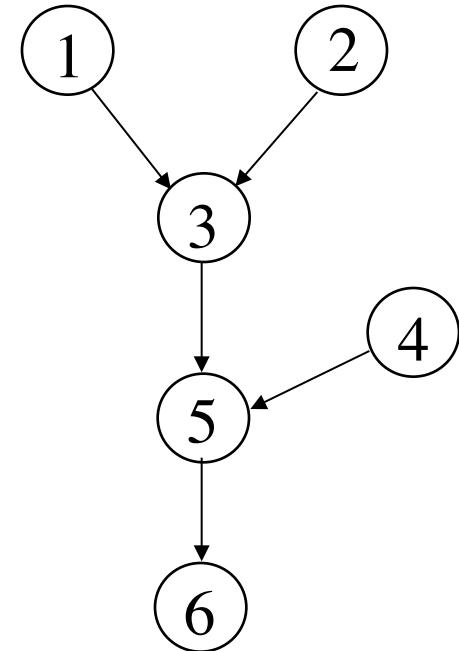
Drainage patterns

Flow accumulation

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

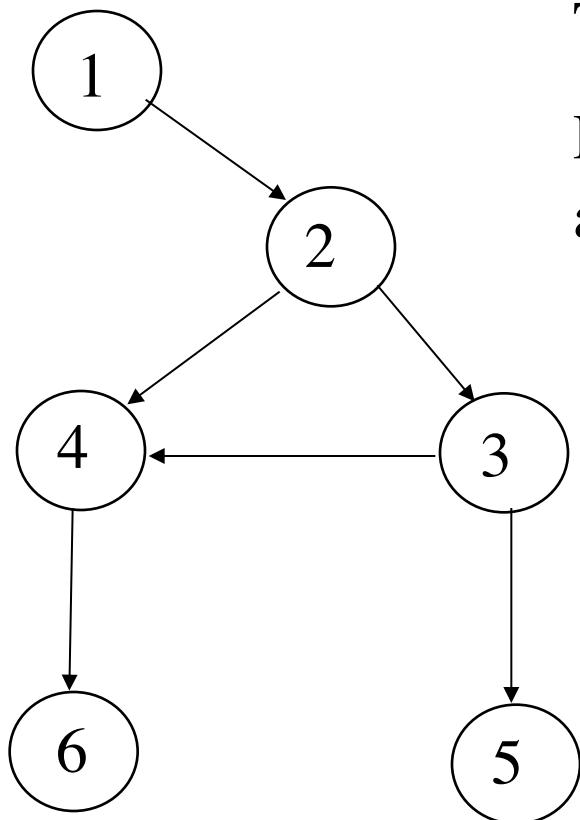
$$Q = [3.2 \ 2.3 \ 0 \ 0 \ 0 \ 0]$$

$$Q^*(\Sigma + I) = [3.2 \ 2.3 \ 5.5 \ 0 \ 5.5 \ 5.5]$$



This gives the total flow accumulated in each node

Water use along river network

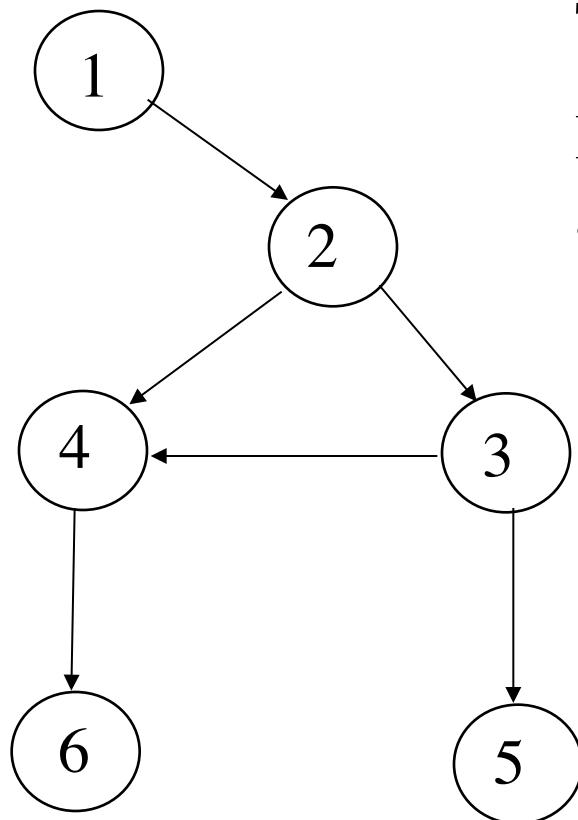


This case will be a bit more complicated.

Let's start by filling in the regular adjacency matrix

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

Water use along river network

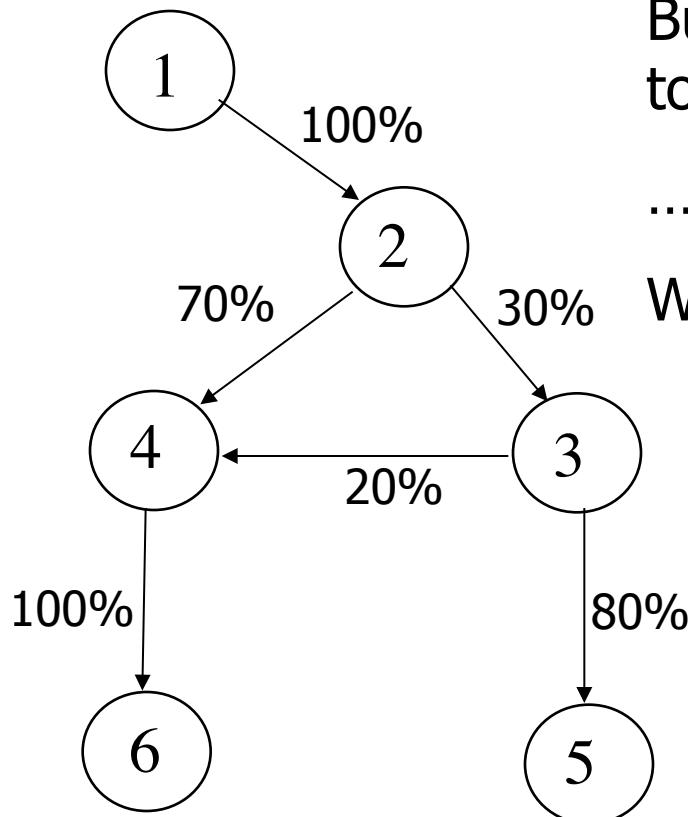


This case will be a bit more complicated.

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



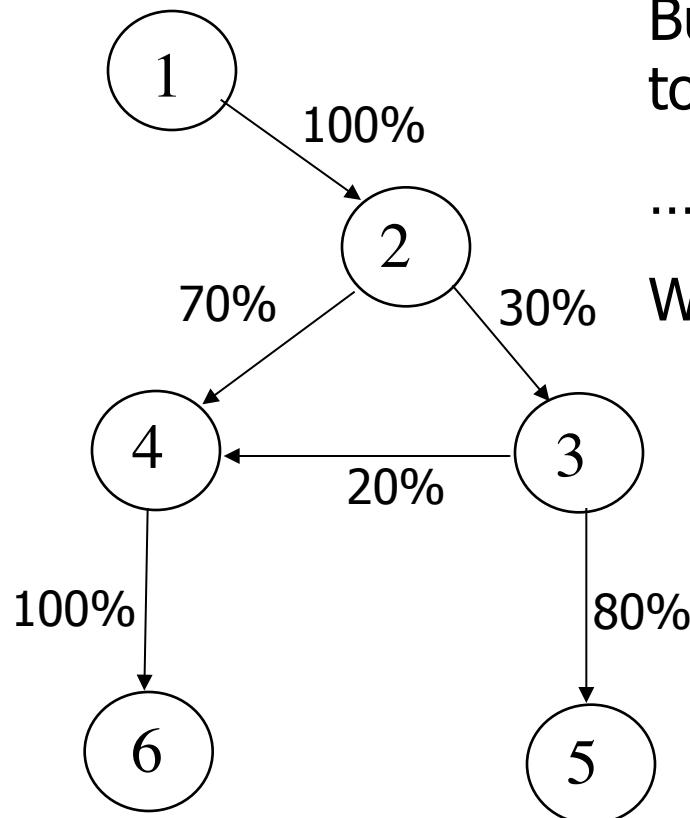
But how can all the water go from node 2 to both nodes 3 and 4?

... It doesn't!

What happens to our adjacency matrix?

$$W = \begin{bmatrix} & & & \\ & ? & & \\ & & & \\ & & & \end{bmatrix}$$

Water use along river network



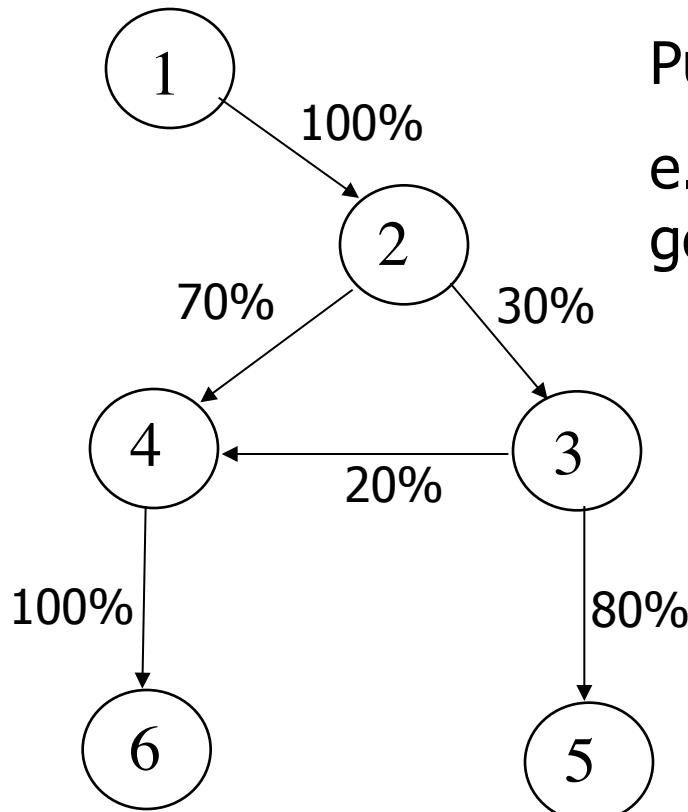
But how can all the water go from node 2 to both nodes 3 and 4?

... It doesn't!

What happens to our adjacency matrix?

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

Water use along river network

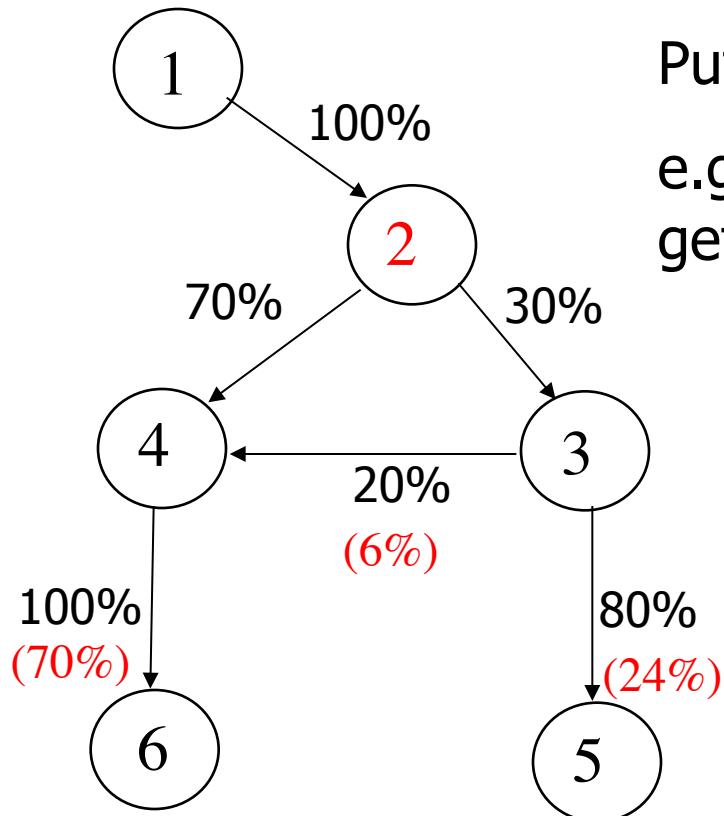


Put W into Matlab/excel and calculate W^2 :
e.g. Where does the water from node 2 get to in two steps?

$$W^2 = \begin{bmatrix} & \\ & \\ & \\ & \\ & \\ & \\ & \end{bmatrix}$$

A large teal button with a white question mark in the center. The button has a black border and a slight shadow. To the left of the button, the text $W^2 =$ is written in a black serif font. To the right of the button, there is a vertical bracket spanning the height of the button, with the numbers 1, 2, 3, 4, 5, 6, and 7 positioned above it, corresponding to the nodes in the network diagram.

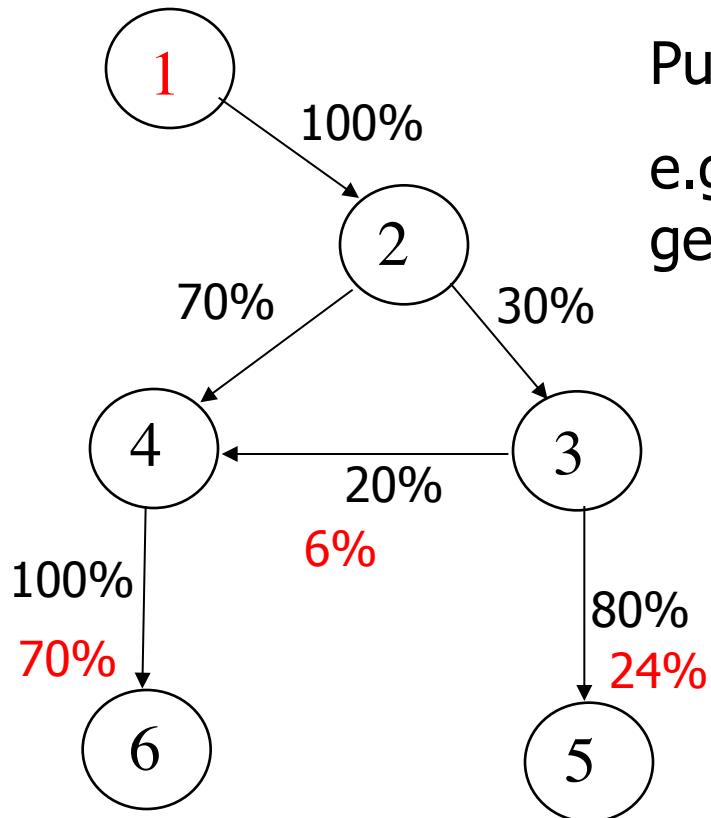
Water use along river network



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

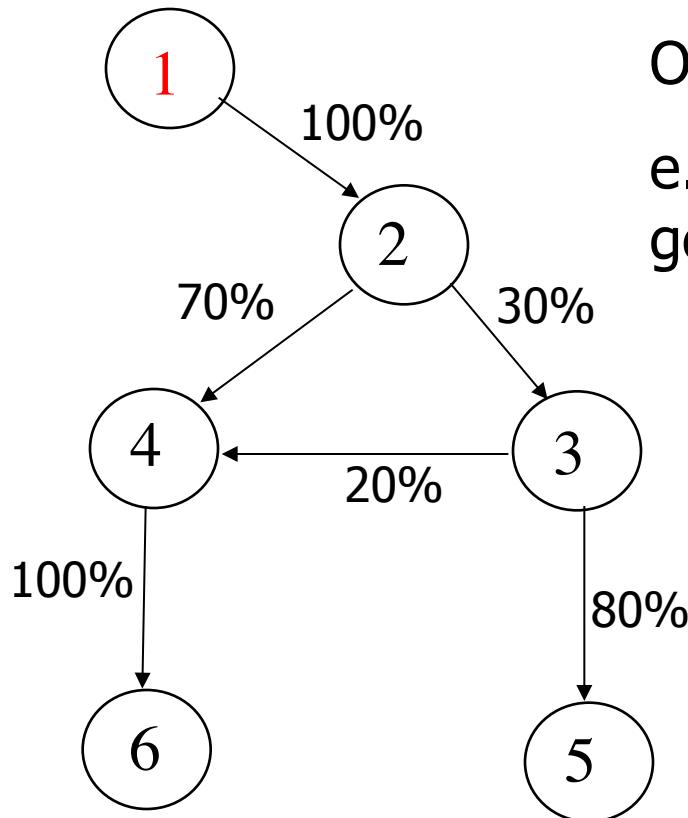


Put W into Matlab/excel and calculate W^3 :
e.g. Where does the water from node 1 get to in three steps?

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

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

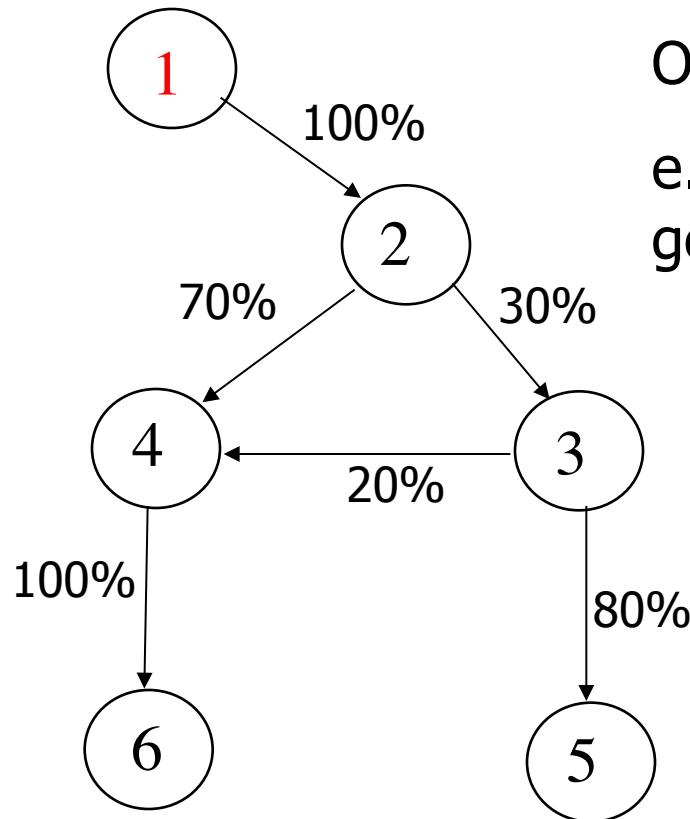


One last time step, let's calculate W^4 :

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

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

Water use along river network

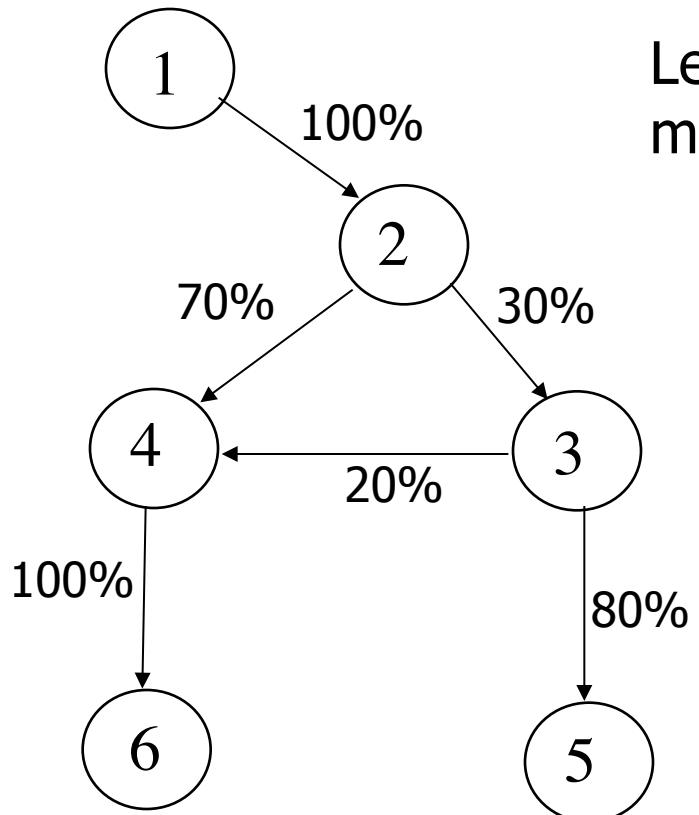


One last time step, let's calculate W^4 :

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

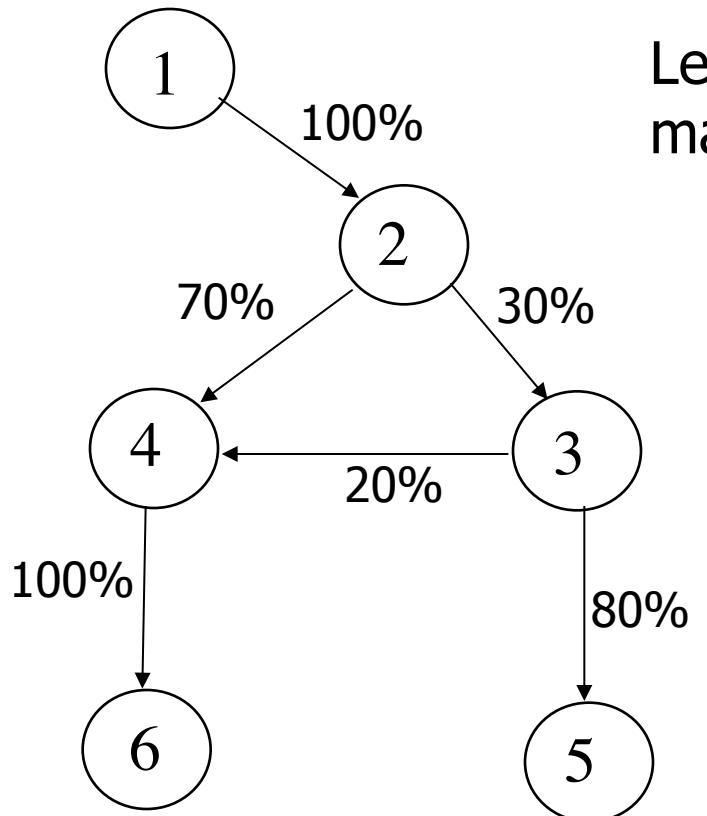


Let's calculate the water availability matrix, Ω , for this case:

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



Water use along river network

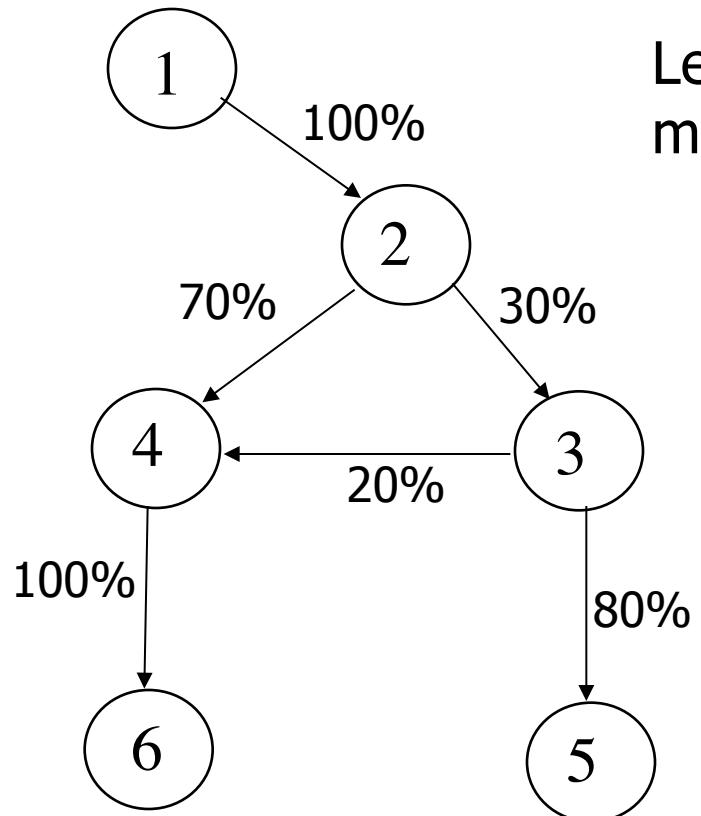


Let's calculate the water availability matrix, Ω , for this case:

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

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

Water use along river network

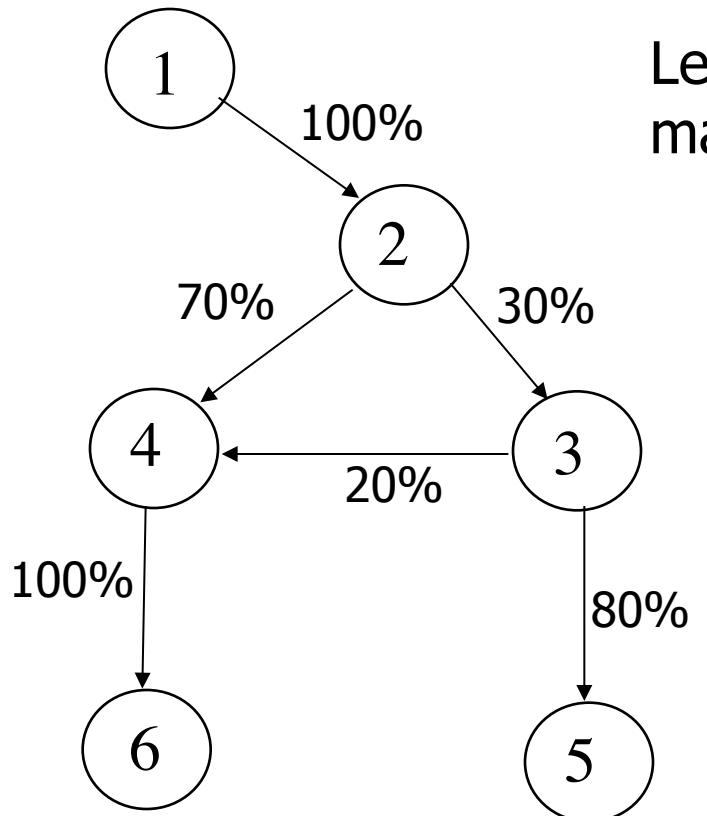


Let's calculate the water availability matrix, Ω , for this case:

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

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

Water use along river network

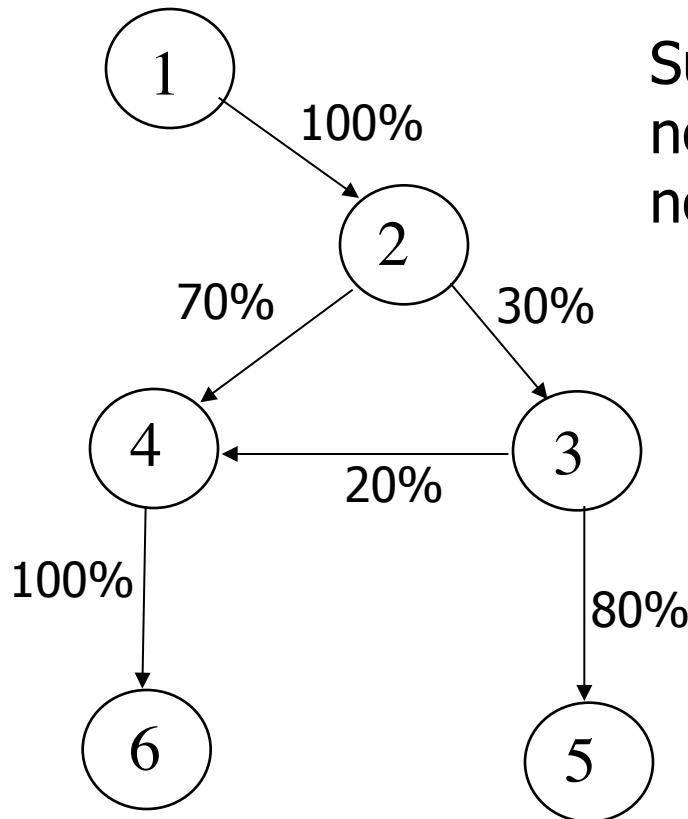


Let's calculate the water availability matrix, Ω , for this case:

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

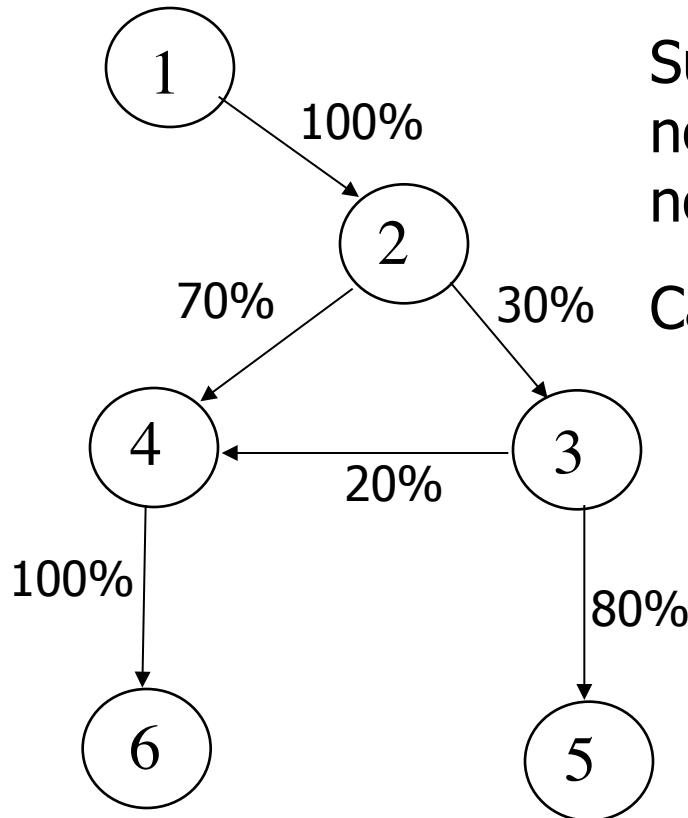
$$\Omega = \begin{bmatrix} 0 & 1.0 & 0.3 & 0.76 & 0.24 & 0.76 \\ 0 & 0 & 0.3 & 0.76 & 0.24 & 0.76 \\ 0 & 0 & 0 & 0.2 & 0.8 & 0.2 \\ 0 & 0 & 0 & 0 & 0 & 1.0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Water use along river network



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

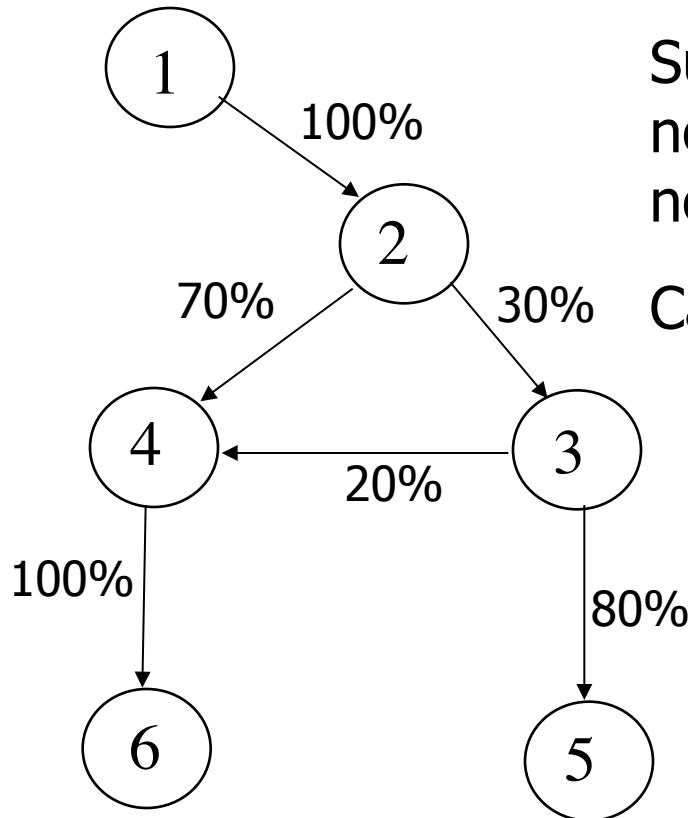
Water use along river network



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

Calculate $P^*\Omega$ where $P=[200 \ 0 \ 0 \ 0 \ 0 \ 0]$

Water use along river network

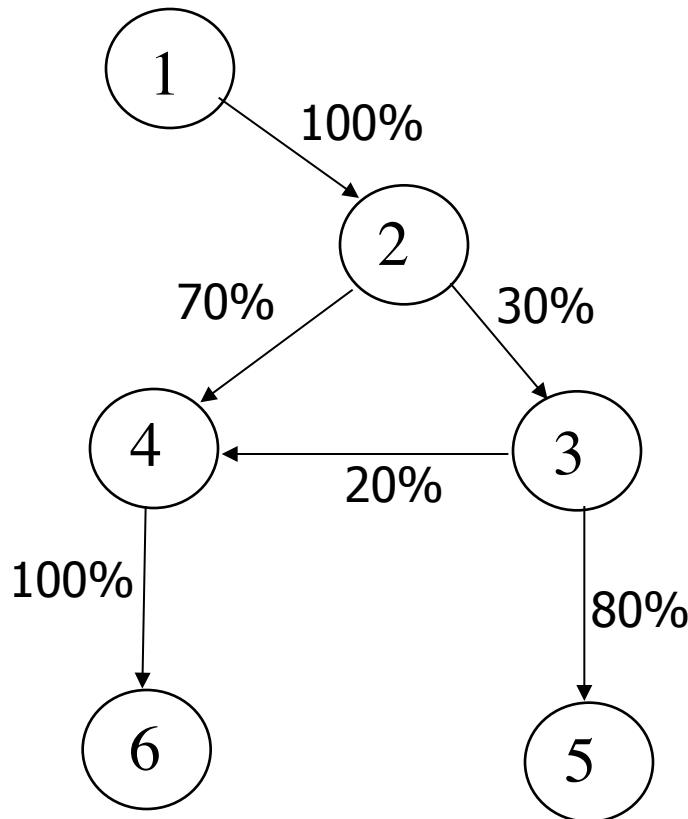


Suppose we inject 200 units of water at node 1. How much will we see at each node?

Calculate $Q = P * \Omega$ where $P = [200 \ 0 \ 0 \ 0 \ 0 \ 0]$

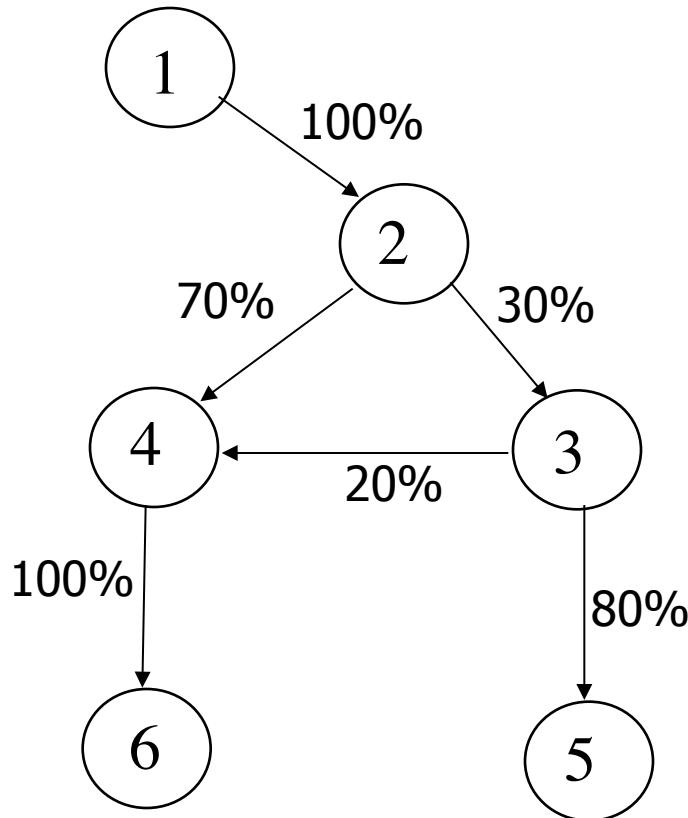
$$Q = [0 \ 200 \ 60 \ 152 \ 48 \ 152]$$

Water use along river network



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

Water use along river network

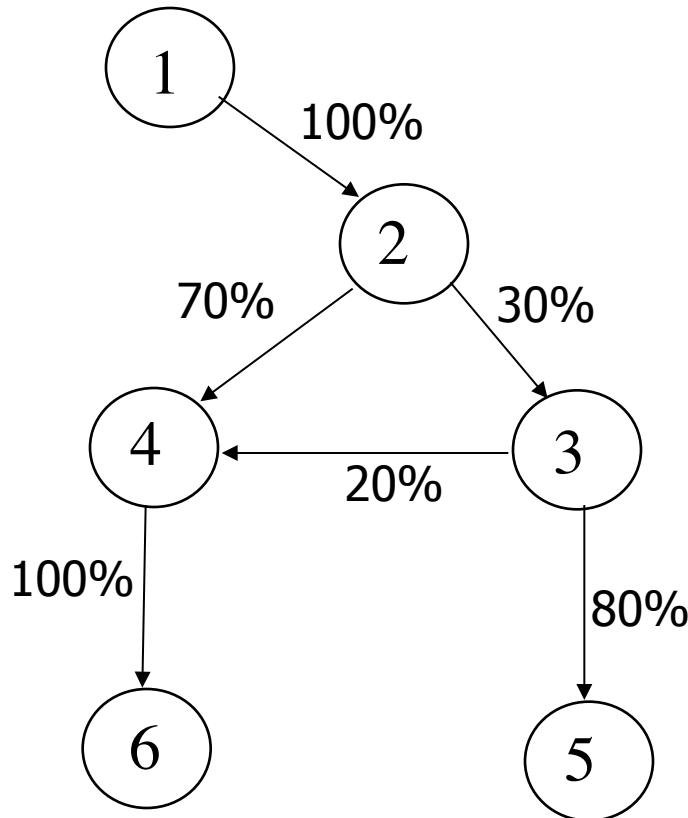


How do you account for water being used at a node?

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

$$P=?$$

Water use along river network

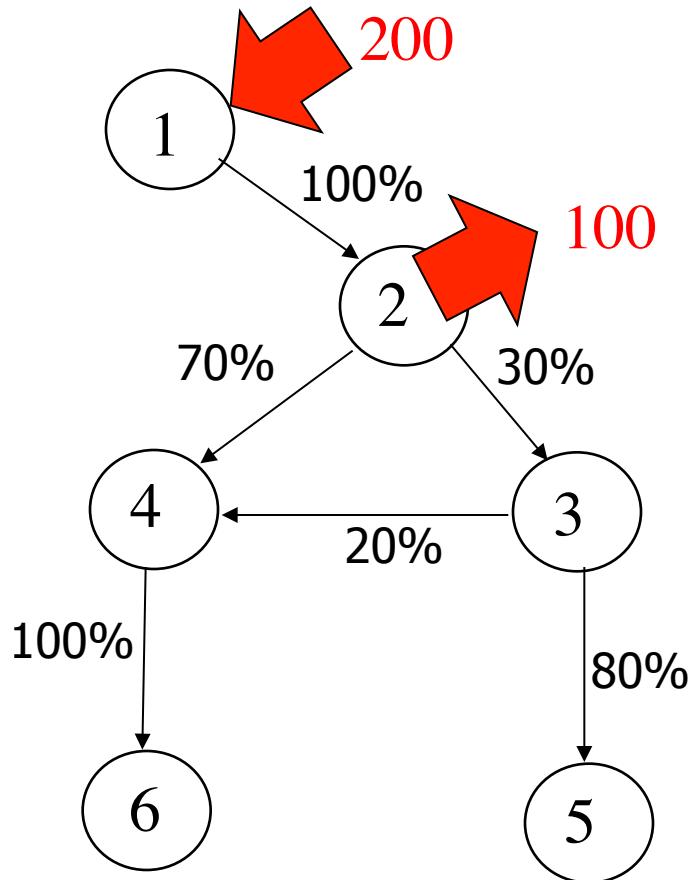


How do you account for water being used at a node?

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

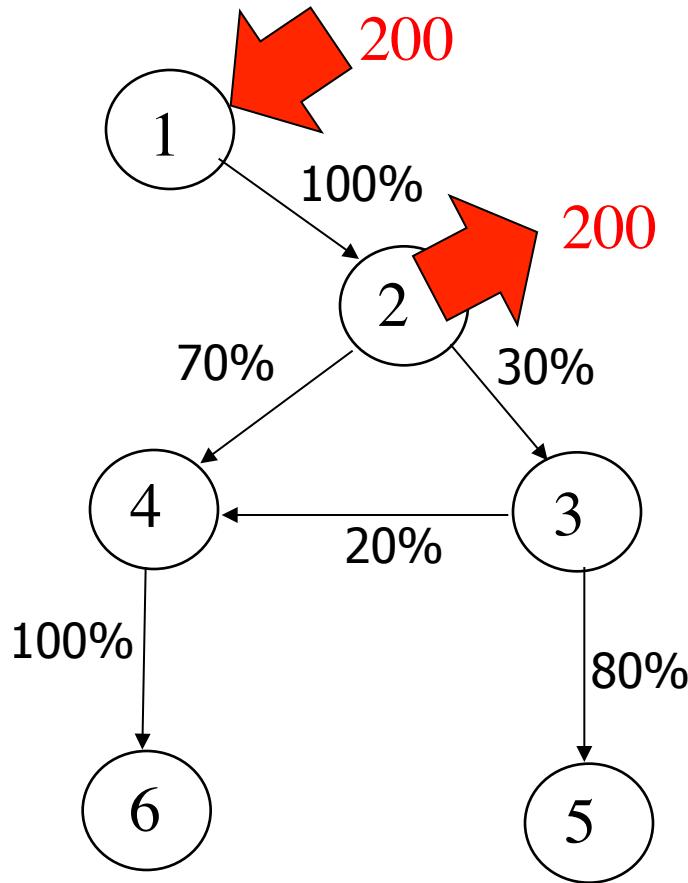


$$P = [200 \ -100 \ 0 \ 0 \ 0 \ 0]$$

$$Q = P * \Omega$$

$$Q = [0 \ 200 \ 30 \ 76 \ 24 \ 76]$$

Water use along river network

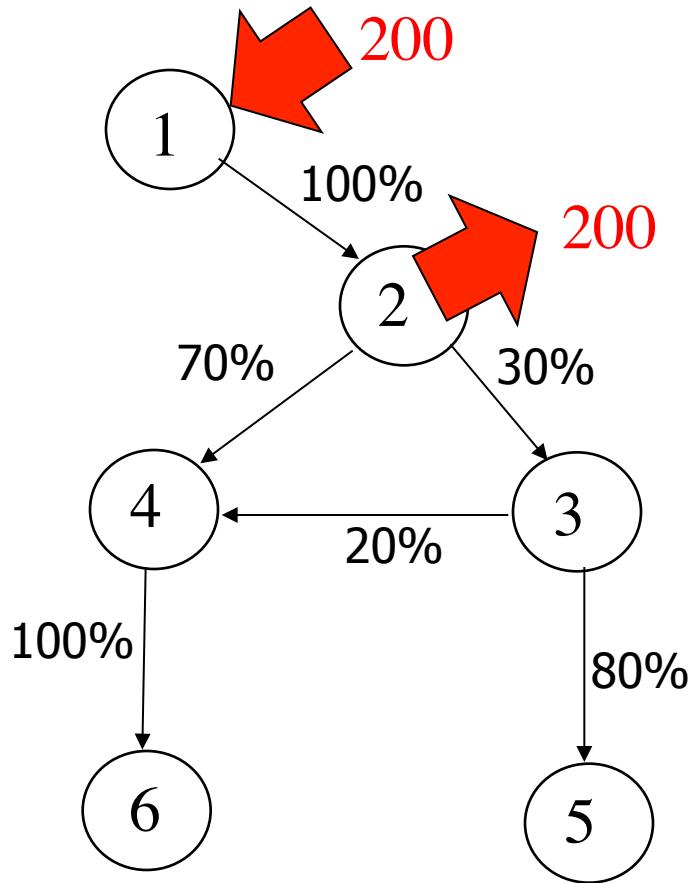


$$P = [200 \ -200 \ 0 \ 0 \ 0 \ 0]$$

$$Q = P * \Omega$$

$$Q = ??$$

Water use along river network

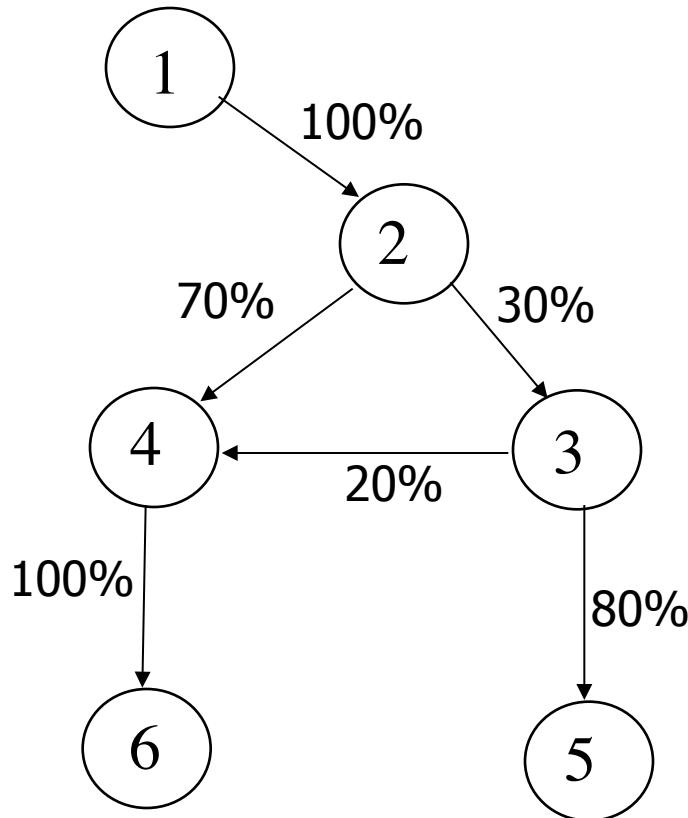


$$P = [200 \ -200 \ 0 \ 0 \ 0 \ 0]$$

$$Q = P * \Omega$$

$$Q = [0 \ 200 \ 0 \ 0 \ 0 \ 0]$$

Water use along river network



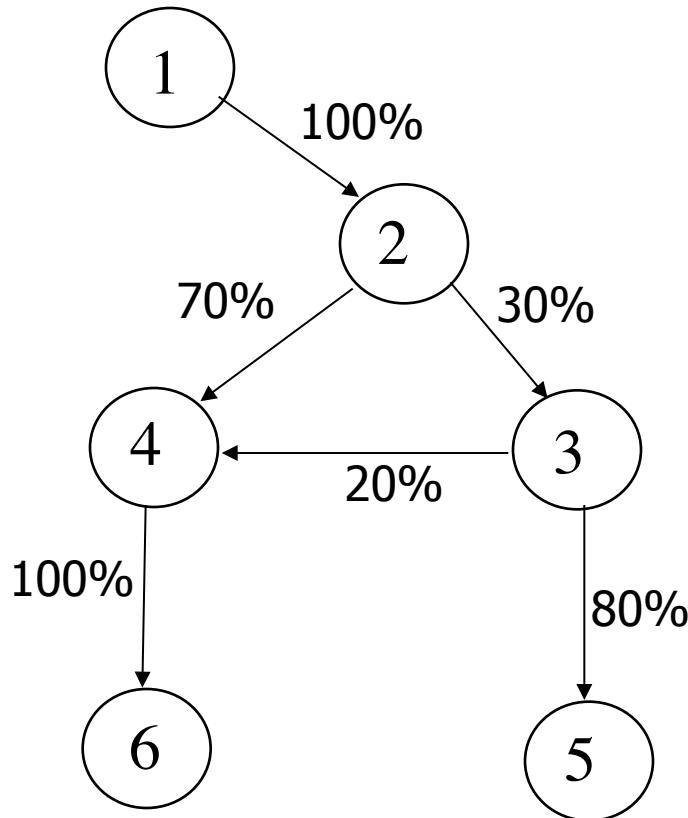
What if you demand too much water??

$$P = [200 \ -300 \ 0 \ 0 \ 0 \ 0]$$

$$Q = P * \Omega$$

$$Q = ?$$

Water use along river network



What if you demand too much water??

$$P = [200 \ -300 \ 0 \ 0 \ 0 \ 0]$$

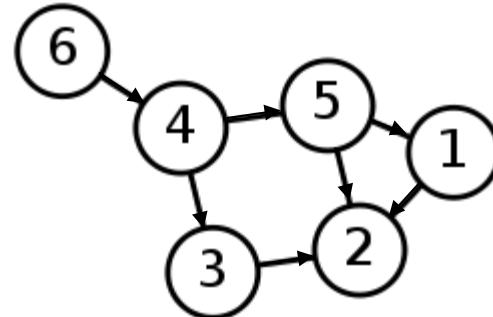
$$Q = P * \Omega$$

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

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



Coffee

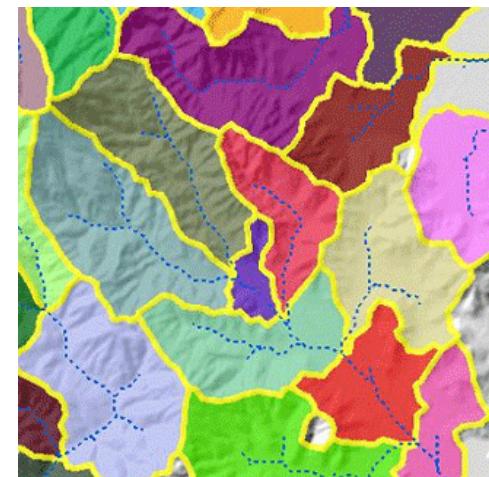
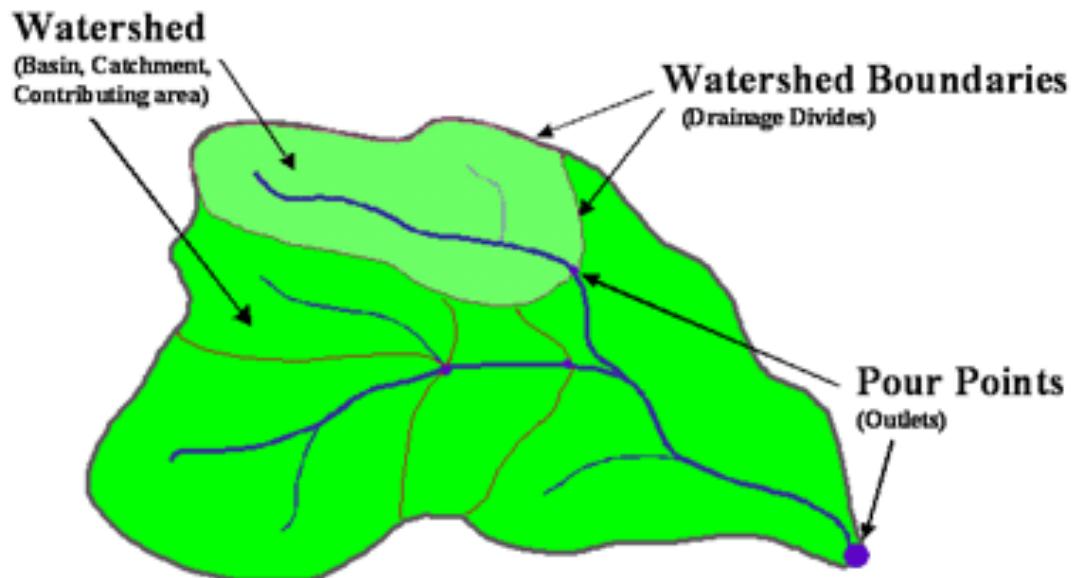
Lecture 3: Watersheds and ArcGIS

- 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.

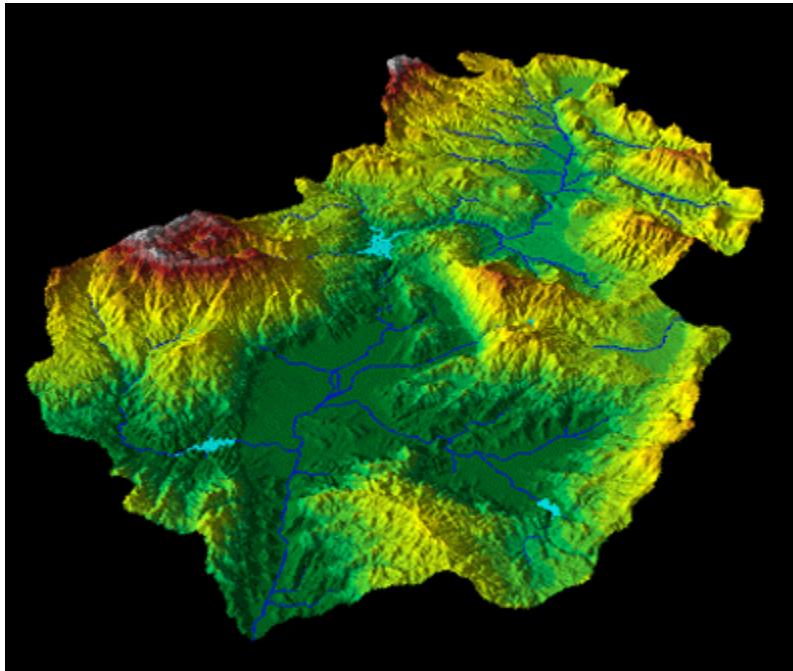


AKA drainage basin, basin, catchment, or contributing area.

Watershed delineation

Digital Elevation Model

Raster data describing surface of earth.



Accuracy depends on:

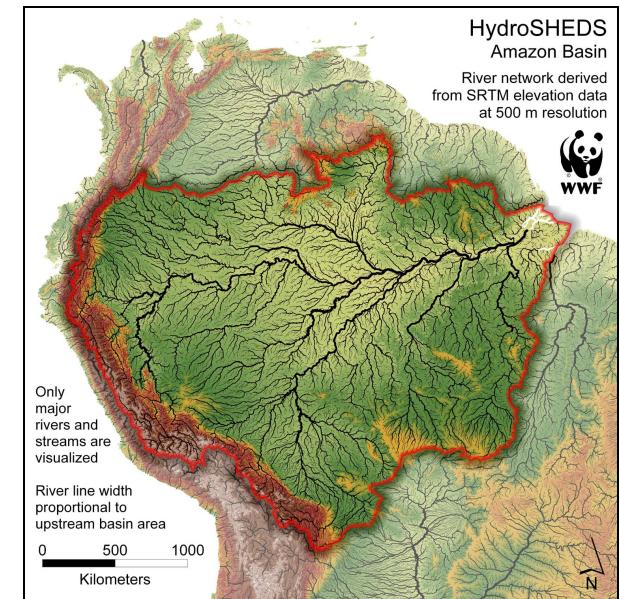
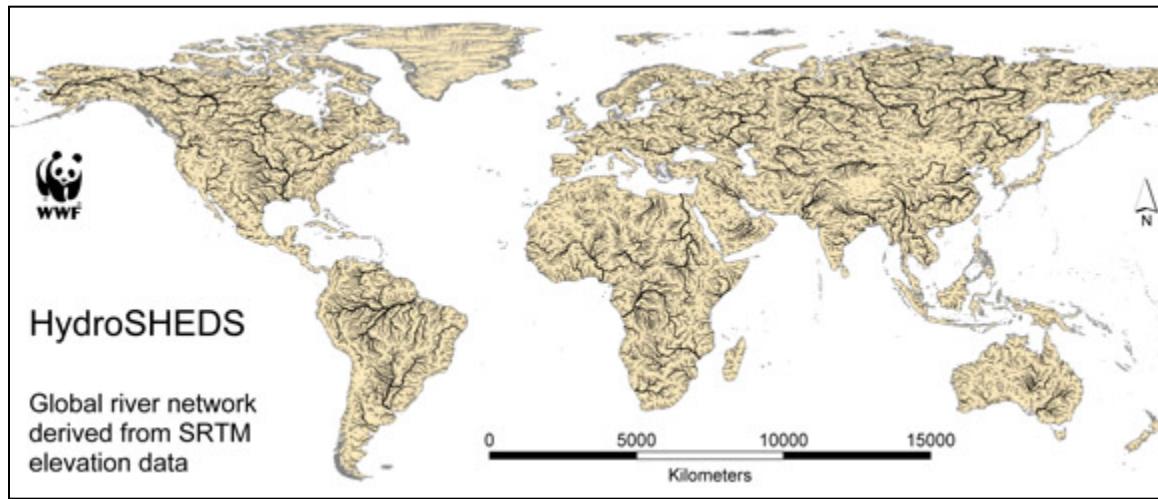
Resolution

Data type

Observation method

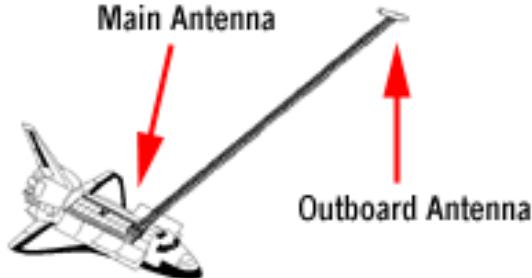
OLD: HydroSHEDS

Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales)

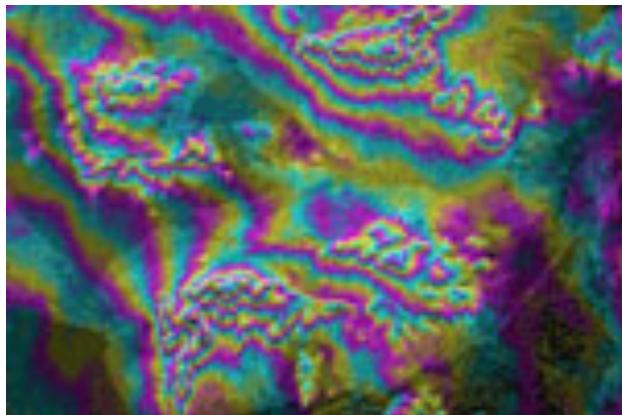


<http://hydrosheds.cr.usgs.gov/>

OLD: HydroSHEDS Shuttle Radar Topography Mission

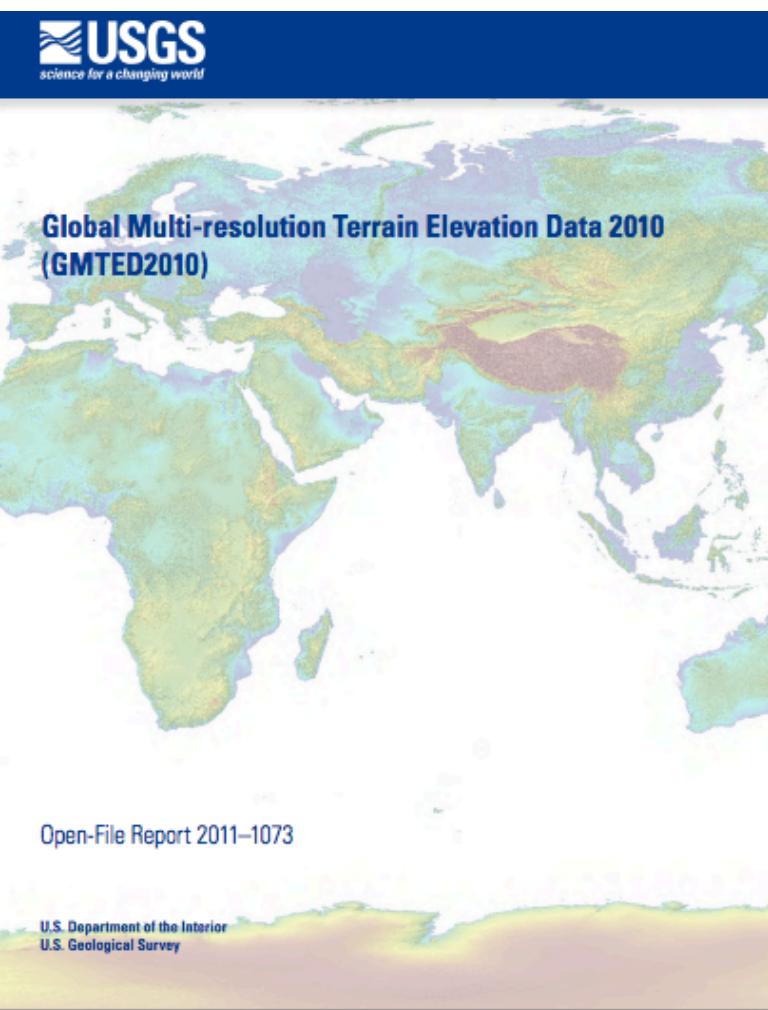


Reflected radar signals collected at two antennas,
providing two sets of radar signals separated by
a distance.



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

NEW: GMTED2010



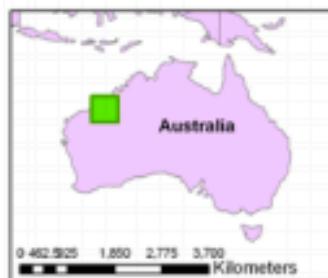
New data sources:

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

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

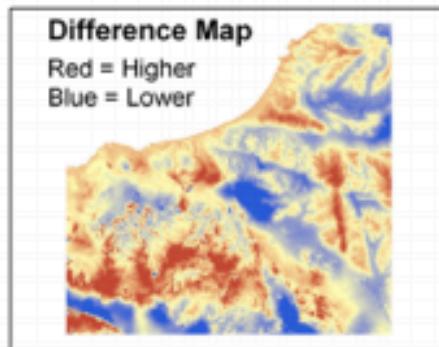
Canadian elevation data.

NEW: GMTED2010

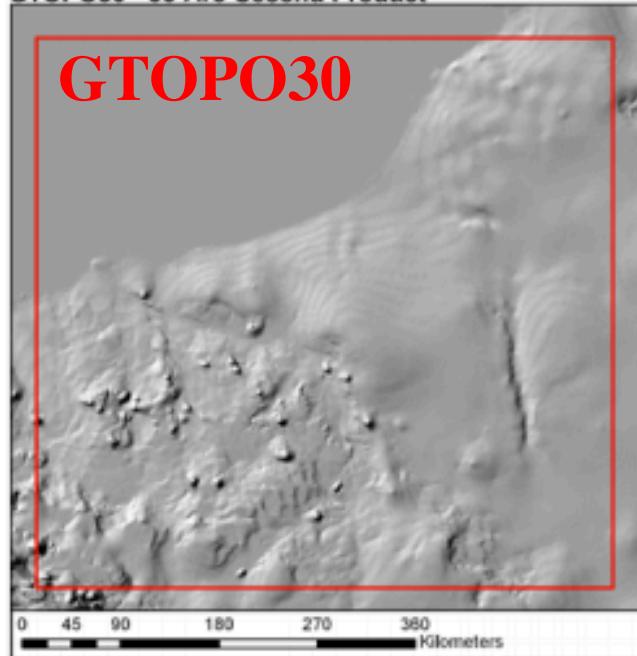


Difference Statistics: (GMTED2010 30-Arc-Second Mean Product Minus GTOPO30)

Minimum = -164.00
Maximum = 310.00
Mean = -17.60
Standard Deviation = 39.49



GTOPO30 - 30-Arc-Second Product



GMTED2010 - 30-Arc-Second Mean Product

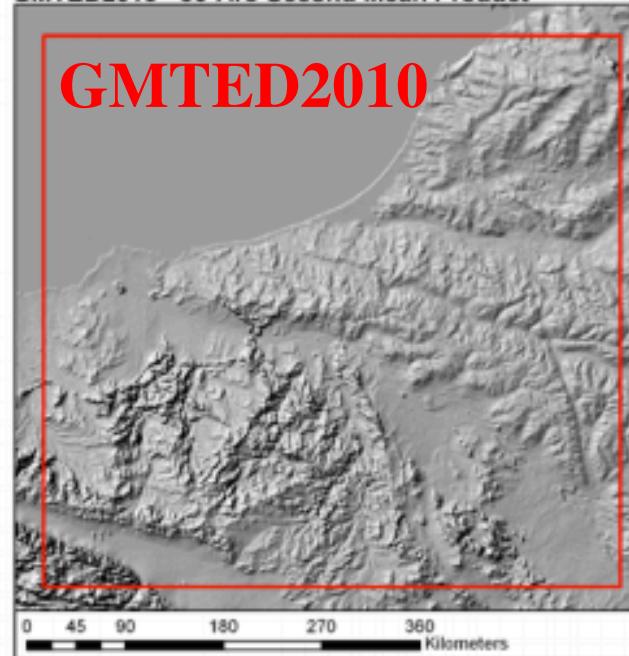


Figure 11. Comparison of the existing GTOPO30 and new GMTED2010 30-arc-second mean elevation product.

NEW: GMTED2010

Download, free from USGS EarthExplorer:

The screenshot shows the USGS EarthExplorer website interface. At the top, there's a banner with the USGS logo and the tagline "science for a changing world". Below the banner, the URL "eartheplorer.usgs.gov" is in the address bar. To the right of the address bar are navigation icons (back, forward, search, etc.) and a star icon.

The main content area has a black header bar with the text "EarthExplorer". Below this, there's a navigation bar with links for "Home", "1 New System Message", "Login", "Register", "Feedback", and "Help".

The main content area is divided into several sections:

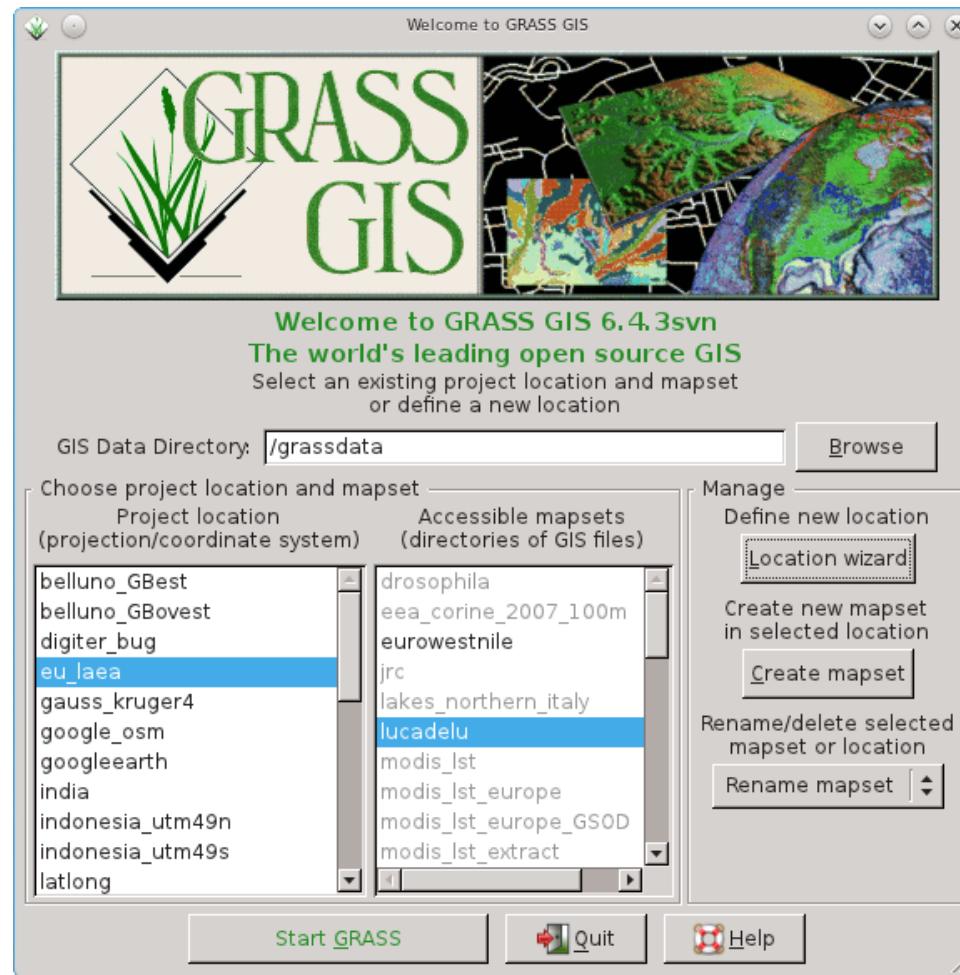
- Search Criteria:** A button labeled "Data Sets" is highlighted in blue, indicating it's the active tab. Other tabs include "Additional Criteria" and "Results".
- 2. Select Your Data Set(s):** A section where users can check boxes for data sets. One box is checked: "Use Data Set Prefilter" (What's This?).
- Data Set Search:** A text input field for searching data sets.
- Category List:** A sidebar on the left containing expandable categories:
 - Aerial Imagery
 - AVHRR
 - Cal/Val Reference Sites
 - Commercial
 - Declassified Data
 - Digital Elevation
 - ASTER GLOBAL DEM
 - GMTED2010** (checkbox checked)
 - GTOPO30
 - GTOPO30 HYDRO 1K
 - SRTM
 - SRTM Void Filled
 - Digital Line Graphs
 - Digital Maps
 - EO-1
- Search Criteria Summary:** A map-based search interface. It shows a satellite view of the North Pacific region, specifically the Bering Sea, Gulf of Alaska, Canada, and the western United States. A specific location is marked with a yellow pin. The map includes state/province abbreviations like AK, YT, NT, AB, BC, SK, WA, MT, ID, OR, NV, UT, CO, AZ, NM, HI, and Mexico. A coordinate box shows "(64° 19' 15" N, 179° 38' 54" E)". Buttons for "Options", "Overlays", "Map", and "Satellite" are present. A "Clear Criteria" button is also visible.

Watershed delineation using FOSS*?

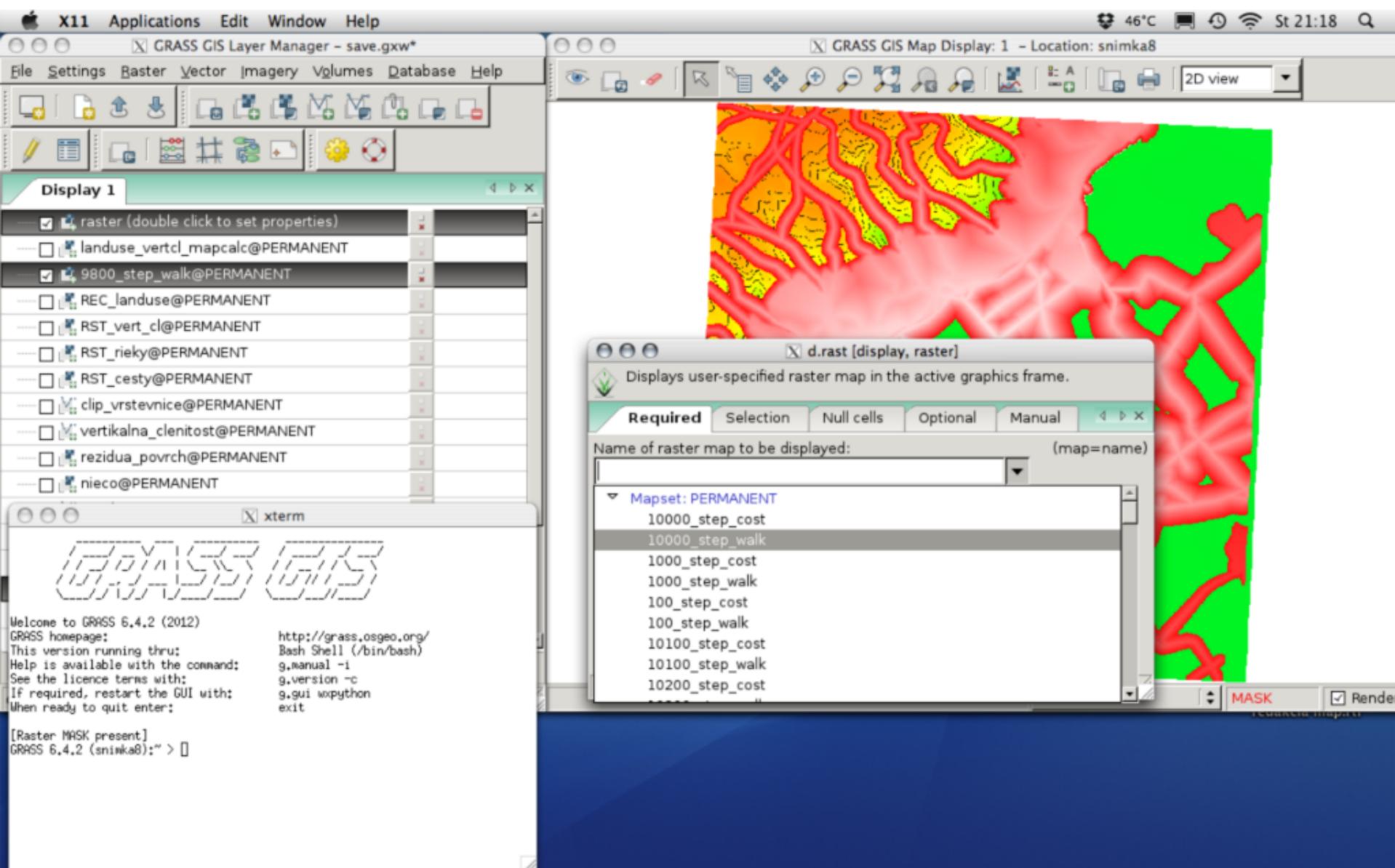
The screenshot shows the official GRASS GIS website at grass.osgeo.org. The header features the GRASS GIS logo and the text "The world's leading Free GIS software". A navigation bar includes links for Home, Download, Documentation, Gallery, Support, Donations, Development, and Get involved!. A search bar is on the left, and the OSGeo Project logo is in the top right. The main content area has a green header "Home". It features a "Celebrating 30 years!" banner. Below it, a paragraph describes GRASS GIS as a free Geographic Information System used for geospatial data management and analysis. Three download links for Mac OSX, Windows, and Linux are shown. A "Newcomers: How to start with GRASS?" section lists links for about GRASS GIS, documentation, tutorials, and migration hints. A "Module of the Day" section highlights the "r.le.trace" module. A "Screenshots" section shows two screenshots of GRASS GIS software interfaces. At the bottom, a footer links to mirror sites and provides the last change date: "Last change: 22-Feb-2013".

*Free Open Source Software

GRASS: Interface



GRASS: Interface



GRASS: QGIS Integration

QGIS File Edit View Layer Settings Plugins Vector Raster Database Window Help (Charged) Mo

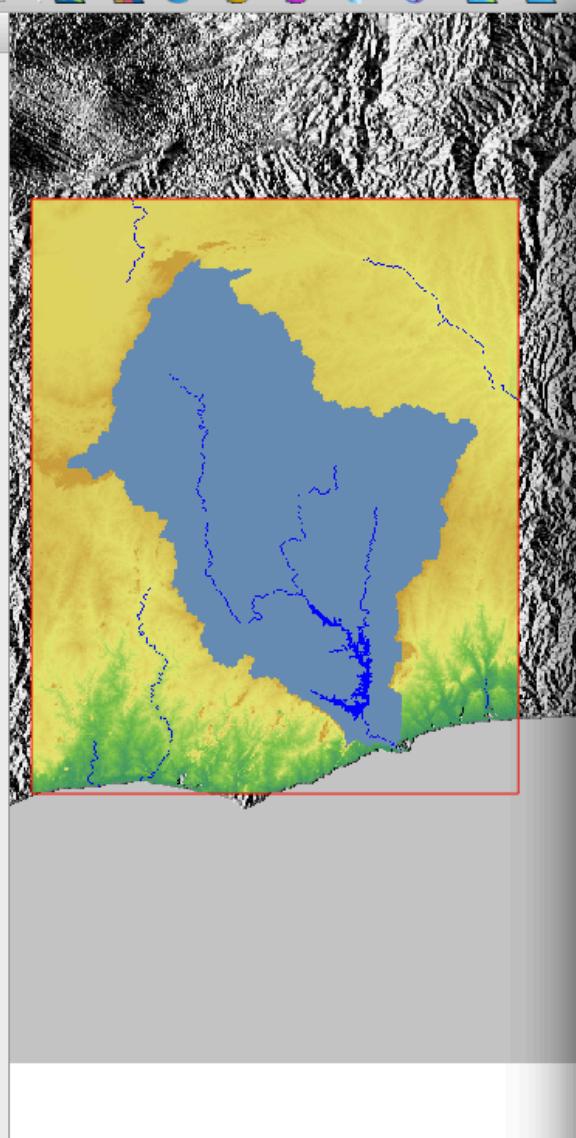
Quantum GIS 1.8.0-Lisboa – TerrainAndWShed

GRASS Tools: Volta3/TAAndWShed

Layers

- VoltaStr8k
- LakeVolta2
- LakeVolta
- 1-5
- VolBa8kmMask
- VoltaBas8k
- MajVolBas
- VoltaDraDirDeg1
- VoltaDraDir
- VoltaAcc
- LandDEM

Control rendering order



Modules Tree Modules List Browser

Filter

- r.texture Create raster images with textural features from raster (first serie of...)
- r.texture.bis Create raster with textural featur...
- r.los Line-of-sight raster analysis
- r.grow.distance Create raster of distance to features in input layer
- r.walk.coord Generate raster of cumulative cost of moving between locations, based on elevation and friction input rasters and starting point(...)
- r.walk_vect Generate raster of cumulative cost of moving between locations, based on elevation and friction input rasters and starting point(...)
- r.clump Recategorize contiguous cells to unique categories
- r.grow Create raster with contiguous areas grown by one ...
- r.thin Thin no-zero cells that denote line features
- r.watershed Watershed Analysis**
- r.carve Take vector stream data, transform it to raster, and subtract depth fr...
- r.fill.dir Filter and create depressionless elevation map and flow direction map from elevation raster
- r.lake.xy Fill lake from seed point at given level
- r.lake.seed Fill lake from seed at given level
- r.topidx Create 3D volume map based on 2D elevation an...
- r.basins.fill Create watershed subbasins raster

GRASS overview

QGIS Project Edit View Layer Settings Plugins Vector Raster Database Web Window Help A 4

Manage and Install Plugins... Python Console Analyses GRASS

Open Mapset New Mapset Close Mapset Open GRASS Tools Display Current Grass Region GRASS Options

Layers Panel

Volta... Volta... LAN... 0.000 0.1 100 200 500 1000 2000 3000 5000 8850 Slop... patc... Shad...

Coordinate -0.24,14.91 Scale 1:6,285,316 Rotation 0.0 Render EPSG:4326

ft 73

GRASS overview

The screenshot shows the QGIS interface with a terrain map displayed in the main window. The map uses a color gradient from yellow to green, indicating elevation or another variable. A legend on the left side of the map provides a scale for these values. The GRASS Tools menu is open on the right, showing a list of modules. The 'Modules' tab is selected, displaying a hierarchical list under 'GRASS MODULES'.

- ▶ GRASS MODULES
 - ▶ shell GRASS shell
 - ▶ Create new GRASS location and transfer data into it
 - ▶ File management
 - ▶ Region settings
 - ▶ Projection management
 - ▶ Raster
 - ▶ Vector
 - ▶ Imagery
 - ▶ Database
 - ▶ 3d Visualization
 - ▶ Convert coordinates
 - ▶ Help

Two ways to run GRASS modules:

- 1) via the GRASS shell
- 2) finding the tool in this menu

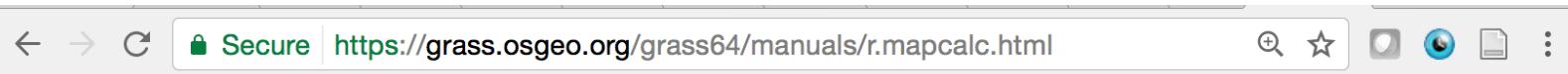
GRASS modules

- 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

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



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*.

77

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

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 Tools: WA_TerAn/WA_TA

Modules Region  Close mapset

Filter

GRASS MODULES

- shell
GRASS shell
 - Create new GRASS location and transfer data in
 - File management
 - Region settings
 - Projection management
- Raster
 - Develop map
 - Manage map colors
 - Spatial analysis
 - Buffer
 - Mask
 - Map algebra
- r.mapcalc
Graphical raster map calculator
 - Module: r.mapcalc
 - Options Output Manual
 - Tool icons: Map, Layer, Vector, Selection, Zoom, Window, Close, Save, Open, Print, Help
 - Input layer: A gray rectangular area.
 - Graphical interface:
 - Two input nodes labeled "10n00e" connected by a red line to a central node.
 - The central node is connected to a plus sign (+) node.
 - The plus sign node has a red line leading to an output node.
 - Output field: An empty text input field.
 - Run, View output, Close buttons at the bottom.
- r.mapcalculator
Simple map algebra
 - Neighborhood analysis
 - Overlay maps
 - Solar and irradiation model
 - Terrain analysis
 - Transform features
- Spatial models
 - Hydrologic modelling
- Change category values and labels

79

elft

GRASS modules

The screenshot shows the GRASS Tools application window. At the top, the title bar reads "GRASS Tools: WA_TerAn/WA_TA". Below the title bar, there are three tabs: "Modules" (which is selected and highlighted in blue), "Region", and a third tab that appears to be "Mapset" or similar. To the right of the tabs is a "Close mapset" button.

On the left side of the window is a tree view of "GRASS MODULES". A red box highlights the "shell" module under the "GRASS shell" category. An arrow points from this highlighted area down towards the terminal window. Other visible modules include "File management", "Region settings", "Projection manager", "Raster" (with sub-modules like "Develop map", "Manage map co...", "Spatial analysis" (with "Buffer", "Mask", "Map algebra"), "Neighborhood", "Overlay maps", "Solar and irradiation model", "Terrain analysis", "Transform features", "Spatial models" (with "Hydrologic modelling"), and "Change category values and labels").

The main workspace contains a terminal window with the following content:

```
bash-3.2$ r.mapcalc "ndvi = float(1sat4-1sat3)/(1sat4+1sat3)"
```

At the bottom right of the slide, the number "80" is displayed, and the word "elft" is partially visible.

GRASS modules

The screenshot shows the GRASS Tools interface with the title bar "GRASS Tools: WA_TerAn/WA_TA". The left sidebar lists "GRASS MOD" with various sub-options like "Create new", "File manager", "Region set", "Projection", "Raster" (selected), "Spatial", "Temporal", "Change category values and labels", and "Neighborhood". The main window displays the "Module: r.watershed" dialog. It has tabs for "Options" (selected), "Output", and "Manual". The "Input map: elevation on which entire analysis is based" field is empty. The "Minimum size for each basin (number of cells)" field is also empty. A checkbox labeled "Enable disk swap memory option; Operation is slow" is unchecked. The "Name for output accumulation raster map" field is empty. The "Output map: drainage direction" field is empty. At the bottom are "Run", "View output", and "Close" buttons.

GRASS Tools: WA_TerAn/WA_TA

Modules Region Close mapset

Filter

GRASS MOD

- >Create new
- File manager
- Region set
- Projection
- Raster
 - Develop
 - Manage
 - Spatial
 - Buffer
 - Mask
 - Map
 - Neigh
 - Over
 - Sol
 - Terr
 - Temp
- Spatial
 - Hydro
- Change category values and labels

Module: r.watershed

Options Output Manual

Input map: elevation on which entire analysis is based

Minimum size for each basin (number of cells)

Enable disk swap memory option; Operation is slow
Name for output accumulation raster map

Output map: drainage direction

Run View output Close

GRASS modules

Secure | <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

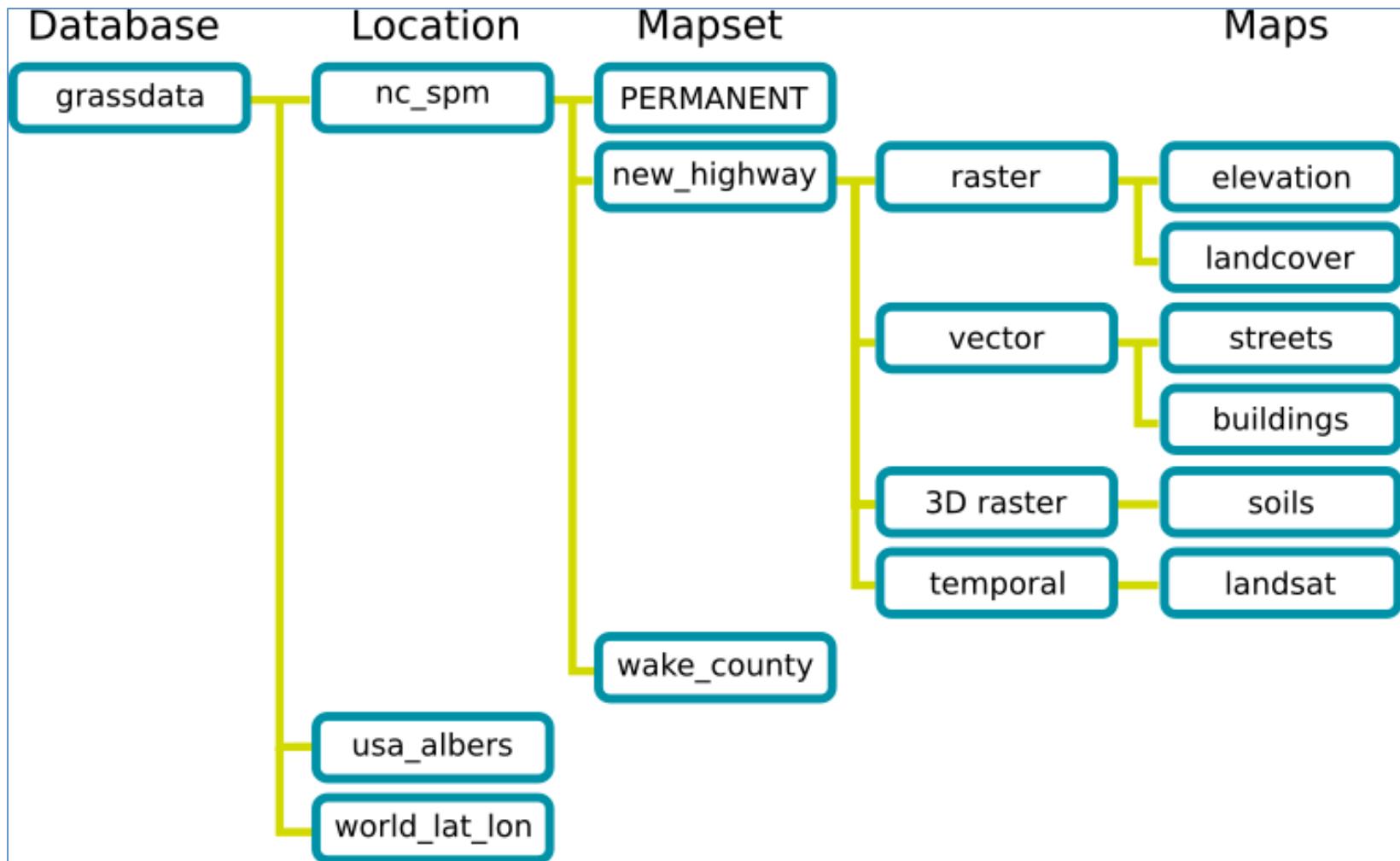
disturbed.land=string

Input map or value: percent of disturbed land, for USLE

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

QGIS Project Edit View Layer Settings Plugins Vector Raster Database Web Window Help

QGIS 2.14.10-Essen - ssd_asst3_terrain

Browser Panel

- Module3_TerrainAnalysis
 - Assignment3
 - LectureAndMaterials
 - MySolution
 - WA_TerAn
 - WA_TerAn
 - PERMANENT
 - WA_TA
 - 10n00e
 - 10n30e
 - 10n30w
 - 10s00e
 - 10s30e
 - 10s30w
 - LANDDEM
 - patchedDEM
 - ShadedDEM
 - SlopeDEM
 - VoltaAcc
 - VoltaDraDir

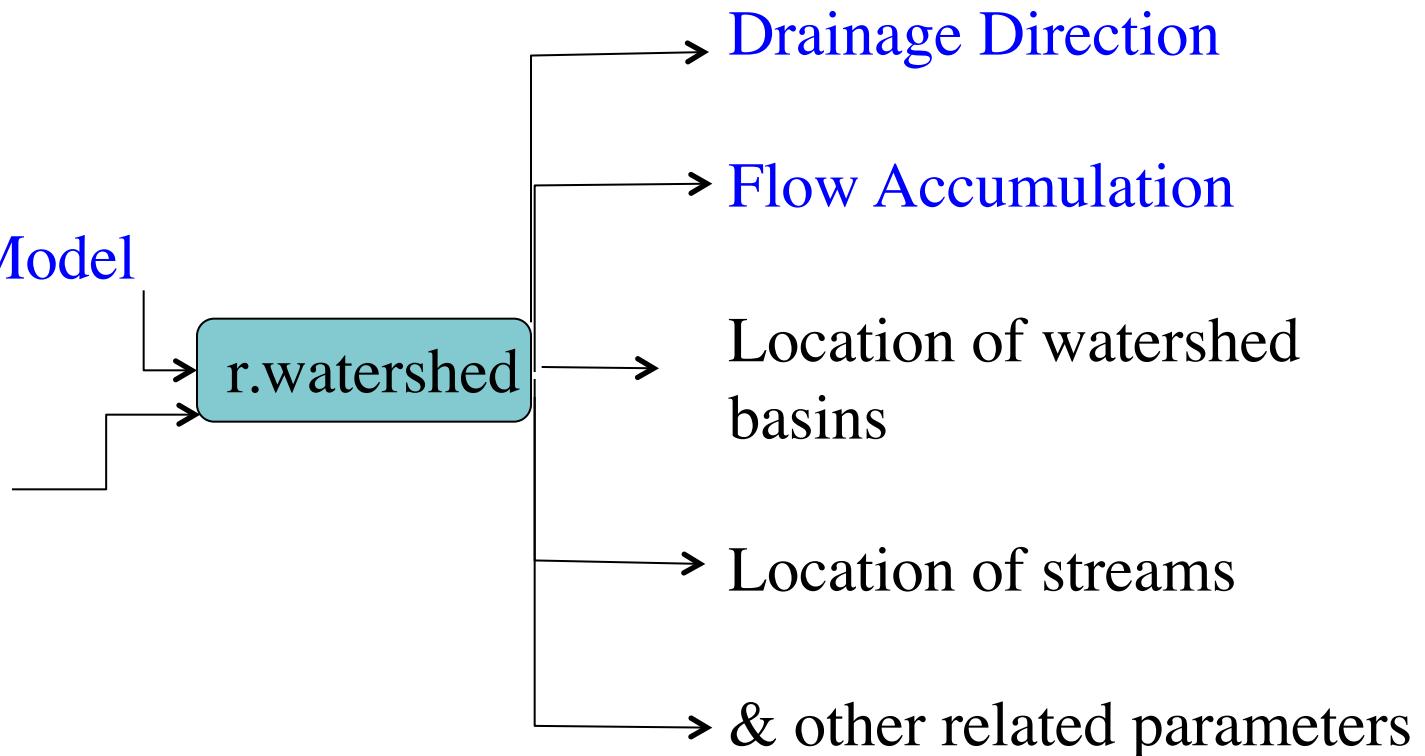
Layers Panel Browser Panel

Coordinate 6.12,9.49 Scale 1:7,018,071 Rotation 0.0 ft

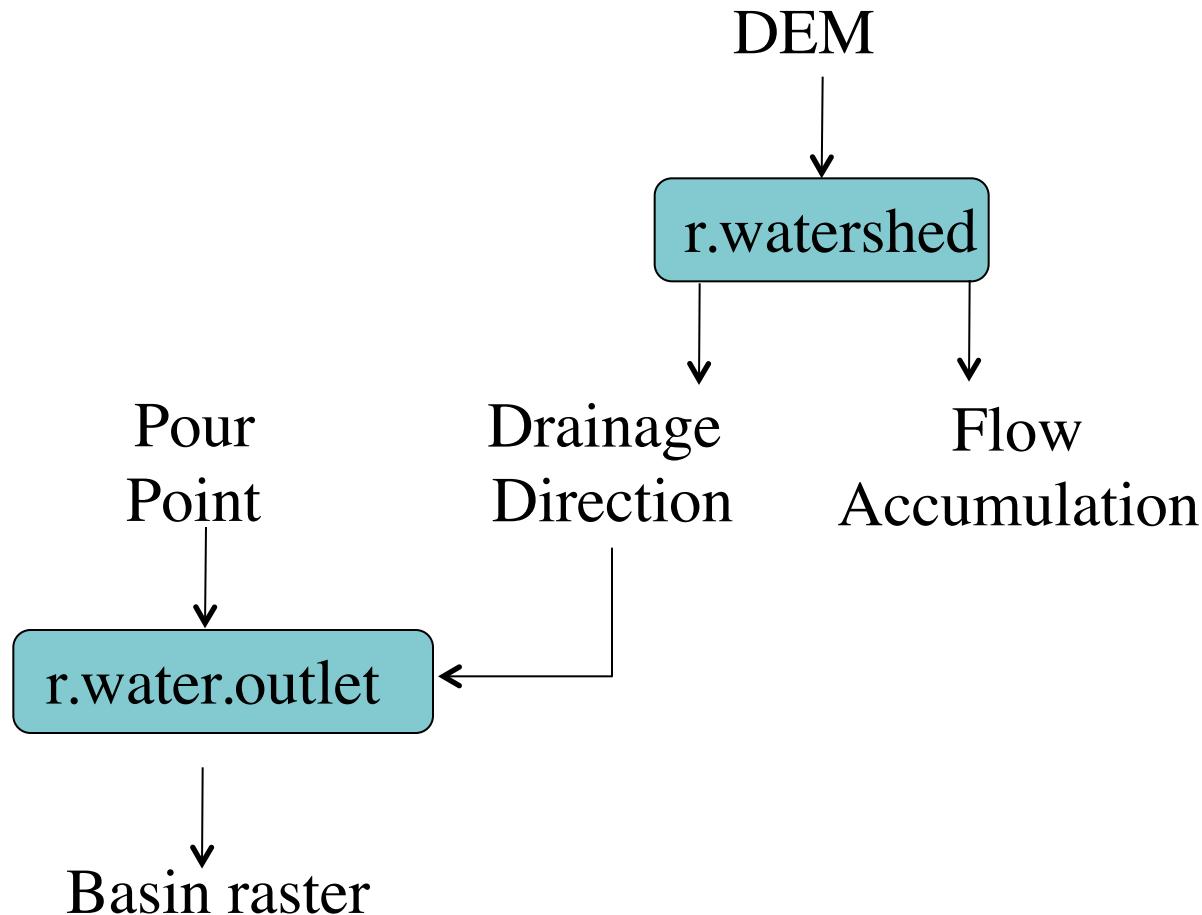
GRASS: Delineating watersheds

Digital
Elevation Model

Threshold

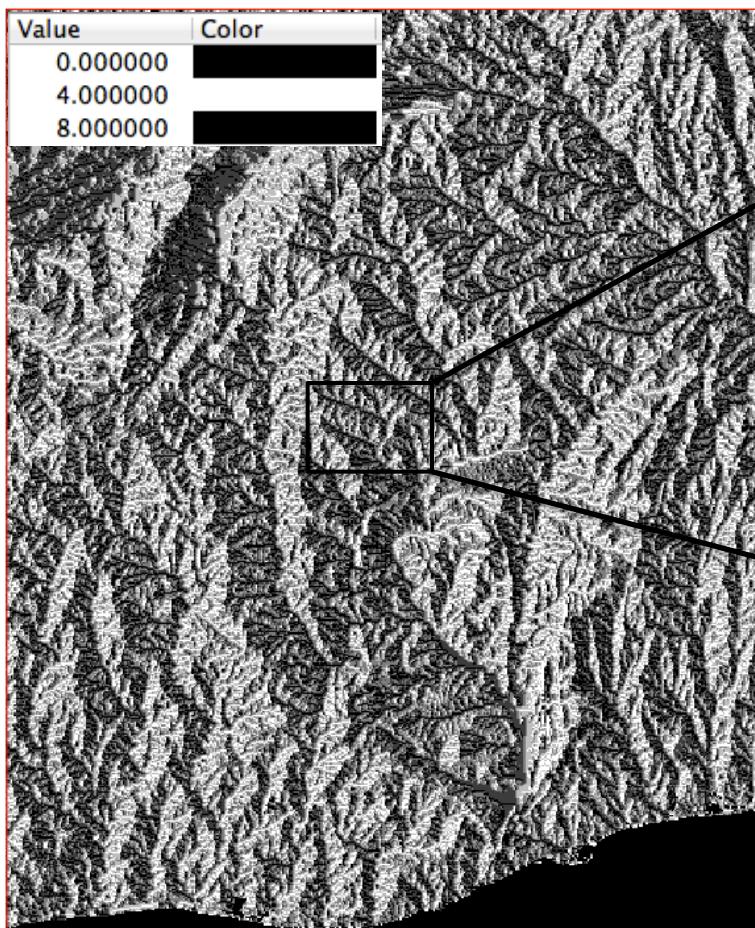


GRASS: Delineating watersheds

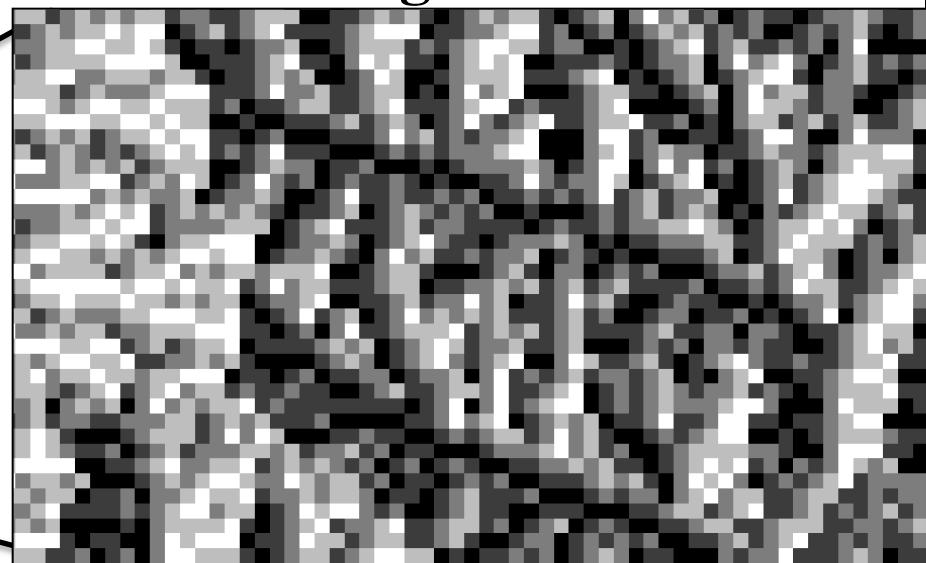


GRASS: Watershed

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

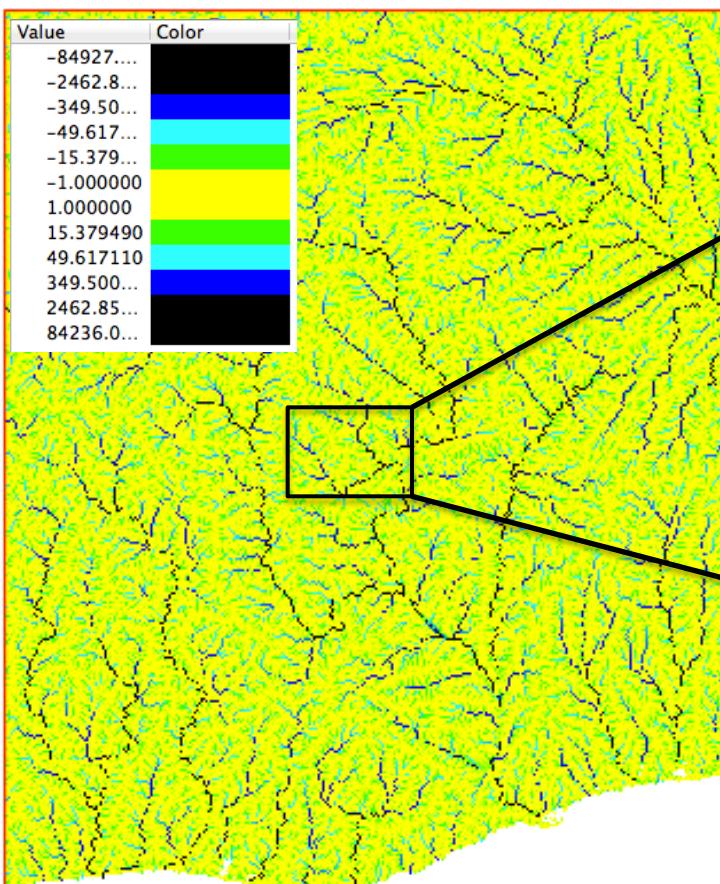


Drainage Direction

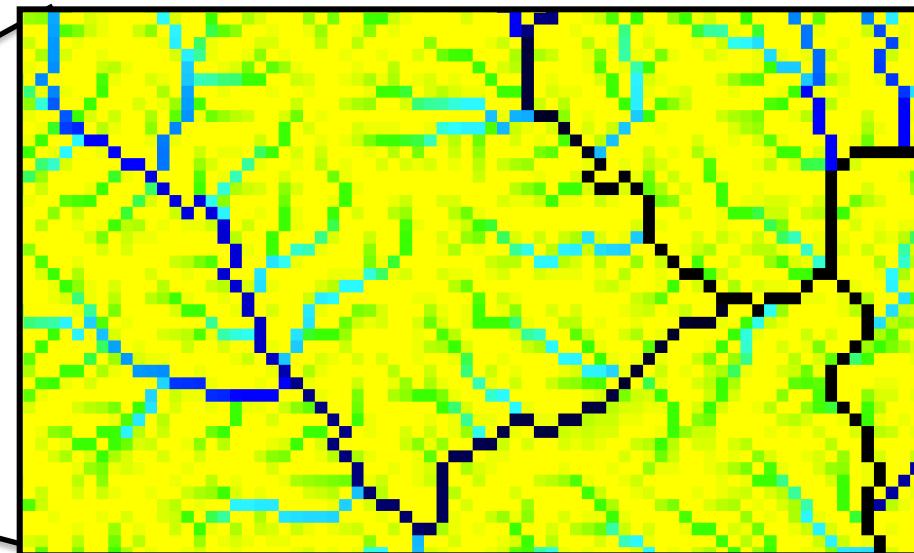


GRASS: Watershed

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



Flow Accumulation



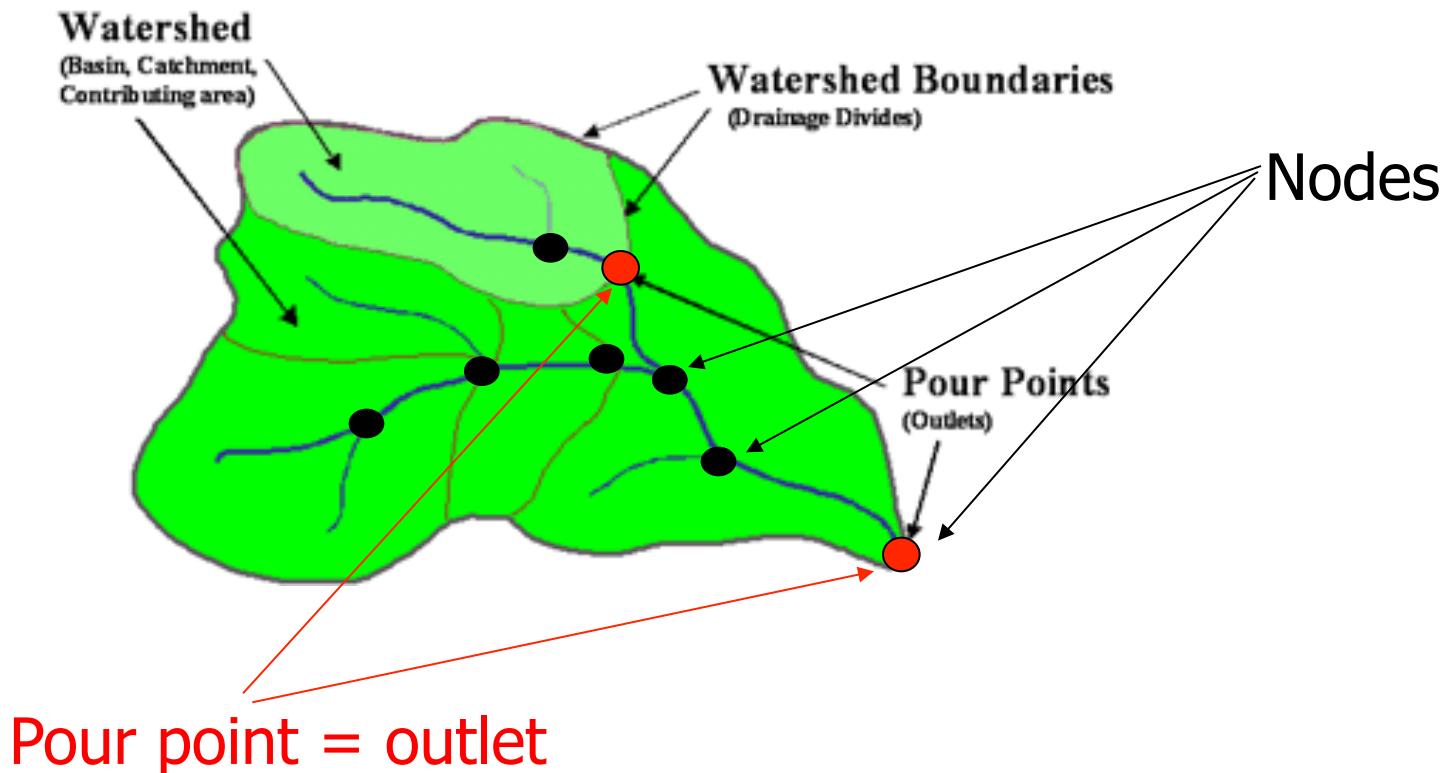
GRASS: Watershed



Better symbology
=> clearer view of
drainage network!

GRASS: Watershed

A stream network is made up of nodes and links



GRASS: Watershed

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

The screenshot shows the GRASS GIS interface with a map window on the left and a toolbars and layers panel on the right.

Map Window: A red rectangle highlights a specific area of the map, and a red circle with a downward arrow points to a small stream segment within that area.

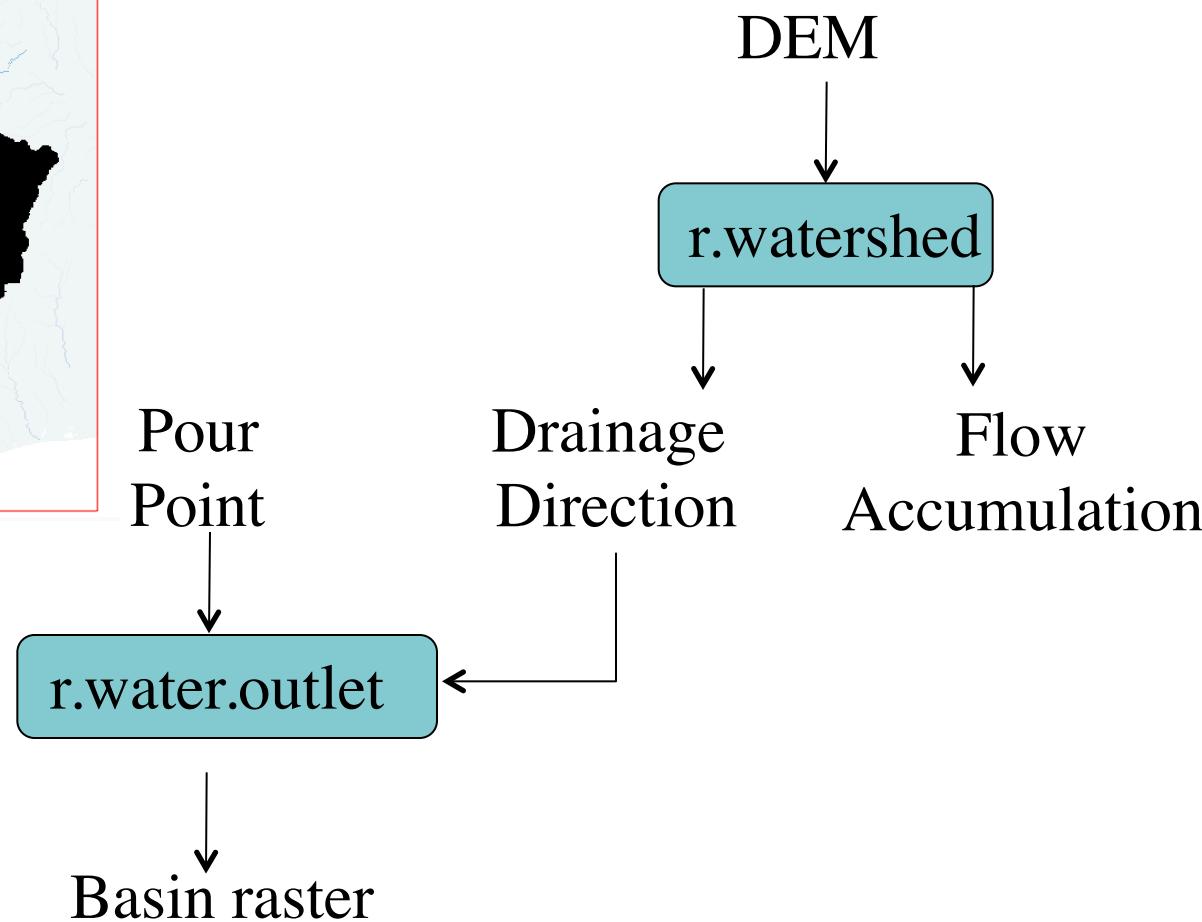
Layers Panel: The "VoltaAcc" layer is selected (indicated by a blue checkmark). The legend shows five color-coded categories: 0.000000 (lightest), 5000.000000, 10000.000000, 20000.000000, and 80000.000000 (darkest).

Identify Results Panel: The "VoltaAcc" layer is selected. The results table shows one feature identified:

Feature	Value
0	VoltaAcc
Identify error	GRASS prov...

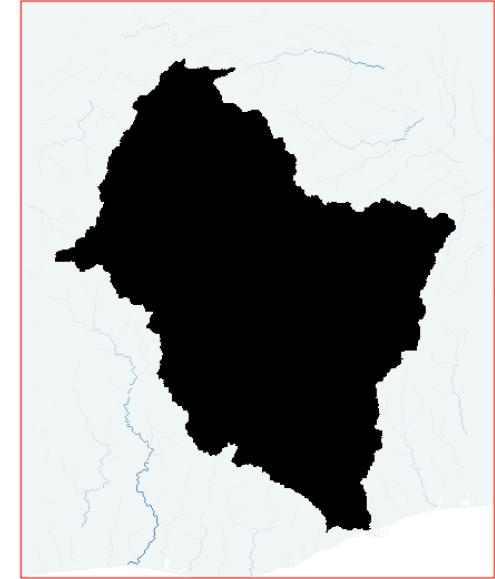
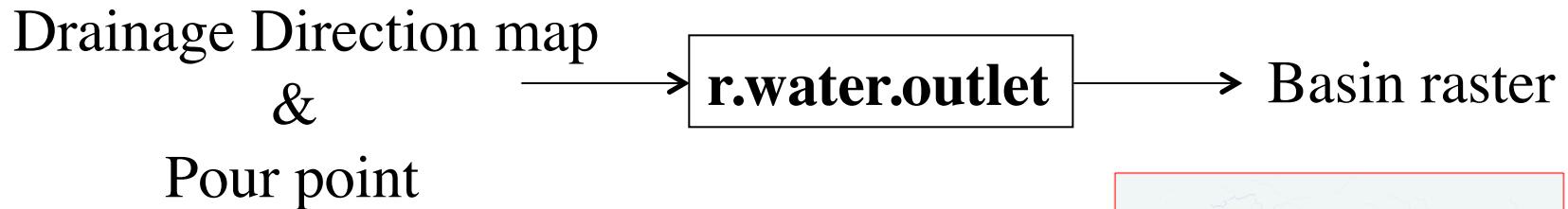
Toolbars and Status Bar: Various toolbar icons are visible. The status bar at the bottom right shows the coordinate **0.648,5.920** and scale **1:430.386**.

GRASS: Delineating watersheds

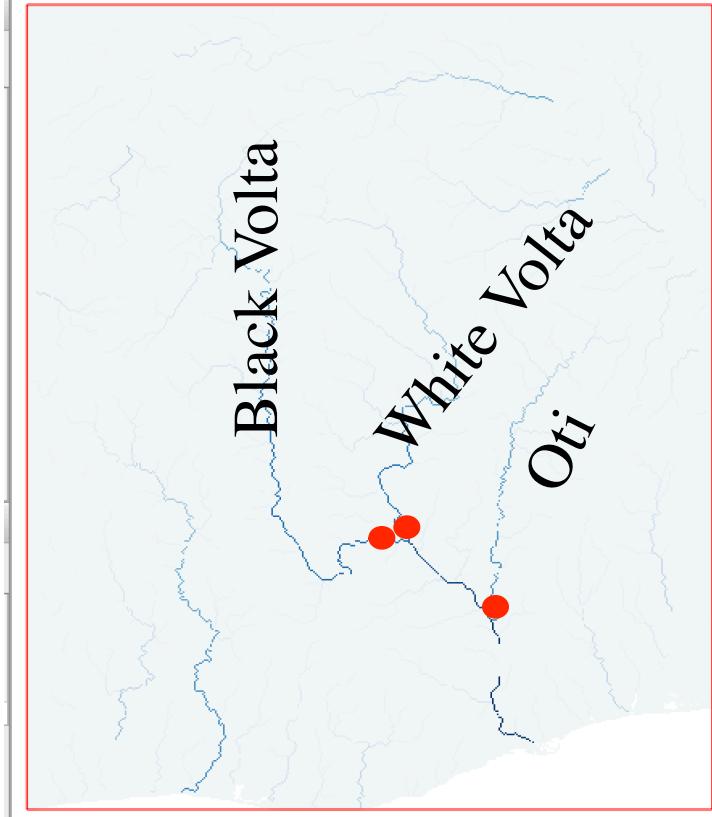


GRASS: r.water.outlet

To delineate the water basin:



GRASS: r.water.outlet



Pour points for sub-basins?

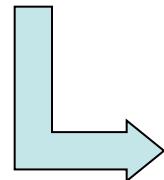
GRASS: Getting Started

CIE5401: GIS and Remote Sensing for
Water Resources Management

Terrain Analysis and Watershed
Delineation using QGIS and GRASS

Susan Steele-Dunne

February 2018



See Assignment 3