GEOGRAPHIC INFORMATION SYSTEM ANALYSIS FOR THE ALTAR AND MIDDLE MAGDELENA RIVER VALLEYS

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The GIS Campus Core Facility at Binghamton University performed spatial analyses for the *Cerros De Trincheras* & Defense Project. Geography Graduate student Justin Knight did the analyses while the Assistant Director of the facility, Kevin Heard supervised and assisted his efforts. We used GIS analyses on three *cerros de trincheras* (Cerro de Trincheras, Tío Benino, and La Hormiga) to determine if terraces on *cerros de trincheras* enhanced or inhibited the natural defensive characteristics of isolated volcanic hills in the Sonoran Desert. We also did regional analyses in the Altar and Middle Magdalena Valleys to examine the relationship between *cerros de trincheras* and village sites in the valley bottoms.

We applied two types of GIS analyses to both the site specific and the regional data, Cost Path Analysis and Viewshed Analysis. Cost Path involves finding the least effort travel paths between designated points on a landscape. For the hills, this analysis took into account varying slope values and terrace heights, while in the regional analysis it tracked the natural topography of the area. The second analysis to be completed was a Viewshed Analysis. For the hills, viewshed can be defined as the portions of the hill an observer can see from particular observation points on the hill. Inputs include the observer's height and the hill elevation. At a regional level, viewshed refers to what *cerros de trincheras* can be seen from village sites and visa-versa.

We used ArcGIS 9.0 to do our analyses. ArcGIS is the top product created by the GIS industry leader, ESRI. Archaeologists provided the data for the analyses from the archives of previous projects and the field work in the spring of 2006. The data provided included a contour topographic layer and a cultural feature layer. We converted each layer into a shapefile. Shapefiles are native to ESRI software and can be edited and manipulated within the program.

The resulting shapefiles included layers such as elevation contours, terraces, buildings, trails, rocks, labels, etc.

ANALYSIS of CERRO de TRINCHERAS

Our first manipulation of the data from Cerro de Trincheras had to do with the elevation contours. The CAD file was quite old and did not have z (elevation) values associated with the contours. In order to assign z values to these contour lines, we made the contour label layer visible and carefully entered the elevation values by hand into the data table. The fact that each contour elevation line was segmented into many separate lines made this process difficult. The addition of z values for every contour interval took several weeks. The result was a 1 meter interval contour elevation layer with z values associated with each line.

In the next step, we converted the contour elevation shapefile into a grid surface so that further analysis could be performed. Before this conversion could take place, we needed to convert the contour elevation lines into points that retained the elevation values. Once this was accomplished we created a grid surface from these points using the Spatial Analyst software extension of ArcGIS 9.0. The grid conversion method used was IDW (Inverse distance weighted). The result of this method is a continuous elevation surface for the entire site which is roughly 2,000 by 2,000 meters. Each pixel represents 7.6 meters in the real world and the elevation of the hill ranged from 53 to 241 meters. From this grid, we derived a degree slope grid with slopes ranging from 3 to 49 degrees. The elevation grid is data for the Viewshed analysis and the slope grid is data in the Cost Path analysis.

Cost Path Analysis

One of the inputs for the Cost Path analysis was the terrace layer. The terrace layer also did not come with elevation values. The archaeologists provided us with a separate data file that contained average, maximum and minimum terrace heights as well as the widths of the terraces. To join this data with the shapefile of the terraces we needed to have a common field, such as a terrace identification number. The data table had this field, but the table associated with the shapefile did not. We had to add the terrace identification number by hand to the shapefile table. With this accomplished we were able to add the terrace data to the shapefile. We then converted the terrace shapefile to a grid representing the terraces' average height. All the areas that were not terraces were given a no data value in the table. The slope grid and the terrace grid provide us with the two pieces necessary to create the Cost Path analysis.

Before creating the Cost Paths, we needed to reclassify both grids to represent some real world experiences of climbing and the height of the historic population. When reclassifying the slope grid we used real world climbing experience in conjunction with a test we performed at a local skating rink. We wanted to determine at what slopes a climber would have to go from a standing hike, to a scramble, to a 3-point climb and finally a 4-point climb. A local skating rink had a rock climbing wall that we could change the slope on. Justin climbed the machine as Professor McGuire and Kevin gradually increased the percent slope. We estimated that at a 30% slope the climber would go to a scramble, at 35% to a 3-point climb and anything over 40% would be a 4-point climb. We implemented this in our slope model by reassigning slope values as shown in Table 1.

Slope (%)	Cost Value Reclass
0 - 20	1
20.01 - 25	5
25.01 - 30	8
30.01 - 35 (scramble)	16
35.01 - 40 (3-point climb)	32
40.01 - 49 (4-point climb)	100

Table 1. Reassessment of slope values based on climbing experiment.

This reclass structure indicates that as a climber goes from a regular hike to a scramble the hike gets twice as difficult. As the climber continues from a scramble to a 3-point climb it gets twice as difficult once again. Finally, as the climber reaches a 4-point climb it becomes nearly impossible to traverse the hill.

We created the terrace grid reclass based on terrace average heights and our estimate of the average height (5’4”) of the people who lived on the hill at the time. The reclass of the terrace grid is shown in Table 2.

Average Terrace Height (m)	Cost Value Reclass
0 - 0.2	0 (act as steps, not barrier)
0.21 - 0.5	2
0.51 - 0.7	5
0.71 - 1	7
1.01 - 1.5	10
1.51 +	No Data (acts as barrier/impassable)
No Data (non-terrace areas)	1 (to influence the path to use steps)

Table 2. Terrace grid reclassification.

At this point we were able to combine these two grids to create a single grid based on the values we gave them in the reclass step. So each cell (pixel size of 7.6 meters) has an additive cost based on the values we gave to the slope grid and the terrace grid.

As a final step we created shapefiles of destination points at six locations on the hill based on Professor McGuire's input. From west to east, this included the Western Summit, Western Saddle, Middle Summit, Eastern Saddle, and Eastern Summit. One other destination referred to as El Mirador was also created. We then created a shapefile of source points at equal, 50 meter intervals along the base of the hill. This was the final piece of the puzzle that allowed Cost Path lines to be created from the each source point, through the combined slope/terrace grid, to the individual destination points at or near the top of the hill.

Using the cost Path tool provided by the software, we created six Cost Path raster grids (one for each destination point). The software performs this by creating its own distance and direction raster grids to use in conjunction with the combined raster grid that we created in the previous steps. The distance and direction grids take into account the distance and direction for each source point to the specified destination point and assign corresponding values to each pixel. The ultimate result of the Cost Path grid is a spider-like pattern of least cost paths traversing the hill, avoiding high slopes and terraces, ending at the destination point.

In order to measure how much of an affect the terraces have on a climber's ability to reach their destination, we created the same six Cost Path raster grids using the slope grid only. This was referred to as natural slope cost paths because the analysis is using only the slope of the hill and not the input of the terraces. Comparisons could then be made between the Cost Path values of a terraced climb versus a non-terraced climb. In all cases, the Cost Path grids were converted to shapefiles because of the shapefile's smoother look in the final map creation.

Viewshed Analysis

The second major analysis, Viewshed, required less preparation than the Cost Path analysis. The most important aspect to consider was where the viewshed observer would be looking from. We decided that the observers would most likely walk around at a specified observing area rather than stand in one spot. To simulate this effect, in the software, we created a circular polygon around each central observation point and converted this polygon to 16 observation points. We vertically offset each observation point 1.67 meters or 5’4” to represent the height of the historic observers. Once these parameters were set up, we ran the Viewshed tool with the software. The result was a raster grid with values of zero through 16. The zero value means that none of the 16 observers can see that particular location. The remaining values 1-16 represent how many observers can see the location. For mapping purposes we reclassed the data values as shown in Table 3.

Viewshed Value	Viewshed Reclass
0	0
16	1

Table 3. Viewshed Reclassification values.

The Viewshed value of zero is all the area that cannot be seen by any of the 16 observers. The Viewshed value of 1 indicates that at least one of the 16 observers can see that particular location. A Viewshed analysis was done in this fashion for each of the five previously described destination points on the top of the hill. Three other Viewshed observation points were setup using only a single observer point instead of 16. These included El Mirador and locations referred to as El Caracol (physical feature location at the top of the hill) and La Cancha (physical feature location near the bottom of the hill). Each of the eight Viewshed Analysis were displayed using two colors, visible versus non-visible.

Output

We created maps in 2-D and 3-D. The 2-D maps were created with the ArcMap software component and the 3-D maps were created with ArcScene. We designed a template in ArcMap so that each map had the same look and feel. This template included the following elements; title, legend, north arrow, scale bar and cost value comparison between a terraced hill and natural sloped hill. The 3-D maps needed to be exported from ArcScene and imported into the ArcMap template.

Each destination point has three maps associated with it. For example, the Western Summit has a 2-D map showing the entire hill and two 3-D maps, one showing the front of the hill and one showing the back of the hill. Each map shows the terraces, the natural slope cost paths, the terraced cost paths, the viewshed, the source points and the destination point. The final product was exported in ArcMap as a .jpeg file.

Results

We asked three questions in the hope of understanding the role defense played at Cerro de Trincheras:

1) Is it harder to climb a terraced hill or a non-terraced, natural slope hill, and how much harder?

2) Do the Least Cost Paths converge near the top of the hill?

3) Does the Viewshed correspond to those converging paths?

Question 1. When comparing the Cost Path values for the terraced hill versus a non-terraced, natural slope hill, a significant pattern emerges. It all cases, the terraced hill is at least 2 times more difficult to climb than the non-terraced hill. The results are as follows (Table 4)

	Hill Type		
Destination	*Natural Slope**	*Terraces**	*Increased Difficulty w/Terraces (%)*
Western Summit	149,613.8	424,130.9	183.5
Eastern Summit	123,167.9	295,389.1	139.8
Western Saddle	113,803.7	304,602.4	167.7
Eastern Saddle	112,808.5	280,485.7	148.6
Middle Summit	113,246.3	304,230.5	168.6
El Mirador	118,365.0	379,901.1	221.0

*Numbers represent additive cost path values by pixel.

Table 4. Comparing the Cost Path values for the Cerro de Trincheras versus a non-terraced Cerro de Trincheras.

Question 2. The number of paths reduces as an individual moves closer to the destination. In other words, the paths are filtered towards one or two main paths close to the top of the hill. This would be optimal as a defensive mechanism. Fewer paths or areas are easier to defend (Figure 1).

*Question 3***.** The defensive use of the terraces would be further supported if their placement enhanced the viewshed of the defender and inhibited the viewshed of attackers. Specifically the viewshed should show that these narrowed paths could all be seen from the destination. However, this analysis does not hold up in all cases. The Viewshed analysis results are very inconclusive and do no clearly support or dismiss this presupposition.

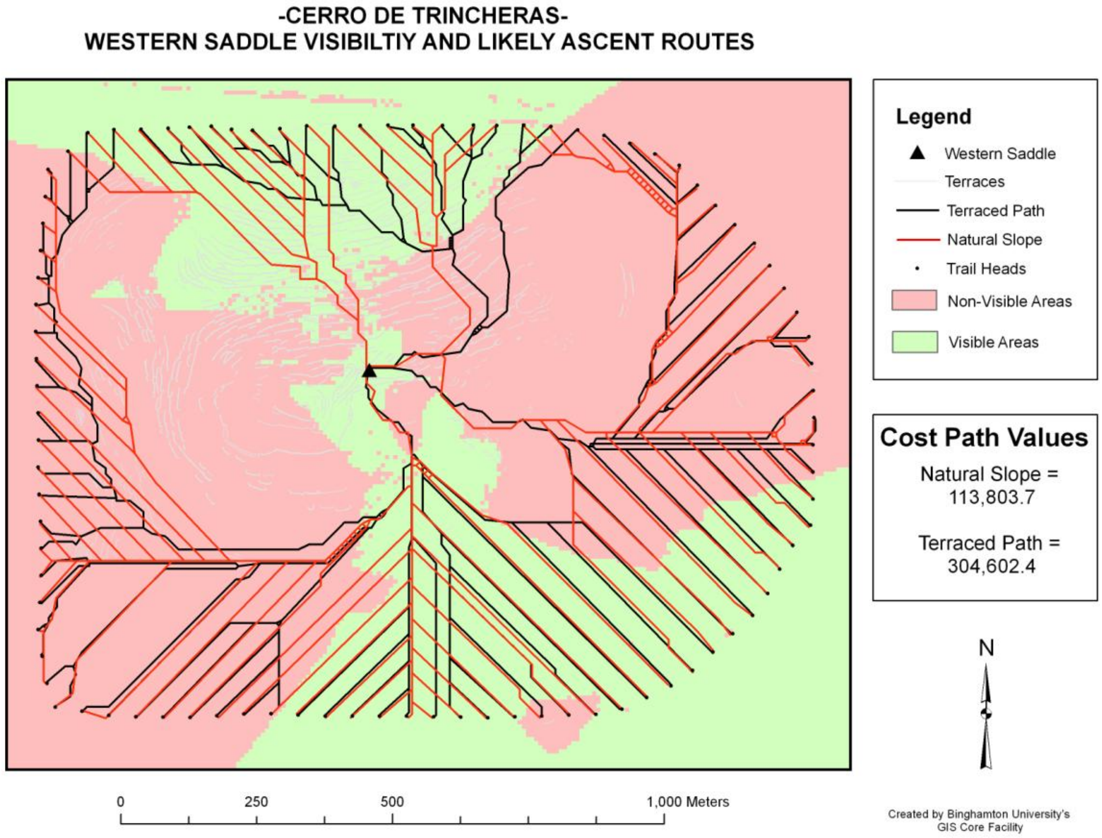

Figure 1. Cerro de Trincheras, western saddle visibility and likely ascent routes.

TÍO BENINO and LA HORMIGA

We also created cost paths and viewsheds for two *cerros de trincheras* in the Altar Valley, Tío Benino and La Hormiga. These analyses required less hand manipulation of the variables than the Cerro de Trincheras study because the archaeologists collected data in the field specifically for these analyses. They used Trimble hand held GPS devices to collect the information and mailed the resulting files to Binghamton for analysis in GPS Pathfinder software. We differentially corrected the GPS files in order to adjust captured spatial locations for errors based on satellite and distance disparities. The software also allowed for the export of the files to a format that can be imported into the GIS software.

Our analysis primarily used the data the field crew collected on terraces. The crews made observations at point locations along the length of the terrace. Any given terrace could have from two points up to five or more points. Using the GIS software we were able to create a line feature to represent the terraces by linking each points terrace identification number. In total, Tío Benino had 288 terraces and La Hormiga had 52 terraces. At each terrace point location the crew recorded the terrace wall length height, width, and overall terrace width. From this information we were able to create averages for the entire terrace using the terrace point wall heights and widths.

Once the terrace data was cleaned up and displayed properly we needed to overlay them onto an elevation map so that the rest of the analysis could take place. A brief summary of the steps include creating a slope grid based on elevation and a terrace grid based on average wall height. We then reclassed these grids into new grids to prepare for cost path determination. From this point forward we used the same methods and assumptions that we had used in the analysis of Cerro de Trincheras.We reclassed the slope grid in the same way as for Cerro de Trincheras but we reclassed the terrace grid as shown in Table 5.

Average Terrace Height (m)	**Cost Value Reclass**
0 - 0.51	2
0.51 - 0.7	5
0.71 - 1	7
1.01 - 1.5	10
1.51 +	No Data (acts as barrier/impassable)
No Data (non-terrace areas)	1 (to influence the path to use steps)

Table 5. Reclassification of slope grid for Tío Benino and La Hormiga.

The analysis used a different terrace reclass because the average height of the terraces on these *cerros de trincheras* was considerably higher than at Cerro de Trincheras. Therefore, there was no class ranging from 0- 0.02. In the analysis of Cerro de Trincheras, we created this category so that the path would use these terraces as steps. The final step before we created the cost path, was to combine these two grids into one.

In analyzing Cerro de Trincheras, we choose specific locations on the hills from which the program calculated the cost paths and viewsheds. These were mainly summits and saddles. In the case of Tío Benino, we choose the five highest elevation points (See Figure 2). Of these points only 1 and 4 were inhabited.

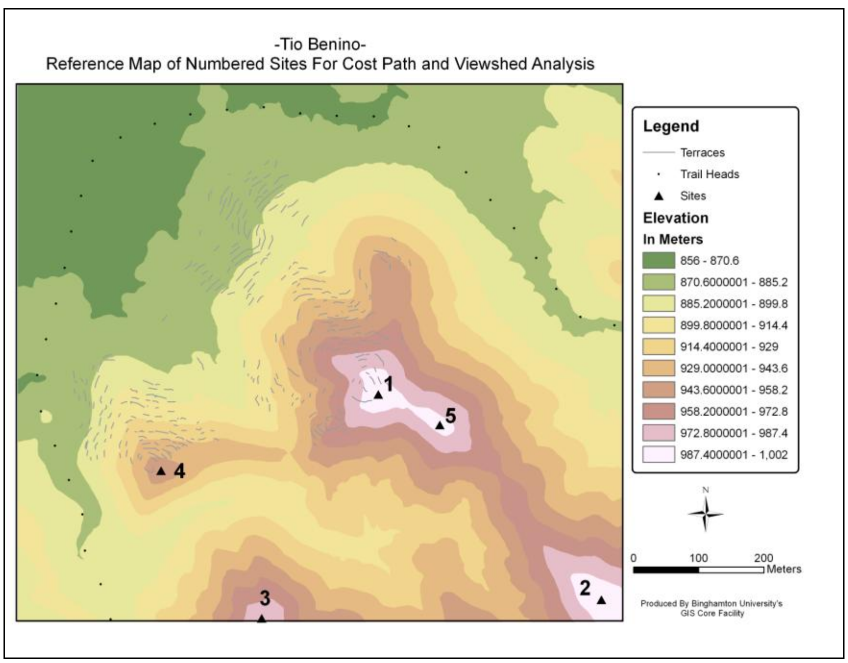

Figure 2. Tío Benino: Reference map of numbered sites.

For La Hormiga we picked one location on top of the main summit and four other locations on the hillside in each direction (Figure 3).

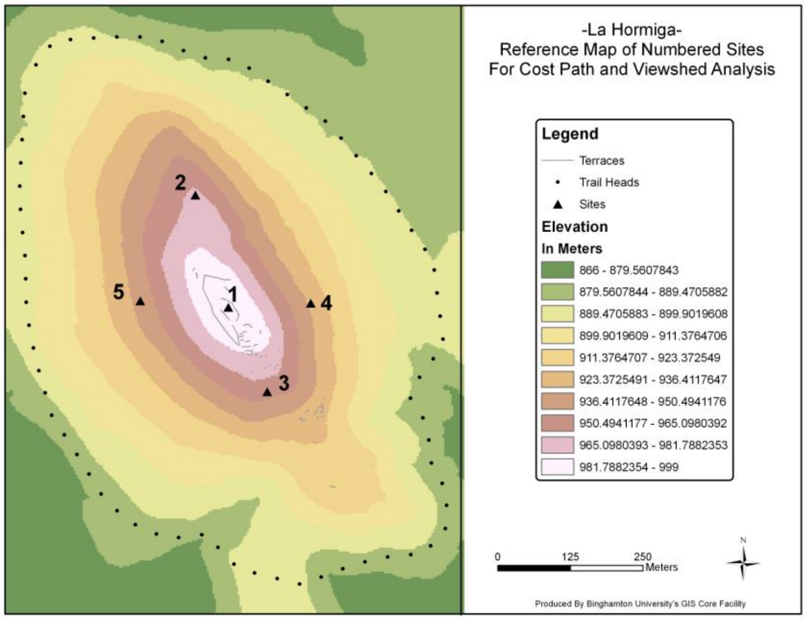

Figure 3. La Hormiga: Reference map of numbered sites.

For each of these *cerros de trincheras,* we created cost paths from each of the source points at the bottom of the hill, to each destination location near the top of the hill. We performed two cost path analyses, one accounting for the terraces and one disregarding them. Table 6 reveals the cost paths values for each hill and compare terraced cost paths and non-terraced cost paths.

The final part of the analysis was to create viewsheds for each of the five locations on each Trincheras. The viewshed was setup and carried out in the same manner as described Cerro de Trincheras. Once again we used the viewsheds to help determine if the majority of the cost paths could be seen from various “lookout” locations on the *cerros de trincheras*.

Path Costs Tio Benino			
Destination	*No-Terraces**	*Terraces**	*% Increase w/Terraces*
1	37989.4	58882.4	55.00
2	38306.3	70144.2	83.11
3	45328.8	72507.8	59.96
4	29261.7	49709.9	69.88
5	40030.2	63373	58.31

La Hormiga			
Destination	*No-Terraces**	*Terraces**	*% Increase w/Terraces*
1	46668.9	98380.6	110.81
2	42873.5	83444.8	94.63
3	47593.1	87771.2	84.42
4	45678.7	83713.1	83.27
5	37047.7	75638.2	104.16

*Numbers represent additive cost path values by pixel.

Table 6. Cost path values for Tío Benino and La Hormiga.

Output

As with the analysis of Cerro de Trincheras, we created output in the form of 2-D and 3-D maps. We output both types of maps as a black and white set and a color set. For Tío Benino and La Hormiga, our analyses resulted in a total of 60 maps.

The analysis asked the same questions as in the analysis of Tío Benino and La Hormiga as with Cerro de Trincheras:

1) Is it harder to climb a terraced hill or a non-terraced, natural slope hill, and how much harder?

2) Do the Least Cost Paths converge near the top of the hill?

3) Does the Viewshed correspond to those converging paths?

For question 1, it appears once again that terraces make it considerably harder to climb a hill than the natural slope without terraces. The effect terraces have on increasing the cost for climbing the hill appeared higher at La Hormiga, than for Tío Benino. The terraces on these two *cerros de trincheras* do not increase the cost path values as drastically as the terraces at Cerro de Trincheras. As expected, the cost paths do coverage into several main paths near the top of the hill. This would concentrate attackers as they approached the summit of the hill. We noted that for La Hormiga there is an ascent route that crests and crosses over the hill with the natural slope. When the paths are calculated for the terraced slope no path crests the hill or passes over the curtain wall on the crest of the hill. Once again this strengthens the theory that terraces were used as defense. The final question regarding the relationship between cost paths and viewshed is up for interpretation as it was with the Cerro de Trincheras analysis (Figures 4 and 5).

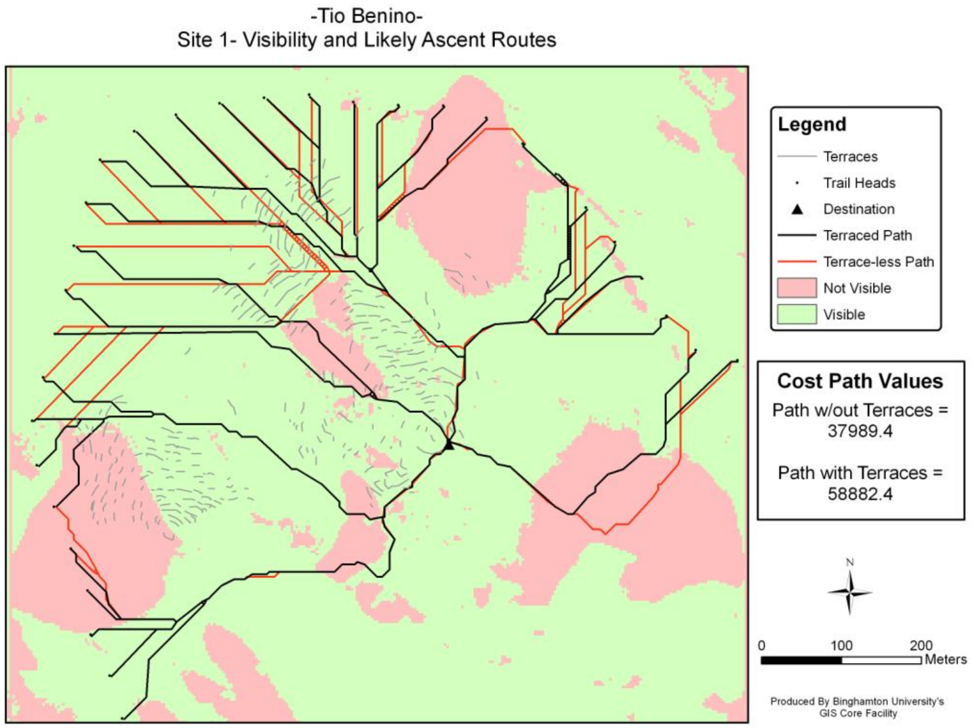

Figure 4. Tío Benino, visibility and likely ascent routes.

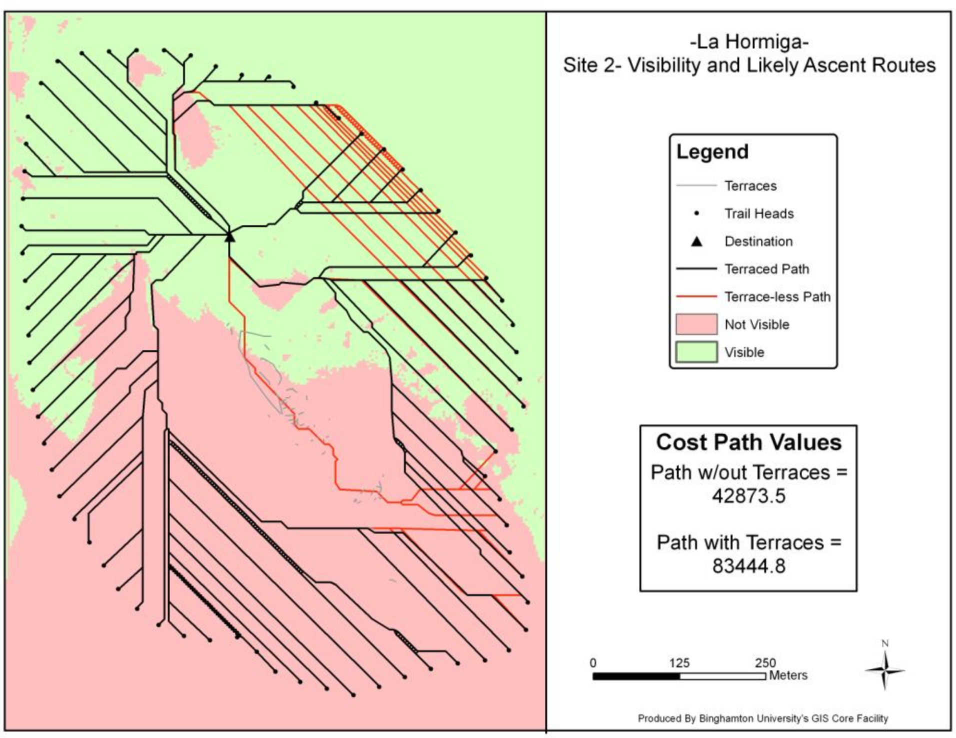

Figure 5. La Hormiga, visibility and likely ascent routes.

REGIONAL ANALYSES

Our regional analyses placed *cerros de trincheras* in a landscape. By looking at the relationship of *cerros de trincheras* to valley floor villages we hoped to generate data that would allow evaluation of defensive, ritual, social, and economic relations between these communities. The most basic question to be asked was if *cerros de trincheras* were associated with specific valley floor villages. The answer to this question and the maps that we generated provided the data for the final analyses in the conclusions of this volume. Our sample includes 33 *cerros de trincheras* and 284 village site components in the Altar and Middle Magdalena River Valleys.

Altar Valley

This analysis examined the locations of *cerros de trincheras* and village sites in the Altar Valley from the town of Altar to the Presa Chuatemoc just northeast of the town of Atil. The Altar Valley survey project generated this data in 1988 (McGuire and Villalpando 1993). During the 2006 field season, researchers revisited numerous of these sites. The survey area formed a rectangle around 11 kilometers wide and 35 kilometers long from the southwest to northeast. Tío Benino and La Hormiga occur approximately in the middle of this area located. The survey recorded 11 of *cerros de trincheras* and 58 village site components spanning four Prehispanic phases. These phases included, from earliest to most recent; Atil, Altar, El Realito, and Santa Teresa (Table 7).

Phase	***Cerros De Trincheras***	**Village Sites**
Atil	0	3
Altar	6	29
El Realito	5	21
Santa Teresa	0	5

Table 7. Count of *cerros de trincheras* and village sites in Altar Valley.

The following steps were completed four times, one for each phase. First we created cost paths from each of *cerros de trincheras*, to all phase contemporary village sites. For example, Atil phase had no cost paths because there were no *cerros de trincheras* in that phase. Altar had 29 cost paths for each of its six of *cerros de trincheras* for a total of 172 cost paths. We made two versions of each cost path; one using the river (Rio Altar) as a barrier and one not taking the river into account. We decided to focus on the "no river" cost path analysis due to the fact that for most of the year the river is dry.

The second part of the analysis looked at the viewshed from each *cerros de trincheras* by phase. The viewshed analysis will help determine how many and which village sites can be seen from each *cerros de trincheras.*

For the final step in this regional analysis, we created an output similar to a trade area study in geography (Figures 6 and 7). For each *cerros de trincheras* we drew an outline that encompassed the closest phase contemporary village sites in terms of cost path. For example, in the Altar phase we drew six outlines. Each outline contained one *cerro de trincheras* and all the village sites that had their least cost path to that *cerros de trincheras*. The following table illustrates this "trade area" analysis showing how many phase contemporary village sites were connected to each *cerro de trincheras* in the Altar Valley. The table also shows, based on the viewshed analysis, how many of the trade area village sites were visible from each *cerro de trincheras* (Table 8).

Phase	***Cerros De Trincheras***	**Village Sites within “Trade Area”**
Atil	None	Not Applicable
Altar	F:5:8	1
	F:6:6	7
	F:2:44	3
	F:2:26	4
	F:2:50	11
	F:2:20	3
El Realito	F:5:12	3
	F:5:13	0
	F:2:78	10
	F:2:26	3
	F:2:80.1	4

Table 8. Village sites in the trade area of *cerros de trincheras* in the Altar Valley.

Middle Magdalena Valley

In the second regional analysis, we applied the methods used in the Altar Valley to the Middle Magdalena Valley. The town of Trincheras and the site of Cerro de Trincheras lie in the center of the Middle Magdalena Valley. We derived this data from the survey of the region that Suzanne and Paul Fish did in 1998 (Fish and Fish 1999, 2009). The survey covered an area approximately 22 kilometers from north to south and 12 kilometers from east to west. Researchers located a total of 13 Cerros de Trincheras sites and 230 village site components in this region. Fish and Fish (1999, 2009) have tentatively defined two Preshispanic Phases for this region, Atil/Altar and El Cerro. The El Cerro Phase corresponds in time to the Realito Phase in the Río Altar.

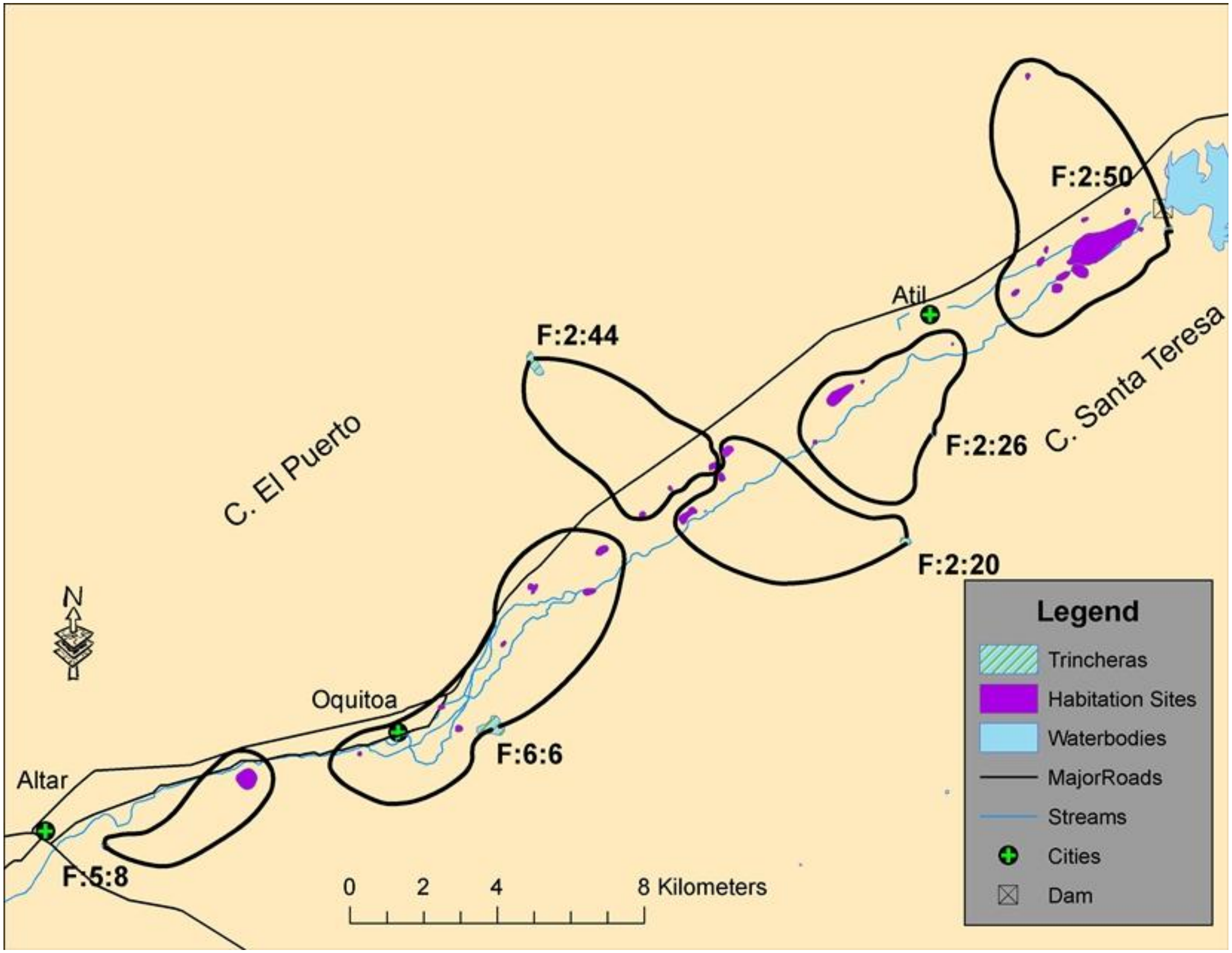

Figure 6. Village sites in the trade area of Altar Phase *cerros de trincheras,* Altar Valley.

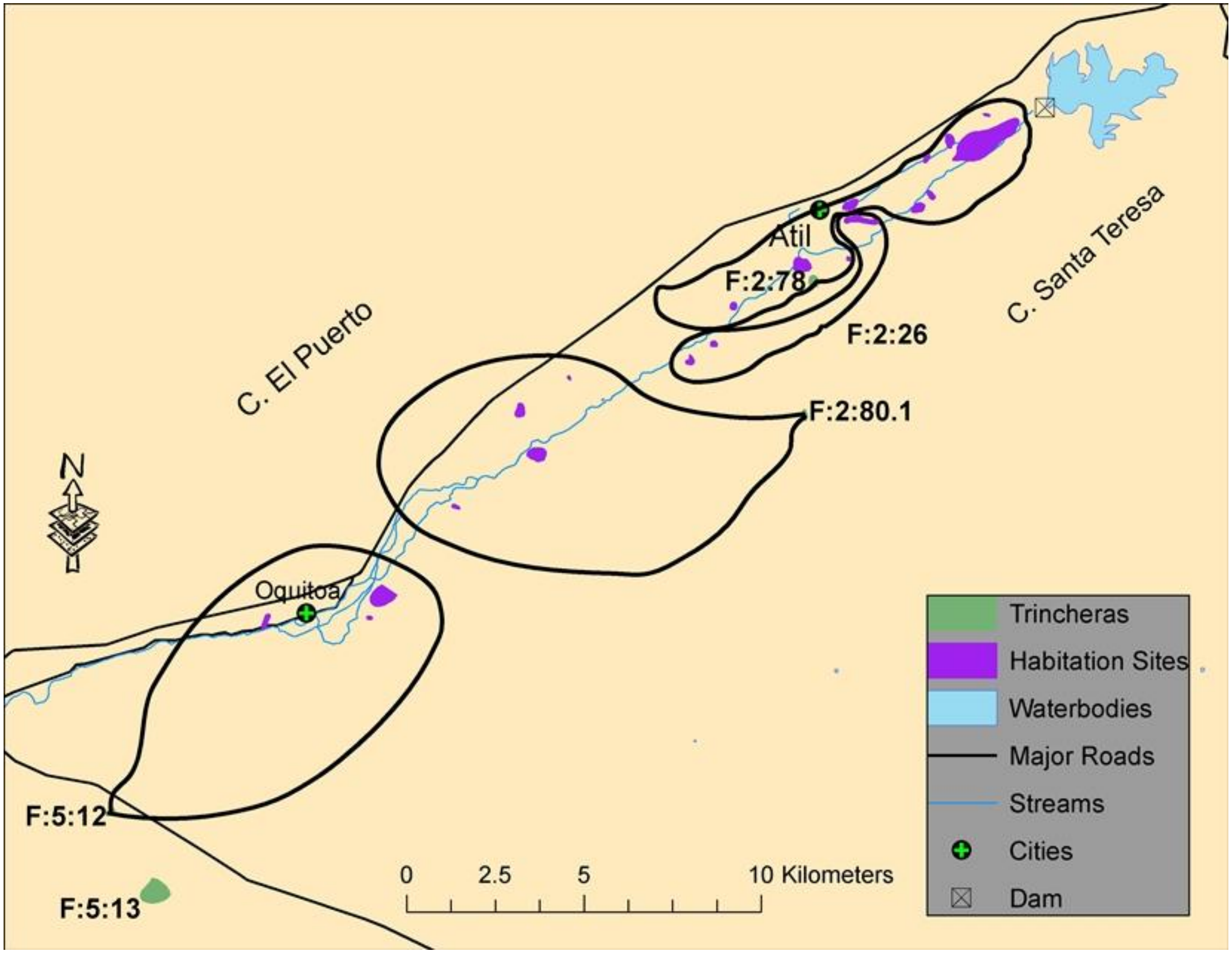

Figure 7. Village sites in the trade area of Realito Phase *cerros de trincheras,* Altar Valley.

Phase	*Cerros De Trincheras*	Village Sites
Atil/Altar	8	89
El Cerro	13	141

Table 9. Count of *cerros de trincheras* and village sites in the Magdalena Valley.

We used the same methods to analyze this region as we used in the Altar Valley. These included the creation of cost paths by phase for each *cerro de trincheras* to each phase contemporary village site, the creation of viewsheds for each *cerro de trincheras*, and finally determining the "trade areas" of each *cerro de trincheras* based on cost path values (Figures 8 and 9). Even though the Magdalena River runs through the region we decided to disregard it for cost path purposes due its intermittent status and because of computational constraints related to the number of village sites in this region. Table 10 contains the results of the "trade area" analysis for the Middle Magdalena Valley.

Phase	*Cerros De Trincheras*	Village Sites within "Trade Area"
Atil/Altar	F:10:6	25
	F:10:9	7
	F:10:34	20
	F:10:150	0
	F:11:16	6
	F:11:69	1
	F:11:89	21
	F:11:94	3
El Cerro	F:10:2	50
	F:10:5	9
	F:10:9	7
	F:10:130	3
	F:11:1	30
	F:11:16	9
	F:11:41	0
	F:11:68	8
	F:11:69	1
	F:11:85	0
	F:11:86	1
	F:11:89	8
	F:11:94	2

Table 10. Village sites in the trade area of each *cerro de trincheras* in the Magdalena Valley.

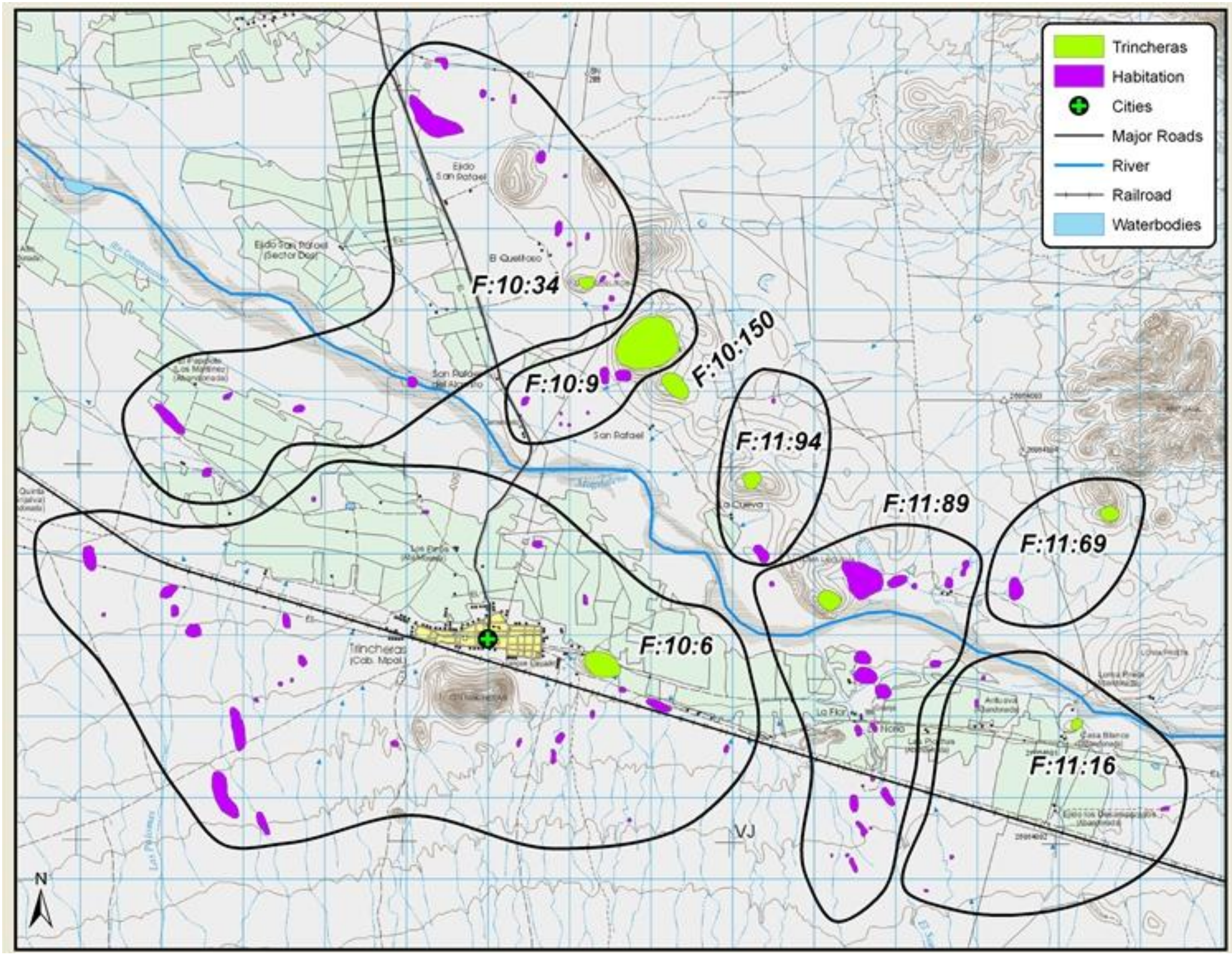

Figure 8. Village sites in the trade area of Atil/Altar Phases *cerros de trincheras,* Magdalena Valley.

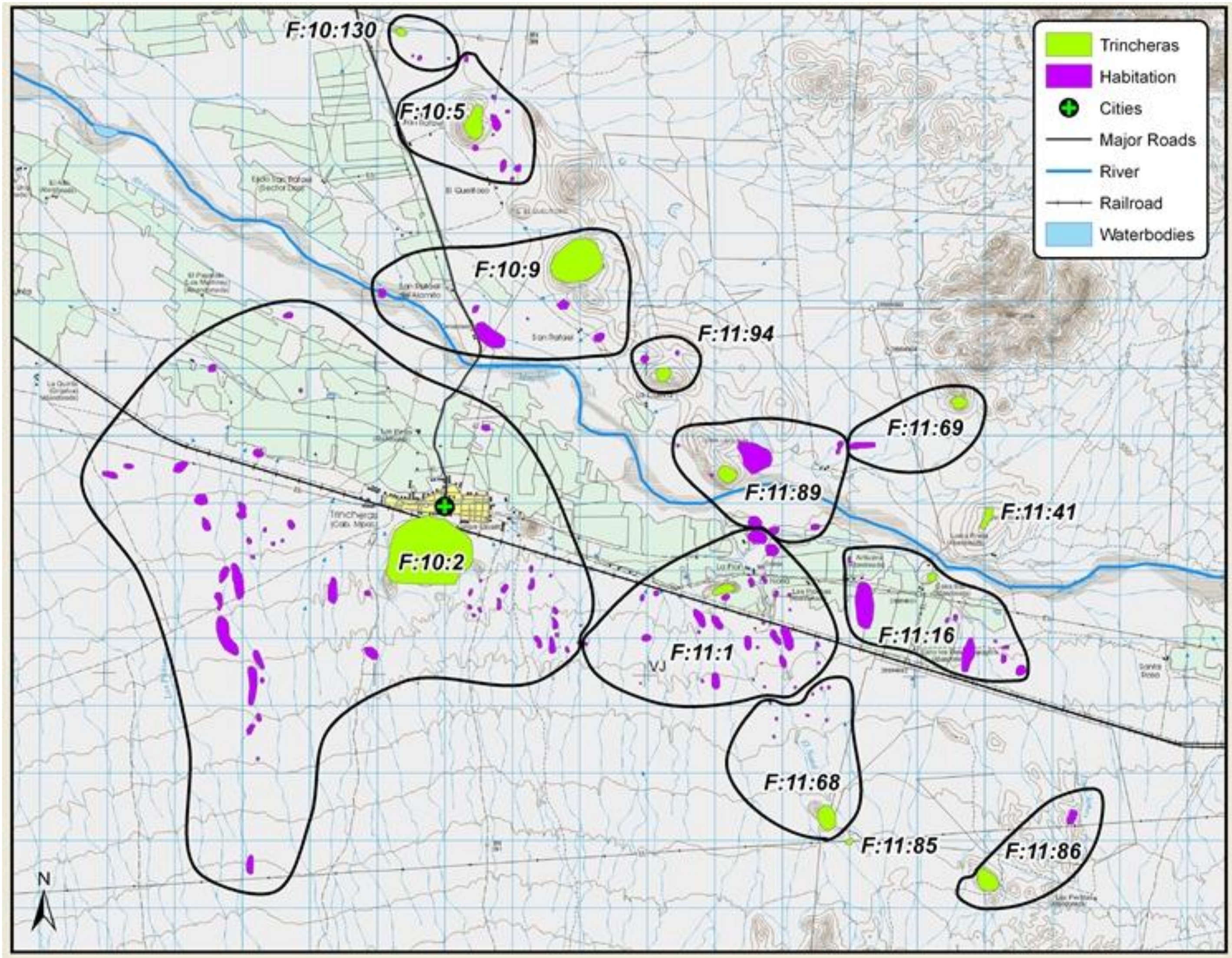

Figure 9. Village sites in the trade area of CerrosPhase *cerros de trincheras*, Magdalena Valley.

CONCLUSIONS

The main question of our GIS analyses has been whether the construction of terraces and walls on *cerros de trincheras* increased or decreased the inherent defensive nature of isolated volcanic hills. Secondarily, we sought to provide some insight into the spatial and temporal relationship between *cerros de trincheras*, and village sites. Our analyses of the three sites do suggest that defense was one major goal of these terraced hillsides. Our regional analyses in both the Río Altar and the Middle Magdalena Valley imply that each *cerro de trincheras* had a set of related valley floor villages associated with it.

FIGURE LIST

Figure 1. Cerro de Trincheras, western saddle visibility and likely ascent routes.

Figure 2. Tío Benino: Reference map of numbered sites.

Figure 3. La Hormiga: Reference map of numbered sites.

Figure 4. Tío Benino, visibility and likely ascent routes.

Figure 5. La Hormiga, visibility and likely ascent routes.

Figure 6. Village sites in the trade area of Altar Phase *cerros de trincheras,* Altar Valley.

Figure 7. Village sites in the trade area of Realito Phase *cerros de trincheras,* Altar Valley.

Figure 8. Village sites in the trade area of Atil/Altar Phases *cerros de trincheras*, Magdalena Valley.

Figure 9. Village sites in the trade area of Cerros Phase *cerros de trincheras*, Magdalena Valley.

TABLE LIST

Table 1. Reassessment of slope values based on climbing experiment.

Table 2. Terrace grid reclassification.

Table 3. Viewshed Reclassification values.

Table 4. Comparing the Cost Path values for the Cerro de Trincheras versus a non-terraced Cerro de Trincheras.

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Table 6. Cost path values for Tío Benino and La Hormiga.

Table 7. Count of *cerros de trincheras* and village sites in Altar Valley.

Table 8. Village sites in the trade area of *cerros de trincheras* in the Altar Valley.

Table 9. Count of *cerros de trincheras* and village sites in the Magdalena Valley.

Table 10. Village sites in the trade area of each *cerro de trincheras* in the Magdalena Valley.