Session 6: Geographic Information Systems (GIS)

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Sunoikisis Digital Cultural Heritage, Spring 2021

Piraye Hacıgüzeller (University of Antwerp)
Rebecca Seifried (University of Massachusetts Amherst)

What we will cover:

1. Basic concepts of GIS
2. Visibility analysis
3. **Exercise**: Running viewshed analysis in QGIS
4. Cost-surface analysis
5. **Case study**: Cost-surface analysis for cultural heritage

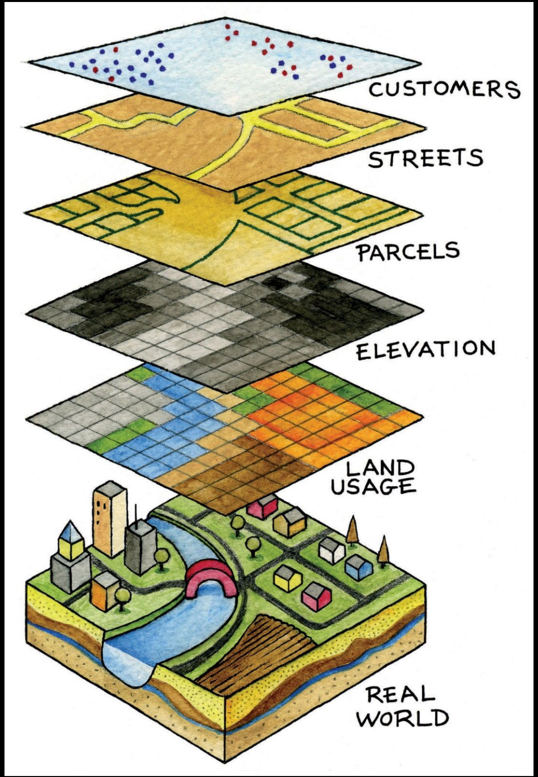
Basic Concepts of GIS

GIS: storing, managing, analyzing, and displaying geospatial data (and making really cool maps!!!)

- geospatial data
- data acquisition
- data management
- data display
- data exploration
- data analysis

Chang, K.-T.. 2019. *Introduction to Geographic Information Systems* (9th Edition). New York: McGraw-Hill Education.

Layers, layers and more layers

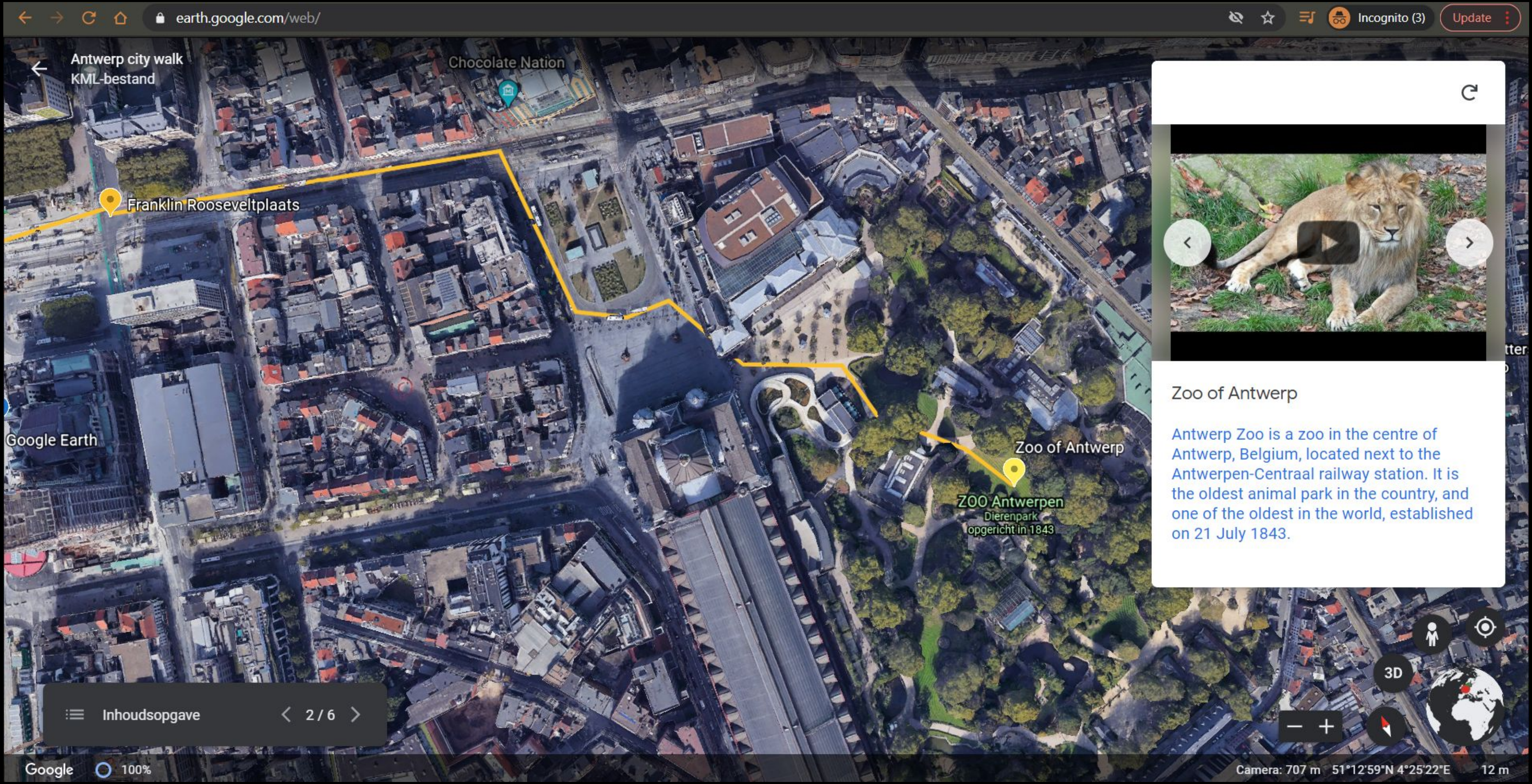


Source: https://www.jmu.edu/facmgt/gis/index.shtml

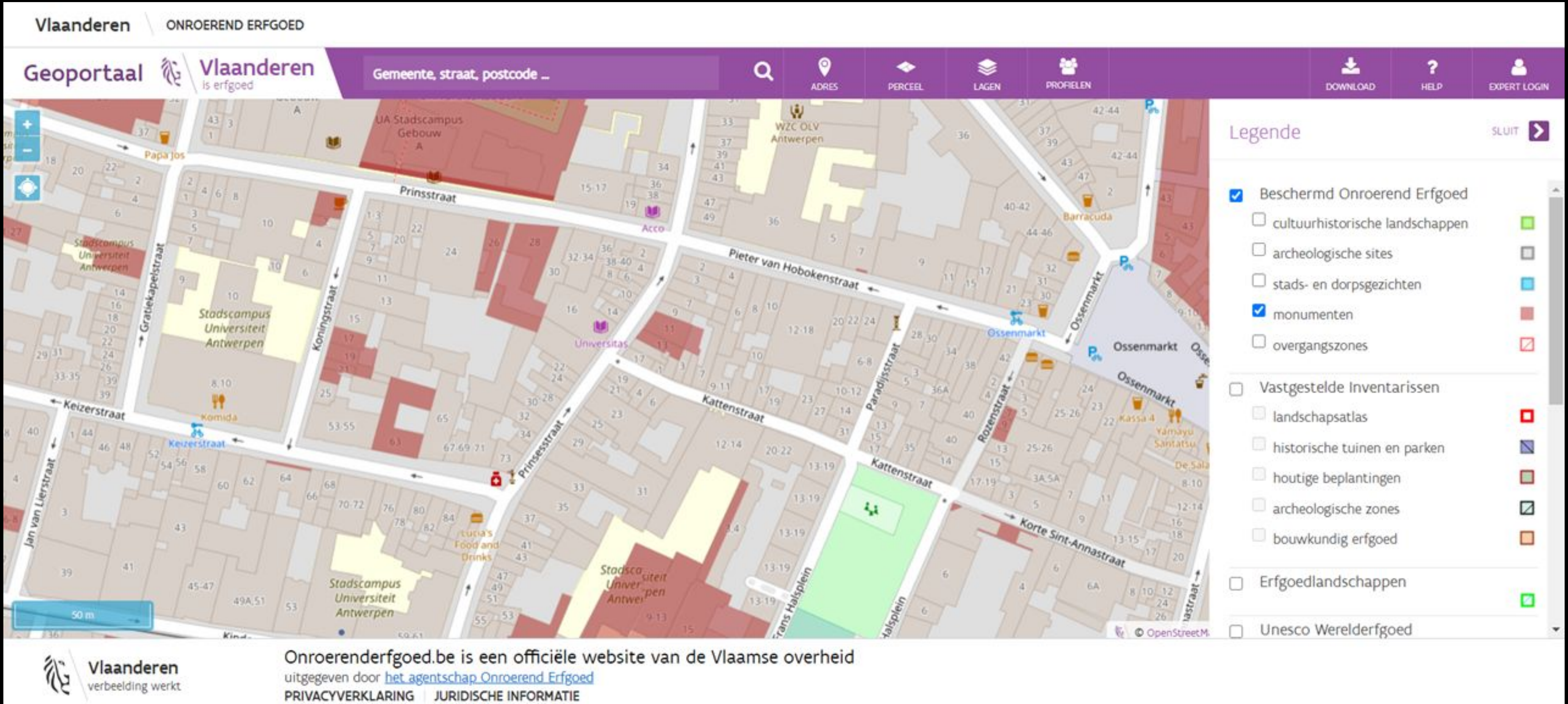
GIS, already an important part of our daily life

Sources: https://www.blog.google/products/maps/view-world-through-someone-elses-lens-google-earth/
https://www.google.com/intl/nl/maps/about/#!/

Navigation & geotagging as daily practices



Web GIS for Heritage



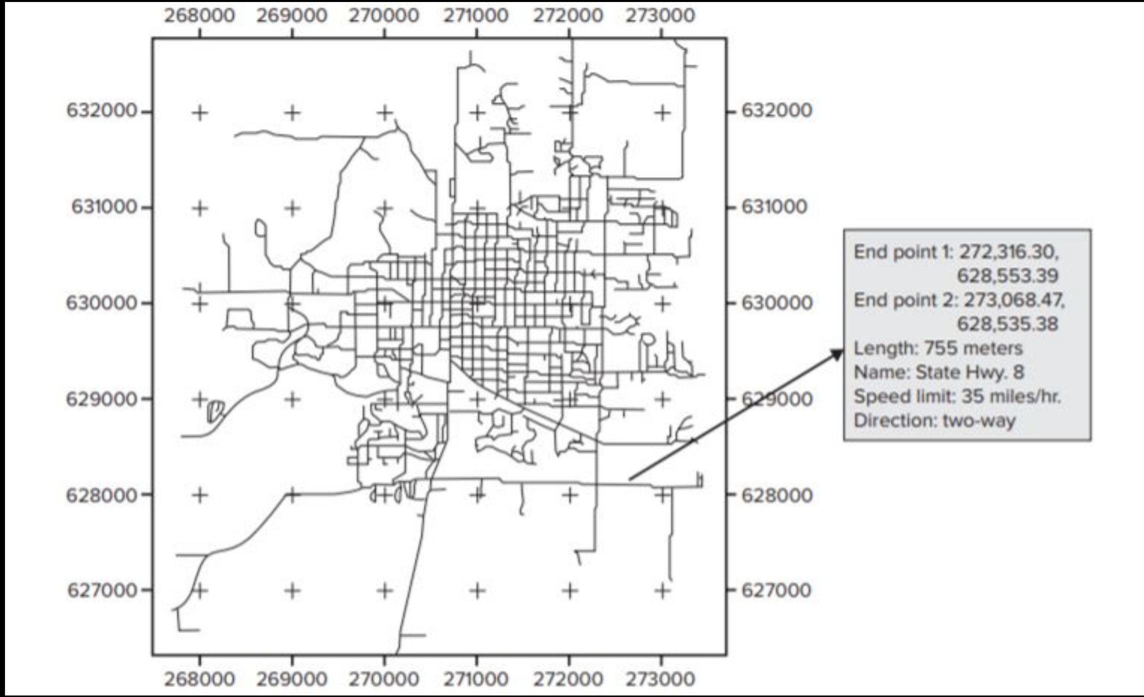


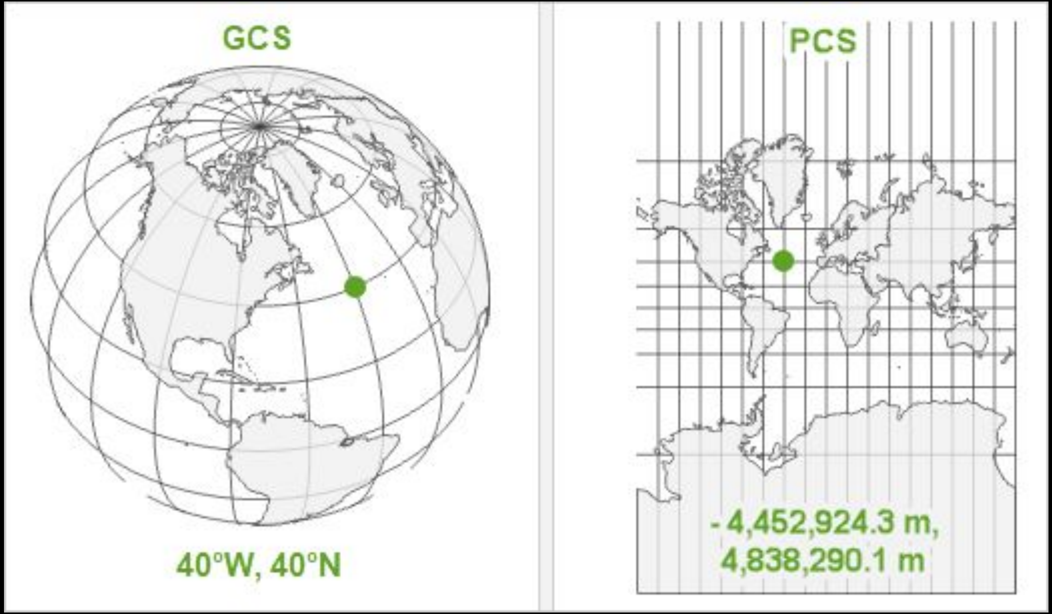
Figure 1.1. Chang, K.-T.. 2019. *Introduction to Geographic Information Systems* (9th Edition). New York: McGraw-Hill Education.

GIS data:

geospatial data

&

attribute (i.e. non-geospatial) data



Geographic vs. projected coordinate systems

Optional reading and source: https://www.esri.com/arcgis-blog/products/arcgis-pro/mapping/gcs_vs_pcs/

What is vector data structure?

What is raster data structure

Raster and vector data structures store, represent and manipulate spatial information in very different ways

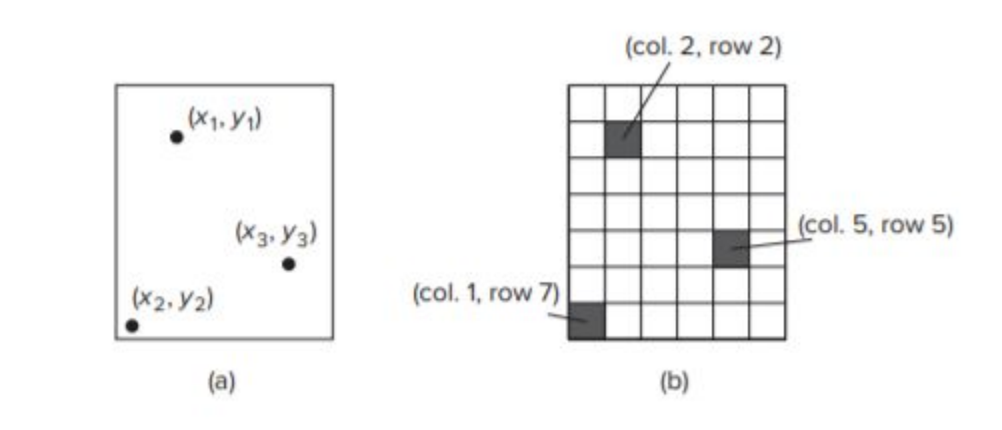
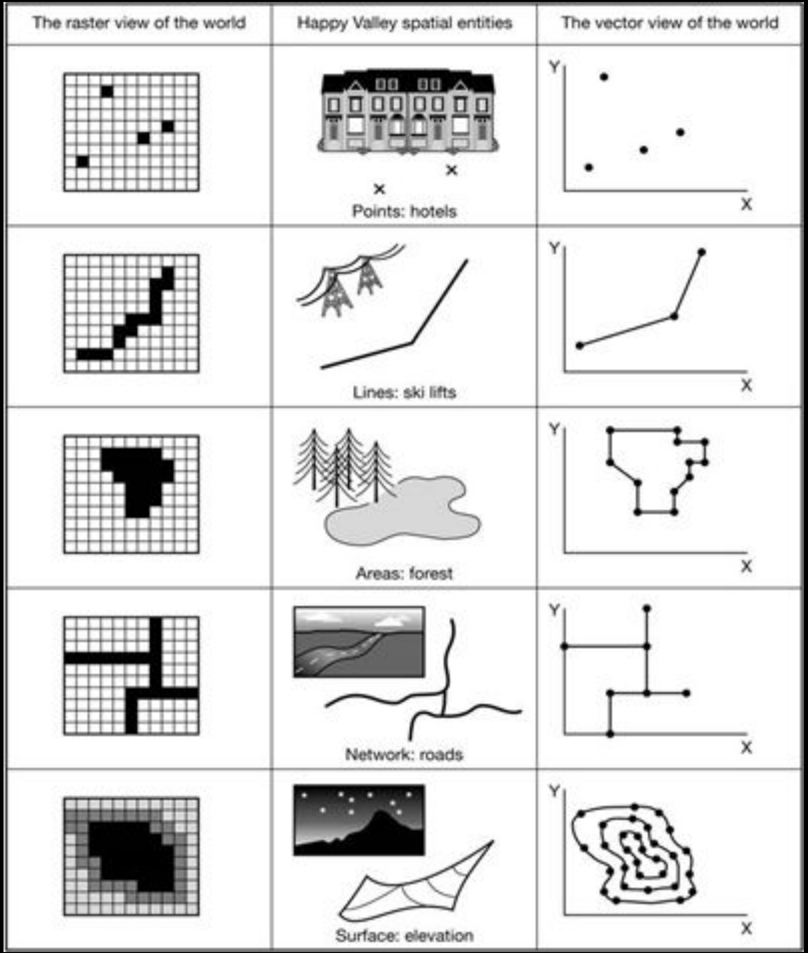
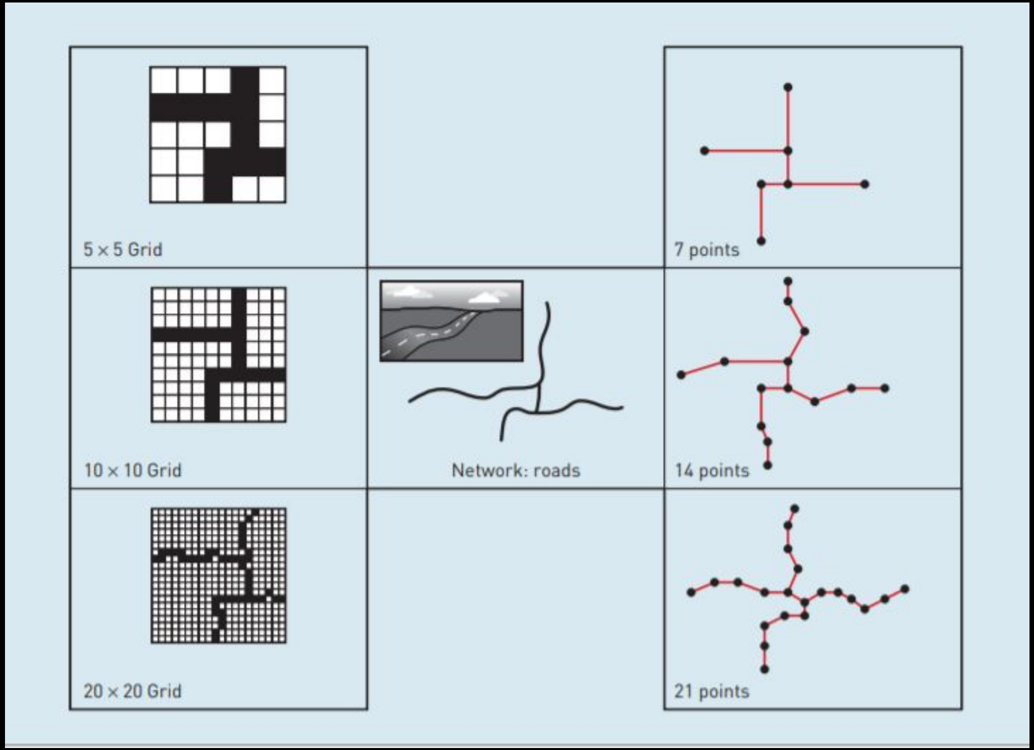


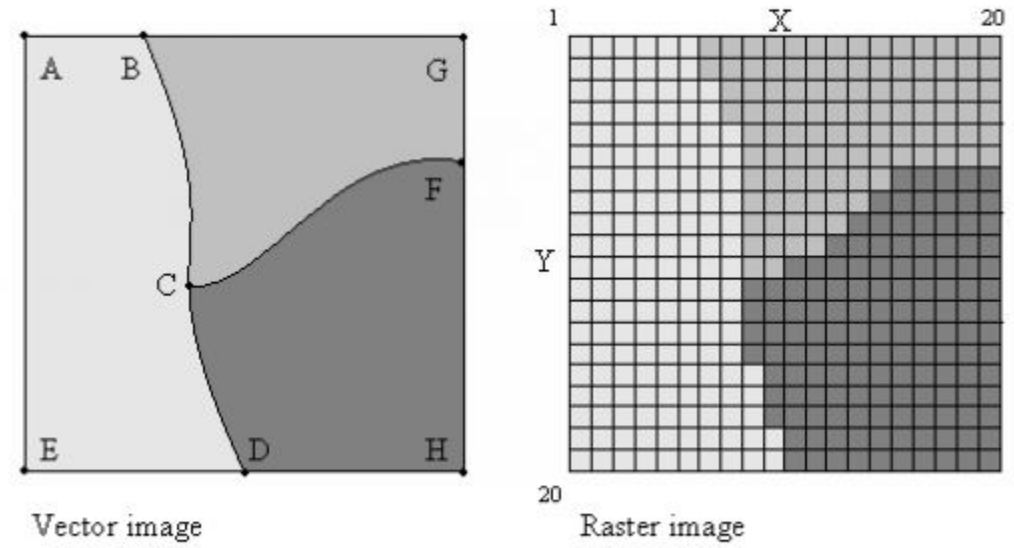
Figure 1.3. Chang, K.-T.. 2019. *Introduction to Geographic Information Systems* (9th Edition). New York: McGraw-Hill Education.





Different resolutions

Figure 3.9 & 3.10. Heywood, Ian, Sarah Cornelius & Steve Carver. 2006. An introduction to geographical information systems, 3rd edn. Harlow, UK: Pearson Prentice Hall.



Vector		
Polygon ID	Coordinates	Soil Type
1	A,B,C,D,E	Chalk
2	B,C,F,G	Clay
3	C,F,H,D	Gravel

Raster	
Grid Ref.	Item
x=1, y=1	Chalk
X=2, y=1	Chalk
X=3, y= 1	Chalk
X=4 ... etc.	...
X=20, y=20	Gravel

Source: esri.com

Vector data

Real-world entities are represented using one of three basic spatial entity types:

---- points

---- lines

---- polygons

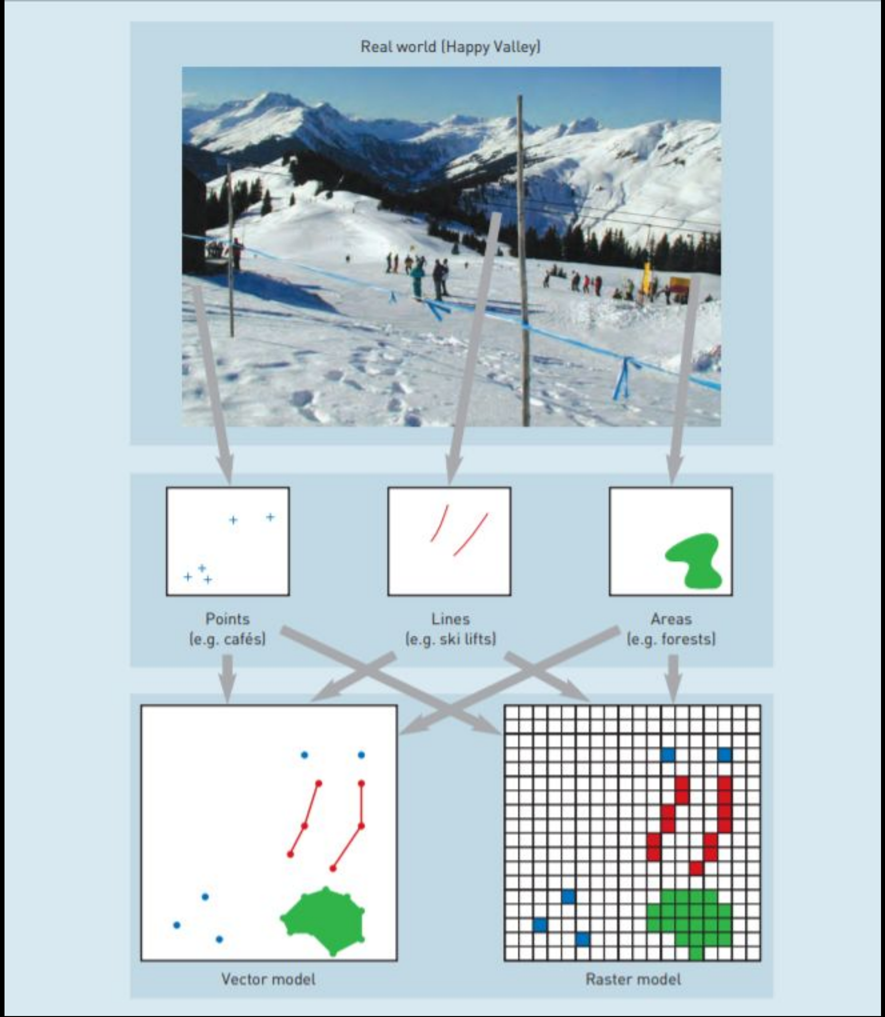
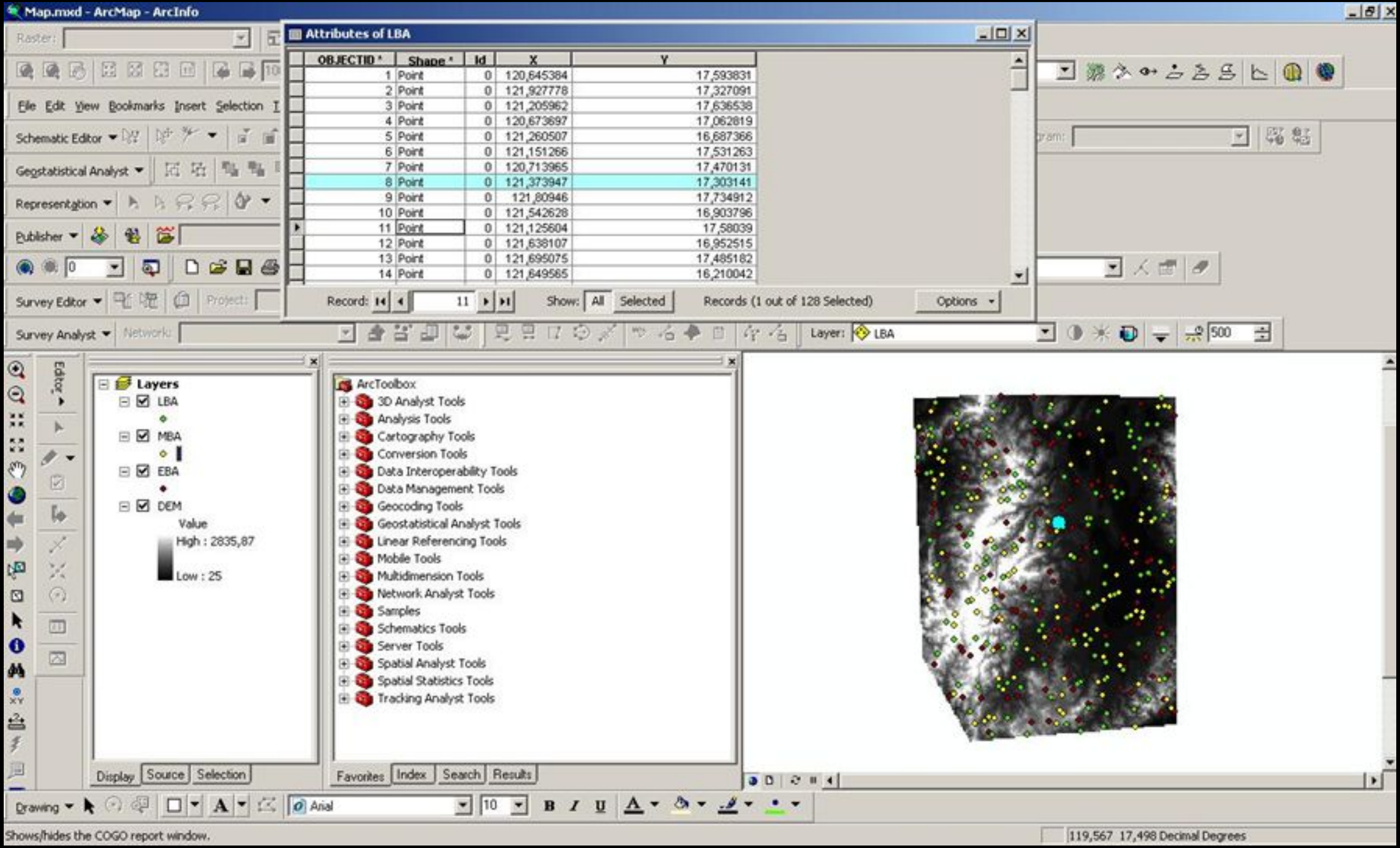
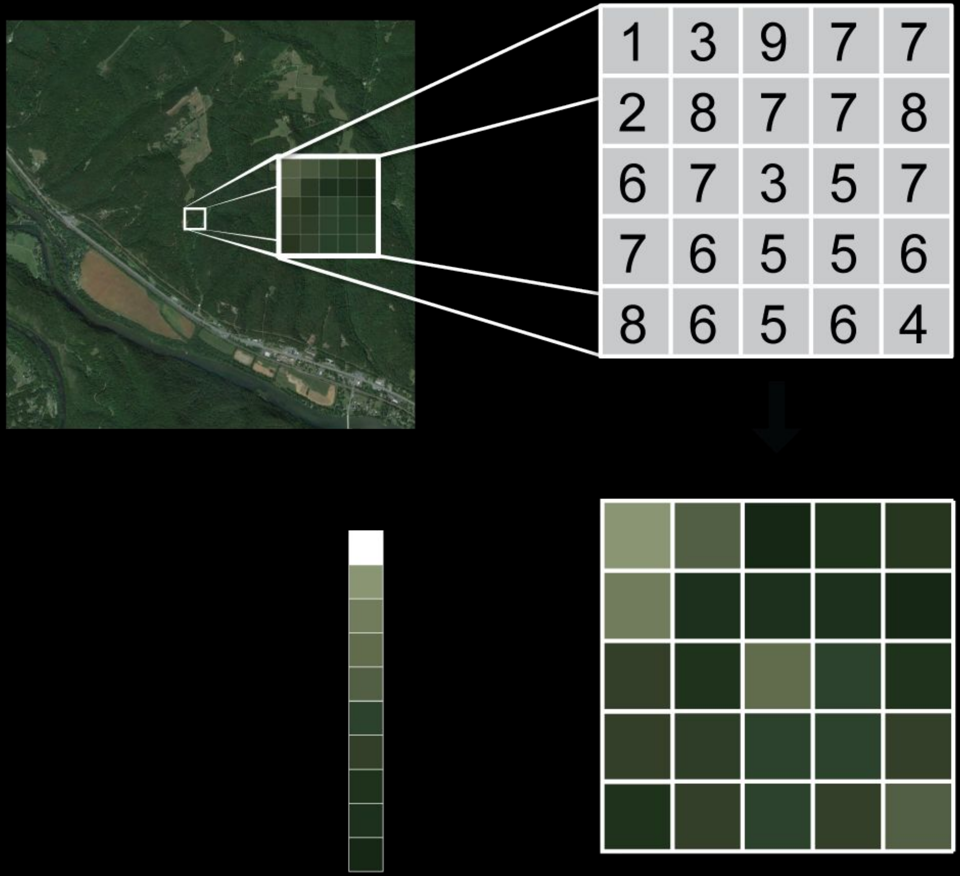


Figure 1.17. Heywood, Ian, Sarah Cornelius & Steve Carver. 2006. An introduction to geographical information systems, 3rd edn. Harlow, UK: Pearson Prentice Hall.


Map.mxd - ArcMap - ArcInfo
Attributes of LBA
OBJECTID * | Shape * | Id | X | Y
1 Point 0 120,645384 17,593831
2 Point 0 121,927778 17,327091
3 Point 0 121,205962 17,636538
4 Point 0 120,673697 17,062819
5 Point 0 121,260507 16,687366
6 Point 0 121,151266 17,531263
7 Point 0 120,713965 17,470131
8 Point 0 121,373947 17,303141
9 Point 0 121,80946 17,734912
10 Point 0 121,542628 16,903796
11 Point 0 121,125604 17,58039
12 Point 0 121,638107 16,952515
13 Point 0 121,695075 17,485182
14 Point 0 121,649565 16,210042
Record: 11 Show: All Selected Records (1 out of 128 Selected) Options
File Edit View Bookmarks Insert Selection
Schematic Editor
Geostatistical Analyst
Representation
Publisher
Survey Editor
Survey Analyst
Network:
Layer: LBA
Layers
LBA
MBA
EBA
DEM
Value
High : 2835,87
Low : 25
ArcToolbox
3D Analyst Tools
Analysis Tools
Cartography Tools
Conversion Tools
Data Interoperability Tools
Data Management Tools
Geocoding Tools
Geostatistical Analyst Tools
Linear Referencing Tools
Mobile Tools
Multidimension Tools
Network Analyst Tools
Samples
Schematics Tools
Server Tools
Spatial Analyst Tools
Spatial Statistics Tools
Tracking Analyst Tools
Display Source Selection
Favorites Index Search Results
Drawing
Arial 10
Shows/hides the COGO report window.
119,567 17,498 Decimal Degrees



Raster data

Source: https://carpentries-incubator.github.io/geospatial-python/aio/index.html

Digital Elevation Models (DEMs)

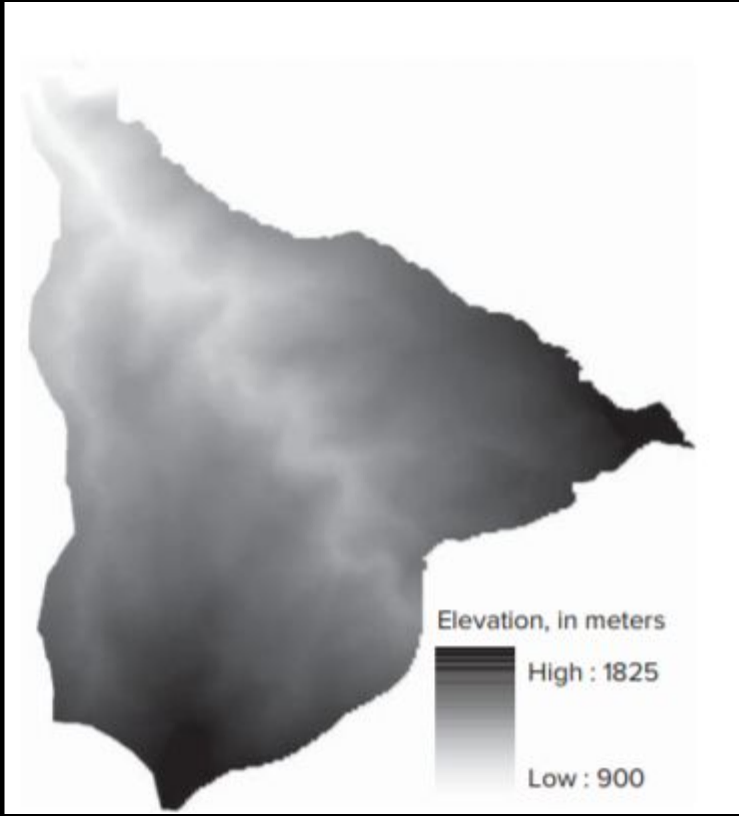
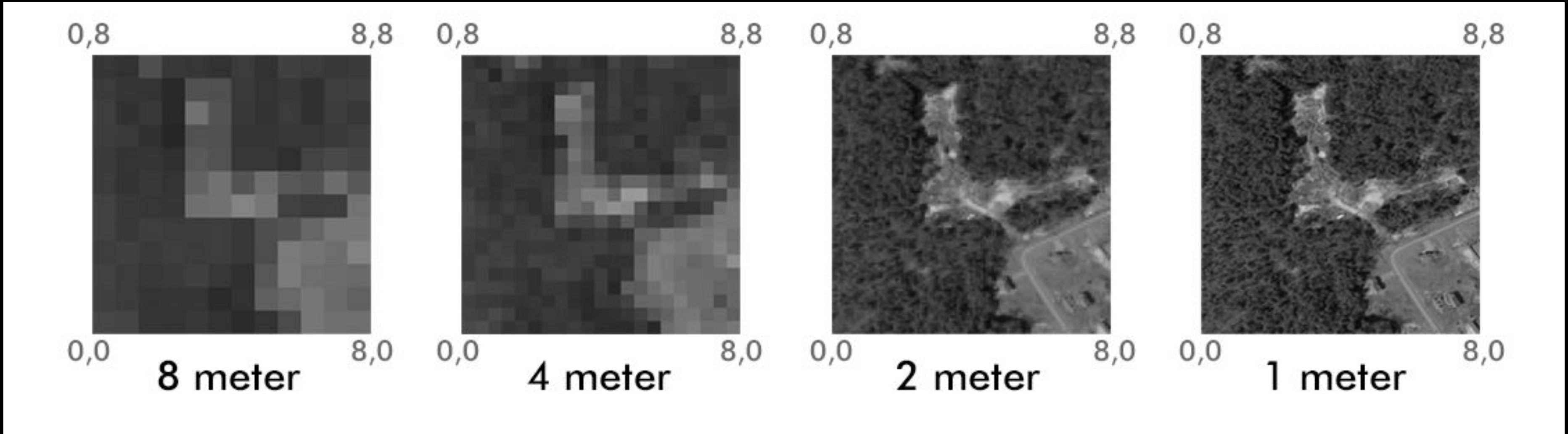


Figure 1.5. Chang, K.-T.. 2019. *Introduction to Geographic Information Systems* (9th Edition). New York: McGraw-Hill Education.



Source: National Ecological Observatory Network (NEON) cited by
https://carpentries-incubator.github.io/geospatial-python/aio/index.html

Visibility Analysis

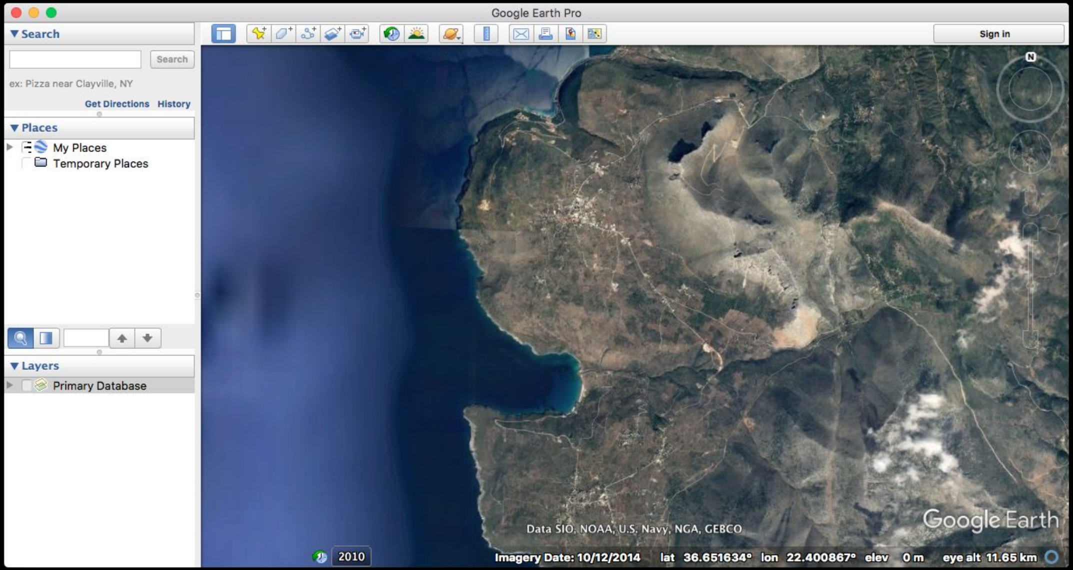
Phenomenological applications of GIS

- Tools to help us understand different aspects of *being* in a landscape...

Photos by Rebecca M. Seifried

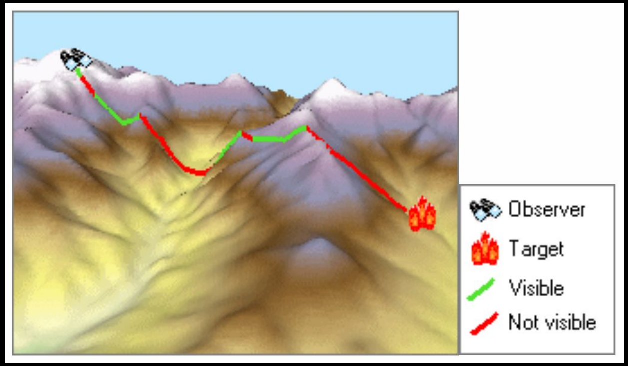
Phenomenological applications of GIS

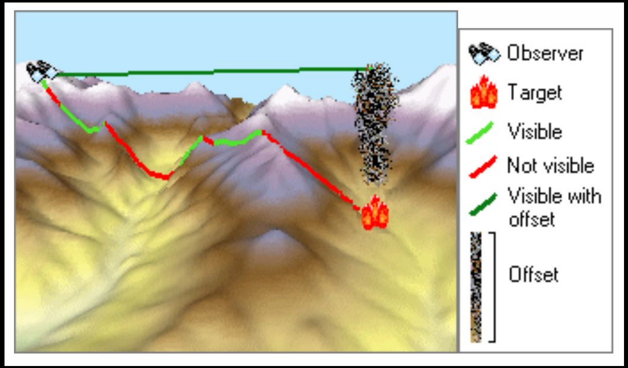
- Tools to help us understand different aspects of *being* in a landscape… without actually being there



How visibility analysis works

- Determines whether one pixel in a raster can be “seen” by another pixel
- Typical inputs:
    - Observer height
    - Target height
    - Distance of vision
    - Resolution / accuracy of the elevation model
    - Earth’s curvature
- Main concern: how accurate and/or reliable are the models?

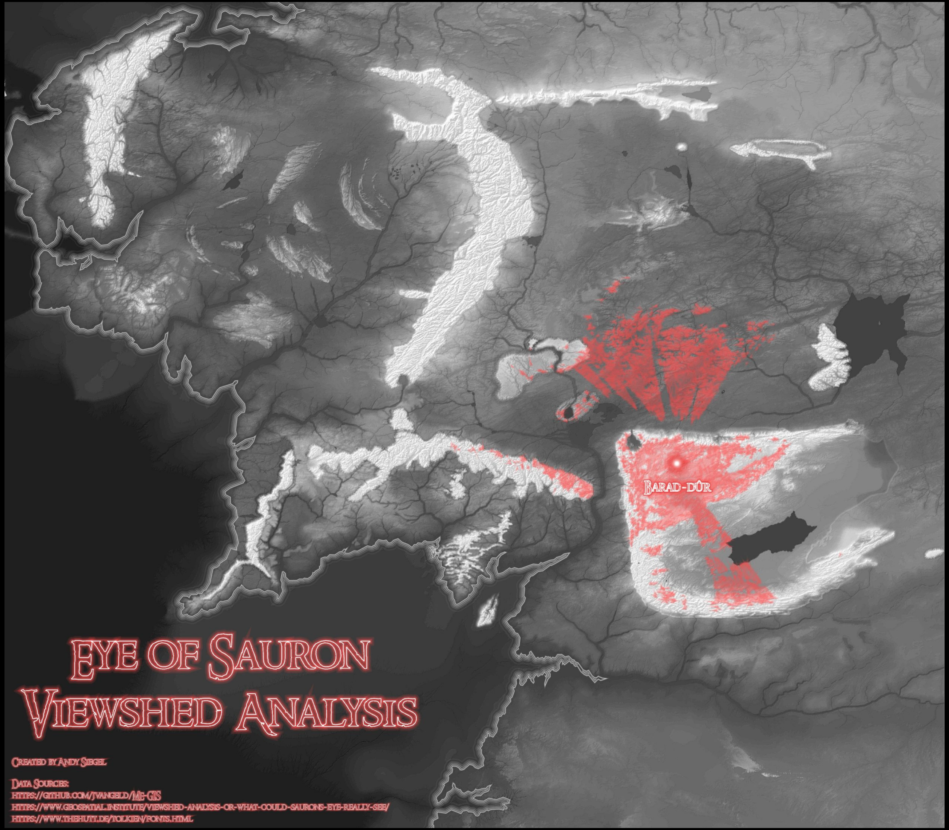




© 2020 Esri – Surface creation and analysis

"For a small area, the curvature of the Earth doesn't really come into play, but when larger areas (Middle Earth) are analyzed, it's definitely important. So, I went back to the data and re-ran the analysis, making sure to check "Use earth curvature corrections", with default refractivity coefficient of 0.13."

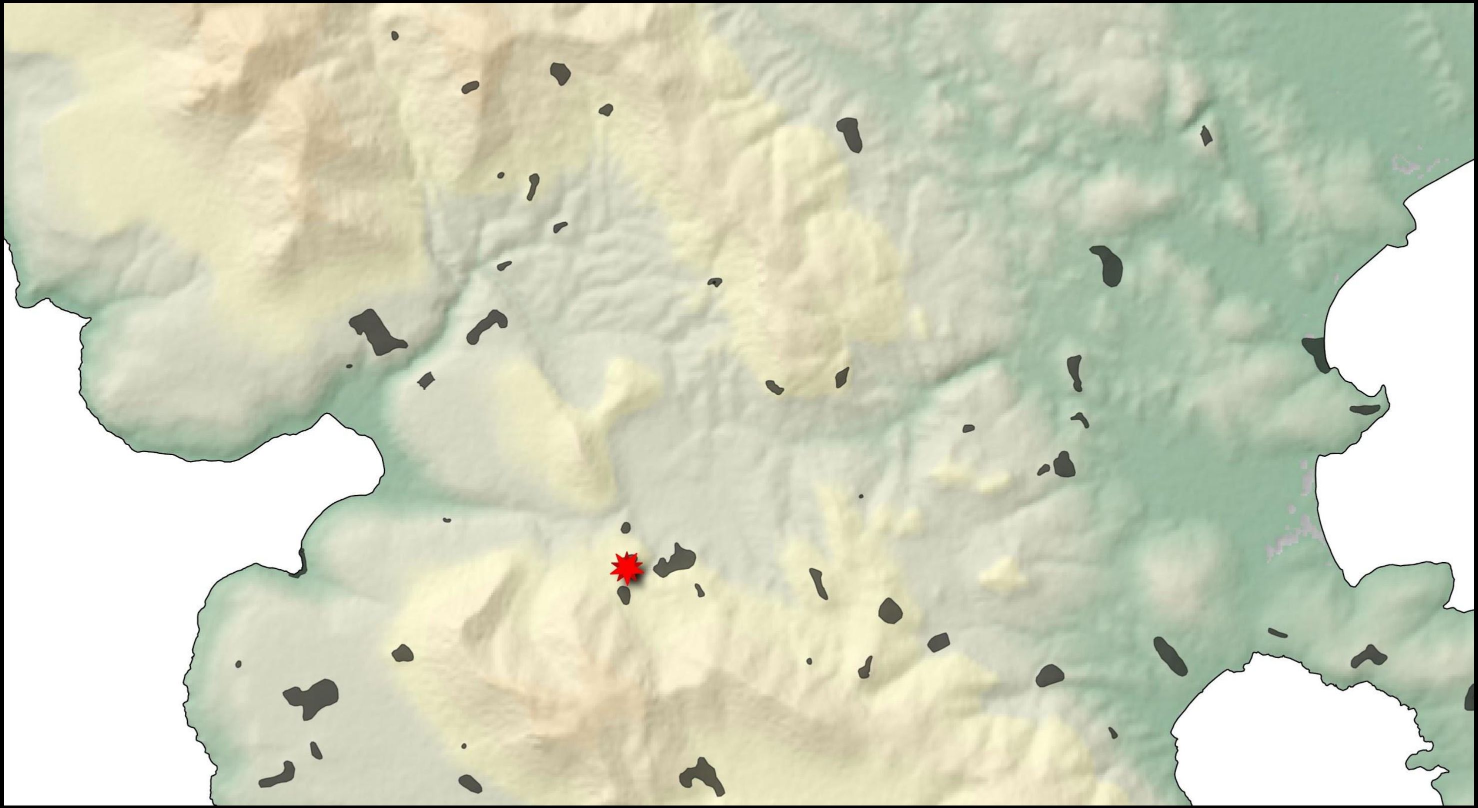
Reddit u/PineconePuffin, "Ever wonder how much of Middle Earth..."



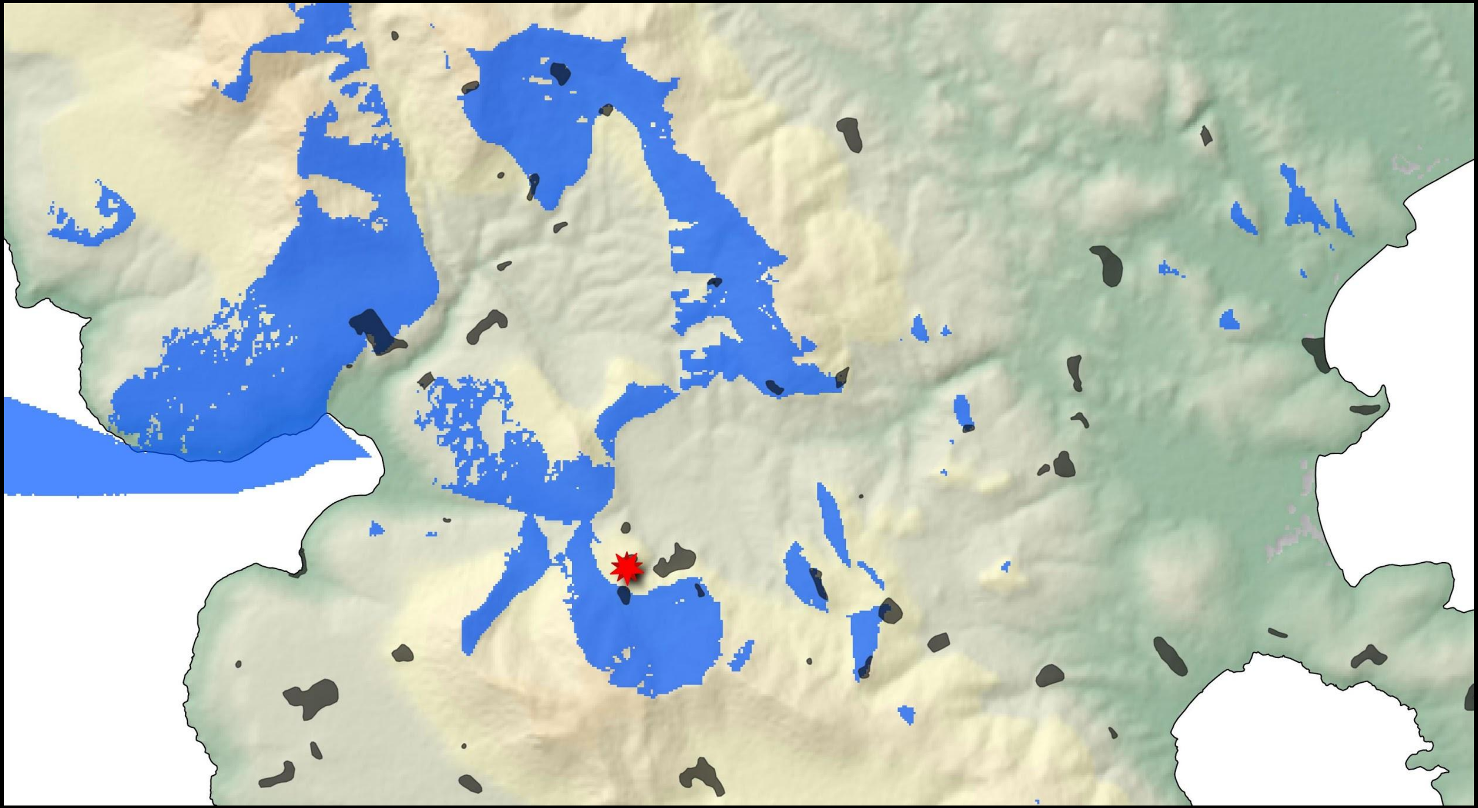
Reddit u/PineconePuffin, "Yesterday, I posted a map of Sauron's sightline..."

View from the highest point in the settlement of Skala (Mani, Greece)

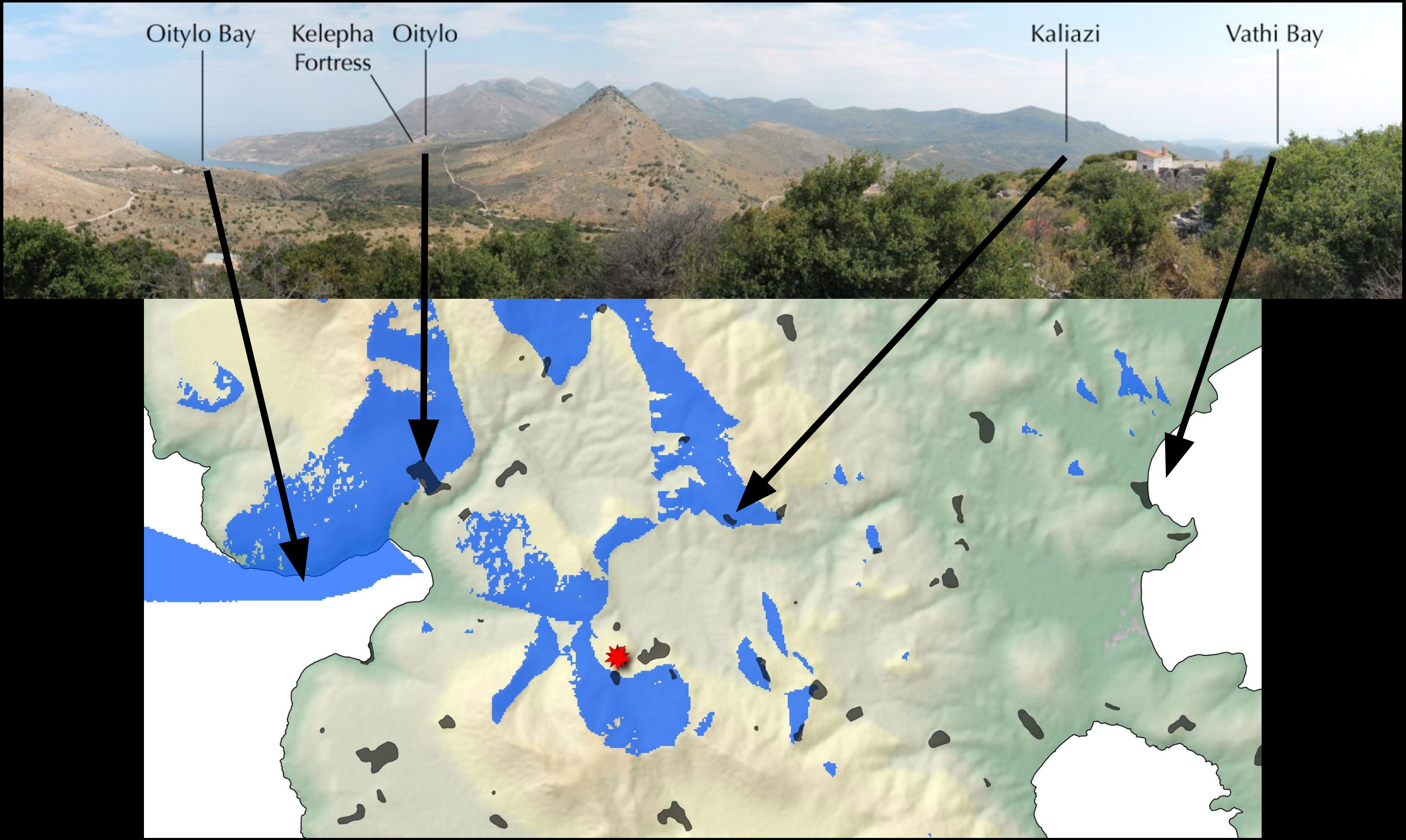
Photo by Rebecca M. Seifried



Skala (red) and footprints of other villages in the region (grey)



Binary viewshed from Skala (1.6m observer height, SRTM1 DEM, 10-km distance)



Oitylo Bay
Kelepha Fortress
Oitylo
Kaliazi
Vathi Bay

Types of visibility analysis

Line of sight	Calculates whether or not two points are intervisible
Binary viewshed	Calculates which raster cells can be seen from point A
Cumulative viewshed	Calculates which raster cells can be seen from points A, B, C (etc.) and adds them together (= how many times a raster cell can be seen by a set of points)
Fuzzy viewshed	Binary viewshed + takes into account the limitations of human vision as distance increases
Probable viewshed	Binary viewshed + takes into account the uncertainty of digital elevation models (DEMs)

Line of sight

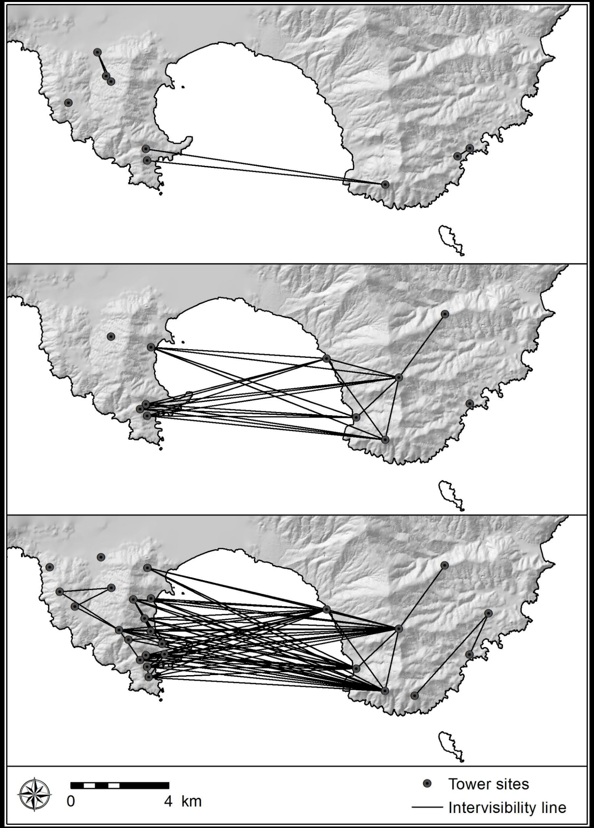


Figure 12. Gardner, C.A.M. and R.M. Seifried. 2016. Euboean Towers and Aegean Powers: Insights into the Karystia's Role in the Ancient World. *Journal of Greek Archaeology* 1:149–176.

Cumulative viewshed

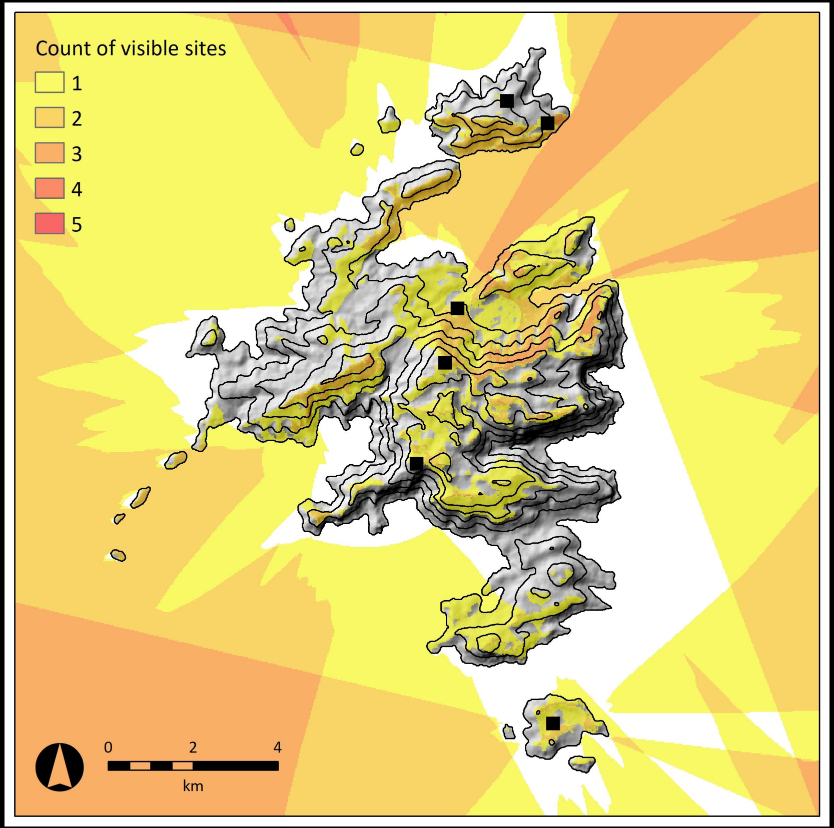
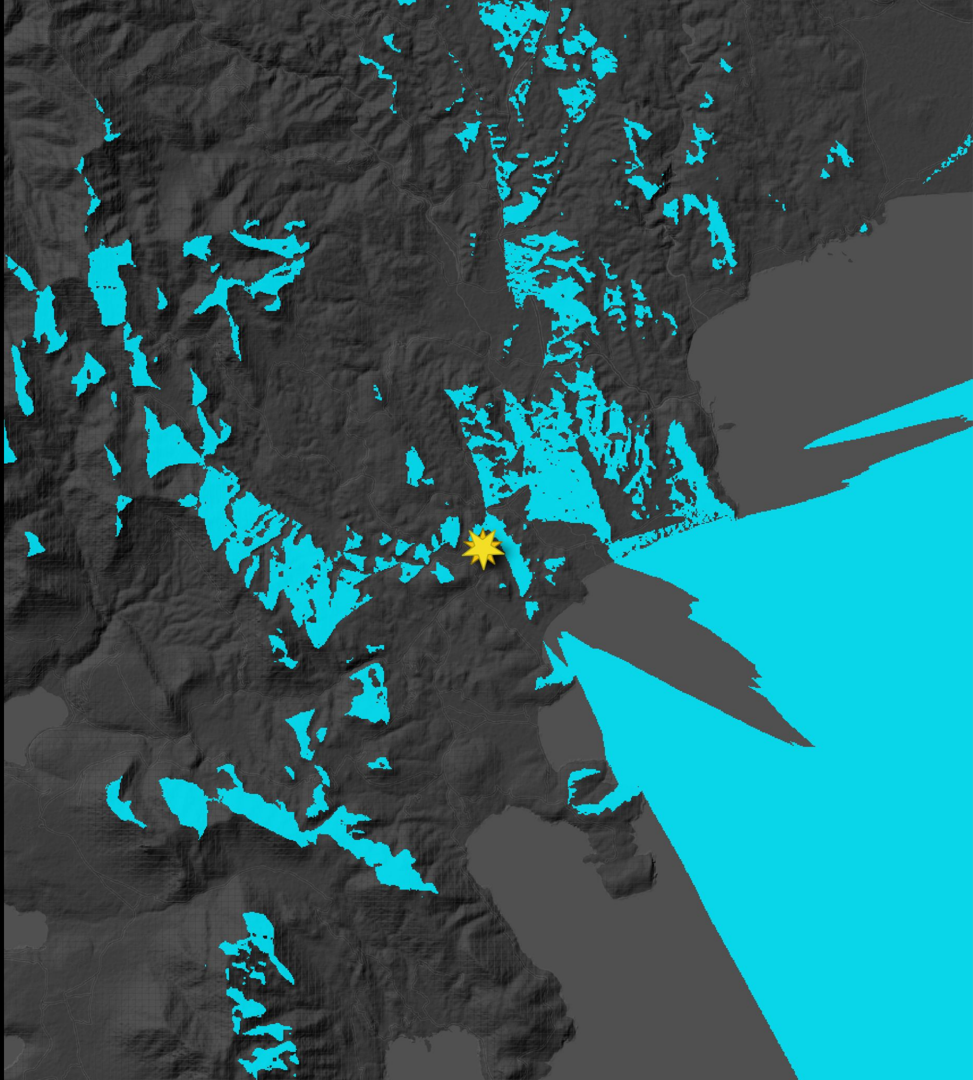


Figure prepared for Heslop, M. 2021. *Medieval Greece Encounters Between Latins, Greeks and Others in the Dodecanese and the Mani*. Routledge.

Exercise

Running viewshed analysis in QGIS



Preparation

1. Download and install QGIS 3.10 (long-term release): https://qgis.org/en/site/forusers/download.html

2. Install the QuickMapServices and Visibility Analysis plugins

3. Get your data ready

    a. Download the example dataset: https://github.com/SunoikisisDC/SunoikisisDC-2020-2021/raw/master/Spring-2021/data/Sunoikisis_Ch6_Data.zip

    b. OR use your own point shapefile and elevation raster

Steps

1. Drag and drop the SRTM1.tif file (the elevation data) into the blank map view.
2. The folder also contains 3 shapefiles (Fortress_Achillio, Fortress_Kelefa, and Fortress_Passava), but shapefiles are each made up of 5-6 separate files with different extensions. Find the 3 files ending with .SHP and drag-and-drop these into your map view.
3. Zoom to the area where the data is. You might need to rearrange the items in the Layers panel (bottom left corner) so that the fortresses are above the SRTM layer (or else this layer will hide them).
4. Open the Processing Toolbox by selecting from the menu Processing > Toolbox. Search for Visibility Analysis. You should see four tools (with gear icons).

Steps, continued

5. Double-click the "Create viewpoints" tool and set the parameters:
   a. Observer location = one of the fortress points
   b. Digital elevation model = SRTM1
   c. Radius = 50,000 m (i.e. 50 km)
   d. Observer height = 1.6 (i.e. a person)
   e. everything else default
6. Click Run, then when it's finished, click Close.

Steps, continued

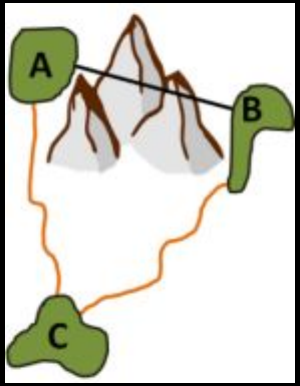
7. Double-click the "Viewshed" tool and set the parameters:
    a. Analysis type = binary viewshed
    b. Observer locations = output layer (the product of the tool you just ran)
    c. Digital elevation model = SRTM1
    d. everything else default
8. Click Run, then when it's finished, click Close.

Voila! You should see a new output layer showing visible (white) and non-visible (black) areas.

Cost Surface Analysis

How cost surface analysis works

- Calculates the “least costly” way to travel between point A and point B
- “Cost” is defined by the user:
  - Elevation change / slope
  - Time
  - Energy
  - Proxies for effort (e.g. river crossings)
- Main concern: how accurate and/or reliable are the models?



Types of cost surface analysis

Least cost analysis	Calculates the least costly route between point A and point B
Corridor analysis	Combines the ACS’s for points A and B to determine the least-costly cells for both points
Focal mobility networks	Calculates all the cheapest routes from point A to a set of other points (i.e. cumulative flow surface)
From Everywhere To Everywhere (FETE)	Calculates the “least costly” route for every pixel-pair in a raster

Basics of least-cost analysis (LCA)

- Step 1: Create a cost raster
- Step 2: Create an Accumulated Cost Surface (ACS) and backlink raster
  - ACS = the cost of moving from pixel A to every other pixel (totals cost along the way)
  - Backlink = points a direction “back” to the lowest cost neighboring pixel
- Step 3: Calculate the Least-Cost Path (LCP)

Time-based LCA in QGIS

- Step 1: Get rasters ready
  - Elevation raster = DEM
  - Friction raster = 0 values
- Step 2: Run r.walk

https://grass.osgeo.org/grass78/manuals/r.walk.html

- Step 3: Run r.drain

https://grass.osgeo.org/grass78/manuals/r.drain.html

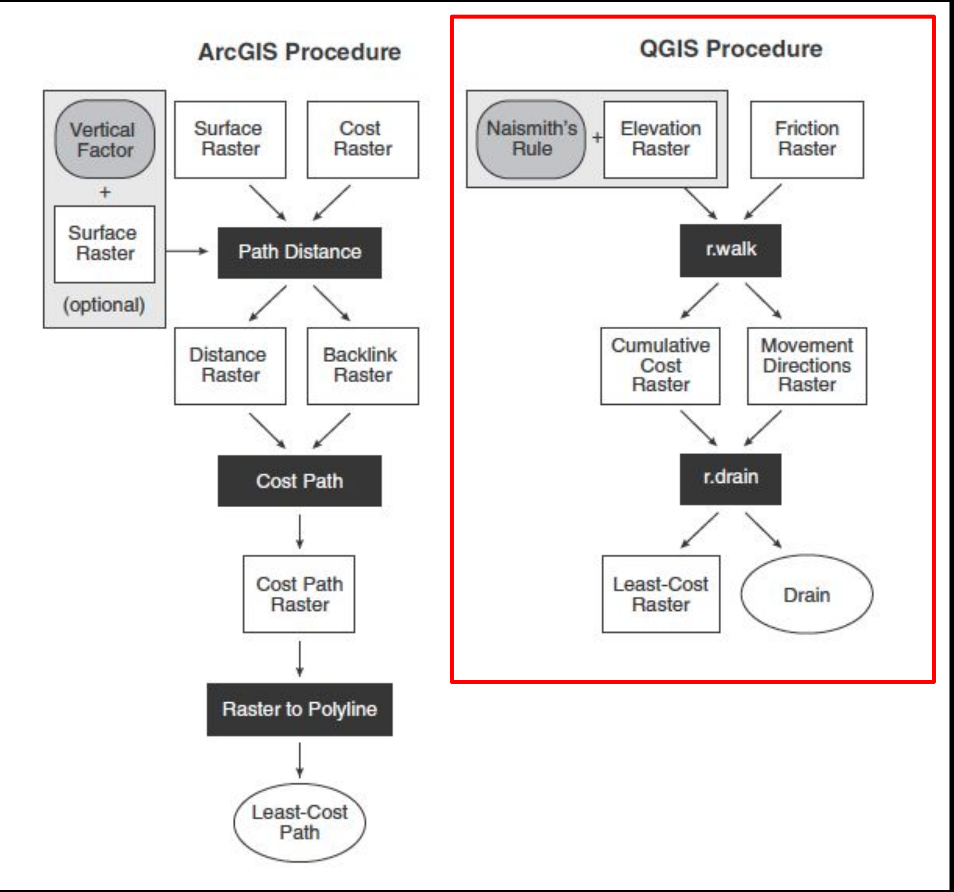


Figure 6. Seifried, R.M. and C.A.M. Gardner. 2019. "Reconstructing Historical Journeys with Least-Cost Analysis: Colonel William Leake in the Mani Peninsula, Greece." Journal of Archaeological Science: Reports 24: 391–411. https://doi.org/10.1016/j.jasrep.2019.01.014

R.walk

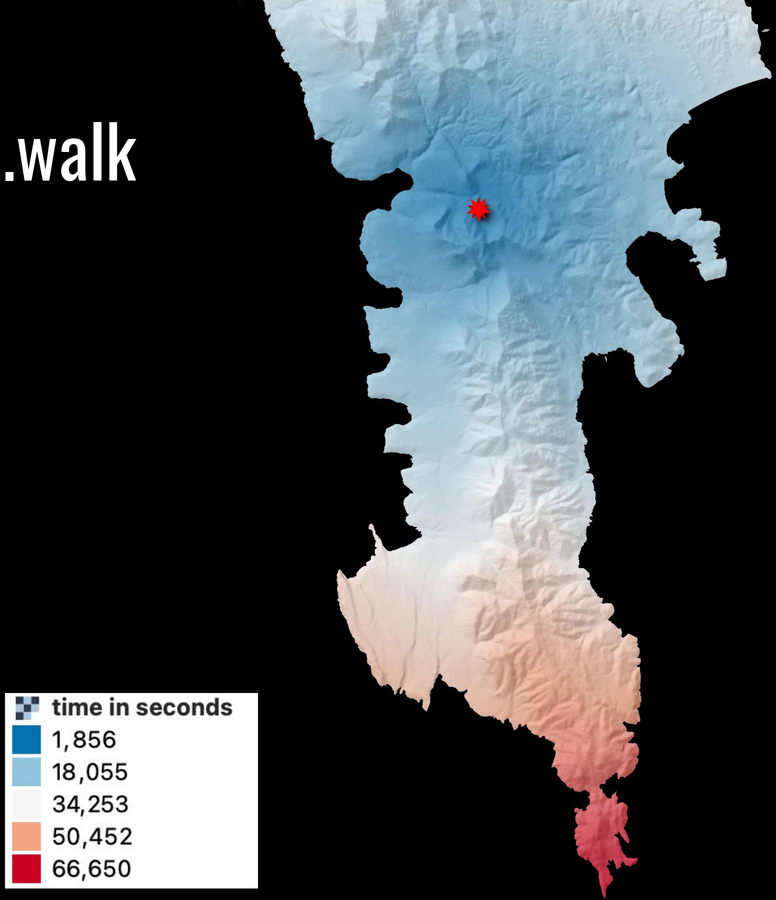
Naismith's rule with the Aitken-Langmuir corrections:

$$T = (a \times (S)) + (b \times (H1)) + (c \times (H2)) + (d \times (H3))$$

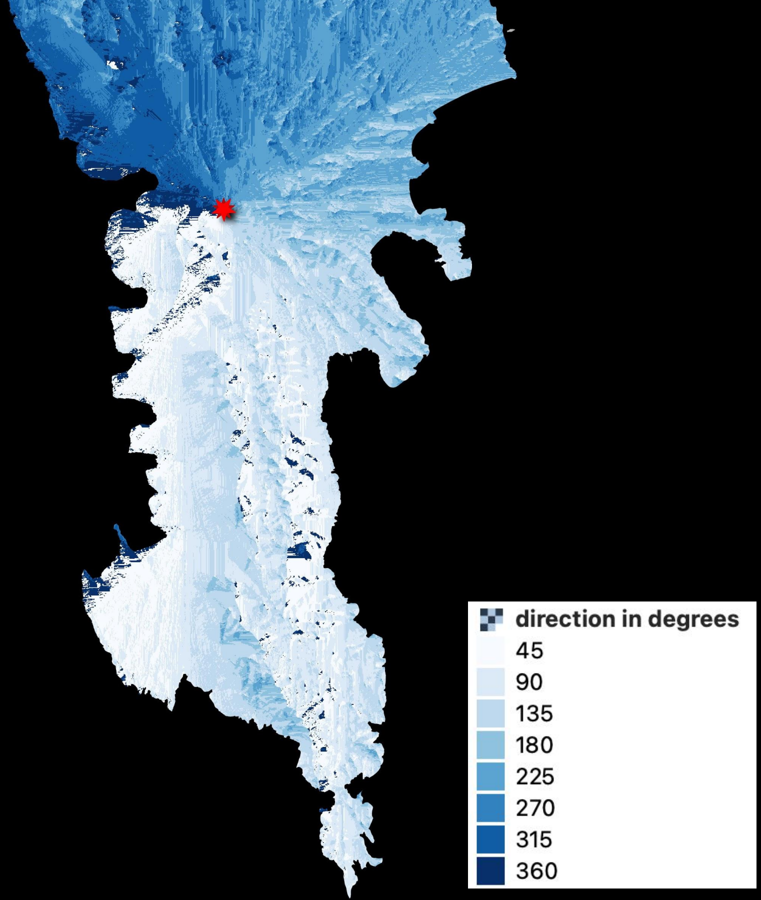
where T is the time in seconds, Δ(S) is the horizontal distance covered, Δ(H1) is the vertical change for uphill slopes, Δ(H2) is the vertical change for moderate downhill slopes (> 5 and ≤12 degrees), and Δ(H3) is the vertical change for steep downhill slopes (> 12 degrees).

Seifried, R.M. and C.A.M. Gardner. 2019. “Reconstructing Historical Journeys with Least-Cost Analysis: Colonel William Leake in the Mani Peninsula, Greece.” Journal of Archaeological Science: Reports 24: 391–411. https://doi.org/10.1016/j.jasrep.2019.01.014

R.walk



Accumulated cost surface (ACS)



Backlink raster

135	90	45
180	x	360
225	270	315

R.drain

According to r.walk, this route should take 535 minutes, or just under 9 hours.

(It’s 18.3 km long)

Least-cost path (LCP) - aka the “drain”

Case Study

Cost-surface analysis for cultural heritage

Alejandro Güimil-Fariña, César Parcero-Oubiña

“Dotting the joins”: a non-reconstructive use of Least Cost Paths to approach ancient roads. The case of the Roman roads in the NW Iberian Peninsula

Journal of Archaeological Science,

Volume 54

2015

Pages 31-44

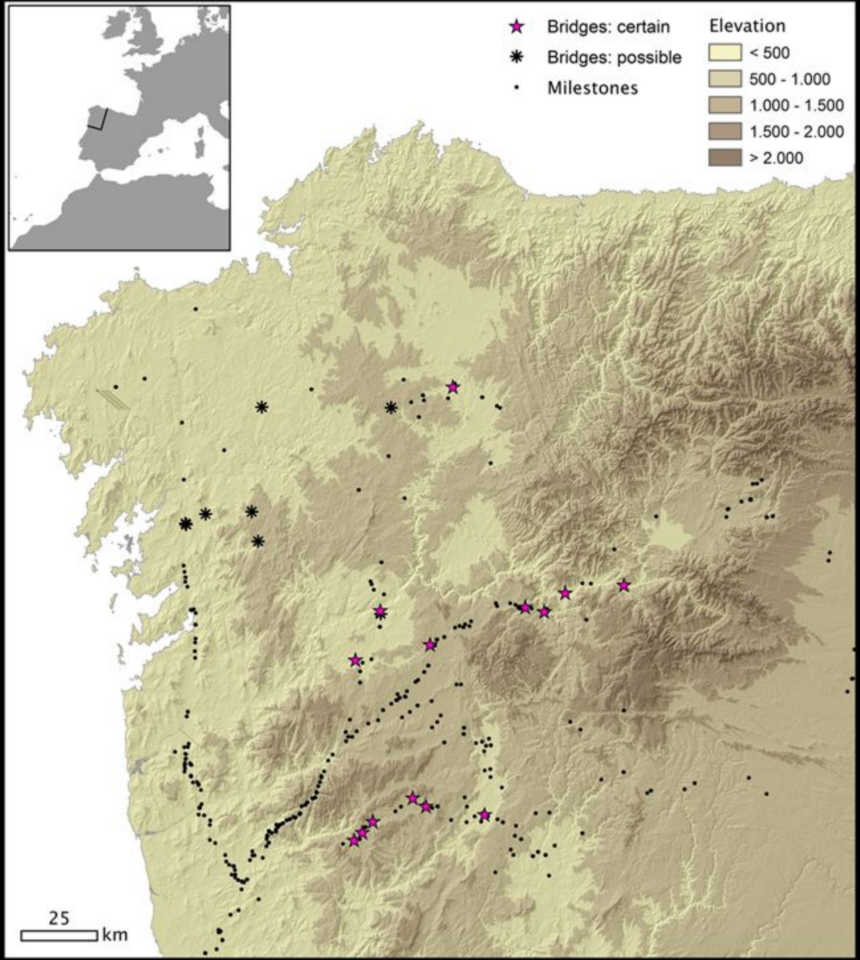


Figure 1. Güimil-Fariña, A. and C. Parcero-Oubiña. 2015 “Dotting the joins”: a non-reconstructive use of Least Cost Paths to approach ancient roads. The case of the Roman roads in the NW Iberian Peninsula,” Journal of Archaeological Science 54: 31-44. https://doi.org/10.1016/j.jas.2014.11.030.

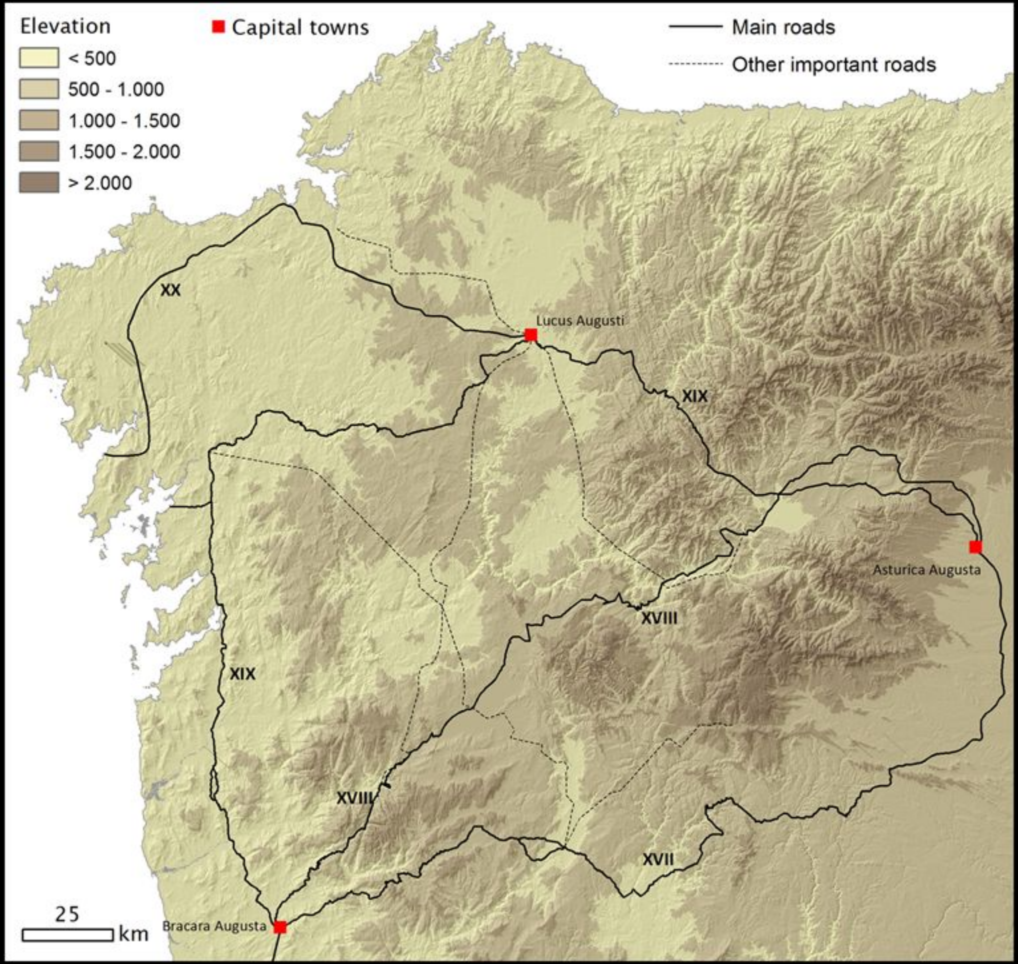


Figure 2. Güimil-Fariña, A. and C. Parcero-Oubiña. 2015 “Dotting the joins”: a non-reconstructive use of Least Cost Paths to approach ancient roads. The case of the Roman roads in the NW Iberian Peninsula,” Journal of Archaeological Science 54: 31-44. https://doi.org/10.1016/j.jas.2014.11.030.

Three steps

- To define a series of locations that could have served as primary movement 'nodes' (starting or arrival points).

- To model the different effort required to cross through the terrain, expressed in terms of 'cost' and 'accumulated cost', that will be the basis to delineate the optimal corridors to join those locations across the landscape.

- To define a series of elements to compare the results provided by our hypothesis, and the situation they represent. In this case, we require direct, spatially located indicators of the actual route of the Roman roads.

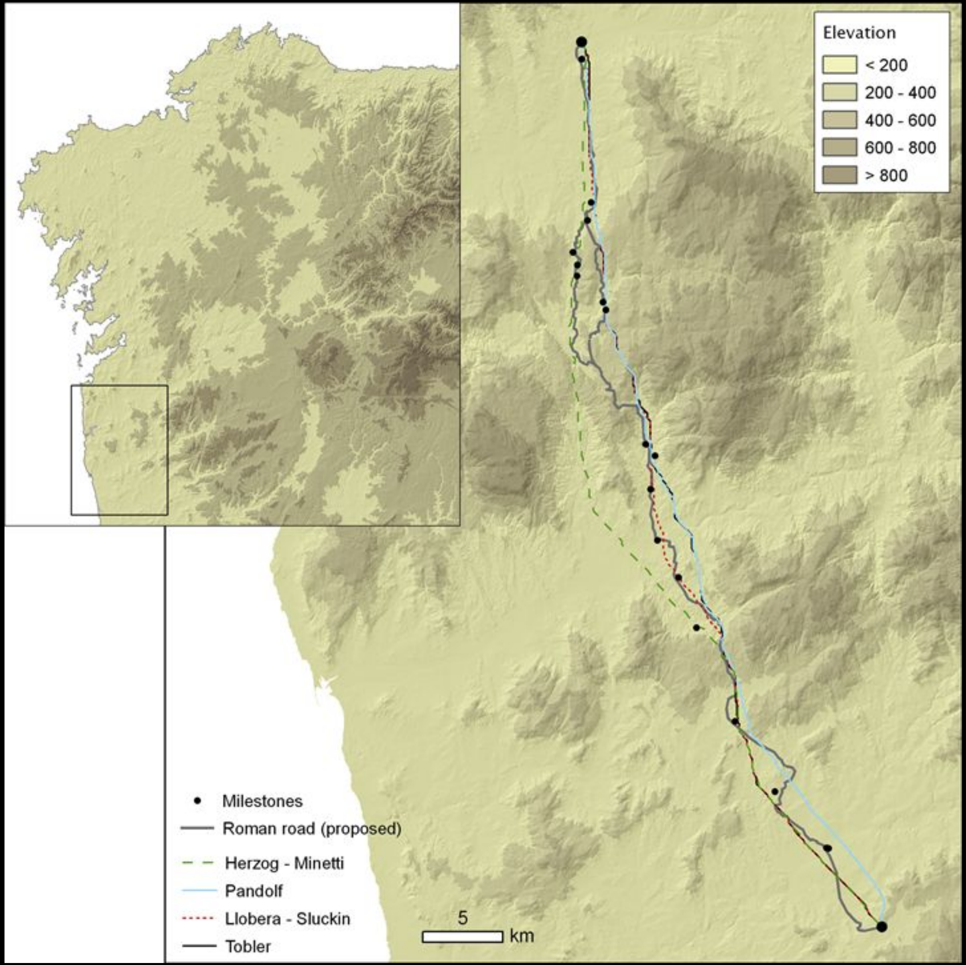
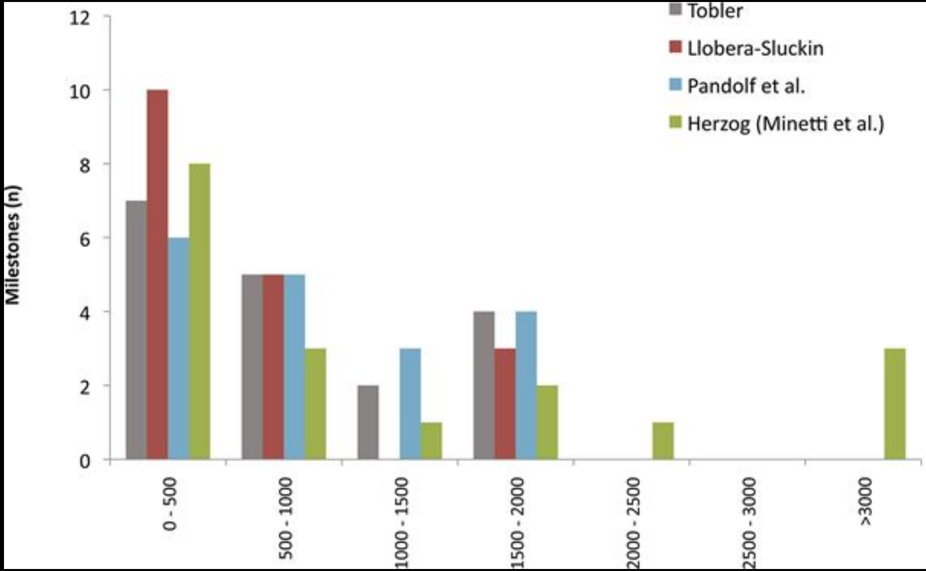


Figure 3. Güimil-Fariña, A. and C. Parcero-Oubiña. 2015 “Dotting the joins”: a non-reconstructive use of Least Cost Paths to approach ancient roads. The case of the Roman roads in the NW Iberian Peninsula,” Journal of Archaeological Science 54: 31-44. https://doi.org/10.1016/j.jas.2014.11.030.



Cost function	% of LCP within route buffer (500 m)	% of LCP within route buffer (1000 m)
Llobera–Sluckin	74.72	88.22
Tobler	60.96	77
Pandolf et al.	56.39	67.89
Herzog (Minetti et al.)	47.73	68.59

Figure 4, Table 1. Güimil-Fariña, A. and C. Parcero-Oubiña. 2015 "Dotting the joins": a non-reconstructive use of Least Cost Paths to approach ancient roads. The case of the Roman roads in the NW Iberian Peninsula," Journal of Archaeological Science 54: 31-44. https://doi.org/10.1016/j.jas.2014.11.030.

“…a single cost value to every water course equivalent to move across a slope of 0.27 gradient (15°).”

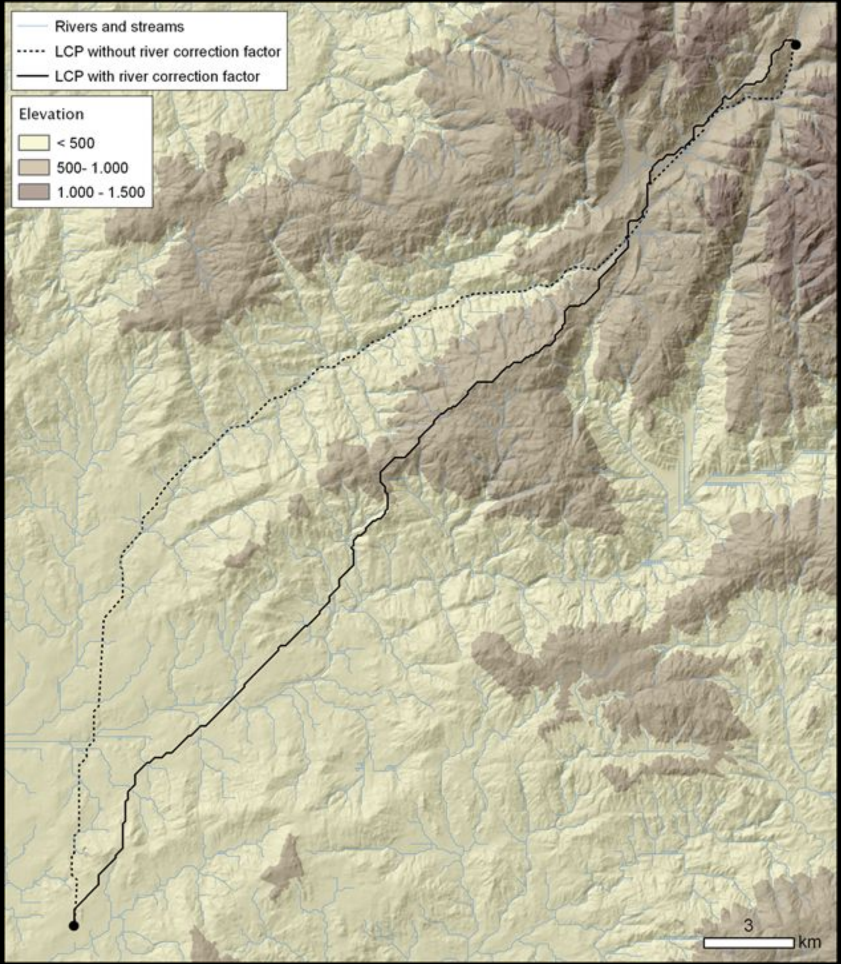


Figure 5. Güimil-Fariña, A. and C. Parcero-Oubiña. 2015 “Dotting the joins”: a non-reconstructive use of Least Cost Paths to approach ancient roads. The case of the Roman roads in the NW Iberian Peninsula,” Journal of Archaeological Science 54: 31-44. https://doi.org/10.1016/j.jas.2014.11.030.

Digital Elevation Model (DEM)

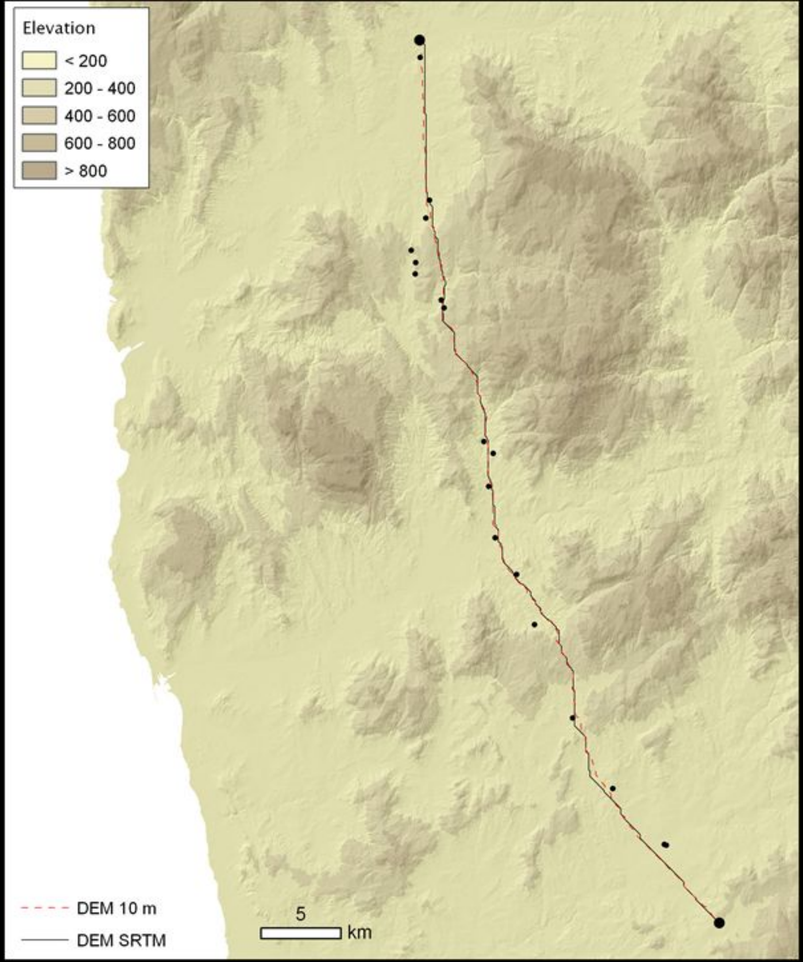
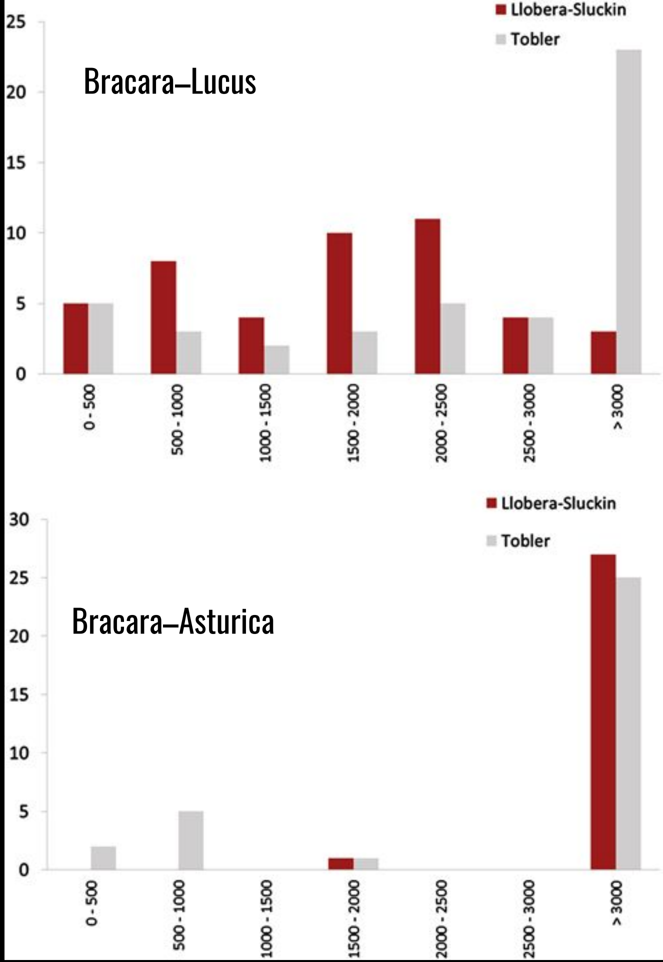


Figure 6. Güimil-Fariña, A. and C. Parcero-Oubiña. 2015 "Dotting the joins": a non-reconstructive use of Least Cost Paths to approach ancient roads. The case of the Roman roads in the NW Iberian Peninsula," Journal of Archaeological Science 54: 31-44. https://doi.org/10.1016/j.jas.2014.11.030.



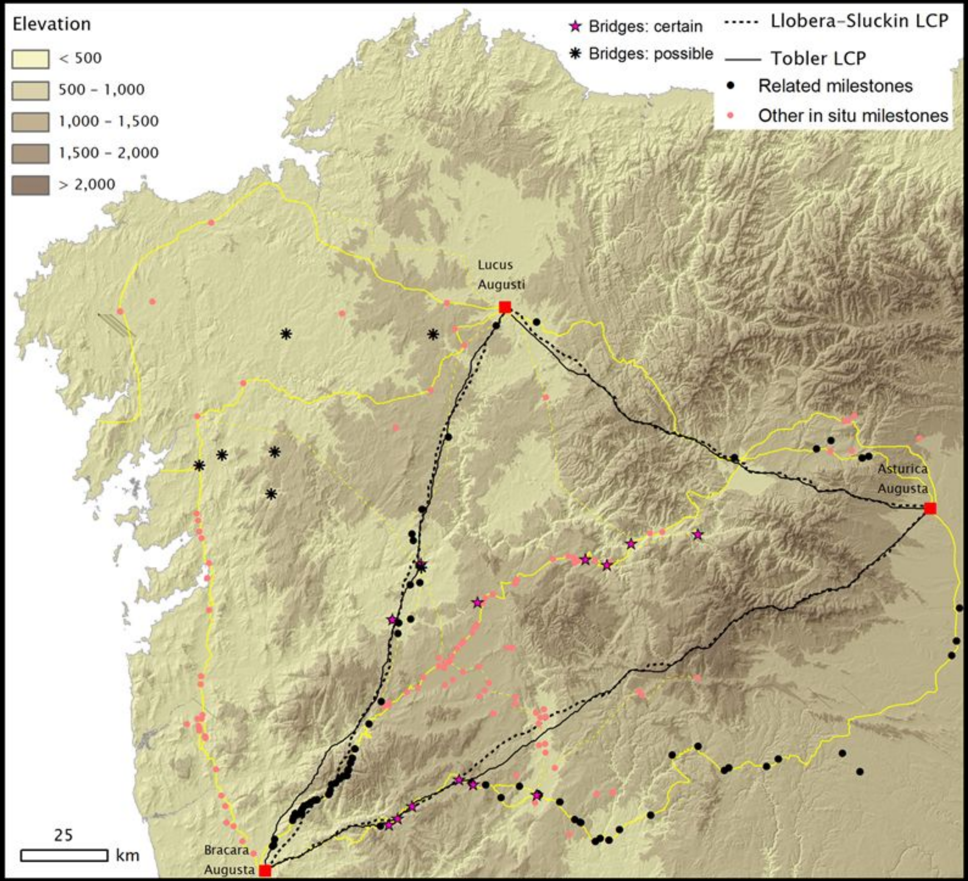


Figure 7 & 8. Güimil-Fariña, A. and C. Parcero-Oubiña. 2015 "Dotting the joins": a non-reconstructive use of Least Cost Paths to approach ancient roads. The case of the Roman roads in the NW Iberian Peninsula," Journal of Archaeological Science 54: 31-44. https://doi.org/10.1016/j.jas.2014.11.030.