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ABSTRACT

This report contains a summary of activities of Gnomon, Inc. and five subcontractors that have taken place during the second six months (July 1, 2003 – December 31, 2003) 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 Loco Hills 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 Loco Hills area of southeastern New Mexico.

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EXECUTIVE SUMMARY

This report summarizes activities that have taken place in the last six (6) months (July 2003 – December 2003) 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. Gnomon delivered a project-tracking tool to WYSHPO and revised the WYSHPO on-line database applications to include links to site form images and review data. Now a user can view the documentation of resources on files and check the review status of sites. The WYSHPO Review and Compliance database can be queried to see when a site was reviewed in the Section 106 process, the status of the property, the official review number and how many times the WYSHPO had dealt with the property. This allows federal agencies to efficiently check the Section 106 status of sites and make more efficient decisions on a site's current eligibility status. Additionally, during the past year all site forms for the study area have been imaged into PDF format for use on our website. Over 21,000 forms were imaged during the calendar year.

William Eckerle of Western GeoArch Research continued to work on the geomorphology of the Power River Basin of Wyoming. In the next six (6) months he will use the results of his geomorphology studies and the data being developed by WYSHPO to create a sensitivity model to predict where buried cultural resources are likely to be found in the Power River Basin of Wyoming.

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. ARMS delivered extracts of these data to SRIF to use in creating sensitivity models for the three study areas: Loco Hill, Azotea Mesa, and Otero Mesa.

Stephen Hall of Red Rock Geological Enterprises (RRGE) completed data entry of SSURGO data (soils) and geomorphology maps for the Loco Hills and Azotea Mesa study areas. Gnomon digitized the geomorphology maps and delivered these to SRIF. Hall completed writing the geomorphology section of *The Loco Hills Technical Summary*, which was produced by SRIF.

SRIF created a sensitivity model for the Loco Hills 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 Loco Hills Technical Summary* that summarizes these data.

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 were reasonably successful in predicting the location of surface-visible archaeological sites.

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

1. Cultural resource surveys in the Loco Hills 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 Loco Hills study area.
3. The logistic regression models and the inventory reconstruction demonstrate that sufficient data were available to support important decisions about cultural resource management and oil and gas development when as little as 6 to 7 percent of the land had been inventoried. But because there has been no mechanism for synthesizing previously acquired survey data, cultural resource managers have neither been able to use previous data to limit duplication of effort nor had available models and other tools to focus management and preservation efforts.
4. Our understanding of the past has not increased proportional to the amount of survey or the number of sites recorded.
5. A possible recommendation that may come out of this report is to change CRM objectives from simply documenting surface-visible archaeological sites and avoiding them to determining and understanding the nature and distribution of archaeological sites. The challenge is to find ways of funding excavation and other scientific inquiries needed to evaluate the information potential of surface-visible sites, to model likely locations of buried sites with important information to offer, and to explain both the distribution and the nature of sites in the Loco Hills area.

EXPERIMENTAL

Experimental Apparatus Used to Complete the Sensitivity Model for the Loco Hills 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 Loco Hills Study Area

Environmental independent variables (primary themes): GIS layers of elevation (DEM) created by USGS, vegetation (Gap Analysis Program of the USGS), and geomorphology (GIS layer created by Gnomon based on analysis completed by Red Rock Geological Enterprises). The geomorphology maps were created 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.

Environmental independent variables (secondary themes): slope, aspect, distance to water, cost to water (derived from DEM).

Archaeological Data (dependent variable): NMHPD 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. Sites were divided between post-European contact and precontact sites. Postcontact sites were excluded from the predictive models. This data was provided in GIS format. For the predictive model, 1625 site polygons were reduced to 779 polygons by combining sites that had multiple entries, and 5196 survey polygons were modified to become 6301 individual polygons, comprising 5099 individual survey episodes. This was done by identifying overlapping areas and splitting out areas that are not spatially contiguous.

Data Reduction in the Sensitivity Model for the Loco Hills Study Area

Each environmental theme was reviewed to determine whether the areas covered by archaeological surveys adequately represent the target environmental attributes. If this were true, we would have confidence that the association between the environmental variable and site location found in the surveyed areas mirrors their relationship in the larger project area. We began 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, 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 theme. This was true for all

environmental themes except for the geomorphology theme, in which eroded limestone covers approximately 13 percent of the Loco Hills study area, but only about 7 percent of the archaeological surveyed areas fell within this geomorphic category. We decided, however, to include this variable in the predictive model. No sites have been found on the portions of the eroded limestone that has been surveyed, and anecdotal evidence from archaeologists and geomorphologists indicates that it is highly unlikely that intact cultural deposits could occur on this landform (see Hall 2002). Thus, even though the eroded limestone has not been adequately surveyed, we believe that the relationship between this landform and archaeological site locations has been established and that the environmental variable can be a useful predictor of site locations (or in this case, of the absence of sites).

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 0.52, and all but two were below 0.4. Based on these results, the variables being used as predictors in the models can be taken as statistically independent. To reinforce this conclusion, we calculated the logistic regression model (see below) without the two most interrelated variables – elevation and cost distance to water. The logistic regression model was very close to the model calculated with all variables (r score of 0.78). Accordingly, we only present the full model below.

Table 1 Pair-wise Spearman's r scores for environmental variables

	Elevation	Geomorphology	Vegetation	Slope	Aspect	Distance to water	Cost distance to water	Distance to quarries
Elevation	1							
Geomorphology	-0.35	1						
Vegetation	-0.33	0.36	1					
Slope	-0.07	0.05	0.04	1				
Aspect	-0.01	-0.03	-0.11	-0.03	1			
Distance to water	0.35	-0.08	-0.21	-0.15	-0.03	1		
Cost distance to water	0.52	-0.08	-0.05	0.23	-0.14	0.46	1	
Distance to quarries	-0.09	0.16	-0.16	-0.13	0.07	0.50	0	1

A second concern of many geographic models is spatial autocorrelation. If knowing the value of one cell helps us 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 Loco Hills model are not randomly distributed. For example, the terrain in the Loco Hills areas gradually rises from the valley floor. Thus, knowing the slope of one cell 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 Loco Hills grid. The program selects a 10 percent random sample of cells, which we used to represent the environment.

Weighted Sensitivity Model. The next step in data reduction was to develop a weighted sensitivity model. In developing the Loco Hills weighted model each environmental variable was divided into discrete states. For instance, the geomorphology theme was divided into nine classes as defined in Table 2. We then calculated the expected percentage of the cells that contain sites that should fall within each of the nine geomorphic classes if sites were randomly distributed. That is, if geomorphic class X constitute 10 percent of the study area and sites are randomly distributed relative to geomorphology, then 10 percent of the cells that contain sites should be found in the area covered by geomorphic class X. The observed percentage of cells containing sites within each geomorphic class was then determined. If the percentage of sites observed for a geomorphic class is less than the percentage expected, then that class receives a negative value, and if the percentage is greater, the class is assigned a positive value. The greater the deviation in either direction, the higher the weight. Weights range from -3 to +3.

Table 2 Weighting of variable classes for weighted sensitivity model.

Class	Description	Expected % of all cells with sites that would be found in this class	Observed % of cells with sites that actually fall in this class	Weight
1	Coppice dunes, thin sand sheet	31.0	54.0	3
2	Eroded Limestone surf, thin soils	13.4	1.2	-3
3	Exposed Pleistocene playa deposits	0.05	0	0
4	Floodplains of large drainages, Holocene deposits	0.26	0	-1
5	Floodplains of small drainages	0.47	0.21	-1
6	Parabolic Dunes, thick sand sheet	54.67	44.31	-2
7	Quarry, potential source of stone materials	0.00003	0	0
8	Sand sheet of undetermined age	0.1	0.08	0
9	Thick, uneroded Holocene playa deposits	0.27	0.15	-1

Using the data presented in Table 2 on geomorphology as an example, we see that coppice dunes cover 31 percent of the study area, but 54 percent of cells with sites are located in these landforms. Coppice dunes, therefore, are strongly associated with archaeological sites and are weighted a score of 3. In contrast, eroded limestone covers 13 percent of the project area, but only slightly more than one percent of eroded limestone cells contain sites. We must remember that eroded limestone areas are underrepresented in archaeological surveys. Thus, the strong negative association between sites and eroded limestone has to be assumed to be a function of insufficient

archaeological investigation. We believe, nevertheless, that this negative association will hold up upon further survey, and accordingly, we weighted the eroded limestone class as a -3.

We performed a similar analysis for the remaining seven environmental themes: aspect, slope, elevation, vegetation, cost distance to water, distance to water, and distance to quarries. With the exception of cost distance to water, all themes had variable states that proved to be positively or negatively associated with archaeological site locations. Because cost distance to water did not exhibit any relationship, it was eliminated from the model.

The weighted scores for each cell were then summed for the seven environmental themes. Theoretically, scores can range from -21 to 21. In practice, scores ranged from -12 to 21. To eliminate the problems of dealing with negative scores, we added twelve points to each score so that the range of weights varied between 0 and 36. To make the results comparable with those of the logistic regression model, the possible weights were grouped to yield four sensitivity zones (Figure 1). Class 3 comprised those cells scoring 21-36 (very good chance of containing a site); Class 2 contained those cells scoring between 18-21 (good chance); Class 1 contained cells scoring between 15-18 (poor chance); and the cells in Class 0 had scores ranging between 0-15 (very poor chance). Class 3 contained 45 percent of the cells with sites in 32 percent of the project area. Classes 1 through 3 combined contain 76 percent of cells with sites in 41 percent of the project area.

Figure 1 Weighted sensitivity model with 3 classes (0-3). Class 4 is outside the boundaries of the project area.

As the above discussion illustrates, the assignment of weights and sensitivity classes is somewhat subjective. One of the advantages of this method is that the scores are easily manipulated so that the model can be re-created, and the results of these manipulations can be observed. It is important to note, however, that there is no “best” or “final” solution. In our original attempts to

create a weighted model for Loco Hills we only used positive weights. A weight of 3 was assigned to those classes that contained 65 percent or more of the total number of cells with sites; a weight of 2 was given to classes that constituted the next 20 percent of site cells; and a weight of 1 to those that contained the last 15 percent. The resulting model worked “poorly” as judged in relation to the logistic regression model. The Spearman’s r between the two models was less than 0.60. In contrast, when we changed the weighted model to include both positive and negative weights, based on relative percentages, the Spearman’s r between the logistic regression and weighted model increased to 0.74.

Linear Regression Model. In classic linear regressions, the predicted values are unbounded; that is, they can take any value between negative infinity and infinity. For archaeological predictive models, however, we are only interested in two outcomes: a location does or does not contain a site. To overcome this problem, we can perform a nonlinear transformation, thereby constraining the dependent variable to probability scores between 0 and 1. The “logistic” distribution is an S-shaped distribution function, which is similar to the standard-normal distribution but easier to work with in most applications because the probabilities are easier to calculate.

For Pump III, we used the IDRISI module, LOGISTICREG, to calculate the logistic regression. The resulting equation is:

$$\text{Logit(site)} = 1.4146 + 0.545241(\text{coppice dune}) + 0.003666(\text{cost distance to water}) - 0.000043(\text{distance to quarries}) - 0.000169(\text{distance to water}) - 0.005068(\text{elevation}) - 2.489208(\text{eroded limestone}) - 0.003594(\text{aspect}) - 0.217984(\text{slope}) - 1.075599(\text{grass cover}) - 0.317156(\text{scrub}) + 0.000689(\text{aspect})$$

In an ordinary least squares regression equation or a linear probability model, the slope coefficients are directly interpretable. The direction and size of the slope coefficient can be interpreted as the strength and nature (positive or negative) of the relationship between the independent and dependent variables. This is not the case in logistic regression. Instead of the slope coefficients being the rate of change in the dependent variable as the independent variable changes, now the slope coefficient is interpreted as the rate of change in the “log odds” as the independent variable changes. This explanation is not very intuitive. While it is mathematically possible to compute the marginal effects of the values of the independent variables, such an option is not available with IDRISI, and this was not done for the Pump III model. Instead, we used the results of the weighted model (see below) to provide insight into the relative importance of the environmental variables as predictors of site location.

The first step in assessing a logistical regression model is to evaluate its overall performance. Most linear regression models can be assessed with an R^2 statistic, which is the proportion of the variance in the dependent variable explained by the variance in the independent variables. Unfortunately, there is no equivalent measure in logistic regression. There are several “Pseudo” R^2 statistics, however. Mathematically, these statistics vary between 0 and 1, but in practice the scores are relatively low. A good regression model should have a Pseudo R^2 greater than 0.2. The Loco Hills model scored 0.1006, indicating a relatively weak fit. Additionally, IDRISI calculates a Goodness of Fit statistic, which measures the difference between the observed and predicted values of the dependent variable; the lower the score, the better the fit. The Loco Hills score of 1,621,930.25 suggests a poor fit.

We ran the model again, using only one cell to represent each site. The cell selected was near the middle of the site, and the resulting equation was termed the “centroid” model. The result of the centroid model was very close to that of the full model (Spearman’s r score of 0.74). Although the Pseudo R² and Goodness of Fit scores suggest a relatively weak model, the centroid model comparison indicates that the logistic regression is accurately reflecting the underlying relationship between the environment and human settlement. This inference also can be tested by a statistic termed the Relative Operating Characteristic (ROC). The ROC compares a Boolean map of “reality” to a suitability map. This measure varies between 0 and 1, with 1 indicating a perfect fit and 0.5 a random fit. The Loco Hills logistic regression model had a ROC score of 0.7953. The relatively high ROC score combined with the comparison of the centroid and full model suggests that the environmental variables used as predictors are strongly associated with archaeological site location.

For each cell, the logistic regression calculates a probability score between 0 (site, less likely) to 1 (site, more likely). To display the results, we need to simplify the infinite number of possible probability scores into a more manageable number of “sensitivity” classes. We defined four classes:

- 0 (0.00–0.09-very poor chance of site presence);
- 1 (0.10–0.39-poor chance of site presence);
- 2 (0.40–0.59-good chance of site presence); and
- 3 (0.60–1.00-very good chance of site presence)

Classes 2 and 3 together contain 95 percent of the site cells, while covering 71 percent of the study area. Class 3 alone contains 58 percent of the site cells and constitutes only 21 percent of the project area.

A probability surface map of these scores is displayed in Figure 2. The four probability classes are displayed along with a fifth class of cells (Class 4) that did not enter into the logistic regression. These cells fall on the edges of the project area. Scores for secondary environmental themes could not be computed for these cells, and thus they were deleted from the model.

Figure 2 Logistic regression model with 3 classes (0–3). Class 4 is outside the boundaries of the study area

Comparison of the Sensitivity Models. Visually, the main difference between the weighted models and the logistic regression model is that the former contain fewer high sensitivity cells and many more very low sensitivity ones. To a large extent, this is a result of the manner in which the independent variables are treated in the analysis. The logistic regression model maximizes the statistical association of all the independent variables as a group with the dependent variable. Some variables are weighted more than others, not because they are more important in human decisions about settlement, but because these variables accounted for more of the variation in site location. Less variation in site location remained to be explained by the other proxy variables, and thus, these variables are much less important to the regression equation.

In contrast, all environmental variables have the same importance in the weighted model. This feature makes weighted models relatively easy to interpret. For example, parabolic dunes were assigned a weight of -2 (see Table 2) because few archaeological sites are visible on their surface. Because this landform covers such a large area of Loco Hills, this weighting has the effect of helping place a substantial part of the project area into the lowest sensitivity class (Class 0) (Figure 3). The logistic regression model, however, weights variables in relation to their association with the dependent variable. Parabolic dunes are given a negative weight, but by comparing the probability surface map, we see that other factors mitigate their presence. Parabolic dunes cover a far smaller percentage of the lowest sensitivity class in the logistic regression model (Figure 4) than they do in the weighted model (Figure 3).

Figure 3 Weighted sensitivity model. Parabolic dunes cover 73% of the low sensitivity area

Figure 4 Logistic regression model. Parabolic dunes cover 53% of the low sensitivity area.

The question immediately arises as to which is the better model. The answer depends on the intended use of the model. The logistic regression model is a better predictor of site location. If one knows the proposed boundaries of a lease area, then the best method for predicting whether a site will be found would be to place the lease area boundaries on the surface probability map. If, on the other hand, one is interested in accounting for the surface distribution of sites, then changing the weights of the various variables in an attempt to maximize the predictive power of the weighted model is an excellent way of beginning to understand the archaeological landscape.

The weighted model, as currently constructed, depends heavily on geomorphology. The distribution of coppice dunes mimics the highest sensitivity zones, whereas that of parabolic dunes mirrors the lowest sensitivity zones. This distribution raises the possibility that the models are not so much reflecting past human behavior as they are modeling depositional environments. Is it possible that archaeological sites are distributed much more evenly over these landforms, but are hidden beneath the parabolic dunes? This is a question that must be addressed if we are to manage cultural resources effectively in the Loco Hills.

RESULTS AND DISCUSSION

During the second six (6) months 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.

Participated in teleconference among task team and peer reviewers on the recommendations from SRIF on how the Otero Mesa study area boundaries might be revised based on feedback from oil and gas people and cultural resource managers.

Convened and led a technical meeting in Albuquerque, New Mexico on October 16, 2003. SRIF presented the draft sensitivity model for the Loco Hills study area. All participants discussed status of their work and this model. Sent out a meeting summary to all attendees.

At the October meeting the proposed new study area boundary for Otero Mesa was presented. It was further modified based on input from attendees. The new boundary was sent to DOE for approval.

Added new data to the data library.

Adjusted GIS data to fit the new Otero Mesa boundary.

Finalized the reviewer list and provided it to the partners.

Worked on Project Tracking for WYSHPO.

Assisted WYSHPO with data automation problems.

Scanned and digitized geomorphology maps for Azotea 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 Loco Hills study area developed by SRIF.

Integrated geomorphology, burial sensitivity, and site likelihood analytical data from New Mexico study areas into the project library.

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

Submitted required reports on time to DOE.

SRI Foundation

Results and conclusions reported in *The Loco Hills Technical Summary*:

Archaeological Implications

In Loco Hills, bigger, more complex sites are found along watercourses in the coppice dunes (Table 3). These settings, which would have supported economically important grasses and attracted small mammals, would have been ideal campgrounds for hunter and gatherers. Not surprisingly, sites in the high sensitivity class are larger, have more features, more formal flaked tools, more milling implements, and more depth of deposit. Sites in the lowest sensitivity zone are smaller and less complicated than their counterparts in the more sensitive classes, but these tendencies are one of degree and not nature. Sites in the lowest sensitivity class contain the same types of artifacts and features, just in smaller numbers and densities than comparable sites in the other classes.

Table 3 Prehistoric site data for a sample from high and low model sensitivity.

	Low sensitivity	High sensitivity
N of prehistoric sites	36	101
Averages site size	19,038 sq. m	173,107 sq. m
Stratigraphy	Unknown	Subsurface deposits present
% with ceramics	39	53
% with ground stone tools	69	86
% with projectile points	8	15
% with hearths	33	43
% with FCR concentrations	11	20
% with lithic quarries	6	0
% with middens	0	2
% in coppice dunes	16	86
% in parabolic dunes	78	13
Average distance to water	1986 m	538 m
% on North facing slopes	2	20
% on South facing slopes	67	18
% on East facing slopes	19	10
% on West facing slopes	10	50

There are two plausible explanations for the observed differences in the nature of sites found in the lowest and highest sensitivity zones. First, the differences may reflect variability in human adaptation to the Loco Hills area. Sebastian and Larralde (1989) review the adaptive models that have been created for southeast New Mexico and note that for the Archaic period most archaeologists argue that humans placed themselves on the landscape in relation to the seasonal availability of particular resources. This system, termed serial foraging (Elyea and Hogan 1983) is based on residential as opposed to logistical mobility.

In serial foraging model, all sites in the Loco Hills region reflect small, mobile groups, performing similar activities. Differences in site size, artifact density, and feature occurrence are not the result of differences in the nature of group composition or site function, but instead reflect the distribution and availability of particular plant and animal resources. The probability surface map, then, can be viewed as a prehistoric resource use map.

During the subsequent Ceramic period, settlement might have become more complex (Sebastian 1989b:82-83). Groups practicing agriculture may have established seasonally permanent sites, although they never achieved year-round permanence. These base camps would have housed larger groups, practicing a wide range of domestic and economic activities. To guard against crop failure, these groups might have gathered plants and hunted animals in the surrounding region, creating small sites consisting primarily of artifact scatters. Alternatively, hunters-and-gatherers and agriculturalists may have co-existed in the same area, developing a mutually cooperative adaptive system. In either case, larger, more permanent sites would have been established near agriculturally viable areas, with small, impermanent camps located at or near targeted wild resources.

The archaeological record of these various settlement systems would be different, although these differences would be slight and subtle. The differences hinge on the nature of the larger sites near the watercourses. Are these sites simply overlapping and repeatedly occupied locales or the remains of structured base camps? Detailed surface mapping could inform on these issues, although definitive answers would require data obtained in controlled excavation.

The relatively small sites in the low sensitivity zones all appear to represent the same cultural behavior: small groups establishing a camp for a day or two near a particular resource, exhausting that resource, and then moving on. If this interpretation is correct, these sites have little research potential. They probably will not be determined eligible for listing in the National Register of Historic Places under criterion d. Even if they are eligible as a class, the likelihood is that data recovery will be needed at only a few before their research potential is exhausted.

Approximately a third of the sites in the low sensitivity zones, however, contain features and more than two-thirds have groundstone tools, suggesting that at least some of these sites may have functioned as more than overnight procurement and processing camps. Are some of the sites in the low sensitivity classes remnants of repeatedly occupied locations? Could some be logistical basecamps? If so, what resource or resources were so attractive that people returned to what was otherwise perceived as an inhospitable region? Is it possible that the model is failing to detect the environmental signature of a key part of the adaptive strategy?

These questions bring up the second possible explanation to account for sites occurring in low sensitivity zones: some of these areas were attractive to prehistoric humans but post-depositional

processes have erased all archaeological surface indications. Archaeological sites in Loco Hills are strongly associated with coppice dunes and rare in the parabolic dunes. Both landforms are recent geomorphic features, resulting from historical period land use. The underlying parent sand sheets are different between the types of dunes, and it is reasonable to infer that the vegetative communities established on these underlying sands would have differed as well. Thus, it is possible that the dunes serve as proxy indicators for the locations of resources targeted or ignored by prehistoric populations.

It is not clear, however, that the prehistoric inhabitants of Loco Hills would have favored one vegetative community over the other. Both of the earlier sand sheets would have supported plants and animals of the desert scrub grasslands, and many of these resources would have been sought after by prehistoric inhabitants. Although the relative biological productivity of the two underlying landforms is debatable, there is no question that surface visibility in the coppice dunes is far greater than within the parabolic dune fields. Coppice dunes are less stable than parabolic dunes, and thus the former evidence more blowouts where archaeological materials can be found eroding out of or lying on the exposed underlying sand sheet. Thus, if the same number of archaeological sites were buried beneath the two recent landforms, we would find more archaeological sites exposed on the surface within coppice dunes than in parabolic dunes.

Such observations beg the question, “Are the differences in the archaeological record simply due to visibility?” This question, which cannot be answered with presently available data, is critical for the management of cultural resources in Loco Hills. If all the sites in the region represent the remnants of a single serial foraging system, any sites that may be buried under the parabolic dunes would be of limited significance, since the overall system could be adequately documented through the study of other, more accessible sites. If, however, sites in the parabolic dunes represent a unique portion of an adaptive system or an entirely different adaptive system then these sites are of exceptional significance, and cultural resource management within the Loco Hills study must take into account these differences.

Management Implications

Our first approach to evaluating the effectiveness of current cultural resource management practices was to answer the question “Has our understanding of site location patterns stabilized or would additional survey data increase our predictive success?” To address this question, 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. The expectation underlying this exercise was that, as our knowledge of the archaeological record improved, so would the predictive success of the models. If we found that the models were continuing to improve with each new iteration, including the final 2002 version, then we would assume that additional archaeological data would permit additional model refinement. Alternatively, if we found that the rate of improvement in predictive power had slowed or stopped, we could assume that we have enough site location data to create an accurate predictive model to be used in support of management decisions.

To determine when, during the history of archaeological survey and identification in the Loco Hills study area, we would have been able to generate predictive models as effective as the current model, we recalculated the logistic regression model based on data available in 1986, 1991, 1995, and 1998, and compared the resulting models with the model based on current data

(2002). At the end of 1985, approximately 10 percent of the 62,875 acres covered by 2002 had been surveyed. This total had risen to 20 percent by 1991; 30 percent by 1995; and 55 percent by 1998. We found that, visually, there was little difference among the models generated. Figures 5 and 6 show the results of a model based on the data available in 1986 and the results of the model based on 2002 data. Spearman's r scores were computed to compare each model's performance against the 2002 model. These scores ranged from a low of 0.88 in 1991 to 0.98 in 1998. The regression line depicted in Figure 7 is nearly flat, indicating that there has been little gain in predictive power since 1985. In short, we knew, or could have known, the basic outline of settlement in Loco Hills after only 10 percent of the region had been surveyed.

Figure 5 Logistic regression model created using prehistoric site data prior to 1986. The correlation score is the relation to the 2002 model.

Figure 6 Logistic regression model created using prehistoric site data prior to 2003. The correlation score is the relation to the 2002 model.

Figure 7 Correlation of each logistic model by year to 2002

Our second approach to evaluating current management practices was to reconstruct the history of cultural resource inventory in Loco Hills. As noted above, we demonstrated that the structure of the logistic regression model of archaeological site location stabilized very early in the development of the Loco Hills gas fields. Areas likely to contain sites could have been differentiated from those unlikely to contain resources within five years of the onset of large-scale gas exploration. This finding begs the questions of whether, armed with this knowledge, we

would have spent so much time and effort finding cultural resources, and whether we would have managed these resources differently. To a large extent, answering these questions depends on the confidence we place in the statistical models. Although the stability in the predictive model indicates that the underlying patterns of site distributions are quite strong, the complexity of the statistical techniques makes it difficult for the non-statistician to assess how much faith they should put in the results.

The inventory reconstruction provides a more intuitive and simpler means of making this assessment. By using the dates when surveys were conducted and sites were recorded, we reconstructed the history of archaeological inventory in the Loco Hills study area. Here we examine this history to determine when, in an ideal setting, we would have been able to recognize that we were not learning significantly more about settlement.

At first glance, the inventory reconstruction seemed simple. The ARMS staff had digitized and attributed all surveys and all individual recording episodes at each site. All we had to do was associate surveys and sites with the year in which they were conducted and recorded. With these data, we could calculate 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 number of acres in any given year, we would arrive at a site density for that year, which could then be 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 including 2002 was an accurate estimate of site density for the entire Loco Hills 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 and determine at what year the running site density consistently fell within the confidence intervals.

As we examined the ARMS data, however, it became clear that the task would be more involved. Many areas had been surveyed multiple times and many sites had been re-recorded; sometimes these events occurred in the same year. The survey history of Loco Hills was so complex that it was impossible to create an accurate summary or even to visually interpret the raw information.

The magnitude of this problem is hard to overemphasize. Between 1975 and 2002, surveys in the study area covered 75,223 acres, yet only 62,875 acres of ground were actually inventoried; the 12,348 acre difference results from resurvey. More than 19 sections of land were resurveyed over the years. The cause of this is that 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.

We decided to analyze the survey data using two different methods. Method I (Figure 8) 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 in Method I, therefore, are inflated. Method II (Figure 9) 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.

The results of the annual site density analyses are intriguing. Both the Method I and Method II graphs show a general rise in site density that peaks in 1997 and then falls off. It is unclear why 1997 is such an anomalous year, but it appears to be the result of targeted survey of one or more very large sites in the Bear Grass Draw area. During normal compliance-driven surveys, the portions of a site outside the boundaries of the survey corridor are not included as “surveyed space.” With this very large site or sites in Bear Grass Draw, however, the entire site area was included as surveyed space, greatly increasing the proportion of site area relative to survey area for that year and thus skewing the annual density figure.

Even with the one anomalous year, the trend in running site density figures is clear. Site density stabilizes at about 0.43 under Method I and 0.40 under Method II. Under Method I, running density falls in the 95 percent confidence intervals between 1984 and 1986, in 1994, and then consistently from 1997 until 2002. About half of the 19 years in question fall outside the confidence intervals, though none in the last 6 years. In contrast, under Method II the running site density stabilizes much earlier, around 1984, and only falls out of the 95 percent confidence intervals in two of the 19 years in question.

Figure 8 Overall site density Method I

Figure 9 Overall site density Method II

The results mimic those of the logistical regression. The estimate of site density stabilizes relatively early, though not as early as it does in the logistical regression model. The robustness of the predictive model reflects the very strong associations of archaeological site location and mappable environmental variables, and indicates that human behavior in this arid region was strongly shaped by the distribution of economic resources. The logistical regression model utilizes environmental themes that proxy the factors influencing human settlement.

Site density, however, is simply a measure of the intensity of human use of a landscape. We are not interested in this figure because it necessarily tells us anything about human behavior. Rather, site density is a good measure of how rapidly we can characterize the archaeological record. This measure is important because surveys are not proceeding according to a sampling design that would allow us to calculate the precision or the reliability of the estimates, but instead have historically followed the dictates of oil and gas development.

The logistic regression models and site density results above show that we stopped learning useful information about the *distribution* of cultural resources in the Loco Hills study area more than a decade ago. We might be tempted to conclude that this is because such a high proportion of the study area has been examined. Surprisingly, however, only about 20 percent of the total acreage has been inventoried. The appearance of greater intensity of coverage is a result of the sheer volume of narrow survey corridors represented by bounding lines, each of which is often nearly as wide as the width of the true survey corridor. An examination of the original paper maps on which the surveys were recorded makes this clear – the width of a pencil line represents approximately 12 meters on a 1:24,000 scale map. Even with GIS generated maps, the boundary lines have to be represented at a scale that makes them visible on electronic or printed media.

Yet both the logistical regression models and the site density analysis demonstrate that site distribution in Loco Hills is highly predictable, and that we could have known the structure of the archaeological record well before even the 20 percent survey coverage was reached. How is this possible? One reason is that oil and gas development is often preceded by seismic testing involving locations arrayed in long linear patterns. The rows of test locations and the associated roads all require survey, which has the effect of creating long transects across much of the study area. Oil and gas development and production also create long linear features, such as pipelines and powerlines; surveys for these facilities create still more long transects, and all of these transects almost invariably cross-cut the various environmental zones represented in the study area. Because human settlement is so strongly correlated with environmental features in southeast New Mexico, these linear surveys provide exactly the types of data required for predictive modeling.

Long linear transects also have a large edge effect, and thus can be expected to “find” a higher proportion of the total universe of sites than small square quadrats covering the same amount of ground. A large number of sites are, therefore, found rather quickly. Given the nature of development and concomitant survey in the Loco Hills study area, it is not surprising that the archaeological record of Loco Hills could be characterized quite accurately with a relatively small percentage of inventory.

We now return to our original question: when could we have had confidence in our predictions? To answer this question, we return to the site density analyses. The graphs of running densities for Method I and II (Figures 8 and 9) exhibit similar trends, but their differences should not be minimized. As noted above, Method I graphs archaeological inventory results in “real time,” that is, as survey was conducted, overlaps and all, and uses data on the total amount of surveyed acres and the reported number of archaeological sites. If these data had been tracked year by year using this method, the relatively wide annual fluctuation in site density would most likely have led cultural resource managers to believe that they still could not estimate density with any degree of reliability at least as recently as 2000.

By using Method II, reliable density figures would have been available by the end of the 1980s. These data, combined with the stable logistical regression models, would have enabled cultural resource managers to have as good an understanding of site densities and site locations relative to environmental parameters as we have today, despite the large amount of additional archaeological survey since that time.

Western GeoArch Research

Data gathering/data entry

- Natural Resources Conservation Service (NRCS)
 - Gathered 95 percent of all available SSURGO county data (soils data)
 - Gathered 95 percent of all available STATSGO statewide data (soils data)
- Wyoming Geological Survey
 - Completed statewide bedrock geology
 - Completed statewide surficial geology
- Stream buffering from USGS vector and raster data
 - Completed stream order delineation

- Completed about 50 percent of the exclusion of steep areas
 - Completed field reconnaissance
- Data modeling
- Completed 80 percent of the modification of Pine Valley model to fit Powder River Hydrological Basin (PRHB)
- Literature research and report writing
- Wrote the introduction text sections including regional setting (first draft prepared – 60 percent complete)
 - Described the geology and soils of the project area including their significance to project goals (first draft prepared – 60 percent complete)
 - Wrote the methodology (first draft prepared – 60 percent complete)

Conferences and presentations:

Partner Technical Meeting, Albuquerque, New Mexico, October 16, 2003

Red Rock Geological Enterprises

Completed data entry of SSURGO data (soils)

Completed geomorphology text for *The Loco Hills Technical Summary*

Complete geomorphology maps for Azotea Mesa study area

Field checked the Azotea Mesa geomorphology map

Assembled topological maps and aerial photographs for the Otero Mesa study area

Started mapping geomorphology of Otero Mesa study area

Attended the partner technical meeting in Albuquerque, New Mexico, October 16, 2003

Collaborated with other partners on what to expect in the Otero Mesa study area

Planned Otero Mesa field trip to verify geomorphology map

New Mexico Historic Preservation Division

To date ARMS has processed a cumulative total of 8708 survey reports and entered them into the production New Mexico Cultural Resource Inventory System (NMCRIS) database. A cumulative total of 3739 sites (5555 digitized boundaries) have been added to the PUMP III geodatabase.

Data for the Azotea Mesa and a much-expanded Otero Mesa study area were delivered to SRIF.

Accounting for the large number of reports that were processed but could not be digitized owing to inadequate source graphics (11 percent in the Loco Hills study area), a little over 51 percent of the total reports have been processed.

Wyoming State Historic Preservation Office

Project and site data have been completed for Campbell, Johnson, Sheridan, and Weston counties. Natrona, Converse and Crook counties are currently about 50 percent complete and Niobrara County has not been started. Overall, we are approximately two months ahead of schedule on this part of the project.

During the past quarter, the project developed a more improved database interface for querying the master database and viewing the spatial data. Gnomon revised our on-line database applications to include links to site form images and review data. Now a user can view the documentation of resources on files and check the review status of sites. The WYSHPO Review and Compliance database can be queried to see when a site was reviewed in the Section 106 process, the status of the property, the official review number and how many time the SHPO had dealt with the property. This allows federal agencies to efficiently check the Section 106 status of sites and make more efficient decisions on a site's current eligibility status.

During the past year all site forms for the study area have been imaged into PDF format for use on our website. Over 21,000 forms were imaged during the calendar year. Funding for this effort is provided by the WYSHPO and Bureau of Land Management.

WYSHPO hosted a project meeting in September, 2003 for the Wyoming project participants. The meeting was held in Estes Park, Colorado in conjunction with the Rocky Mountain Anthropological Biannual conference. The focus of the September meeting was to gain input from potential users on how the application would be used in a federal agency or in a private consulting firm. We did an on-line demo of the application and gathered input from participants. We discussed training schemes and how it might be best to implement this application in the coming year. Potential locations for training include Laramie, Casper, Lander and Rock Springs. Western Archeological Services is willing to test the application and provide comment.

In December of 2003, a meeting was held in Rock Springs with the WYSHPO to discuss the application and train staff. User input from this meeting was positive and anticipation of the use of the application was successful.

Presentations during period:

Wyoming Water Planning groups
ESRI Southwest User Group
Independent Petroleum Association of America Annual Meeting

TO BE ACCOMPLISHED JANUARY 1, 2004 – JUNE 30, 2004

Gnomon

Participate in review of *The Loco Hills Technical Summary*.

Continue to integrate geomorphology, burial sensitivity, and site likelihood analytical data from New Mexico and Wyoming study areas into the project library.

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

Digitize geomorphology map of the Otero Mesa study area created by Steve Hall and deliver it to SRIF for model creation.

Review report draft of technical summaries for Azotea Mesa and Otero Mesa created by SRIF and Steve Hall.

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

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

Visit the WYSHPO office to see how the tracking tool and data entry tool are working and check on how digitization is progressing.

Plan one more technical project meeting for all participants.

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.

SRI Foundation

Complete models for Azotea Mesa and Otero Mesa.

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

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

Complete Final Report drafts for Chapters 1- 8.

Attend technical project meeting.

Western GeoArch Research (William Eckerle)

Gather remaining SSURGO and STATSGO data (soils data).

Complete exclusion of steep areas in stream buffer data.

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

Complete geology and soils data in project area including their significance to project goals.

Complete data compilation, up to six detailed risk models, GIS and other datasets.

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

Attend technical project meeting.

Red Rock Geological Enterprises (Stephen Hall)

Conduct fieldwork in Otero Mesa.

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

Complete data compilation; up to six detailed risk models, GIS and other datasets.

Complete draft of final report for geomorphology studies in the New Mexico study areas.

Attend technical project meeting.

New Mexico Historic Preservation Division

Process survey reports for the remaining project area, which is three 1-degree lat/long blocks of 64 quads each. ARMS has completed 84 percent of 32103, 36percent of 32104, and 19 percent of 32105. At the current productivity rate, they anticipate processing the remaining data by October 2004.

Attend technical project meeting.

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. We anticipate this application to be in use by April 1, 2004. A training schedule will be developed in January of 2004.

Move our GIS applications to ESRI's ArcSDE.

Attend technical project meeting.

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 Loco Hills 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 Loco Hills and Azotea Mesa in New Mexico and for the Powder River Basin in Wyoming. 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.

Geomorphology studies in New Mexico and Wyoming are now almost complete. Most of the data entry of site records and inventories in New Mexico and Wyoming has been completed. SRIF has started to write a draft of possible CRM recommendations.

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

1. Cultural resource surveys in the Loco Hills 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 Loco Hills study area.
3. The logistic regression models and the inventory reconstruction demonstrate that sufficient data were available to support important decisions about cultural resource management and oil and gas development when as little as 6 to 7 percent of the land had been inventoried. But because there has been no mechanisms for synthesizing previously acquired survey data, cultural resource managers have neither been able to use previous data to limit duplication of effort nor had available models and other tools to focus management and preservation efforts.
4. Our understanding of the past has not increased proportional to the amount of survey or the number of sites recorded.
5. A possible recommendation that may come out of this report is to change CRM objective from simply documenting surface-visible archaeological sites and avoiding them to determining and understanding the nature and distribution of archaeological sites. The challenge is to find ways of funding excavation and other scientific inquiries needed to evaluate the information potential of surface-visible sites, to model likely locations of buried sites with important information to offer, and to explain both the distribution and the nature of sites in the Loco Hills area.

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