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ARCH2010f  
Class Exercise

### **Travel, Trade, and Communication Routes On the North Edge of the Anatolian Plateau**

In this exercise, you will be working in the area of the Avkat Archaeological Project, which centers on the modern village of Beyözü (Roman/Byzantine Euchaita, Ottoman Avkat) in the Çorum province of modern Turkey, which is located at the northern edge of the Central Anatolian Plateau. The project is a diachronic regional survey that aims to discover more about the settlement and environs of a provincial town of middling size and import, as well as its role in the larger region. This latter endeavor includes a focus on routes of communication and how they might have affected life in the ancient town. In the exercise you will use GIS tasks including acquiring data, mosaicking, coordinate transformations, slope and aspect, reclassifying, generating a cost-surface coverage and determining the least-cost, most efficient paths through the landscape between two larger cities in the region, Amasya and Çorum, in an attempt to identify where these routes may have been situated and whether, if it all, they passed near Beyözü. This exercise takes multiple factors into account and an anisotropic – direction dependent – approach.

#### Preparatory Reading:

Minetti, Alberto E., Christian Moia, Giulio S. Roi, Davide Susta and Guido Ferretti  
2002 Energy cost of walking and running at extremem uphill and downhill slopes.  
*Journal of Applied Physiology* 93: 1039-46.

Bell, Tyler and Gary Lock (recommended)  
2000 Topographic and cultural influences on walking the Ridgeway in later Prehistoric times. In *Beyond the Map: archaeology and spatial technologies*, edited by Gary Lock, pp. 85-100. IOS Press, Amsterdam and Washington, D.C.

This exercise includes the following files:

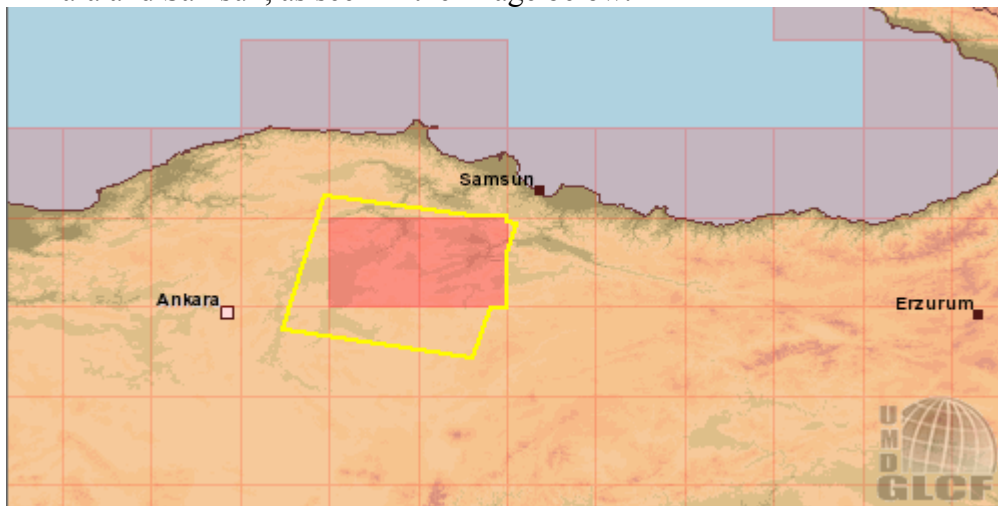
/class\_exercise/Towns/Towns.shp  
/class\_exercise/Towns/Amasya.shp  
/class\_exercise/Towns/Corum.shp  
/class\_exercise/Towns/AmasyaCorum.shp  
/class\_exercise/Towns/BeyozuAmasya.shp  
/class\_exercise/landsatbandstack

#### **Step 1: Acquiring Data**

After copying the data to your folder/drive, take some time to go through the folder hierarchy so that you know where the different data files are located. Create a folder called “Generated” in the structure, where you will save all the files generated in the

exercise; this way, you know that all the files you've created will be accessible in one location.

- a) Open ArcMap and start a new map. Add the "Towns" shapefile and turn on the labels. Save the map as "LastName\_Roads.mxd".
- b) The next step is to find and download SRTM data for building a cost-surface: navigate to the "Useful Links" page under Class Resources on the wiki, and look for suitable links to download SRTM. (For this particular area, I recommend the Global Land Cover Facility page).
- c) On the GLCF page, click on the "Map Search" tab at the top of the page. Under "Elevation Data," select "SRTM, Degree Tiles" and "SRTM, WRS2 Tiles." Using the zoom tool (it looks like a magnifying glass), zoom into northern Turkey.
- d) Using the select tool (a pointer with plus sign), click the two squares between Ankara and Samsun, as seen in the image below.



The region for this exercise falls into two zones, 36N and 37N; in order to perform analyses on the area as a whole, they must be downloaded and later you will mosaic them together.

- e) Click "Preview & Download." In the resulting list, download both 131-323 and 131-324. After clicking on the 131-323 ID, select "Download" at the top of the screen. On the next page, download the .tif.gz file; save it to your drive. When it has finished downloading, unzip it to the same folder.
- f) In ArcMap, add the .tif file to your map (allow it to build pyramids). You will see that its extent is not the entire area of the study area, but only covers Çorum. Repeat steps e) and f) with 131-324 to get coverage for Beyözü and Amasya.

Now that the SRTM data covers the whole study area, we need to mosaic the two (already georeferenced!) files together. This will allow for the cost surface and paths to cross the boundary between the two files.

## Step 2: Mosaicking and Projecting the SRTM.

- a) Open ArcToolbox → Data Management Tools → Raster → Raster Dataset → Mosaic to New Raster.

- b) Under Input Rasters, select the two SRTM .tif files. Save the file as “Lastname\_Mosaic” in the Generated folder on your drive.

Remember to save your map often. While created files will not be lost if ArcMap crashes and has to be closed, if the map has not been saved in the Layers toolbar before the crash, you will have to manually reload them upon reopening.

Now you need to project the raster into the appropriate coordinate system in order to put it into UTM format and correct the pixel size to 90 (all SRTM is 90 meter). This will put your mosaic into such a form that it can be used to generate all the necessary rasters for performing the shortest path analysis in Step 9.

- c) Open ArcToolbox→Data Management Tools→Projections and Transformations→Raster→Project Raster.
- d) Use “Lastname\_mosaic” as the Input Raster.
- e) In the Output Coordinate System, choose Select→Projected Coordinate System→UTM→WGS 1984→WGS 1984 UTM Zone 36N.prj and click Add. Hit OK. In the Output Cell Size, enter 90.
- f) Save the file in your folder as “LastName\_mosaic\_projected.” Click OK.
- g) Zoom in to the map until you can see the individual pixels of the projected raster. The pixels should appear fairly straight, both vertically and horizontally.

### **Step 3: Slope and Aspect**

Now that the files are mosaicked, you can create slope and aspect.

- a) Go to Tools → Extensions to make sure that Spatial Analyst is turned on. If it is not present, select it in the View → Toolbars menu.
- b) Go to Spatial Analyst → Options and select the Extent tab. Make sure that the “Lastname\_Mosaic\_projected” file is selected as the Analysis Extent. This ensures that any raster you generate in the rest of the exercise will cover the full extent of the study area and create meaningful files for analysis.
- c) Go to Spatial Analyst → Surface Analysis → Aspect. Select “LastName\_Mosaic\_projected” as the Input Surface, and save the raster as LastName\_aspect in the Generated folder. Aspect is an important step in the context of this exercise, as it enables you to take the *direction* in which a person is moving into account rather than just the absolute cost of ascending or descending a slope.
- d) Go to Spatial Analyst → Surface Analysis → Slope. Select “LastName\_Mosaic\_projected” as the Input Surface, and save the raster as “LastName\_slope” in the Generated folder. (Now would be a good time to save.)

### **Step 4: Reclassifying**

Reclassifications of the slope and aspect values prepares them for map algebra operations; aspect, which denotes which direction the slope is facing in each pixel,

has been assigned a value between 0 and 360; thus, we will reclassify aspect so as to denote both the cardinal and inter-cardinal directions, based on the table below.

*Reclassifying Aspect*

- a) Go to Spatial Analyst → Reclassify.
- b) Select “LastName\_aspect” as the input raster.
- c) Type the information in the table below (except for the notes, which indicate which direction you are classifying) in the “Set values to reclassify” dialogue. Please note the spaces between the hyphens; these must be entered for the reclassification to execute successfully. The new values are to the hundredth place, so that they are identifiable (for example, a value in the 300s = an east aspect) when you later combine them with the slope values.
- d) Delete any extra entries. Save the output raster as “aspctrcls” to your Generated folder.

Aspect Reclass

Old Values	New Values	Notes
-1	0	no aspect
0 - 22.5	100	N
22.5 - 67.5	200	NE
67.5 - 112.5	300	E
112.5 - 157.5	400	SE
157.5 - 202.5	500	S
202.5 - 247.5	600	SW
247.5 - 292.5	700	W
292.5 - 337.5	800	NW
337.5 - 360	900	N

*Reclassifying Slope*

These values have been determined on the basis of the function  $\tan\theta/\tan 1$  where  $\theta$ =slope, which takes into account that the cost of traveling a slope is not a linear progression but increases more in line with the comparative difficulty in traversing steep terrain (Bell and Lock 2000: 88). The graph of the relationship between the angle of slope and the relative cost to ascend or descend it is provided below.

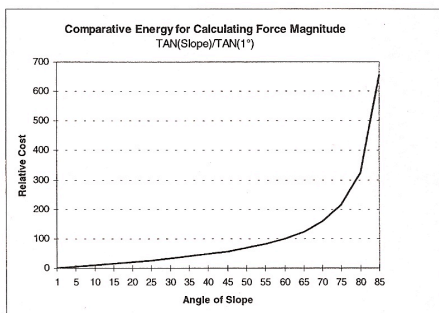


Figure 3. The non-linear relationship of cost, based on the tangent of slope

(From Bell and Lock 2000: 89).

To carry out such a calculation, divide the tangent of the upper limit of each slope by the tangent of 1 to calculate the new values for reclassifying the slope. Enter them into the table on the next page for your reference.

- a) Go to Spatial Analyst → Reclassify.
- b) Select “LastName\_slope” as the input raster.
- c) Enter the values in the Slope Reclass table below in the “Set values to reclassify” dialogue. Round the values to the hundredth decimal place for manageability’s sake. Delete extra entries.
- d) Save the output raster as “slope\_rcls” in your Generated folder.

#### Slope Reclass

Old Values (Slope)	Formula	Calculated Values (New Values)
0 - 0.5	$\tan 0.5 / \tan 1$	
0.5 - 5	$\tan 5 / \tan 1$	
5 - 10	$\tan 10 / \tan 1$	
10 - 15	$\tan 15 / \tan 1$	
15 - 20	$\tan 20 / \tan 1$	
20 - 25	$\tan 25 / \tan 1$	
25 - 30	$\tan 30 / \tan 1$	
30 - 35	$\tan 35 / \tan 1$	
35 - 40	$\tan 40 / \tan 1$	
40 - 45	$\tan 45 / \tan 1$	
45 - 90		100

Note that the table above classifies the 45-90 degree slopes as a very high cost value; this is based on human physiological research that asserts that humans find it nigh impossible to ascend or descend (unless falling, I suppose) slopes  $\pm 45^\circ$  (Minetti et al. 2002).

#### Step 5: Combining Slope and Aspect

In order to generate a cost-surface, you now need to combine the reclassified slope and aspect rasters. This will create a raster that you can reclassify once more to account for not just the relative cost of movement, but also the efficiency of human movement.

- a) Go to Spatial Analyst → Raster Calculator. Add together the RECLASSIFIED slope and aspect rasters, and hit “Evaluate.” The new raster will automatically be added to your map as “Calculation”. Go to the layer properties of the Calculation raster and change its symbology to Unique Values. Unique Values allows enough entries for you to reclass with the appropriate number of cost values in Step 6.

## Step 6: Reclassifying the Combined Slope and Aspect for Amasya → Çorum

Minetti (1995) and Minetti et al. (2002) have done studies on the efficiency of human movement on slopes up to  $\pm 45^\circ$ . These studies conclude that the optimum efficiency for human movement on a slope takes place at  $25\text{-}28^\circ$ , meaning that the minimum metabolic cost per meter of vertical displacement occurs at this slope. To account for this in the cost surface, you will need to calculate the combination (new) values for one last reclassification.

Though the initial reclassification of slope already took account of the relative cost of slope as part of the operation  $\tan\theta/\tan 1$  where  $\theta$ =slope (cf. Bell and Lock 2000: 88-89), that reclass did not consider the optimum efficiency of human movement; for instance, while going up a hill may “cost” more metabolically, there is a potential that it is much more efficient with regard to metabolic output to work hard to go up a short hill than to walk a long time to go around it.

Cost surfaces are only capable of calculating the cost of getting to or from a specific site in the landscape; as such, they are strictly site-specific, and cannot model bidirectional movement among multiple points in one analysis (Bell et al. 2002: 177). Because you are trying to determine the least-cost, most efficient path between Amasya and Çorum *in both directions*, you will need to generate a separate cost-surface for both cities. To do this, you will need to perform this reclassification on two separate occasions to prep for two separate shortest path analyses: one accounting for the path from Amasya to Çorum (east to west), and one from Çorum to Amasya (west to east). Because these paths will run roughly on an east-west axis, the 300 values (east) will be downhill in one analysis and uphill in the other; thus, in each reclass they will assigned cost values accordingly. If you do not understand the reasoning behind this exercise after examining the two tables provided below, please ask.

Minetti et al. (2002) provide the following graph, which, based on multiple lab studies, has determined efficiency values for walking and running at different slopes, taking into account whether the walker or runner is going up or downhill, a key issue in this exercise. Based on this table, I have created the reclassification tables below; the costs, depending on whether one is going up or downhill (which, in turn, depends on which direction one is travelling), are calculated by the difference of their mechanical efficiency value from 27, the number assigned to the mechanical efficiency value of  $25^\circ$ , which, as the ideal slope for maximizing vertical displacement by minimum metabolic cost, has been assigned the easiest cost of 1. Examine the graph and the tables; if you still do not understand how the values were calculated, please ask.

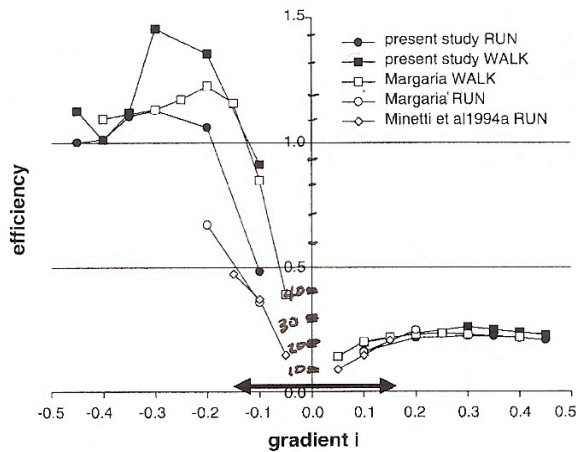


Fig. 3. Mechanical efficiency of the work done for the vertical displacement of the body during locomotion as a function of the gradient. Data are from the present investigation, from Margaria (14, 15) and from Minetti (20). Double-headed arrow parallel to the x-axis defines the gradient range where the external work of locomotion is contributed by a combination of positive and negative work. Note that the y-axis scale reports the absolute value of efficiency: the sign ought to be negative for downhill locomotion, positive for uphill locomotion.

(From Minetti et al. 2002: 1042).

- Calculate the old values for this reclassification by adding together the reclassified slope and aspect values.
- Create a new folder in your own called “AtoC” (=Amasya to Çorum). While performing the following steps relevant to travel in this direction, you’ll need to save all your generated files here to keep them separate from the files relevant to the west→east direction.
- Go to Spatial Analyst → Reclassify. Choose “Calculation” (the result of adding together the aspect and slope reclasses) as your input raster. Reclass the values according to the table below (Amasya→ Çorum); save the map to your folder as “combo\_rcls”.

Amasya → Çorum

Aspect	Direction	Slope	Combo (Old Values)	Cost (New Values)	Notes
flat	none	0 - 0.5	0	12	
N	uphill	0.5 - 5	105.01	13	
N	uphill	5 - 10		8	
N	uphill	10 - 15		6	
N	uphill	15 - 20		5	
N	uphill	20 - 25		5	
N	uphill	25 - 30		1	optimal efficiency (Minetti et al. 2002)
N	uphill	30 - 35		3	
N	uphill	35 - 40		4	
N	uphill	40 - 45		4	

N	uphill	45 - 90	200	NoData	It is very difficult for humans to ascend or descend slopes above 45 degrees.
NE	uphill	0 - 5	205.01	13	
NE	uphill	5 - 10	210.10	8	
NE	uphill	10 - 15		6	
NE	uphill	15 - 20		5	
NE	uphill	20 - 25		5	
NE	uphill	25 - 30		1	optimal efficiency (Minetti et al. 2002)
NE	uphill	30 - 35		3	
NE	uphill	35 - 40		4	
NE	uphill	40 - 45		4	
E	uphill	45 - 90		NoData	impassable
E	uphill	0 - 5		13	
E	uphill	5 - 10		8	
E	uphill	10 - 15		6	
E	uphill	15 - 20		5	
E	uphill	20 - 25		5	
E	uphill	25 - 30		1	optimal efficiency (Minetti et al. 2002)
E	uphill	30 - 35		3	
E	uphill	35 - 40		4	
E	uphill	40 - 45		4	
SE	uphill	45 - 90		NoData	impassable
SE	uphill	0 - 5		13	
SE	uphill	5 - 10		8	
SE	uphill	10 - 15		6	
SE	uphill	15 - 20		5	
SE	uphill	20 - 25		5	
SE	uphill	25 - 30		1	optimal efficiency (Minetti et al. 2002)
SE	uphill	30 - 35		3	
SE	uphill	35 - 40		4	
SE	uphill	40 - 45		4	
SE	uphill	45 - 90		NoData	impassable
S	downhill	0 - 5		13	
S	downhill	5 - 10		62	
S	downhill	10 - 15		84	
S	downhill	15 - 20		105	
S	downhill	20 - 25		109	
S	downhill	25 - 30		115	



S	downhill	30 - 35		84	
S	downhill	35 - 40		74	
S	downhill	40 - 45		84	
S	downhill	45 - 90		NoData	impassable
SW	downhill	0 - 5		13	
SW	downhill	5 - 10		62	
SW	downhill	10 - 15		84	
SW	downhill	15 - 20		105	
SW	downhill	20 - 25		109	
SW	downhill	25 - 30		115	
SW	downhill	30 - 35		84	
SW	downhill	35 - 40		74	
SW	downhill	40 - 45		84	
SW	downhill	45 - 90		NoData	impassable
W	downhill	0 - 5		13	
W	downhill	5 - 10		62	
W	downhill	10 - 15		84	
W	downhill	15 - 20		105	
W	downhill	20 - 25		109	
W	downhill	25 - 30		115	
W	downhill	30 - 35		84	
W	downhill	35 - 40		74	
W	downhill	40 - 45		84	
W	downhill	45 - 90		NoData	impassable
NW	downhill	0 - 5		13	
NW	downhill	5 - 10		62	
NW	downhill	10 - 15		84	
NW	downhill	15 - 20		105	
NW	downhill	20 - 25		109	
NW	downhill	25 - 30		115	
NW	downhill	30 - 35		84	
WN	downhill	35 - 40		74	
NW	downhill	40 - 45		84	
NW	downhill	45 - 90		NoData	impassable
N	uphill	0 - 5		13	
N	uphill	5 - 10		8	
N	uphill	10 - 15		6	
N	uphill	15 - 20		5	
N	uphill	20 - 25		5	
N	uphill	25 - 30		1	optimal efficiency (Minetti et al. 2002)
N	uphill	30 - 35		3	

N	uphill	35 - 40		4	
N	uphill	40 - 45		4	
N	uphill	45 - 90	1000	NoData	impassable

These values are based on research on human physiological slope preferences: Minetti 1995 and Minetti et al. 2002.

### Step 7: Creating a cost-weighted surface

Now you need to create a raster made up of pixels that model the way humans may have moved through the ancient landscape of our study area, based on the cost and efficiency of *pedestrian* travel.

- a) Add the “Amasya” shapefile from the Towns folder to the map.
- b) Go to Spatial Analyst → Distance → Cost-weighted. Use “Amasya” for Distance to, “combo\_rcls” for the Cost raster.
- c) Create direction and allocation. Save these under the AtoC folder. Save the Output raster as “cost\_wtd” in the same folder.

### Step 8: Determining the shortest path

Now that you have generated a cost surface, you need to perform one last analysis to determine what is, in fact, the shortest path from Amasya to Çorum, and whether Beyözü falls along that line.

- a) Add the “CorumBeyozu” shapefile to the map.
- b) Go to Spatial Analyst → Distance → Shortest Path.
- c) Assign CorumBeyozu as your Path to, cost\_wtd as the Cost distance raster, and direction as the Cost direction raster. Leave For Each Cell as the Path type. Save the Output features as “AtoC\_shortestpath” in the AtoC folder.

This should create a line file that demonstrates the most efficient path traveling from Amasya to Çorum, and from Amasya to Beyozu. **Repeat steps 5-6**, saving the “combo\_rcls” raster under a “CtoA folder” (implying travel from Çorum to Amasya). The Çorum→Amasya table is provided below as a reference for assigning new values, based on the logic in the Amasya→ Çorum table in Step 6. Don’t forget to assign unique values to the symbology when the calculated raster is added to the map!

Aspect	Direction	Slope	Combo (Old Values)	Cost (New Values)	Notes
flat	none	0 - 0.5			relatively easy cost
N	downhill	0 - 5			flat terrain
N	downhill	5 - 10			
N	downhill	10 - 15			
N	downhill	15 - 20			

N	downhill	20 - 25			
N	downhill	25 - 30			Minetti: minimum cost + progress
N	downhill	30 - 35			
N	downhill	35 - 40			
N	downhill	40 - 45			
N	downhill	45 - 90			impassable
NE	downhill	0 - 5			flat terrain
NE	downhill	5 - 10			
NE	downhill	10 - 15			
NE	downhill	15 - 20			
NE	downhill	20 - 25			
NE	downhill	25 - 30			Minetti: minimum cost + progress
NE	downhill	30 - 35			
NE	downhill	35 - 40			
NE	downhill	40 - 45			
E	downhill	45 - 90			impassable
E	downhill	0 - 5			flat terrain
E	downhill	5 - 10			
E	downhill	10 - 15			
E	downhill	15 - 20			
E	downhill	20 - 25			
E	downhill	25 - 30			Minetti: minimum cost + progress
E	downhill	30 - 35			
E	downhill	35 - 40			
E	downhill	40 - 45			
SE	downhill	45 - 90			impassable
SE	downhill	0 - 5			flat terrain
SE	downhill	5 - 10			
SE	downhill	10 - 15			
SE	downhill	15 - 20			
SE	downhill	20 - 25			
SE	downhill	25 - 30			Minetti: minimum cost + progress
SE	downhill	30 - 35			
SE	downhill	35 - 40			
SE	downhill	40 - 45			
SE	downhill	45 - 90			impassable
S	uphill	0 - 5			flat terrain
S	uphill	5 - 10			
S	uphill	10 - 15			
S	uphill	15 - 20			
S	uphill	20 - 25			

S	uphill	25 - 30			Minetti: minimum cost + progress
S	uphill	30 - 35			
S	uphill	35 - 40			
S	uphill	40 - 45			
S	uphill	45 - 90			impassable
SW	uphill	0 - 5			flat terrain
SW	uphill	5 - 10			
SW	uphill	10 - 15			
SW	uphill	15 - 20			
SW	uphill	20 - 25			
SW	uphill	25 - 30			Minetti: minimum cost + progress
SW	uphill	30 - 35			
SW	uphill	35 - 40			
SW	uphill	40 - 45			
SW	uphill	45 - 90			impassable
W	uphill	0 - 5			flat terrain
W	uphill	5 - 10			
W	uphill	10 - 15			
W	uphill	15 - 20			
W	uphill	20 - 25			
W	uphill	25 - 30			Minetti: minimum cost + progress
W	uphill	30 - 35			
W	uphill	35 - 40			
W	uphill	40 - 45			
W	uphill	45 - 90			impassable
NW	uphill	0 - 5			flat terrain
NW	uphill	5 - 10			
NW	uphill	10 - 15			
NW	uphill	15 - 20			
NW	uphill	20 - 25			
NW	uphill	25 - 30			
NW	uphill	30 - 35			Minetti: minimum cost + progress
WN	uphill	35 - 40			
NW	uphill	40 - 45			
NW	uphill	45 - 90			impassable
N	downhill	0 - 5			flat terrain
N	downhill	5 - 10			
N	downhill	10 - 15			
N	downhill	15 - 20			
N	downhill	20 - 25			
N	downhill	25 - 30			Minetti: minimum cost + progress

N	downhill	30 - 35			
N	downhill	35 - 40			
N	downhill	40 - 45			
N	downhill	45 - 90			impassable

### Step 9: Creating a cost-weighted surface and shortest path for Çorum → Amasya

- Go to Spatial Analyst→Distance→Cost-weighted. Use “Corum” as the Distance to, “combo\_rcls” as the Cost raster, and save direction, allocationa and cost\_wtd to the CtoA folder.
- Go to Spatial Analyst→Distance→Cost-weighted. Assign “BeyozuAmasya” as the Path to, “cost\_wtd” as the Cost distance raster, direction as the Cost direction raster, and save the Output features to the CtoA folder as “CtoAshortestpath.”

Notice that the optimal paths in each direction are rather drastically different. What does this imply about roads and way-making in antique central Anatolia?

### Step 10: Examining the Data

Bring up both sets of paths on the map; compare them to the “Towns” shapefile from the very beginning of the exercise. What are some of the possible reasons behind the divergence of the two paths, depending on direction? The modern road between Amasya and Çorum follows the Roman military road, which is roughly along the same route as the path from Çorum to Amasya. Is the radically divergent path from Amasya to Çorum a result of the GIS analysis, the places where archaeological survey has taken place, or from the dynamics between the Roman colonizers and native inhabitants of Avkat? What would you do differently or in addition to the steps outlined in the exercise in order to further explore these questions?

Import “Landsatbandstack” from your folder to ArcMap. This file was created in ENVI based on Landsat data. Vegetation in this area is fairly uniform, which is why it was not included as a variable in the cost-surface generation; but when added to the map, do the relative differences in vegetation appear to correllate with the paths generated by the GIS?

Some issues to consider are impact of colonization; factors beyond environmental concerns in choosing routes; resistance; etc. The following readings would be a good starting point in further exploring some of these questions:

Given, Michael

2004 *The Archaeology of the Colonized*, esp. pp. 49-68. Routledge, New York.

Trombley, Frank

2001 Town and *territorium* in Late Roman Anatolia (late 5<sup>th</sup>-early 7<sup>th</sup> c.). In

*Recent Research in Late-Antique Urbanism*, edited by Luke Lavan, pp. 217-232.