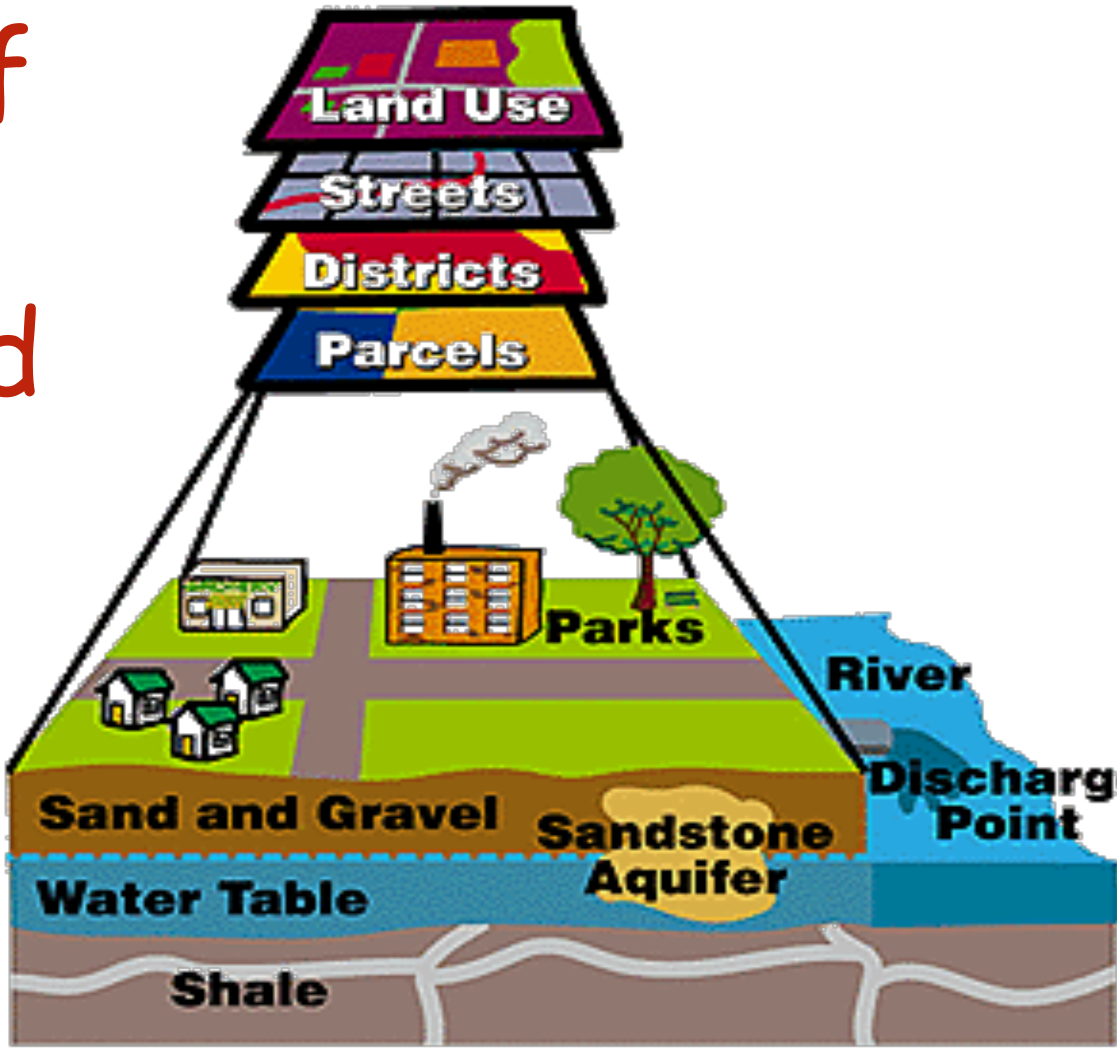
Application of GIS in Hydrology and Water Resource Management



New Technologies for water management

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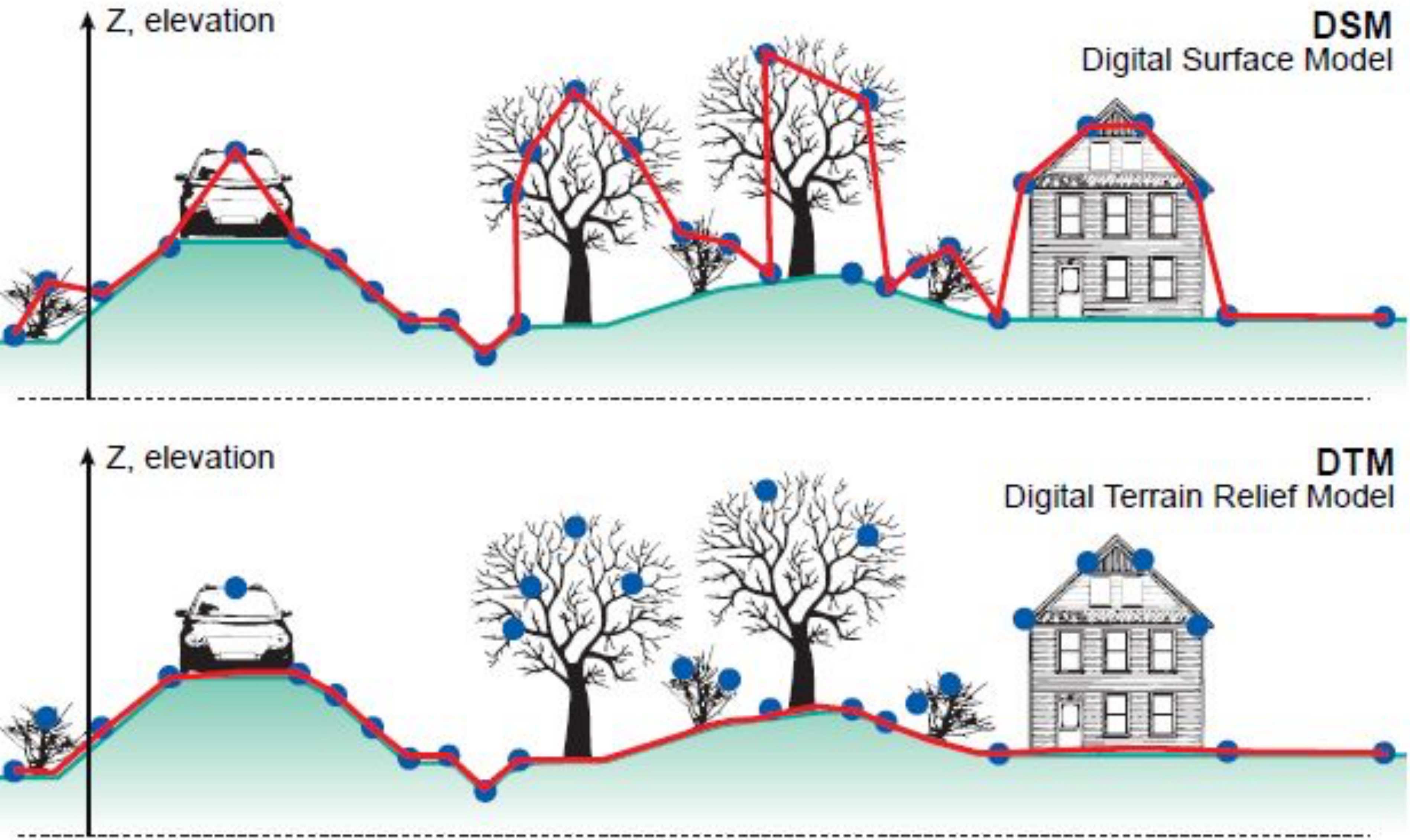
What is a Digital Elevation Model ?

A Digital Elevation Model (DEM) is a digital model or three dimensional (3D) representation of a terrain's surface created from elevation data. The term DEM was introduced in the 1970s with the purpose of distinguishing the simplest form of terrain relief modelling from more complex types of digital surface representation. Originally the term DEM was exclusively used for raster representations (thus elevation values given at the intersection nodes of a regular grid).

DEM - DTM - DSM

Digital Terrain Model (DTM) is a DEM of the shape of the ground surface. Digital Surface Model (DSM) is a DEM of the shape of the surface, including vegetation, infra-structures etc. Both a DTM and DSM can be a DEM and, moreover, "elevation" would not have to relate to terrain but could relate to some subsurface layer such as groundwater layers, soil layers or the ocean floor.



Z, elevation
DSM
Digital Surface Model
Z, elevation
DTM
Digital Terrain Relief Model

As topography is one of the major factors in most types of hazard analysis, the generation of a Digital Elevation Model (DEM) plays a major role.

Digital Elevation Models (DEMs) can be derived through a variety of techniques, such as digitizing contours from existing topographic maps, topographic levelling, EDM (Electronic Distance Measurement), differential GPS measurements, (digital) photogrammetry, Radar remote sensing (InSAR), and Light Detection and Ranging (LiDAR).

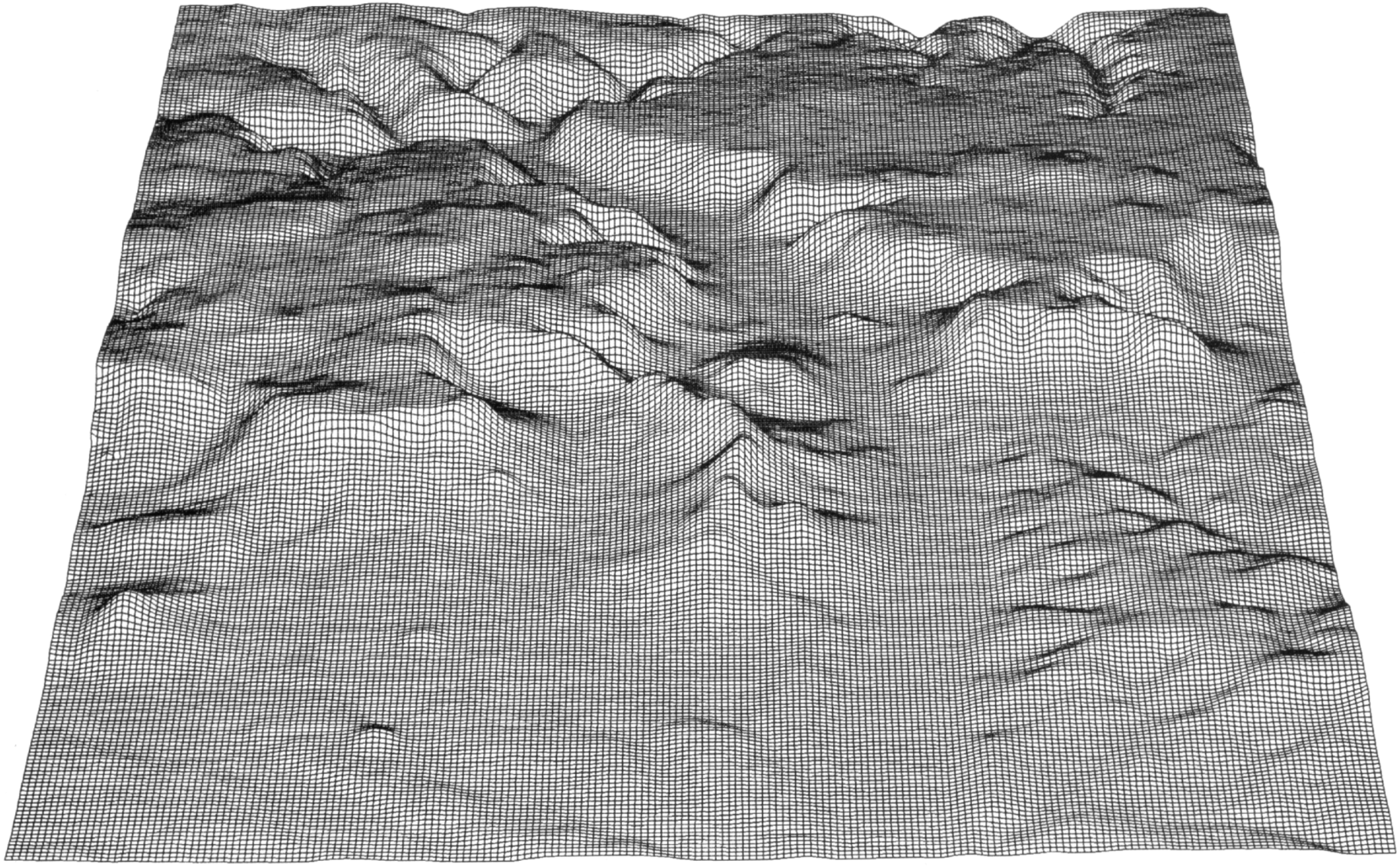
Many derivate maps can be produced
from DEMs using fairly simple GIS operations.

These days a wide range of data sources can be selected for the generation of DEMs.

The selection depends on the data availability for a specific area, the price and the application.

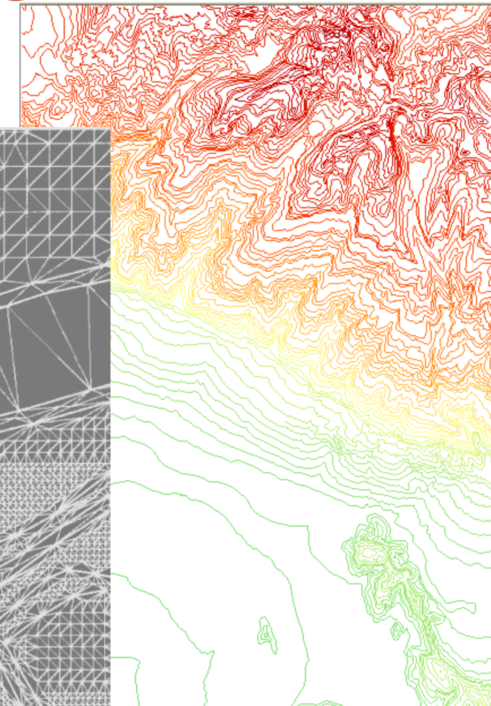
DEMs and their application in Hydrology

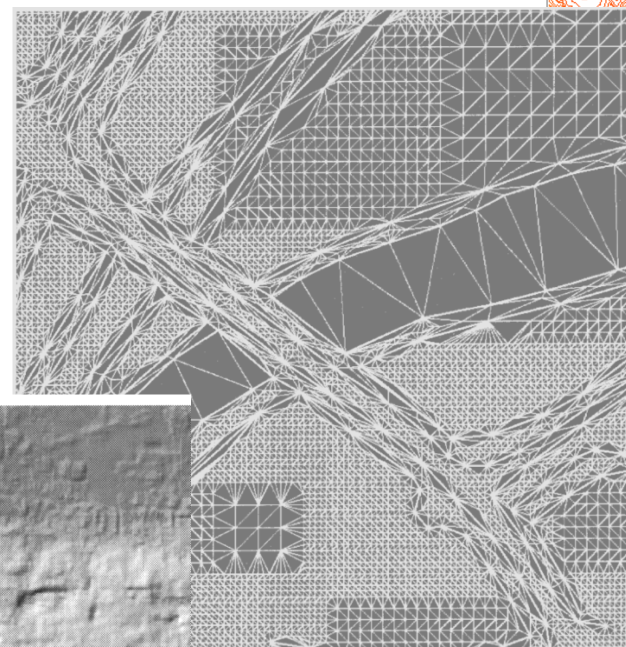
(drainage, erosion, evapotranspiration, snow melting, ground water,...)

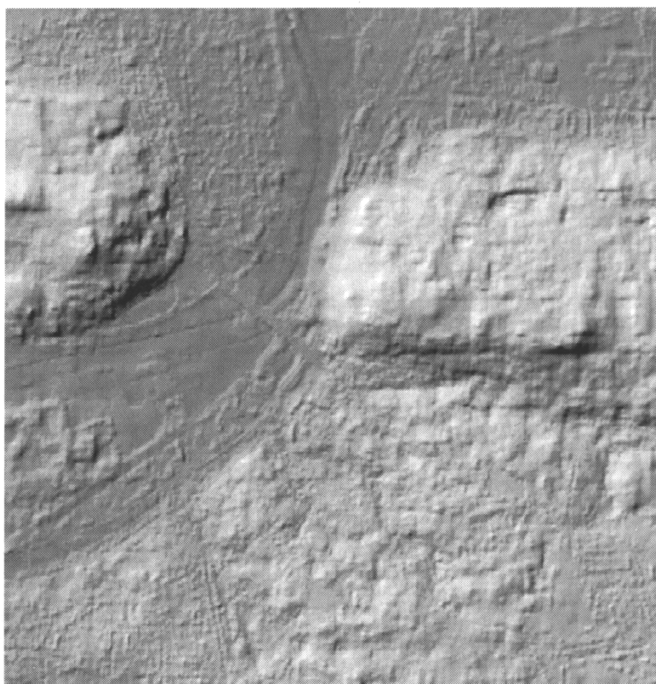


Data Structures

- contour lines
- TIN
- Raster







→ almost all DEM analysis are based on Raster representation

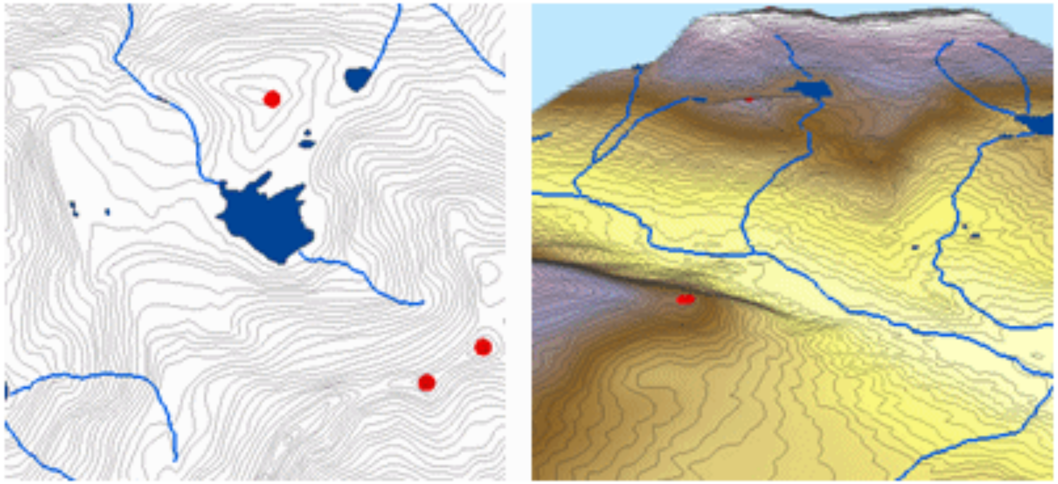
Sources for DEMs

- Photogrammetric processing of stereo aerial photos
- Laserscanning (LIDAR)
- Interpolated digitized contour lines from topographic maps (still one of the most important method) drawbacks:
  - unfavorable distribution of points: dense on contours, gaps in between
  - generalization on the original map depending on the map scale

  improvements:
  - add singular points for prominent morphological lines and points
  - use specialised interpolation algorithm, e.g. Topo to Raster in ArcGIS

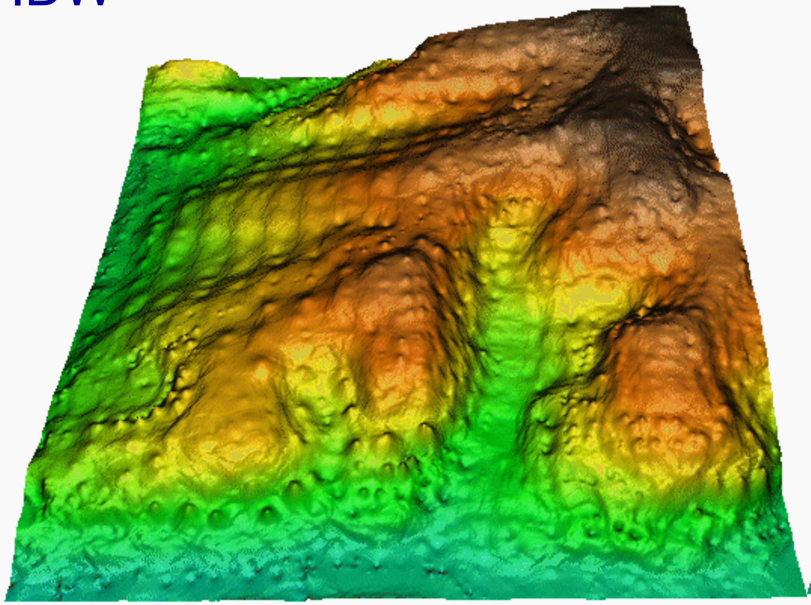
Topo to Raster (contour interpolation)

is a specialized tool for creating hydrologically correct raster surfaces from vector data of terrain components such as elevation points, contour lines, stream lines, lake polygons, sink points, and study area boundary polygons.

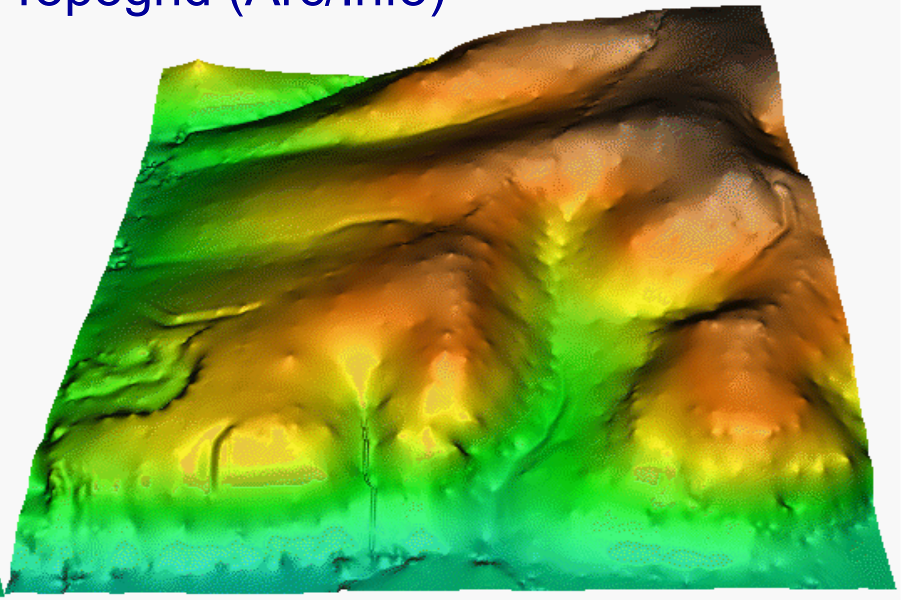


(iterative finite difference interpolation technique, uses this knowledge of surfaces and imposes constraints on the interpolation process that results in a connected drainage structure and correct representation of ridges and streams, drainage enforcement algorithm, …)

IDW

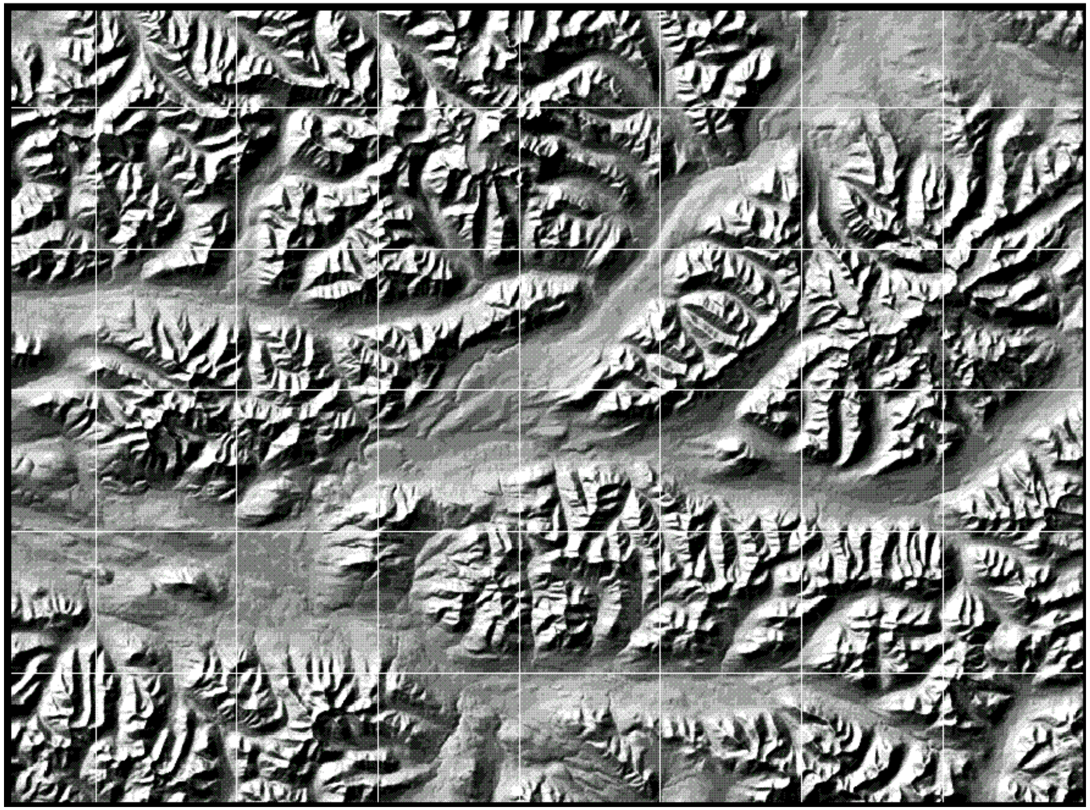


Topogrid (Arc/Info)



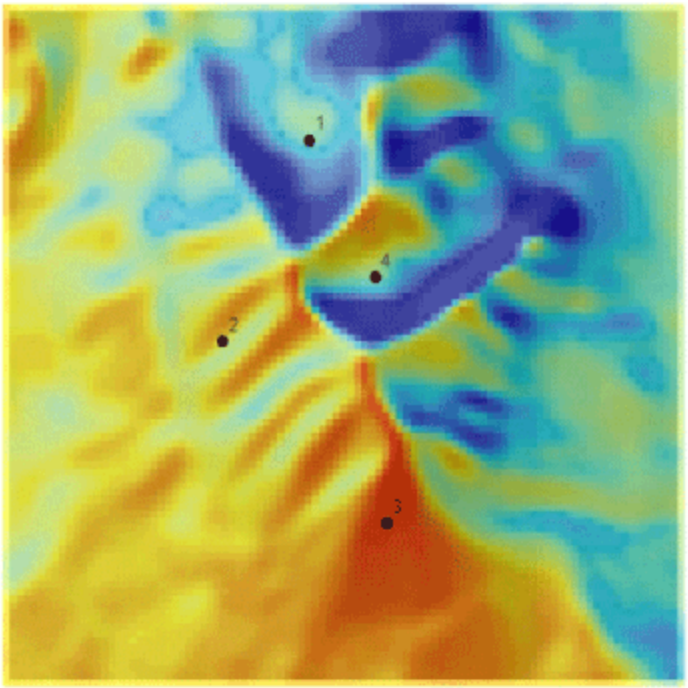
Other DEM derivatives based on filter kernels

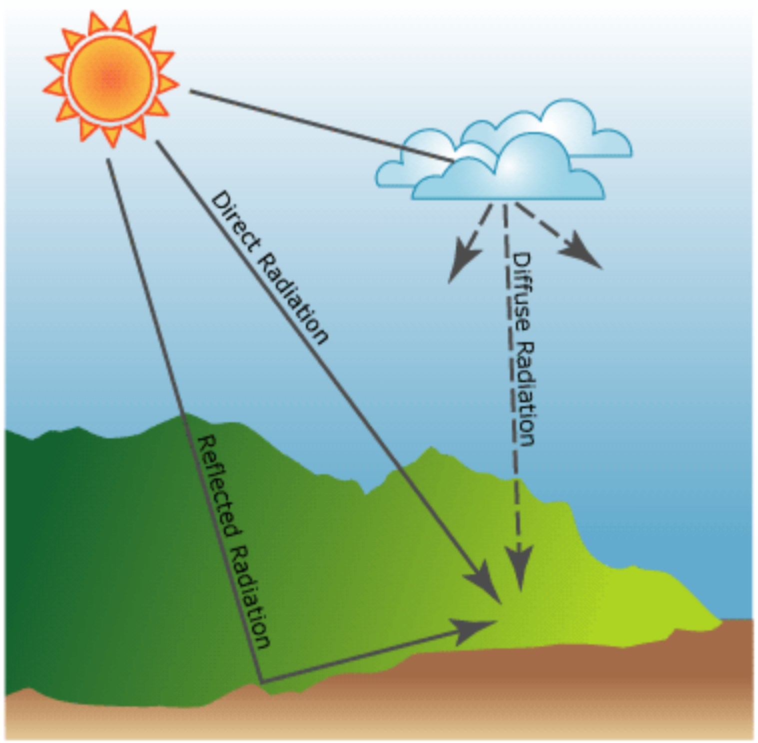
- hill shading (pseudo terrain)



Other DEM derivatives based on filter kernels

- solar radiation





Using the area solar radiation analysis, the global insolation (direct+diffuse, WH/m2) has been calculated for the entire study area showing where the highest amounts of radiation are during the summer months. (red = high insolation, blue = low insolation).

Application	Mapping scale	Specification	EO S	EO sources	Remarks
		Horizontal (resolution)	Vertical (Accuracy)		
- Topographic mapping	1:200.000	30 m.	1 m.	SRTM, ASTER	Free download
	1:50.000	10-15 m.	1 m.	WorldDEM / Terra SAR-x, SPOT 5	DEM Derivatives : • Hill-shading • Contour lines / spot heights
	1:10.000	5 m. or <	1 m.	Aerial photo, LiDAR WorldView2 / GeoEye2	
	1:5.000 or larger	1 m.	1 - 0.5 m.	Aerial photo, LiDAR	
- Flood modelling	1: 5.000 or larger	0.5 - 1 m.	0.5 m or <	LiDAR DTM/ DSM	DEM Derivatives: • Slope aspect • Slope form / length • 3-D Visualization
• Landslide mapping	1:2.000 or larger	0.5 m. or <	0.5 m. or <	LiDAR DTM	
• **Coastal** mapping	1:2.000 or larger	0.5 m. or <	0.5 m. or <	LiDAR DTM	
• **O**ther detailed hazard mapping	1:2.000 or larger	0.5 m. or <	0.5 m. or <	LiDAR DTM	
- **E**lements at risk mapping	1:2.000 or larger	0.5 m. or <	0.5 m. or <	LiDAR DSM	DEM Derivatives: • Height & volume of buildings • 3-D Visualization

where to find DEM?

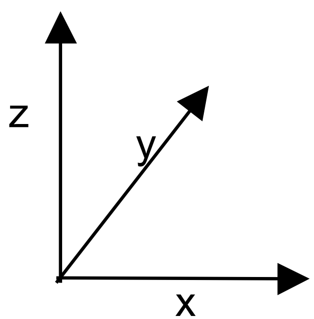
- **ASTER GDEM:** *http://asterweb.jpl.nasa.gov/gdem.asp*
- **SRTM:** *http://www2.jpl.nasa.gov/srtm/*
- **WorldDEM™:** *http://www.geo-airbusds.com/worlddem/*
- **GTOPO30:** *https://lta.cr.usgs.gov/GTOPO30*
-

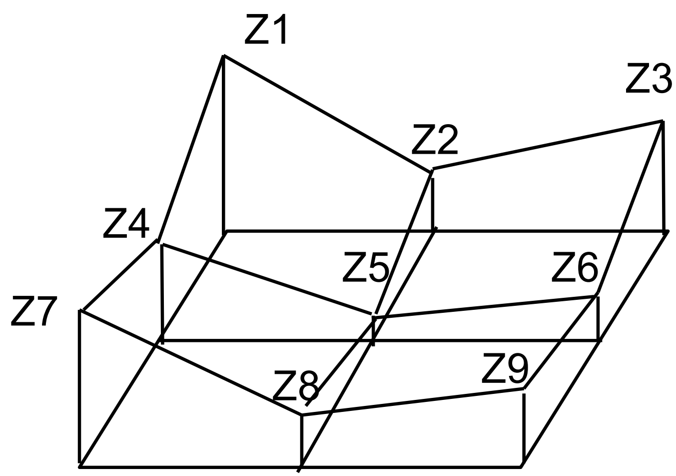
Applications in Hydrology

Watershed characteristics:

- terrain elevation
- aspect
- slope
- size of watershed
- maximum and average flow length
- plan and profile curvature
- …

slope, aspect and curvature





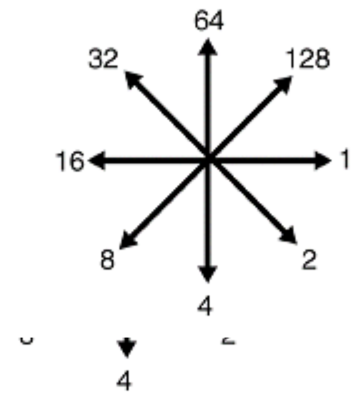
	6	**3**	**4**	
	4	**1**	**2**	
	3	**1**	**2**	

- based on 8 neighbor cells
- realized as different filter kernels

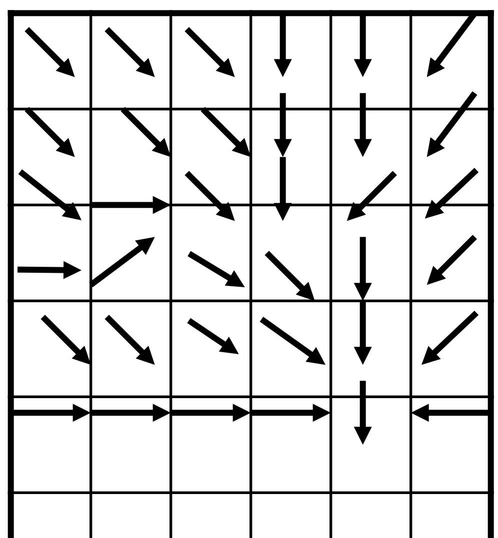
Flow direction (ldd = local drain direction)

D8 (deterministic) agorithm:

- steepest downhill slope
- discretization: only steps of 45°
- whole drainage into one neighboring cell

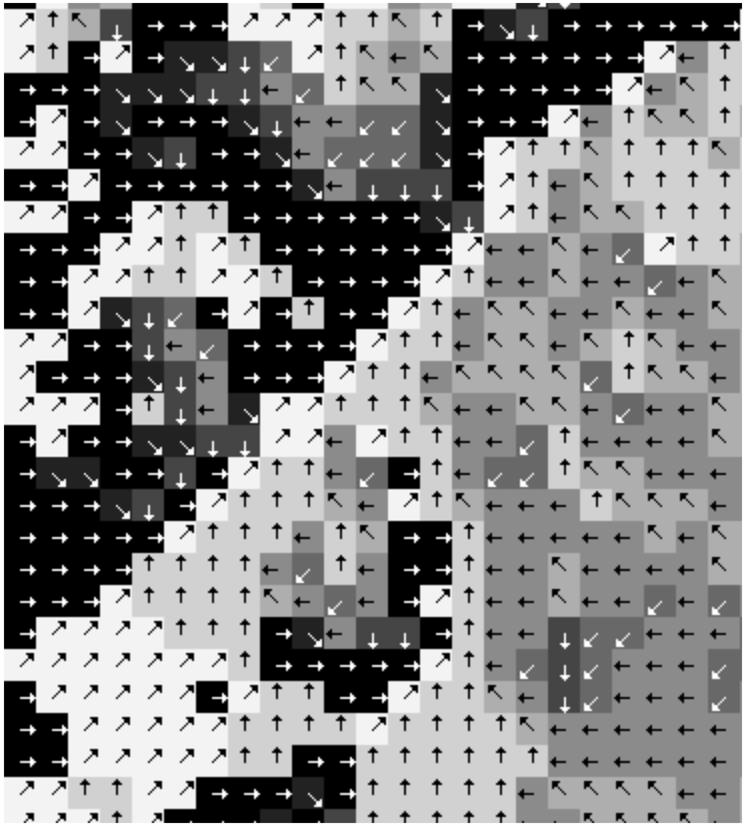


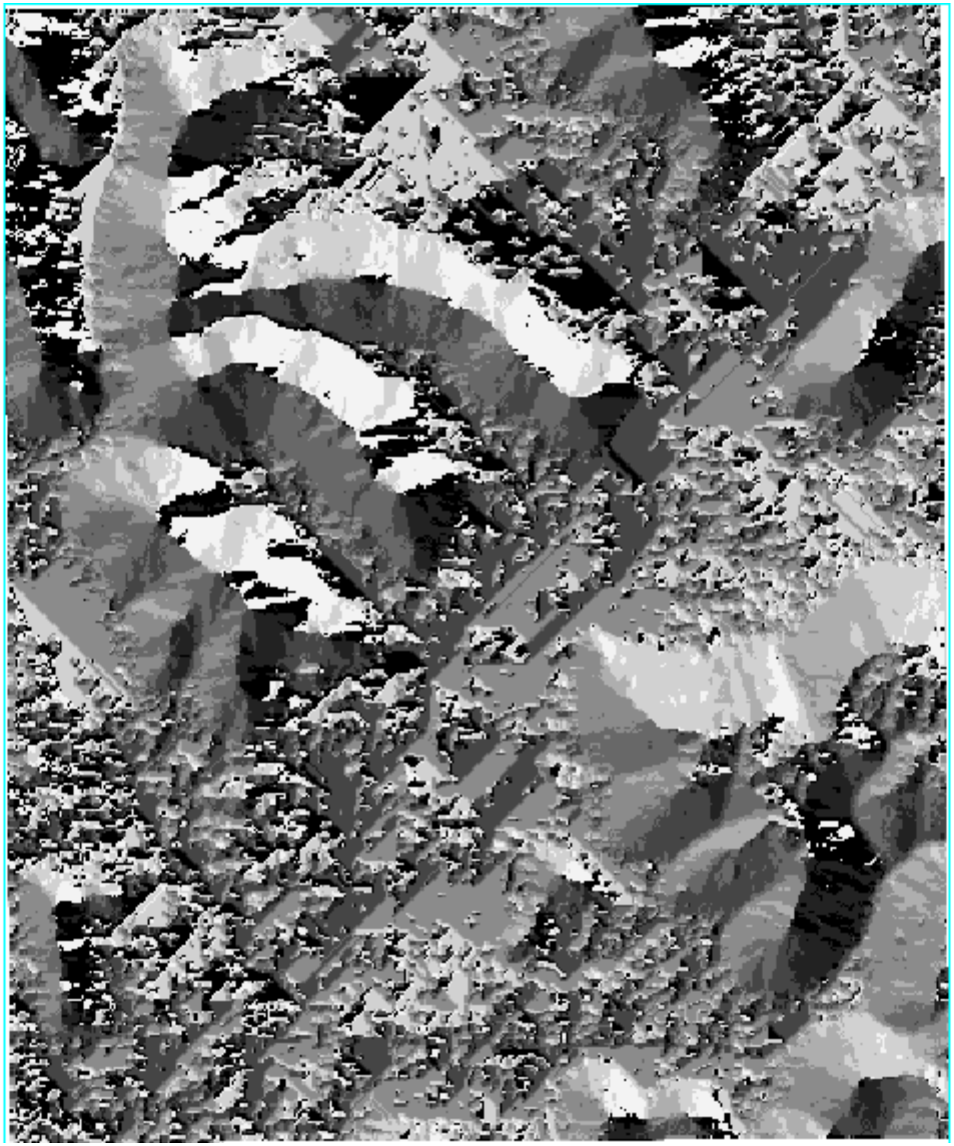
78	72	69	71	58	49
74	67	56	49	46	50
69	68	44	37	38	48
64	58	56	29	31	34
68	61	47	21	18	19
74	60	34	12	10	12



2	2	2	4	4	8
2	2	2	4	4	8
2	1	2	4	8	8
1	128	2	2	4	8
2	2	2	2	4	8
1	1	1	1	0	16

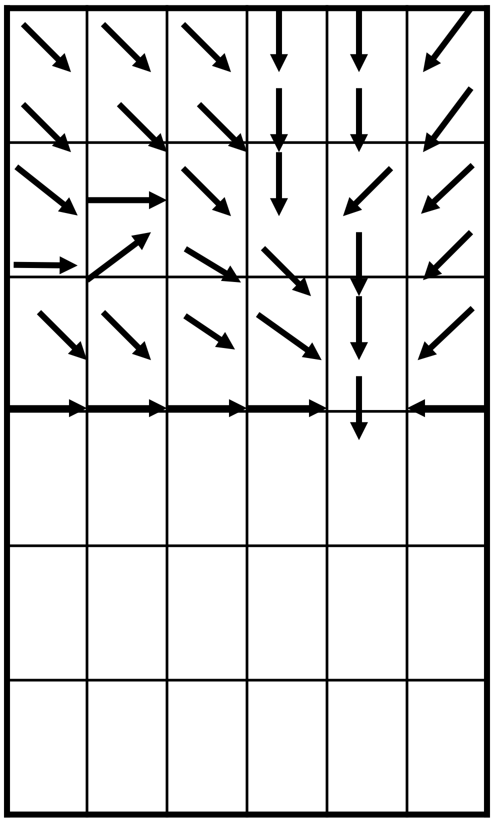
ldd



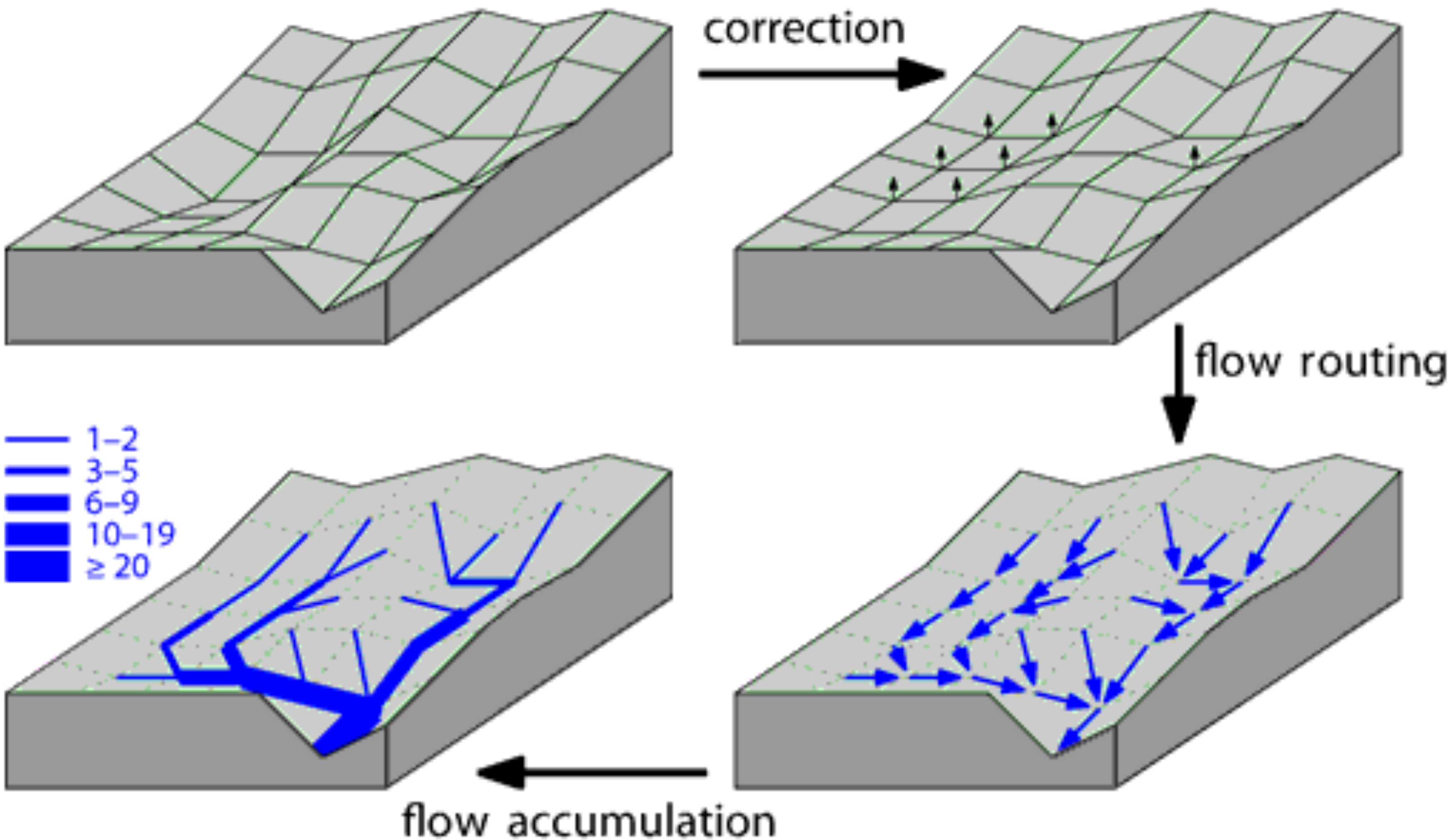


Flow accumulation

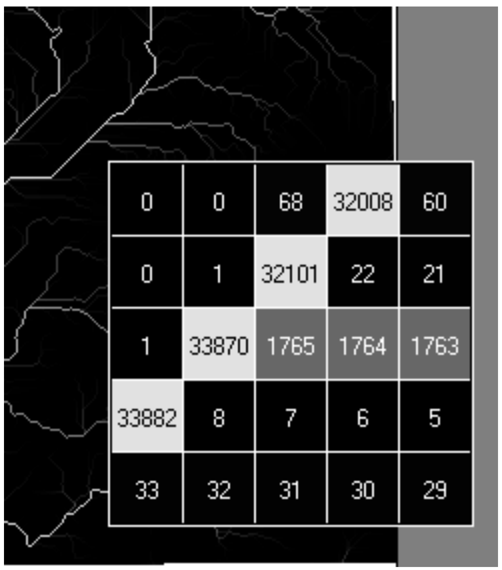
Downhill accumulation (upstream element map):
number of cells on a direct uphill path



0	0	0	0	0	0
0	1	1	2	2	0
0	1	4	5	3	0
…					


correction
flow routing
1–2
3–5
6–9
10–19
≥ 20
flow accumulation

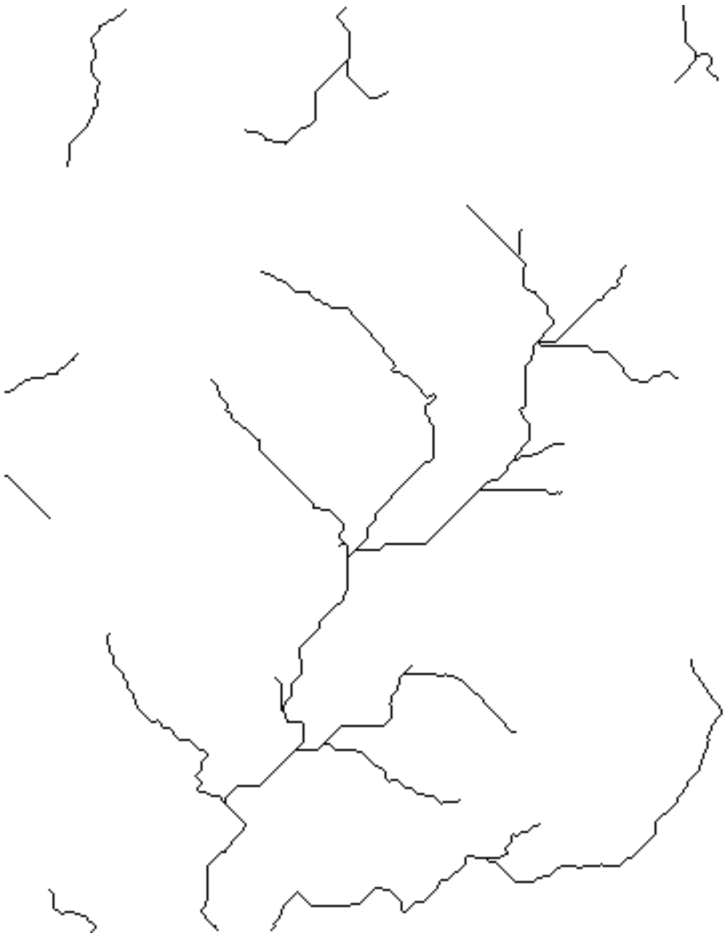
Upstream element map



Stream network

Defining stream channels: all cells with value above a threshold,
e.g.

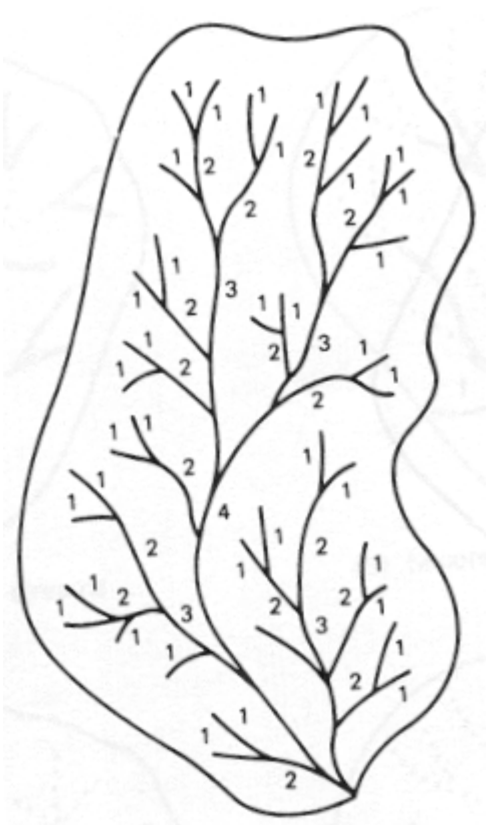
if (upstreamelements > 2000) then
value = 1
else
value = 0
end if



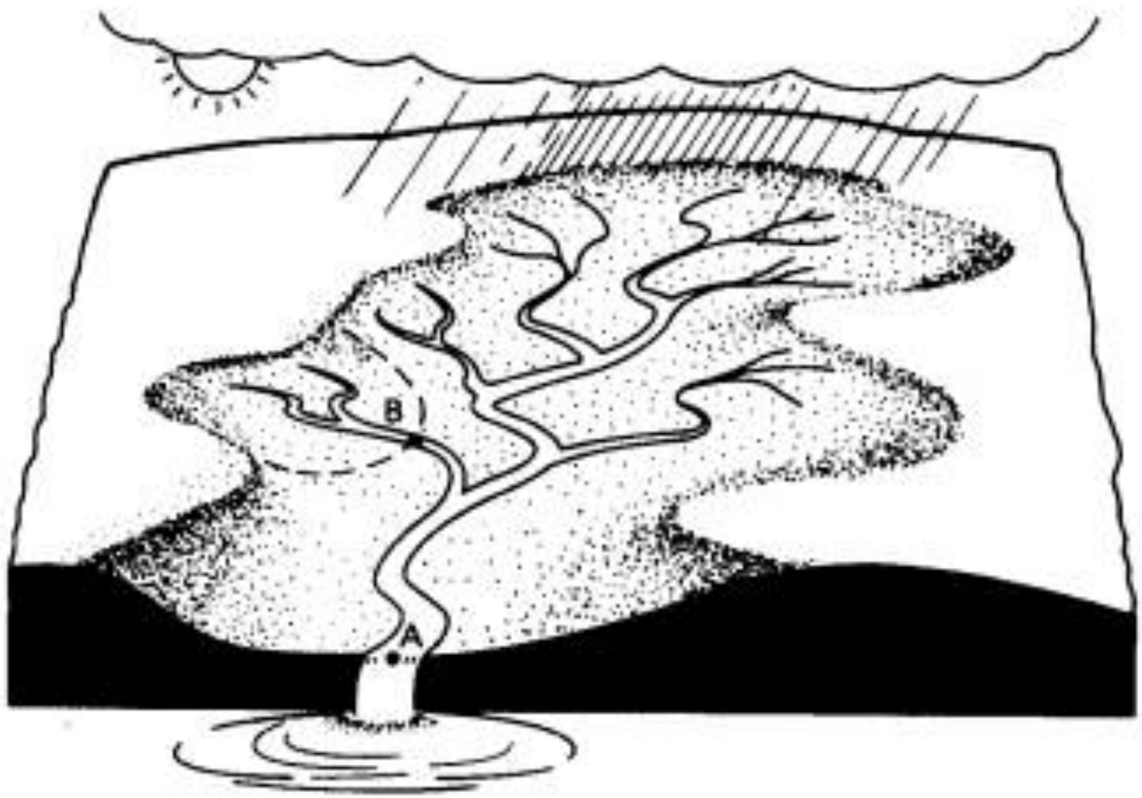
Operations on stream network

- ordering of segments (e.g. Strahler numbering)
- calculation of a time-area diagram to determine a instantaneous unit hydrograph (IUH)
- characteristic parameters of the stream network
  - Channel Length
    - The distance measured along the main channel from the watershed outlet to the end of the channel
    - The distance measured along the main channel between two points located 10 and 85% of the distance along the channel from the outlet
  - Channel Slope
  - Drainage Density

    The drainage density, ratio of the total length of streams within a watershed to the total area of the watershed A high value of the drainage density would indicate a relatively high density of streams and thus a rapid storm response. Values typically ranges from 1 to 4 1/km.

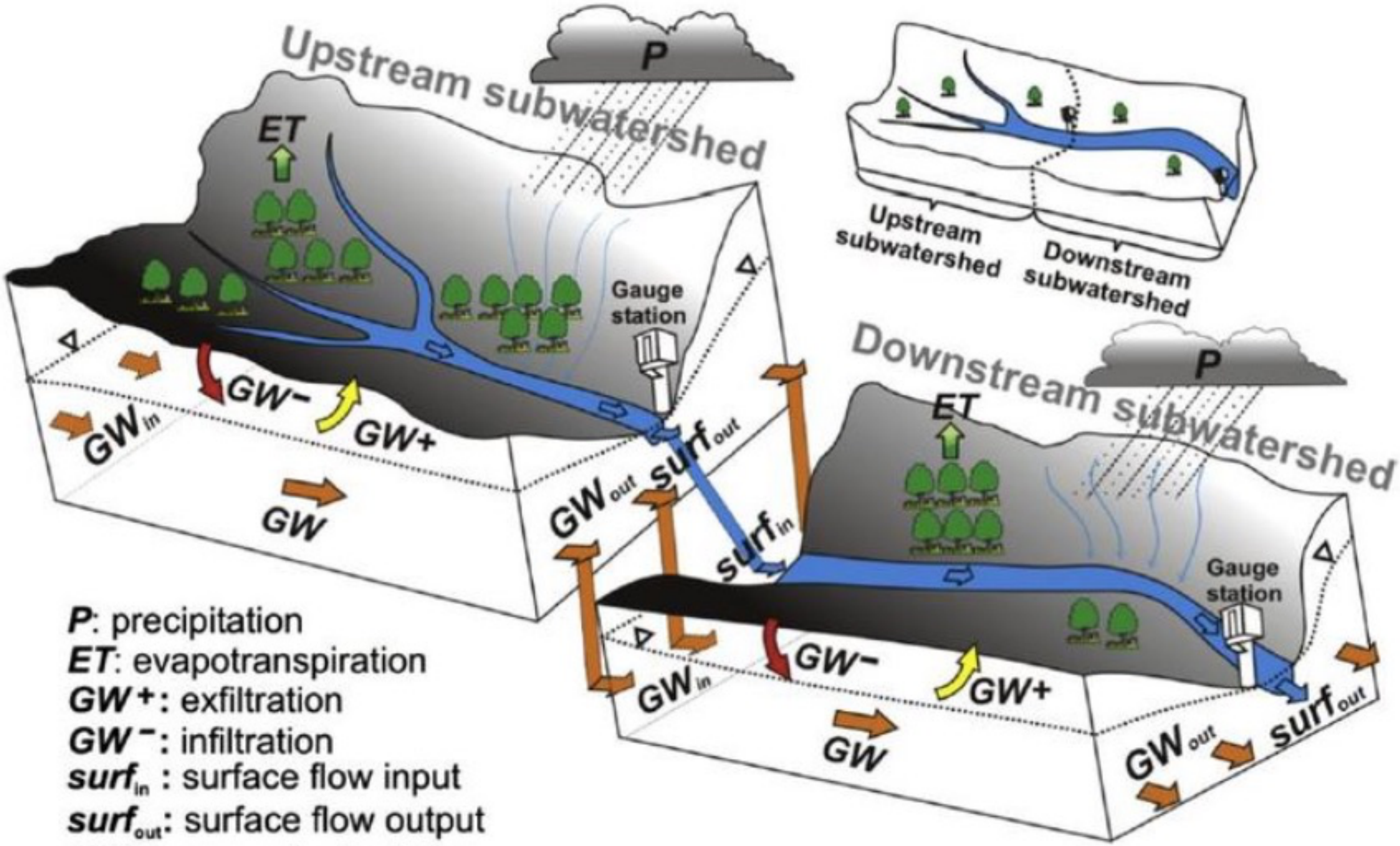


Watershed delineation



A simple iterative method for estimating evapotranspiration with integrated surface/subsurface flow models

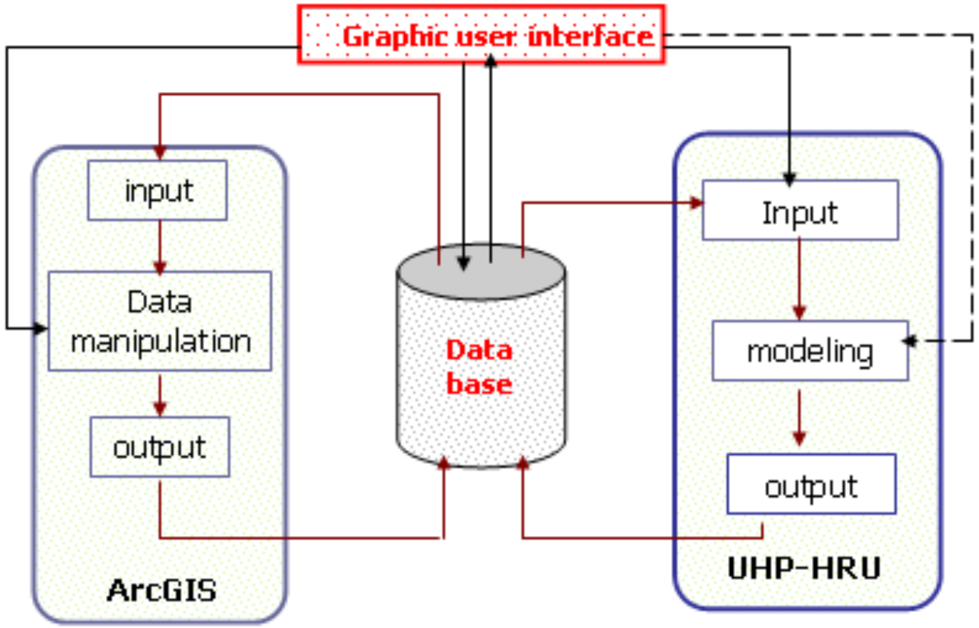
Authors: Hyoun-Tae Hwang, Young-Jin Park, Steven Frey, Steven Berg, and Ed Sudicky



P: precipitation
ET: evapotranspiration
***GW*+**: exfiltration
***GW*−**: infiltration
***surf*$_{in}$** : surface flow input
***surf*$_{out}$**: surface flow output
***GW*$_{in}$** : groundwater inflow
***GW*$_{out}$** : groundwater outflow

https://www.aquanty.com/blog/2015/11/4/hgs-research-highlight-a-simple-iterative-method-for-estimating-evapotranspiration-with-integrated-surfacesubsurface-models

Coupling of GIS and numerical models



coupling:

- same data base
- GUI

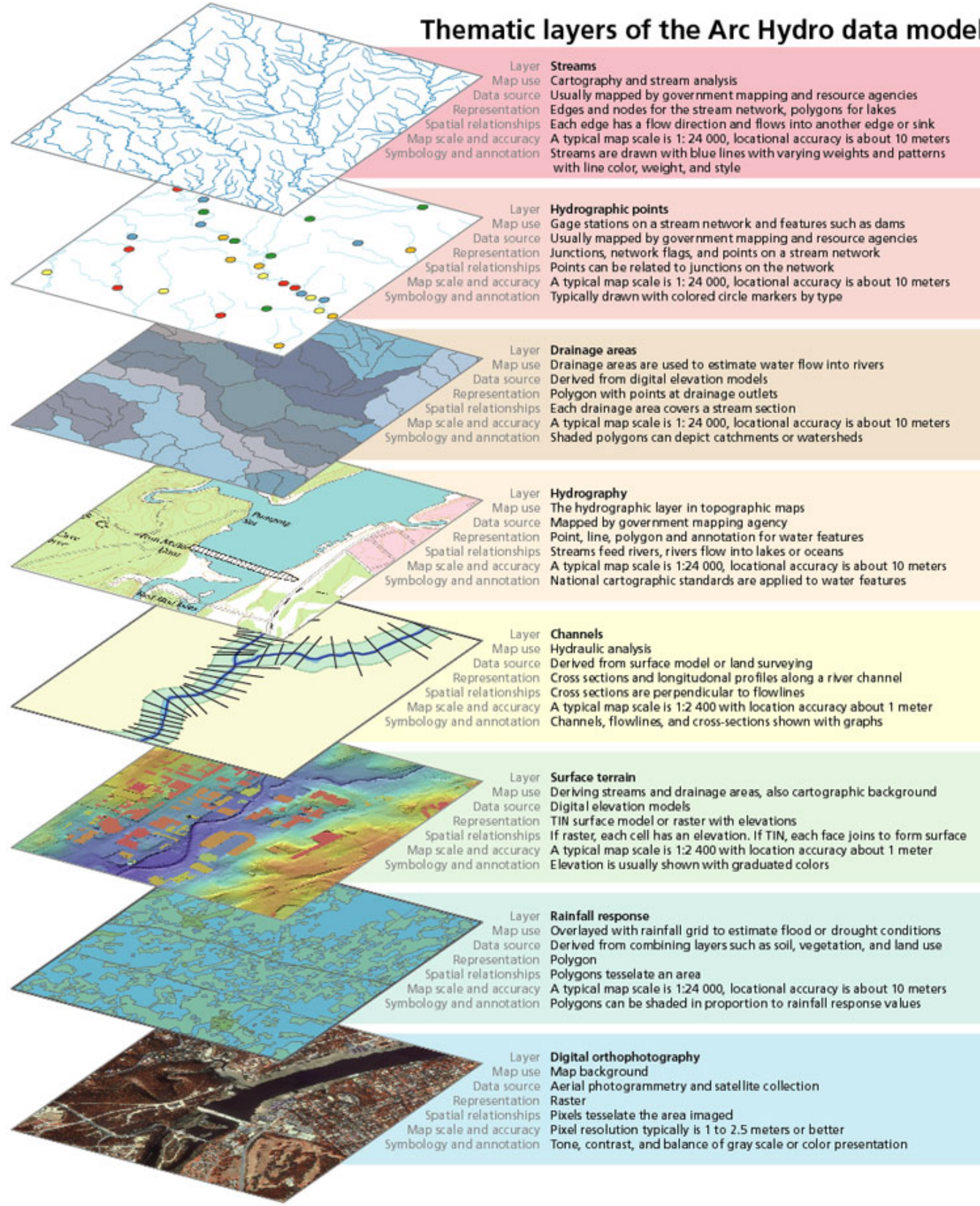
GIS:
- data preparation
- zoning
- creating input data
- visualization of results

numerical model:
- solving the numerical hydrological equations

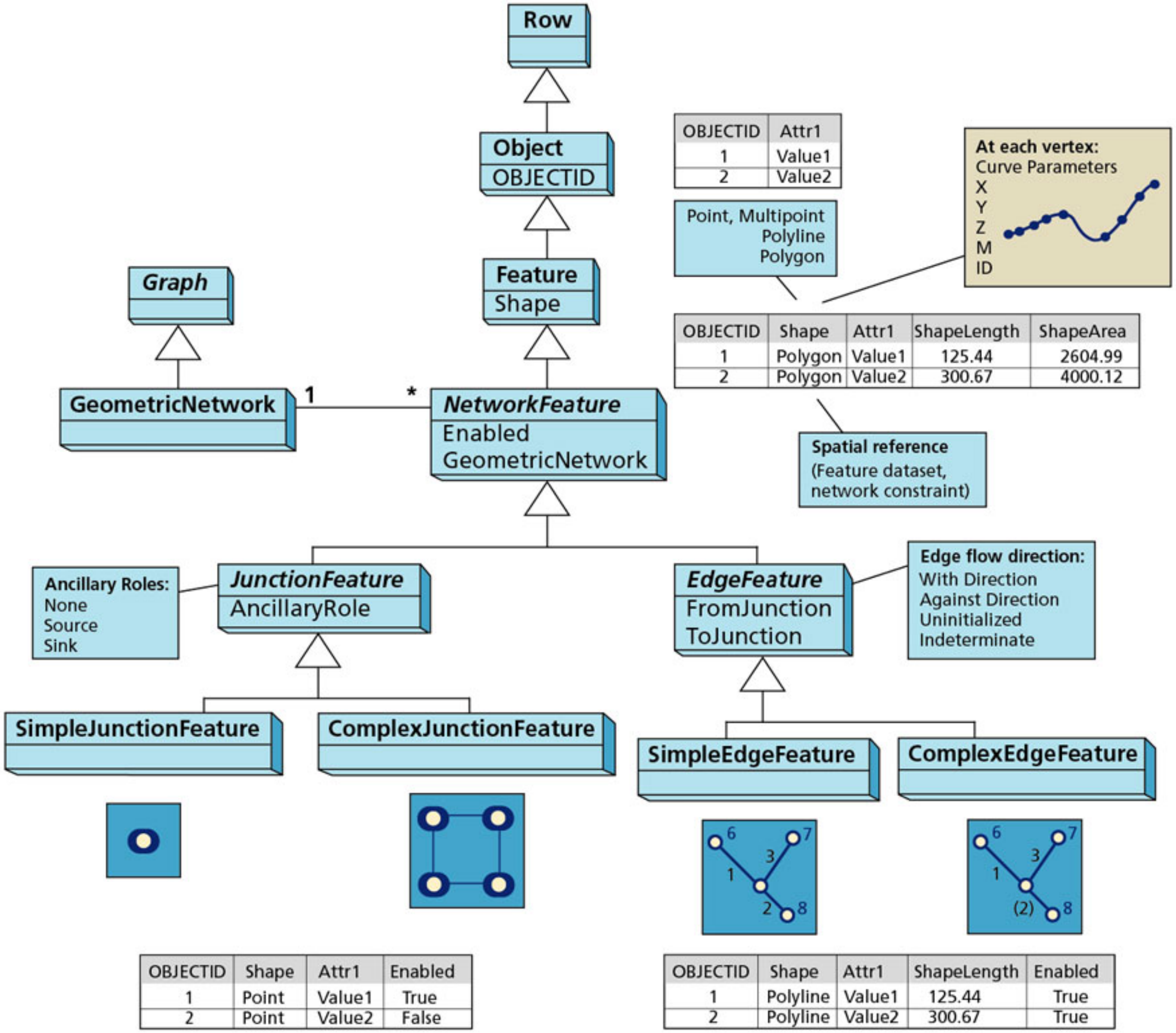
A sample tool: ArcHydro

- a geospatial and temporal data model for water resources linked to ArcGIS
- a set of tools to populate the features in the data framework and to support hydrological analysis
- it provides the data structure but it is not a hydrological simulation model itself!

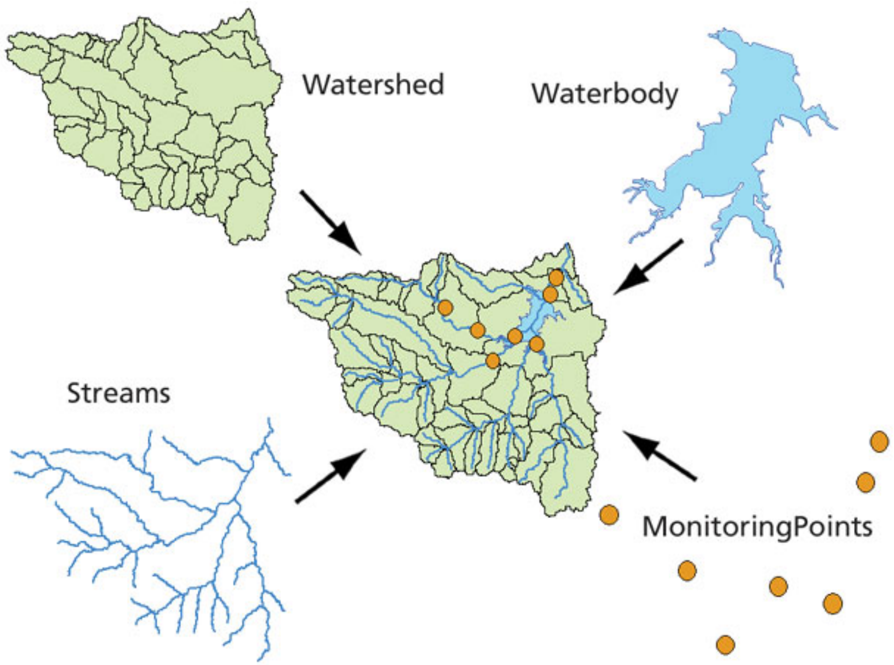
Thematic layers



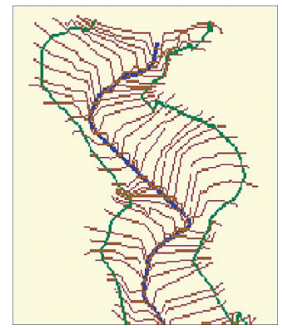
UML based object model



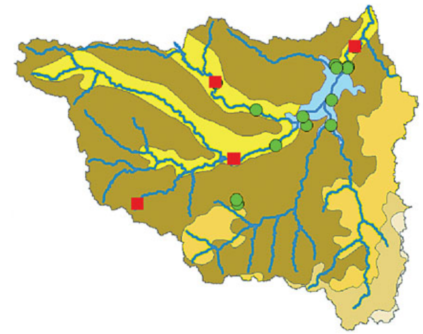
the basic framework



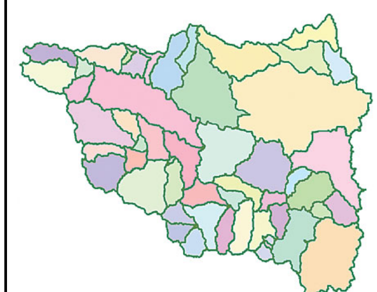
additional components



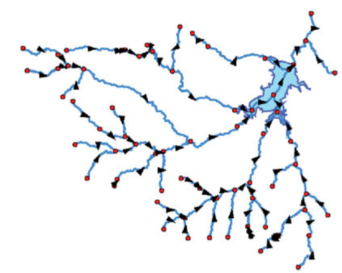
channel



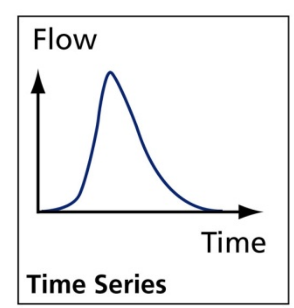
hydrography



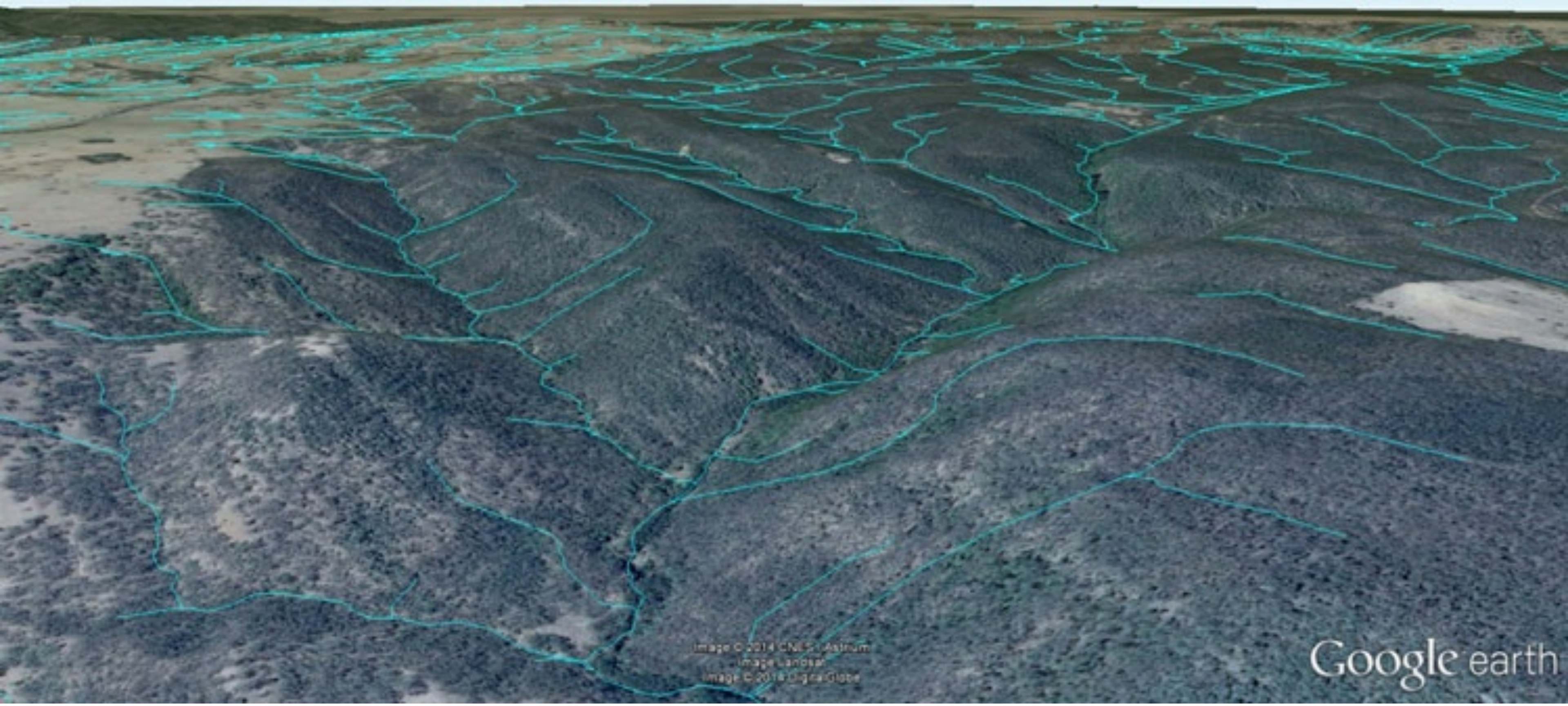
drainage

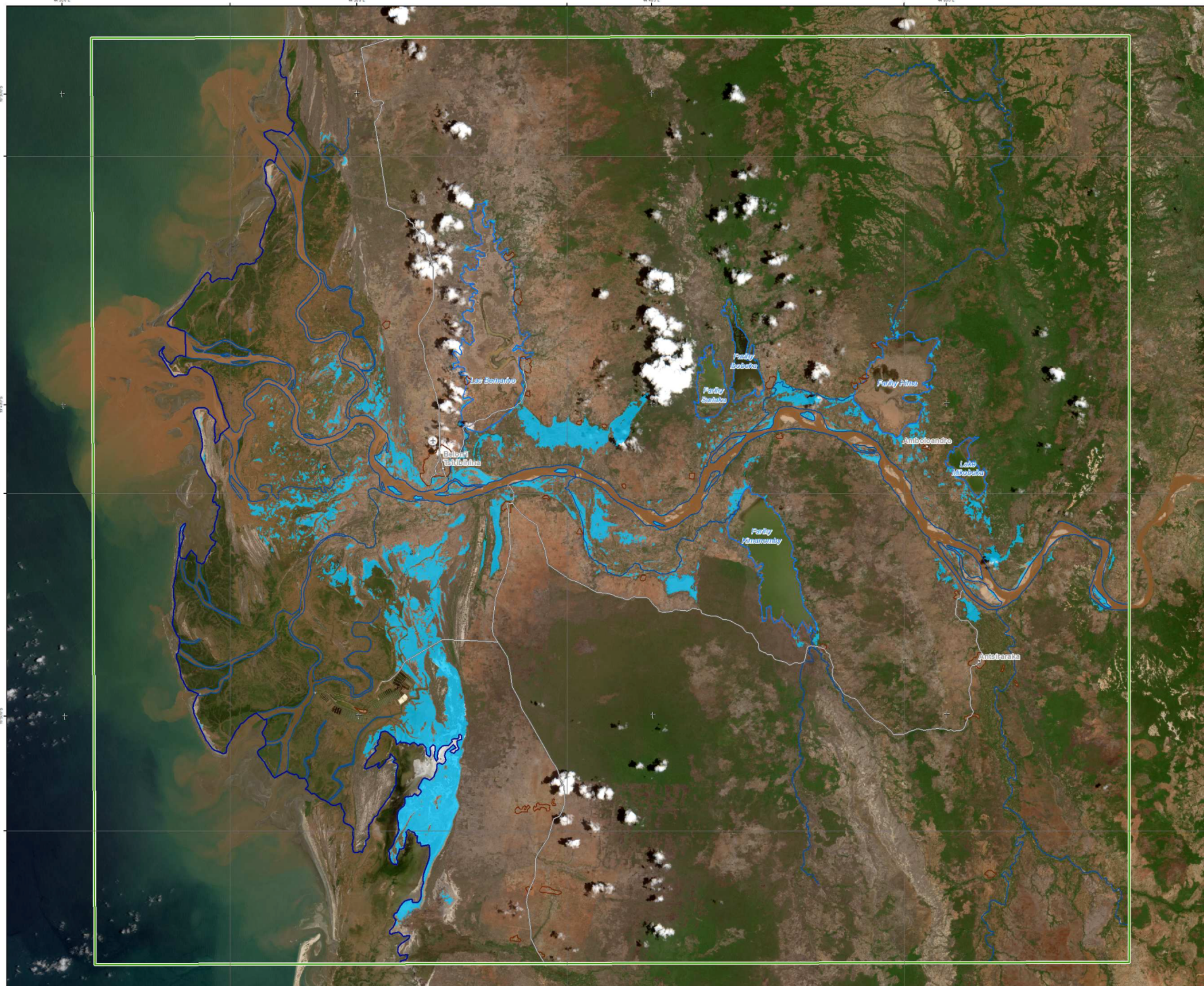


network



Hydrology lines automatically extracted from 5m DEM displayed in Google Earth.



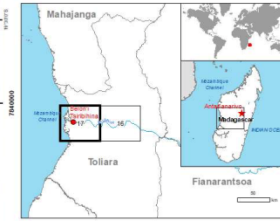


GLIDE number: TC-2018-000001-MDG   Activation ID: EMSR264
Product N.: 17BELONITSIRIBIHINA, v1, English

Belon'i Tsiribihina - MADAGASCAR

Wind storm - Situation as of 11/01/2018

Delineation Map



Cartographic Information

1:105000   Full color ISO A1, low resolution (100 dpi)

0 2 4 8 km

N

Grid: WGS 1984 UTM Zone 38S map coordinate system
Tick marks: WGS 84 geographical coordinate system

Legend

Crisis Information
Flooded Area (11/01/2018 02:27 UTC)

General Information
Area of Interest

Placenames
Placename

Built-Up Area
Built-Up Area

Land use - Land Cover
Features available in vector data

Hydrography
Coastline
River
Lake
River

Transportation
Airfield runway
Local Road

Consequences within the AOI				
		Unit of measurement	Affected	Total in AOI
Flooded area		ha	10003.7	
Estimated population		No. of people	257	37883
Settlements	Built-up Area	ha	5.5	813.5
Transportation	Airfield runway	No.	0.0	1
	Local Road	km	1.8	124.8
Land use	Permanent crops	ha	7022.2	18122.0
	Heterogeneous agricultural areas	ha	2834.5	210634.5
	Forests	ha	147.0	165940.4

Map Information

Tropical Cyclone AVA made landfall on the north-east coast of Madagascar on 5 January, moving south and west over the course 6 January, causing heavy rainfall and strong winds. Flooding, interruptions to communications networks and power cuts have been reported in the north, north-east and eastern area of the country.

The present map shows flood delineation in the area of Belon'i Tsiribihina (Madagascar). The thematic layer has been derived from post-event satellite image using a semi-automatic approach. The estimated geometric accuracy is 5 m CE90 or better, from native positional accuracy of the background satellite image.

Relevant date records			
Event	05/01/2018	Situation as of	11/01/2018
Activation	06/01/2018	Map production	12/01/2018

Data Sources

Pre-event image: Sentinel 2A/B (2017) (acquired on 05/12/2017 at 08:13 UTC, GSD 10 m, approx. 0.62% cloud coverage in AoI, 22.88° off-nadir angle) provided under COPERNICUS by the European Union and ESA.
Post-event image: Sentinel-1A/B (2018) (acquired on 11/01/2018 at 02:27 UTC, GSD 20 m) provided under COPERNICUS by the European Union and ESA.

Base vector layers: OpenStreetMap © OpenStreetMap contributors, Wikimapia.org, GeoNames 2015, refined by the producer.
Inset maps: JRC 2013, Natural Earth 2012, GeoNames 2013.

Population data: Landscan 2010 © UT BATTELLE, LLC
Digital Elevation Model: SRTM (30m) (NASA/USGS)

Disclaimer

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Please be aware that the thematic accuracy might be lower in urban and forested areas due to inherent limitations of SAR analysis technique.

Map produced by SERTIT released by SERTIT (ODO).

For the latest version of this map and related products visit
http://emergency.copernicus.eu/EMSR264

jrc-ems-rapidmapping@ec.europa.eu

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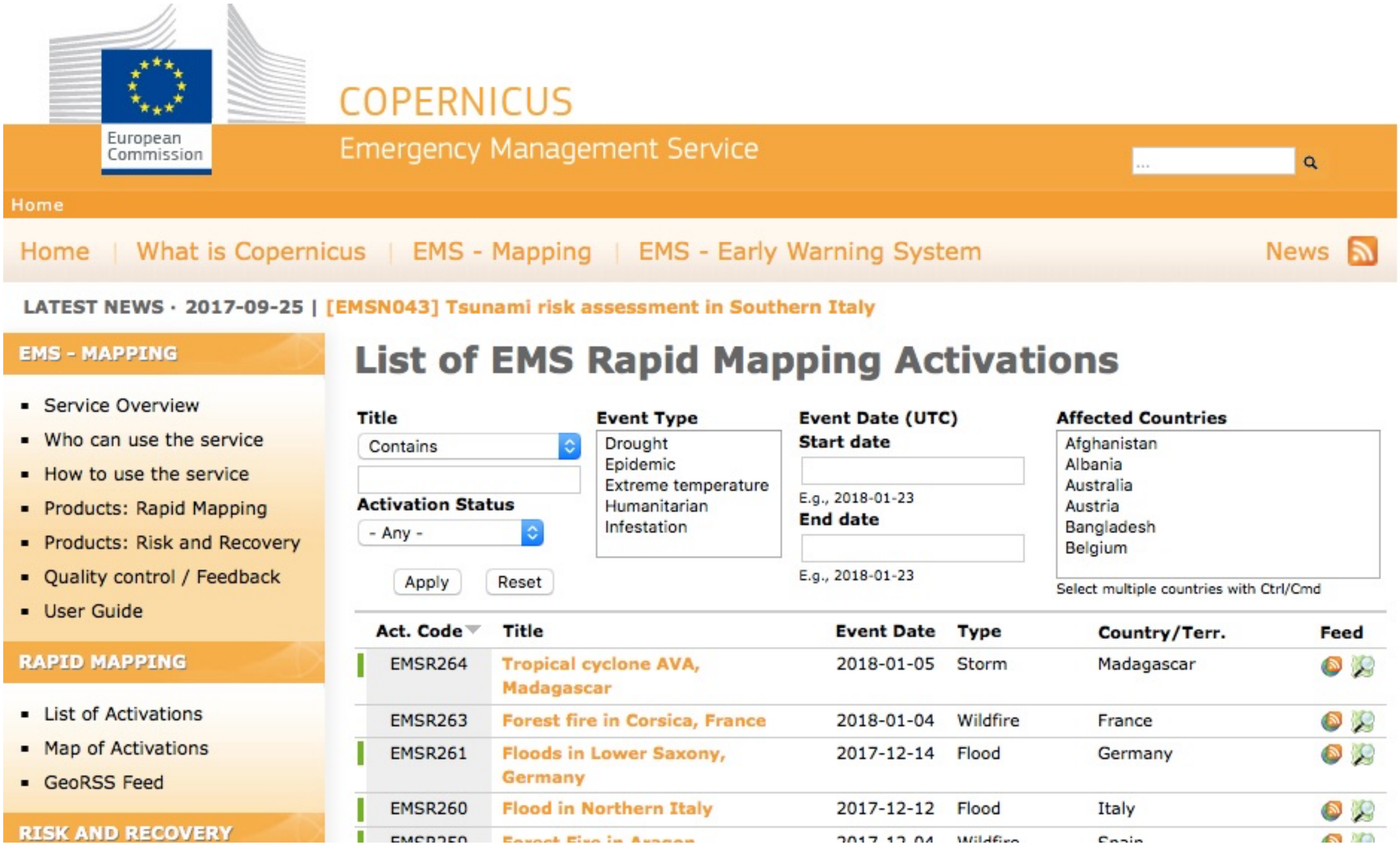

- http://emergency.copernicus.eu/mapping/list-of-activations-rapid

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