Geography 4203 / 5203

GIS Modeling

Class 7:

Terrain Analysis 2 - Hydrologic Functions

Terrain Analysis 3 - Viewsheds/Hillshades

Some Updates

- Project Proposals due…

Last Lecture(s)

- Terrain part 1
- **Slope**, gradient, **aspect**, slope direction,…
- Impact on slope and aspect due to **resolution** reduction
- **Curvature** (plan, profile),…
- **Mathematical approaches** for computation
- Some **calculation examples**

Today‘s Outline

- We are coming to **hydrologic functions** and will have a closer look into the concepts behind the „toolbox“
- Hydrologic functions are complex and often imply variables such as slope or aspect
- We will see some **mathematical approaches** for hydrologic functions

Learning Objectives

- You will understand the **concepts** behind the computation of hydrologic functions
- You will see some understandable computation examples
- You will have some insights into algorithms behind indices used for hydrologic modeling

Back to: Why Terrain Matters…

- **Hydrological derivatives** from terrain
- **Topography** influences and is shaped by hydrological processes
- **Catchments** as central unit in understanding the **landscape** and impacts on it

Hydrologic Functions

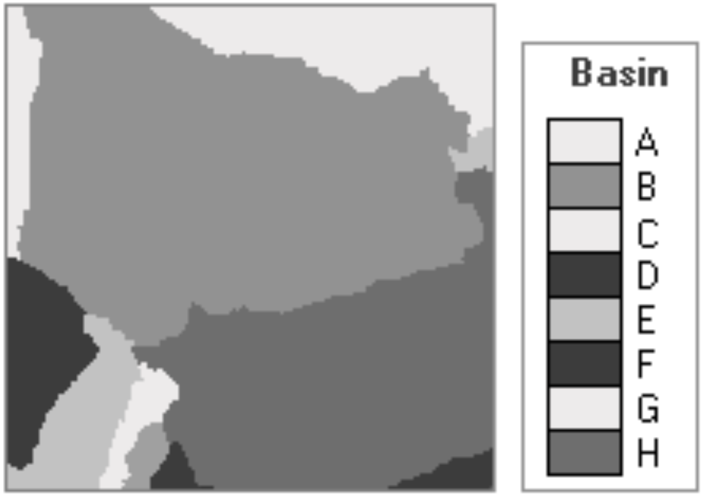
- Water and its **importance** for our life
- Water resource **monitoring**, **gathering**, **protection**, **management**, **disaster prevention, erosion**
- Hydrologic functions embrace a set of commonly used operations for spatial analysis and **modeling of water resources**

Frtom http://rcswww.urz.tu-dresden.de/~uzeuner/tharandt/tharandt3.htm

The Set of Hydrologic Functions

- Flow direction
- Sinks / pits
- Fill
- Watershed
- Drainage network

- You worked already with some of them and got an impression of how they work


Basin
A
B
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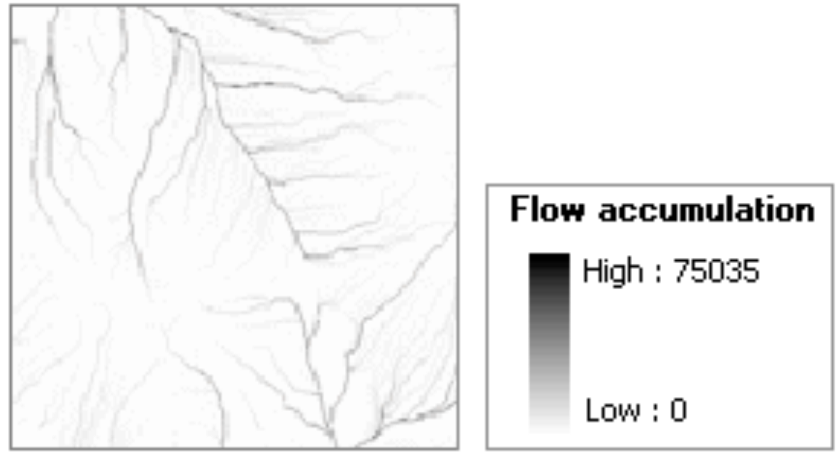
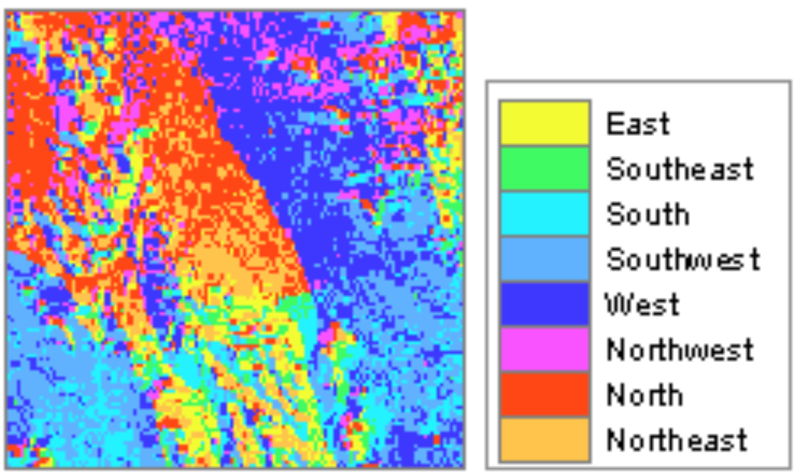
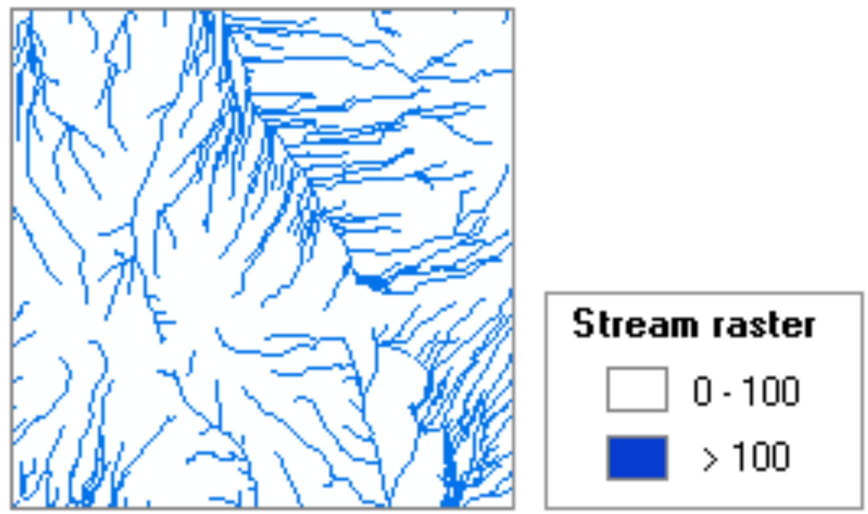
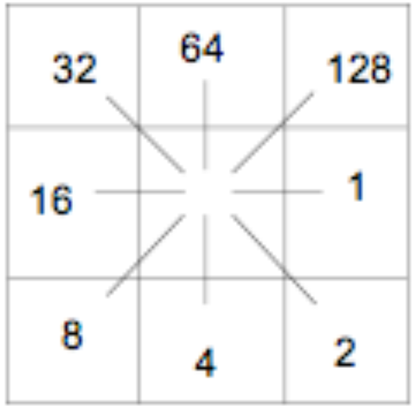

Flow accumulation
High : 75035
Low : 0

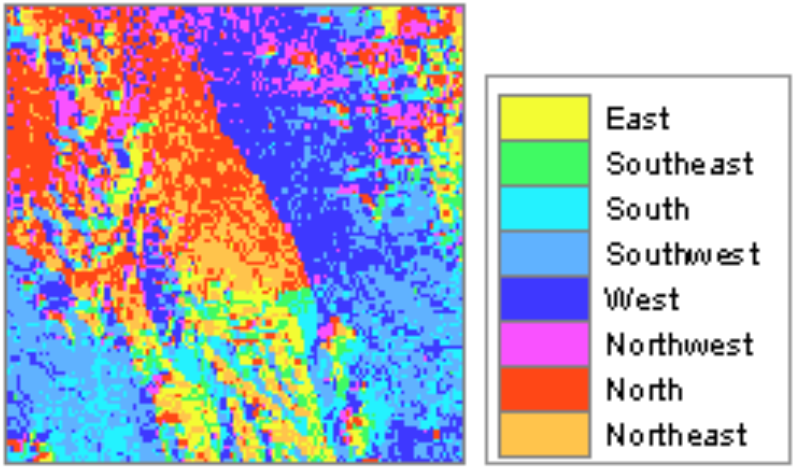

East
Southeast
South
Southwest
West
Northwest
North
Northeast


Stream raster
0 - 100
> 100

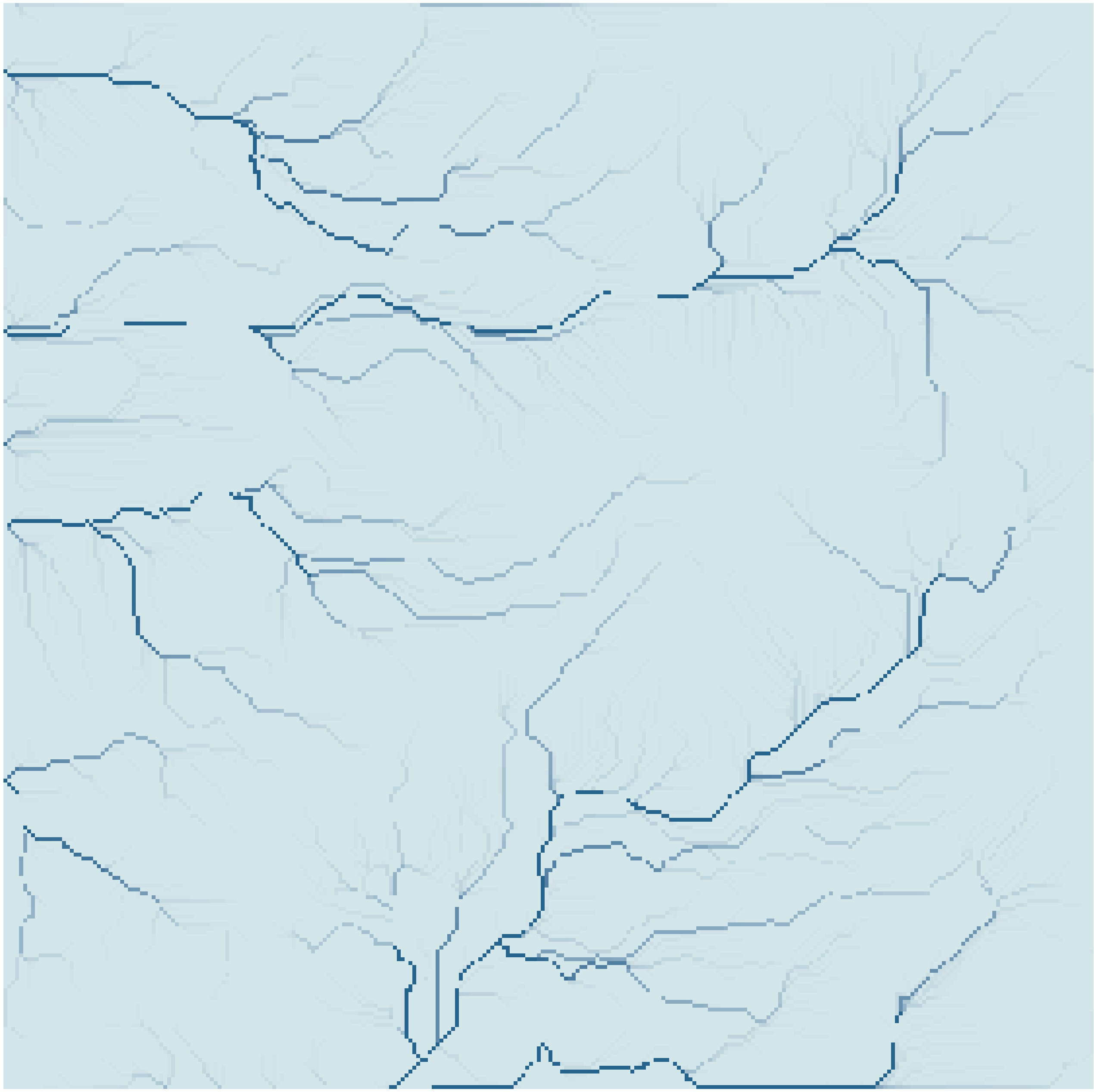
Flow Direction

- Direction of **water flow** on or below the surface
- Mostly in the direction of the **steepest descent** (this is local aspect) within adjacent cells
- Given in **angles** [0,360˚] in a data layer (degrees azimuth)
- Alternatively direction expressed by **index** [1,8] indicating the **neighbor** to which water flows (D8 approach, Jensen and Domingue (1988) most common)
- Rho8 another one to prevent parallel flow



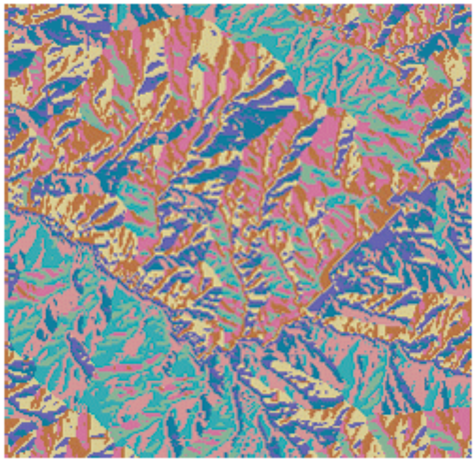


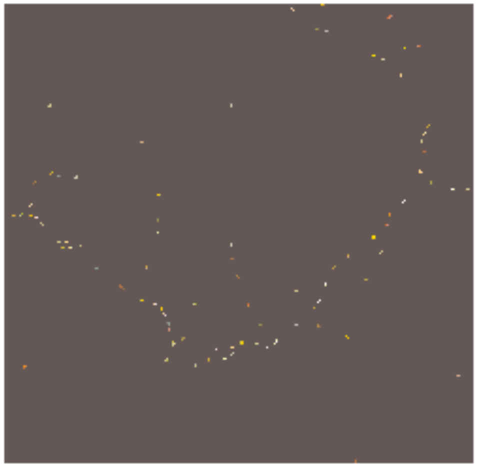
Rough intervals…

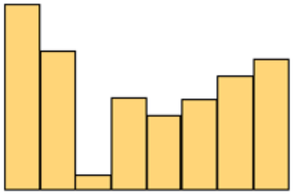


Identifying Pits / Sinks

- **Random errors** in DEM surfaces create cells that are lower than surrounding values
- Consequence: No direction of steepest descent and erroneous results of hydrologic functions
- As **artifacts** from interpolation processes (water can flow into but not out)
- Can occur in reality (caves,…)







Filling the Pits

- To identify **watercourses** data-driven pits should be removed
- **Thresholds** (less than expected error in the data and less than true pit depths) below which a pit is not removed
- Any known pits?
- Radial search (hard coding)
- Sink filling (increase elev)

Profile view of a sink before and afterrunning FILL

filled sink

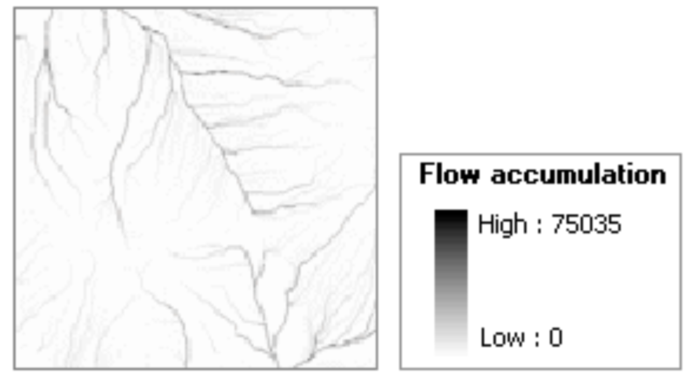
Flow Accumulation

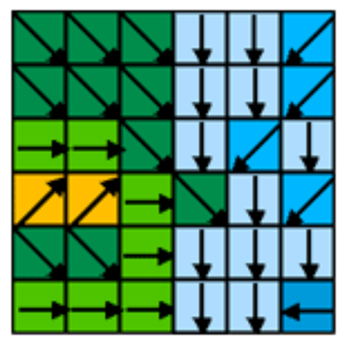
- Uses **flow direction (broken when?)**
- Sum of **upstream** elements **draining into** the considered cell

  - count for each cell how many neighbors drain into it

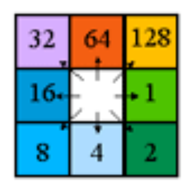
  - do the same with each of these neighbor cells

  - repeat until margins reached or no upstream cells exist
- Contributing cells indicate the boundary of the catchment
- Using a pour point…





0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2



Direction Coding

Drainage Networks

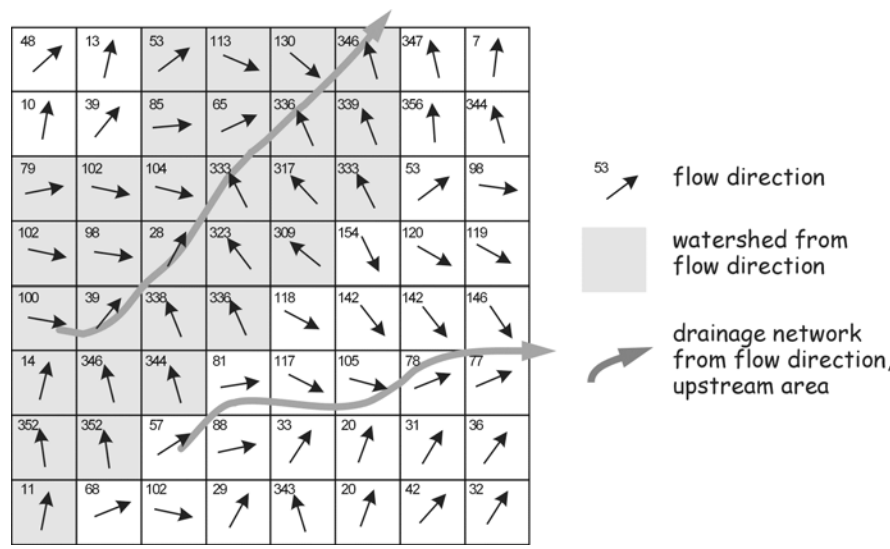
- Different approaches and thus **varying perspectives** how to define and identify elements of a drainage network
- **(1) Watershed area threshold**, (3) **convergence**, (2) using **flow accumulation** surfaces
- What happens if there are **sinks** in the area?

Drainage Network 1

- Set of cells through which **surface water** flows
- Based on **flow direction** (drains occur where flow directions **converge**)
- => **Convergence** of flow direction as indicator to produce maps of **likely stream** locations (prior to field surveys)

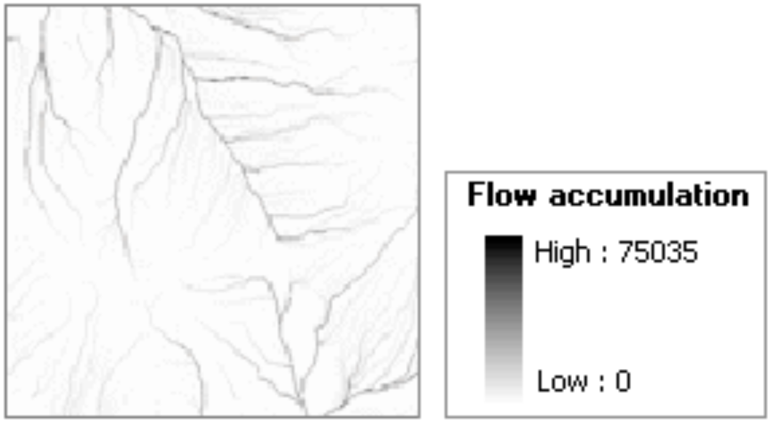
Drainage Networks 2

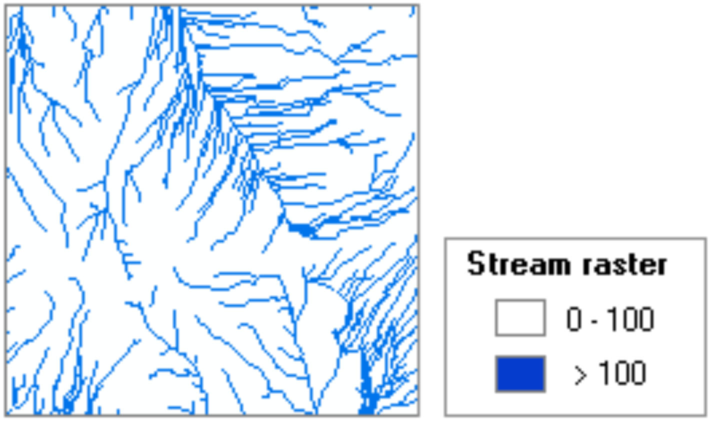
- Any cell which has a **contributing watershed** larger than a locally-defined **threshold** area
- **Subsurface** properties not included
- Watershed for each cell is calculated and compared to the threshold area
- Cells that surpass this threshold are **part** of the drainage network



Stream Network Raster

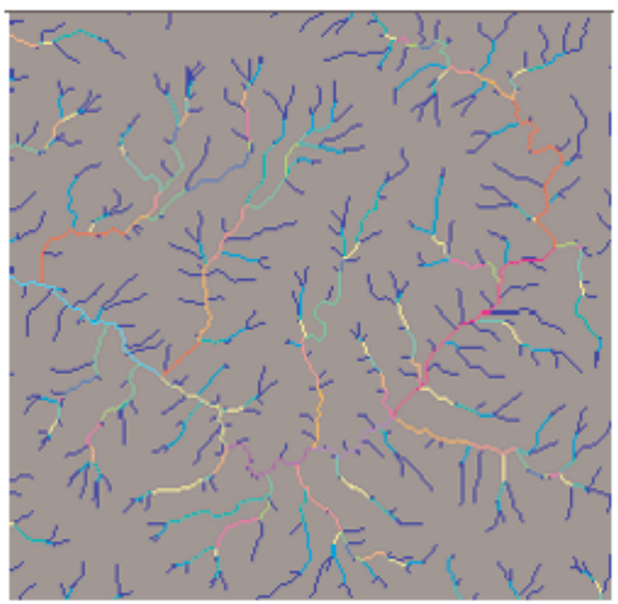
- **Conditional** queries from Flow Accumulation (inpiut precipitation could come from a second grid)
- Producing a **Boolean** Raster showing the elements of a channel system

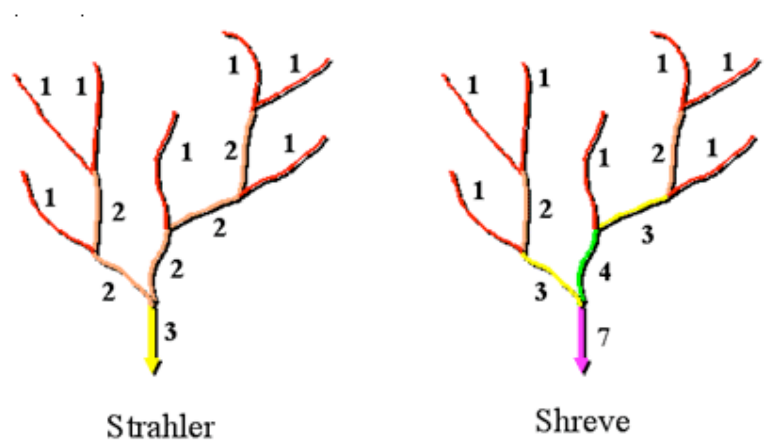




Stream Order and Stream Link

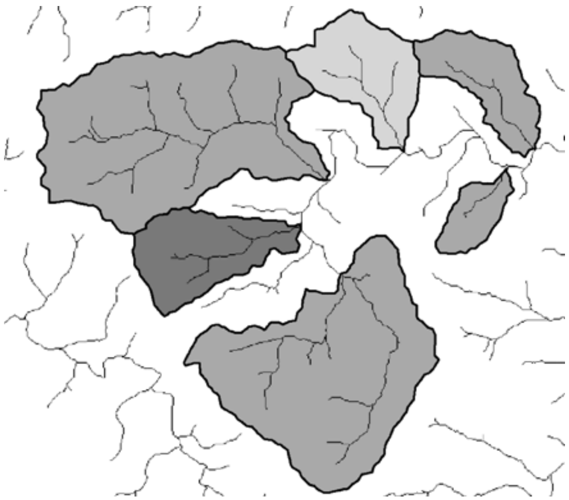
- **Ordering** the linked streams within a stream network
- Stream **Linking** assignes unique values to segments for quick computation of **watersheds** based on **junctions**





Watershed

- An **area** that contributes **flow** to a point on the landscape
- = basins / contributing areas / catchments / drainages / sub-basins / sub-catchments
- E.g., the **uphill area** that drains to any point on a landscape is the watershed for that point… Water falling anywhere upstream within a watershed will **pass through** that point
- How big is the watershed of a **Peak** point

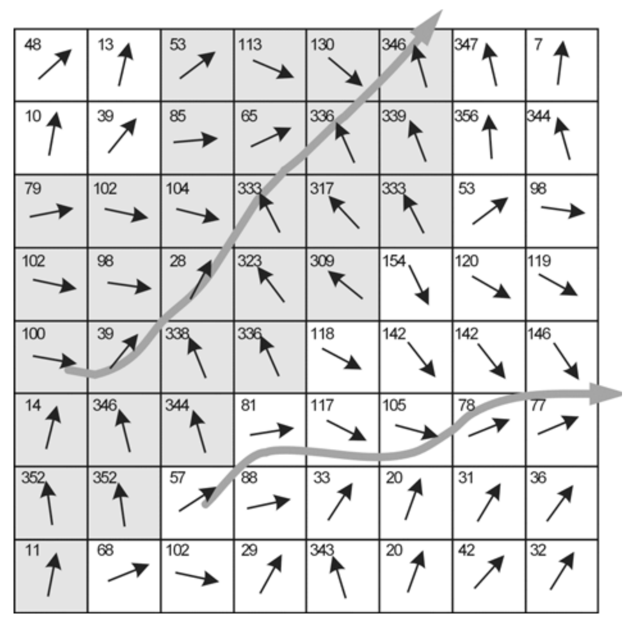


Identifying Watersheds

- Using **flow direction** surfaces
- Flow direction is followed “**uphill**” from a point, until a **downhill** flow direction is reached
- “**Contributing cells**” to these uphill cells by uphill flow following
- **Recursively** creating uphill list (accumulative) to find all contributing cells to a point = watershed

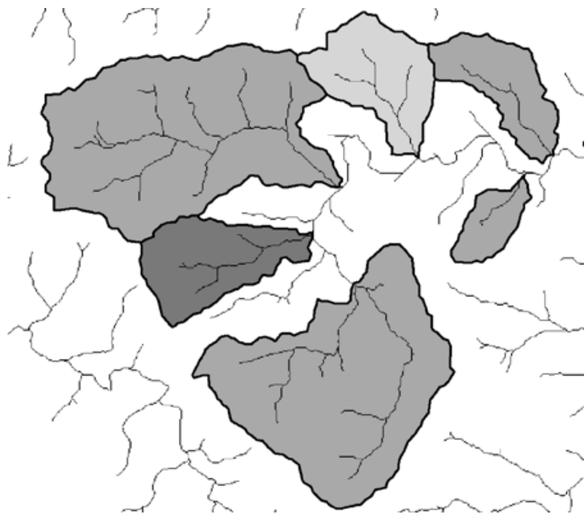
Upslope area

- Applied to a DEM
- Return values: **Area** that **drains through** that cell
- Meaning: Cell values are the **watershed area** for each **individual cell**
- Initial estimator for a drainage network (index of stream occurrence based on threshold uphill area)
- This indicates if cell is within a "**permanent stream channel**" or not



Calculating Upslope Area

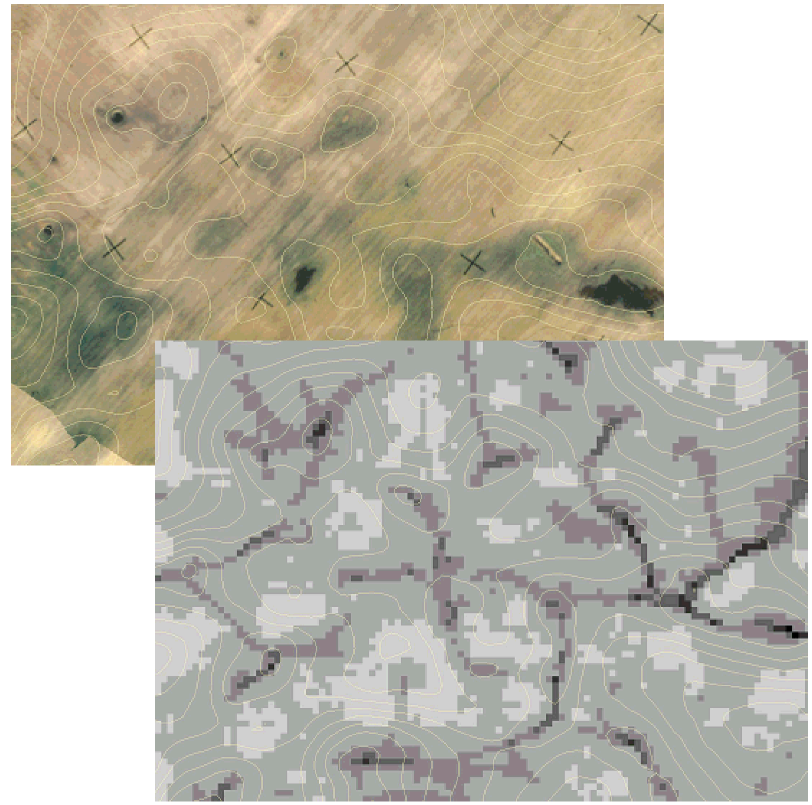
- Start at one of the local "**high points**" (max)
- Summing area as one moves **down-slope**
- Next local max to do the same but area is added to the **accumulated areas** from before
- Repeat the process until there is **no local max** left
- So, how can we make sure we derive the watershed of an entire drainage channel system?



Wetness Indices

- **Compound index** for plant community compositions or to derive likelihood and intensity of **flooding** (rainfall until soil saturation)
- Identify **locally convergent** or **divergent** terrain positions
- Increased soil wetness due to **large upslope** areas (per unit width of contour), A_s and **low slopes** (β)

$$W = \ln\left[\frac{A_S}{\tan\beta}\right]$$



from http://www.regional.org.au/au/

For **homogenous** soil, otherwise **transmissivity** is needed

Slope and Area

- While we are talking about **slope** and **area** of individual units…
- Did you think about consequences if we are taking just **area as represented by pixel cells**?
- What are the **impacts** and possible **examples**…?

Further Compound Indices

- **Stream power** $W = A_S * \tan\beta$

  (for estimating erosion)
- USLE and **LS factor** to evaluate the physical potential for erosion

Summary I

- Hydrologic functions based on **DEMs** (…and hydrologic derivatives!)
- Understanding of **modeling approaches** for **hydrological processes** in the landscape (physical conditions)
- What “**non-natural**” factors could influence hydrologic processes
- Some basic **principles** and **mathematical solutions**
- Learned about some important **terms** and understood their **meaning** and **interrelationship** for hydrologic modeling

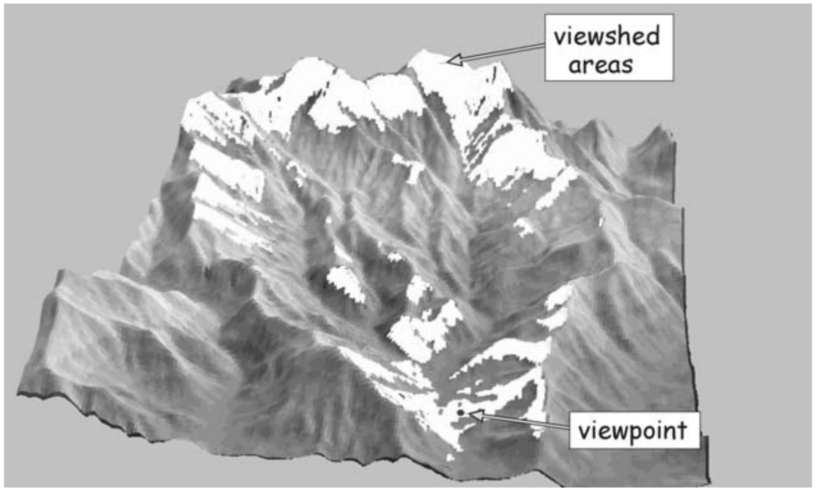
VIEWSHEDS AND HILLSHADES…

What are we going to look at?

- What is a **viewshed**, what is a **hillshade**
- How can we **compute** viewsheds and hillshades?
- Some **algorithmic** insights…
- Why are viewsheds important and how hillshades can support our work

Viewsheds

- The viewshed of a point is the collection of areas **visible from that point**
- Are there elevations higher than the **line of sight** between the **viewing** and **target point**?
- Examples: placement of power lines, parks, protected areas

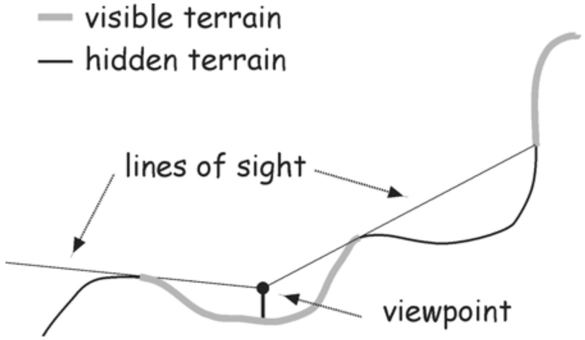


Calculating Viewsheds

- Based on cell-to-cell **intervisibility** (visible / hidden as a **binary** output)
- **Line-of-sight** between the view cell and the potential target cell (from **each viewpoint** to each cell in the DEM)

  -> Elevation for each cell **along** this line

  -> If **slope** to a target cell is **less** than the slope to a **cell closer** to the viewpoint => target cell is not **visible** from the viewpoint



Important Aspects of Viewsheds

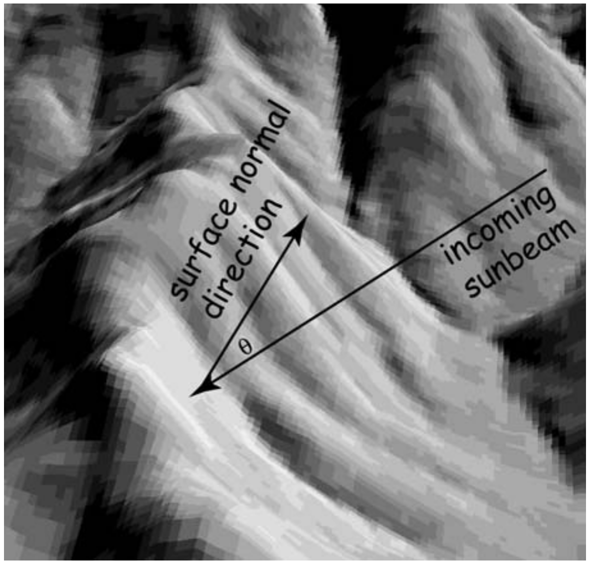
- Different algorithms have different **impacts** on viewshed analysis… how?
- How **sensitive** is viewshed analysis to **errors** in **elevation**?
- What are the **fields** that could make use of viewsheds, basically?
- Pete Fisher investigated viewsheds as related to these questions in several articles…
- He proposed **alternative algorithms** to circumvent the output in only binary format but rely on something like **probability**

Some Viewshed Application Examples

- Forest Fires
- Forest visibility
- Residence location choice and traffic visibility
- Electric power lines

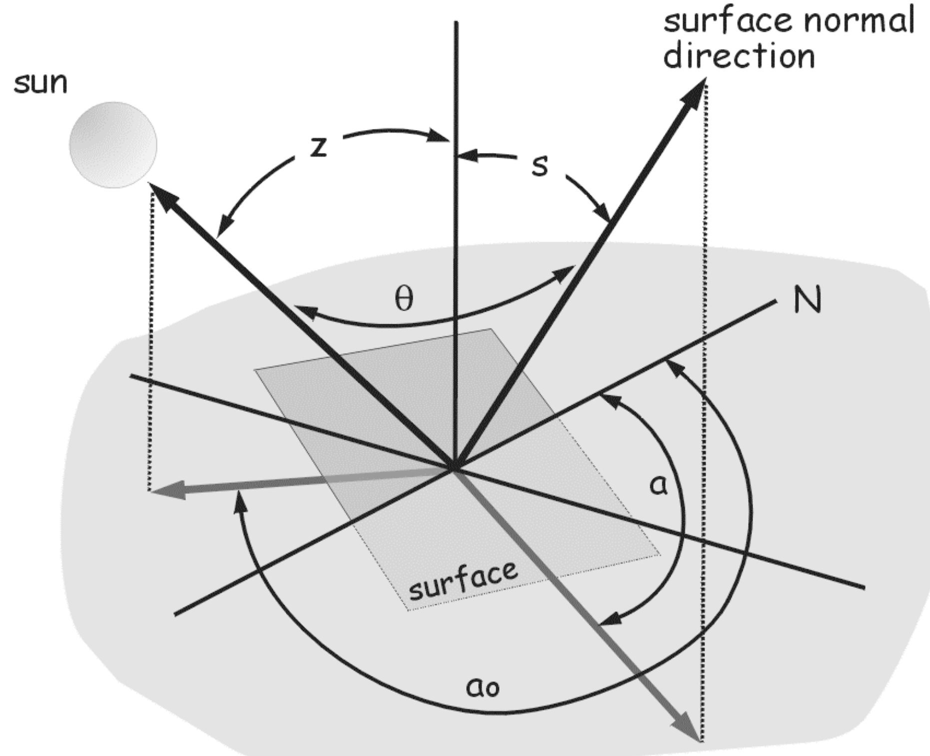
Hillshades

- **Shaded relief maps** depict the brightness of terrain reflections (**terrain surface** and **sun location** given)
- **Communicating** the shape and structure of terrain features
- Based on **DEM** and **models of light reflectance** (for direct beam or diffuse sunlight)
- Brightness of reflected direct beam depends on local **incidence angle**



Calculating Hillshades

Where is the connection between visibility and cell brightness value?



incidence angle θ is equal to:

$$\cos^{-1}[\ \cos(z)\cos(s) + \sin(z)\sin(s)\cos(a_o - a)\ ]$$

where: z is the solar zenith angle

a_o is the solar azimuth angle

s is the surface normal slope angle

a is the surface normal azimuth angle

Summary II

- Viewsheds, intervisibility, line-of-sight to evaluate **landscape alterations**
- Viewsheds are normally **binary** outcomes but there are alternatives proposed by Fisher to **redefine** and **communicate** visibility
- Relief shading or hillshades to **visually communicate shapes** in the terrain
- Visibility of landscape elements as a critical element of **landscape architecture** and **development** of **urban, conservational** or **industrial** spaces