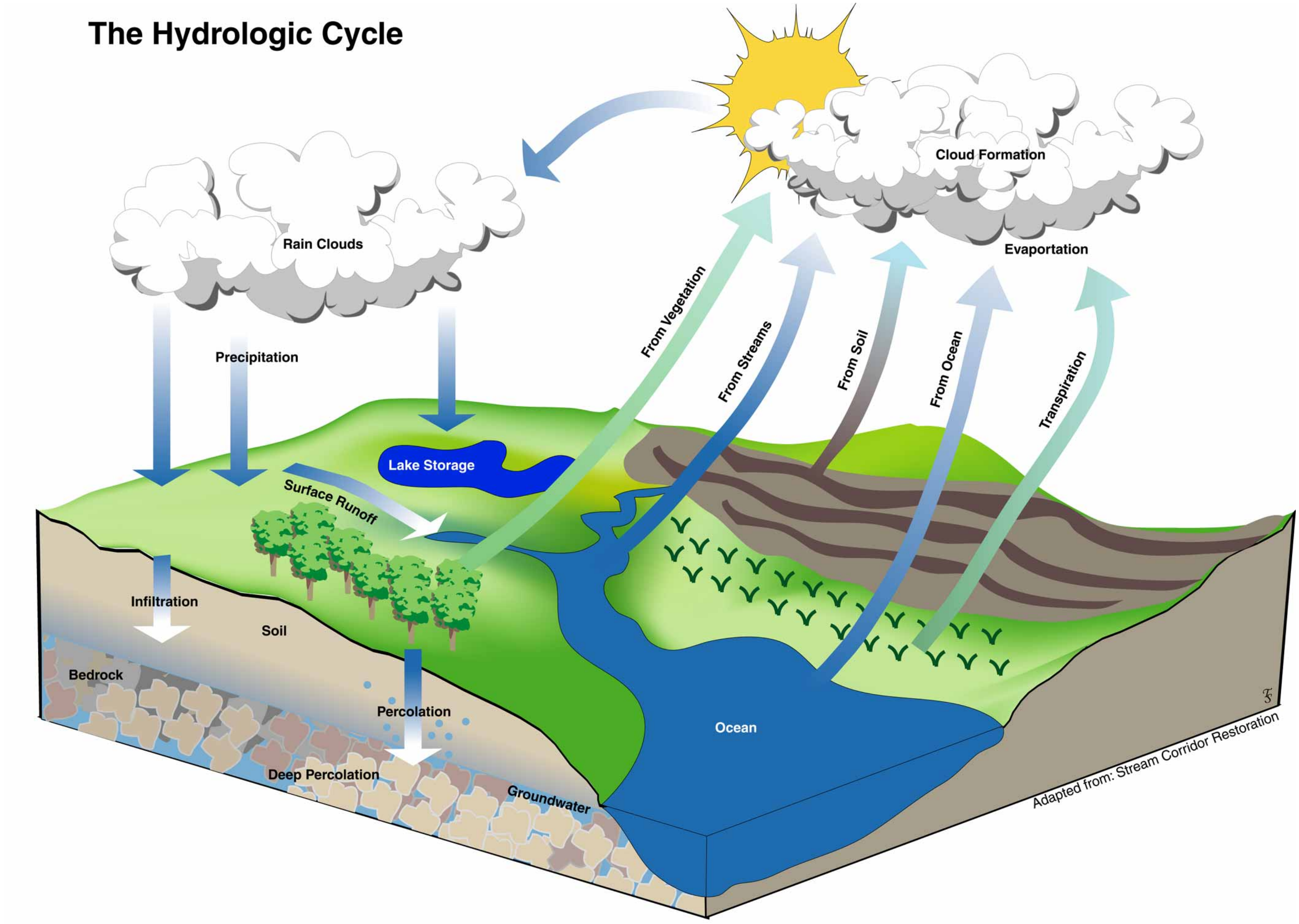
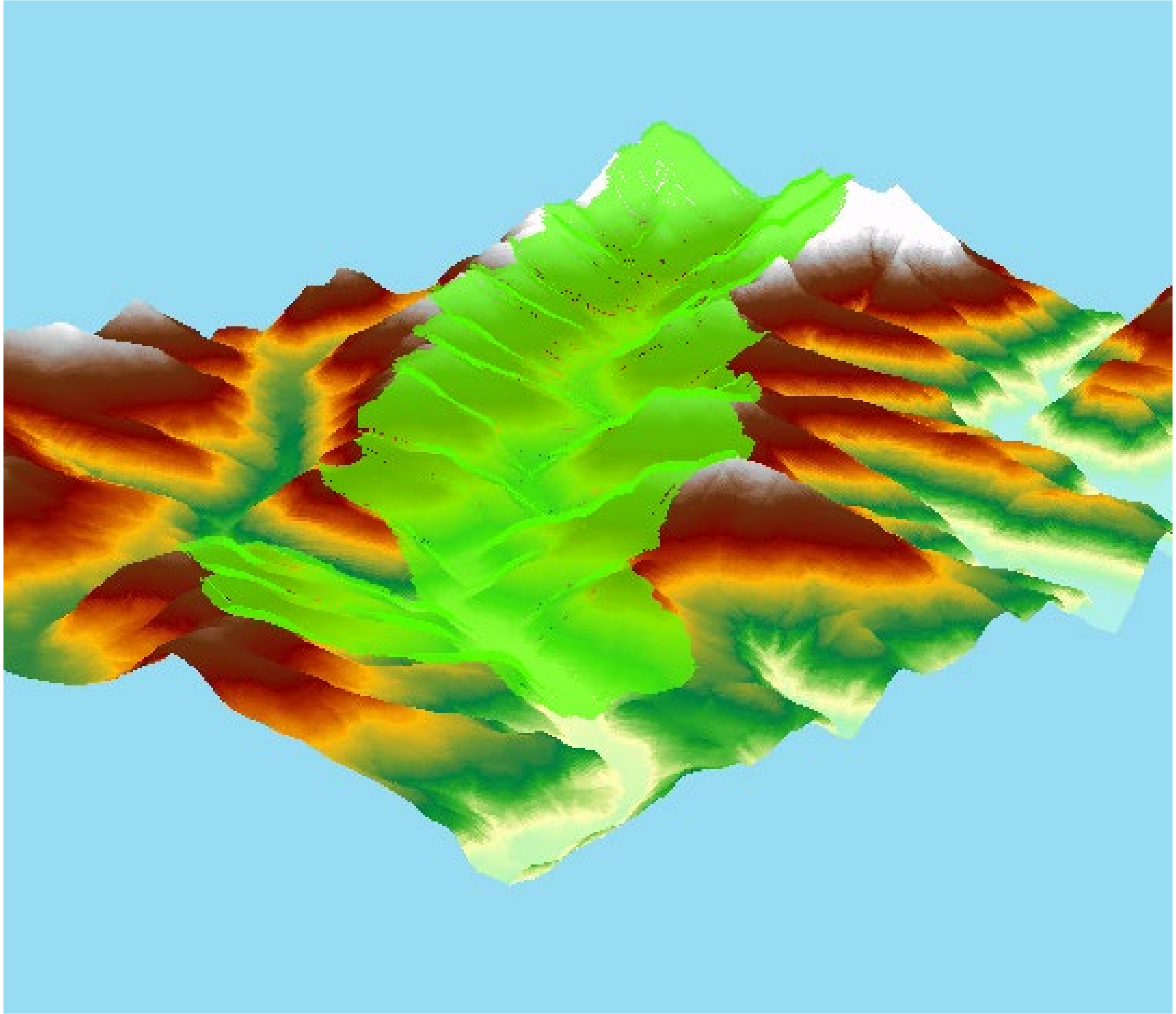
Terrain – Surface Hydrology Integration



Photos courtesy of Iowa State University Department of Natural Resource Ecology and Management
http://www.buffer.forestry.iastate.edu/Photogallery/illustrations/Images/Hydrologic-Cycle.jpg

Watershed depicted in GIS, over terrain



Terrain Topography

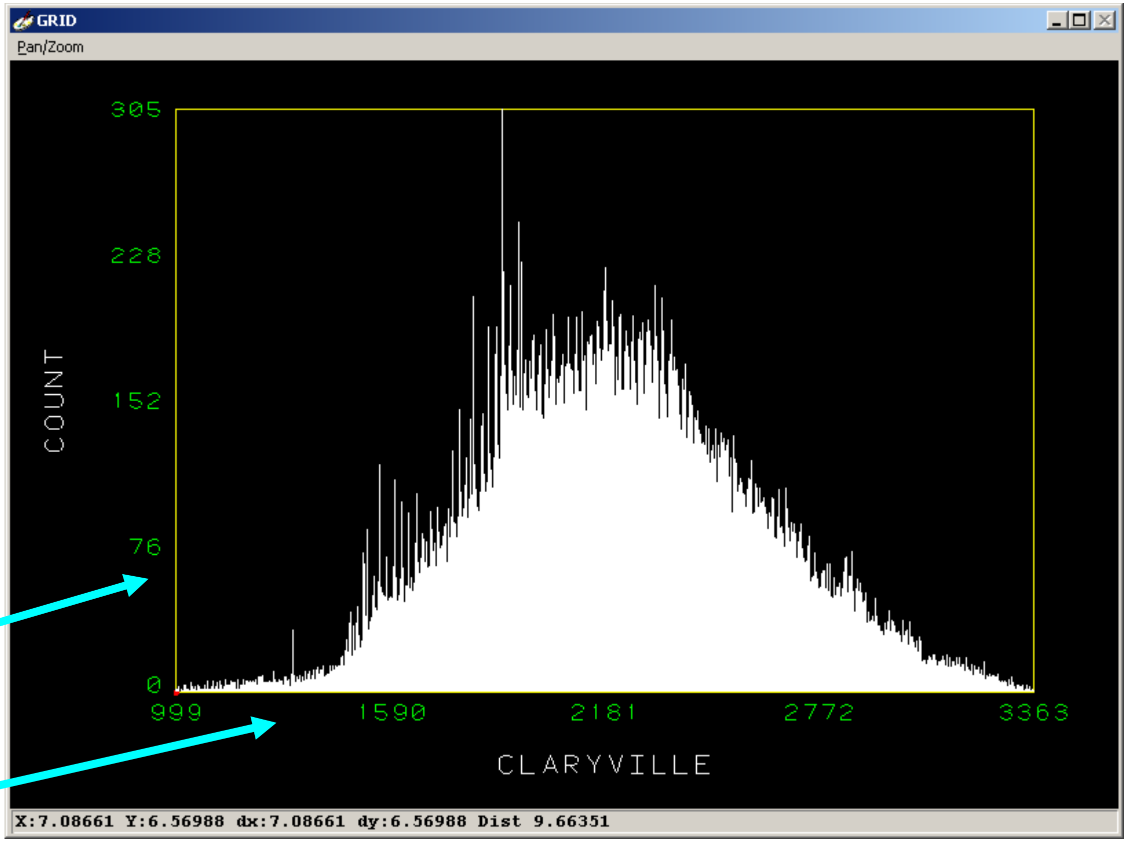
1. Relief: difference between max and min elevations

2. Minimum elevation

3. Maximum elevation

4. Even or uneven topography (normal distribution of elevation values or not)

Histogram of elevations in DEM (or frequency):



Pixel counts

Elevation values

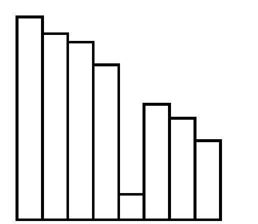
Sinks and DEM

1. A sink is a cell or set of spatially connected cells whose flow direction cannot be assigned one of the eight valid values in a flow direction grid. This can occur when all neighboring cells are higher than the processing cell, or when two cells flow into each other creating a two-cell loop.
2. Spurious sinks are errors in DEM processing that have to be removed. hese errors are often due to sampling effects and the rounding of elevations to integer numbers.
3. **<u>Sink removal creates a better hydrological surface that describes water transport.</u>**

Flowdirection

coding in ArcGIS

32	**64**	**12 8**
16	**?**	**1**
8	**4**	**2**

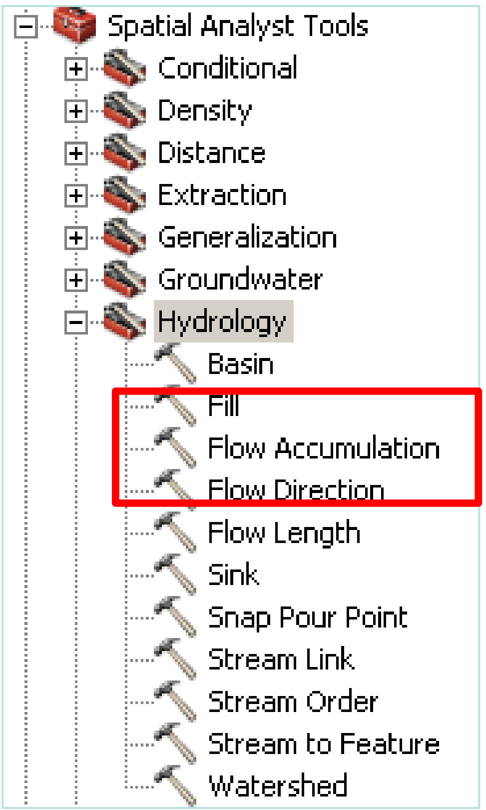


Profile view of a sink

Sinks are considered to have undefined flow directions and are assigned a value that is the sum of their possible directions. For example, if the steepest drop, and therefore flow direction, is the same both to the right (1) and left (16), the value 17 would be assigned as the flow direction for that cell.

ArcGIS Hydrology Tools:

ArcToolbox → Spatial Analyst Tools → Hydrology

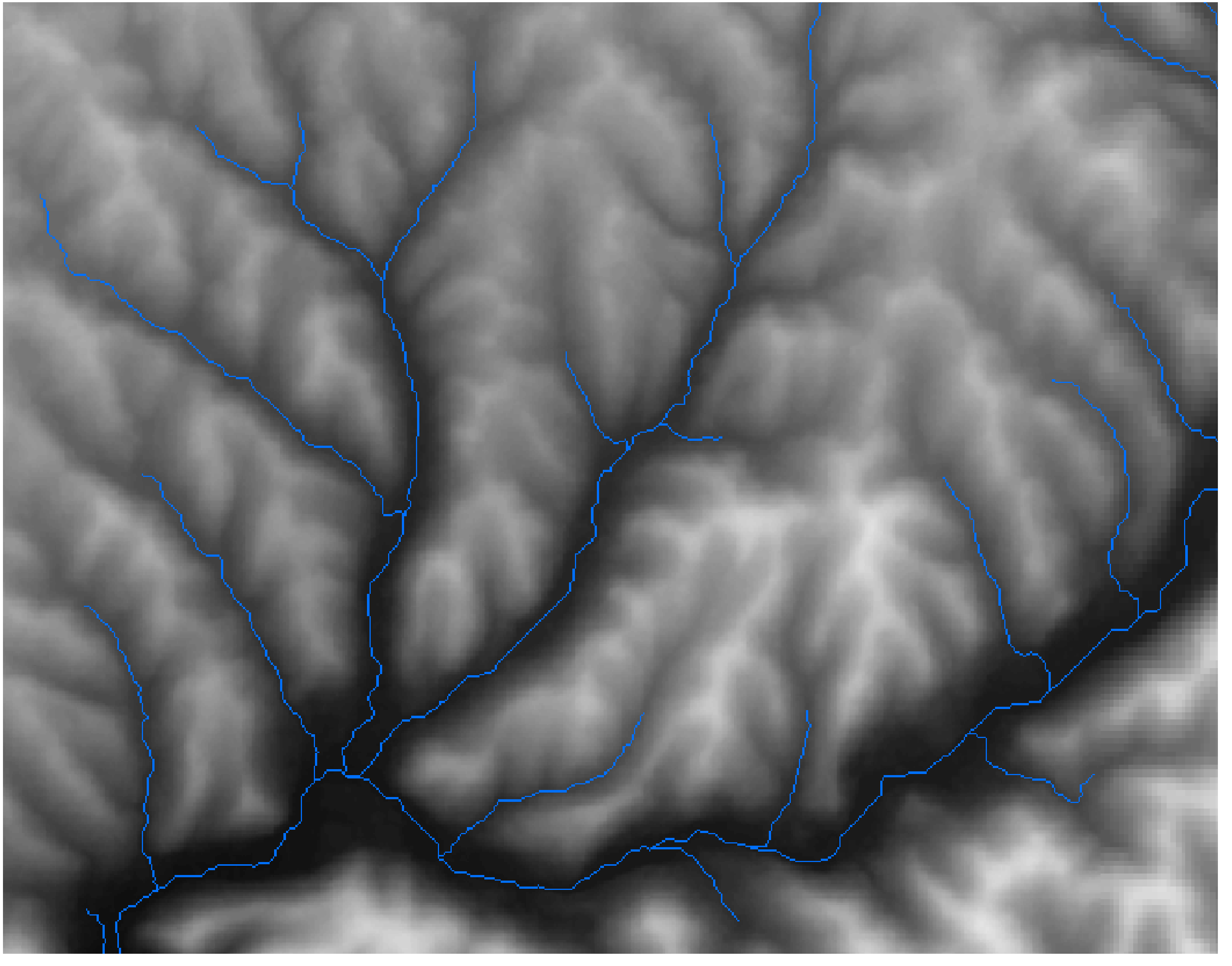


<u>Suggested general analytical sequence to create watershed basins and flow lines (stream networks):</u>

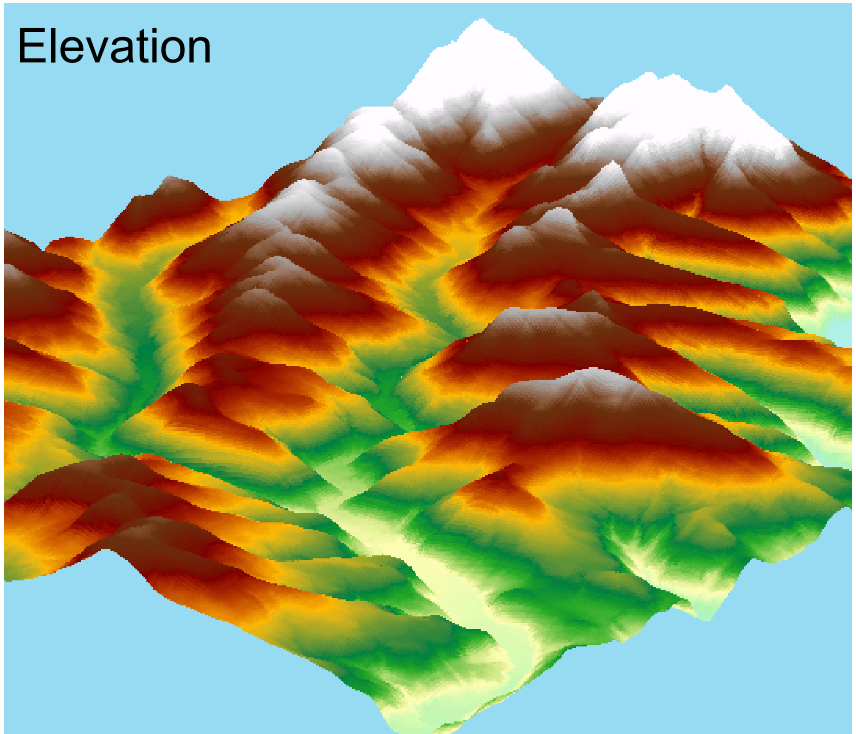
1. **Fill: fill DEM and remove sinks**
2. **Flow direction**
3. **Flow accumulation**

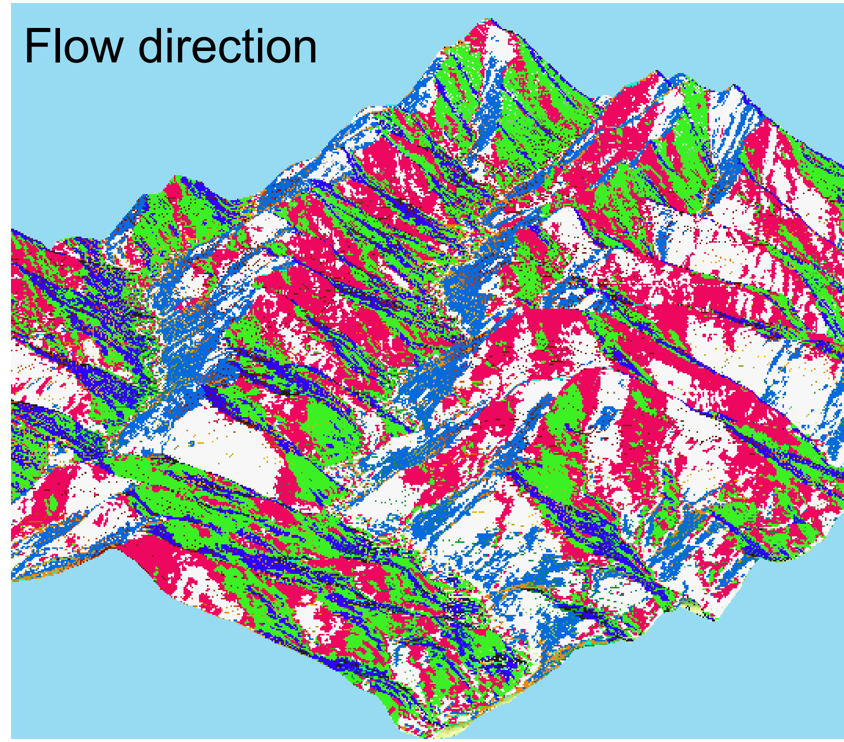
At this point you can create stream network or watershed basin(s)

Derivation of stream network (as a model) from DEM



FLOW DIRECTION GRID





Flow direction coding:

32	64	128
16	?	1
8	4	2

For example, if the direction of steepest drop was to the left of the current processing cell, its flow direction would be coded as 16.

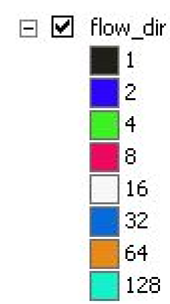
78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

ELEVATION

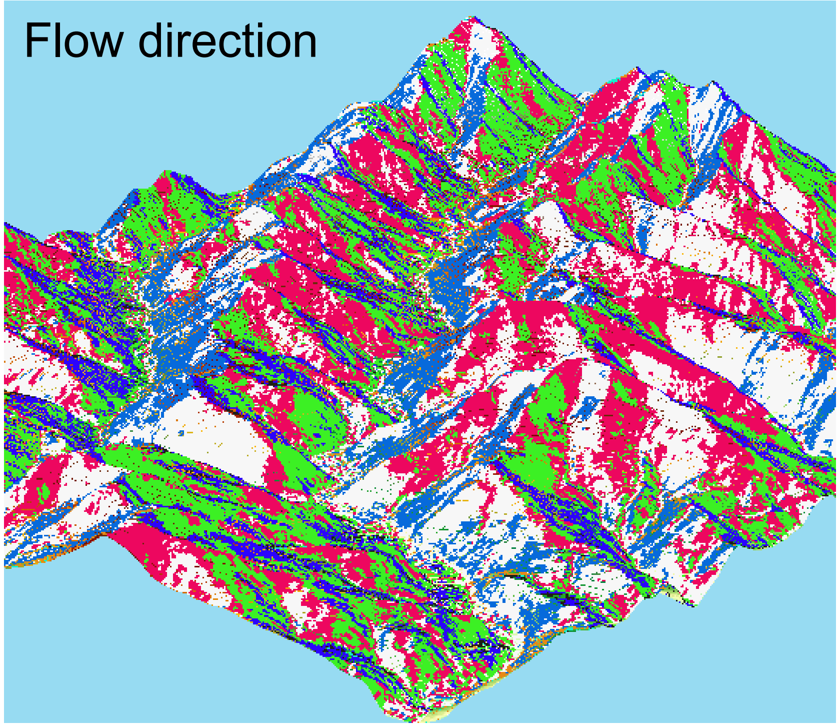
=

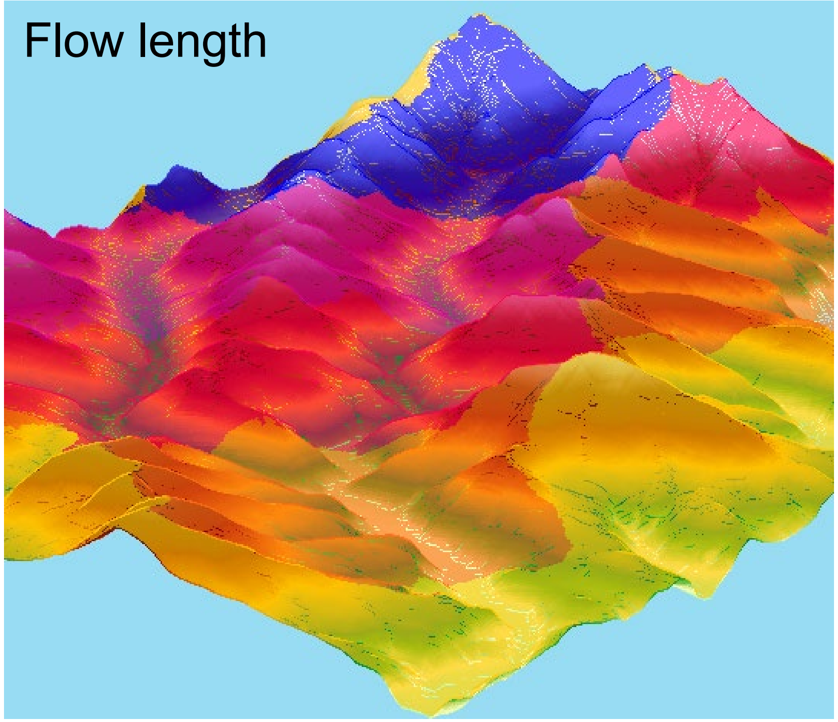
2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

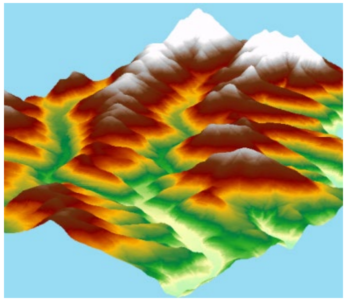
FLOW_DIR



FLOW LENGTH GRID

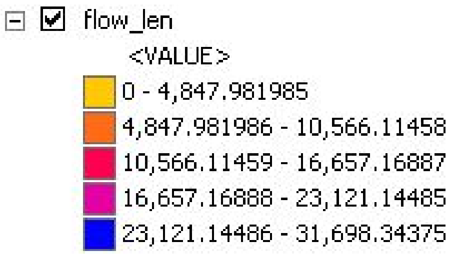




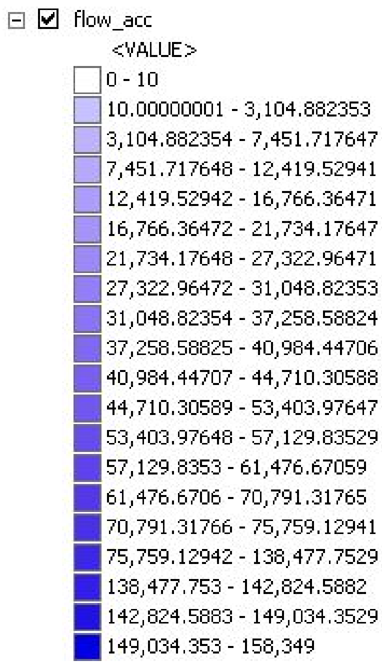


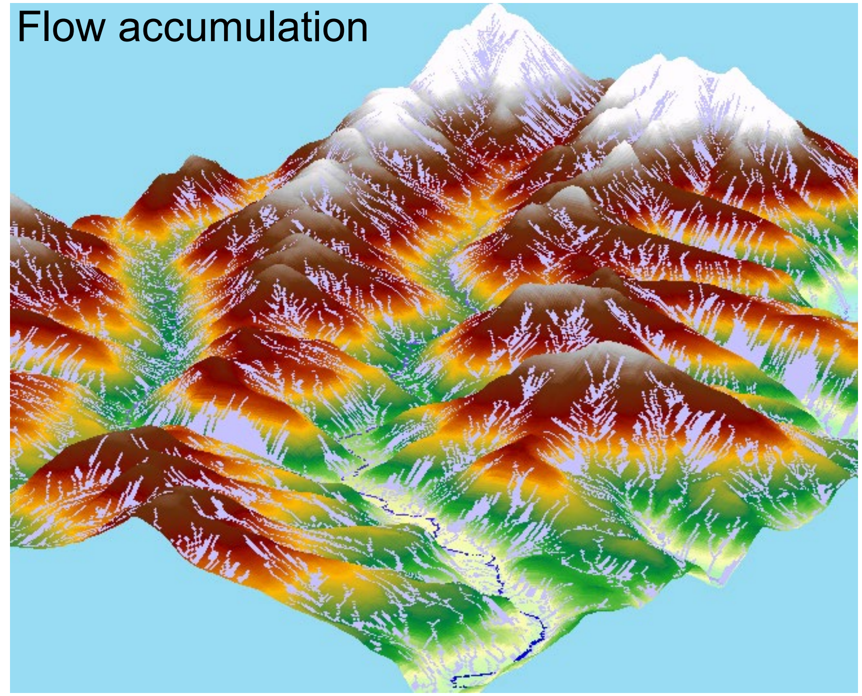
Calculates upstream or downstream distance from the outlet along a flow path for each cell.

A primary use of the FLOWLENGTH command is to calculate the length of the longest flow path within a given basin. This measure is often used to calculate the time of concentration of a basin. This can be done with the UPSTREAM option.



FLOW ACCUMULATION GRID





Direction Index

32	**64**	**128**
16		**1**
8	**4**	**2**

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

FLOW_DIR

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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

FLOW_ACC

Creates a grid of accumulated flow to each cell, by accumulating the weight for all cells that flow into each downslope cell.

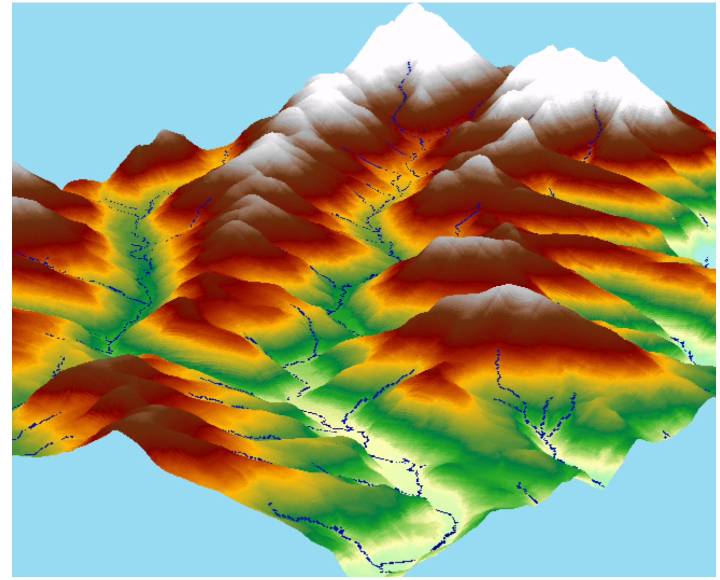
The accumulated flow is based upon the number of cells flowing into each cell in the output grid. The current processing cell is not considered in this accumulation.

Output cells with a high flow accumulation are areas of concentrated flow and may be used to identify stream channels.

FLOW ACCUMULATION GRID

Threshold = 600

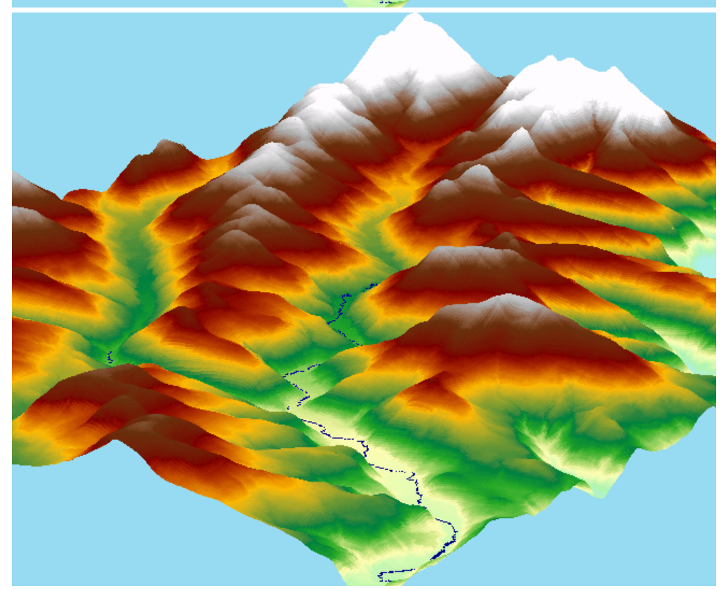
flow_acc
<VALUE>
0 - 600
600.0000001 - 21,734.17647
21,734.17648 - 44,710.30588
44,710.30589 - 75,759.12941
75,759.12942 - 158,349



Extraction of streams can be done by selecting thresholds of flow accumulation values

Threshold = 44,710.30589

flow_acc
<VALUE>
0 - 600
600.0000001 - 21,734.17647
21,734.17648 - 44,710.30588
44,710.30589 - 75,759.12941
75,759.12942 - 158,349



Creating a raster based stream network model

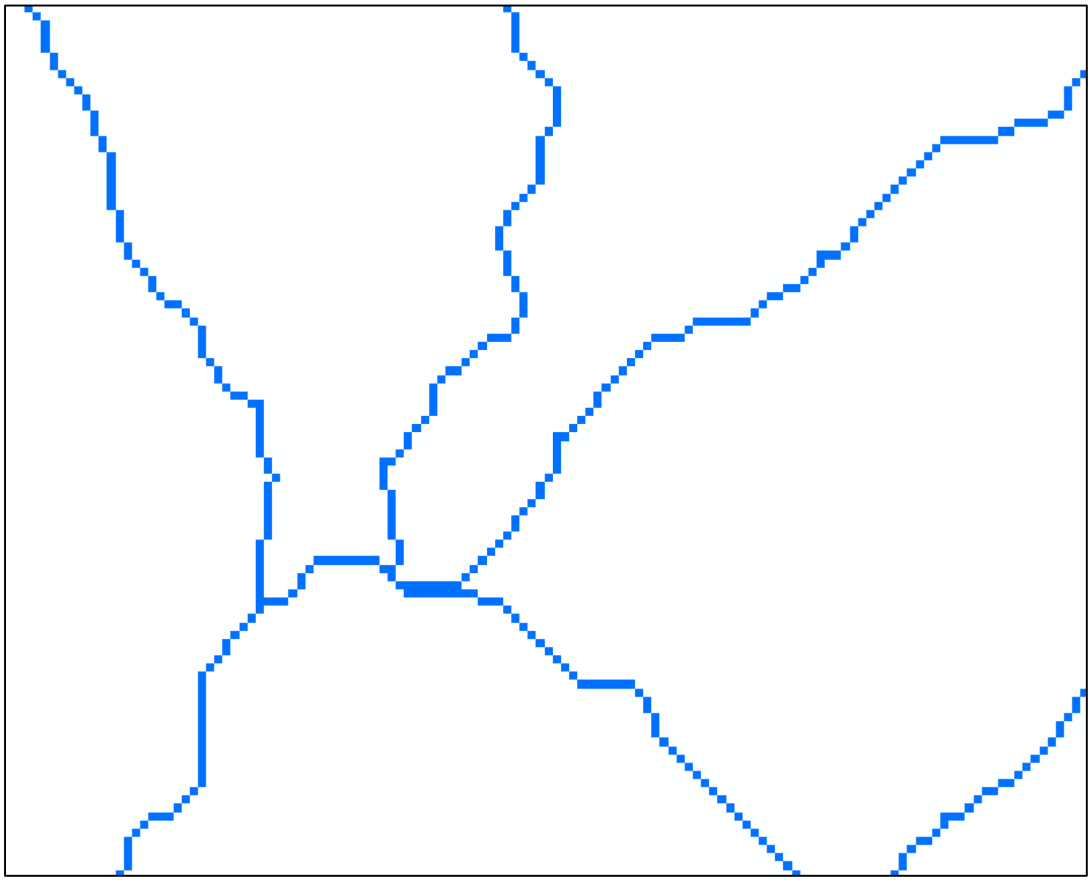
Con ( ) Function in Raster Calculator can be used to extract stream network:

Typical condition for Raster Calculator: (flowacc_grid > 600, 1, 0)

Threshold value from the flow accumulation grid

The lower the threshold value, the less or more streams will be delineated?

Raster based stream network model



1. You can convert your model to a shapefile (vector) or leave it as a raster dataset;
2. For just visual appearance on the map no need to export or convert, just use Symbology settings; keep in mind that one class should be No Color and another should have a color. In this case it is blue.

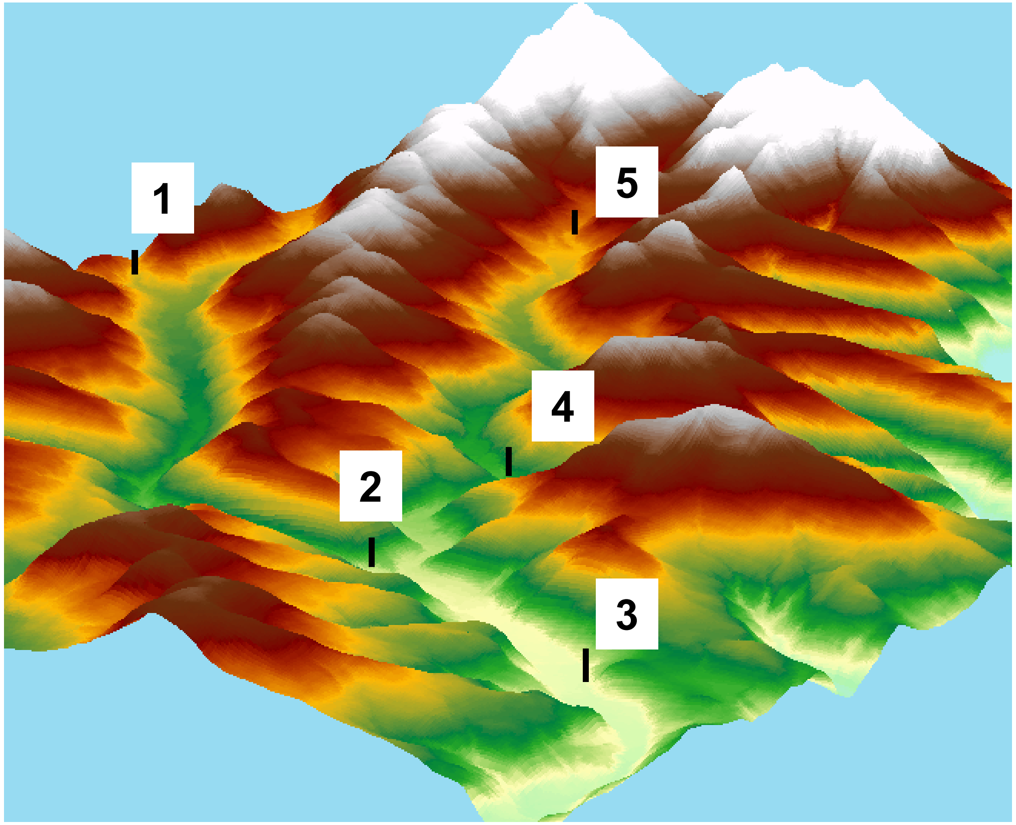
Delineation of the watersheds

Points at the watershed outlet are called “pour points”.

These points can be locations of stream gauges or any other meaningful sites.

Pour points can be feature class or raster grid, but for analysis they have to be in raster format.

Hydrology tool “Snap Pour Point” creates them in raster format for use in “Basin” or “Watershed” function.

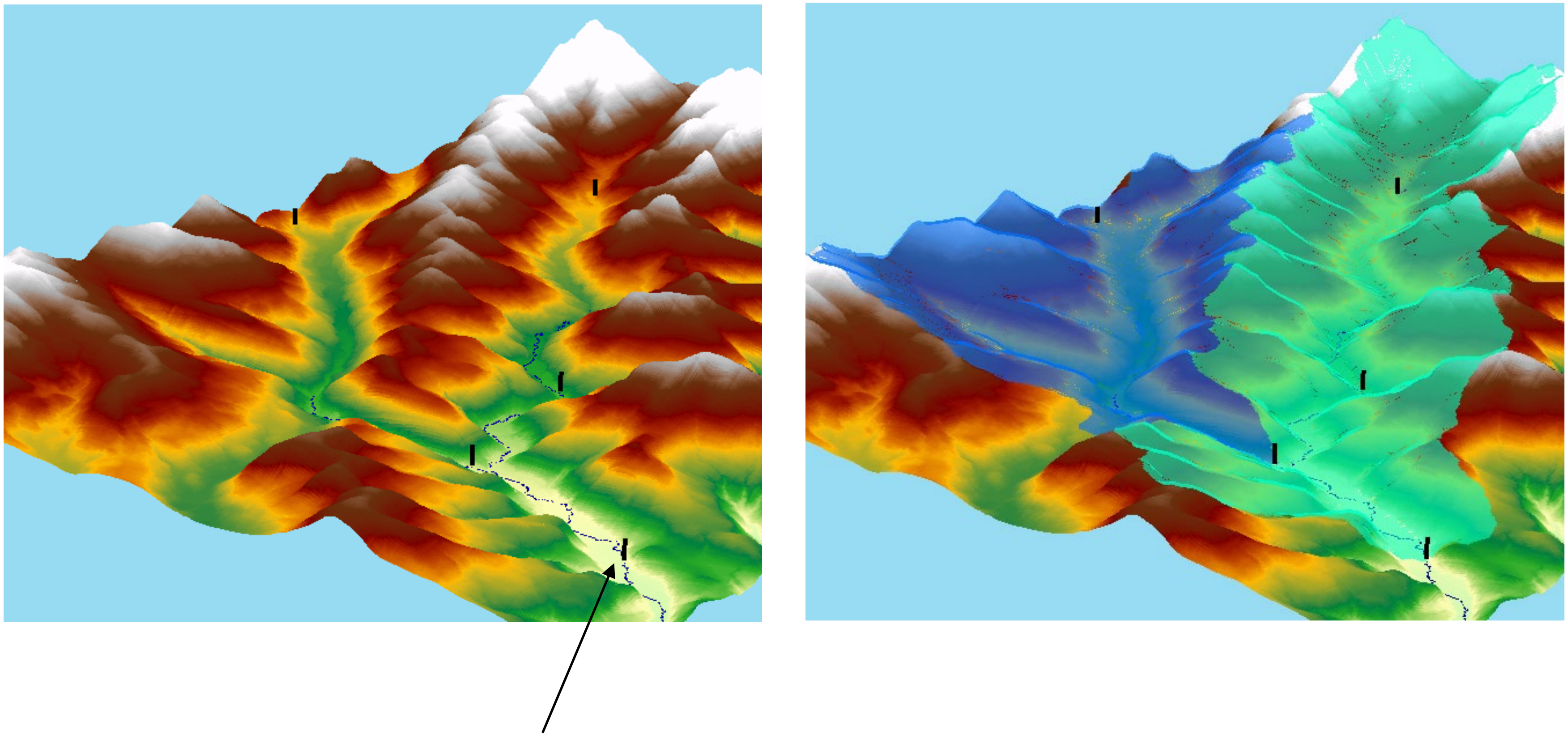


Practical use:

- Estimate area contributing to each gauge (vertical black mark with number)
- Use delineated areas as a weighting factor for calculation of surface water quality or other measured parameters
- Key component in comparative analysis for water quality/conservation/ecology, etc.

Delineation of the watersheds

Terrain and stream network mode | **Terrain and delineated basin**



Pour point should be located exactly on the stream network.

Digitize it first as a point, then use “Snap Pour Point” tool.

Using watershed tool in GIS to test the hypothesis about ancient water supply source in roman settlement Aptera (Crete)

Gorokhovich Y., A. Alexopoulos, V. Gikas, A. Angelakis, P. Gikas. 2012. Water Supply and Use in the Roman City of Aptera, Crete, Greece: the mystery of the ancient water system. In: Proceedings of the International Water Association(IWA) Specialized Conference on Water& Wastewater Technologies in Ancient Civilizations, 22-24 March, 2012, Istanbul, Turkey.

Gorokhovich, Y., Papadopoulos, N., Soupios, P., Barsukov, P. 2014. Application of Geographic Information Systems, Ground Penetrating Radar and Transient Electromagnetic Methods for Locating Water Supply Structures at the ancient site of Aptera in Crete. Boletín Geológico y Minero, 125 (3): 273-284

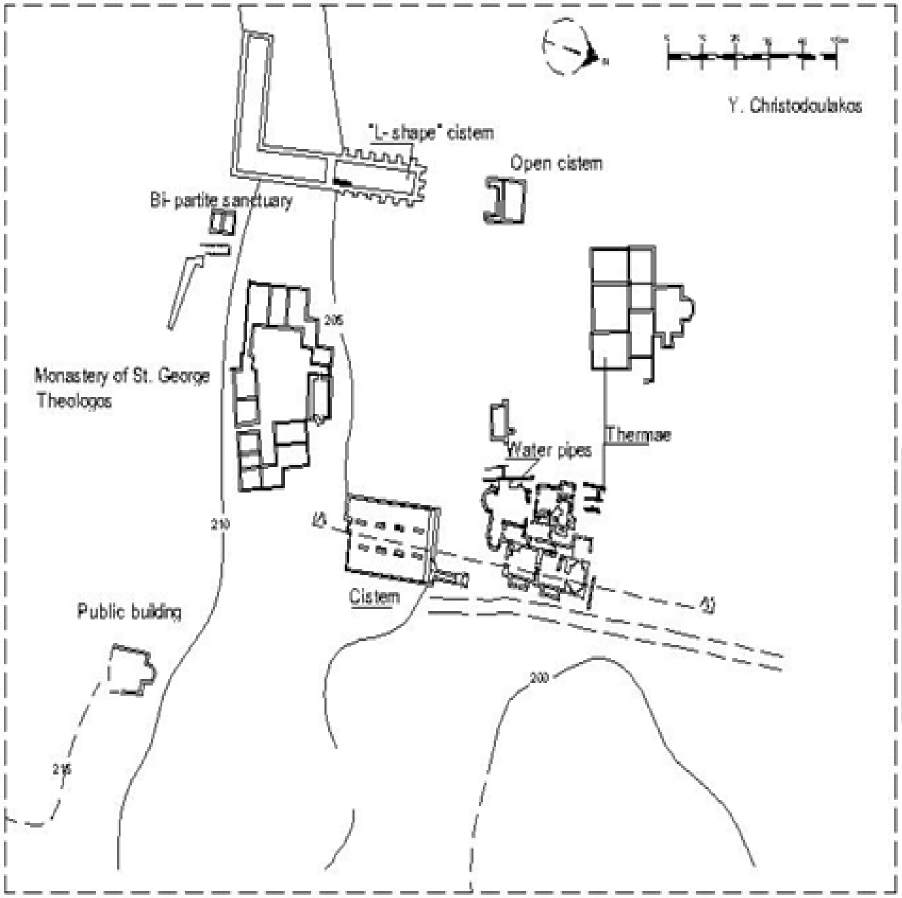
Island of Crete and location of Aptera

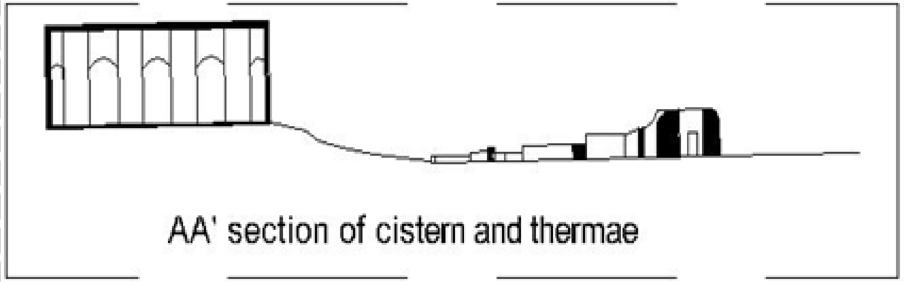
Location of Aptera: hill over the Souda Bay

Aptera's details

Water structures in Aptera

Link between cisterns and thermae





(Adapted from Niniou-Kindeli and Christdoulakos, 2004; Gikas et al, 2009).

Mystery:

How large water structures in Aptera could receive water supply and maintained it throughout the year?

- **No remnants of aqueduct structures**
- **No remnants of water harvesting structure**
- **No visible watershed basin**
- **No significant aquifers at reachable depth**

Earlier studies:

Rainwater harwesting?

Runoff?

Niniou-Kindeli and Christodoulakos (2004)

Christodoulakos et al., 2009

Gikas et al (2009)

The results of these studies indicate the possibility of the surface runoff as a main source of water

Methodology:

1. Hydrologic and terrain modeling:
   a. Delineate contributing area for the surface runoff.
   b. Using contributing area estimate volume of the surface runoff entering the main L-shaped cistern and compare it with a volume of the cistern itself.

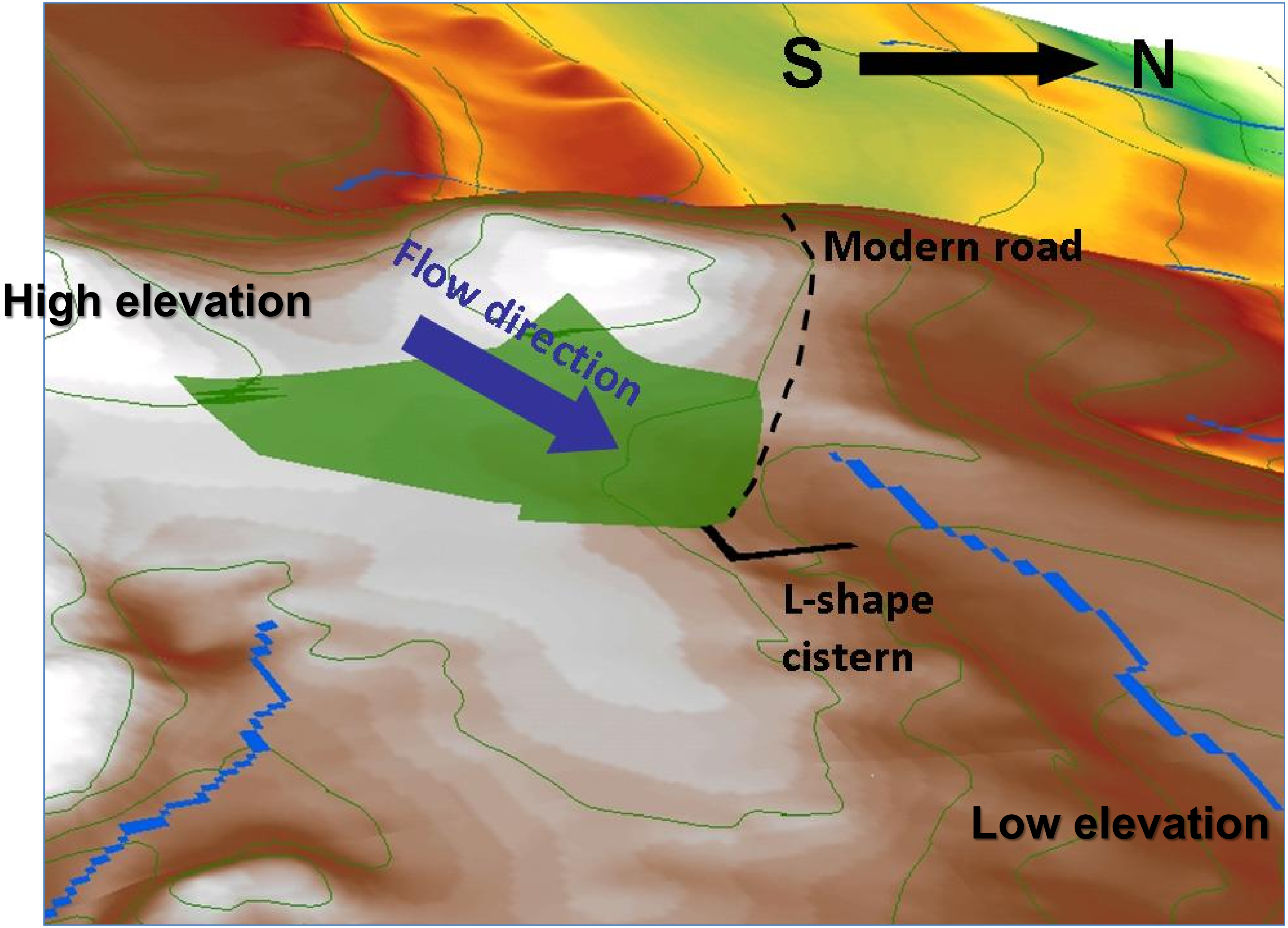
2. Meteorological data analysis:

   Using precipitation data estimate precipitation level.

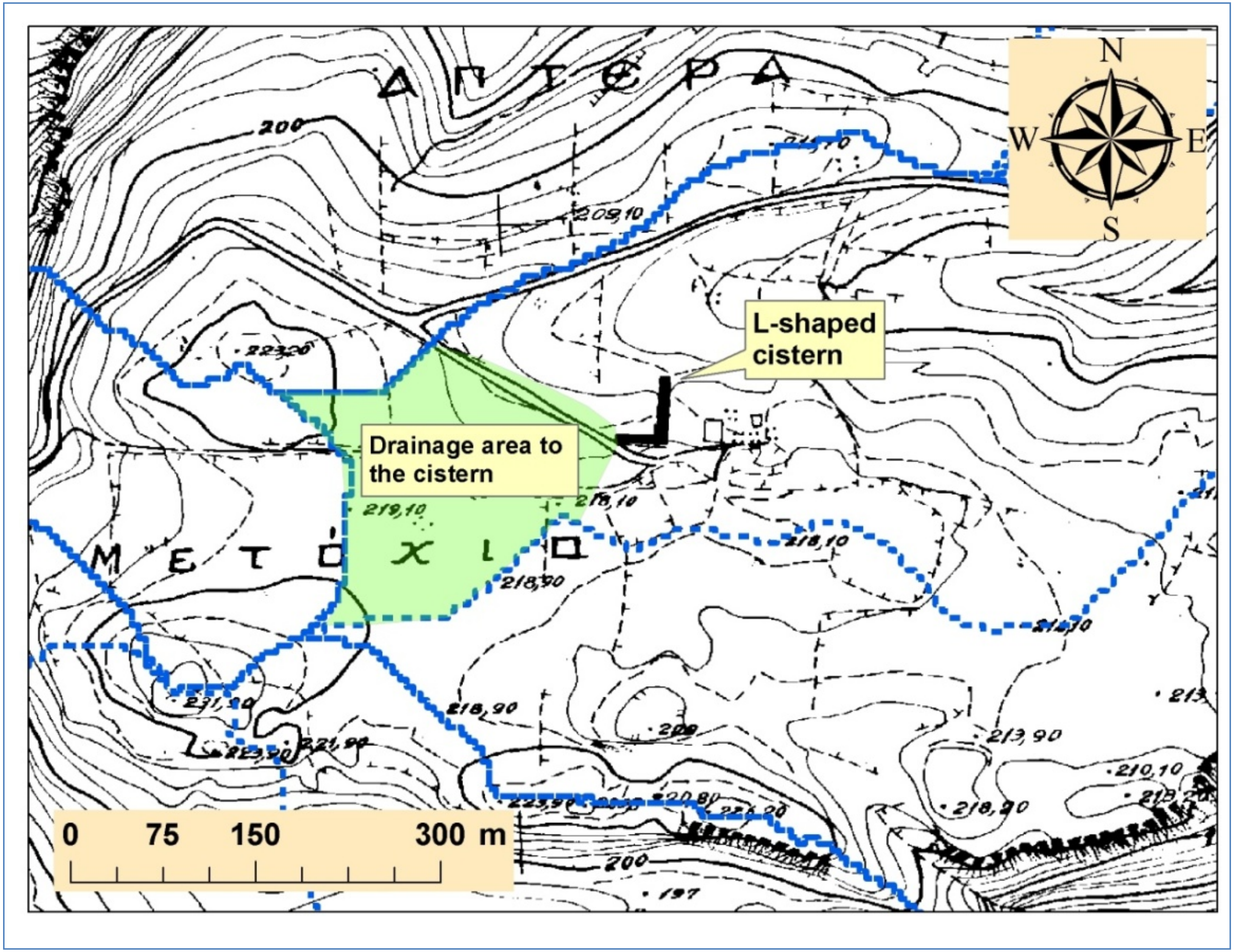
Hydrologic and Terrain Modeling:

1. Obtain data from photogrammetry (contour lines)
2. Convert contour line data into DEM surface
3. Use cistern's western corner as a "pour point" and delineate watershed area that potentially could deliver water in the cistern by surface runoff

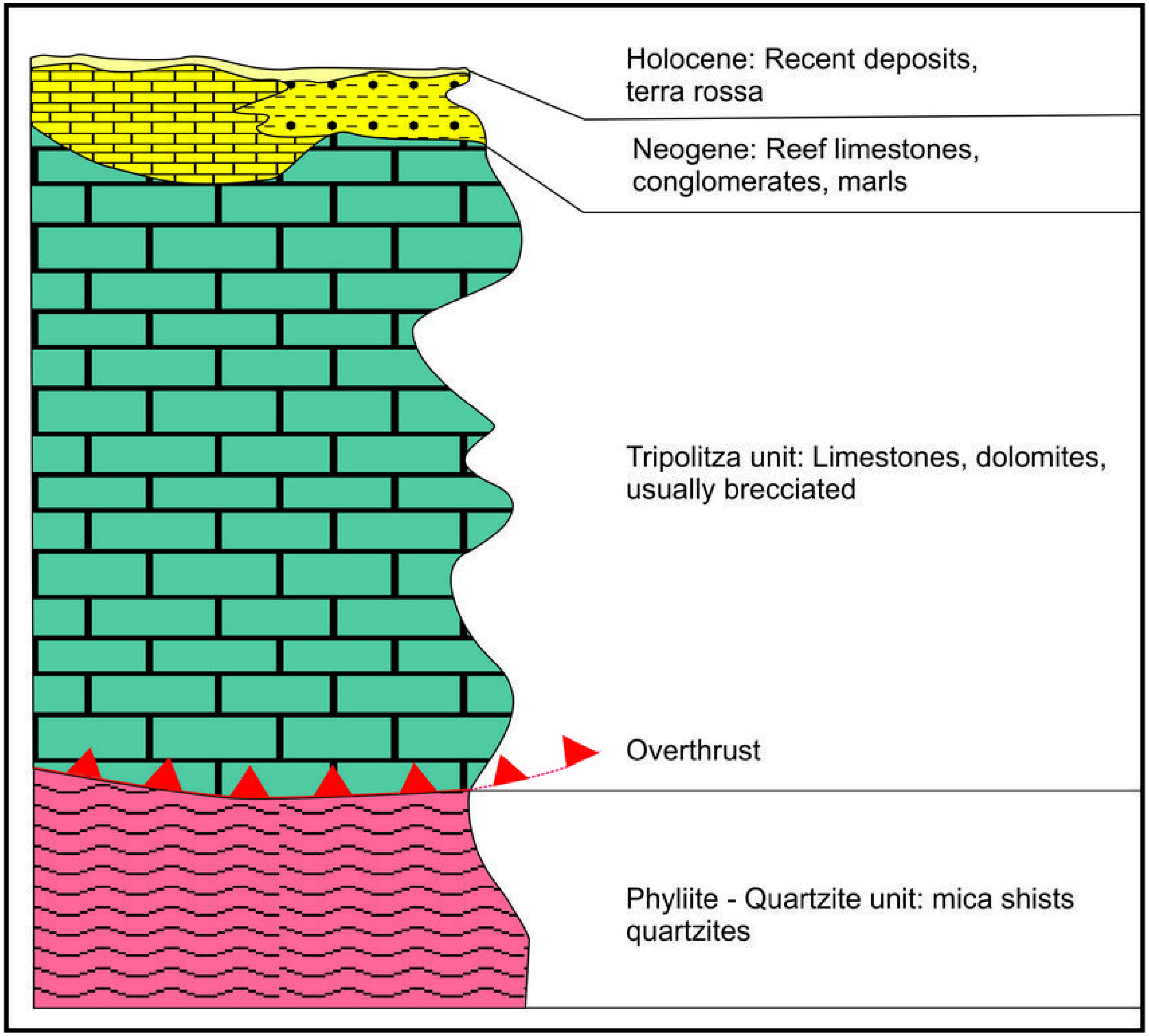
Modeling results



Modeling results overlaid on topo map



Geologic and surface conditions



Average monthly temperatures and precipitations as measured at the Souda meteorological station (minimum period of records is 30 years).

View: English | **Metric** Daily Records and Averages at weather.com

Month	Avg. High	Avg. Low	Avg. Precip
January	14.0 °C	8.0 °C	14.22 cm
February	15.0 °C	8.0 °C	11.18 cm
March	17.0 °C	9.0 °C	8.13 cm
April	20.0 °C	11.0 °C	3.30 cm
May	24.0 °C	15.0 °C	1.27 cm
June	29.0 °C	19.0 °C	0.51 cm
July	30.0 °C	21.0 °C	0.25 cm
August	30.0 °C	21.0 °C	0.25 cm
September	27.0 °C	18.0 °C	1.78 cm
October	23.0 °C	15.0 °C	8.13 cm
November	20.0 °C	12.0 °C	7.37 cm
December	16.0 °C	9.0 °C	9.40 cm

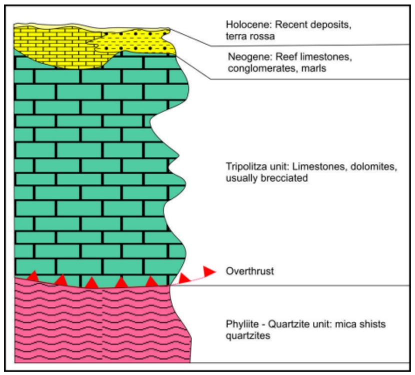
We can assume two conditions:

1. **Downpour of the rain with maximum precipitation of 142 mm;**
2. **A period of several rain storms with duration 2-3 hours, each approximately with 30 – 45 mm of precipitation.**

Taking the second condition as a case it is reasonable to assume that rain intensity should be within 10 – 15 mm/hr.

(Data source: http://www.weather.com/weather/climatology/monthly/GRXX0032)

Estimation of the surface runoff volume from the derived contributing area using rational method



$$Q = 0.00278\ C\ I\ A$$

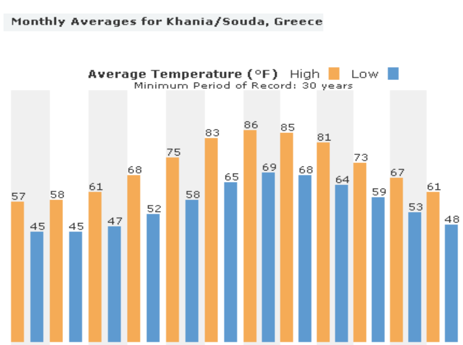
where:

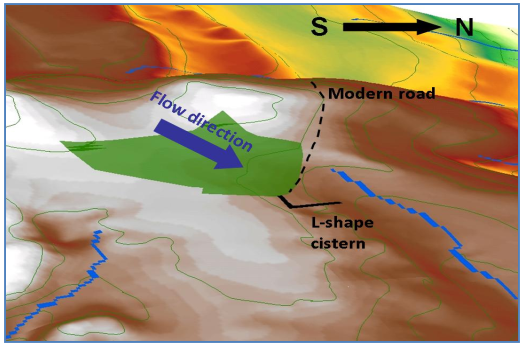
Q – surface runoff volume (m^3/sec);

C – runoff coefficient;

I – rainfall intensity (mm/hr);

A – contributing area (ha);





Hydrologic calculations:

Contributing area for the L-shaped cistern is approximately 29,946 m^2 (3 ha); low (< 3 degree) slope in all directions.

Surface runoff yields the following results:

$$Q = 0.00278 \times 0.7 \times 10 \times 3 = 0.058 \ m^3/sec$$

For the period of 2 – 3 hrs this runoff will provide approximately 522 m^3 of water.

The volume of the L-shaped cistern is 3050 m^3 (Niniou-Kindeli and Christodoulakos, 2004). Therefore, if we consider our estimated runoff volume, it will take more than 6 storm events to fill up L-shaped cistern completely.

Main conclusions and results are:

- **Hydrologic modeling shows the possibility of enough surface runoff during late autumn - winter months to the L-shaped cistern. Approximate amount of 522 m^3 would result from a single rain storm. Therefore, at least 6 storms would be required to fill up the L-shaped cistern, considering surface runoff as the only source of water. This is quite possible over the five months period.**

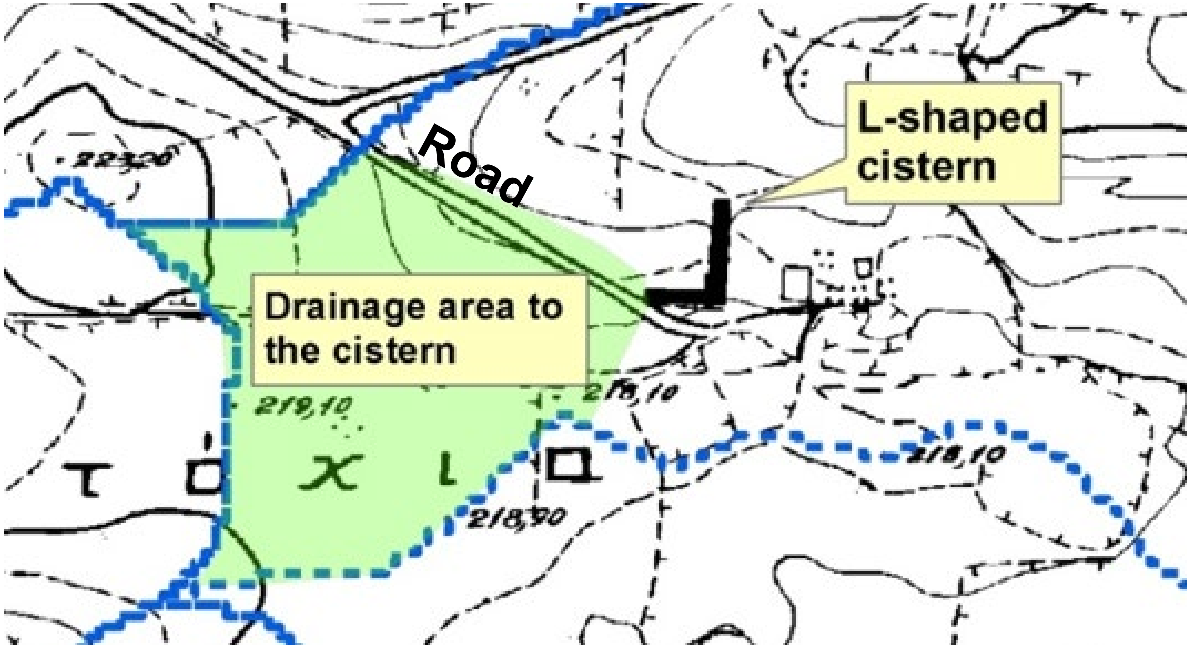
- **Until more archaeological findings of water related structures and accurate dating are available, it is hard to interpret water related infrastructure of the city of Aptera as a whole; however, it is quite possible that ancients used a combination of water harvesting techniques.**

- **Northern side of the drainage area delineated by hydrologic model coincides with the contemporary road leading to the L-shaped cistern and entrance to the city of Aptera complex. We suggest that this road was built on the top of the ancient cut-off ditch that would divert the surface runoff into the L-shaped cistern. Further subsurface investigation can provide better information on this fact.**

How ancients could optimize surface runoff delivery to the cistern?

Almost flat surface with low slope could possibly provide enough water but would be there any way to optimize the surface flow and capture the maximum of water?

The possible key to this issue is suspicious correspondence of the road leading to the cistern with the northern watershed boundary. Road could be build above existing interception ditch that ancients could possibly use to optimize surface flow.



How ancients could optimize surface runoff delivery to the cistern?

Example from China:

(6) Purpose-built catchment

When the climate is too dry and runoff small, it may be necessary to treat the natural catchment slope to raise RCE. The treatment could include paving the ground with concrete, cement soil, or covering it with plastic film.

An interception ditch is used to intercept the rainfall-runoff on the slope and the collection ditch collects water from the interception ditches. The conveyance ditch transports water to the tank.

Note: RCE is "rainwater collection efficiency"

In case of ancients in Aptera they did not need to use cement or concrete or plastic. Terra rossa is a specific, hard soil cover that has very low impermeability.

Source: Rainwater Harvesting for Agriculture and Water Supply. 2015. Eds: Qiang Zhu, John Gould, Yuanhong Li, Chengxiang Ma

How ancients could optimize surface runoff delivery to the cistern?

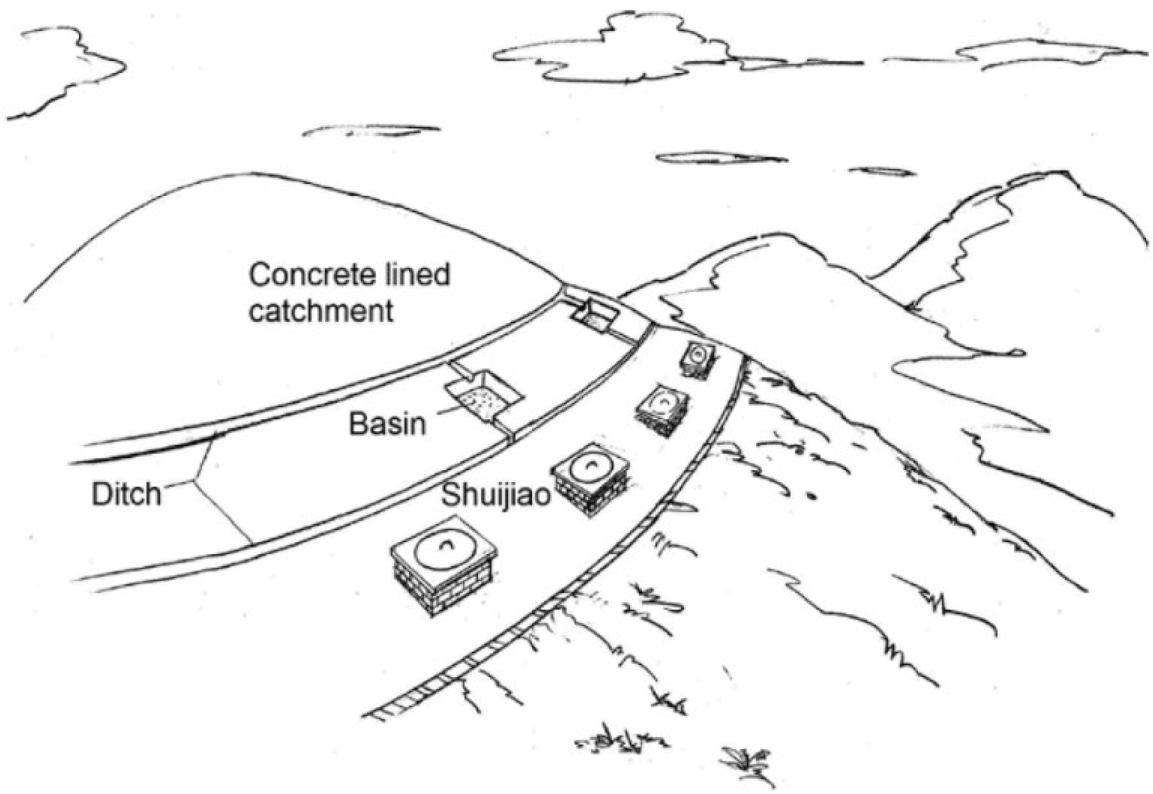


Fig. 1.17 A purpose-built concrete catchment on a hill top supplied a number of tanks

Source: Rainwater Harvesting for Agriculture and Water Supply. 2015. Eds: Qiang Zhu, John Gould, Yuanhong Li, Chengxiang Ma

How ancients could optimize surface runoff delivery to the cistern?

Example from Mediterranean:

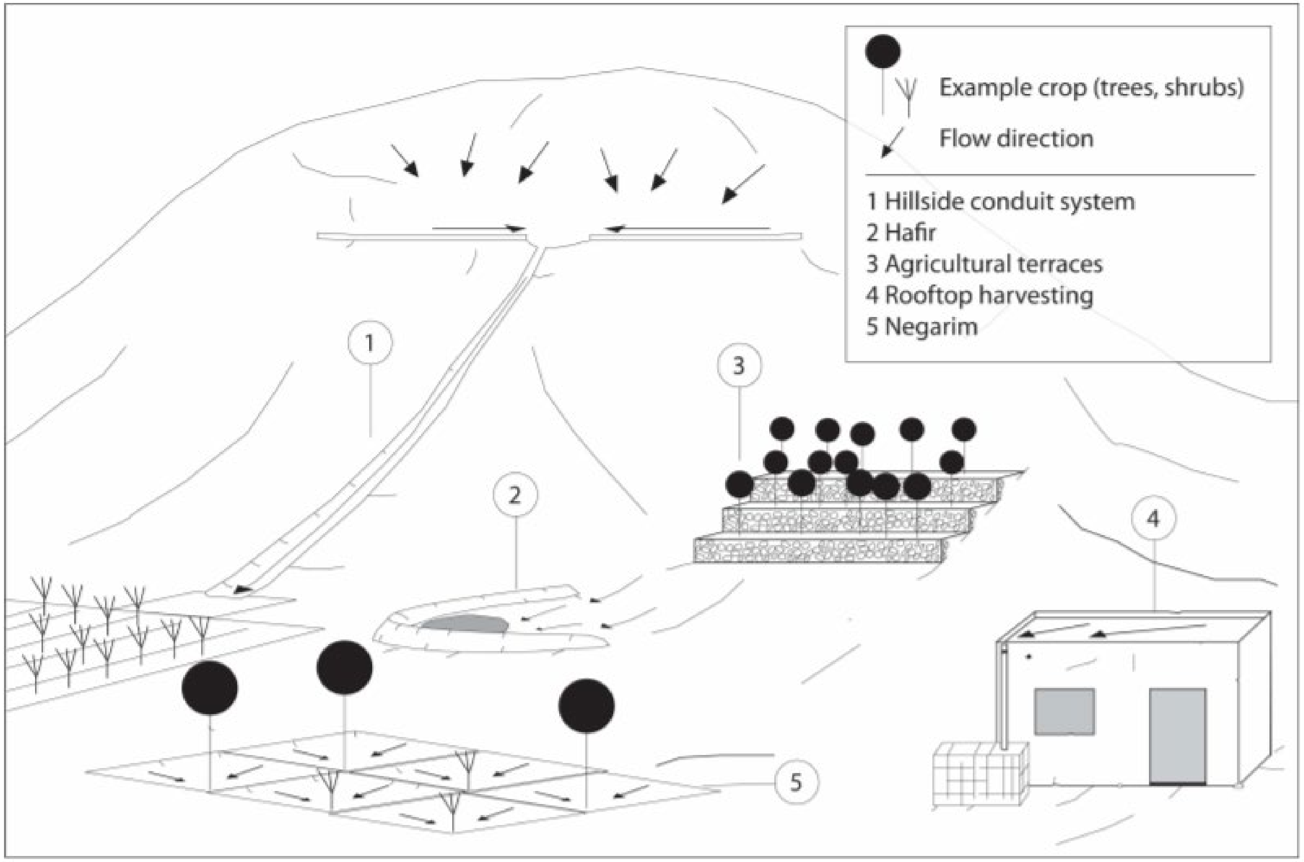


Fig. 3 | Examples of micro- and macro runoff harvesting techniques. Slopes are exaggerated.

Brian Beckers, Jonas Berking and Brigitta Schütt. Ancient Water Harvesting Methods in the Drylands of the Mediterranean and Western Asia. eTopoi, Journal for Ancient Studies, Volume 2 (2012/2013), pp. 145–164
http://www.topoi.org/wp-content/uploads/2013/06/174-693-1-SM.pdf

Follow up research using geophysics:

Area of the GPR (Ground Penetration Radar) survey. The direction of survey was from A to B.

Preparation of the 10 x 5 m single loop for the TEM (Transient Electromagnetic Method) survey in the Aptera site.

Combined TEM and GPR results: anomaly exists, possibly can be remnants of ancient interception ditch