Semi-Annual Technical Progress Report for
Adaptive Management and Planning Models for Cultural Resources in Oil & Gas Fields in New Mexico and Wyoming,
DE-FC26-02NT15445

Semi-Annual Technical Progress Report

January 1, 2004 – June 30, 2004

Principal Author: Peggy Robinson

July 2004

DOE Award Number: DE-FC26-02NT15445

Submitting Organization

Gnomon, Inc.
1601 Fairview Drive
Carson City, Nevada 89701

Subcontractors

SRI Foundation
P.O. Box 31865
Tucson, Arizona 85751-1865

New Mexico Historic Preservation Division
228 East Palace Avenue, Room 320
Santa Fe, New Mexico 87501

Wyoming State Historic Preservation Office
Barrett Bldg., 2301 Central Ave.
Cheyenne, Wyoming 82022

William Eckerle
Western GeoArch Research (WGR)
P. O. Box 521124
Salt Lake City, Utah 84152-1124

Stephen Hall
Red Rock Geological Enterprises (RRGE)
17 Esquina Road
Santa Fe, New Mexico 87508-9172

DISCLAIMER

ABSTRACT

This report contains a summary of activities of Gnomon, Inc. and five subcontractors that have taken place during the first six months of 2004 (January 1, 2004 – June 30, 2004) under the DOE-NETL cooperative agreement: *Adaptive Management and Planning Models for Cultural Resources in Oil & Gas Fields in New Mexico and Wyoming*, DE-FC26-02NT15445. Although Gnomon and all five subcontractors completed tasks during these six months, most of the technical experimental work was conducted by the subcontractor, SRI Foundation (SRIF). SRIF created a sensitivity model for the Azotea Mesa area of southeastern New Mexico that rates areas as having a very good chance, a good chance, or a very poor chance of containing cultural resource sites. SRIF suggested that the results of the sensitivity model might influence possible changes in cultural resource management (CRM) practices in the Azote Mesa area of southeastern New Mexico.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report summarizes activities that have taken place in the last six (6) months (January 2004 – June 2004) under the DOE-NETL cooperative agreement *Adaptive Management and Planning Models for Cultural Resources in Oil and Gas Fields, New Mexico and Wyoming* DE-FC26-02NT15445. This project examines the practices and results of cultural resource investigation and management in two different oil and gas producing areas of the United States: southeastern New Mexico and the Powder River Basin of Wyoming. The project evaluates how cultural resource investigations have been conducted in the past and considers how investigation and management could be pursued differently in the future. The study relies upon full database population for cultural resource inventories and resources and geomorphological studies. These are the basis for analysis of cultural resource occurrence, strategies for finding and evaluating cultural resources, and recommendations for future management practices. Activities can be summarized as occurring in either Wyoming or New Mexico.

Wyoming Activities:
Wyoming State Historic Preservation Office (WYSHPO) continued to enter cultural resource data into a master database and to create Geographical Information System (GIS) data to link to the database. All projects have been digitized for seven of the eight counties. A total of 33,276 inventory spatial entities have been created for the study area. The project has currently exceeded the estimated inventory creation records of 9,329 projects. A total of 11,830 (89%) sites have been digitized. A total of 5091 sites have been encoded into the extensive site attribute database. Encoding is currently focusing on sites with known buried components and radiocarbon dates. This dataset will be used to test the geomorphological model prepared in Task 10. Approximately 50% of all sites in the eight counties have been encoded. Overall, entering data into the master database is currently five months ahead of the projected project schedule. Encoding of the Powder and Tongue River Basins has been completed and initial training on the new tracking tool has taken place.

William Eckerle of Western GeoArch Research continued to work on the geomorphology of the Power River Basin of Wyoming. He completed analysis of soils data and creation of meaningful stream buffers and completed the first draft of a sensitivity study for the Wyoming study area. This was presented at a PUMP III meeting in Wyoming. He began work on the protocol handbook summarizing fieldwork documentation, and continues to refine the sensitivity models.

New Mexico Activities:
The Archaeological Records Management Section (ARMS) of New Mexico Historic Preservation Division (NMHPD) continued to enter data for cultural resource sites and surveys into a master database. In addition they created GIS data showing the locations of these sites and surveys and linked the GIS to the data. After ARMS delivered extracts of these data for Loco Hill, Azotea Mesa, and Otero Mesa to SRIF in 2003, they moved on to work on three one-degree lat/long blocks of 64 quads each to extend the area where they have good data in southeastern New Mexico. To date they have completed all of block 32103 and 32104 and 50% of block 32105.

Stephen Hall of Red Rock Geological Enterprises (RRGE) completed data entry of SSURGO data (soils) and geomorphology maps for Otero Mesa and Gnomon digitized the geomorphology maps and delivered these to SRIF. Hall completed writing the geomorphology section of *The*

Azotea Mesa Technical Summary in February and for *The Otero Mesa Technical Summary* in May 2004. He started work on his draft of Chapter 6 for the New Mexico final report outlining the work he conducted on the geomorphology of the three study areas in New Mexico.

SRIF created a sensitivity model for the Azotea Mesa area of southeastern New Mexico that rates areas as having a very good chance, a good chance or a very poor chance of containing cultural resource sites. They wrote *The Azotea Mesa Technical Summary* that summarizes these data and sent it out for peer review in May. The authors are: Jeffrey H. Altschul, Lynne Sebastian, Chris M. Rohe, William E. Hayden, and Stephen A. Hall.

The data used to create the sensitivity model included:

- Primary environmental independent variables*:* GIS layers of elevation (digital elevation model [DEM] created by the United States Geological Survey [USGS]), vegetation (Gap Analysis Program of the USGS), and geomorphology (GIS layer created by Gnomon based on analysis completed by Red Rock Geological Enterprises).
- Secondary environmental independent variables*:* slope, aspect, distance to water, cost to water (derived from DEM).
- Dependent variable archaeological data*:* ARMS provided GIS data indicating the areas in the Loco Hills study area where archaeological surveys have been conducted, sites that have been recorded, and various characteristics of those sites.

SRIF concluded that the predictive models had limited predictive success, because they do not allow one to confidently identify high and low archaeological probability areas for planning purposes. This may be partially as a result of the fact that the scale of the study area was not large enough and the environmental attributes of the area are very homogenous. SRIF suspects that the human adaptation to this environment included resources from the mountains to the west and resources to be found along the Pecos River to the east. Larger residential settlements were almost certainly located outside our study area. People would have moved into and through the study area in small groups, sometimes specifically to procure targeted animal, plant, or mineral resources, and other times expediently collecting plants and game animals as they moved through the area while passing from one resource zone to another. Under this scenario, the areas of higher site probability are associated with drainages because this is where most of the specifically targeted resources would have been found and because these would have been the routes of travel between the riverine and montane resource zones.

Even though the predictive success of the models was low, the dendritic patterning of the areas of higher probability of containing sites is very clear and could be useful for planning. In the still-to-be developed portions of the Azotea lease area, concentration of lease-related developments, including roads and ancillary facilities such as power lines, in low probability areas could reduce both the risk of encountering sites during lease development and the risk of long-term and cumulative damage to sites as a result of well servicing.

The results described in *The Azotea Mesa Technical Summary* indicate that the current CRM practices in the Azotea Mesa area of southeast New Mexico are probably not the best possible practices. The summary concluded with these points:

1. Cultural resource surveys in the Azotea Mesa study area in southeastern New Mexico that are required in areas of oil and gas exploration tend to be linear. This method

provides reasonable data for the creation of predictive models that associate human settlement with environmental features.

2. There has been a great deal of re-survey of land and re-recording of sites in the Azotea Mesa study area.
3. The study area is too small and too homogenous to discern human patterns in settlement and land use. To make the models more useful the study area should be expanded to include the Pecos River in the east and the Guadalupe Mountains in the west. This would provide more environmental diversity.
4. Excavation data from a representative sample of the sites in the Azotea Mesa lease area would help provide understanding of the function and temporal placement of sites in this area, and their potential role in the larger settlement system of which they were a part. This would help archaeologists make well-founded decisions about the significance of the archaeological sites found on Azotea Mesa.
5. In undeveloped areas of Azotea Mesa concentration of lease-related developments, including roads and ancillary facilities such as power lines, in low probability areas could reduce both the risk of encountering sites during lease development and the risk of long-term and cumulative damage to sites as a result of well servicing.
6. There is a need to be cognizant of the highly variable quality of the data that have been contributed to NMCRIS over the years. Some large sites were recorded as points and some small sites with large boundaries. The problems in the past may be very difficult to correct, but it is important to have a strong quality assurance program in place now to ensure that future work does not repeat these errors.

EXPERIMENTAL

Experimental Apparatus Used to Complete the Sensitivity Model for the Azotea Mesa Study Area

IDRISI GIS) software installed on standard desktop computers.

ESRI ArcGIS 8.x GIS software installed on standard desktop computers.

Topcon mirror binocular stereoscope at X3 magnification to analyze photographic data (see "Environmental independent variables [primary themes]" below) to identify landforms.

Experimental and Operating Data Used to Complete the Sensitivity Model for the Azotea Mesa Study Area

Location and Topography

The Azotea Mesa study area (Figure 1) is rectangle covering approximately 1200 square kilometers (460 square miles) and located immediately west and southwest of the city of Carlsbad; the easternmost edge of the study area actually includes part of the city. The Pecos River runs through the northeastern corner of the study area, and the western escarpment of the river valley runs north/south through approximately the center of the study area. The southwestern corner of the study area contains a small section of the lower slopes of the Guadalupe Mountains.

Elevations within the study area (Figure 2) vary from about 1700 meters (5600 feet) in the southwest to 950 meters (3100 feet) in the northeast; the edge of the Pecos Valley escarpment is at about 1200 meters (3950 feet).

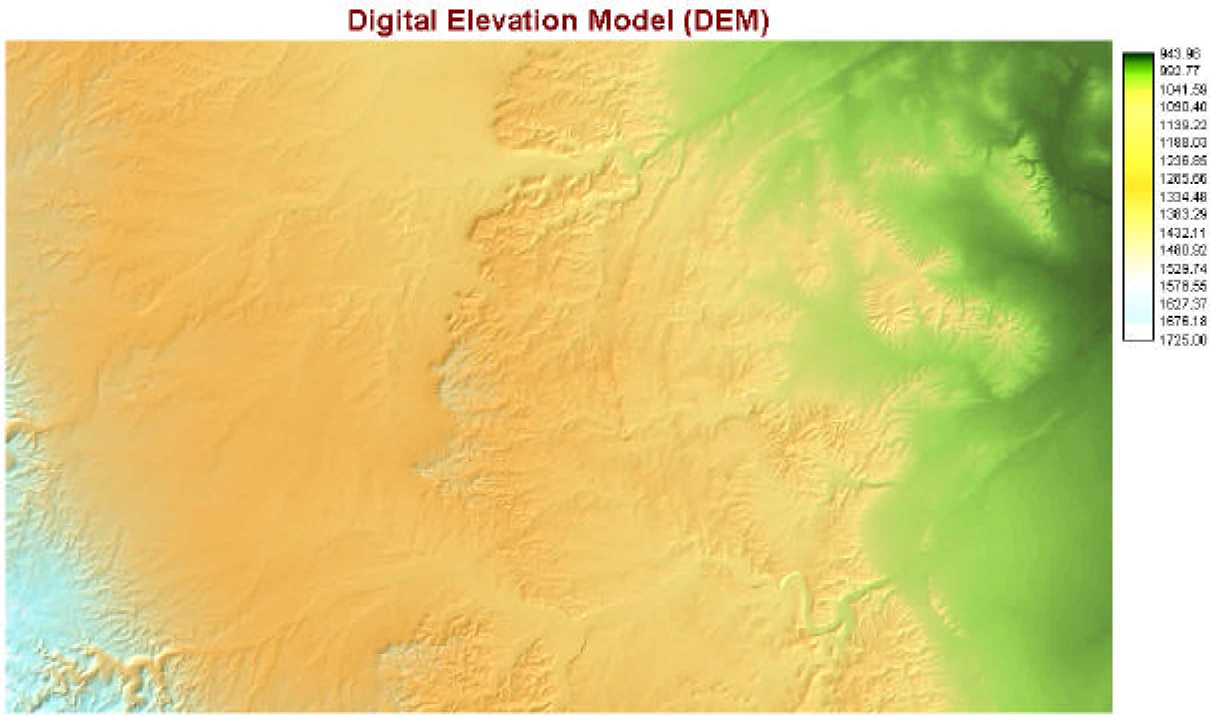

Figure 2. Terrain of the Azotea Mesa study area

Geomorphology

The Azotea Mesa project area (Figure 3) is characterized by marine Permian (late Paleozoic) limestone bedrock. A few small streams have eroded moderately deep canyons. The limestone hills are largely denuded of sediments and soils. The limestone is karstic with several sinkhole depressions, especially in the western portion of the project area.

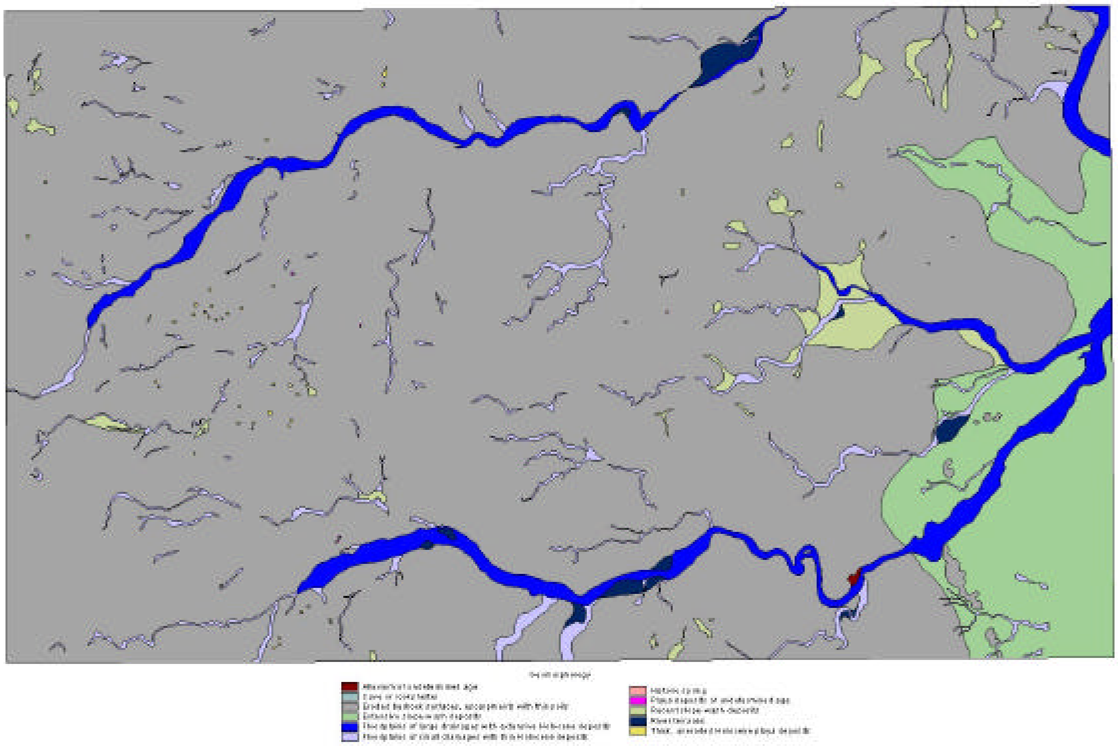

Figure 3. Geomorphology of the Azotea Mesa study area

Eroded bedrock surfaces The most prominent geomorphic characteristic of the project area is denuded limestone bedrock. The modern surface of the entire project area is eroded limestone with the exception of stream deposits and areas of low-gradient colluvial flats.

Erosion of old soils that once mantled the landscape and the continued denudation of the limestone may have been initiated during the transition from glacial-age to postglacial-age vegetation and climate about 14,000 to 12,000 years ago. Today, the old soils are gone and Permian limestone occurs at the surface. Accordingly, archaeological sites are found on the eroded surface and are not buried in soils or deposits. Thus, sites have 100 percent visibility over much of the project area, although because these sites have not been buried and have always been exposed at the surface, site integrity may be low, owing to continual erosion and bioturbation.

Alluvium The streams in the area are generally high-gradient and incorporate thick deposits of limestone gravels. Topographically high late Pleistocene terraces are preserved in wider stretches of the narrow canyons, while the stream channels and adjacent floodplains are characterized by Holocene deposits. Most of the deposits are coarse gravels, and very little of the sediment fill is fine textured. While many stream valleys contain young deposits, buried archaeological sites may be rare because of continued scour-and-fill processes that dominate the development of these streams. Sites may be more commonly present and preserved on higher flat terrace surfaces adjacent to stream channels and along valley margins.

Colluvium Colluvial silt deposits occupy a large area west of the community of Carlsbad in the eastern portion of the project area. The colluvium is composed of uniformly massive silt (44 percent), very fine sand (25 percent), and clay (24 percent) with occasional scattered small pebbles of caliche and limestone. The colluvium in the Carlsbad area is in excess of 1 m thick and mantles coarse limestone gravels that represent older (Pleistocene) alluvium and alluvial fans derived from adjacent canyons. Thin mantles of recent colluvium also occur in small areas of low-gradient terrain in the eroded limestone hill country, especially along stream valleys and upland drainages.

The nature and origin of the colluvial deposits have not been previously investigated. The fine texture and recent age of the sediments, however, suggest that they may represent a thin veneer of late Pleistocene loess on the limestone hills that subsequently has been washed and eroded from the hills and redeposited as fine alluvium and colluvium. A second possible explanation is that the fine-textured sediments are a clastic residue from the weathered Permian limestone.

Archaeological sites may be buried in the Holocene colluvium, although none were seen in the field. The fine texture of the colluvium attracts burrowing animals that, over the centuries, will have obliterated archaeological site stratigraphy.

Summary Most of the Azotea Mesa project area is terrain characterized by denuded Permian limestone. Archaeological sites will have 100 percent visibility, although the integrity of artifacts and features will be low because of erosion and bioturbation. Large and small areas of colluvium may also incorporate archaeology, although the colluvium is likely to be strongly bioturbated, resulting in loss of site stratigraphy. Streams in the area are characterized by thick deposits of coarse limestone gravels. While buried sites may occur in the coarse alluvium, they are more likely to occur on flat terrace surfaces topographically above channels and along valley margins.

Climate

The climate in southeastern New Mexico is semi-arid with hot summers and mild winters. During the period 1914–2003, average high temperature in July was 96 degrees F, although daytime temperatures over 100 are very common. The highest recorded temperature was 114 degrees. The July low temperatures averaged 67 degrees F, although nighttime temperatures in the 70s are very common. The average high temperature in January was 59 degrees F with an average low of 28 degrees F, although daytime temperatures in the 60s and even 70s and nighttime temperatures in the teens are not uncommon. The frost-free season averages 200 days per year.

Average annual precipitation varies substantially with elevation. Over the period 1914–2003, the average in Carlsbad was 12.6 inches per year, with most of the precipitation falling between May and October. The primary source of this summer precipitation is moist, warm air that pushes inland from the Gulf of Mexico. The moist air combined with surface solar heating, results in localized afternoon and evening thunderstorms. During the winter months, the main source of moisture for precipitation is Pacific storm systems, and the Guadalupe Mountains to the west of the study area tend to block many of these systems. A combination of high evaporation rates (approximately 100 inches per year) and frequent strong winds, especially in the spring, contribute to the aridity of the climate and the xeric nature of the vegetation.

Vegetation

As Figure 4 shows, most of the vegetation in the study area is Chihuahuan desert grassland, dominated by black grama (*Bouteloua eriopoda*) and dropseed (*Sporobolus flexuosus*), and desert scrub dominated by creosotebrush (*Larrea tridentate*), with some areas of chaparral. In the highest elevations there is an open woodland of one-seed juniper (*Juniperus monosperma*).

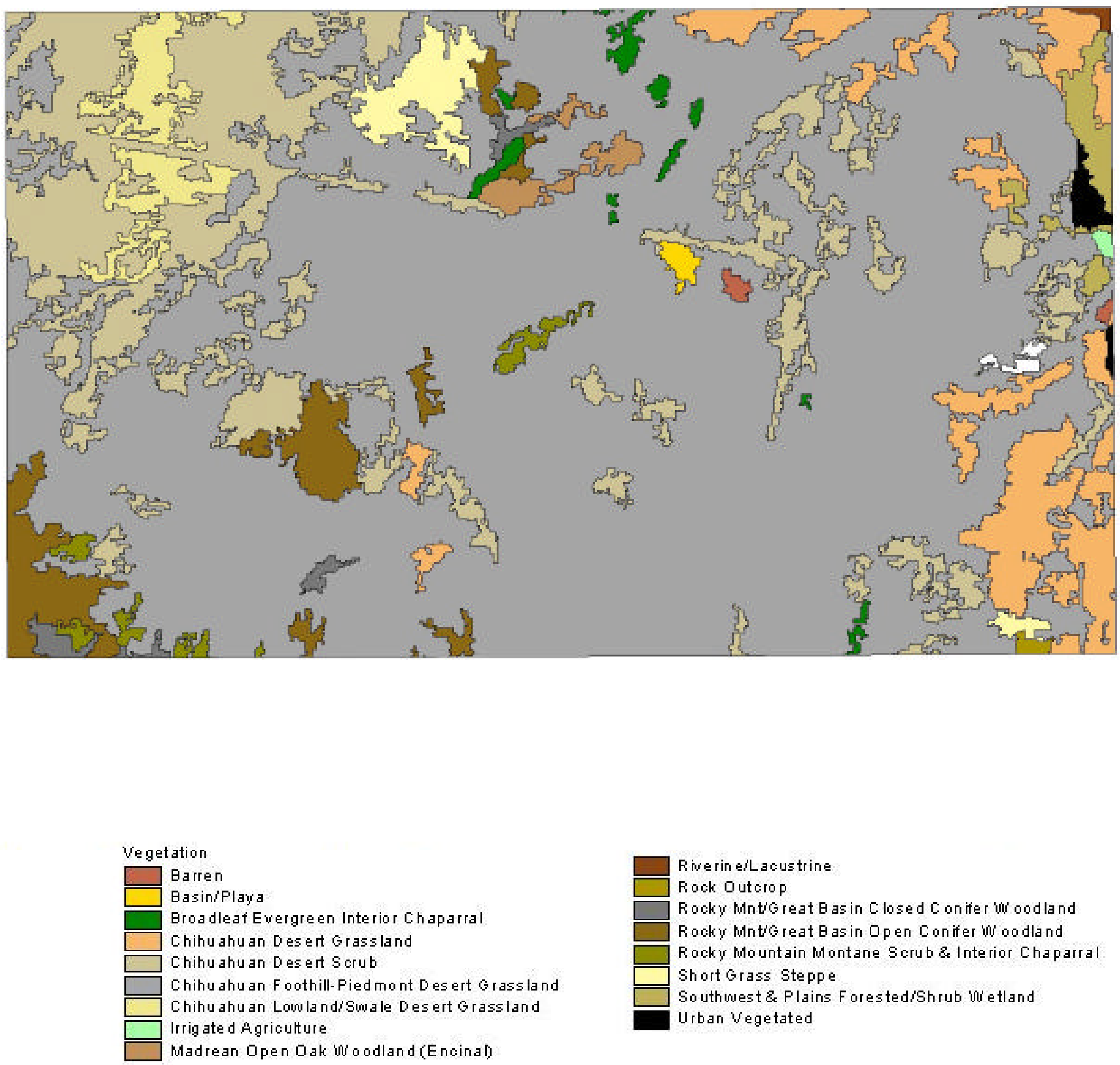

Figure 4. Vegetation of the Azotea Mesa study area

Predictive Models

One of the goals of the PUMP III project is to use spatial modeling techniques to assist in the interpretation and management of cultural resources that may be affected by oil and gas development. The premise of this aspect of the project is that human behavior is patterned, and that decisions about where to place settlements on the landscape are likewise patterned. These patterns are conditioned by a variety of influences, many of them environmental. Human settlements, therefore, should be correlated to some degree with environmental features. If we can determine which features, and find ways of objectively measuring the correlations, then we can predict where, within a given landscape, we might expect to find archaeological sites.

Environmental Data

In developing predictive models, we begin by assembling data on all types of environmental variables, some of which will be found to be correlated with archaeological sites, others of which will not. We need to ensure that we cast our net wide enough so that the variables used in modeling will include those that most strongly affected human decision-making about where activities will be carried out.

As noted above, the eastern boundary of the Azotea Mesa study area lies within the city of Carlsbad and the western boundary just to the east of the Guadalupe Mountains. The study area incorporates very little environmental diversity and consists mostly of relatively flat eroded bedrock surfaces. Soil is thin and dissected by a braided network of small drainages that ultimately feed two larger east flowing washes. The Pecos River is just to the east of the study area; a very short segment of the river actually runs through the northeastern corner.

Azotea Mesa does not represent an ideal setting for predictive modeling because the study area lacks environmental diversity and was almost certainly marginal in terms of the types of resources sought by indigenous people. The lack of places where either a particularly favored resource exists in abundance or a variety of resources coalesce leads us to suspect that there was no impetus to establish seasonal or permanent settlements or even logistical base camps. Observations of modern and ethnohistoric foragers suggest that humans would most likely have established short term camps at or near specific targeted resources, exhausted those resources, and then moved on to another similarly situated camp.

These expectations appear to be substantiated by the nature of the archaeological resources recorded during surveys performed in conjunction with lease development in the Azotea Mesa oil and gas field. The vast majority of the 550 archaeological sites recorded are small artifact scatters that cannot be distinguished from one another in terms of time of occupation or function. This lack of both environmental and cultural diversity within the study area means that correlative models that use environmental variables to predict archaeological site locations will not work well.

Although not ideal, Azotea Mesa does represent a real life situation. It is where energy-related development is occurring, and it is where cultural resources will be affected by that development. The management goal for this area is to determine where cultural resources are most likely to be found in order to make informed decisions about development locations. Our goal, then, is to identify subtle associations between past land use and the environment and, to the extent that we can identify these associations, to magnify them so that the predictive power is increased.

The environmental variables used in predictive models are best viewed as proxy variables and not as aspects of the environment that humans would have specifically targeted when making decisions about where to locate activities. Humans use a complicated and largely intuitive “calculus” in assessing potential locations in which to live, obtain and process resources, and commune with the gods. People do not generally measure the slope of the land where they place their house or measure the exact distance to water, but they do choose land that is flat and near water. The indigenous people of Azotea Mesa probably did not know, much less care, at what elevation they placed their camps, for example, but they certainly knew where the stands of black grama and tobosa grasses occurred. Elevation, though it would not have been part of any consciously applied prehistoric “calculus,” is strongly correlated with the vegetative communities of southeast New Mexico, and thus can be used as a predictor of site location.

We restricted our search for environmental data to those that already existed in digital formats and could easily be converted into layers in a geographic information system (GIS). We used the IDRISI GIS package to store data, calculate the statistics, and display the results of the predictive models for Azotea Mesa. This GIS package is a raster-based system as opposed to a vector-based system; that is, instead of storing the data in shape files, the program imposes a grid of a specified size over the area and codes each cell with specific information. We chose a 30-by-30-m cell as our grid size, which generated 1,622,691 cells for the Azotea Mesa study area.

To build the layers of environmental variables, we obtained GIS data covering elevation, vegetation, and geomorphology. Because these data relate to empirical observations (e.g., someone actually measured the elevation of some of the points in the project area), these layers are termed primary themes. It is important to point out that in GIS the designation primary theme does not mean that the score of each cell was derived from an empirical observation, only that the interpolation is based on source data. For example, the elevation theme is a digital elevation model (DEM) created by the United States Geological Survey. DEMs are created by interpolating between a set of points with known elevations at a specified contour interval. In the case of Azotea Mesa, the contour interval is 40 feet. The DEM for Azotea Mesa is shown in Figure 5.

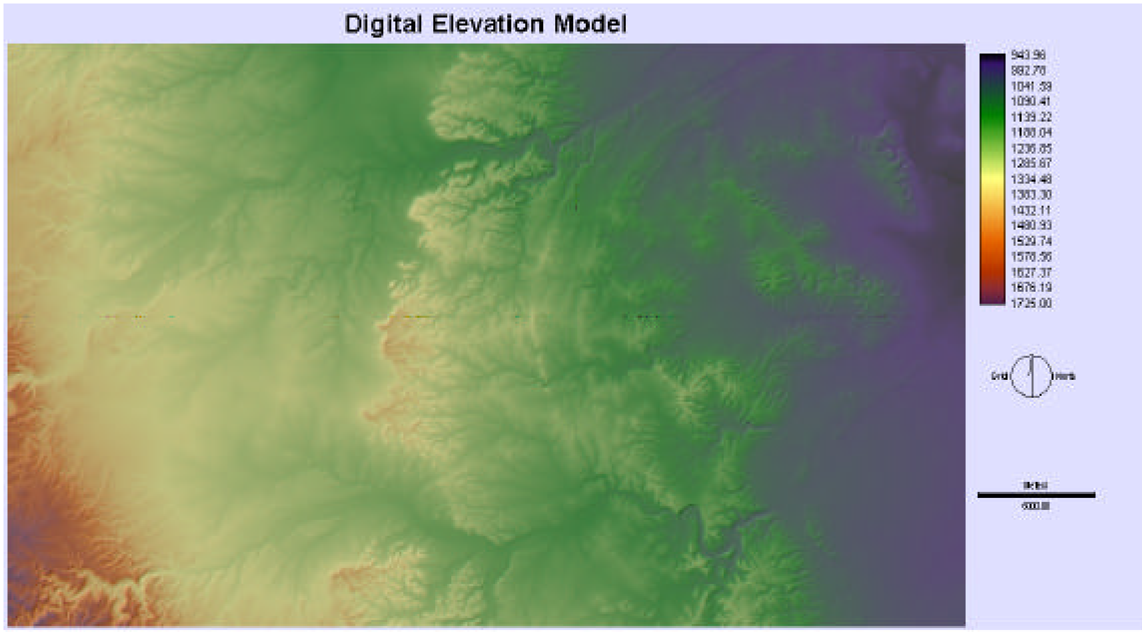

Figure 5. Digital Elevation Model (DEM)

Algorithms exist within GIS packages to transform data from primary themes into derived, or secondary, environmental themes. In many cases, DEMs serve as the primary data theme from which secondary themes, such as slope and aspect, are created. As an example, IDRISI calculates the slope (Figure 6) of a given cell by using the elevation scores of the four cells located to its north, south, east, and west to compute an “average” slope. Similarly, “aspect,” or the prevailing direction of exposure of the cell, is calculated by determining whether the elevation of the subject cell is higher or lower than each of its eight neighbors, and then assigning the direction to which the cell is “open” as its score.

Five secondary themes were developed to display the distance from a particular cell to specific environmental variables: distance to streams, distance to ridges, distance to stream intersections, cost distance to streams (stream cost), and cost distance to ridges (ridge cost). To create these variables, we first had the GIS use the DEM data to create a layer showing major streams and ridgelines (Figure 7). From this layer, the GIS then computed the shortest distance from each cell to the closest stream or ridgeline. Distances from major stream intersections were also computed.

The cost distance variables use slope and distance to compute the effort required to travel between a cell and the nearest stream or ridgeline. The algorithm used by IDRISI generates a distance/proximity surface (also referred to as a cost surface) in which distance is measured as the least effort required to move over a friction surface. For Azotea Mesa, the friction surface was defined as the slope. The unit of measurement in the cost variables is termed "grid cell equivalents" (gce). A gce of 1 is the cost of moving through a grid cell when the friction equals 1. A cost of 5 gces might arise from a movement through 5 cells with a friction of 1, or 1 cell with a friction of 5. Thus, a high cost indicates either a long distance over a flat surface or a much shorter distance up a steep slope.

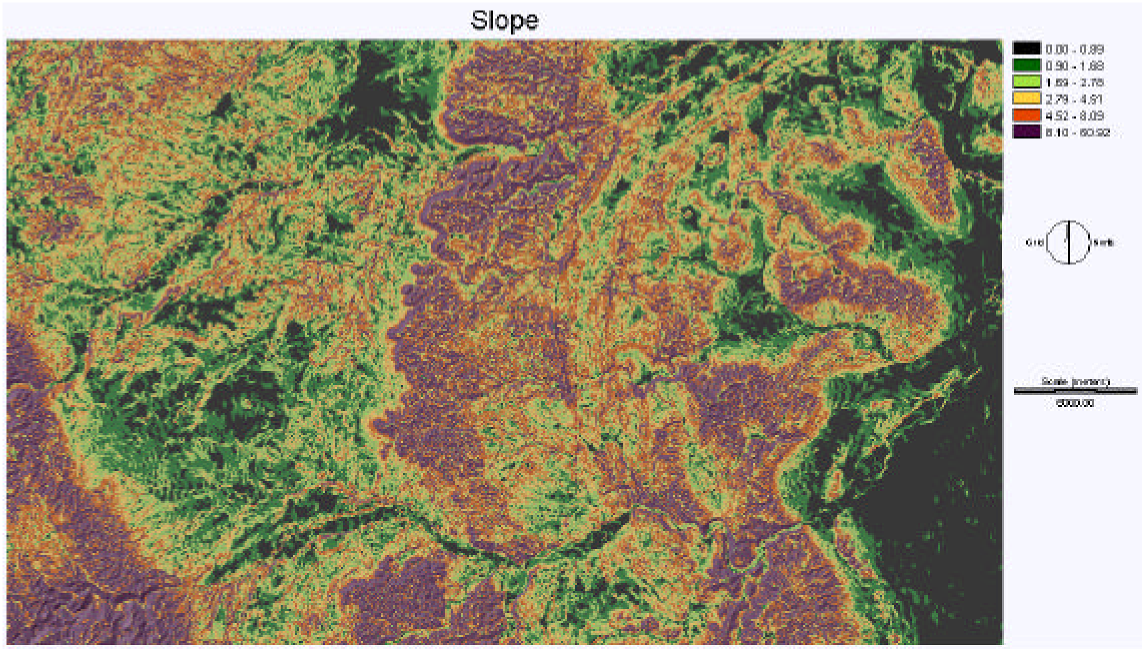

Figure 6. Slopes for Azotea Mesa

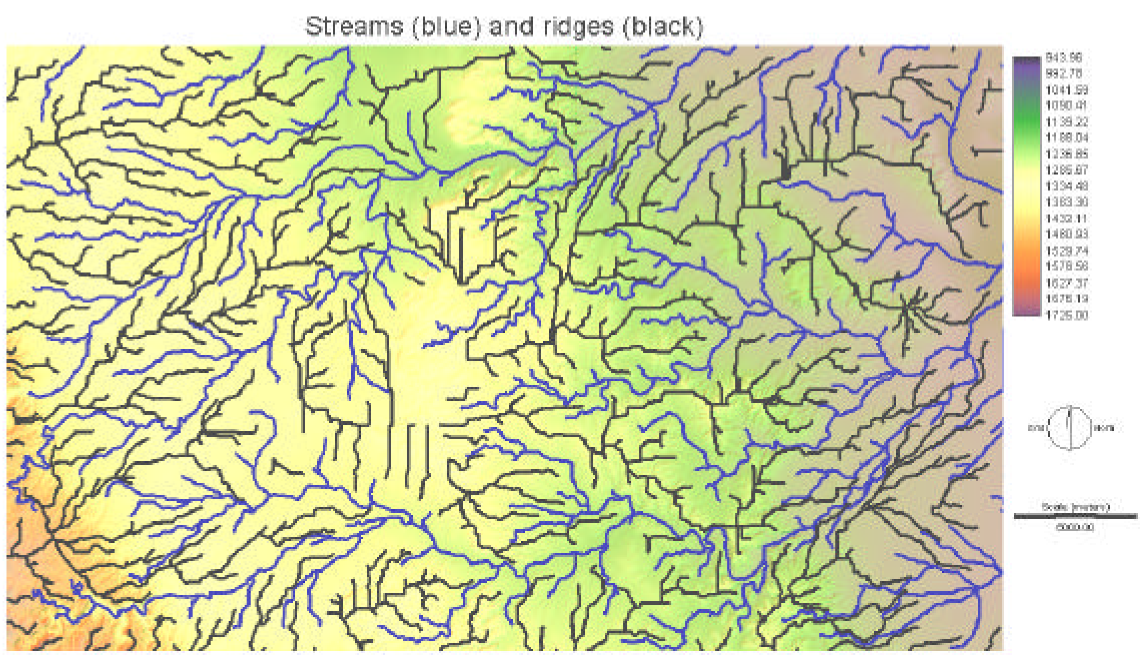

Figure 7. Streams and ridges for Azotea Mesa

In addition to the environmental themes based on the DEM, we acquired a vegetation layer and a geomorphology layer. The vegetation data (Figure 4 above) are from the Gap Analysis Program (GAP) of the USGS, which provides information on biodiversity and conservation gaps. The data comprise major vegetation categories that are divided into 17 subcategories, based upon common descriptions of vegetation**.**

The geomorphology data (Figure 3, above) were provided by Gnomon, Inc., based on maps prepared by Steve Hall of Red Rock Geological Enterprises. The Azotea Mesa study area was mapped using black-and-white stereo aerial photographs (scale about 1:52,000) and color infrared stereo aerial photographs (scale about 1:86,000) available from the EROS Data Center, Sioux Falls, SD. Landforms were identified from the stereo aerial photographs using a Topcon mirror binocular stereoscope at X3 magnification, and the location and spatial distribution of the landforms were then plotted on 7.5-minute topographic maps (scale 1:24,000), the base-map standard for this project. Landforms smaller than about 200 feet in greatest dimension (ca. 1/10 inch on topographic maps and smaller yet on the aerial photos) were not mapped.

An examination of Figures 3-5 makes very clear the high level of uniformity in the environment within the study area. Even before we examined the archaeological data or began the modeling process, the lack of variability within the environmental themes gave us reason to be concerned about the effectiveness of correlation models at the scale of this study area.

Archaeological Data

The dependent variable in the Azotea Mesa model is the presence or absence of precontact archaeological sites. Archaeological data were obtained from the New Mexico Historic Preservation Division's Archaeological Records Management System (ARMS). ARMS provides data on areas that have been subject to archaeological surveys, the sites that have been recorded, and various characteristics of those sites. Ideally, for this predictive modeling exercise we would have created a series of models by dividing the sites into classes based on time of occupation and/or function. Unfortunately, current knowledge about the archaeological record within the Azotea Mesa study area is not sufficiently to allow us to classify sites into temporal or functional classes. The most apparent categories of sites in the ARMS database for this study area are those based on site size, which could be an indicator of differences in site function, length of use, and/or the number of times of use. Although very few sites in this area have dates associated with them, we were at least able to distinguish between post-European contact and precontact sites. Because these two temporal categories represent fundamentally different cultural systems, we excluded postcontact period sites from the predictive models.

Site Data. The archaeological site data provided by ARMS are shown graphically in Figure 8. Because the data used in the models are in vector format, a GIS convention that stores spatial data using corresponding point, line, or area features, the site data were provided as polygons, where every site is represented as an area within the GIS theme. Each site polygon is also linked to related information such as area, site number, and a site description.

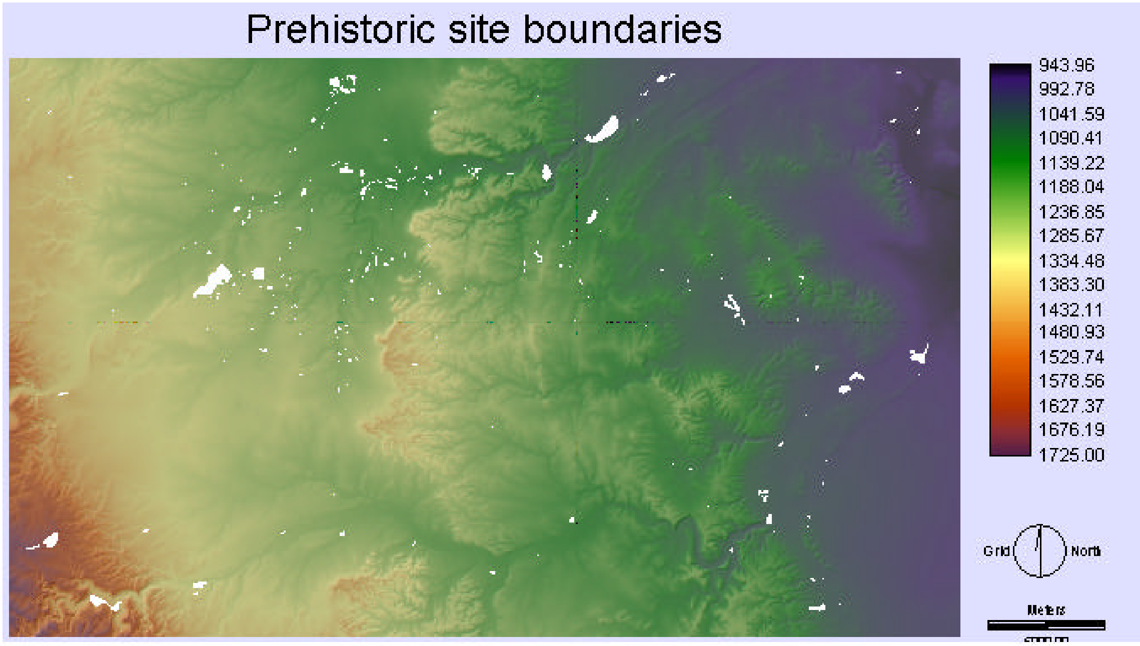

Figure 8. Recorded precontact archaeological sites of Azotea Mesa

GIS data are spatially oriented in real world coordinates. The ARMS data were already georeferenced in Universal Transverse Mercator (UTM), Zone 13 grid format, using the North American Datum of 1927, which was converted to the North American Datum of 1983. The UTM georeference system is common for archaeological applications and measurements on the x and y axes are given in meters.

The site data originally contained 935 polygons, each of which supposedly represented one archaeological site. This number was reduced to 550 polygons by combining sites whose polygons overlapped and removing all single component, historical/Euroamerican sites. The resulting 550 polygons were converted to raster format for modeling purposes. Sites were transformed into blocks of 30-by-30-m cells that encompassed each polygon. The site layer created in this fashion consisted of 12,155 cells coded ‘1’ where a portion of one of the sites was found in that cell and 1,610,536 cells coded ‘0’ because they did not contain any portion of any of the sites.

Nearly all sites on Azotea Mesa are recorded as artifact scatters. Few have features, and even fewer have temporally diagnostic artifacts. Because the only measurable differences among the sites was size, we divided them into five size classes: very small, small, medium, large, and very large (Table 1). Ninety percent of the sites on Azotea Mesa can be classified as very small (< 7 acres), with another 7 percent falling into the small category (8-26 acres). The sites falling into the medium class (27-60 acres) account for nearly 2.5 percent of the total number of sites.

Although very small sites represent 90 percent of all sites, they constitute less than 25 percent of all site cells, while large and very large sites (those > 61 acres), which combined constitute just over 1 percent of all sites, comprise more than 35 percent of all site cells.

Table 1. Site breakdown by size

Classification	***Acres***	***# of sites***	***Percentage of site pixels***
Very small	0.1- 7	494	24
Small	8 – 26	37	18
Medium	27 - 60	13	22
Large	61 - 100	4	11
Very large	>100	2	25

We wanted to explore the disparity in site size in the course of the modeling exercise, because we postulated that the differences in site size might reflect prehistoric behavioral patterns. The larger sites, for example, might have functioned as base camps, whereas the smaller sites might have served as resource procurement camps. If the size differences did, in fact, represent functional differences, we would expect the placement of these sites to be governed by different cultural rules. The choice of location for a base camp should be based on a number of factors, such as availability of potable water and large, flat spaces in which multiple domestic groups could camp together. Resource procurement camps, on the other hand, should be located close to the targeted resource, with less regard for factors of slope and the availability of water. Of course, other behavioral interpretations could be forwarded. Our purpose here is not so much to provide an analytical interpretation as it is to discern patterns in the data that could guide and inform future research.

To assess whether site size is related to settlement location, we split the sample. Very small sites were not used in the model formulation, instead they served as "test" cases. If we found no difference in the settlement preferences for sites of very different sizes, then we could argue that sites of all sizes followed the same behavioral "rules" in terms of placement. If, on the other hand, sites of different sizes were found to be located in slightly different environmental settings, this might indicate that adaptive patterns on Azotea Mesa were more complex than simple foraging and involved a number of related but differentiated site types.

Survey Data. In addition to the archaeological site data, ARMS provided data on all of the archaeological surveys that had been performed within the Azotea Mesa study area through the 2002 cutoff date (Figure 9). The data are stored as polygon features, in which every survey is represented as an area within the GIS. Each survey polygon is linked to related information such as area, identification number, and some basic methodological descriptions within the vector database. The ARMS survey data were georeferenced in Universal Transverse Mercator (UTM), Zone 13 grid format, using the NAD27 datum. The ARMS data included information on 1,233 surveys totaling 33,960 acres.

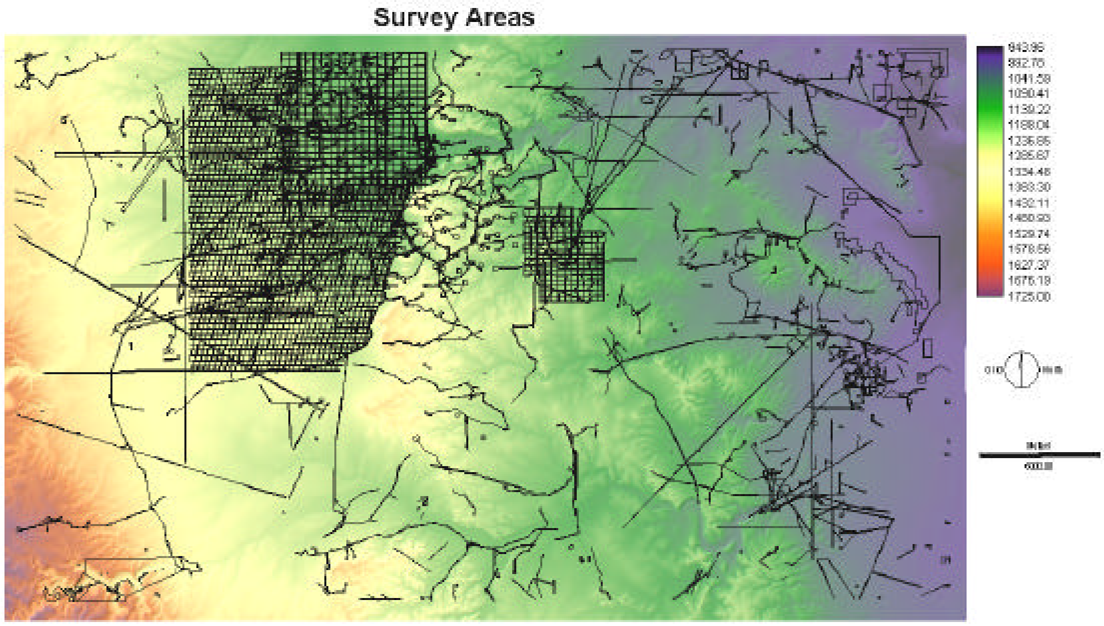

Figure 9. Survey data from Azotea Mesa

Data Reduction in the Sensitivity Model for the Azotea Mesa Study Area

Confidence and Statistical Independence

Once the environmental and cultural resource data had been acquired and the GIS layers assembled, each environmental theme was reviewed to determine whether the areas covered by archaeological surveys adequately represent the target environmental attributes. If the environmental variability within the survey areas is representative of the environmental variability within the study area as a whole, we can have confidence that any association between the environmental variables and site location found in the models is an accurate reflection of the relationship between environment and site locations in the larger project area.

Ideally, of course, surveys would have been designed and carried out to ensure adequate sampling of the environmental zones through probabilistic techniques. In reality, the surveys were performed as part of compliance procedures for natural gas development; they were located without reference to environmental factors and with no attention t providing a “random” sample in the statistical sense.

We began our efforts to assess the representativeness of the Azotea Mesa survey data by examining Figure 9. It is clear that linear surveys, such as those performed prior to road construction or seismic exploration, have occurred throughout Azotea Mesa. These surveys have sampled all environmental settings to some degree. Leasehold developments, in contrast, have been concentrated in two blocks in the northwest and north central portion of the study area. It was possible, then, that there were strong biases in the sample represented by the archaeological surveys.

If we are going to generalize from the results of the compliance-driven cultural resource surveys, we must first demonstrate that there is no bias in the survey coverage. If we are unable to demonstrate that the survey data are unbiased, we need to compensate for any bias before generalizing the relationship between environmental variables and archaeological site locations found in the surveyed areas to the larger study area. We have found that a simple visual assessment often provides the confidence needed to proceed with the modeling exercise.

We begin by creating a histogram of the distribution of the individual values for a particular environmental variable for the entire study area. This histogram is then compared visually with a similar histogram for the areas covered by archaeological surveys. If the two histograms are similar in shape, and if the surveys cover at least 9-10 percent of the variable's area, then we can assume that the raster cells that fall in the surveyed areas can be taken as a representative sample for that particular environmental variable. As an example of this process, the histogram for the slope of all cells in Azotea Mesa (Figure 10) is nearly identical to that for cells that have been covered by archaeological surveys (Figure 11), indicating that all slopes present in Azotea Mesa are adequately represented by the surveyed areas.

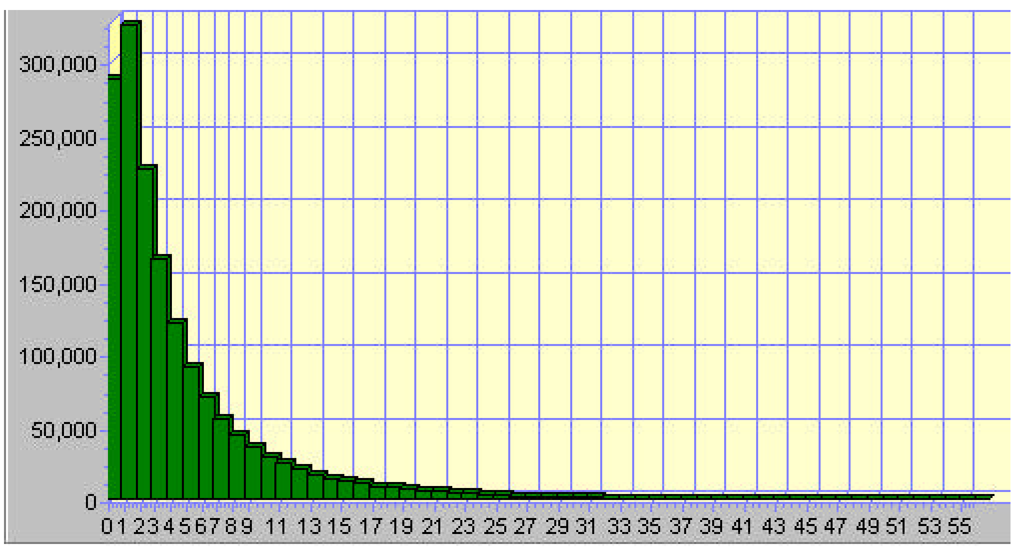

Figure 10. Slope values for the entire Azotea Mesa study area (mean = 4.57 degrees)

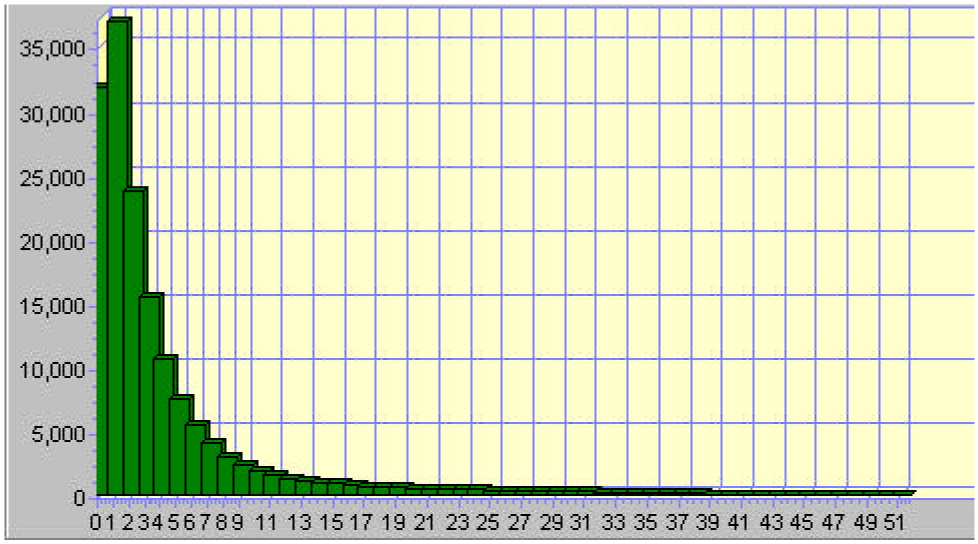

Figure 11. Slope values for the surveyed cells within the Azotea Mesa study area (mean = 4.39)

Similar pairs of histograms were generated and visually compared for all environmental variables. This analysis indicated that the surveyed cells adequately represent the values for all environmental variables.

Beyond demonstrating that the environment of the surveyed areas adequately represents the general Azotea Mesa environment, we want to be sure that the environmental variables that will be used in the predictive models are statistically independent of each other. Statistical independence is an assumption of most statistical techniques that involve multiple variables. Violations of this assumption often lead to overstating the predictive power of the resulting model. For example, soils and vegetation are often very closely related; that is, certain vegetation only grows on particular soil types. By including both variables as predictors, one runs the risk of having the predictive value inflated.

To guard against including independent variables that are related to each other, we calculated the pair-wise Spearman's *r* between each environmental variable (Table 1). No *r* score exceeded 0.6, and all but three were below 0.5. Based on these results, the variables being used as predictors in the models can be taken as statistically independent. To further test this conclusion, we calculated the logistic regression model both with and without using the three most interrelated variables: slope, cost distance to streams, and cost distance to ridges. The results of the two logistic regression models were very similar(*r* score of 0.92).

Table 2. Pair-wise Spearman's *r* scores for environmental variables.

	Elev.	Geomor-phology	Veg	Slope	Aspect	Dist to water	Cost dist to water	Dist to ridges	Cost ridges	Dist strm int
Elevation	1									

	Elev.	Geomor-phology	Veg	Slope	Aspect	Dist to water	Cost dist to water	Dist to ridges	Cost ridges	Dist strm int
Geomorpho logy	-0.42	1								
Vegetation	-0.11	0.23	1							
Slope	0.31	-0.26	-0.07	1						
Aspect	0.05	-0.13	0	0.14	1					
Distance to water	0.19	-0.19	-0.16	0.13	0	1				
Cost distance to water	0.46	-0.28	-0.20	0.6	0.04	0.59	1			
Distance to ridges	-0.16	0.12	-0.05	-0.05	-0.09	-0.33	-0.22	1		
Cost distance to ridges	0.22	-0.17	-0.06	0.57	0.03	-0.07	0.32	0.5	1	
Dist to stream int	0.31	-0.18	-0.27	0.13	-0.05	0.42	0.31	-0.18	0.03	1

A second concern when developing geographic models is spatial autocorrelation. If knowing the value of one cell helps us to guess the value of nearby cells, then the distribution of that variable is said to exhibit spatial autocorrelation. This property violates the assumption that variable scores are distributed randomly over the project area. Yet, most of the variables used in the Azotea Mesa model are not randomly distributed. Knowing the slope of one cell, for example, allows one to guess within reason the slope of its neighbor. To overcome spatial autocorrelation, we used a feature of IDRISI that placed a "filter" over the Azotea Mesa grid. The program selects a 10 percent random sample of cells, which we then used to represent the environment. It is important to note that this filter was not used on the archaeological site layer. For that layer, all cells containing portions of sites in all size categories except "very small" were used in the initial modeling.

Variable Evaluation

The next step in the modeling process is to determine which environmental variables are associated with site location. Those that are found to have been either favored or avoided by humans are then used in the modeling efforts. For continuous variables (i.e., those with values measured on an interval scale, such as slope, elevation, and distance to water), we tested for significance by using simple one-mean "z-score" tests. If a z-score was significant at the 0.05 level (>1.96), then the layer was deemed statistically significant with reference to site distribution. The z-score is computed by the formula *z= sample mean – population mean / (population standard deviation/ square root of sample size)*

where the "population" is made up of cells representing the entire study region and the "sample" is composed of cells that contain archaeological sites. The test determines how different the sample (sites) is from the overall background environment (population). For modeling purposes, we want to include those variables for which sites cells are found to be significantly different from the general population of cells.

An example may help. For slope, we find that the mean score for cells with larger (i.e., eliminating the very small site category) archaeological sites is 3.457, whereas the average slope for the entire study area is 4.57. To determine if sites really fall on steeper landforms, we need to divide the population mean by the quotient of its standard deviation (5.068) divided by the square root of the number of cells containing sites. Or,

z= 3.457-4.57/ (5.068/Ö9526) = -21.43

The z score should fall between –1.96 and 1.96 if there is no relationship between site location and slope, assuming a relatively low risk (5 percent) of being wrong by chance alone. A score of –21.43 indicates there is a relationship between the variables. Accordingly, slope will be included in the modeling effort.

For categorical variables (i.e., variables measured by mutually exclusive states, such as geomorphology or vegetation), we assessed the relationship between cells that contain portions of sites and cells that represent the entire study area using a chi-square goodness-of-fit test. Each state of a categorical variable was tested separately. For example, eroded limestone is a state of the geomorphology variable. Site-positive cells of eroded limestone were compared with all cells of eroded limestone. If a significant relationship at the 0.05 level was found to exist, that state for that categorical value was used for modeling.

Chi-square is computed according to the following formula:

$$c^2 = \sum_{i=1}^{c} \frac{(O_i - E_i)^2}{E_i}$$

where O is the observed number of cells with sites in each state of a categorical variable and E is the expected number of cells with sites based on the proportion of the study area covered by that variable state. For example, if eroded limestone covers 50 percent of the study area then the expected number of site cells found on eroded limestone should be 50 percent of the total number of site cells. Chi-square scores over 124.342 at 100 degrees of freedom are significant at the 0.05 level. Although the degrees of freedom in the raster is much larger than 100, we chose this figure because the probability calculations for 100 degrees of freedom are readily available. Table 3 presents the geomorphological variables that have significant chi-square scores.

Table 3. Chi Square Goodness-of-Fit Scores for Significant Geomorphology Categories.

Geomorphology	*Eroded Bedrock*	*Floodplains of small drainages with thin Holocene deposits*	*River terraces*
Proportion	0.827	0.027	0.005
Site cells	5640	494	397
Expected	6942	230	40
Chi-square	244	303	3186

Based on the z- and chi-square scores, we included 11 environmental variables in the Azotea Mesa predictive models. These included four variables related to aspect (North, South, East, and West facing), two vegetative zones (Short grass steppe and Chihuahuan foothill-piedmont desert grassland), two geomorphic variables (river terraces and eroded bedrock), elevation, distance to streams, and slope. The last three variables are continuous variables measured on an interval scale, whereas the aspect, vegetative, and geomorphic variables are all categorical in nature.

Sensitivity Models

There are many different types of predictive models, ranging from subjective statements about where archaeologists have found sites in a region to highly sophisticated multivariate statistical models. For Azotea Mesa, we used three modeling techniques: Boolean intersection, weighted method, and logistic regression. All three allow the use of variables measured on different scales, although the first two require transforming data measured on interval scales into data measured on ordinal or nominal scales. We used the weighted method and logistic regression in our work on Loco Hills. The reader is referred to that technical summary (Altschul et al. 2003) for a description of those methods and how we applied them to Pump III project data. The Boolean model, which was not used in Loco Hills, is described below

A Boolean model is perhaps the simplest of all predictive modeling techniques. Every pixel of the digital study region is classified as either “site” or “non-site” based on one rule. “Sites” are defined as pixels that score favorably on every environmental variable; “non-sites” contain one or more unfavorable environmental scores. For example, if 90 percent of all the known-site pixels are located within 500m of water and on slopes of less than 10 degrees, then the GIS layers for distance to streams and slope can be “clipped” to those ranges and intersected within the GIS. The result is a single layer that has a value of 1 or 0, where 1 indicates an area likely to contain a site and 0 indicates an area that is not likely to contain a site. Although simple, Boolean intersection models work well in areas characterized by strong spatial autocorrelation and where environmental variables exert an overwhelming influence on human settlement. In the remainder of this section, we present the results of the three modeling techniques. We begin with the simplest (Boolean) and end with the most complex (logistic regression).

Boolean Model. The first step in creating a Boolean model is to define those states that are favorable for human settlement for each variable. For categorical variables, this step involves simply determining the appropriate states. For continuous variables we need to define break points, or cut-off ranges, for each variable that distinguish the cells likely to contain sites from those that probably do not. In Boolean models, it is preferable to be generous with categorical states and cut-off ranges because the intersecting properties of the method have a tendency to greatly reduce the favorable zone. For each variable, we chose states and cut-off ranges such that a large percentage (80-95 percent) of the known site cells were included in the favorable category (Table 4).

Table 4. Boolean Model Variables.

Environmental Variable (favored categorical states)	Cut-off range for continuous variables	% of site pixels contained in favored state/range	% of study area contained in favored state/range
Elevation	958-1400m	89	94
Geomorphology			
River terraces	N/A	5	0.47
Floodplains of large drainages	N/A	10	4
Eroded bedrock	N/A	67	82
Floodplains of small drainages	N/A	6	3
Vegetation			
Short grass steppe	N/A	4	1
Rky.Mtn./Great Basin Closed Conifer	N/A	0.1	0.5
Chihuahuan Desert Scrub	N/A	17	15
Chihuahuan Foothill-Piedmont Grassland	N/A	65	68
Ridge cost	0-195	94	96
Distance from ridges	0-1180m	96	96
Stream cost	0-170	94	89
Distance from streams	0-1300m	93	90
Aspect	N, S, E	91	84
Slope	0-9^{o}	96	89
Distance from stream intersections	0-3200m	93	92

The sensitivity map generated by the Boolean model is presented in Figure 12. The locations of sites used to develop the model are shown in white. The blue polygons represent site areas that are not correctly predicted by the model. For the Boolean model, 11 sites located in areas incorrectly identified as unlikely to contain sites. Two of these sites were also not correctly predicted by the other two modeling techniques. These two sites will be discussed in more detail below.

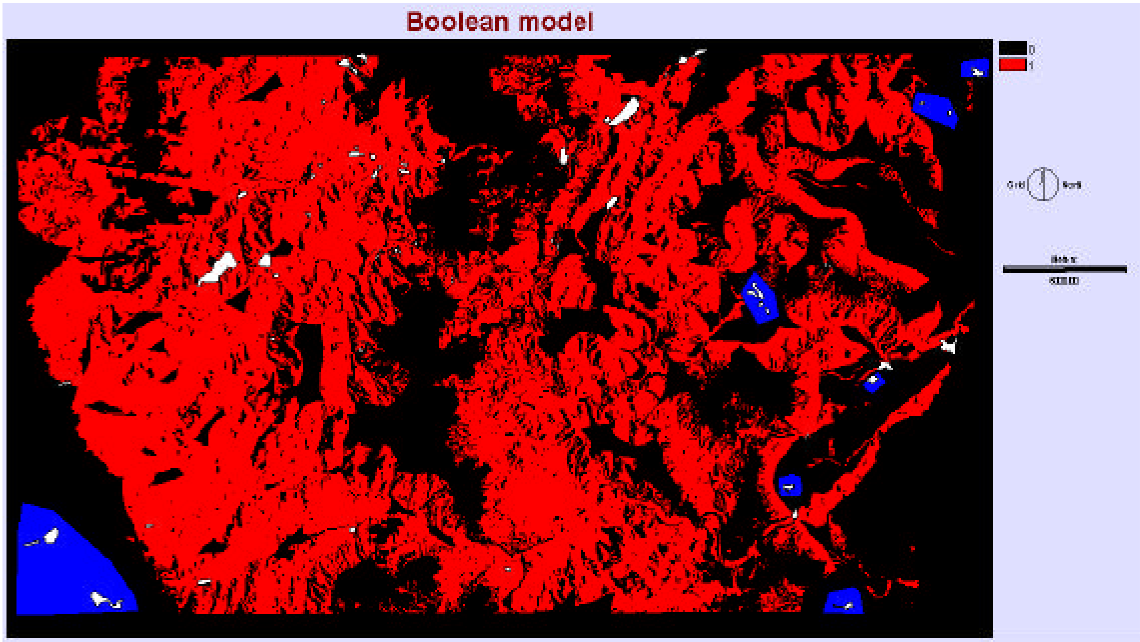

Figure 12 Boolean model: 0 (black) = site unlikely, 1 (red) = site likely, sites are in white, and blue are sites that are not captured by the model.

The Boolean model was tested using the Gain Statistic (Kvamme 1988), which compares the proportion of site cells correctly located to the proportion of the model area that contains sites. The score can range from –infinity to 1, where 1 is a perfect relationship. A score of 1 does not necessarily mean the model works well. More often, a high score is indicative of overmodeling in which the variables are so highly trained on the data set that they are not reflective of larger settlement patterns. For instance, in the case of Azotea Mesa, if the Gain score were 1 then the model would only predict sites to occur at the locations of the site cells used in model development. This would be a very poor model because it would not predict where future sites could be found.

The Gain Statistic is calculated as,

Gain Statistic = 1- (proportion of model area / proportion of sites correctly located)
Gain= 1-(0.46/0.58) = 0.21

A gain score of 0.21 indicates a weak model. To measure exactly how weak, we calculated the model's performance relative to a random predictor by applying the equation,

Gain over random = Proportion of sites correctly located- proportion of model
Gain over random = 0.58-0.46= 0.12

This score means that our chance of locating an archaeological site by using the Boolean model is about 12 percent better than if we were to randomly pick areas.

Finally, we used the locations of sites in the "very small" site class as independent test data. The scores for very small sites are,

Gain Statistic for small site class = 1-(0.46/0.62)= 0.26
Gain over random = 0.62-0.46= 0.16

The Boolean model predicts the locations of very small sites with about the same success rate as it predicts larger ones used to develop the model. This could mean that small sites are located in settings similar to those of large sites. Alternatively, because the model is a relatively poor predictor, it may be that only a small proportion of small and large sites follows the same settlement rules, with other sites in each category reflecting behavioral patterns that are not captured. Indeed, what the statistics really demonstrate is that, at least in this particular environmental setting, the Boolean model is not a strong predictor of any type of archaeological site. The exercise of developing this model was important, however, because many archaeologists and managers rely entirely on these types of intersection models, and at least for Azotea Mesa, such reliance would be misplaced.

Weighted Model. The weighted model depends on a more sophisticated intersection technique than the Boolean model. Each variable is divided into categorical states that are then weighted by virtue of the strength of their relationship with archaeological site location. For Azotea Mesa, we calculated the weights by first determining the proportion of the study area covered by each categorical variable as well as the proportion of site cells coded as being in each category. By subtracting the proportional representation of each categorical variable in the environment from the proportional site coverage, we derive weights, rounded to the nearest integer value, that vary from –26 to 27. Negative weights indicate that humans tended to avoid these environment features when selecting locations for their activities, positive weights suggest just the opposite.

Table 5 lists the environmental variables, the cut-off ranges, the proportion of site pixels in each variable state/range, and the proportion of the study area in each variable state/range. The last column in the table provides the weighted scores for each variable that were used to construct the weighted model.

Table 5. Weighted Model Variables

Environmental Variable	Cut-off range for continuous variables	proportion of site pixels contained in state/range	Proportion of study area contained in state/range	Weighted score
Vegetation	N/A			
Rky.Mtn closed conifer	N/A	0.1	0.5	0
Rky.Mtn open conifer	N/A	5.27	3.01	2
Madrean open oak woodland	N/A	0	0.6	-1
Rky.Mtn. Montane scrub	N/A	1.6	0.6	1
Broadleaf evergreen interior chaparral	N/A	0	0.6	-1

Chihuahuan Desert Scrub	N/A	17	15	2
Short grass steppe	N/A	4	1	3
Chihuahuan Desert grassland	N/A	4.23	5.47	-1
Chihuahuan Foothill-Piedmont grassland	N/A	65	68	-3
Chihuahuan Lowland/Swale desert grassland	N/A	0	2	-2
Southwest plains forested/shrub wetland	N/A	0.5	0.9	0
Irrigated agriculture	N/A	0	0.06	0
Barren	N/A	0	0.1	0
Rock outcrop	N/A	0	0.08	0
Urban vegetated	N/A	0	0.3	0
Riverine/Lacustrine	N/A	0.05	0.07	0
Basin Playa	N/A	0	0.2	0
Geomorphology	N/A			
Eroded bedrock	N/A	67	82	-15
Floodplains of small drainages	N/A	6	3	3
Floodplains of large drainages	N/A	10	4	6
River terraces	N/A	5	.5	5
Alluvium	N/A	0	0.02	0
Thick, uneroded Holocene deposits	N/A	0	0.03	0
Playa deposits	N/A	0	0.003	0
Recent slope-wash deposits	N/A	3.3	1.48	2
Extensive slope-wash deposits	N/A	8.07	8.6	-1
Cave or rockshelter	N/A	0	0.0007	0
Historic spring	N/A	0.03	0.002	0
Elevation	950-1320m	85.85	81.48	4
	1320-1500m	7.94	15.17	-7
	1500-1720m	6.21	3.35	3
Ridge cost	0-102	89.43	88.08	1
	102-230	4.58	8.71	-4
	230-500	5.99	3.21	3
Distance from ridges	0-470m	40.75	61.67	-21
	470-1180m	54.86	34.56	20
	1180-2000m	4.39	2.47	2
	>2000m	0	1.3	-1
Stream cost	0-50	73.23	53.64	20

	50-120	18.08	28.55	-10
	120-250	8.69	13.59	-5
	>250	0	4.22	-4
Distance from streams	0-600m	82.17	54.88	27
	600-1400m	11.61	37.62	-26
	1400-1920m	6.22	5.69	1
	>1920m	0	1.81	-2
Distance from stream intersections	0-2100m	62.57	66.86	-4
	2100-3600m	35.65	28	8
	3600-4860m	1.78	3.09	-1
	>4860	0	2.05	-2
Aspect	North	34.91	27.81	7
	East	39.34	37.76	2
	South	16.52	19.33	-3
	West	9.23	15.1	-6
Slope	0-9^0	94.03	85.25	9
	9-17^0	3.64	10.03	-6
	17-33^0	2.33	3.41	-1
	>33^0	0	1.31	-1

Once the variables were weighted, the variable scores for each cell were added together. Table 6 presents the results in relation to the area and the proportion of site cells associated with various score ranges. The final step was to reclassify the scores into four states that best represent site sensitivity. In this case, the four sensitivity states were coded as poor (1), average (2), good (3), and excellent (4).

Table 6. Weighted Model Scores and Reclassification.

Model Score	Proportion of Study Area	Proportion of Site Pixels	Reclassification
-100 to -80	0.62	0	0
-79 to -60	10.05	0.84	1
-59 to -40	12.65	7.23	1
-39 to -20	12.09	6.28	2
-19-0	12.65	7.25	2
1-20	9.04	8.11	2
21-40	15.29	15.36	3
41-60	8.77	9.53	3
61-80	14.32	28.06	4
81-100	4.51	16.94	4
101-120	0.02	0.4	4

Figure 13 presents the sensitivity map for the weighted model with sites overlain in black. Seven sites fell in average or poor areas; these are outlined with white polygons. Of these, three sites were also classified as being in average or poor areas by the logistic regression model; these sites are discussed later in this report.

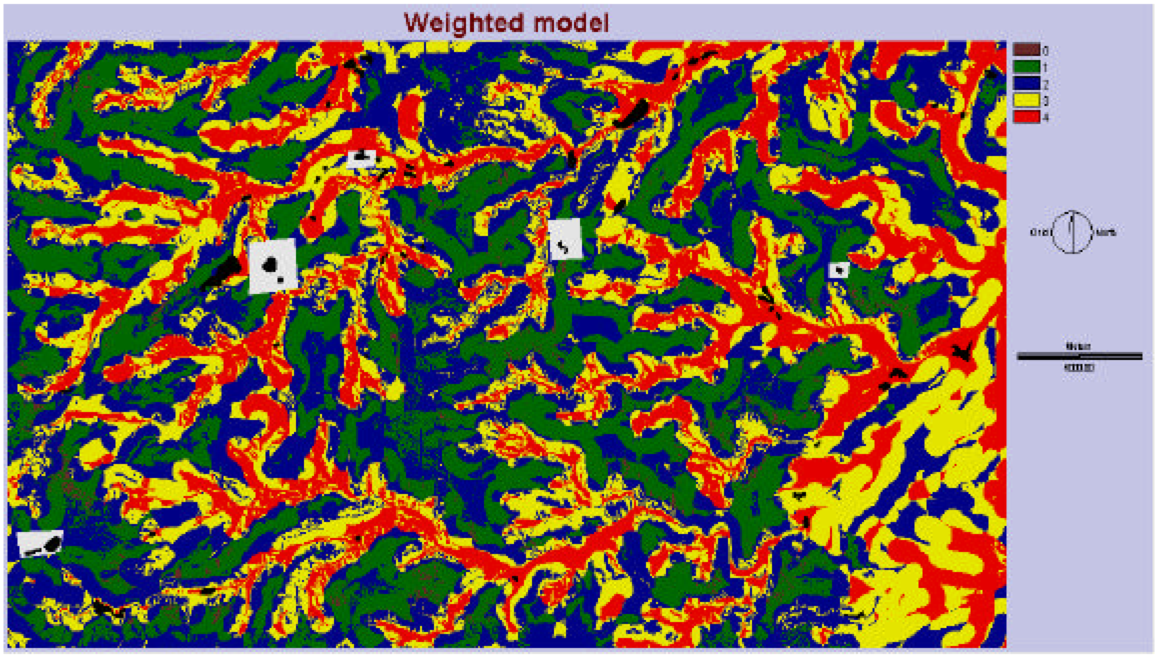

Figure 13 Weighted model with sites in white: 1 (green) = poor, 2 (blue) = average, 3 (yellow) = good, 4 (red) = excellent. White polygons = site areas that are poor or average.

As with the Boolean model, we used two statistics, Gain Statistic and Gain over Random, to evaluate the weighted model. For these statistics, the proportion of the model area is defined as the cells classified as good and excellent for site sensitivity.

Gain Statistic = 1- (proportion of model area / proportion of sites correctly located)
Gain= 1-(0.43/0.70) = 0.39

The gain score shows that the weighted model performs considerably better than the Boolean model. We also tested the weighted model using a gain over random score as,

Gain over random = Proportion of sites correctly located - proportion of model
Gain over random = 0.70-0.43= 0.27

The weighted model allows one to predict archaeological site locations with about a 27 percent better chance of being correct than if one guesses randomly. The weighted model, then, is about 6 percent more accurate than the Boolean model.

We also tested the weighted model by using the cells containing sites in the "very small" category as an independent test group. As stated above, the very small sites were not used in the development of the model, and thus can be used as a blind test group.

Gain Statistic for small site class = 1-(0.43/0.67)= 0.36
Gain over random = 0.67-0.43= 0.24

The placement of small sites is predicted with about the same accuracy as larger sites. This suggests that small sites are located according to the same human 'calculus' as larger sites.

Examining the weights in Table 6, it is clear that the most important factor in human settlement on Azotea Mesa involves water. Sites are found close to streams, away from ridges, and in places where the effort to reach water was minimal (i.e., flat land near streams). The effects of these variables are illustrated in Figure 13, which shows the linear and dendritic nature of site sensitivity.

Although the model accurately predicts about 70 percent of site locations, it is not a particularly powerful model. We need almost 40 percent of the area to be classified as good or excellent in terms of site sensitivity to capture this high a proportion of sites. The inability to hone the area down to a smaller "favored" zone suggests that Azotea Mesa lacks the environmental diversity that would have been necessary to shape human behavior into more recognizable patterns. The weighted model indicates that people spread out over much of Azotea Mesa, with only a modest tendency to keep close to streams.

Logistic Regression Model. Logistic regression is a complex statistical technique (see *The Loco Hills Technical Summary*, [Altschul et al. 2003], for more detailed discussion). The great advantage of logistic regression over other modeling techniques is the ability to incorporate variables measured on various scales: the relationships between site location and environmental variables measured on interval scales are not sacrificed in logistic regression as they are in Boolean and weighted modeling techniques. The great disadvantage is that the results of logistic regression models are not as easily interpreted as those of the other modeling techniques.

Table 7 presents the environmental variables used in the logistic regression and the coefficients created by the regression formula. At first glance, it appears that some of the variables are much more important in predicting site location than others. The coefficient for distance to water, for example, is only slightly negative (-0.001), whereas north aspects have a relatively large positive coefficient (2.960). But these coefficients are not comparable. Distance to water on Azotea Mesa varies from 0 to more than 2,000 m, so that the regression coefficient is multiplied by numbers varying from zero to very large. For North Aspect, on the other hand, a cell can only have one of two scores – 0 or 1. This score is then multiplied by a coefficient that takes into account the categorical nature of the variable.

Table 7. Computed coefficients for variables used in the logistic regression model.

Variable	Coefficient	Coefficient without aspect
Distance from streams	-0.00122318	-0.00122661
Distance from ridges	0.00054383	0.00054599
Chihuahuan Foothill-Piedmont	0.07353178	0.06888962
Short grass steppe	1.33956144	1.30428528
Slope	-0.0419244	-0.04463399
North	2.96050762	N/A
South	2.57331814	N/A
East	2.74273073	N/A
West	2.48460818	N/A
River terraces	1.96534996	1.97969398
Extensive slope wash	0.127371170	0.13443338

Elevation	0.00201439	0.00200162
Stream intersection distance	-0.00014958	-0.00013742

To check this interpretation, we re-ran the logistic regression without aspect. The regression coefficients were very similar to those of the full model, and the correlation between the two models was 0.78. Thus, although it may appear that aspect is an extremely important variable, statistically the impact of view and sunlight on the placement of settlements is not strong. In short, when examining logistic regression coefficients, it is important to compare variables measured on the same scale with each other.

Table 8 summarizes the results of the logistic regression. The results have been collapsed into 10 probability classes, with details presented on the size of the area captured by each probability class and the proportions of sites found in each class. The probability classes were then reclassified into four groups – poor (1), average (2), good (3), and excellent (4) – in terms of their site sensitivity.

Table 8. Logistic Regression probability scores and reclassification values.

Probability	**Proportion of Study Area**	**Proportion of site Pixels**	**Reclassification**
0-10	0.18	0.02	1
11-20	1.97	0	1
21-30	6.28	0.27	1
31-40	11.23	3.86	2
41-50	17.01	10.49	2
51-60	21.57	12.52	3
61-70	23.14	36.16	3
71-80	15.11	25.65	4
81-90	2.9	5.19	4
91-100	0.62	5.84	4

Figure 14 is a sensitivity map displaying the results of the logistic regression model after the reclassification. The number of sites located in poor or average areas has dropped from seven in the weighted model to three in the logistic regression, but the amount of land

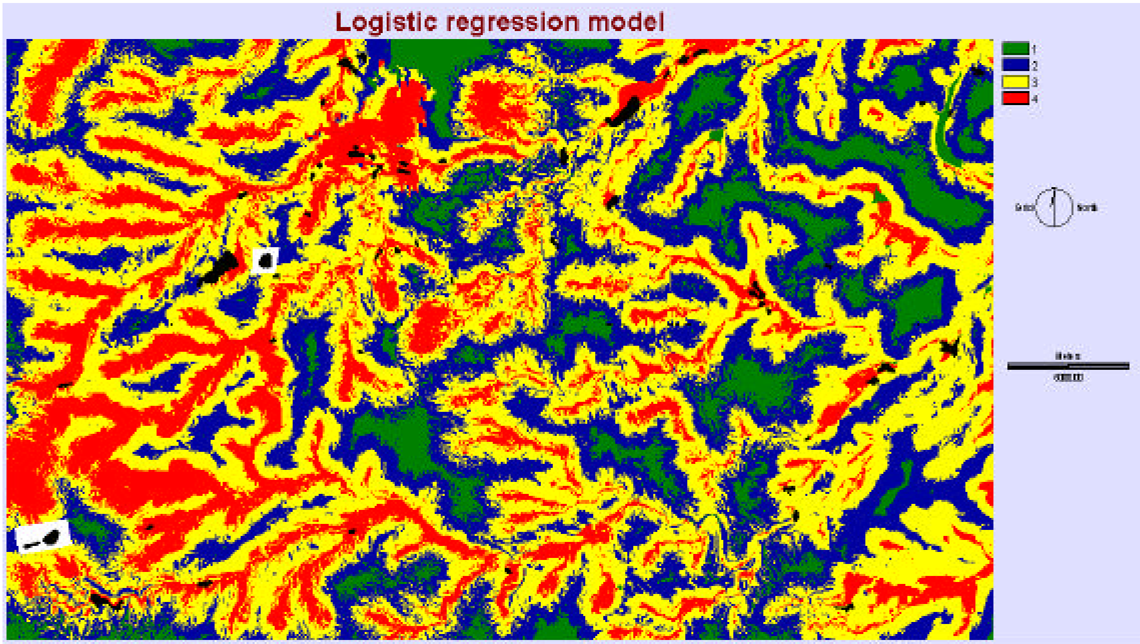

Figure 14 Logistic regression model with sites in white: 1 (green)= poor, 2 (blue)= average, 3 (yellow)= good, 4 (red)= excellent and white polygons are site areas that are in the poor or average class.

classified as good or excellent has shifted from around 45 percent in the Boolean and weighted models to more than 60 percent in the logistic regression model. These shifts are reflected in the relatively low Gain and Gain over random scores as seen below:

Gain = 1- (Proportion of model area / Proportion of correctly identified sites)
Gain = 1-(63.34/85.36) = 0.26

Gain over random = Proportion of correctly identified sites – Proportion of model
Gain over random = 85.36-63.34 = 22

These statistics also were calculated for the "very small" site category.

Gain = 1-(63.34/85.09)= 0.26
Gain over random= 85.09-63.34= 22

The logistical regression model works slightly worse as a predictor than the weighted model (27 percent better than random for the weighted model versus 22 percent better than random for the logistic regression model). Both models, however, have about the same accuracy (22-24 percent better than random) in correctly classifying the independent group into sensitivity areas. Visually, both models appear to be capitalizing on distance to water variables, though this is much more pronounced in the weighted model than in the logistic regression model.

Comparison of the Sensitivity Models

A comparison of the three predictive models is presented in Table 9. The weighted model scores the highest on the Gain Statistic because it provides the smallest sensitive area relative to the number of sites correctly identified. The logistic regression model, however, is statistically more robust. It accurately placed about 85 percent of the test group, a gain of about 20 percentage points on the other models. All three models predict large and small site locations correctly in roughly the same proportions. The size of a site, therefore, has little bearing on where it was placed on Azotea Mesa. A probable corollary is that site size is not associated with differences in site function.

Table 9. Comparison of the Predictive Models

Model	**Proportion of area that is good or excellent**	**Proportion of large site cells classified as good or excellent**	**Proportion of small site test class classified as good or excellent**	**Gain Score**
Boolean	.46	.58	.62	.21
Weighted	.43	.70	.67	.39
Logistic regression	.63	.85	.85	.26

RESULTS AND DISCUSSION

During the first six (6) months of 2004 of this project, work has been performed by Gnomon and five (5) subcontractors:

SRI Foundation, Western GeoArch Research, Red Rock Geological Enterprises, Wyoming State Historic Preservation Office, and New Mexico Historic Preservation Division

There have been no major problems encountered and all parties have been able to meet their deadlines on time and within budget. Below is a summary by participant of what has been accomplished and what each hopes to accomplish in the next six (6) months.

Gnomon, Inc.

Added new data to the data library.

Delivered Project Tracking application to WYSHPO for testing and training and continued to refine the application. Gnomon and Wyoming SHPO worked closely with BLM and the professional cultural resource consultants to devise standards for project information entry.

Assisted WYSHPO with data automation problems.

Scanned and digitized geomorphology maps for Otero Mesa study area created by Steve Hall (RRGE) and sent the shape file to SRIF to be used to create burial sensitivity and site likelihood models.

Reviewed analytical data and results from geomorphological studies in Azotea Mesa study area developed by SRIF.

Worked with William Eckerle (WGR) on refining the stream buffer areas.

Provided on-going technical support to all parties and monitored progress and budgets for all parties.

Worked on the lease/APD desktop information tool.

Submitted required reports on time to DOE.

Attended Wyoming Pump III multi-agency meeting in Rock Springs. Topics discussed at the meeting included how the results of the study will be used in BLM field offices where oil and gas leasing are active, how to implement project tracking most efficiently, how anthropological/scientific information is being created and used in the study, and ways in which the overall APD and APE evaluation process can be streamlined.

Western GeoArch Research

Data modeling

- Completed stream buffers with steep area exclusions
- Completed modification of Pine Valley model to fit Powder River Hydrological Basin (PRHB)
- Completed draft of sensitivity model and delivered to PUMP III meeting in Wyoming
- Implemented modifications to the sensitivity models

Literature research and report writing

- Wrote the introduction text sections including regional setting (first draft prepared)
- Described the geology and soils of the project area including their significance to project goals (first draft prepared)
- Wrote the methodology (first draft prepared)
- Worked on appendix summarizing fieldwork documentation
- Gnomon assisted Western Geoarch in revising the site burial model. Work was also started on a viewshed model for cultural resources that are known to be placed in "vista" areas (stone circle sites).

Red Rock Geological Enterprises

Completed geomorphology maps for Otero Mesa study area

Completed geomorphology text for *The Azotea Mesa Technical Summary* and *Otero Mesa Technical Summary*

Worked on chapter 6 for final report.

New Mexico Historic Preservation Division

Completed entering data for all of blocks 32013 and 32104. Completed 50% of block 32105. Each block consists of three one-degree lat/long blocks of 64 quads each.

Tim Seaman, of the New Mexico State Historic Preservation Office, attended the Four Corners Oil and Gas Conference. This conference brings together producers, land managers, and other interested parties to discuss energy development in the Four Corners region. A poster presentation summarizing the Pump III project was created by Gnomon and displayed at the meeting. This lead to many interested discussions with agency staff, producers, and other parties.

Wyoming State Historic Preservation Office

All projects have been digitized for seven of the eight counties.

A total of 33,276 inventory spatial entities have been created for the study area.

The project has currently exceeded the estimated inventory creation records of 9,329 projects. A total of 11,830 (89%) sites have been digitized. A total of 5091 sites have been encoded into the extensive site attribute database.

Encoding is currently focusing on sites with known buried components and radiocarbon dates. This dataset will be used to test the geomorphological model prepared in Task 10.

Encoding of the Powder and Tongue River Basins is complete.

Project tracking training is complete, and WYSHPO is giving feedback to Gnomon on this application.

In June, Gnomon and the Wyoming SHPO prepared and gave presentations at the BLM National Petroleum Forum and Fluid Minerals Conference in Cheyenne, Wyoming. Two poster presentations were placed in a booth, which we manned as a team (WY SHPO and GNOMON). Ingbar gave an invited presentation on the Pump III project during the Fluid Minerals Conference. We also participated in various work sessions (breakout groups) held during the meeting. These pertained to environmental compliance and cultural resources. From these, we gathered some interesting information about strategies that have worked well elsewhere, and factors that are a concern to energy developers.

Gnomon and Wyoming SHPO also met with state and federal government staff in several small meetings. We met with Linda Jones, Director of Intergovernmental Affairs for State Parks and Cultural Resources in the State of Wyoming and asked her assistance in meeting with the Petroleum Association of Wyoming. We also met with John Keck, former Wyoming State Historic Preservation Officer. Keck is currently the interagency National Park Service coordinator for Wyoming. We interviewed Keck on ways to increase the effectiveness of the Pump III work through multiple agency involvement.

SRI Foundation

Results and conclusions reported in *The Azotea Mesa Technical Summary*:

In discussions of the three models above, we noted cases where known sites exist in areas that the models have classified as being unlikely to contain sites. Two such sites are common to all three models; one additional site was shared by the weighted model and the logistic regression model. Altschul (1990) has term sites that are conspicuously located where models predict that they won't be "red flags." He has argued that these red flag sites often provide insights into both prehistoric settlement and the inner workings of predictive models. In an attempt to account for these sites in locations where they would not be expected based on the predictions of the models, we examined the characteristics of the three sites (Table 10) and the characteristics of the set of large sites used to develop the models (Table 11). We then compared the environmental characteristics of red flag sites and with those of the correctly predicted sites (Table 12); note that because of the small sample size, these sets of sites are only compared descriptively, not statistically.

Table 10. Red Flag Sites

ARMS/ NMCRIS Site #	Time Period	Area (Acres)	Number of Features	Number of Artifacts	Multi-component?
67519 / 26732	Early Archaic	23.21	5	>1000	No
67520 / 24731	Unspecified prehistoric	90.68	9	>1000	No
130417 / 83187	Late Archaic; Mogollon	81.49	3	>1000	Yes

Table 11. Sites Used to Create the Predictive Models

Time Period/ # of components (N)	Area (Acres)	Number of Features	% of Sites with >1000 Artifacts
Clovis (1)	8.97	3	0
Late Paleoindian (1)	36.61	0	100
Unspecified Paleoindian (1)	313.82	0	100
Early Archaic (2)	N= 45.19 mean= 22.59 std. dev= 0.86	N =39 mean= 19.5 std. dev= 21	100
Middle Archaic (1)	7.23	6	0
Late Archaic (6)	N= 293.13 mean= 48.86 std. dev= 36.07	n=64 mean= 13 std. dev=11	50
Unspecified Archaic (2)	N=324.78 mean= 162.388 std. dev= 214.16	N=3 Mean= 2 std. dev.= 1	50
Mogollon (21)	N=478.68	246	33

	mean= 22.79 std. dev= 18.26	mean =12 std. dev= 11	
Protohistoric (1)	36.39	0	0
Unknown (24)	N=739.251 mean= 30.80 std. dev.= 45.81	n=218 mean= 9 std. dev= 17	25
All sites (53)[1]	1729.39 mean= 32.64 std. dev.= 51.99	527 mean= 10 std. dev.= 14	28.3

1. Because some sites have multiple components, the total number of sites (53) is lower than the total number of components (60).

Table 12. Comparison of Red Flags and Correctly Predicted Sites

Variable	Red Flag Sites	Correctly Predicted Sites
Site area in acres (range)	22-91	7-314
Mean	65.14	32.64
Standard Deviation	36.60	51.99
Elevation m (range)	1264-1686	952-1452
Mean	1493.747	1151.976
Standard Deviation	182.38	131.958
Distance from streams m (range)	880-1620	0-1197
Mean	1458.304	264.368
Standard Deviation	306.337	231.065
Slope degrees (range)	0-7	0-31
Mean	3.942	3.40
Standard Deviation	2.068	4.228
Aspect (Largest percentage)	South (45%)	East (39%)
(Second largest percentage)	East (37%)	North (38%)
Geomorphology (largest percentage)	Eroded bedrock (100%)	Eroded bedrock (64%)
Second largest percentage		Floodplains of large drainages (11%)
Third largest percentage		Extensive slope-wash (9%)

It is tempting to speculate that the predictive models reflect primarily “Mogollon” settlement patterns. This time period represents nearly 60 percent of the components of known time periods. If we assume that the sites in the “unknown” temporal category represent similar proportions of the different temporal periods, then this inference becomes even more reasonable. Unfortunately, only more fieldwork can resolve this question. Even so, it is interesting to point out that the two red flag sites for which temporal information is available are predominantly Archaic, with only a minor Mogollon component (based on one projectile point) represented at site LA130417/83187. Although this conclusion is speculative, it is intriguing to suggest that because the Mogollon sites are so much more heavily represented in the archaeological record, the predictive models are largely modeling the activities of Formative stage agriculturalists who foraged in the area from residential sites on the Pecos River.

In contrast, the numerically rare Archaic sites may reflect an adaptation focused on seasonal hunting. Relative to the correctly predicted sites, these sites are large, located at higher elevations and away from streams. They face south and east as opposed to the more common orientation of north and east. Visibility of prey as well as the need to keep away from areas where game animals tended to travel may have factored into the establishment and repeated use of camps at higher elevations at some distance from streams.

As the preceding discussion indicates, correlative predictive models may allow us to discern patterns in settlement. They do not explain such patterns, but they can point research into avenues that may eventually lead to such explanations.

Modeling and Management

Evaluation of our predictive models demonstrated that they are limited in their predictive power. The goal of the New Mexico Pump III project is not just to develop successful predictive models, however, but also to evaluate the effectiveness of current cultural resource management practices in oil and gas fields and to provide data, technical support tools, and procedural recommendations for improving management in the future. The final section of this Azotea Mesa technical summary uses a variety of modeling approaches to examine the effectiveness of current management practices and identifies some implications of the results for future management practices. The final report for the project will include much more detailed management recommendations based on the results of all three technical summaries.

Model Stability

The logistic regression model for Azotea Mesa correctly predicted the locations of 85 percent of the sites, a considerable gain in accuracy over the other two models. It is, nonetheless, a poor predictor of site location because more than 60 percent of the study area is classified as having a good or excellent likelihood of containing sites. One possible explanation for this poor performance is that not enough sites have been located to provide a clear "environmental signature." Alternatively, it may be that sites within this study area are not strongly correlated with environmental variables, and that no matter how many more sites were recorded, the predictive performance of the model would not improve.

To examine these issues, we developed a series of logistic regression models using the same environmental themes but including only the site and survey data that would have been available at various points in the past. If we were to find that the models continued to improve with each new iteration, including the final 2002 version, then we would be able to infer that additional archaeological data would permit additional model refinement. Alternatively, if we were to find that the rate of improvement in predictive power has slowed or stopped at the very poor level that we see in the 2002 model, we would conclude that the proxy variables are not capturing aspects of the environment critical to human settlement behavior and/or that other factors were more important than the physical environment in placing humans on the landscape.

To be consistent with our work in Loco Hills, we recalculated the logistic regression model for Azotea Mesa based on data available in 1982, 1992,1997, and 2000 and compared the resulting models with the model based on current data (2002). At the end of 1982, approximately 6 percent of the 33,960 acres covered by 2002 had been surveyed. This total had risen to 34 percent by 1992, 64 percent by 1997, and 94 percent by 2000. Only 7 percent of the 550 currently known sites had been recorded by 1982. By 1992, 29 percent of the currently known sites had been recorded; by 1997, 58 percent of these sites had been found; and by 2000, 78 percent of all currently known prehistoric sites had been recorded.

Figures 15-19 shows the results of models based on the data available in 1982, 1992, 1997, and 2000 and the results of a model based on all available site data from 2002. The 2002 model shown in Figure 19 differs slightly from the model displayed in Figure 14 in the previous section, which used only the data from large sites. The Spearman's r score between the two 2002 models is 0.90.

Visually, the models appear quite similar. This impression is reinforced by Spearman's r scores, which were computed to compare each model's performance against the 2002 "all sites" model (Figure 20). These scores ranged from a low of 0.7 for the 1982 model to 0.999 for the 2000 model. Beginning in 1997, additional data do not cause any significant change in the predictive success of the models; no correlation is below 0.995. A review of the regression coefficients for the five models (Table 13) reinforces this observation. Although wide fluctuations are noted in the 1982 and 1992 models, the coefficients vary little in the last three models.

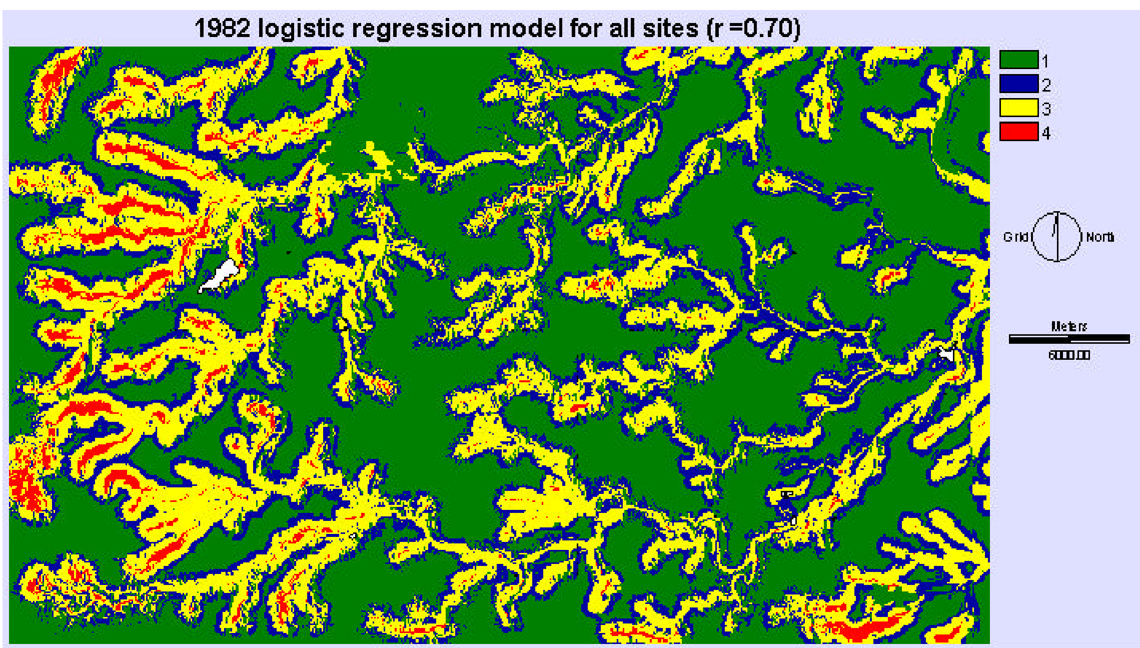

Figure 15. Logistic regression model created using all sites recorded through 1982. The correlation score is the relation to the model based on 2002 data.

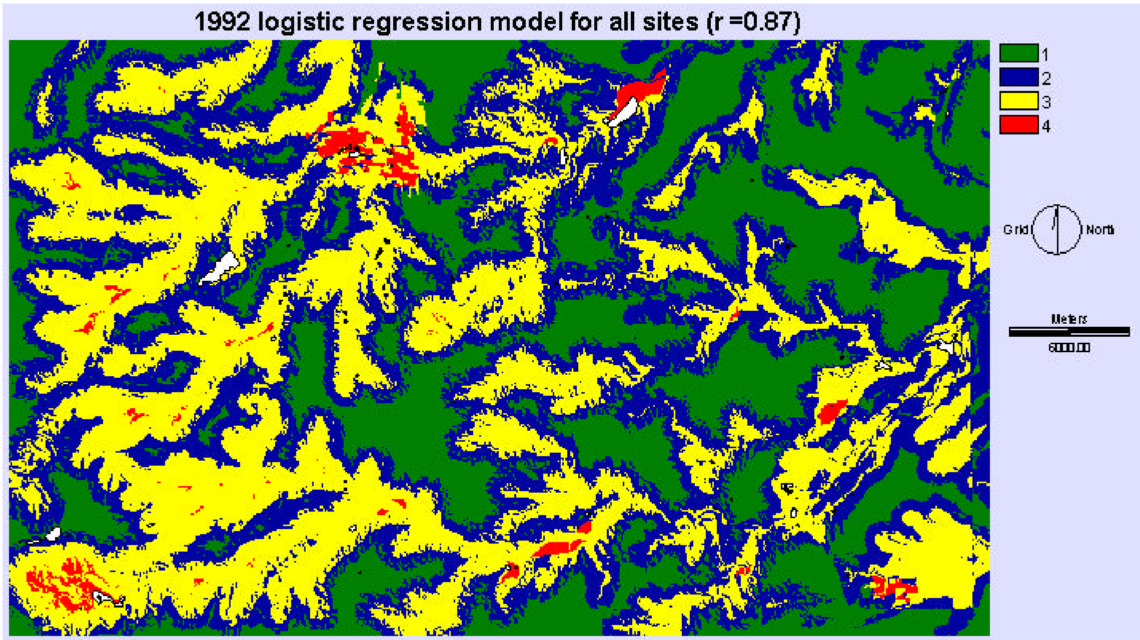

Figure 16. Logistic regression model created using all sites recorded through 1992. The correlation score is the relation to the model based on 2002 data.

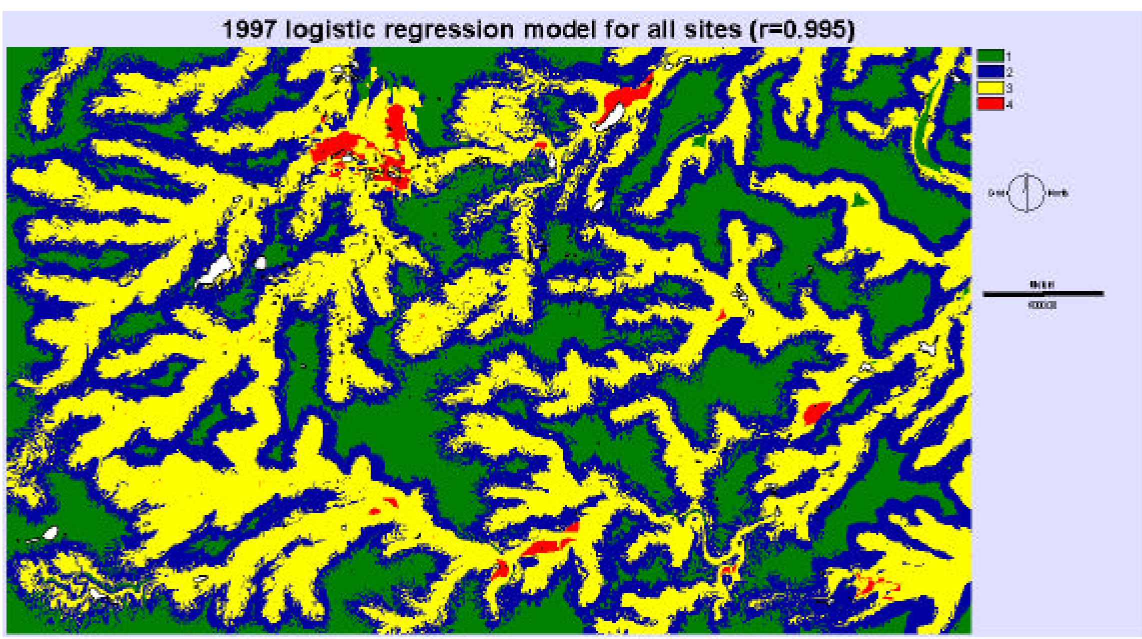

Figure 17. Logistic regression model created using all sites recorded through 1997. The correlation score is the relation to the model based on 2002 data.

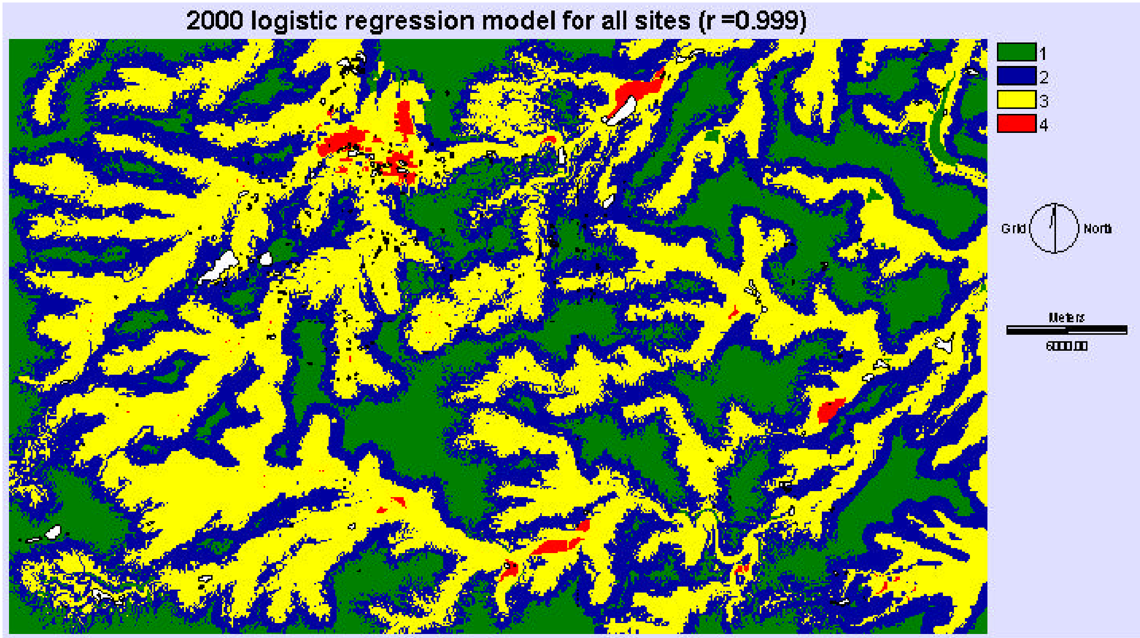

Figure 18. Logistic regression model created using all sites recorded through 2000. The correlation score is the relation to the model based on 2002 data.

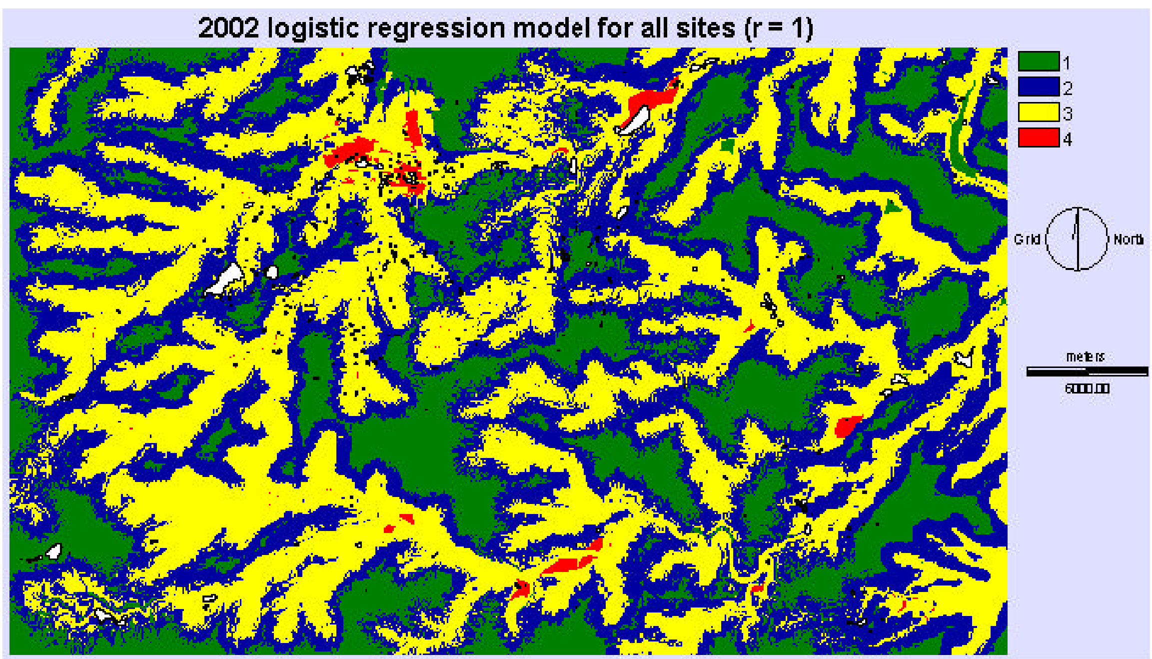

Figure 19. Logistic regression model created using data from all prehistoric sites recorded prior to 2002. The correlation score is the relation to the 2002 model.

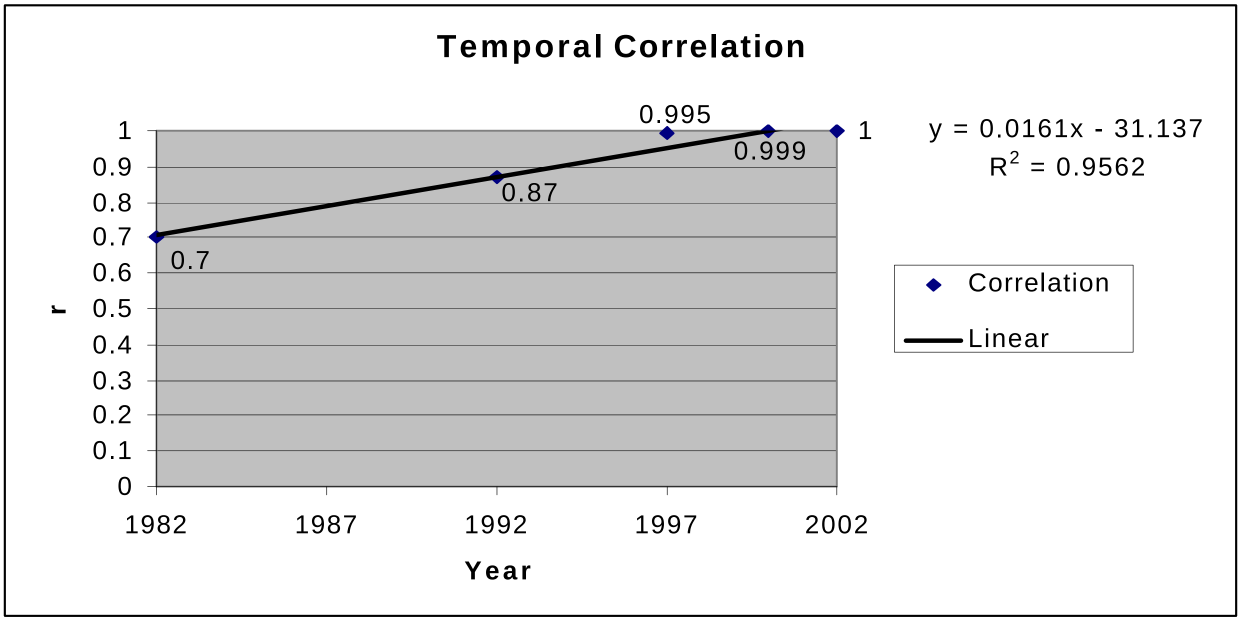

Figure 20. Correlation of each logistic model by year to 2002 (r= 0.98).

Table 13. Comparison of logistic regression coefficients

	1982	1992	1997	2000	2002
Distance from streams	-0.00338826	-0.00133068	-0.00124655	-0.00117728	-0.00121604
Distance from ridges	-0.00091792	0.00026141	0.00051181	0.00044912	0.00045861
Chihuahuan foothill-piedmont desert grassland	-0.51498404	-0.13275334	-0.00686350	0.00335138	0.00215109
Short grass steppe	-18.95510762	1.54981816	1.39244750	1.25407640	1.23422307
Slope	-0.06301770	-0.01121114	-0.04376925	-0.04645208	-0.04570684
North	18.49441267	1.37578453	2.19733547	2.33641498	2.24024762
South	18.46219677	0.97058514	1.77860719	1.91828232	1.82313037
East	18.68033657	1.30033149	1.96868271	2.07221704	1.97888617
West	17.19018185	0.78585357	1.84743658	2.01590354	1.93885246

River terraces	-0.91378613	2.53793309	1.73569545	1.63539326	1.60230620
Extensive slope wash	0.62766508	0.63787012	-0.05461136	-0.20132832	-0.23994516
Elevation	0.00180167	0.00342427	0.00117176	0.00115405	0.00106291
Distance from stream intersection	0.00014312	-0.00031192	-0.00009975	-0.00013687	-0.00013192

This analysis demonstrates clearly that a predictive model can be very stable and still be a poor predictor of site location. In the case of Azotea Mesa, it is likely that additional data will not improve the model. Does this result indicate that humans in this area did not place their settlements with regard to local environmental conditions? We don't think so. Instead, we believe the model's behavior reflects a failure to appreciate the proper scale of human adaptive systems in this portion of the Pecos River Valley.

We suspect that the human adaptation to this environment included resources from the mountains to the west and resources to be found along the Pecos River to the east. Larger residential settlements were almost certainly located outside our study area. People would have moved into and through the study area in small groups, sometimes specifically to procure targeted animal, plant, or mineral resources, and other times expediently collecting plants and game animals as they moved through the area while passing from one resource zone to another. Under this scenario, the areas of higher site probability are associated with drainages because this is where most of the specifically targeted resources would have been found and because these would have been the routes of travel between the riverine and montane resource zones.

If we look only at the small window on past human adaptations provided by the study area, it appears that human settlement was rather arbitrary; most places on Azotea Mesa were as "good as any other. Environmental diversity is minimal and the targeted resources appear to have been widely distributed. But would this characterization hold if we enlarged the study window? It is possible that Azotea Mesa as a unit held a unique environmental signature that was quite distinct from other areas in this part of the Pecos River Valley. In this case, a strong predictive model could be developed in which Azotea Mesa as a unit might be correlated with a specific part of the archaeological record.

The danger of developing a model of past human behavior based on an arbitrarily defined segment of the environment can be easily illustrated with an "outtake" from our experience during this project. In our first round of modeling, none of the three techniques described above produced a usable predictive model. Given the environmental uniformity of the study area, we had not expected *great* predictive performance, but this was ridiculous! The modelers, Altschul and Rohe, began to think that the environment of Azotea Mesa was not a strong influence on human settlement and might have continued to argue in this vein had not Sebastian, who is more familiar with the region's archaeology and environments, pointed out that the stream map did not seem to include the Pecos River.

How could we have made such a fundamental error? The answer is surprisingly simple. To create a "stream" layer, we used the DEM layer to compute a hydrological score for each cell. This score is a measure of how much water would pass by this cell based on its slope and elevation relative to other cells. Those cells having scores higher than an arbitrary number that the modeler selects are designated streams. Our problem was that the Pecos River only cuts through the very northeastern-most corner of the study area. Because only a very small portion of the river's catchment is actually inside the study area, the hydrological score of its constituent cells was lower than the score we had chosen for streams. After Sebastian pointed out the problem, we lowered the hydrological score needed to classify a cell as a stream to capture the Pecos River. Not surprisingly, the predictive power of each of the models increased dramatically. The lesson is that GIS models do not automatically represent the physical or cultural environment. Instead, human judgment is required at all steps of the modeling process, including the selection of an appropriate study area.

For a manager, the results of the Azotea Mesa modeling effort may appear discouraging because the limited predictive success of the models does not allow us to confidently identify high and low archaeological probability areas for planning purposes. The dendritic patterning of those areas that have been identified as having higher probability of containing sites is very clear, however, which could be useful for planning. In the still-to-be developed portions of the Azotea lease area, concentration of lease-related developments, including roads and ancillary facilities such as power lines, in low probability areas could reduce both the risk of encountering sites during lease development and the risk of long-term and cumulative damage to sites as a result of well servicing.

The modeling results lead us to believe that the study area does not provide the proper scale at which to evaluate the archaeological record on Azotea Mesa. If we could include a broader area in the model, we could determine what role the Azotea Mesa sites played in the larger regional record and how the mesa was used during the course of prehistory. By placing these sites within various human adaptive systems, we could better evaluate their significance as part of the Section 106 process. Clearly the "red flag" sites that do not follow the pattern established by the majority of sites on which the models are based would require additional evaluation, but if the majority of the Azotea Mesa archaeological record proves to be as homogeneous as it appears, we could identify research questions to be addressed through sampling and provide archaeologists, managers, and lease holders with a scientifically based and predictable management process.

Inventory Reconstruction

One of the goals of the Pump III project is to investigate the effectiveness of existing cultural resource management practices, in particular whether the current Section 106 compliance practices lead to inefficient or redundant results. For the Loco Hills study area (Altschul et al. 2003), we found that the logistic regression models stabilized very early in the history of gas field development. By reconstructing the history of archaeological inventory in the Loco Hills study area, we determined that our understanding of site density within the study area also stabilized early. What this means is that constant and consistent application of standard "well pad" archaeology, in which individual development areas are surveyed and facilities are moved if a site is found, has led to a situation where we are expending time and money without a commensurate gain in information that would lead to a better resource management and efficient energy development.

Having demonstrated, as described in the previous section, that the logistic regression model for Azotea Mesa has stabilized, we next examined the history of inventory in this area to determine whether the same is true of site density. As with the Loco Hills study area, we used the dates when surveys were conducted and sites were recorded to reconstruct the history of archaeological inventory in the Azotea Mesa study area. Using the digitized data provided by the ARMS staff, we associated surveys with the year in which they were conducted and sites with the year in which they were recorded. Based on these data, we calculated for each year the number of acres of sites recorded and the number of acres surveyed. By dividing the number of “site” acres by the total number of acres surveyed in any given year, we arrived at a site density figure for that year, which was then compared with a running density figure that included all sites and acres surveyed up to that date.

We assumed that the cumulative site density figure for all years through the year 2002 was an accurate estimate of site density within the entire Azotea Mesa study area. This assumption allowed us to use the yearly running site density figures to compute the standard deviation and confidence intervals around the 2002 figure, which captured 95 percent of the estimates. We then examined the annual history to determine when during the history of archaeological survey in the area the running site density began to consistently fall within the confidence intervals.

As we examined the ARMS data, however, it became clear that the task would be more complicated than we thought. Many areas had been surveyed multiple times and many sites had been re-recorded, sometimes within the same year. There were the usual data glitches, including the same site being recorded more than 10 km away from itself and recording episodes tied to surveys that were nowhere in the vicinity. A more difficult problem involved “site boundaries” that are actually arbitrary buffers around map points. Some of these seem to be randomly sized and inconsistent with the written descriptions of site size. For example, there is at least one instance of a site with a recorded area of approximately 180,000 square meters, which appears in the database as a 30 m diameter circle.

Figure 20 illustrates some of these overlap and re-recording problems. This figure shows a small portion of the study area, which, though somewhat more densely inventoried than the majority of the area, is by no means exceptional in its complexity. The figure reflects the raw data as captured by ARMS. Each survey was recorded fully, including portions that overlap previous surveys. The site recording episodes reflect the extent to which a site or a portion of a site was recorded during any particular survey event.

Figure 20. Examples of survey and recording episodes

To compensate for these problems, we aggregated the data by year. All surveys and site recording episodes were assigned to the year in which field activity concluded, as reflected in the ARMS data. Figure 21 shows surveys within the same small portion of the study area, coded by year, and Figure 22 shows a time sequence of cumulative survey, aggregated by year, within the whole study area.

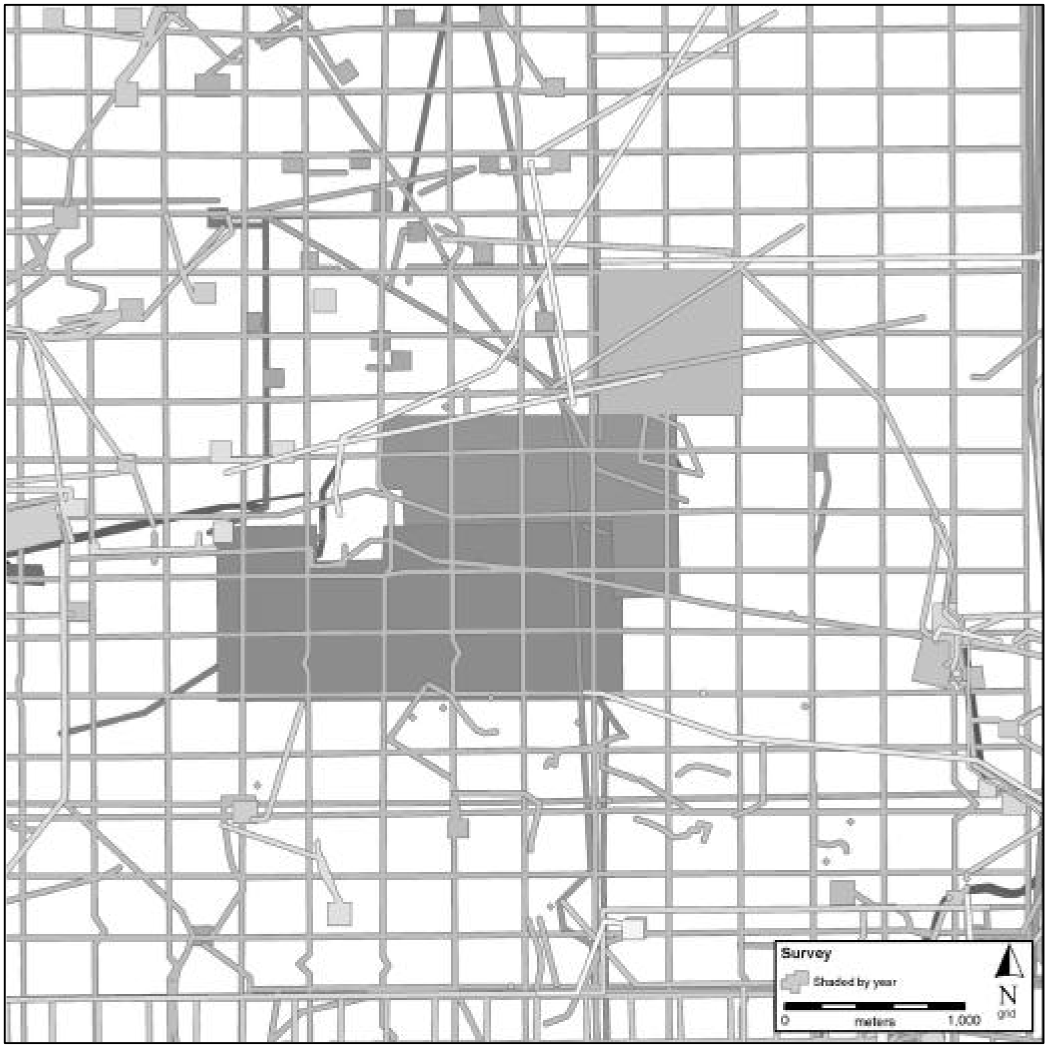

Figure 21. Example of survey coverage aggregated by year

Even after aggregating the data, we found that the process of estimating site density on an annual basis was complicated by the large amount of resurvey and the concomitant re-recording of sites. Between 1976 and 2002, surveys in the study area covered 33,960 acres, yet only 29,720 acres of ground were actually inventoried; the 4,240 acre difference results from resurvey. Nearly seven sections of land were resurveyed over the years. A quick look at Figure 22 makes it clear why and how this happened. As roads and pipelines and seismic grids were overlaid one on top of the other, it became virtually impossible to complete a project-specific inventory *without* resurveying at least some ground that had already been surveyed.

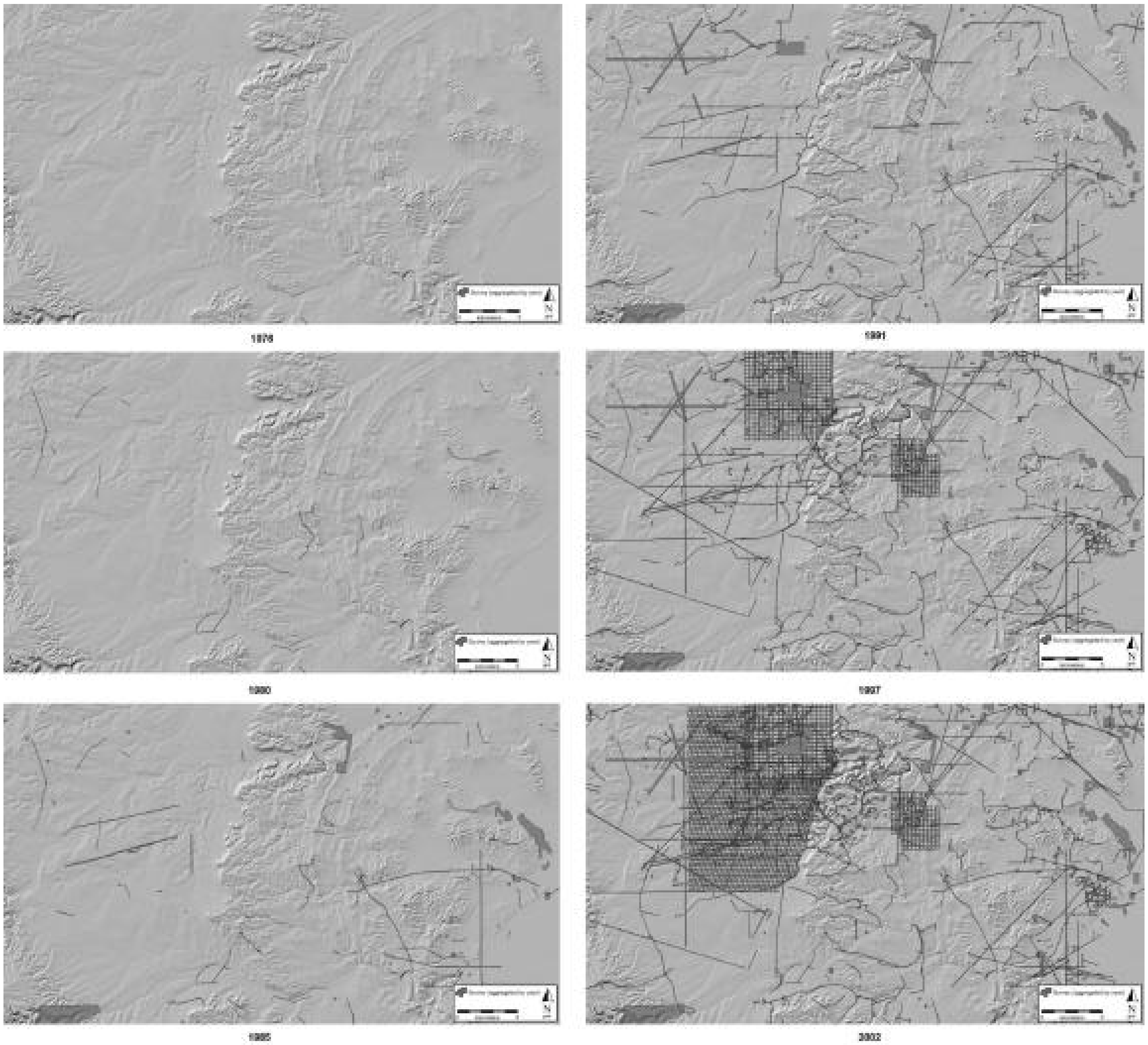

Figure 22. Time sequence for cumulative survey in the study area, aggregated by year

Figure 23 graphically displays the history of survey in the Azotea Mesa study area with special attention to this issue of resurvey. For each year there are three bars, one which represents the reported number of surveyed acres, one which represents the reported acreage minus the overlapping surveys that occurred within that same year, and one which represents the actual new ground surveyed with all overlaps removed.

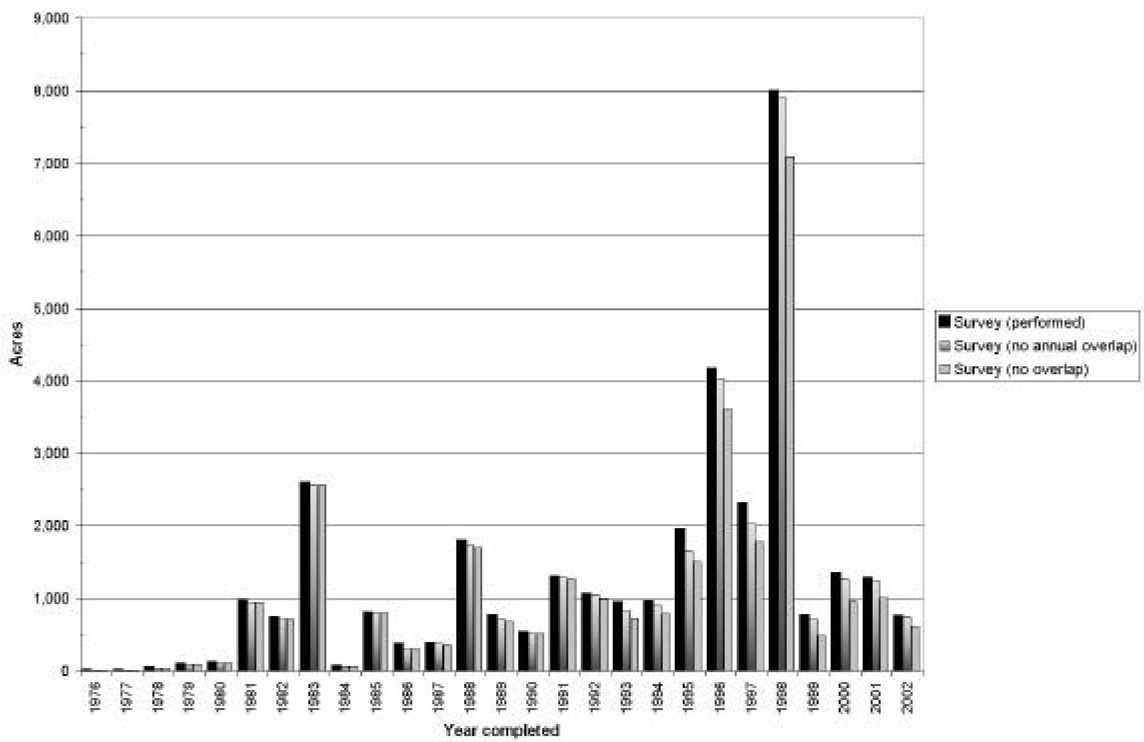

Figure 23. Annual survey statistics

These data allow us to calculate site density using two different methods. Method I (Figure 24) was based on survey as it was actually performed. In this analysis, sites that were recorded more than once and areas that were surveyed more than once in different years are included in the calculations for *each* year fieldwork took place. The site density figures calculated using Method I are, therefore, inflated. Method II (Figure 25) eliminated survey overlap and site re-recording; it provides a more accurate estimate of site density but masks the inefficiency of the piecemeal survey history. In short, Method I calculates site density as it would have been available to managers under existing survey strategies, whereas Method II provides the density figure that would have been available in an ideal world where there were no survey overlaps or site re-recording.

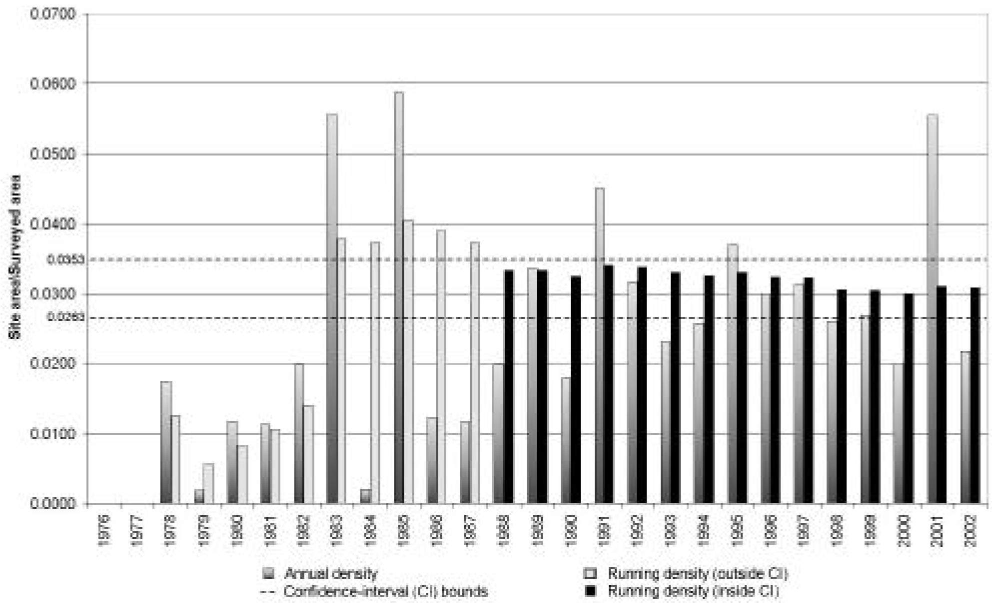

Figure 24 Overall site density Method I

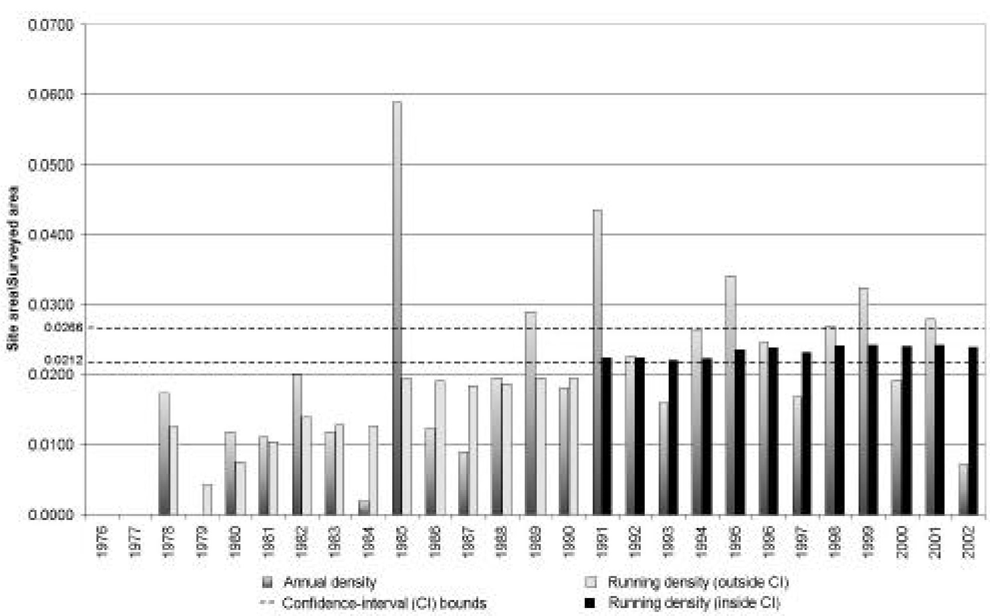

Figure 25 Overall site density Method II

The trend in running site density figures is very clear, despite the one anomalous year. Site density stabilizes at about 0.031 under Method I and 0.024 under Method II. Running density falls in the 95 percent confidence intervals beginning in 1988 under Method I and in 1991 under Method II.

The results of the inventory reconstruction indicate that sites are adequately represented by the survey results in terms of size and distribution. Most are small and evenly distributed throughout the study area. This is consistent with the results of the logistic regression model, which had limited predictive success because of the lack of environmental diversity within the study area. As noted above, this does not necessarily mean that the locations of human activities were not correlated with environmental factors. It is more likely that the scale on which those activities were organized is simply far larger than the study area.

CONCLUSION

Gnomon and its five (5) subcontractors continue to work together as a team to complete the DOE PUMP III project. The major accomplishment in the last six (6) months is the completion of *The Azote Mesa Technical Summary*. This is one of three (3) technical summaries that will be created by SRIF and sent out for peer review. The information contained within these technical summaries will be integrated into the final project report. All geomorphology work has been completed for both the New Mexico and Wyoming study areas. The project-tracking tool has been created and is being tested by WYSHPO. ARMS and WYSHPO continue to add and QC data to be included in the state cultural resource databases.

To date there have been no major problems and each participant is meeting their deadlines and is within mandated schedule.

Management implications cited in the conclusion of *The Azotea Mesa Technical Review* written by SRIF:

In some ways our findings for Azotea Mesa are like those from the Loco Hills study area. As was the case with the Loco Hills study area, we found that on Azotea Mesa oil and gas development, while not a random process, has yielded archaeological data that are sufficiently representative to be used in predictive modeling, largely because seismic investigations and other linear projects like roads and pipelines produced a substantial portion of the data. Also as in the Loco Hills case, we found that there has been a great deal of re-survey of land and re-recording of sites in the Azotea Mesa study area. For example, surveys totaling 33,960 acres have been completed, but only 29,720 of those acres were new ground, the rest is overlap. This is not an efficient approach, but given the overlapping nature of the development, under the current case-by-case approach to inventory, such duplication is unavoidable. And again, as at Loco Hills, both the logistic regression models and the site density estimates stabilized quite early in the development of the field, with subsequent survey yielding new observations but not improving our understanding of the archaeological record.

There are also some observations that are particular to Azotea Mesa, however. One clear lesson learned is that simply because archaeological surveys record the same type of sites distributed in the same manner, this does not mean the “redundant” locational pattern translates into redundant information. In truth, we know very little about what these patterns mean. To move toward such an understanding, we need to place the environmentally homogeneous Azotea Mesa study area into its proper context. Human use of the region clearly extends beyond the oil and gas lease. By focusing solely on the study unit, we do not have a big enough spatial window to discern adaptive patterns and consequently cannot evaluate how sites in the study unit might or might not inform on these patterns.

One might argue that a second lesson of Azotea Mesa is that not all areas are candidates for predictive modeling. While it is true that the developed models are relatively weak, we believe that drawing such a lesson would be wrong. Indeed, we suggest that predictive modeling is more useful in situations such as Azotea Mesa than in areas where site distribution patterns are so strong that they can be discerned simply by looking at a map. The logistic regression models for Azotea Mesa demonstrate that no amount of survey and site discovery is likely to increase our knowledge of how humans used the study area. We know that people came into the area, presumably in small, mobile groups that exploited locally available resources and then left. What we don't know is where they came from and where they went, how this changed over time, and whether the structure of resource procurement changed as a result of organizational changes at a larger scale.

In the absence of such knowledge, we cannot make good decisions about the significance of the sites within the Azotea Mesa study area. Were they part of a ubiquitous pattern of dispersed, low-intensity resource acquisition? Was this a unique resource zone where residents of the Pecos Valley went to acquire specific plants, animals, or minerals that were not available in the riverine zone? Was this an environmentally marginal zone through which people simply passed when going from the river to the mountains? As with Loco Hills, we need excavation data from Azotea Mesa sites to enable us to understand what activities were being carried out, what resources were being targeted, and what time period or periods are reflected in these remnants of human activities. Without an understanding of the larger settlement picture, however, no amount of research – survey or excavation – within the Azotea Mesa study area itself is likely to yield important insights on which to base management decisions. A regional perspective is critically needed, and GIS-based predictive modeling is one tool for creating such a perspective.

We have three basic management recommendations for Azotea Mesa. First, the study area is too small to discern human patterns in settlement and land use. We need to increase the size of the modeling area to at least include the adjacent portions of the Pecos River and the foothills of the Guadalupe Mountains. In this way, the model could be expanded to reflect the actual environmental diversity of this portion of the Pecos River Valley and the effects of that diversity on human settlement decisions. Second, we need excavation data from a representative sample of the sites in the Azotea Mesa lease area. Only if we understand the function and temporal placement of sites in this area, and their potential role in the larger settlement system of which they were a part, can we make well-founded decisions about the significance of the archaeological sites found on Azotea Mesa.

And third, we need to be cognizant of the highly variable quality of the data that have been contributed to NMCRIS over the years. The inventory reconstruction assumes that errors in the ARMS data will cancel out, so that large sites recorded as points will be compensated by small sites with large boundaries. Both errors are known to exist. The former type of error appears to be much more prevalent, however, and it is possible that the stabilization in site density that we found during the inventory reconstruction is the result of systematic errors in recording. This problem may be extremely difficult to correct for data already in the ARMS database; at the very least, it indicates the need for a strong quality assurance program to ensure that future work does not repeat these errors.

TO BE ACCOMPLISHED July 1, 2004 – December 31, 2004

Gnomon

Participate in review of *The Azotea Mesa Technical Report* and *The Otero Mesa Technical Report*.

Plan and convene technical meeting in Albuquerque, NM for September 1 – 2, 2004.

Review report draft of field manual for geomorphic assessment of archaeological potential created by Steve Hall.

Review draft Cultural Resource Management (CRM) recommendations created by SRIF for the Azotea Mesa and Otero Mesa study areas.

Participate in writing chapters for the final report on IT management and broader implications.

Review report draft of report created by Bill Eckerle on geomorphology studies in the Wyoming study area.

Complete the desktop information tool for WYSHPO.

Review/comment on draft CRM recommendations.

Review/comment on final report.

Review/comment on WYSHPO training guide and final report.

Continue to improve WYSHPO website.

Revise WYSHPO tracking tool upon request.

Continually coordinate the activities of the participants, interested parties, and peer reviewers.

Provide ongoing technical support.

With SRIF prepare final New Mexico report. With WYSHPO prepare final Wyoming report. Deliver to DOE.

Prepare final invoices and submit to DOE.

SRI Foundation

Complete models for Otero Mesa.

Write technical summaries for Otero Mesa based on geomorphology and sensitivity models and send out for peer review.

Write draft of CRM recommendations for the Otero Mesa study areas and submit for peer review.

Complete Final Report drafts for Chapters 1- 12.

Attend technical project meeting in September.

Western GeoArch Research (William Eckerle)

Refine sensitivity models.

Complete modification of Pine Valley model to fit Powder River Hydrological Basin (PRHB) data.

Complete draft of final report for geomorphology studies in the Powder River Basin of Wyoming.

Attend technical project meeting in September.

Red Rock Geological Enterprises (Stephen Hall)

Write the geomorphology section of the technical summary for Otero Mesa.

Complete chapter 6 of the final report: Geomorphology of NM study areas.

Attend technical project meeting in September.

New Mexico Historic Preservation Division

Process survey reports for the remaining project area, which is block 32105 (64 quads each).

Attend technical project meeting in September.

Write chapter for final report on IT and management aspect of New Mexico project.

Wyoming State Historic Preservation Office

Continue to enter data and digitize inventories and site records for the Powder River Basin.

Continue to test the tracking tool and recommend modifications.

Install and test the new desktop information tool developed by Gnomon.

Move GIS applications to ESRI's ArcSDE.

Attend technical project meeting in September.

REFERENCES

Altschul, Jeffrey H.

1988 Models and the Modeling Process. In *Quantifying the Past and Predicting the Future: Theory, Method, and Application of Archaeological Predictive Modeling*, edited by W. James Judge and Lynne Sebastian, pp. 61-96. U.S. Department of the Interior, Bureau of Land Management, Denver.

1989 Red Flag Models: The Use of Modeling in Management Contexts. In *Interpreting Space: GIS and Archaeology*, edited by Kathleen M.S. Allen, Stanton W. Green, and Ezra B.W. Zubrow, pp. 226-238. Taylor and Francis, London.

1990 Flag Models: The Use of Modeling in Management Contexts. In *Interpreting Space: GIS and Archaeology*, edited by Kathleen M.S. Allen, Stanton W. Green, and Ezra B.W. Zubrow, pp. 226-238. Taylor and Francis, London.

Altschul, Jeffrey H., Lynne Sebastian, and Kurt Heidelberg

2003 *Predictive Modeling in the Military: Similar Goals, Divergent Paths*. Preservation Research Series 1. SRI Foundation, Rio Rancho, New Mexico. Draft.

Altschul, Jeffrey H., Lynne Sebastian, Chris M. Rohe, William E. Hayden, and Stephen A. Hall

2004 *Adaptive Management and Planning Models for Cultural Resources in Oil and Gas Fields: The Loco Hills Technical Summary.* SRI Foundation, Rio Rancho, New Mexico. Draft.

Elyea, James M., and Patrick Hogan

1983 Regional Interaction: The Archaic Adaptation. In *Economy and Interaction along the Lower Chaco River: The Navajo Mine Program*, edited by Patrick Hogan and Joseph C. Winter, pp. 393-402. Office of Contract Archaeology and Maxwell Museum of Anthropology, University of New Mexico, Albuquerque.

Hall, Stephen A.

1982 Late Holocene Paleoecology of the Southern Plains. *Quaternary Research* 17:391-407

2002 *Field Guide to the Geoarchaeology of the Mescalero Sands, Southeastern New Mexico:* Bureau of Land Management, Santa Fe, and State of New Mexico, Historic Preservation Division, Santa Fe, NM, 55 p., 17 figs., 7 tables, 6 pls.

Katz, Susana R., and Paul Katz

2001 The Southeast. In *The Archaeological Record of Southern New Mexico: Sites and Sequences in Prehistory*, edited by Susana R. and Paul Katz. State of New Mexico, Historic Preservation Division, Santa Fe.

Kohler, Timothy A.

1988 Predictive Locational Modeling: History and Current Practices. In *Quantifying the Past and Predicting the Future: Theory, Method, and Application of Archaeological Predictive Modeling*, edited by W. James Judge and Lynne

Sebastian, pp. 19-60. U.S. Department of the Interior, Bureau of Land Management, Denver.

Kohler, Timothy A. and Sandra C. Parker
1986 Predictive Models for Archaeological Resource Location. In *Advances in Archaeological Method and Theory*, Volume 9, edited by Michael B. Schiffer, pp. 397-452. Academic Press, New York.

Kvamme, Kenneth L.
1988 Development and Testing of Quantitative Models. In *Quantifying the Past and Predicting the Future: Theory, Method, and Application of Archaeological Predictive Modeling*, edited by W. James Judge and Lynne Sebastian, pp. 325-428. U.S. Department of the Interior, Bureau of Land Management, Denver.

Roney, John R.
1984 *Prehistory of the Guadalupe Mountains.* MA Thesis, Department of Anthropology, Eastern New Mexico University, Portales.

Reeves, C. C., Jr.
1972 Tertiary-Quaternary Stratigraphy and Geomorphology of West Texas and Southeastern New Mexico. In *Guidebook of East-Central New Mexico*, edited by V.C. Kelley and F.D. Trauger, pp. 108-117.New Mexico Geological Society 23rd Field Conference. New Mexico Bureau of Mines and Minerals, Socorro.

Sebastian, Lynne
1989a The Archaic Period. In *Living on the Land: 11,000 Years of Human Adaptation in Southeastern New Mexico*, by Lynne Sebastian and Signa Larralde, pp. 41-58. Cultural Resources Series 6. Bureau of Land Management, Roswell District, Roswell, New Mexico.
1989b The Ceramic Period. In *Living on the Land: 11,000 Years of Human Adaptation in Southeastern New Mexico*, by Lynne Sebastian and Signa Larralde, pp. 73-92. Cultural Resources Series 6. Bureau of Land Management, Roswell District, Roswell, New Mexico.

Sebastian, Lynne and Signa Larralde
1989 *Living on the Land: 11,000 Years of Human Adaptation in Southeastern New Mexico*. Cultural Resources Series 6. Bureau of Land Management, Roswell District, Roswell, New Mexico.

Stafford, Thomas J.
1981 Alluvial Geology and Archaeological Potential of the Texas Southern High Plains. American Antiquity 46:548-565.

Van Devender, Thomas R.
1980 Holocene Plant Remains from Rocky Arroyo and Last Chance Canyon, Eddy County, New Mexico. *The Southwestern Naturalist* 25(3):361-372.

Van Devender, Thomas R., W.G. Spaulding, and M.R. Phillips

1979 Late Pleistocene Plant Communities in the Guadalupe Mountains. In *Biological Investigations in the Guadalupe Mountains National Park, Texas,* edited by Hugh H. Genoways and Robert J. Baker, pp. 13-30. *National Park Services Proceedings and Transactions Series* No. 4. Washington, D.C.