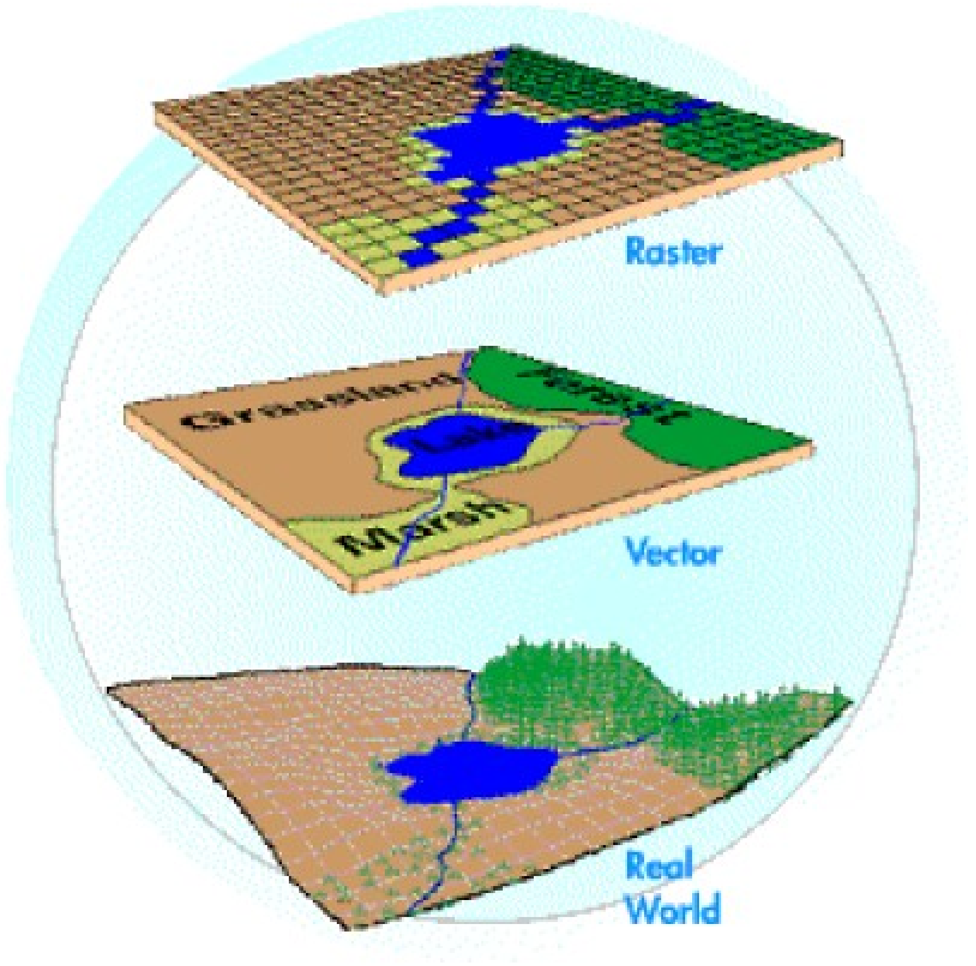
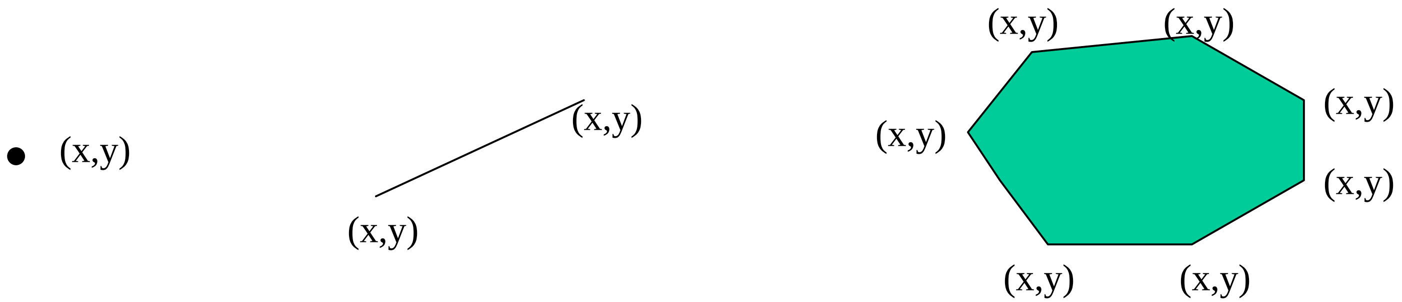
Spatial Data Models

- **Raster**
  uses individual cells in a matrix, or grid, format to represent real world entities

- **Vector**
  uses coordinates to store the shape of spatial data objects



Geographic Features (Vector Model)



point

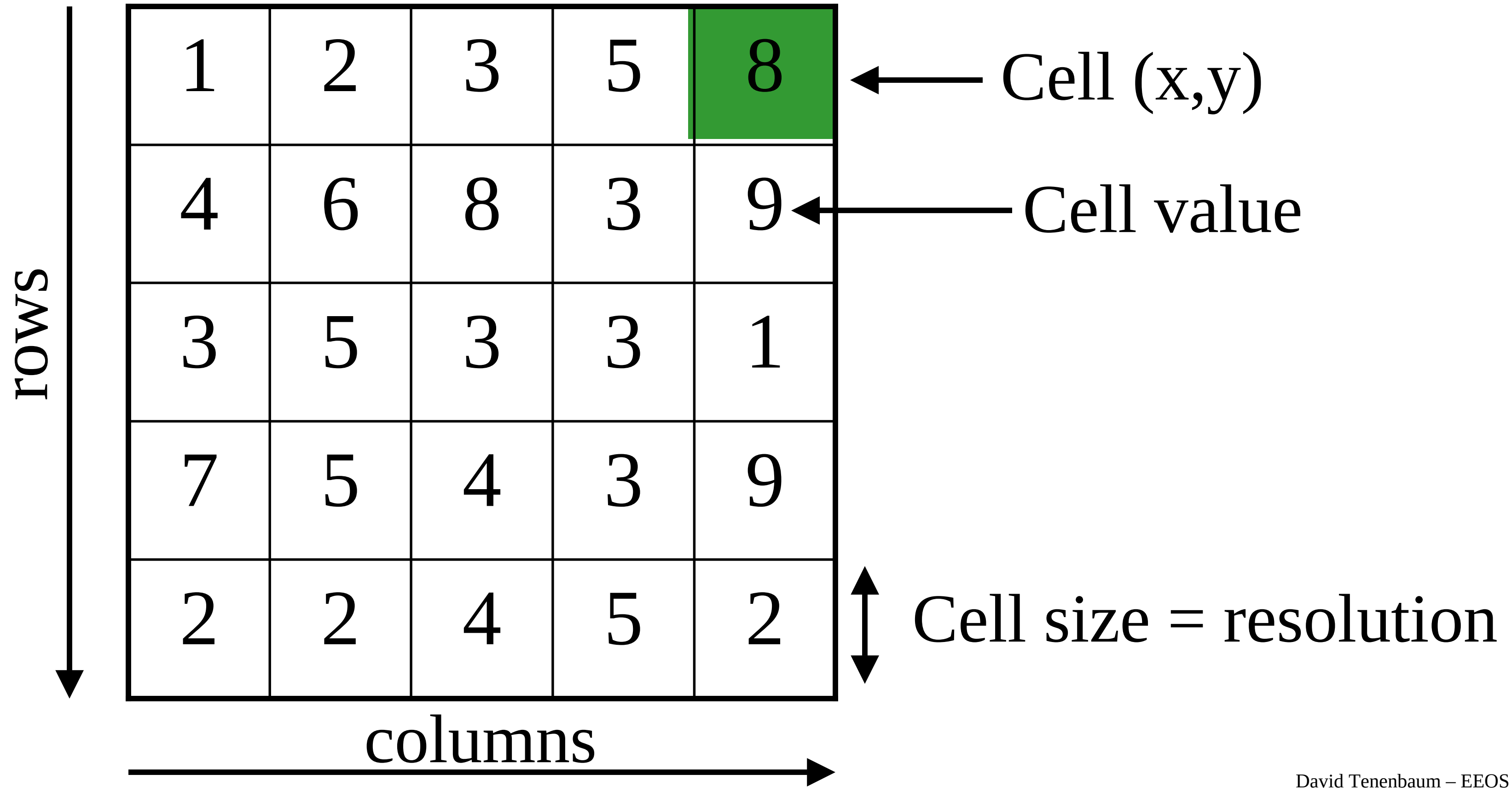
line

polygon (area)

- **A point:** specified by a pair of (x,y) coordinates, representing a feature that is too small to have length and area.
- **A line:** formed by joining two points, representing features too narrow to have areas
- **A polygon (area):** formed by a joining multiple points that enclose an area

Raster Data Model

- The raster data model represents the Earth’s surface as an **array** of two-dimensional grid cells, with each cell having an associated value:



1	2	3	5	8
4	6	8	3	9
3	5	3	3	1
7	5	4	3	9
2	2	4	5	2

rows

columns

Cell (x,y)

Cell value

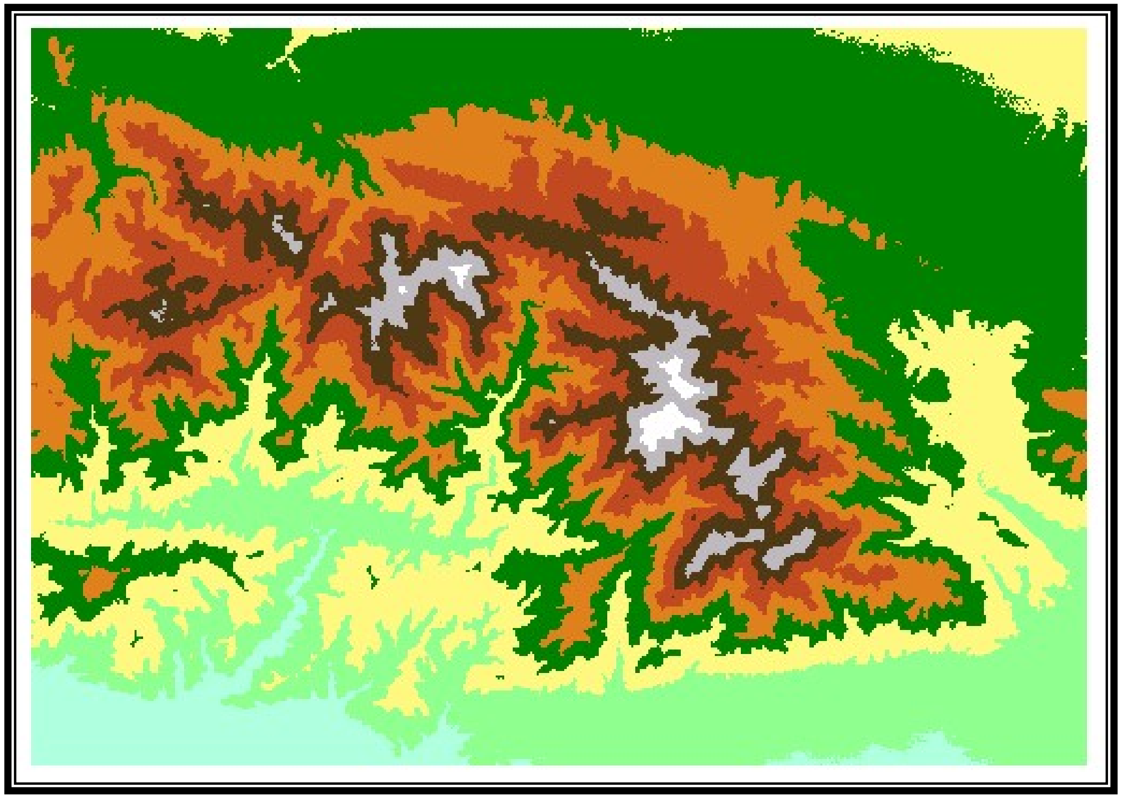
Cell size = resolution

Raster Data Model

- Each grid cell in a raster data layer is one **unit** (the minimum amount of information in the raster data model)
- Every cell has a **value**, even if it is a special value to indicate that there is “no data” or that data is “missing” at that location
- The values are numbers, either:
  - **absolute values** **OR**
  - **codes** representing an **attribute**

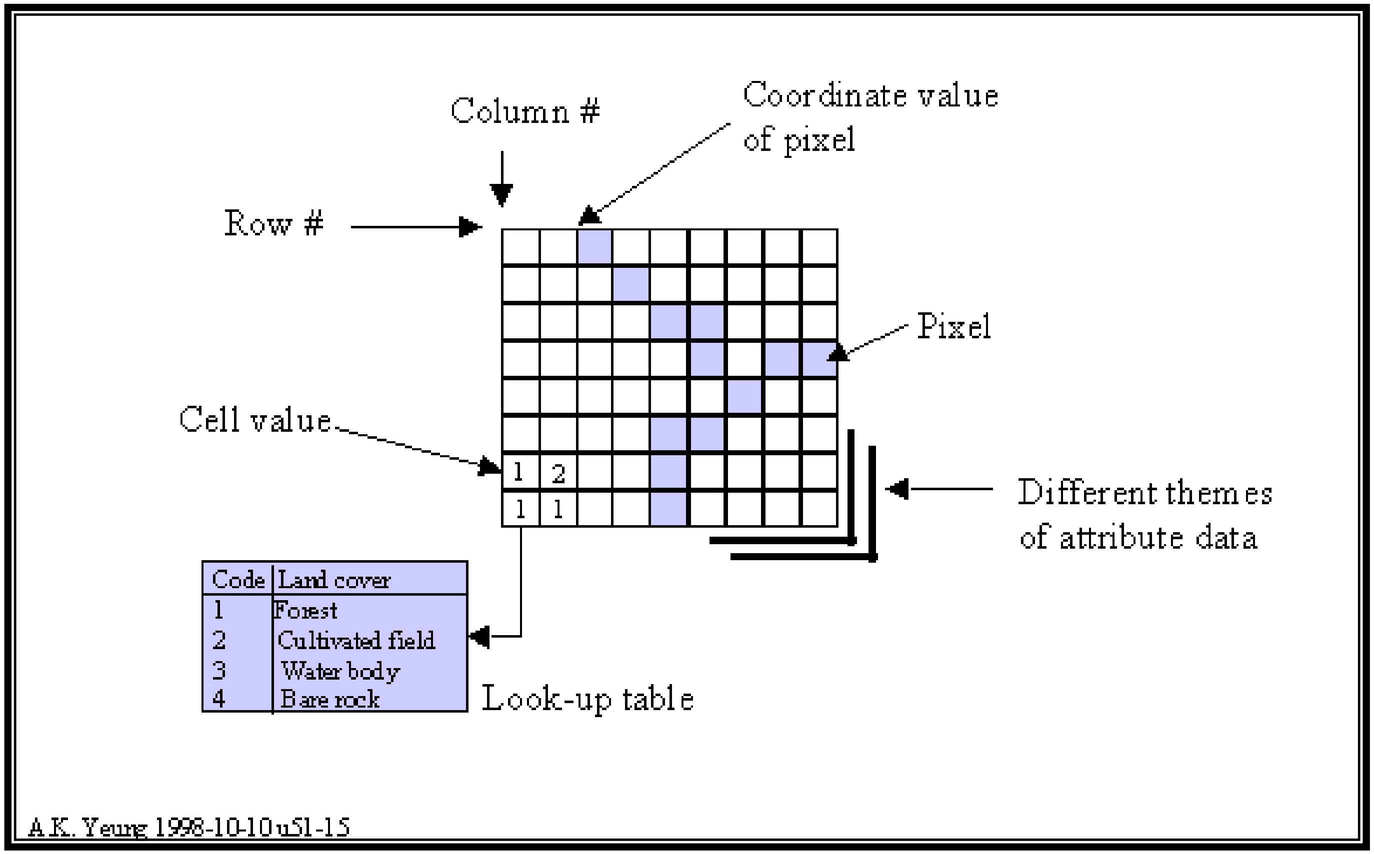
Cells - Absolute Values

- In this instance, the **value** of the cell is actually the value of the phenomenon of interest, e.g. elevation data (whether floating point or integer):



Cells – Coded Values

- The coded values can then **link** to one (or more) attribute tables that associate the cell values with various themes or attributes:

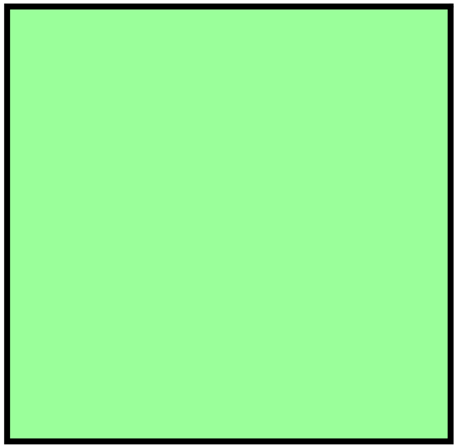


Code	Land cover
1	Forest
2	Cultivated field
3	Water body
4	Bare rock

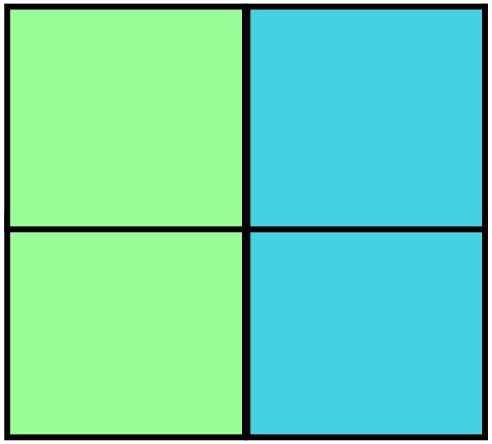
A.K. Yeung 1998-10-10 u51-15

Cell Size & Resolution

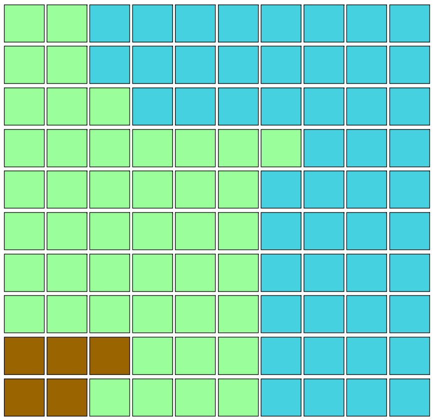
- The **size** of the **cells** in the raster data model determines the **resolution** at which features can be represented
- The selected **resolution** can have an **effect** on how features are represented:



10 m Resolution

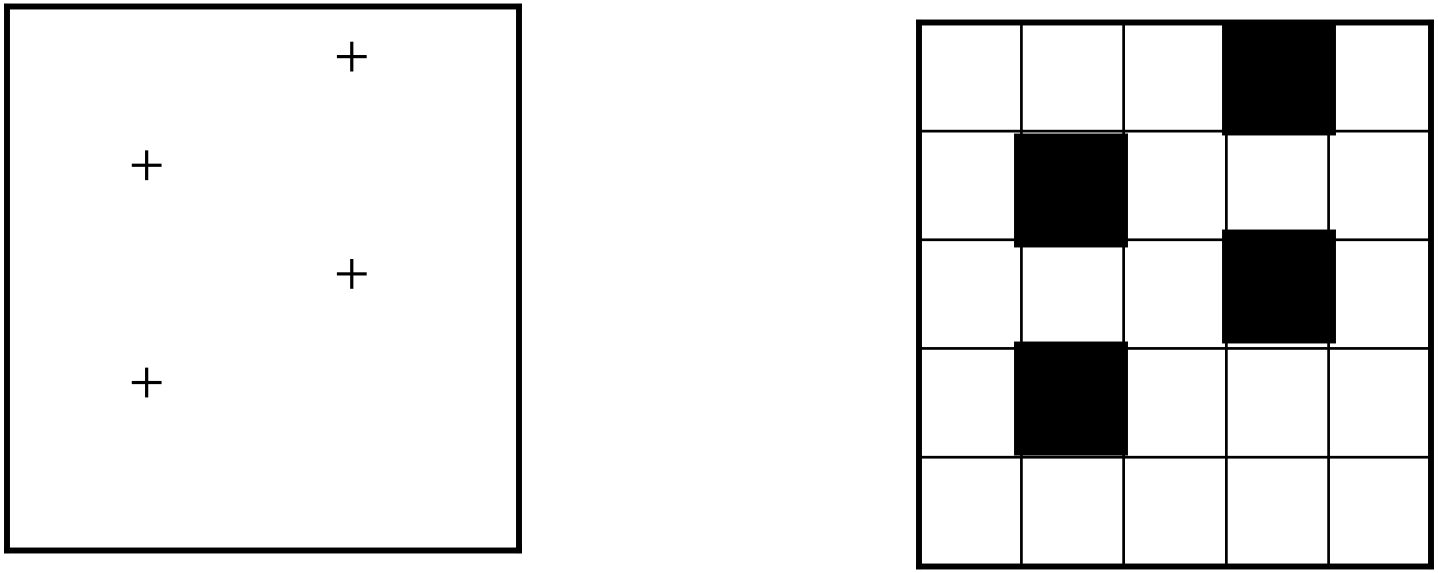


5 m Resolution



1 m Resolution

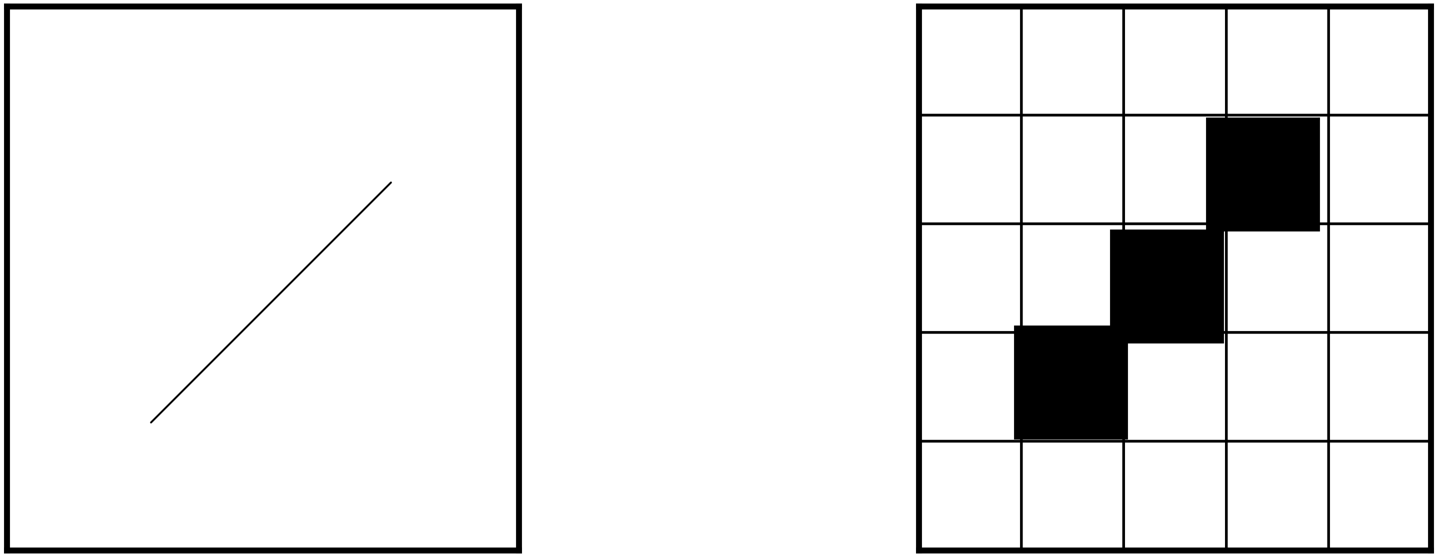
Raster Data Model - Points



1 point = 1 cell

What problem do we have here? How can we solve it?

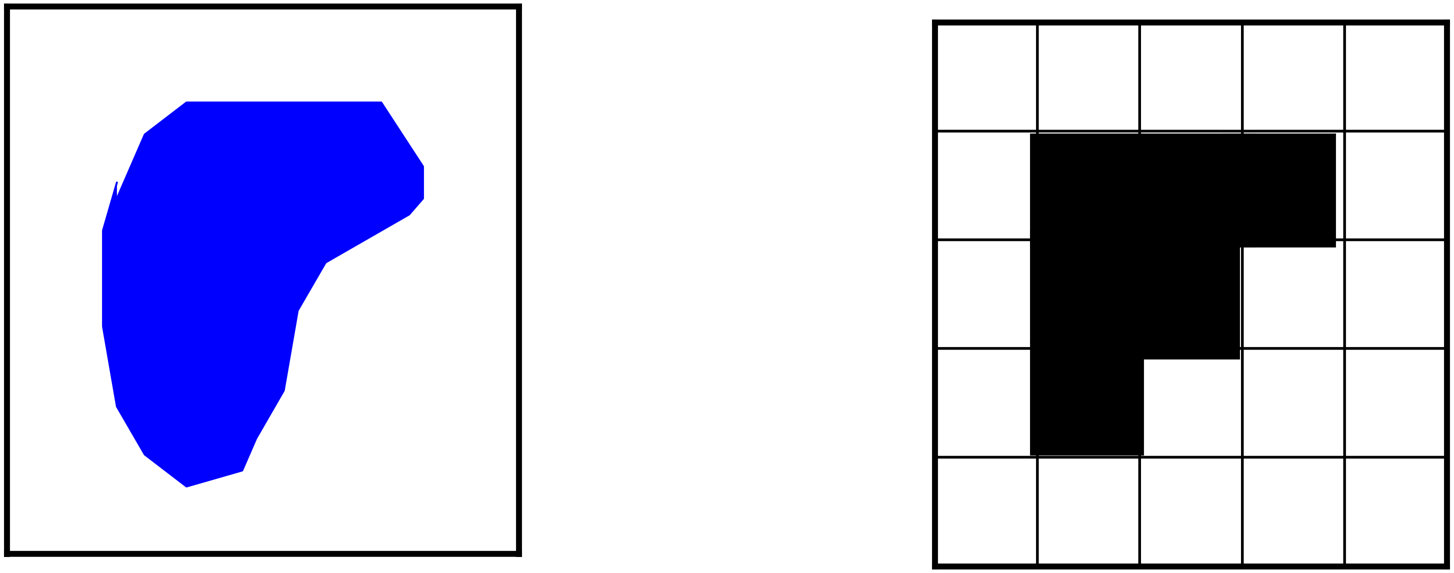
Raster Data Model - Lines



A line = a series of connected cells that portray length

Is there a problem with this representation?

Raster Data Model - Areas

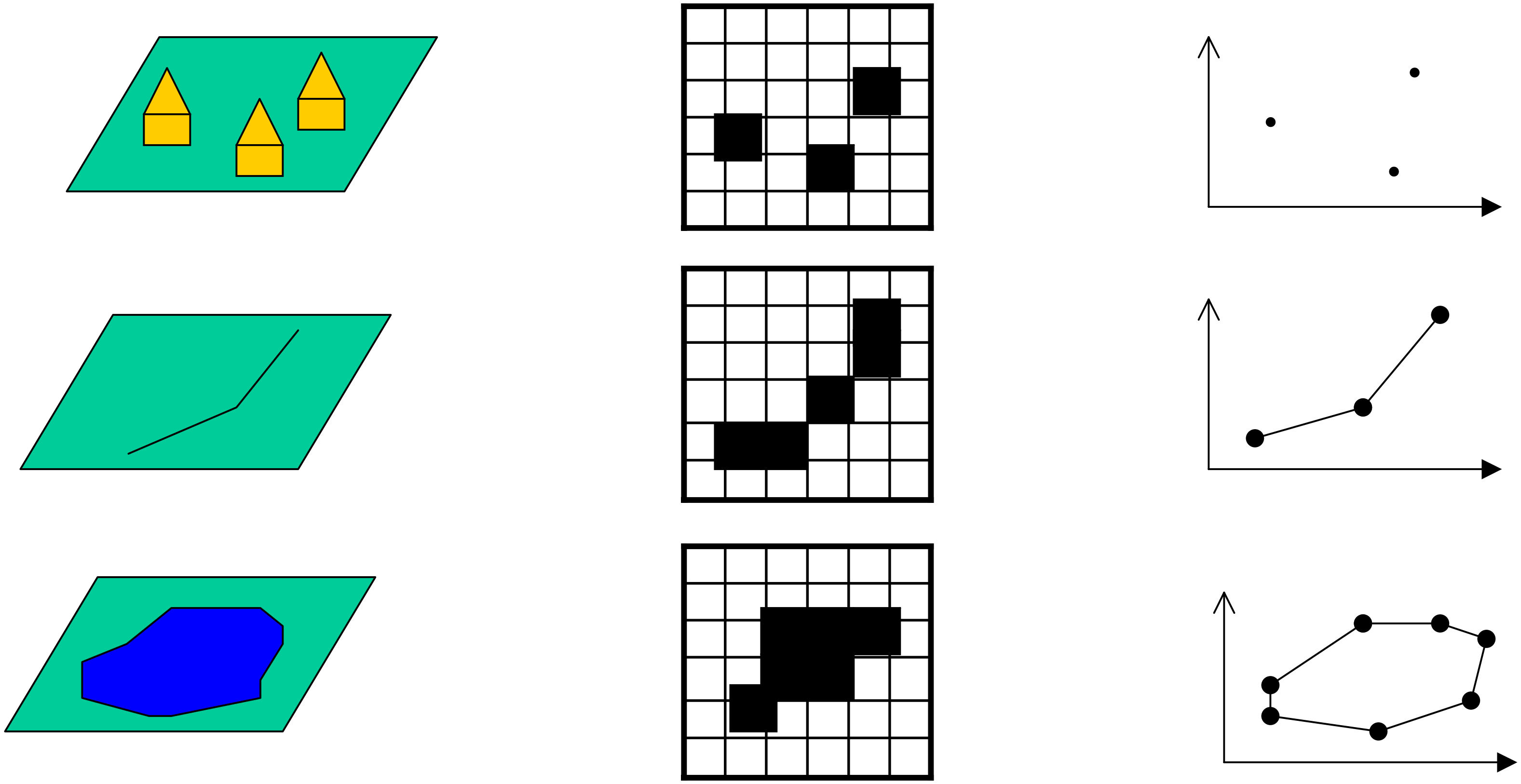


Area = a group of connected cells that portray a shape

What problems could we have with this representation?

Raster and Vector Data Model Comparison

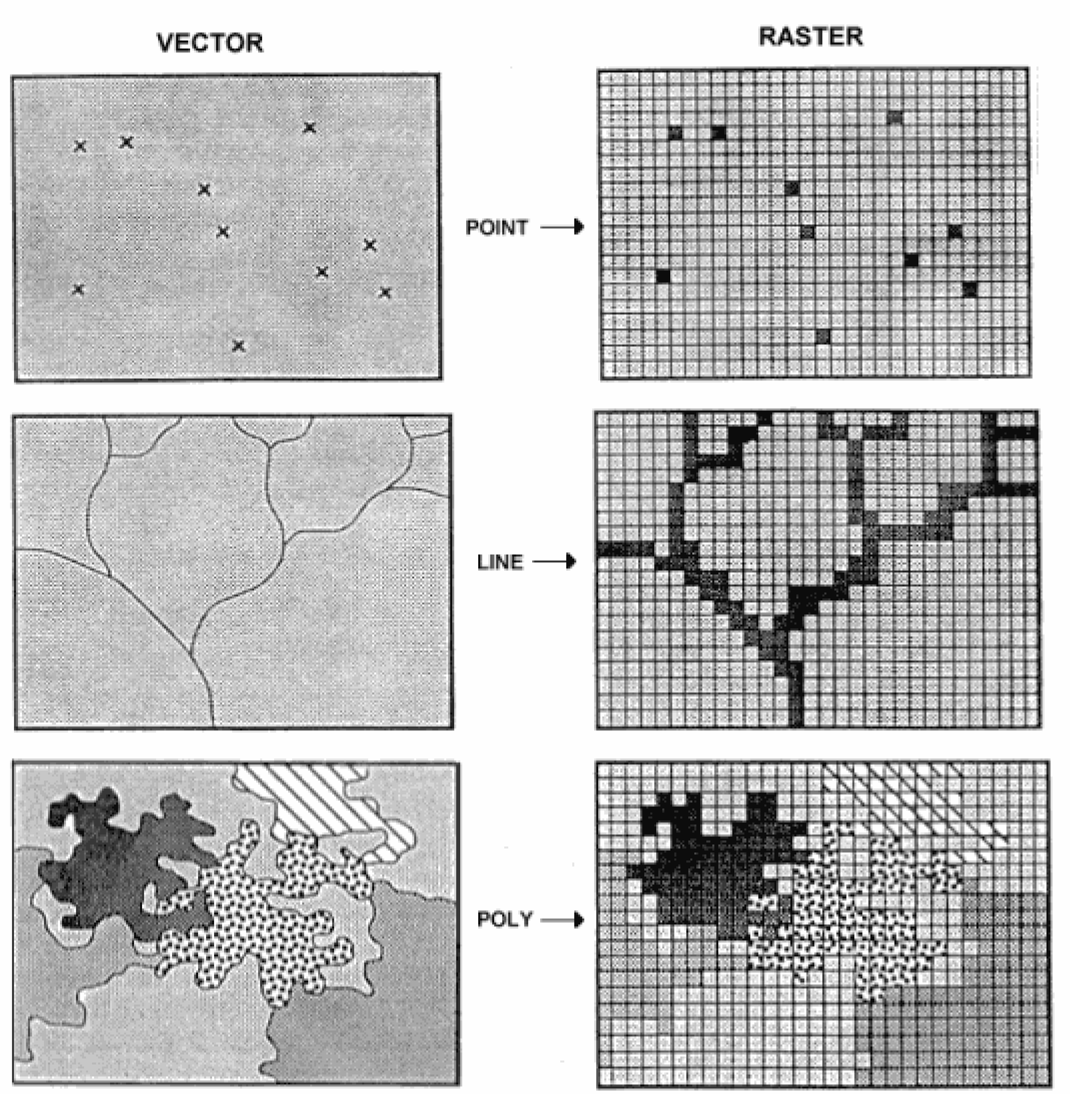
Real World Features **Raster** **Vector**



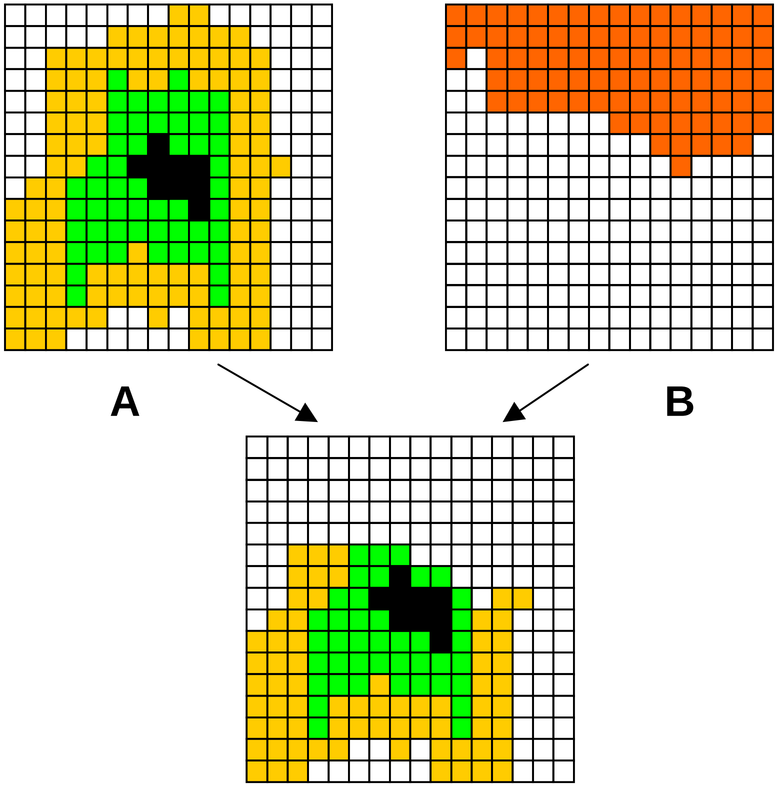
“A raster model tells what occurs everywhere, while a vector model tells where every thing occurs”

Rasterization - Issues

- The **key issues** to are:
- **cell size**, and its effect on the spatial representation of entities **<u>AND</u>**
- how we choose **cell values** to represent attributes
- This is **simpler** compared to vectorization.



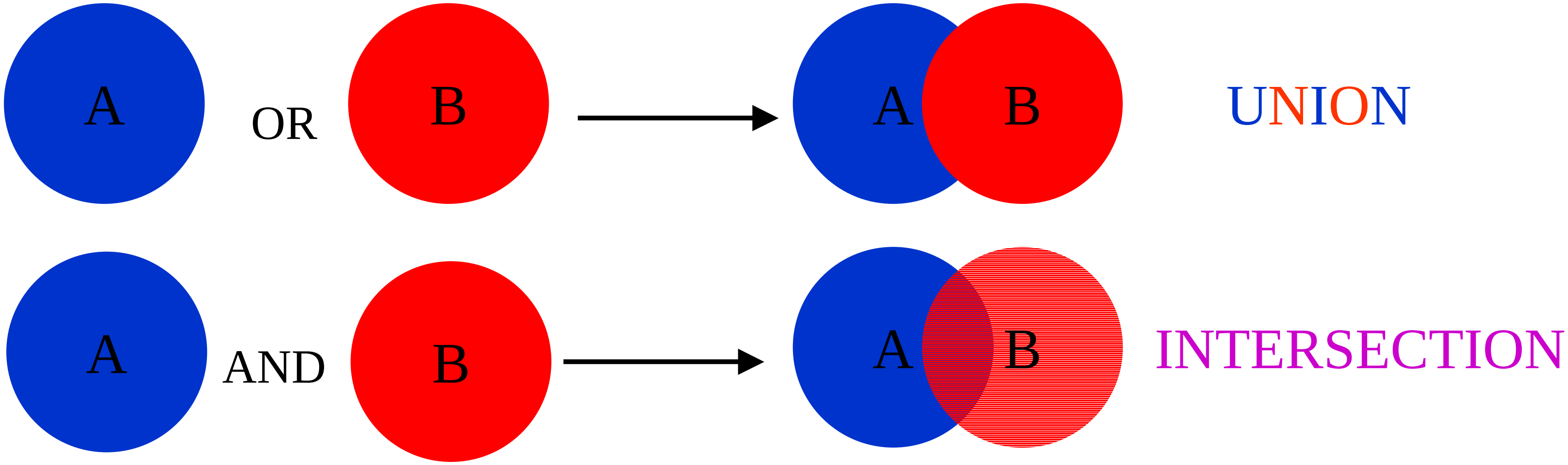
Overlay of Fields Represented as Rasters



The two input data sets are maps of (A) travel time from the urban area shown in black, and (B) county (red indicates County X, white indicates County Y). The output map identifies **travel time to areas in County Y only**, and might be used to compute average travel time to points in that county in a subsequent step

Boolean Operations

- In both **Venn probability diagrams** and **vector overlay analysis**, we used **UNION & INTERSECTION** operations, corresponding to Boolean operations of **OR & AND**



- We can apply these concepts in the **raster** spatial data model as well, but on a **per cell basis** with two input layers that contain true/false or 1/0 data:

Boolean Operations with Raster Layers

- The AND operation requires that the value of cells in **both** input layers be **equal to 1** for the output to have a value of 1:

0	1	1
0	0	1
1	0	1

AND

0	0	0
1	1	1
0	0	1

=

- The OR operation requires that the value of a cells in **either** input layer be **equal to 1** for the output to have a value of 1:

0	1	1
0	0	1
1	0	1

OR

0	0	0
1	1	1
0	0	1

=

Simple Arithmetic Operations

Summation

$$\begin{array}{|c|c|c|}\hline 0 & 1 & 1 \\ \hline 0 & 0 & 1 \\ \hline 1 & 0 & 1 \\ \hline \end{array} + \begin{array}{|c|c|c|}\hline 0 & 0 & 0 \\ \hline 1 & 1 & 1 \\ \hline 0 & 0 & 1 \\ \hline \end{array} = \begin{array}{|c|c|c|}\hline 0 & 1 & 1 \\ \hline 1 & 1 & 2 \\ \hline 1 & 0 & 2 \\ \hline \end{array}$$

Multiplication

$$\begin{array}{|c|c|c|}\hline 0 & 1 & 1 \\ \hline 0 & 0 & 1 \\ \hline 1 & 0 & 1 \\ \hline \end{array} \times \begin{array}{|c|c|c|}\hline 0 & 0 & 0 \\ \hline 1 & 1 & 1 \\ \hline 0 & 0 & 1 \\ \hline \end{array} = \begin{array}{|c|c|c|}\hline 0 & 0 & 0 \\ \hline 0 & 0 & 1 \\ \hline 0 & 0 & 1 \\ \hline \end{array}$$

Summation of more than two layers

$$\begin{array}{|c|c|c|}\hline 0 & 1 & 1 \\ \hline 0 & 0 & 1 \\ \hline 1 & 0 & 1 \\ \hline \end{array} + \begin{array}{|c|c|c|}\hline 0 & 0 & 0 \\ \hline 1 & 1 & 1 \\ \hline 0 & 0 & 1 \\ \hline \end{array} + \begin{array}{|c|c|c|}\hline 0 & 0 & 0 \\ \hline 1 & 1 & 1 \\ \hline 0 & 0 & 1 \\ \hline \end{array} = \begin{array}{|c|c|c|}\hline 0 & 1 & 1 \\ \hline 2 & 2 & 3 \\ \hline 1 & 0 & 3 \\ \hline \end{array}$$

Geographic Surfaces

- Up to this point, we have talked about spatial data models that operate in **two dimensions**
- How about the **3rd** dimension?
  - **Surface** – the continuous variation in space of a third dimension (elevation in a physical context, but it could be other ‘virtual’ 3rd dimensions for other purposes, e.g. modeling population density using a surface)
- We can use either the vector or raster data model to represent a surface, but **raster** models are **most commonly** used for because they are good at representing **continuous variation**

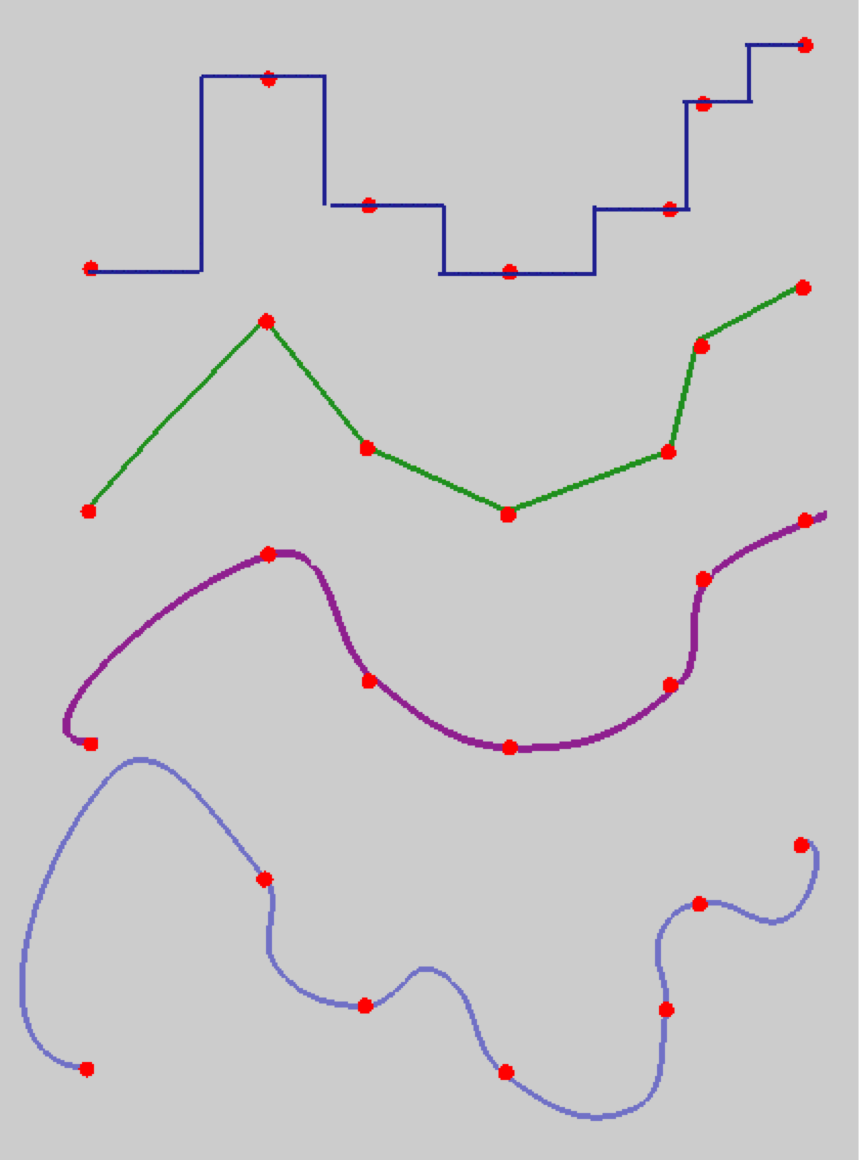
Spot Elevations – The Starting Point

- **Where** do DEMs come from?
  - We create them from **another representation** of terrain
- Fundamentally, terrain data is collected in the field as a **set of spot elevations**
- Traditionally, **survey or photogrammetric** methods are used to collect these
- Now we have an alternative source at a higher density – **LIDAR** (LIght Detection And Ranging)
- Why does the **density** of spot elevations matter?

Interpolating a DEM

- Getting from a set of spot elevations to a DEM requires the use of **interpolation:**
- Interpolation **creates a continuous field** representation (like a raster grid, or TIN, or contours) **from discrete objects** (like spot elevation samples)
  - This is **necessary**: There isn't really a way to **capture a continuous field** other than by **sampling it discretely** at some **chosen resolution** …
  - Our **models of reality** will always be **less detailed than reality** itself, but we hope to **capture enough variation** to support whatever purposes we have in mind

The Interpolation Problem



http://skagit.meas.ncsu.edu/~helena/gmslab/viz/interp1d.html

- If we look at interpolation in a **2-dimensional** sense (as shown to the left), what we are trying to do is:

- **Find a function** that passes through (or close to) a set of points

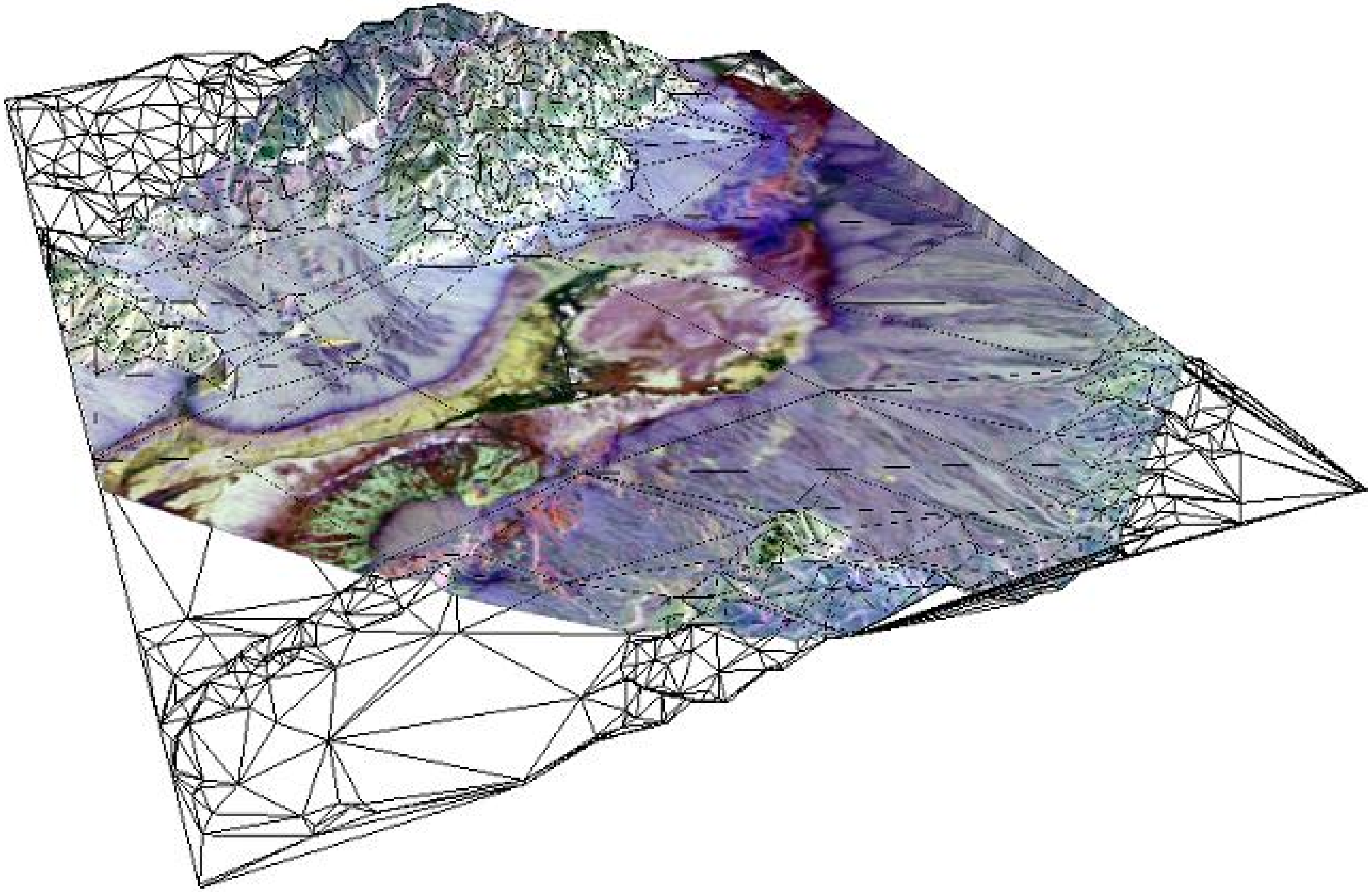
- There is **no unique solution** to this problem, so we want to pick a function that produces a result that has the **properties we want** in our surface

Representing terrain using data

- We can **represent terrain** using various sorts of digital elevation models (DEMs). We will briefly look at each of these representations:
  - **Triangulated Irregular Network** (TIN) – a model made up of triangular facets
  - **Contours** – a vector/arc based model with elevations associated with each contour
  - **Raster grid** – a cell-based model with elevations associated with each cell
- From DEMs, we can derive **how water moves through a landscape** (via drainage networks) by using a variety of **spatial analysis** operations

Digital Elevation Models

Triangulated Irregular Network (TIN)

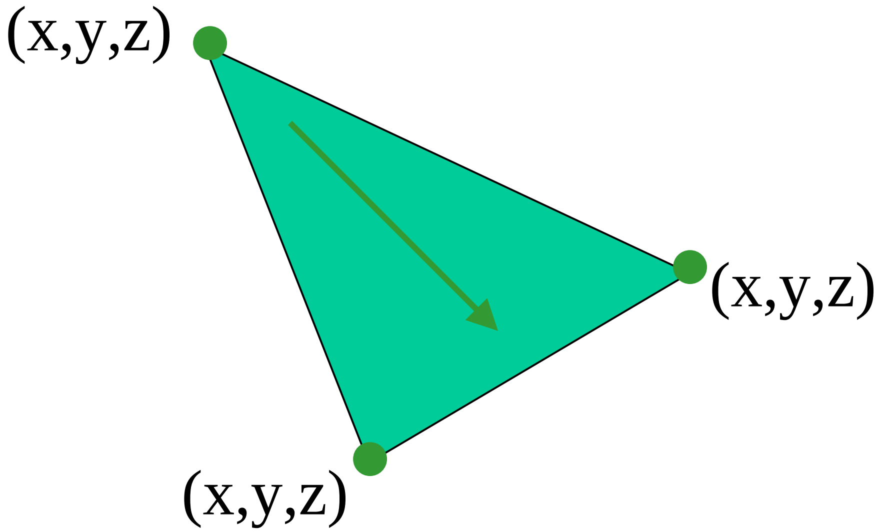


Triangulated Irregular Networks

- Triangle **vertices** represent certain kinds of terrain features – **peaks & depressions**
- The **edges** of the triangles represent other terrain features – **ridges & valleys**
- Elevation at any **vertex** is known
- Elevation can be **calculated** at **other points** on the surface using using geometry
- **Tightly-packed** triangles indicate **rapid terrain change** (variable density of representation)
- **Large** triangles indicate **little** change (flat areas)

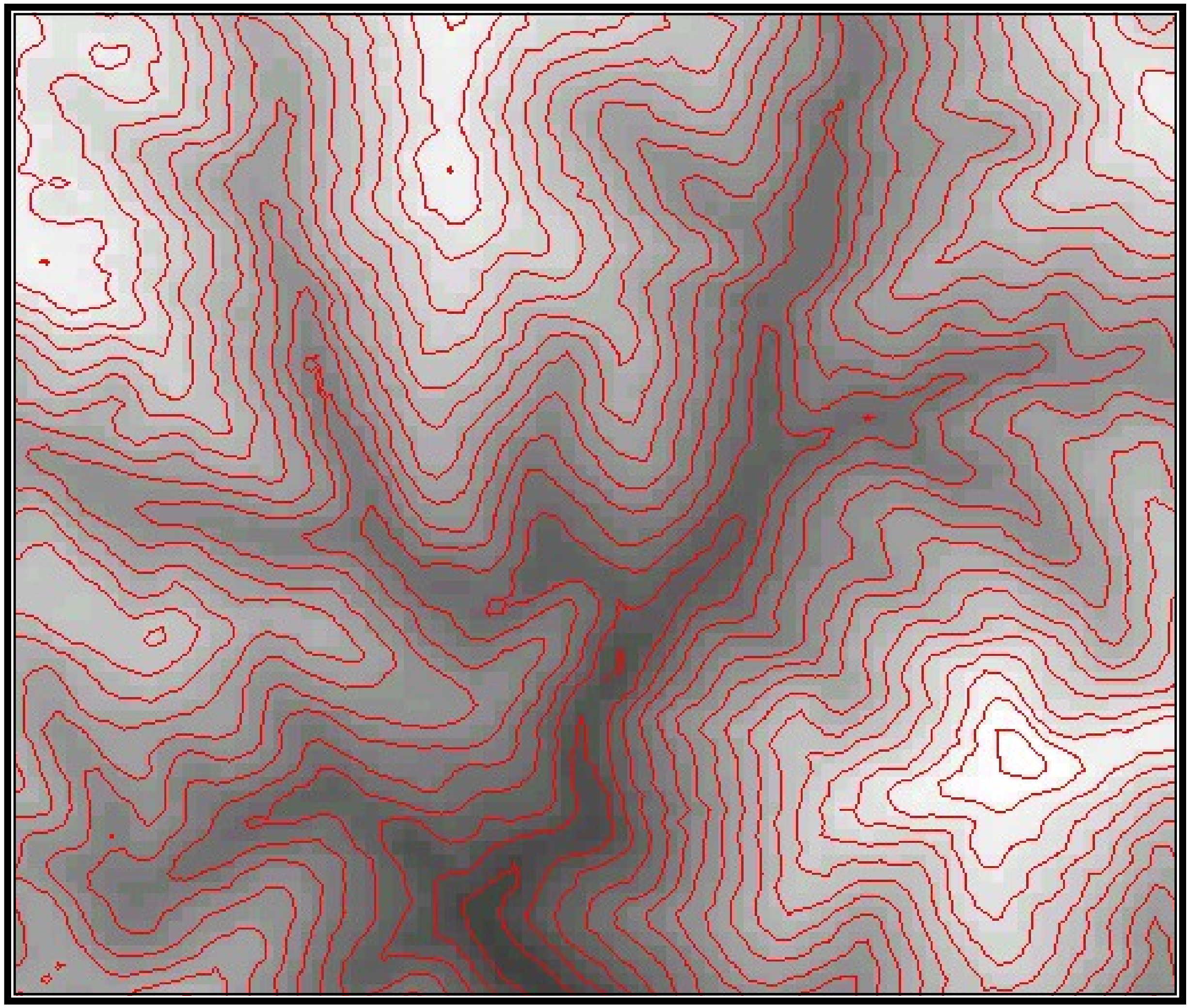
Triangulated Irregular Networks

- Slope and aspect can also be **derived** from a TIN
- **Slope** can be **calculated** using simple geometry
- The **direction** of a triangle's face can be used to obtain **aspect**



Digital Elevation Models

Contours

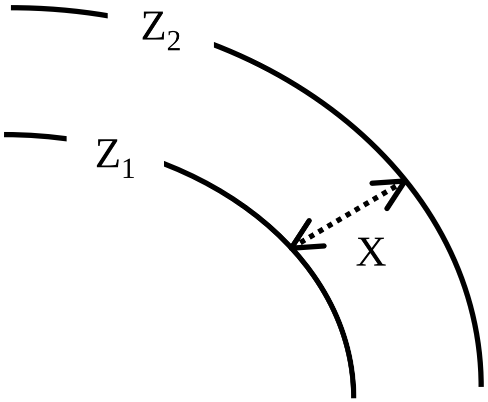


Contours

- Contours represent terrain using **isolines or isopleths**, which are lines of constant value
- Terrain features are represented by the shape of the isolines (their path and how close they are together)
- Elevation on any **contour line** is known
- Elevation can be **calculated/interpolated** at **other points** on the surface by measuring the distance to nearby isolines
- **Tightly-packed** isolines indicate **rapid terrain change** (variable density of representation)
- **Large** spaces between contour lines indicate **little** change (flat areas)

Contours

- Slope can also be **derived** from contours
- **Slope** can be **calculated** by taking rise / run, where **rise** is the **difference in elevation** between two contour lines ($Z_1 - Z_2$) and **run** is the **distance between them** (X), ideally measured orthogonal to both contour lines



Contours

- Through visual interpretation, we can **find critical points** in the landscape (points where the first derivative, slope, is zero):
  - **Peaks** at local maxima
  - **Pits** at local minima
  - **Passes** at saddle points
- Further, we can **connect critical points** to find some useful sorts of lines:
  - A slope line that connects a pass to a peak is a **ridge line**
  - A slope line that connects a pass to a pit is a **course line**

Watershed Delineation using Contours

- **Watershed boundaries** can be determined by finding ridge lines (locate the appropriate critical points, and join them, perpendicular to the contour lines)
- **Stream channels** (which are specific course lines) also flow perpendicularly to the contour lines, from passes to pits
- The **boundary lines** are drawn through the center of saddles (pass critical points) and closed contour lines (peak critical points)

Saddle

Closed Contour

Stream Channel

Governing Rules of Water Movement

- Like all physical processes, the flow of water always occurs across some form of **energy gradient** from high to low…
  - e.g., a topographic (slope) gradient from high to low elevation
  - Or a **concentration gradient, pressure gradient**, etc.
- All other things being equal, in a fluvial landscape that **has some relief**, water movement near the surface is going to follow the **topographic gradient downhill**
- Thus, by **modeling terrain** using a continuous surface, we can learn some useful things about the **movement of water** through a landscape

Watershed (a.k.a. Drainage Basin, Catchment)

- A geomorphically distinct **landscape unit** defined by topographic boundaries, or drainage ‘divides’ that acts as a spatially discrete hydrological system

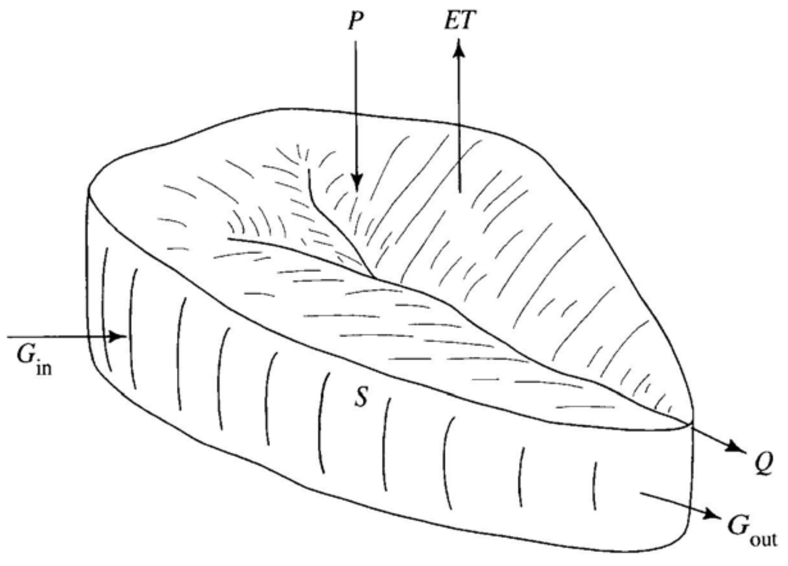
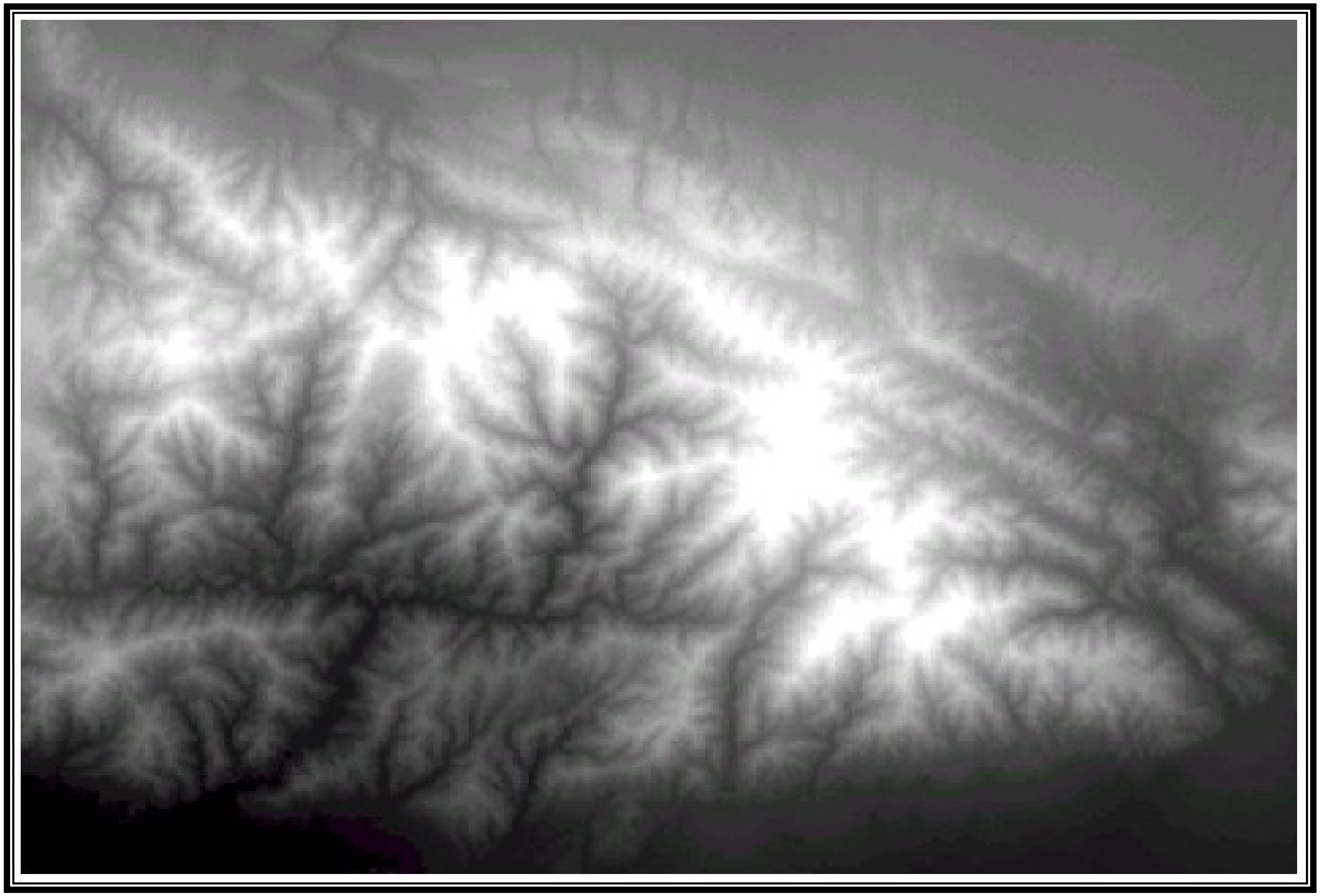


FIGURE 2-3

Schematic diagram of a watershed, showing the components of the regional water balance: P = precipitation, ET = evapotranspiration, Q = stream outflow, G_{in} = ground-water inflow, G_{out} = ground-water outflow.

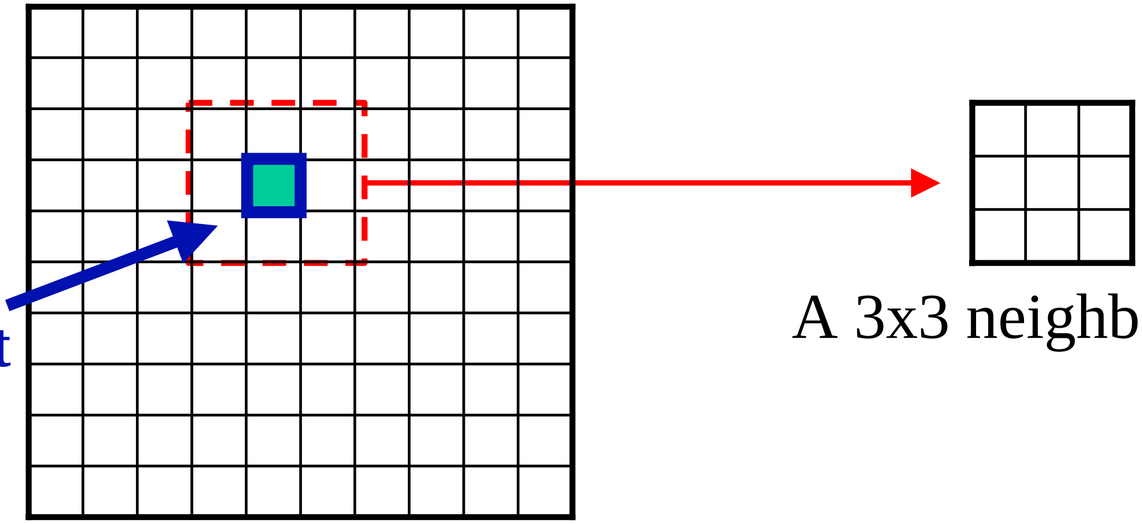
Digital Elevation Models

Raster Grid



Neighborhood Operations

- In raster overlay analysis, we compared **each cell** in a raster layer with another cell in the **same position** on another layer
- In neighborhood operations, we look at a **neighborhood** of cells **around the cell of interest** to arrive at a new value:



Cell of Interest

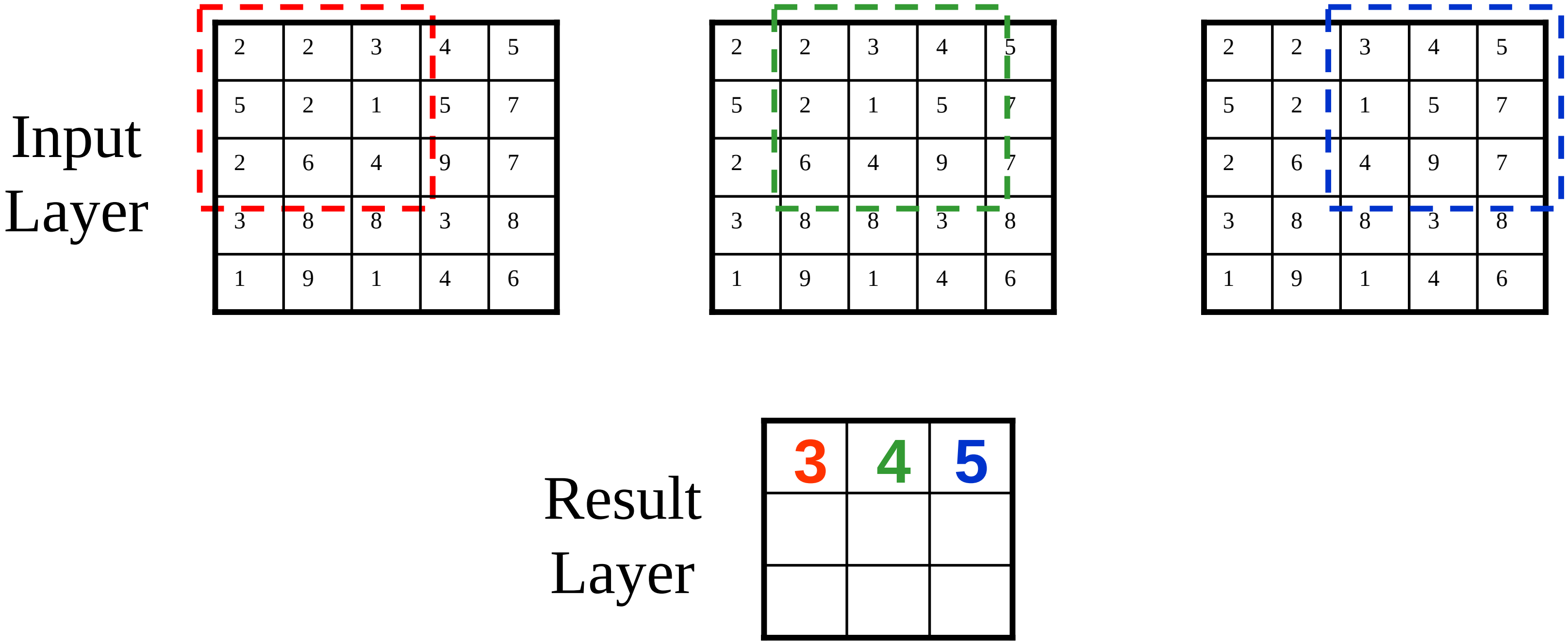
A 3x3 neighborhood

An input layer

- Neighborhoods can be of any possible size; we can use a 3x3 neighborhood for any cell except on the **edge** of the layer

Neighborhood Operation - Mean

- One neighborhood operation is to calculate the **mean** for all pixels in the neighborhood and put the result in the center of the neighborhood. This is why a neighborhood size is often an **odd number** (3x3, 5x5, 7x7, …) because these have a well defined center for the result value:



Input Layer

2	2	3	4	5
5	2	1	5	7
2	6	4	9	7
3	8	8	3	8
1	9	1	4	6

2	2	3	4	5
5	2	1	5	7
2	6	4	9	7
3	8	8	3	8
1	9	1	4	6

2	2	3	4	5
5	2	1	5	7
2	6	4	9	7
3	8	8	3	8
1	9	1	4	6

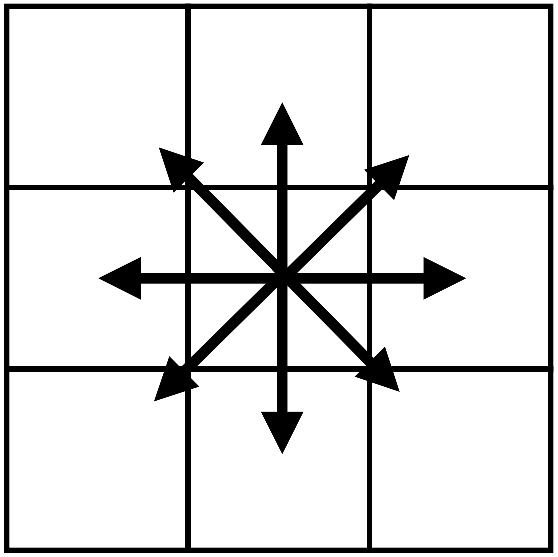
Result Layer

3	4	5

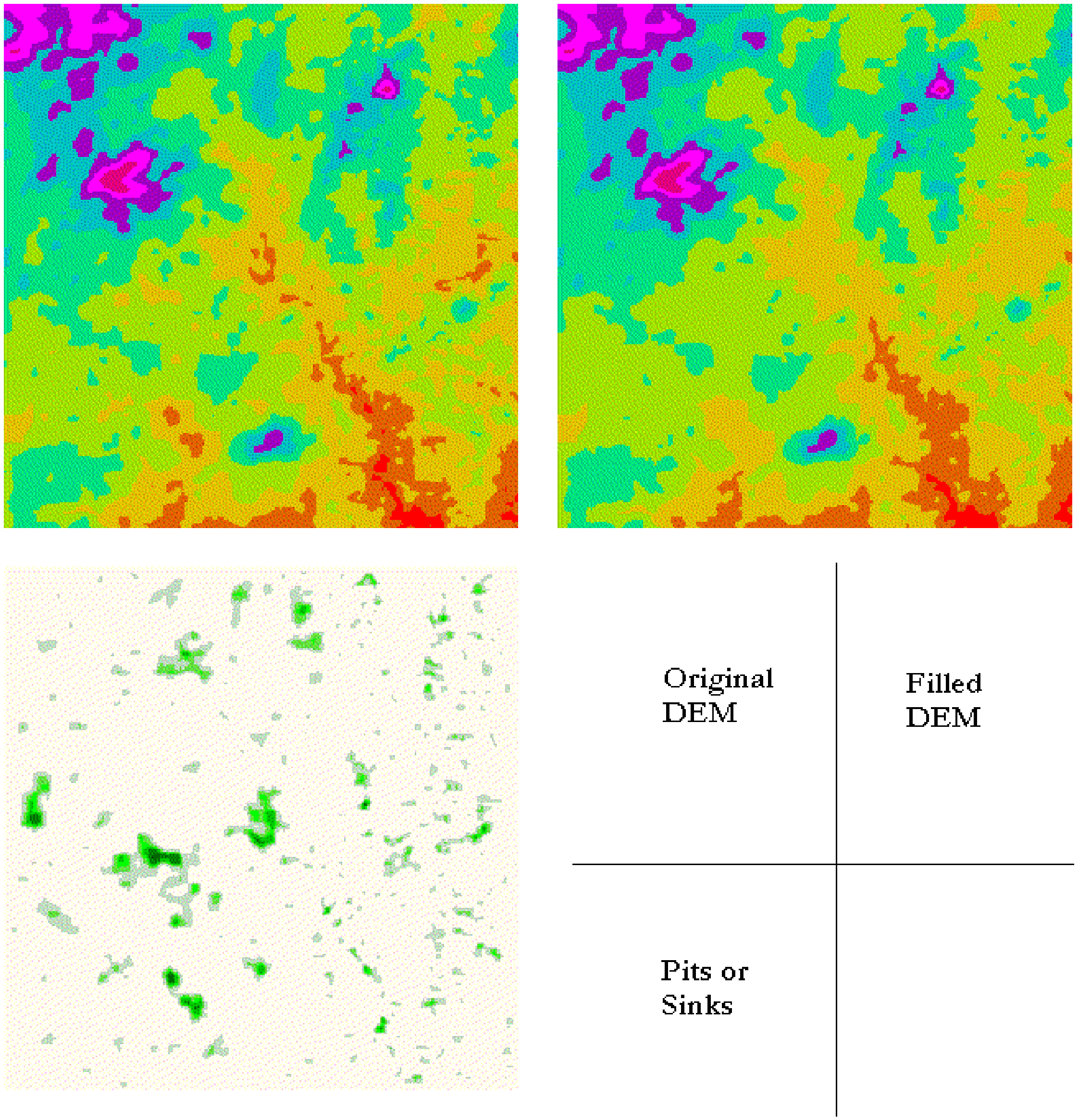
D8 Analysis Sequence

- Assume we now have a raster DEM and we want to use it **find a watershed and drainage network** through D8 analysis
- We can follow this **sequence of analysis** steps, each of which involves a neighborhood analysis operation:
  - Fill Sinks
  - Slope
  - Aspect
  - Flow Direction
  - Flow Accumulation
  - StreamLink & StreamOrder
  - Watershed

D8 Analysis

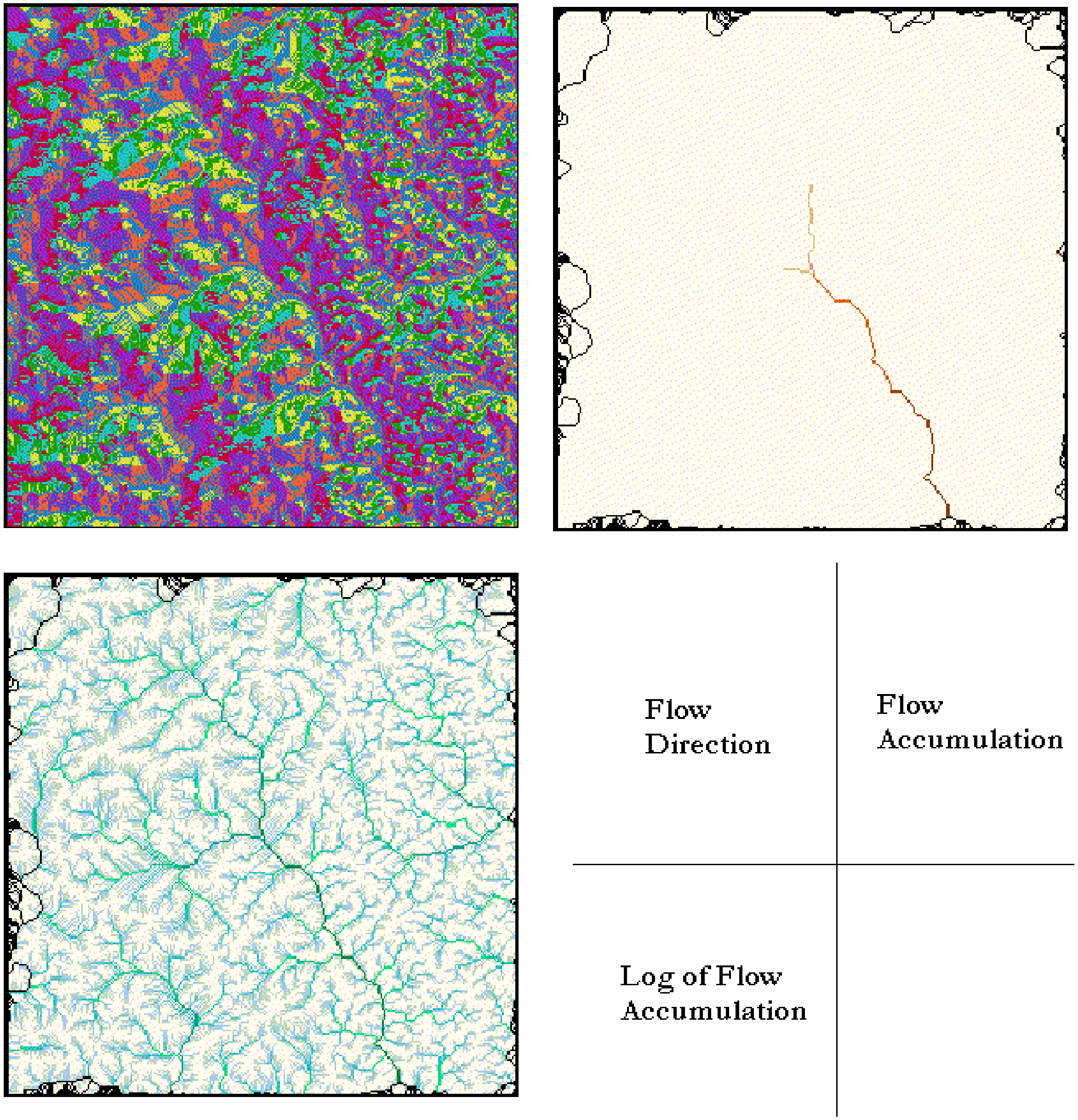


Fill Sinks



- We need a DEM that does not have any **depressions or pits** in it for D8 drainage network analysis
- The first step is to **remove all pits** from our DEM using a **pit-filling algorithm**
- This **illustration** shows a DEM of **Morgan Creek**, west of Chapel Hill

Flow Direction and Accumulation



- Slope and aspect are needed to produce **flow direction**, which assigns each cell a **direction of steepest descent**
- **Flow accumulation** uses flow direction to find the **number of cells** that **drain to each cell**
- Taking the **log** of accumulation makes the **pattern** much easier to see

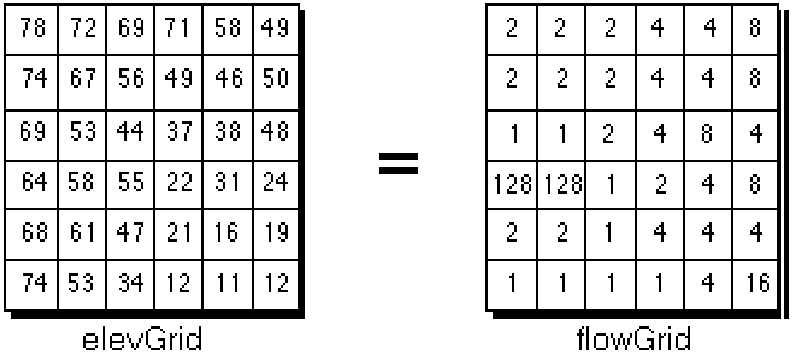
Flow Direction

- Flow Direction evaluates the **direction of steepest decent** for each cell in the grid by **comparing a cell with its eight neighbors** in the following fashion:
  - drop = change in z value / distance * 100
  - Note that diagonal neighbors are 1.414214 times as far away as 4-connected orthogonal neighbors
- ArcGIS **encodes** the resulting direction of steepest decent in the grid using **the following scheme**:

32	64	128
16	X	1
8	4	2

- For example:

From ArcView 3.2 Help



78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

elevGrid

=

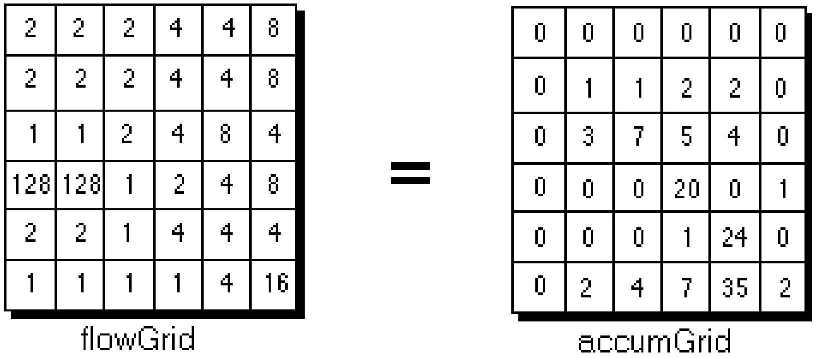
2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

flowGrid

Flow Accumulation

- Flow accumulation find the **number of cells that drain to any cell** in the grid, taking the flow direction grid as input:
  - Output cells with a **high flow accumulation** are areas of concentrated flow and may be used to **identify stream channels**.
  - Output cells with a **flow accumulation of 0** are local topographic highs and may be used to **identify ridges**.
- For example:

From ArcView 3.2 Help



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

flowGrid

=

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

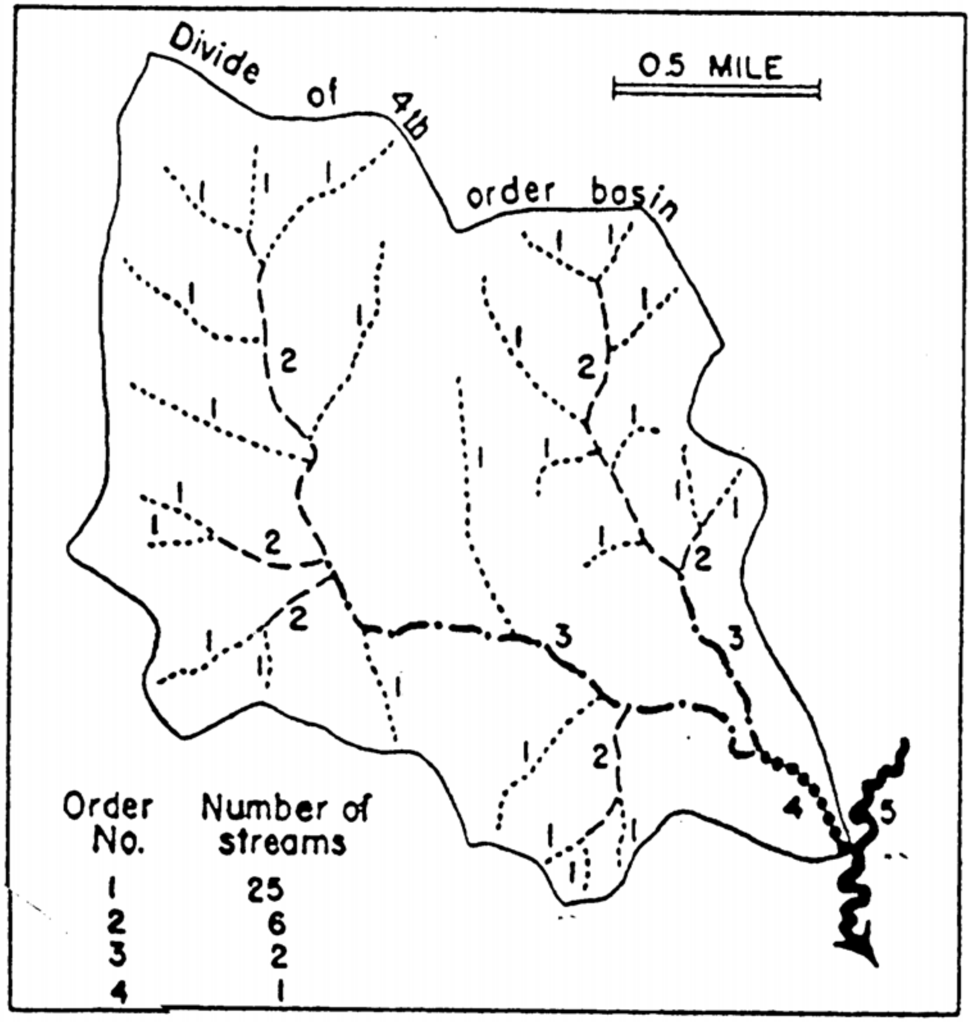
accumGrid

Davis' (1899) Notion of a Watershed

- Davis provided the very useful metaphor of **the river as a leaf**, such that:
  - "one may **extend the 'river' all over its basin** and up to its very divides. Ordinarily treated, the river is like the veins of a leaf; broadly viewed, it is like the entire leaf" (Chorley, 1969, p.78).

Stream order (Horton 1945, Strahler 1954)

- **hierarchy of channels** from 1st order tributaries to nth order main channel
  - e.g., Mississippi R. at New Orleans is 14th order
- **Strahler's rules**:
  - junction of 2 streams of order 'x' form next downstream order 'x +1'
  - junction of 2 streams of different orders x & y, where y > x, creates order equal to higher order stream (y)



Order No.	Number of streams
1	25
2	6
3	2
4	1

FIG. 2 – Method of designating stream orders (Strahler, 1954a, p. 344)

Stream Order/Magnitude Methods

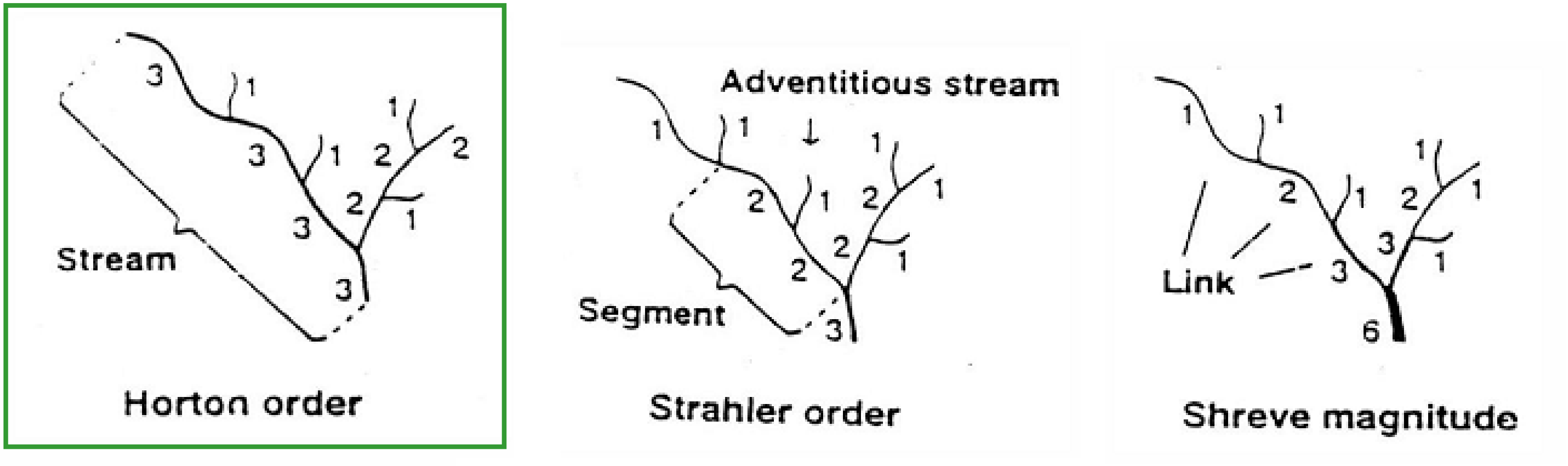


Figure 5: Stream Ordering Methods (Jones, 1997, p.176)

- **Horton** sub-divided the stream network on a **stream-ordering** basis, where the drainage network was broken into component parts, or reaches, and these reaches were assigned a stream-order, **descriptive of their size** (Chorley et al., 1984, p.317)

Stream Order/Magnitude Methods

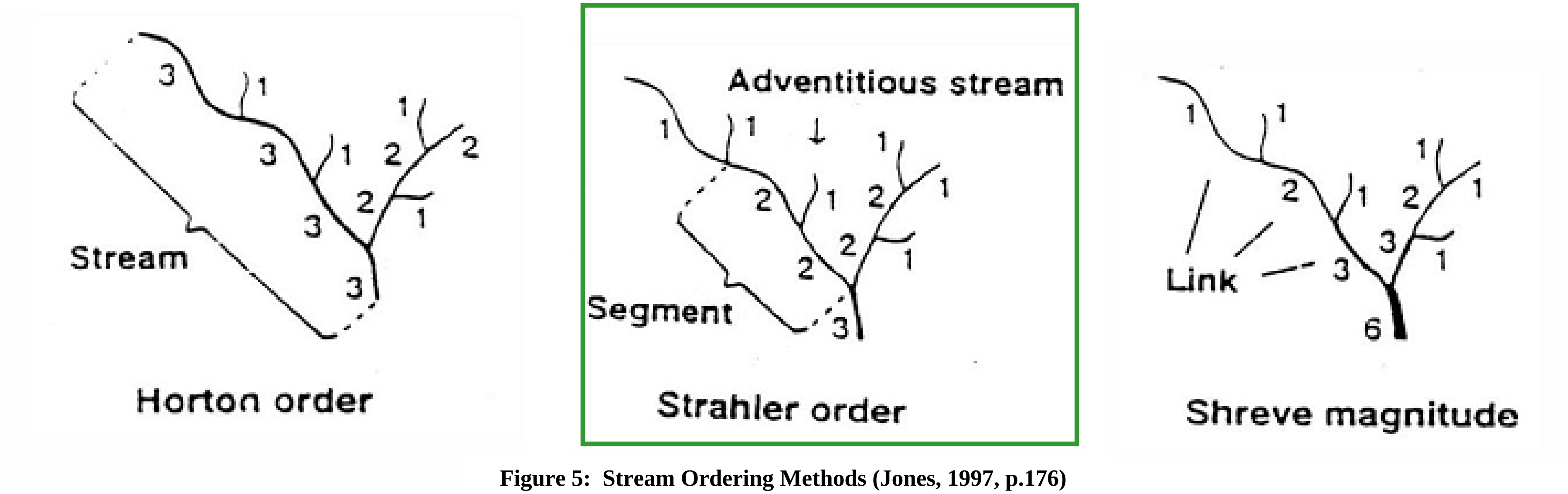


Figure 5: Stream Ordering Methods (Jones, 1997, p.176)

- In 1964, **Strahler improved** Horton’s stream-ordering approach. Horton’s assignment of order values **underestimated** the importance and number of **lower-order tributaries**. Strahler’s scheme corrected this, and assigned values more impartially, rather than extending the higher-order stream further up the divide as Horton did (Jones, 1997, p.176).

Stream Order/Magnitude Methods

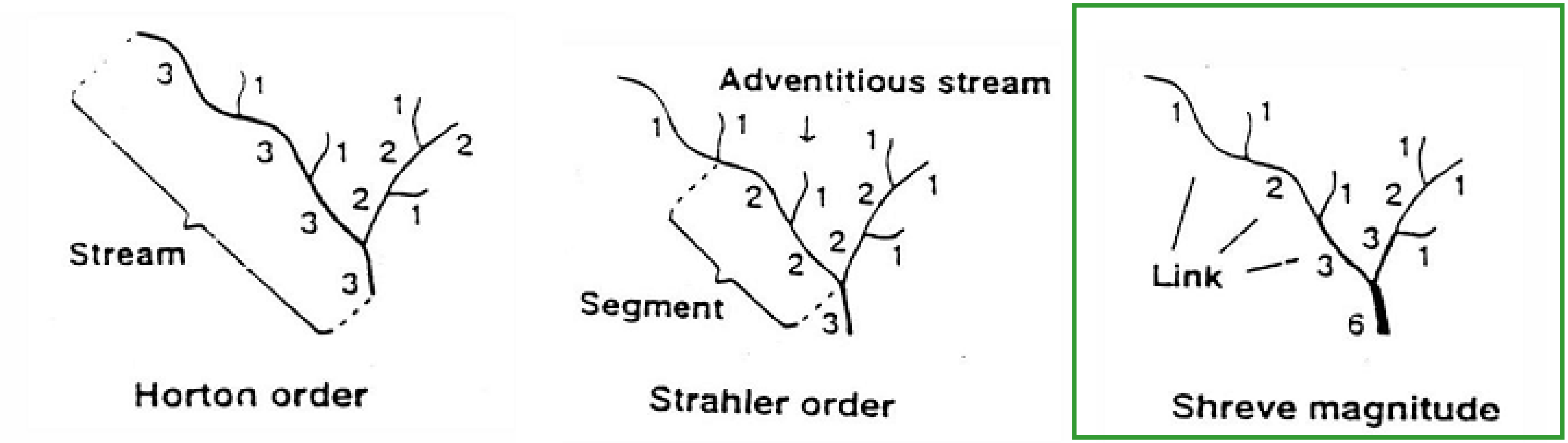
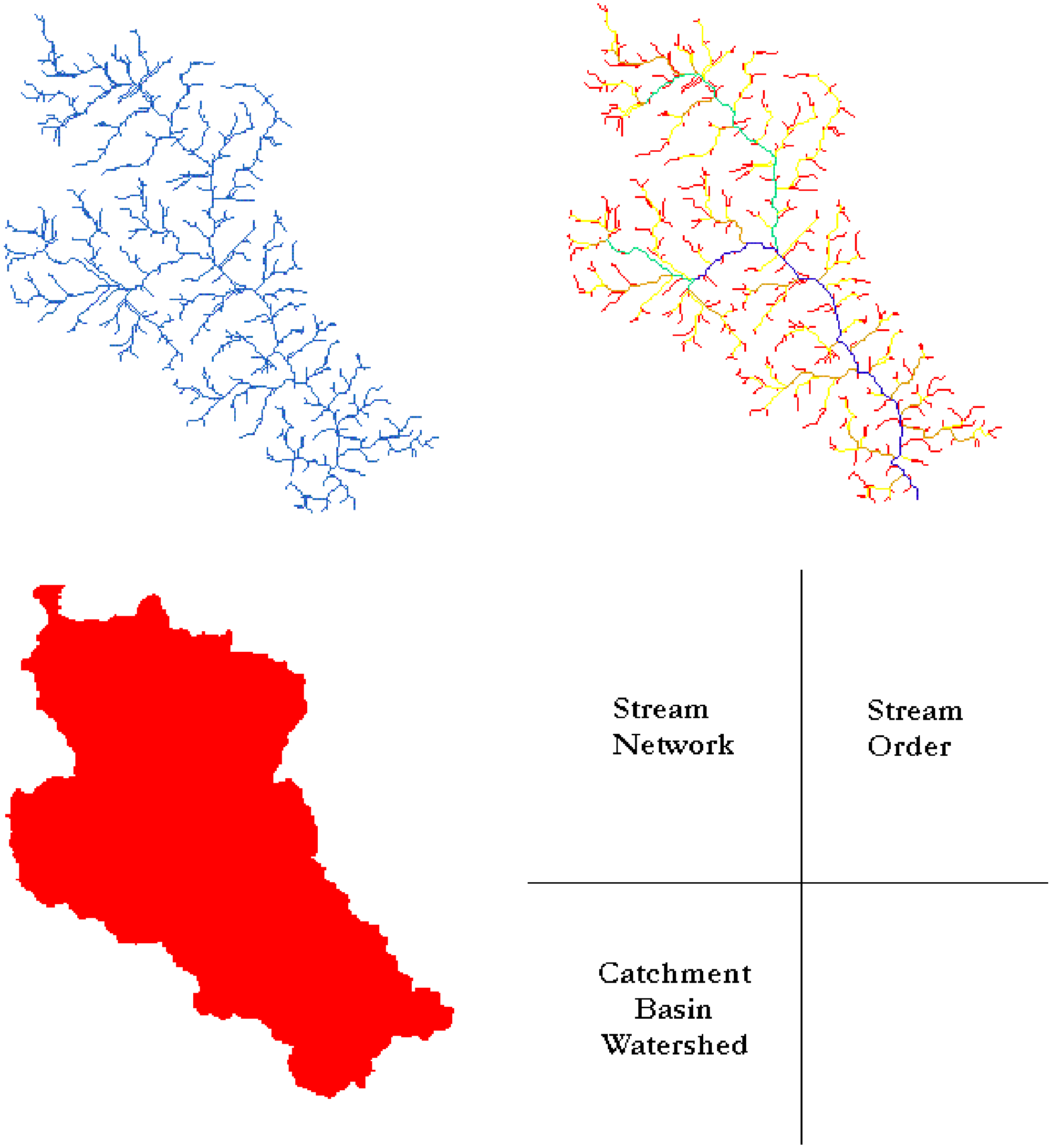


Figure 5: Stream Ordering Methods (Jones, 1997, p.176)

- **Shreve further improved** stream ordering in 1966 by introducing the concept of **stream magnitude**: Values assigned to a reach represented the **sum of contributing reaches**. This scheme better preserves the sense of the contribution of a given reach's drainage (Jones, 1997, p.176).

Stream Links, Order, and Basins



- By selecting a **threshold value** for flow accumulation, we can produce a **stream network**
- This network can **divided** into **stream links**, which can in turn be assigned **stream order** values using network analysis methods
- Threshold=1 gives the **watershed**

Products of D8 Analysis

- Producing a drainage network using D8 provides some very **useful descriptions** of the landscape from a sinkless raster DEM:
  - For each cell we can determine which neighboring cell will **receive its drainage** (flow direction)
  - We can use the flow directions to find the **flow accumulated** at each cell
  - We can threshold flow accumulation to find a **stream network**
  - Through network analysis we can find **stream links** and assign **order** values to links
  - Using flow accumulation we can also find the set of cells that drain to a cell, its **catchment/basin/watershed**

TOPMODEL Background –

Adapted from Ch.9 of *Elements of Physical Hydrology*

- Let's begin with the idea that the **topography** of the landscape exerts an **enormous influence** on the **movement of water** in the **subsurface** and likewise should control the movement of **surface water**.
- Therefore, we can base a model of catchment dynamics on the idea that **topography** is the **most important** landscape feature **controlling water flow**.
- Next, let's extend the idea of catchment "reservoirs" to **elements** of the landscape. If we could break the catchment up into **blocks of a given size**, we might be able to **route water through each block** as we move down a **hillslope**.

TOPMODEL Background –

Adapted from Ch.9 of *Elements of Physical Hydrology*

- Each block would **differ in its position** along the hillslope and in the slope of the land surface (and probably the water table) through the block.
- If the water table is **relatively flat** within a given block, the hydraulic gradient is small and we might **expect an increase in water storage** through time within that block.
- The **increase in storage** is **even greater** if the block is at the base of **a convergent hillslope**, such that a **great deal of upslope flow** into the block occurs (Figure 9.6).

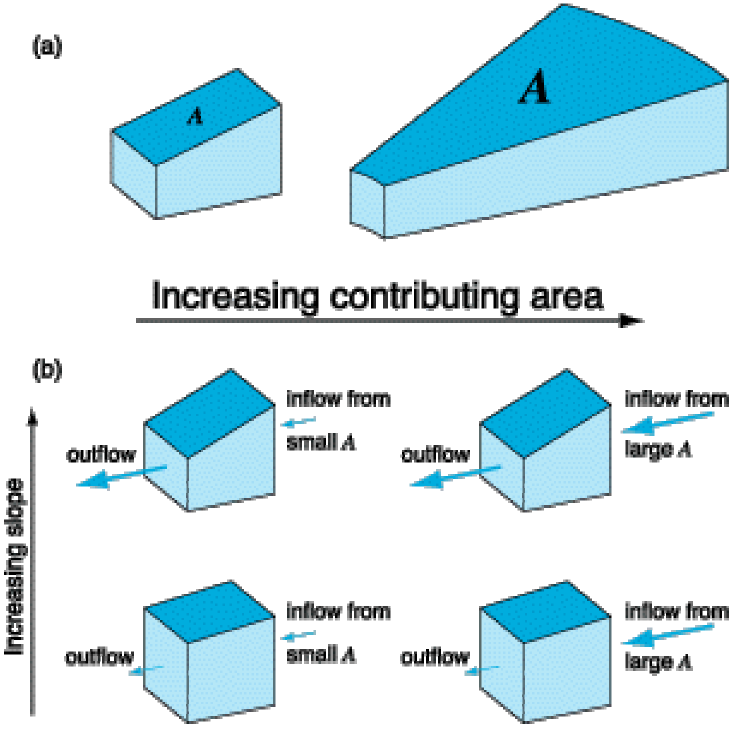


Figure 9.6 Local slope and contributing area control the water balance for a catchment "block." The inflow rate is proportional to the contributing area *A*, which depends on how long the hillslope is as well as whether it is convergent, divergent, or planar (a). The local slope controls the outflow from the blocks (b). If inflow is smaller than outflow (upper left in b), the water table declines. Conversely, if inflow is greater than outflow (lower right in b), the water table will rise and surface saturation may occur. (Hornsberger, G.M., Raffensberger, J.P., Wiberg, P.L. and K.N. Eshleman. 1998. *Elements of Physical Hydrology*, Johns Hopkins Press, U.S.A.)

TOPMODEL Background –

Adapted from Ch.9 of *Elements of Physical Hydrology*

- One catchment model that is based on the idea that **topography exerts a dominant control on flow routing** through upland catchments is called **TOPMODEL** (Beven and Kirkby, 1979).
- TOPMODEL uses the **equation for conservation of mass** ("inflow rate minus outflow rate equals rate of change of storage") for **several "reservoirs" in a catchment**.
- By **linking together** the water balance equations for all of the hypothetical reservoirs in the catchment, a routing computation can be completed.

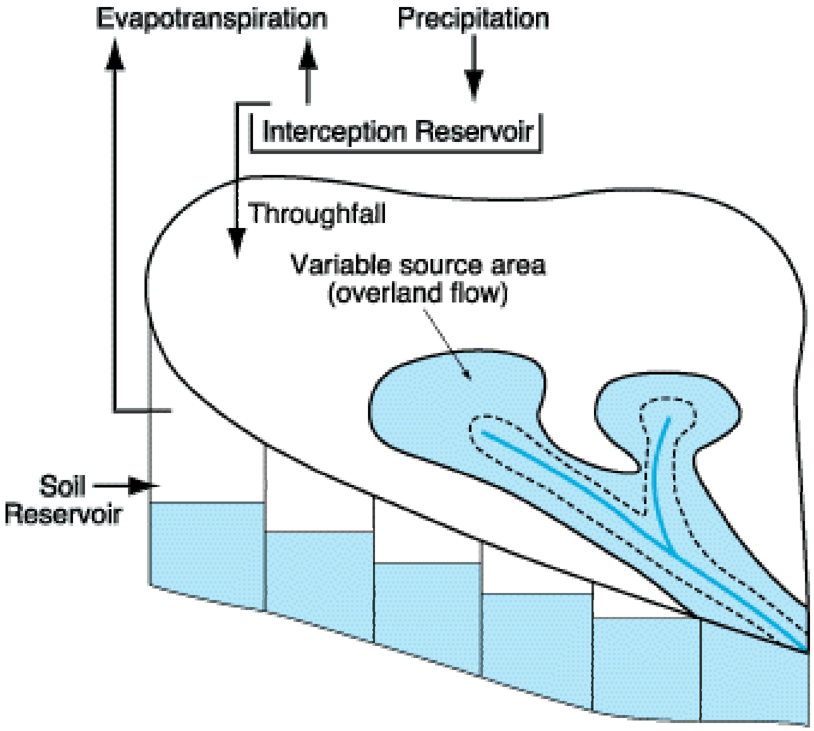


Figure 9.7 Schematic diagram of the TOPMODEL concept. (Hornsberger, G.M., Raffensberger, J.P., Wiberg, P.L. and K.N. Eshleman. 1998. *Elements of Physical Hydrology*, Johns Hopkins Press, U.S.A.)

TOPMODEL Background –

Adapted from Ch.9 of *Elements of Physical Hydrology*

- **TOPMODEL** performs the bookkeeping for the water balance computations in the **framework of topographically defined elements** and uses Darcy's law to calculate flow rates through the soil.
- Consider **a segment of a catchment** defined by a cut along an elevation contour line at the bottom, and "sides" running perpendicular to contours up to the catchment divide. Recall our assumption that flow is driven by topography; hence, the flow of subsurface water is conditioned strongly by the local topography. **The degree of convergence of "flow lines"** (lines perpendicular to the contours) determines **how much upslope area drains to a unit length of contour at any given point**.

TOPMODEL Background –

Adapted from Ch.9 of *Elements of Physical Hydrology*

- The local slope, the thickness of the soil, and the hydraulic conductivity of the soil determine the **"ability" of the soil to move water farther down the slope** once it has arrived at the given point. Source areas for surface runoff occur where **subsurface water accumulates**-points to which large upslope areas drain (such as convergent hillslopes or "hollows") and where **the capacity to drain the water downslope is limited** (where slopes flatten at the base of hollows). Conservation of mass can be applied to the segment depicted in Figure 9.8 to determine the fluxes.

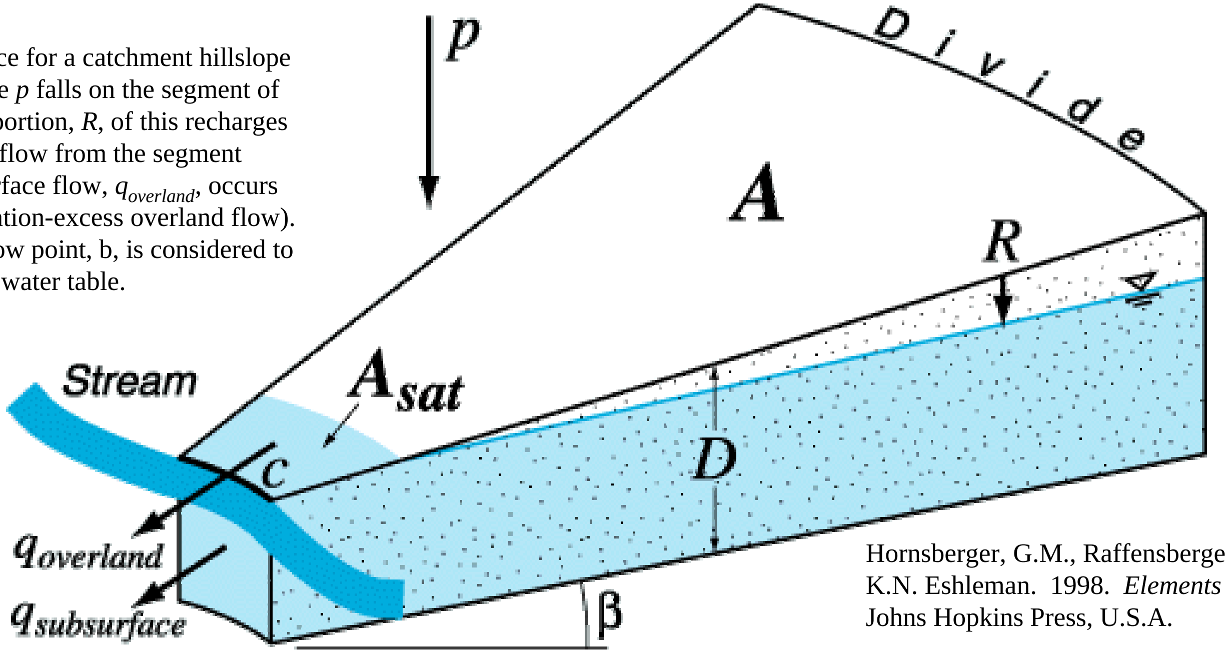


Figure 9.8 The water balance for a catchment hillslope segment. Throughfall at rate *p* falls on the segment of area *A* and thickness *D*. A portion, *R*, of this recharges the subsurface. Subsurface flow from the segment occurs at rate $q_{subsurface}$. Surface flow, $q_{overland}$, occurs from saturated areas (saturation-excess overland flow). The local slope at the outflow point, b, is considered to be equal to the slope of the water table.

Hornsberger, G.M., Raffensberger, J.P., Wiberg, P.L. and K.N. Eshleman. 1998. *Elements of Physical Hydrology*, Johns Hopkins Press, U.S.A.

TOPMODEL Background –

Adapted from Ch.9 of *Elements of Physical Hydrology*

- For our purposes here, we are **not going to develop the TOPMODEL equations** (you can always refer to Beven and Kirkby, 1979 for the full details)
- However, we are interested in **the means** by which TOPMODEL **characterizes the important characteristics of a hillslope** that influence the likelihood of areas of saturation developing as a function of the upslope "contributing area" and the slope of the block:

$$\mathrm{TMI} = \ln(a/\tan\beta)$$

where ***a*** is the **upslope contributing area per unit contour length** (A/c) and **tanβ** is **the local slope**, quantitatively captures the effect of topography. The upslope contributing area is determined by **finding flow paths** through the catchment, based only on the catchment topography. The contributing area is related to the **accumulation of the flow paths** above each point

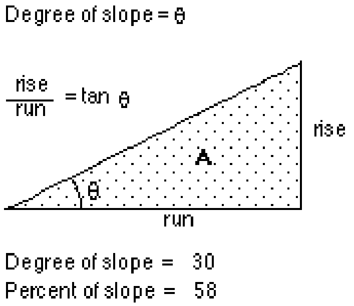
Slope and Aspect

- These are **measurements of terrain attributes**, usually calculated from a digital elevation model
- **Slope and aspect** are calculated for each cell in the grid, by comparing a cell’s elevation to that of its neighbors
  - Usually **eight neighbors** are used and the result is expressed as an angle, but the exact method varies
  - It is important to know exactly what method is used when calculating slope, and exactly how slope is defined, because **different methods** can give **different results**

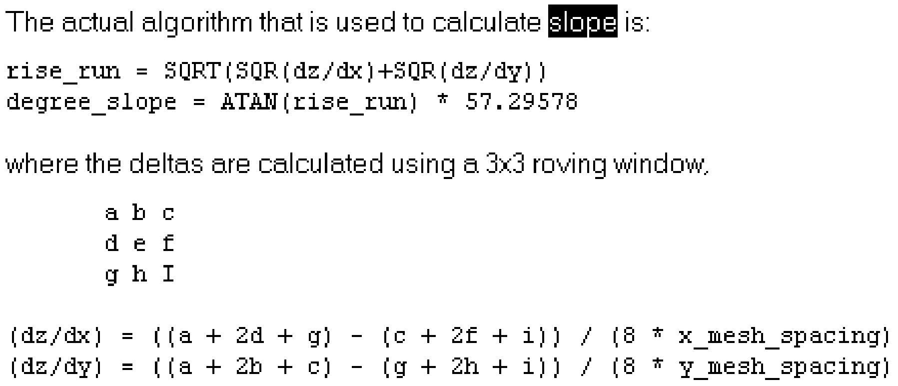
Slope and Aspect

- We can **calculate** these topographic attributes directly from the grid-elevation values using a second-order finite difference scheme applied over a 3x3 neighborhood

From ArcView 3.2 Help



Slope



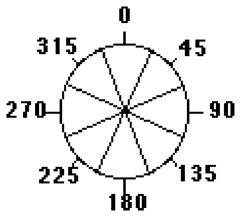
The actual algorithm that is used to calculate slope is:

```
rise_run = SQRT(SQR(dz/dx)+SQR(dz/dy))
degree_slope = ATAN(rise_run) * 57.29578
```

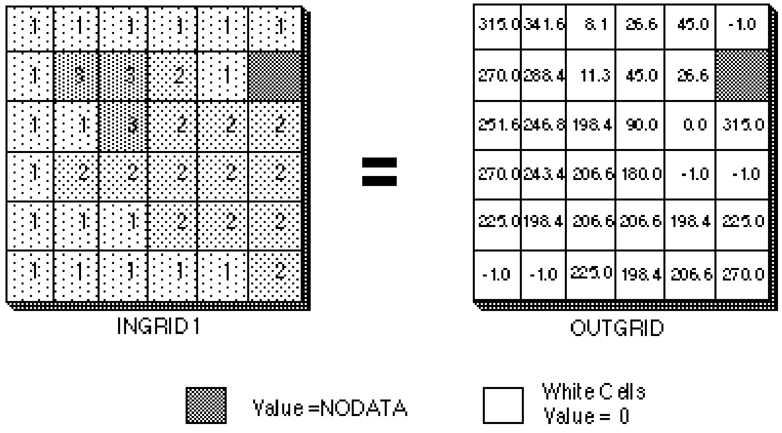
where the deltas are calculated using a 3x3 roving window,

```
a b c
d e f
g h I
```

```
(dz/dx) = ((a + 2d + g) - (c + 2f + i)) / (8 * x_mesh_spacing)
(dz/dy) = ((a + 2b + c) - (g + 2h + i)) / (8 * y_mesh_spacing)
```



Aspect



1	1	1	1	1	1
1	3	3	2	1	▨
1	1	3	2	2	2
1	2	2	2	2	2
1	1	1	2	2	2
1	1	1	1	1	2

INGRID1

=

315.0	341.6	8.1	26.6	45.0	-1.0
270.0	288.4	11.3	45.0	26.6	▨
251.6	246.8	198.4	90.0	0.0	315.0
270.0	243.4	206.6	180.0	-1.0	-1.0
225.0	198.4	206.6	206.6	198.4	225.0
-1.0	-1.0	225.0	198.4	206.6	270.0

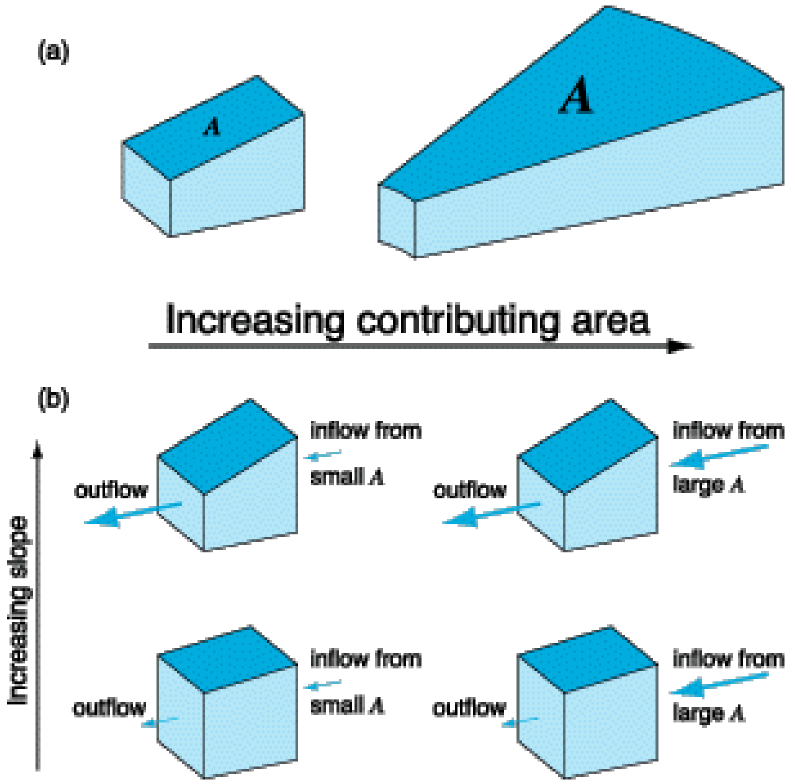
OUTGRID

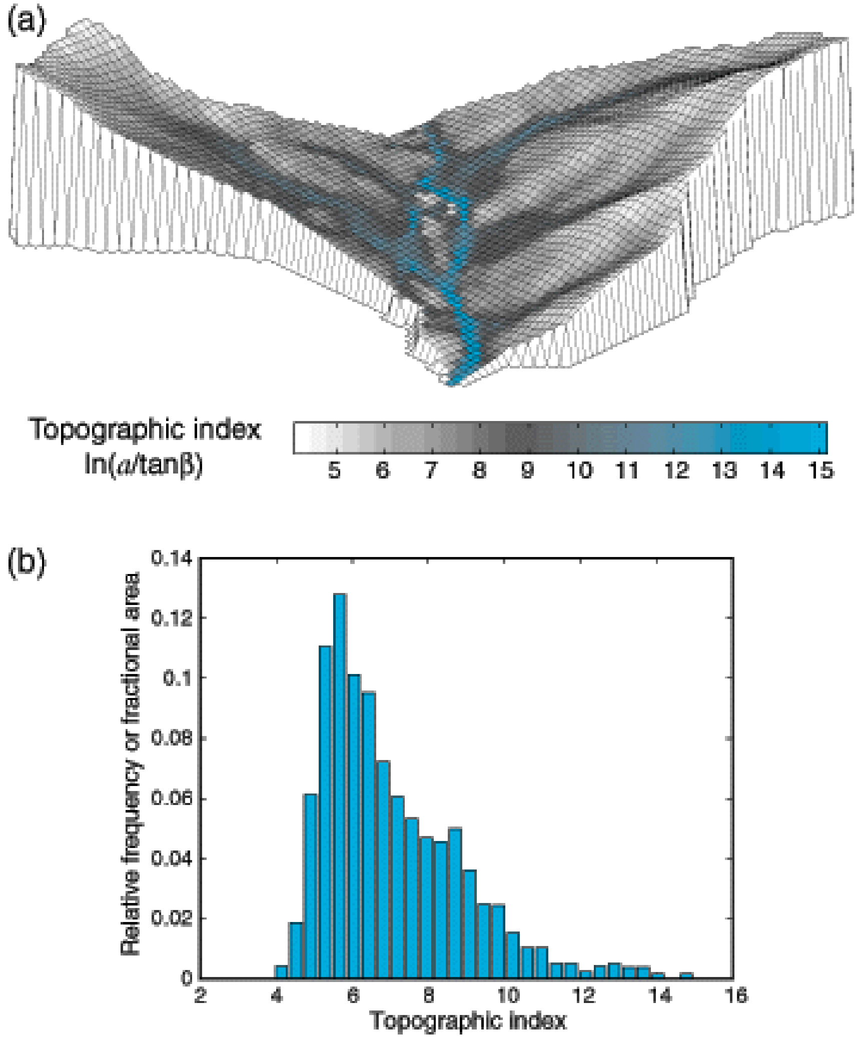
▨ Value =NODATA

☐ White Cells Value = 0

Topographic Moisture Index

$$\mathrm{TMI} = \ln(a/\tan\beta)$$



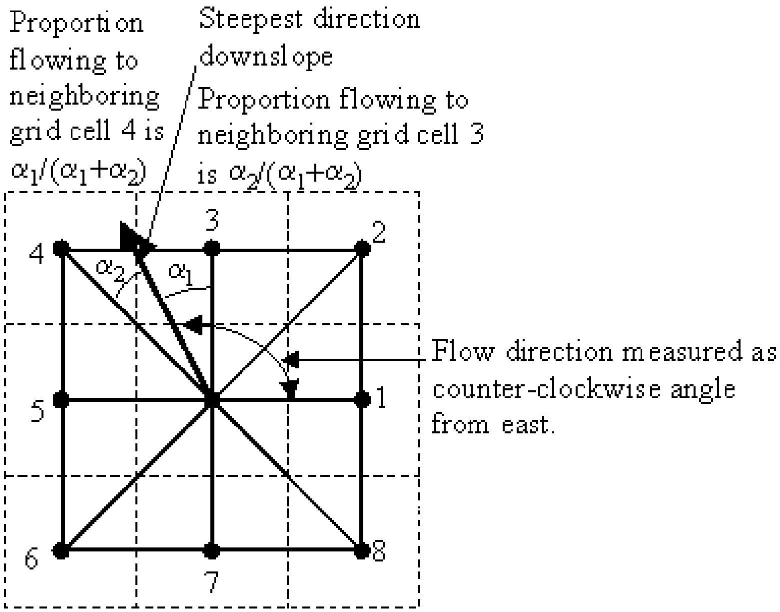


Hornsberger, G.M., Raffensberger, J.P., Wiberg, P.L. and K.N. Eshleman. 1998. *Elements of Physical Hydrology*, Johns Hopkins Press, U.S.A., p. 210 & p. 216.

Dinf Flow Directions

- Method: The Dinf approach assigns a flow direction based on steepest slope on a triangular facet (Tarboton, 1997):

•Flow direction is encoded as an **angle in radians counter-clockwise from east** as a continuous (floating point) quantity between 0 and 2 pi.
•The flow direction angle is determined as the **direction of the steepest downward slope** on the **eight triangular facets** formed in a 3 x 3 grid cell window centered on the grid cell of interest. A block-centered representation is used with each elevation value taken to represent the elevation of the center of the corresponding grid cell.
•Eight planar triangular facets are formed between each grid cell and its eight neighbors. Each of these has a **downslope vector** which when drawn outwards from the center may be at an angle that lies within or outside the 45^{o} (pi/4 radian) angle range of the facet at the center point.
•If the slope vector angle is **within** the facet angle, **it represents the steepest flow direction on that facet**. If the slope vector angle is **outside** a facet, the steepest flow direction associated with that facet is **taken along the steepest edge**. The slope and flow direction associated with the grid cell is taken as the magnitude and direction of the steepest downslope vector from all eight facets. Slope is measured as drop/distance, i.e. tan of the slope angle.



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Dinf Contributing Area

- Method: Contributing area **counted in terms of the number of grid cells** (or summation of weights) is calculated for the multiple flow direction Dinf approach using a recursive procedure that is an extension of the very efficient recursive algorithm for single directions (Mark, 1988).
- The contribution at each grid cell is **taken initially as one** (or from the weight grid when the optional weight grid input is used). The contributing area of each grid cell is then taken as **its own contribution plus the contribution from upslope neighbors that have some fraction draining to it**. The flow from each cell either all drains to one neighbor, if the angle falls along a cardinal ($0, \pi/2, \pi, 3\pi/2$) or diagonal ($\pi/4, 3\pi/4, 5\pi/4, 7\pi/4$) direction, or is on an angle falling between the direct angle to two adjacent neighbors. In the latter case the flow is **proportioned between these two neighbor pixels according to how close the flow direction angle is to the direct angle to those pixels**, as illustrated in the previous slide.
- The result is reported in terms of **specific catchment area**, the **upslope area per unit contour length**, taken here as the **number of cells times grid cell size** (cell area divided by cell size). This assumes that **grid cell size is the effective contour length**, in the definition of specific catchment area and does not distinguish any difference in contour length dependent upon the flow direction

http://hydrology.neng.usu.edu/taudem/