Adaptive Management and Planning Models for Cultural Resources in Oil and Gas Fields in New Mexico and Wyoming

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Final Technical Report

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ABSTRACT

In 2002, Gnomon, Inc., entered into a cooperative agreement with the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) for a project entitled, *Adaptive Management and Planning Models for Cultural Resources in Oil and Gas Fields in New Mexico and Wyoming* (DE-FC26-02NT15445). This project, funded through DOE's Preferred Upstream Management Practices grant program, examined cultural resource management practices in two major oil- and gas-producing areas, southeastern New Mexico and the Powder River Basin of Wyoming (Figure 1). The purpose of this project was to examine how cultural resources have been investigated and managed and to identify more effective management practices. The project also was designed to build information technology and modeling tools to meet both current and future management needs.

The goals of the project were described in the original proposal as follows:

Goal 1. Create seamless information systems for the project areas.

Goal 2. Examine what we have learned from archaeological work in the southeastern New Mexico oil fields and whether there are better ways to gain additional knowledge more rapidly or at a lower cost.

Goal 3. Provide useful sensitivity models for planning, management, and as guidelines for field investigations.

Goal 4. Integrate management, investigation, and decision-making in a real-time electronic system.

Gnomon, Inc., in partnership with the Wyoming State Historic Preservation Office (WYSHPO) and Western GeoArch Research, carried out the Wyoming portion of the project. SRI Foundation, in partnership with the New Mexico Historic Preservation Division (NMHPD), Statistical Research, Inc., and Red Rock Geological Enterprises, completed the New Mexico component of the project.

Both the New Mexico and Wyoming summaries concluded with recommendations how cultural resource management (CRM) processes might be modified based on the findings of this research.

INTRODUCTION

Eric Ingbar, Lynne Sebastian, and Mary Hopkins

Overview

In 2002, Gnomon, Inc., entered into a cooperative agreement with the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) for a project entitled, *Adaptive Management and Planning Models for Cultural Resources in Oil and Gas Fields in New Mexico and Wyoming* (DE-FC26-02NT15445). This project, funded through DOE's Preferred Upstream Management Practices grant program, examined cultural resource management practices in two major oil and gas-producing areas, southeastern New Mexico and the Powder River Basin of Wyoming (Figure 1). The purpose of this project was to examine how cultural resources have been investigated and managed and to identify more effective management practices. The project also was designed to build information technology and modeling tools to meet both current and future management needs.

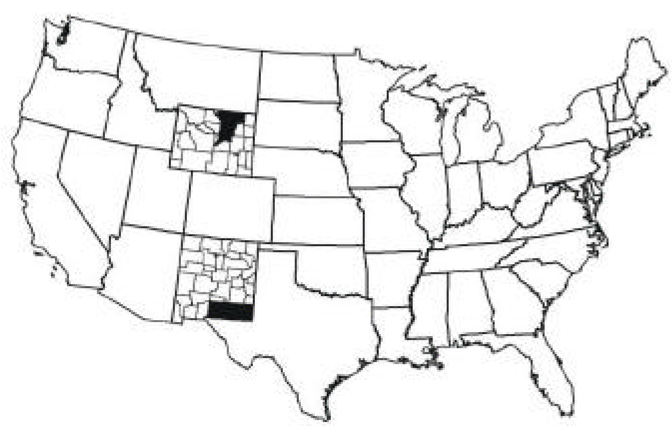

Figure 1. New Mexico and Wyoming project areas

Oil and gas exploration and development are long-term, enduring, uses of public lands. Every exploration and development effort on public lands for the past 30 years has in some fashion addressed impacts to cultural resources, especially archaeological sites. Today, far more archaeological fieldwork is done because of oil and gas development than because of traditional, academic research. The volume of work is truly stunning: within the Powder River Basin, Wyoming study area of this project over 16,000 archaeological sites have been revealed by more than 10,000 archaeological inventories. In the southeastern New Mexico study area, more than 21,000 inventories have been conducted and over 8,000 archaeological sites are known to be present.

Cultural resources are often considered an impediment to development of oil and gas fields, in part because they differ from many other regulated environmental resources. Some classes of regulated resources have the potential to be regenerated as a means to offset their destruction. Loss of a wetland can be mitigated by creating new wetlands. Loss of habitat for a rare species can be offset by protection or even creation of appropriate habitat elsewhere. Cultural resources are different from these examples, for they exist only once and cannot be re-created in some other locale; indeed, integrity of location is one of the primary analytical values of an archaeological site.

The National Historic Preservation Act of 1966 (NHPA) and subsequent federal land management legislation and policy (e.g., the Federal Land Policy Management Act [FLPMA, 1976]) recognize that part of the value of cultural resources is the scientific information they contain. This is especially true of historic and prehistoric archaeological sites. Management of archaeological resources on public lands over the past 30 years has focused on retaining high-information sites and site settings. Other factors are important too but far less common: historically important places, important examples typical of a time or place in our past, places of deep religious interest to Native Americans, and places or sites amenable to interpretation for the public.

An important consideration in this study was whether current practices in archaeological fieldwork, management, and decision-making are efficient. Management of cultural resources has focused on the identification, evaluation, and mitigation of impacts to resources through standard field and management procedures that, through time, have become routine. Familiarity has not necessarily bred efficiency, by any one of a number of measures. Cultural resource clearances were identified as a problem in a 1996 interagency document on applications for permits to drill entitled "Report on Problems Identified with Processing Timeframes and Recommendations to Resolve Identified Issues". More recently, the Bureau of Land Management's 2002 Application for Permit to Drill (APD) Task Force identified cultural resource management practices as being in need of practical reform as they relate to oil and gas leasing

The study was staged in two locations because oil and gas development and the management of its effects varies. There are many reasons for this, but foremost among them is that exploration and extraction vary by the sort of resource, and by land ownership and management .The archaeological record itself is different from one place to the next, so different sorts of investigation, mitigation, and management strategies are used even under similar modes of energy development. By using two study areas in very different settings, the project avoided bogging down in issues pertinent to a particular energy development mode or specific archaeological record.

During the course of this study, we sought opinions about how to reform cultural resource management within the multi-use mandates of the federal land-managing agencies. We collected a variety of ideas covering the full range of land use planning. From resource management plans to pre-lease sale stipulations to mitigation strategies, there was no lack of interesting and potentially useful recommendations from industry, government, and private consultants. Some of these thoughts affected how we achieved the goals of the project.

Gnomon, Inc., served as the managing partner in a consortium effort that involved many other firms and agencies. Our primary partnerships included: the Wyoming State Historic Preservation Office (WYSHPO), and Western GeoArch Research, the SRI Foundation, the New Mexico Historic Preservation Division (NMHPD), Statistical Research, Inc., and Red Rock Geological Enterprises. The Bureau of Land Management state offices in Wyoming and New Mexico, the Carlsbad and Las Cruces Field Offices (New Mexico), and the Buffalo, Worland, Kemmerer, and Casper field offices were federal partners. The oil and gas commissions, oil and gas industry associations, and specific energy firms were helpful collaborators.

Early on, this project was given the shorthand designation "PUMP III" in reference to the funding source – the third round of PUMP grants. Like most nicknames, "PUMP III" seems to have become a permanent label despite our best efforts to find some other, more descriptive name. And at that, it is probably a big improvement over the alternative, which would most likely have been some unpronounceable acronym, using the first letters of the formal project title: AMPMCROGF? PUMP III it is!

Goals and Outcomes

The goals of the project, and a short summary of the project outcome are described below:

Goal 1. Create seamless information systems for the project areas.
Both New Mexico and Wyoming state historic preservation offices have long-term investments in automated data systems. These have been "internal" systems for the most part. As part of this project, both New Mexico and Wyoming added large volumes of data to the information systems used by cultural resources professionals to plan, report, and evaluate archaeological fieldwork. These same data systems are used by cultural resource managers in federal and state agencies to evaluate land use proposals, including oil or gas proposals. Tens of thousands of existing paper information was converted to readily accessible digital formats (available via secured internet access). The Wyoming part of this study includes an analysis of the time and cost savings from automating basic archaeological site and investigation records Both states improved the accessibility of the information as well by improving the on-line services already available and by adding new kinds of information services.

Goal 2. Examine what we have learned from archaeological work in the southeastern New Mexico oil fields and whether there are better ways to gain additional knowledge more rapidly or at a lower cost.
This question was addressed in consultation with the Bureau of Land Management (BLM) and the New Mexico Office of Cultural Affairs, Historic Preservation Division. Examining this question involved the project team assessing how much new archaeological *information* (not just observations) has been gained over the past twenty

years of fieldwork. Unfortunately, the consensus was that professional knowledge of the archaeology of southeastern New Mexico had gained in volume, but not in quality. Our recommendations discuss this finding in detail.

The project examined different field inventory techniques that could have been used to gain similar archaeological knowledge more rapidly. Here, we used the ability to rapidly analyze inventory results at different times (by using the electronic data system populated by the project). This allowed us to simulate several inventory configurations (e.g., project-based, lease-based, and energy-field-based inventory strategies). We did find that there are more effective means of doing inventory within oil and gas fields, at least using the measures of "knowledge" that we employed.

In the New Mexico study area, there is an obvious bias in the archaeological sites that have been recorded. This is an outcome of the way in which management and activities have proceeded: avoiding archaeological sites is the common practice. This biased view of the archaeological record, the study suggests, has limited management of archaeological sites to aself-perpetuating management process, in which one cannot let of a particular site (so it is avoided) because so little knowledge has actually been gained.

A related question addressed in the simulation studies and in our discussions with participants in the development and management process is when archaeological information is most useful and can be gathered most effectively. The unsurprising outcome is that most participants desire more information far in advance of any proposed action, including leasing. The paradox is that no one is willing to pay the cost of fieldwork (even in its most efficient configurations) without a project in sight. The common good is served by work in advance.

Despite these findings, there are junctures at which one can gain significant widespread archaeological knowledge efficiently and fairly early in the oil and gas development timeline. The study finds that three-dimensional seismic work could provide an excellent means of gaining a widespread archaeological sample. Again, there are economic exigencies to be overcome; these are discussed in the New Mexico study report.

Recommending ways to change field and information practices is relatively fruitless unless there is a means to capture the outcomes of these new ways of doing archaeology and management. In both the Wyoming and New Mexico studies, this project provided applications and guidelines for retaining new sorts of results.

Goal 3. Provide useful sensitivity models for planning, management, and as guidelines for field investigations.

Geomorphic processes affect the surface occurrence of archaeological sites. Buried archaeological materials present one of the greatest challenges to management and development of cultural resources in oil and gas settings. Surprise "discoveries during ground-disturbing actions hamper development. So, one goal of this project was to provide assessments of the risk of finding materials in archaeologically useful buried contexts. The project is to provide assessments of the risk of finding materials in archaeologically useful buried contexts. The "burial risk" model has utility in several ways. Prior to lease formulation, an agency can assess the likelihood of buried cultural materials being present and reformulate a lease area appropriately. A prospective bidder can make a better-informed decision about a given lease and its potential for undesirable (from the bidder's viewpoint) cultural resource complications. In planning on-the-ground actions, the least sensitive locations could be favored for ground-disturbing actions. Using information on the potential for buried sites, agency staff can better evaluate areas with existing inventory data to determine whether additional effort to identify cultural resources are needed.

Goal 4. Integrate management, investigation, and decision-making in a real-time electronic system.

New Mexico and Wyoming have been developing on-line information services available to state and federal agencies and private cultural resource consultants. To date, these systems have not included a shared application between land-managing federal agencies, the state historic preservation offices (SHPOs), and consultants doing the work on the ground. Currently, the investigation-decision-management process for actions like APDs is mostly done via paper. A consultant originates the document, the federal agency reviews the document and its findings, then the SHPO may review and comment, and only then will a finding be made on the undertaking (e.g., as APD) itself. In Wyoming, for example, the transit time from fieldwork to presence in the data system required three months of more.

Using a web-based project tracking application, enhanced and improved by this project, Wyoming cultural resource consultants and agencies have a single database of fieldwork and results. This system increases the efficiency of managers as they cope with the paper flood of permit-related requests, reports, and records.

Project Funding

This project is primarily funded by Department of Energy (DOE) funds. DOE is contributing $1,416,121, which is 79.0% of the total project budget. The remaining 21% of the project budget was comprised of matching goods and services provided by the primary project partners.

Adaptive Management & Planning Models for Cultural Resources in Oil & Gas Fields

New Mexico Pump III Project

BY

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Introduction

Lynne Sebastian, Eric Ingbar, Stephen A. Hall, Tim Seaman, and Stephanie A. Ford

In 2002, Gnomon, Inc., entered into a cooperative agreement with the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) for a project entitled *Adaptive Management and Planning Models for Cultural Resources in Oil and Gas Fields in New Mexico and Wyoming* (DE-FC26-02NT15445). This project, funded through DOE's Preferred Upstream Management Practices (PUMP) grant program, examined cultural resource management practices in two major oil- and gas-producing areas: southeastern New Mexico and the Powder River Basin of Wyoming (Figure 1.1). The purpose of this project was to examine how cultural resources have been investigated and managed in these areas and to identify more effective management practices. The project also was designed to build information technology and modeling tools to meet both current and future management needs.

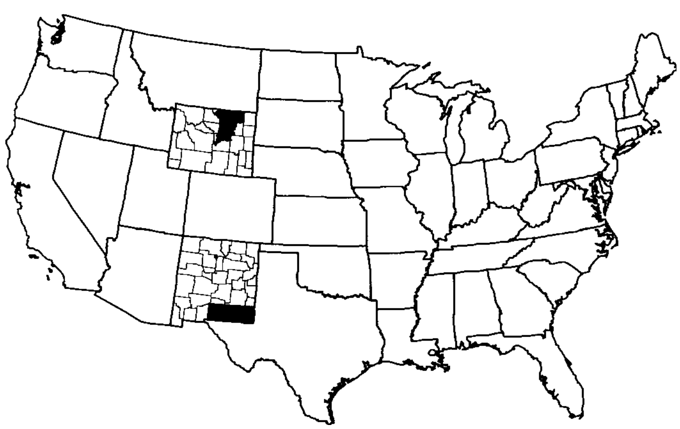

Figure 1.1. New Mexico and Wyoming project areas.

Gnomon, Inc., served as the managing partner in a consortium effort that involved many other firms and agencies. Our primary partnerships included the Wyoming State Historic Preservation Office (WYSHPO), Western GeoArch Research, SRI Foundation, the New Mexico Historic Preservation Division (NMHPD), Statistical Research, Inc., and Red Rock Geological Enterprises. The Bureau of Land Management state offices in Wyoming and New Mexico, the Carlsbad and Las Cruces field offices (New Mexico), and the Buffalo, Worland, Kemmerer, and Casper field offices (Wyoming) were federal partners. The oil and gas commissions, oil and gas industry associations, and specific energy firms were helpful collaborators.

Early on, this project was given the shorthand designation "PUMP III" in reference to the funding source—the third round of PUMP grants. Like most nicknames, "PUMP III" seems to have become a permanent label despite our best efforts to find some other, more descriptive name. And at that, it is probably a big improvement over the alternative, which would most likely have been some unpronounceable acronym, using the first letters of the formal project title: AMPMCROGF? PUMP III it is!

The New Mexico Pump III Project

The New Mexico component of the Pump III project focused on the southeastern quadrant of the state (Figure 1.2) and comprised three study areas: Loco Hills, Azotea Mesa, and Otero Mesa. The Loco Hills study area encompasses most of a mature, heavily developed oil and gas field in Lea and Eddy counties, managed by the Carlsbad Field Office of the Bureau of Land Management (BLM). Azotea Mesa, which is also managed by the Carlsbad Field Office, is a currently developing oil and gas field in Eddy County. Otero Mesa, which is under the jurisdiction of the BLM's Las Cruces Field Office, is an area that has experienced a marked increase of interest in oil and gas development and was covered in a recent Resource Management Plan amendment and Environmental Impact Statement for fluid mineral leasing and development (BLM Las Cruces Field Office 2003).

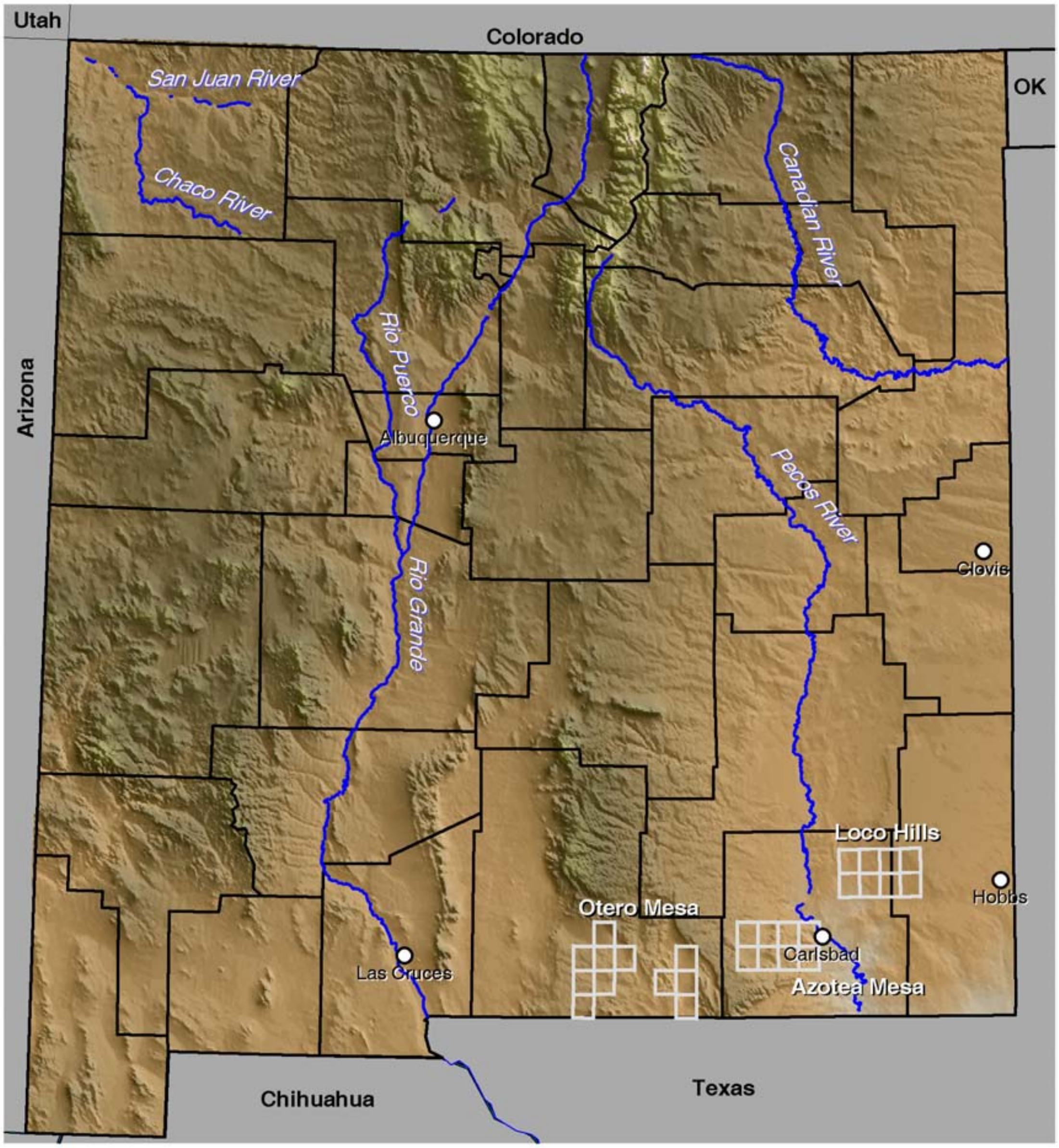

Figure 1.2. Location of the three study areas in New Mexico.

The New Mexico component of the Pump III project includes development of

- digitized archaeological survey and site location information for the entire project area; this information will be made available through the New Mexico Cultural Resource Information System (NMCRIS) maintained by the Historic Preservation Division
- a geomorphology study for each of the three study areas
- predictive models of archaeological site locations based on correlations with environmental variables for each of the three study areas
- inventory simulations to reconstruct the history and evaluate the effectiveness of archaeological survey within each of the study areas
- management recommendations for more predictable, efficient cultural resource compliance processes for oil and gas development as well as better management of cultural resources on public lands

The overall project area encompasses much of the current and projected venues for oil and gas development on public lands in the New Mexico portion of the Permian Basin. The three detailed study areas were chosen specifically because they represent different phases in the development life of oil and gas fields—a heavily developed field (Loco Hills), a currently developing field (Azotea Mesa), and a potential field that is the subject of ongoing land use planning (Otero Mesa). The underlying premise of the New Mexico project is that we can learn from the decisions that worked well in previous developments and from the decisions that did not work as well. Ultimately we hope to devise better, more efficient, and more effective management strategies for future developments.

The individual components of the New Mexico project are described briefly below.

NMCRIS Data Project

The New Mexico Historic Preservation Division's Archaeological Records Management Section (ARMS) maintains an inventory of all recorded archaeological sites and investigations in the state. ARMS is the official state clearinghouse and repository for data derived from more than 80 years of archaeological research, describing more than 145,000 archaeological sites and 93,255 inventory and excavation projects (Tim Seaman, ARMS, personal communication, August 2004).

In 1993, the original computerized ARMS database was upgraded to a more comprehensive system known as the New Mexico Cultural Resource Information System (NMCRIS), designed to serve the needs of a broader user community that includes industry as well as government and researchers. NMCRIS is based on modern relational database technology in a multiuser operating environment. The database can be accessed locally at the Laboratory of Anthropology in Santa Fe, New Mexico, or at remote locations via the Internet. NMCRIS provides information to both government and private entities so that cultural resources can be considered in early stages of project planning, and damage to archaeological resources can be minimized.

The NM Data Collection Effort

The objectives of the New Mexico portion of the PUMP project required the development of a database to support the project's modeling efforts and to serve as a basis for future management. Although ARMS has been digitizing survey areas for many years, statewide coverage is not yet complete. Within the PUMP III project area the number of surveys in need of digitizing surpassed 20,000. ARMS approached this massive backlog by first identifying all surveys conducted within the project area prior to June 2002 using NMCRIS database tables. After merging this target list with the current NMCRIS GIS layers, ARMS identified surveys in need of digitizing and scheduled them for processing. Although archaeological sites already have statewide coverage in NMCRIS as centroids (points) and as simple proxy boundaries (polygons) computed from reported size figures, for the current project all site boundaries were digitized from the processed reports. Site boundaries were thus associated with multiple events in this GIS layer.

It is important to note that this process focused entirely on the information actually housed at the Laboratory of Anthropology. The effort was not coordinated with BLM field offices, where substantial numbers of reports are being held for submission to NM SHPO and ARMS. As these reports made their way to ARMS during the project, they were added to NMCRIS and extracted for analysis if the report was completed prior to June 2002. Based on survey registration data in NMCRIS, it is estimated that more than 150,000 acres of survey from the Carlsbad Field Office were not included in PUMP III modeling activities. This represents more than 260 reports dating prior to the June 2002 cutoff. PUMP III has made significant inroads in creating a seamless cultural resource database for southeastern New Mexico, but with persistently high volumes of survey work in the Carlsbad Field Office this backlog will continue to be a hurdle for management.

Data Quality and Limitations

NMCRIS data represent the cumulative record of archaeological survey investigations in southeastern New Mexico between approximately 1975 and June 2002. Data quantity and quality are variable, depending on the specific site form used, the intensity of the recording effort, and the level of experience of the recorders. Although each site and survey record in NMCRIS contains metadata that allows investigators to filter or control this variability when creating a dataset, the PUMP III modeling effort was of sufficiently broad scope to posit that these recording variations would not affect the validity of the modeling results.

By statewide standards, much of the data for southeastern New Mexico is of low quality, especially in areas of intensive oil and gas development. For example, more than 30% of the surveys processed in the Loco Hills study area could not be digitized owing to poor source graphics. Maps were often illegible and/or at insufficient scale, and the locations of site and survey boundaries could not be interpreted by the digitizers.

Site data too are of low quality. Almost all survey in the Loco Hills and Azotea Mesa study areas has been conducted in response to industry requirements for leasing on BLM lands. Archaeological survey has been uncoordinated, redundant, and inefficient. Variability in recorded site data about chronology, site function, or settlement pattern are rarely if ever considered in any comparative or analytical framework. Because site recording events rarely take previous work into consideration, the analyst is left, in many cases, with a series of independent observations, often with varying descriptions and even different locations for the same archaeological sites. Sorting out the most reliable observations for any given site is extremely difficult. For PUMP III, the scale of analysis and the overwhelming size of the data collection task precluded any systematic approach to squeezing out the best information.

Implications for NMCRIS

PUMP III has provided ARMS with a unique opportunity. This project required a systematic, report-by-report method to process the backlog of survey reports quickly. This in turn allowed ARMS to build a historical GIS layer of site boundaries. With multiple, often highly variable boundaries for many archaeological sites, this layer has been troublesome for the analysts. We tend to assume in our models that survey covers an area once, and that once discovered, a site is located on a map, described on a form, and the records filed for future management and research needs. The truth in places like Loco Hills is that the same ground may be covered multiple times, and that archaeologists typically record known sites without taking previous observations into consideration. The apparent differences in a site's location, configuration, and description may be influenced by the action of eolian forces over extended periods of time, but one cannot rule out differences in observer perception (lumpers vs. splitters) or the pressure to flag-and-avoid sites to facilitate development. From this perspective, the site boundary layer should be worrisome for cultural resource managers and SHPO as well.

For ARMS, the PUMP III site boundary layer presents some conversion and database design challenges. To integrate the PUMP III site boundaries into the current NMCRIS design, ARMS will have two choices: (1) conflate all site boundaries into a single polygon for each site, or (2) choose a single boundary based on the latest (or first?) recording date. Both strategies are viable from a data-processing standpoint, but the historical associations will be lost. Alternatively, ARMS could develop a project-specific NMCRIS site boundary layer. Site boundaries would be linked to surveys as well as sites, thus maintaining a source lineage. A substantial redesign effort would be required, the new layer would foster some user confusion, and managers would need to think about "official" site boundaries in areas like Loco Hills, but the effort might well be worth it.

Geomorphology Study

Geomorphology was important to this project for two reasons: (1) Geomorphology is a major component of the natural environment and thus may be an important factor in site-location decisions by prehistoric people, and (2) Once a site is formed and abandoned, geomorphology and geomorphic processes are pivotal in determining whether the site is preserved or destroyed. Thus, the preserved archaeological record that can be seen and inventoried and analyzed is, in part or wholly, a consequence of geomorphology. Also, site visibility is a key ingredient of the archaeological record. If sites are mantled by sediments and bioturbation has not brought artifacts to the surface, the site is invisible and will not be detected in surface site surveys.

The geomorphic circumstances also pertain directly to site preservation. Sites that are covered by sand and invisible at the surface, ironically, may be well preserved in the subsurface. In contrast, the erosion that provides 100% site visibility also destroys those sites; their stratigraphic contexts are completely lost, and the spatial distribution of artifacts may be severely altered.

Methodology

The surficial geology of the Loco Hills, Azotea Mesa, and Otero Mesa areas in southern and southeastern New Mexico was evaluated using (*a*) stereo-paired color infrared aerial photography (scale 1:58,000), (*b*) stereo-paired black-and-white aerial photography (scale 1:40,000), and (*c*) U.S. Geological Survey topographic maps (scale 1:24,000; contour interval 10 and 20 feet). The aerial photographs are available to the general public via the Internet from the EROS Data Center, Sioux Falls, South Dakota. Geomorphic and geologic features with archaeological significance were identified on the aerial photographs and the distribution of the features was transferred by hand onto topographic maps. The mapping of the sand dune–dominated Loco Hills area was facilitated by prior studies of the area by one of the authors of this chapter (Hall 2002). USDA county soil maps and various geologic maps of the study areas were of limited value owing to their more general nature, which does not show features or landforms that are applicable to the archaeological record.

Color infrared aerial photographs were especially valuable in the identification and mapping of small basins and associated wet ground in the arid lands of southeastern New Mexico. Wet-ground plant cover shows up as red or pink on the infrared photographs, in contrast to the gray colors of the surrounding shrub grassland plant communities. Some ephemeral basins that contain water only during wet seasons are unclear on black-and-white aerial photographs, and some smaller basins do not show up on topographic maps with 10-foot or 20-foot contour intervals. A disadvantage of the color infrared aerial photographs is their coarse scale compared with the finer scale of the black-and-white aerial photographs.

Surficial geology/geoarchaeological maps of the project areas were produced in the office and then field checked. For the most part, the maps produced from aerial photographs were accurate, although field inspection indicated that minor adjustments to the definition and boundaries of some mapping units were necessary.

Mapping Categories

Because of differences in bedrock geology and recent geologic history, the landforms and geoarchaeology of the three study areas are vastly different. Twenty-one mapping units were established for the three study areas. The 21 units are permutations of three separate, coarser categories that represent major aspects of archaeological-site geology: (*a*) site landscape context, (*b*) ages of surfaces/soils, and (*c*) potential surface visibility.

Site Landscape Context. Landscape context refers to the major landform categories on which sites were formed. The three New Mexico study areas comprise five landform categories along with a sixth category of "unique places," such as caves, springs, or quarries.

1. Stable surfaces/soils: absence of or less than 0.3 m of late Quaternary sediments, presence of well-developed Pleistocene soils or paleosols, denuded surfaces, escarpments; sites likely have 100% visibility and poor preservation.
2. Eolian: sand sheets, dunes, loess; high variability in thickness over short distances.
3. Alluvium: floodplain and overbank deposits by small and large streams, fluvial terraces, alluvial fans; on the sand sheets, alluvium may be partly buried by eolian sand.
4. Lacustrine environments: playas, ponded sediments, wetlands; includes small depressions that likely held water during periods of wetter climate; tributaries feeding into playas are fluvial.
5. Colluvium: slope-wash deposits, landslides.
6. Other: unique places, such as rockshelters, caves, springs, quarries; marked on map with a dot.

Ages of Surfaces/Soils. The age of surfaces and soils can be estimated from geomorphic and soil-geomorphic field information in the absence of specific geochronological controls. For archaeological purposes, it is desirable to have, for example, surface-age determinations on a 1,000-year interval. However, the physical landscape does not operate on that time scale. Most surfaces in the project areas will be either more than 12,000 years of age, owing to long-term erosion, or less than 5,000 years old, owing to recent sediment accumulation.

A. <5,000 years: archaeological sites on this surface will be less than 5,000 years old; may include some sediments deposited since European contact.
B. >12,000 years: archaeological sites of all ages or of any age may be present on this surface as a result of deflation; a thin veneer of young sediments <0.3 m thick may be present.
C. undetermined: the age of the deposits is unknown and could not be estimated in this study.

Potential Surface Visibility. Archaeological site "potential surface visibility" requires the presence of sediments of an age that could *potentially* contain sites. In the study areas, this means that sedimentary deposits would have to be less than 12,000 years old. "Potential surface visibility" does not imply that sites are present or are not present, only that they *could* be present. Implicit in this category of site visibility is the actual thickness of sediments less than 12,000 years old. If the sedimentary deposits are less than 1 meter in thickness, sites will likely be exposed and have a high visibility. If the deposits are of greater than 1 meter thickness, sites may be buried and thus have a low visibility. If the age of the sediments at the landscape surface is older than 12,000 years, sites of all ages will be at the surface.

H. High visibility. Sediments <1 m thick; sites will be exposed and perhaps eroded.
L. Low visibility. Sediments >1 m thick; sites may be buried and not exposed at the surface.

Mapping Categories and Mapping Units

As already stated, different combinations of the three map categories defined above make up the mapping units that are drawn on the topographic maps. For example, all of the maps have a map unit "**1**" that is the same for all three project areas (not always the case). Map unit 1 is defined as "**1-B-H**." The **1** is *stable surface*, the **B** is a *surface greater than 12,000 years old*, and **H** is *high visibility*. As a second example, map unit 2 is defined a "2-A-H." The **2** is *eolian*, the **A** is *surface younger than 5,000 years old*, and **H** is *high visibility*.

We attempted to use the same definitions for the same numerical map units throughout the three project areas. In practice, however, the geomorphic features of one area are not identical to the features in another area. Alluvial deposits, for example, are not the same everywhere. In the Loco Hills area, the areal extent of alluvium is generally narrow and the deposits thin, whereas in Azotea Mesa alluvial valleys are comparatively wide and alluvial deposits are thick and varied. Nevertheless, the diversity of deposits was evaluated with the archaeological record in mind, so the geoarchaeological aspects of the landscape in one area should be similar to those of another.

Site Preservation

The preservation of stratigraphy, artifact distribution, and features at archaeological sites is pivotal to determining what the sites represent in the context of human behavior. In this project, however, we did not attempt to include site preservation potential as a mapping category because of the uncertainty involved in assessing site preservation at the scale of a map unit. Nevertheless, some comments can be made and some conclusions can be drawn from the other mapping categories with regard to site preservation.

In southern and southeastern New Mexico, archaeological site preservation tends to be poor. A realistic approach would be to assume that sites are severely disturbed and to look for field evidence that they are not, instead of the other way around. Sites on ancient, stable surfaces will be severely disturbed as well as eroded. Sites in sand sheets and colluvium may be severely disturbed by burrowing animals that tend to be drawn to soft sediments. Sites in alluvium, however, may be moderately well protected by deposits that cap and seal a floodplain site. In general, deeply buried sites may be better preserved than shallow sites. In practice, however, a deeply buried site may have been disturbed before younger deposits covered it. The state of preservation of the archaeological record must be assessed on a site-by-site basis.

Predictive Models

Predictive modeling is a term that covers a wide array of techniques, all of which capitalize on the empirical observation that archaeological site locations tend to be associated with particular environmental features. Mappable environmental features are treated as independent variables that are either individually or in combination associated with the dependent variable, archaeological site locations. Such techniques have been used in cultural resource management (CRM) for more than two decades (Altschul et al. 2003; Kohler 1988; Kohler and Parker 1986). Although quite variable in design, predictive models are developed following a fairly standard process (Altschul 1988, 1990).

Mathematically derived predictive models can be one of the most valuable tools available to land managers for managing archaeological resources. The end product of such a model is a set of probability statements, generally displayed as a map, that indicate the likelihood that an archaeological site will be found at a particular location. Such models are based on the correlation between known archaeological site locations and a variety of environmental variables, and they can be easily tested and upgraded as additional sites are recorded.

Models can be and often are developed intuitively, of course, based on experience and knowledge of the archaeology of a particular area: e.g., "agricultural villages will be located on low ridges overlooking shallow drainages." And such models may be quite accurate—that is, successful at predicting the locational characteristics of agricultural villages. But we have no means of estimating their precision—that is, of knowing how likely it is that the prediction will be correct. For land use planning purposes, it is critical to know the likelihood that significant archaeological resources will be found in specific areas, and this is only possible with statistically based models.

For each study area we assembled environmental data, which were then compared with the locations of known archaeological sites. Through statistical manipulations, some environmental variables were found to be positively correlated with the locations of past human activities and some were not, but in all cases it is important to note that these are simply mechanical correlations, not explanations. The models do not necessarily indicate which aspects of their environment indigenous people consciously valued; they simply track the cumulative record of human behavior. The results of the correlation models were displayed as sensitivity maps which graphically indicate the likelihood that archaeological sites will be found at any given point on the landscape. The modeling techniques used are described in Chapter 4; the environmental variables and archaeological data are discussed in Chapters 5–7.

Inventory Reconstruction

In order for land-managing agencies such as the BLM to meet, in part, their responsibilities under federal law to consider the effects of their actions on historic properties, they generally require archaeological surveys prior to oil and gas development projects. Currently, these surveys are carried out on a case-by-case basis. Each individual request to the BLM for approval of a portion of a project triggers a requirement for an individual survey. Clearly this is inefficient, time-consuming, and potentially costly both for the oil and gas industry and for the BLM. For this project, we also wanted to assess the implications of the case-by-case survey process for effective management of archaeological resources on the public lands.

This issue will be addressed by reconstructing the history of inventory for each study area and then examining the results in terms of data needed for improved resource management and cost-effectiveness. The purpose of the reconstruction is to determine whether our level of archaeological knowledge and confidence in that knowledge could have been achieved more effectively and efficiently.

Management Recommendations

The ultimate purpose of the entire Pump III project is to provide recommendations and create tools that will help land managers to do a better, more effective and efficient job of managing cultural resources in oil and gas leasing and development situations. By "better," we mean both a more predictable, timely, and cost-effective process for oil and gas exploration and development *and* serving the public interest through more effective stewardship of the historical and prehistoric archaeological record.

The management recommendations component of the New Mexico Pump III project begins with the existing process, from resource management plans through lease parcel development, lease sales, and all the steps in development, production, abandonment, and reclamation. Through examination of the current process and discussions with BLM technical staff, state agencies, oil and gas industry representatives, cultural resource professionals, and Native American tribes, SRI Foundation has developed a set of management recommendations. These suggestions include both general recommendations for managing archaeological resources in oil and gas fields and specific recommendations for each of the three study areas.

The Project Area

Geography

The project area (Figure 1.3) encompasses a variety of landforms from mesas to mountains to valleys. The western portion of the project area lies within the Basin and Range physiographic province and includes the Sacramento Mountains and Guadalupe Mountains, as well as the Brokeoff Mountains and a number of lesser ranges such as the Cornucopia Hills. These uplands, which dominate the western half of the project area, are a southern branch of the Rocky Mountains.

The Sacramento escarpment rises abruptly some 4,000 feet above the neighboring Tularosa Basin; the highest peak, Sierra Blanca, attains an elevation of 11,977 feet. The southern terminus of the Sacramentos forms the eastern edge of Otero Mesa. The western and southern slopes of the mountains drain into the closed Tularosa Basin; the eastern slope drains into tributaries of the Pecos River.

The Guadalupe Mountains lie approximately 35 miles southwest of Carlsbad and continue south over the Texas border. The highest elevation in this range, at 8,749 feet, is Guadalupe Peak in Texas. Runoff from the west side of the mountains drains into the Salt Basin on the eastern edge of Otero Mesa. The east side runoff is part of the Pecos River watershed and includes the drainages running through Azotea Mesa.

South of the Sacramento Mountains and east of the Guadalupe Mountains lies Otero Mesa, which comprises some 1.2 million acres of Chihuahuan Desert grassland, the Collins Hills and Cornucopia Hills, and Crow Flats, a closed drainage basin that empties into the Salt Basin graben at the southwest end of the Brokeoff Mountains. The southern portion of the greater Otero Mesa area is dominated by the Cornudas Mountains, including Wind Mountain, which rises to a height of 7,280 feet, or 2,000 feet above the desert floor.

The eastern portion of the project area is located in the Pecos River Valley and the Llano Estacado. The Pecos River, which runs north to south through the eastern portion of the project area, flows for 926 miles from its headwaters in the Sangre de Cristo Mountains in north-central New Mexico into Texas, where it joins the Rio Grande. For most of the period of human occupation in southeastern New Mexico the Pecos has been the primary perennial water source and a major determinant of land use and settlement.

The Llano Estacado is a flat, semiarid plateau covering some 32,000 square miles in eastern New Mexico and west Texas and ranging in elevation from 5,000 feet on the northwest to less than 3,000 feet on the southeast. It is bounded on the

Figure 1.3. The New Mexico project area.

north by the Canadian River and on the west by the Mescalero Ridge, which forms the eastern edge of the Pecos River Valley. The eastern boundary of the Llano Estacado, the Caprock Escarpment, is a steep cliff about 300 feet high. The "caprock" layer is not really rock at all but is instead a layer of caliche, which is soil that has been hardened by minerals. The southern end of the Llano Estacado lacks a distinct physical boundary and blends into the Edwards Plateau of Texas.

Climate

The climate in the project area is semi-arid with hot summers and mild winters. The summer high temperatures average in the mid nineties (F), but daytime temperatures over 100 are very common. Temperatures in the 115º F range have been recorded at two stations within the project area. The summer low temperatures average in the high sixties, although nighttime temperatures in the seventies are very common. In winter, the high temperatures average in the high fifties and the low temperatures average in the high twenties. Winter daytime temperatures in the sixties and even seventies and nighttime temperatures in the teens are not uncommon, however. The frost-free season averages nearly 200 days per year.

The precipitation in the study area ranges from 10 to 16.5 inches per year. Average annual precipitation varies substantially with elevation, with higher precipitation occurring at higher elevations. Most of the precipitation falls between May and October. The primary source of 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 moving in from the west. The Guadalupe and Brokeoff mountains tend to block many of these systems from reaching the Azotea Mesa and Loco Hills study areas; Otero Mesa is more likely to receive some portion of this winter moisture. A combination of high evaporation rates and frequent, strong winds, especially in the spring, contributes to the aridity of the climate and the xeric nature of the vegetation.

Paleoenvironment

Although there are a number of important paleoenvironmental studies from the Southern Plains (Hall 1982; Johnson and Holliday 1989, 1995; Reeves 1972; Stafford 1981) and the northern Chihuahuan Desert, the only reconstructions specific to this general area are for the Guadalupe Mountains (Roney 1985; Van Devender 1980; Van Devender et al. 1979).

The earliest human occupation in southeastern New Mexico took place during the last Late Pleistocene/Early Holocene pluvial, which dates from approximately 13,000 to 6000 BP. The early part of this San Jon pluvial was a time of greater effective moisture owing to both increased precipitation and lower summer temperatures. The Southern Plains were covered with a mixed grassland/open woodland vegetation, and there were numerous small and large playas. After about 11,000 BP the climate became drier with warmer summers and possibly cooler winters. Precipitation was increasingly concentrated in the winter, and the vegetation shifted to largely grasslands. It was during this period from 11,000 to 10,000 BP that the Pleistocene megafauna—mammoths and *Bison antiquus*—went extinct. It was also during this time that the Pleistocene sand sheet, the earlier of the two major sand deposits that underlie the recent coppice and parabolic dunes in the project area, underwent considerable erosion.

Between approximately 10,500 and 9500 BP there was some fluctuation of wetter and drier periods, but generally the trend was one of increasing dryness. By 9000 BP woodland vegetation had disappeared from the Southern Plains, which now formed an immense desert grassland, and all but the largest playas dried up. The last period of increased moisture during the San Jon pluvial dates from about 8500 to 7000 BP; from that time onward the climate and vegetation of southeastern New Mexico came to resemble the modern climate and vegetation of the region.

Hall's (2002) Mescalero Sands study provides detailed information about recent paleoclimatic events in the Loco Hills area, but this level of information is not available for the other two study areas. In the Mescalero Sands area, between 9000 and 5000 BP the more recent of the two major sand sheets that underlie the modern coppice and parabolic dunes was deposited. From that time until about 500 years ago this Holocene sand sheet was covered with desert grassland and shrub grassland vegetation and remained largely stable or underwent a small amount of deflation. Between 500 and 100 years ago the landscape in this part of southeastern New Mexico was quite stable and a soil A horizon developed on the exposed Holocene and Pleistocene sand sheets in conjunction with a stable grassland and the expansion of shin oak.

As noted in the Loco Hills discussion (Chapter 5), during the past 100 years, owing to changes in land use that have disturbed the desert grasslands, the earlier sand sheets have been severely deflated. In areas where the sand sheet is thin, Torrey mesquite have expanded and a mantle of coppice dunes has formed. Where the sand sheet is thicker, shin oak and parabolic dune fields cover the earlier deposits.

Project Area Culture History

What follows is a very brief overview of the prehistory and history of the project area. For more detailed information the reader should consult the major syntheses for the region (Katz and Katz 2001; Kirkpatrick et al. 2001; Sebastian and Larralde 1989).

The earliest human inhabitants of the project area were the people referred to by archaeologists as Paleoindians, highly mobile hunters and gatherers adapted to the open savanna environment and abundant big game species of the late Pleistocene. Paleoindian sites are rare everywhere but are found most frequently above the caprock on the Llano Estacado, in the Guadalupe Mountains, and around the margins of Lake Lucero, the large, late Pleistocene ancestor of modern Lake Otero. Given the prevalence of recent sand sheets in the Loco Hills area, it is likely that most evidence of Paleoindian occupation will be buried and not detectable during surface survey in that part of the project area.

The earliest Paleoindian sites in the region date to the Clovis (ca. 11,000 years BP) and Folsom (ca. 10,500 years BP) periods. Famous for their extraordinary fluted spear points and for their apparent ability to use those fragile weapons to bring down large, now-extinct species such as mammoths and *Bison antiquus*, the Clovis and Folsom people remain shadowy figures to us. We have examples of kill sites and butchering sites, but because we have no material culture markers to help us identify the non-hunting components of their adaptation, we know very little about the rest of their technology and overall subsistence practices. Most recorded finds of early Paleoindian materials are isolated tools; selective collection of projectile points, both prehistorically and in recent times, has undoubtedly limited our ability to recognize these sites during surface surveys.

Later Paleoindian sites (8500–10,500 years BP) reflect the changing adaptation required by the drying and warming trends of the early Holocene. The smaller modern bison (*Bison bison*) became a major prey species, and there is some evidence to suggest specialization in bison hunting in the eastern portion of the project area. Again, however, our inability to identify the non-hunting-related components of the late Paleoindian settlement system has almost certainly skewed our understanding of the adaptation. In the western portion of the project area, later Paleoindian tool kits (those associated with Scottsbluff and Eden projectile point forms) suggest a more generalized subsistence strategy and a settlement pattern focused on playas and springs.

By about 7,000 years ago, the generalized hunting and gathering adaptation that archaeologists call the Archaic was firmly established in the project area. Much of what we know about the Archaic adaptation of this region is a result of excavations in dry caves in the Guadalupe Mountains, but a number of open-air sites in the Pecos Valley and southern Tularosa Basin have also been excavated. These excavation data indicate substantial dependence on plant foods of many types and consumption of a wide range of animal species from bison and antelope to rabbits and small rodents.

Archaic hunting technology was focused on dart points hafted to short shafts and thrown by means of an atlatl or spear thrower. A variety of scrapers and cutting tools as well as handstones and basin metates round out the nonperishable toolkit, but materials preserved in dry cave sites include a wealth of basketry, cordage, woven nets and snares, as well as hide and wooden implements of many varieties.

The large number of aceramic sites found within the study area indicates a substantial presence of mobile, broad-spectrum hunters and gatherers. Some of these "sites" are very large scatters of lithic artifacts with multiple concentrations of burned caliche and other evidence of thermal features—most likely hearths or roasting pits. These locations are often interpreted as favored gathering or hunting areas where multiple reoccupations have created the appearance of a single, very large site. Other Archaic period sites are small, perhaps single-use locations, generally without surface-visible features.

Sometime in the mid to late Archaic period, prior to 1,000 BC, corn was introduced into southern New Mexico from Mexico. Over subsequent centuries this cultigen formed a minor part of the Archaic diet, but it was only in the early centuries AD after new and more productive varieties of corn as well as beans and possibly amaranth spread north from Mexico that dependence on cultivated plants increased.

The Archaic period in southern New Mexico is traditionally viewed as ending sometime between AD 600 and 900 with the introduction of ceramics and the bow and arrow. One of the interesting questions about this region, however, is whether the Archaic *lifeway* also ended at this time or whether these new technologies were simply added to the Archaic repertoire. There is clear evidence of corn agriculture and relatively sedentary village or farmstead settlements on alluvial fans at the edges of the desert basins in the western part of the project area and along east-flowing tributaries of the Pecos River in the eastern part by AD 900. There were some substantial pithouse sites in these favored locations for agriculture by the AD 1000s and 1100s and even some modest pueblo sites in the AD 1200s. What is particularly interesting about the project area, however, is that much of southeastern New Mexico does not conform to the traditional image of Formative cultures in the American Southwest. Rather than being based predominantly on corn, beans, and squash, much of the post-Archaic subsistence intensification in this region seems to have been based on agave and shin oak, and in many ways it appears to have been a continuation of an otherwise largely Archaic lifeway.

By approximately AD 1400 southeastern New Mexico was largely abandoned by agricultural peoples, and the population that remained became increasingly mobile and focused on bison hunting. In the western portion of the project area, agricultural villages were abandoned at this time as well, but there is no clear evidence of continued occupation by nonsedentary groups as there is in the east. At the time of European contact, the project area was within the territory of the Kiowa, the Mescalero Apache, and by the 1700s the Comanche. Once mounted on horseback, groups in the eastern part of the region became increasingly focused on bison hunting, although other resources such as agave were of considerable importance. In the western portions of the project area Apache people hunted and gathered in the mountainous regions and practiced some corn agriculture along the permanent streams. Although we know from historical records that these groups made considerable use of the project area, their considerable mobility resulted in ephemeral sites with very few diagnostic artifacts, making them difficult to identify in the archaeological record.

Chapter 8 provides an overview of historical period settlement in the western portions of the project area. Euroamerican settlement in the eastern portion of the project area did not occur until after the establishment of Fort Stanton in 1855, and even then was concentrated in the uplands and drainages to the northwest of our study area. It was not until after the Civil War that substantial settlement occurred within the Pecos Valley itself, nearly all of it based on cattle and sheep ranching. In the 1880s and 1890s, homesteading and land development based on actual and fictitious water and railroad development brought considerable additional settlement into the Pecos Valley.

As early as 1908, water well drillers noticed traces of oil in some of the wells in Lea and Eddy counties. Good shows of oil and some indications of natural gas were encountered at approximately 1,200 feet, but the technology of the time was not sufficient to prevent water contamination. By 1923, the search for economically recoverable oil and gas was well underway. Two successful wells had been drilled in northwestern New Mexico only a few months before, and in April of 1924 the Illinois #3 became the first viable producing well in southeast New Mexico. In 1939, Martin Yates II and three partners brought in the first well in the Loco Hills field in what proved to be the second largest pool in the United States.

The New Mexico Pump III Project Report

This report describes the current cultural resource management (CRM) process in the project area and the current and potential future uses of information technology in CRM in southeastern New Mexico. After a discussion of the theory and methods of predictive modeling, the predictive models and inventory simulations for the three study areas are presented. Because management of historical as well as prehistoric resources will be an issue for management on Otero Mesa, this report includes a brief historical overview and summary of known and potential historical resources for that study area. Finally, we provide a set of recommendations for future management of cultural resources in the study area and for developing oil and gas fields in general, along with some suggestions about the broader management implications of the New Mexico Pump III project.

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CHAPTER

2

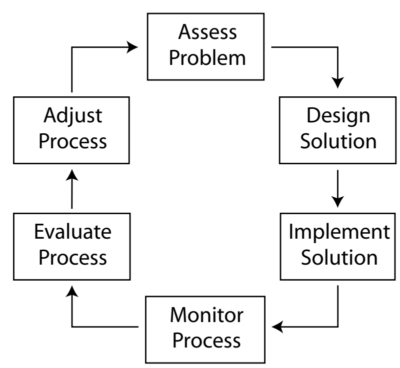
Adaptive Management, Planning, and Oil and Gas: The Current Situation

Lynne Sebastian, David W. Cushman, and Sarah Schlanger

The overall goal of the PUMP III project is to evaluate current and past cultural resource management practices as they relate to archaeological sites in oil and gas leasing areas and to identify changes in management practices that would foster energy development while maintaining a high level of stewardship for these cultural resources. By analyzing the results of past cultural resource management practices in well-developed fields, we hope to recommend more efficient and appropriate management for future development both in the mature fields and in developing and proposed fields. Because effective decision-making requires interpretation of data, the secondary goal of the project is to create regional cultural resource information management tools and models whose potential utility extends beyond energy-specific uses to multi-agency regional land use planning.

Adaptive Management

As the title of this chapter and that of the report as a whole imply, the underlying philosophy of this project was *adaptive management*. Adaptive management, as the accompanying graphic indicates, is a systematic process for continually improving management policies and practices based on an evaluation of the outcomes of operational programs. Too often management practices become stuck in a loop at the *implement* and *monitor* stages. The PUMP III project was designed to move our understanding of cultural resource management practices in oil and gas fields in southeastern New Mexico through the *evaluate* stage and to propose *adjustments*. One of the challenges for the project is to suggest measures to ensure that the cycle will continue to be a *cycle* rather than once again getting stuck at *implement* or *monitor*.



The Bureau of Land Management (BLM) views adaptive management as an approach in which monitoring and feedback—the “monitor and evaluate” portion of the management cycle—are continually used to measure progress toward defined resource objectives or goals. The information captured in the monitoring programs informs decisions that either maintain the direction developed during the “implement solution” stage or change current management direction—the “adjust process” portion of the management cycle. The adaptive management paradigm depends on a clear understanding of operational program goals, an equally clear understanding of both management practices and operational outcomes, and a commitment to developing appropriate means to monitor and evaluate the effects of management decisions and implementation actions.

Cultural Resource Management and the BLM

The BLM administers 261 million surface acres of America’s public lands, located primarily in 12 western states. In New Mexico, the BLM manages 13.4 million acres. The cultural resource program goals, both nationally and in New Mexico, are:

1. Respond in a legally and professionally adequate manner to the statutory authorities concerning historic preservation and cultural resource protection and to the principles of multiple use and ecosystem management;
2. Recognize the potential public and scientific uses of, and the values attributed to, cultural resources on the public lands, and manage the lands and cultural resources so that these uses and values are not diminished, but rather are maintained and enhanced;

3. Contribute to land use planning and the multiple use management of the public lands in ways that make optimum use of the thousands of years of land use history inherent in cultural resource information, and that safeguard opportunities for attaining appropriate uses of cultural resources;
4. Protect and preserve in place representative examples of the full array of cultural resources on public lands for the benefit of scientific use and public use by present and future generations; and
5. Ensure that proposed land uses initiated or authorized by the BLM avoid inadvertent damage to federal and non-federal cultural resources.

The BLM actively manages a variety of cultural resources, such as historic structures and traditional cultural properties, but because the focus of this project is largely on archaeological resources, only the legal constraints and management practices related to archaeology are described below.

Legal and Regulatory Constraints

As a land-managing agency with a multiple-use mandate, the BLM operates under a myriad of statutory and regulatory constraints. The Federal Land Policy and Management Act of 1976 (P.L. 94-579) is often called the Bureau's "Organic Act" because it consolidated and articulated the BLM's many management responsibilities. The three major tenets of FLPMA can be summarized as multiple use, sustained yield, and environmental protection. As a general charge, FLPMA provides that

> the national interest will be best realized if the public lands and their resources are periodically and systematically inventoried and their present and future use is projected through a land use planning process coordinated with other Federal and State planning efforts. [Section 102(2)]

In addition, FLPMA specifies that the United States will receive fair market value for the use of public lands and that

> the public lands will be managed in a manner that will protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archeological values; that where appropriate, will preserve and protect certain public lands in their natural condition; that will provide food and habitat for fish and wildlife and domestic animals; and that will provide for outdoor recreation and human occupancy and use. [Section 102(8)]

Under FLPMA, the BLM strives to manage public lands so that they are used in whatever combination will best meet the present and future needs of the American people for renewable and nonrenewable resources.

The major federal statutes affecting the management of archaeological sites on federal lands are the National Environmental Policy Act (NEPA), the National Historic Preservation Act (NHPA), the Archeological Resources Protection Act (ARPA), and the Native American Graves Protection and Repatriation Act (NAGPRA). NEPA, NHPA, and NAGPRA also address cultural resources other than archaeological sites, and a number of additional federal laws and other authorities (e.g., Executive Orders) address these other kinds of cultural resources as well.

NEPA

Although many people think of NEPA as a law focused on impacts to the natural environment, in fact, Section 101(b) of NEPA describes the purpose of the law as being to "preserve important historic, cultural, and natural aspects of our National Heritage." In a general sense, NEPA compliance for oil and gas development begins with the development of a Resource Management Plan that is supported by analyses reported in an Environmental Impact Statement. The analysis developed for the RMP describes current conditions, outlines reasonably foreseeable developments, considers the cumulative impacts foreseeable under those development conditions, and describes management practices that will achieve or maintain desired resource conditions in light of those potential impacts.

NEPA compliance for most specific oil-and-gas-related actions is carried out on a right-of-way (ROW) or application for permit to drill (APD) basis. As part of agency decision-making, an Environmental Assessment (EA) is prepared for each action to determine whether that action will have a significant impact on the quality of the human environment. The EAs are based on the environmental impact analyses underlying the governing RMP, which explicitly addresses cumulative effects of foreseeable developments, including the actions ordinarily evaluated through the EA process. Not surprisingly, the finding, in virtually all cases, is that individual actions will not have a significant impact (a "finding of no significant impact" or FONSI). Actions that are anticipated to have a significant effect—that is, an effect not mitigated by the application of current management practices or of a scale or character that is outside the scope of the impacts considered in the development of the RMP—will trigger the preparation of an Environmental Impact Statement (EIS).

The problem, from a cultural (and natural) resource standpoint, is that while each individual ROW or APD may not have a significant impact, over time thousands of such actions may be carried out within a very limited geographic area (Figure 2.1). This possibility, of course, is central to the development of a strong RMP, and particularly one that is based on an explicit adaptive management strategy. To date, BLM has not used the management opportunities inherent in the RMP process to best advantage where cultural resources are concerned. Unless the population of cultural resources is well-understood at the onset of development, the impacts of the development cannot be addressed or evaluated in a systematic fashion. Important aspects of the population of cultural resources include site type (i.e., habitation site, campsite, resource procurement site, chipping station, hunting blind, rock art panel, etc.); resource value, including National Register eligibility as well as scientific, recreational, and educational value; and the quantity and distribution of sites.

The traditional tool for both discovery of resources and evaluation of resource values is the archaeological survey. Survey in southeast New Mexico today is generally restricted to small samples of the larger area that will eventually be developed, and those samples are not chosen to maximize their potential to characterize the broader region. Therefore, cultural resource managers currently have no mechanism for determining how confident they should be that the sample approximates the true population of cultural resources that they manage. More importantly, what they know about archaeological resources from sampling the region in this way may not meet the program goals enumerated at the

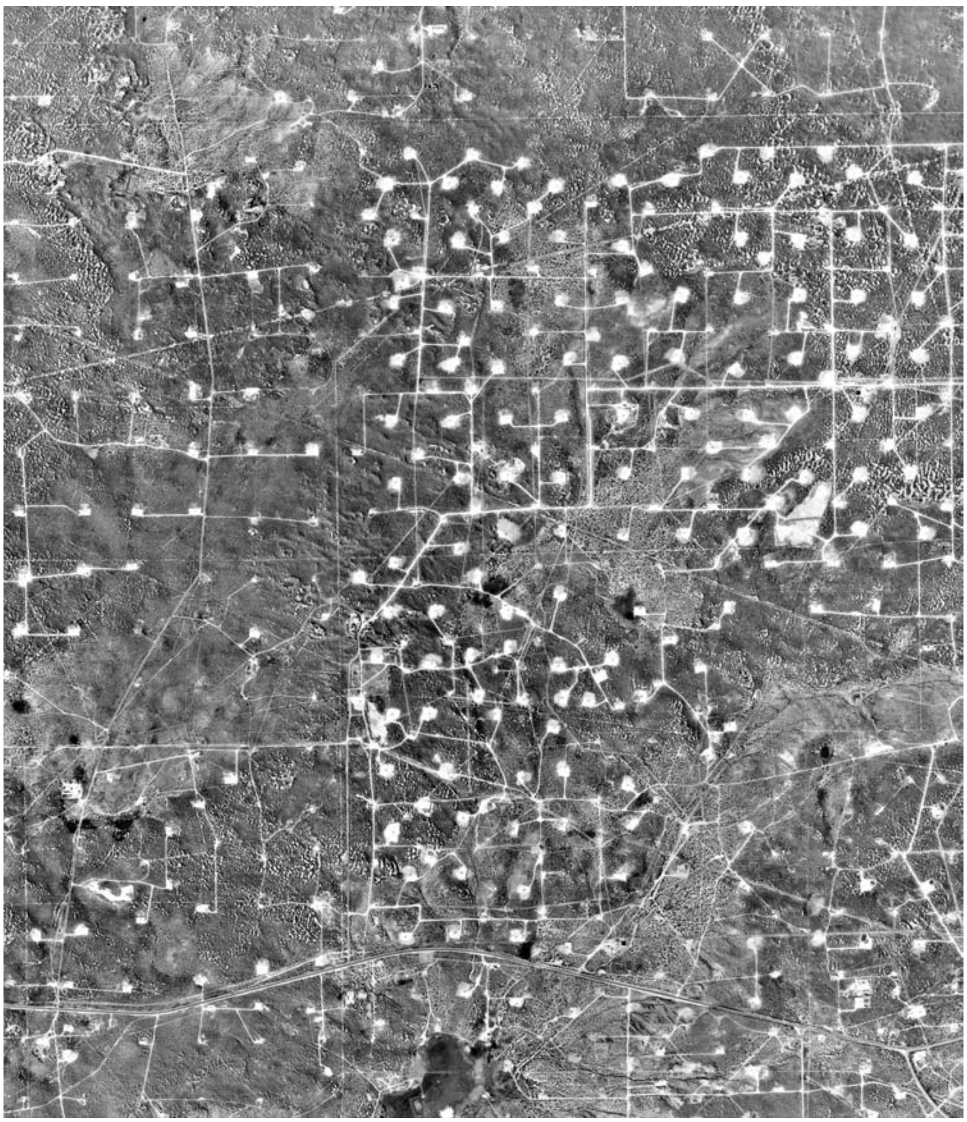


Figure 2.1. An example of the cumulative impact of oil and gas development.
This 1996 image shows an area within the Loco Hills field.

beginning of this section. Simply put, the practice of "surveying as you go," from well pad to well pad, does not ensure that the BLM will be able to maintain and enhance the values of cultural resources, use thousands of years of local occupancy to assist present land-use planning, protect and preserve representative samples of archaeological resources, or prevent proposed land uses from inadvertently damaging cultural resources.

One key way to address these difficulties would be to develop stronger RMPs, plans that specify how and where cultural resources may be impacted or involved in future land uses and where more resource data are needed. Such plans would also indicate how proposed management techniques would integrate anticipated uses with the collection of more data, allow for appropriate and timely evaluation of those data, and adjust management practices to achieve resource goals.

Another way to address the cumulative effects of multiple developments on cultural and natural resources would be to carry out NEPA compliance at a broader scale—a lease, a set of leases, a physiographic unit, etc. This is difficult to do, however, because of the nature of oil and gas development. Decisions about the location and nature of future development are contingent upon initial development, market conditions, and many other factors, so often there is insufficient information to evaluate impacts at a broader scale.

NHPA

The NHPA requires that the BLM both proactively manage archaeological sites and other cultural resources under its jurisdiction and reactively identify and take into account the effects of its actions on those resources. The proactive requirements of NHPA—to identify, evaluate, and nominate properties under federal jurisdiction to the National Register of Historic Places—are largely contained in Section 110 of the law, while the reactive requirements—to take into account the effects of proposed undertakings on historic properties—are established in Section 106 of the law and in the implementing regulation, 36 CFR Part 800. Clearly, Section 110's mandate to identify and evaluate properties could be used to gather information needed for broad-level management decisions relative to cultural resources, but this directive is unfunded. And the reality of the situation is that BLM cultural resource staff is stretched to, and often beyond, capacity simply managing the large number of ROW- and APD-based Section 106 undertakings each year. There is simply no time to gather non-project-specific data to supplement project-specific surveys.

ARPA

The Archeological Resources Protection Act requires permits for excavation of archaeological sites on federal and tribal lands and establishes criminal and civil penalties for violation of the law. This statute affects cultural resource management in oil and gas leasing and development situations both when permits are requested for scientific excavation of sites as part of Section 106 mitigation efforts and in cases of purposeful damage or destruction of sites during development activities.

NAGPRA

Both Section 106 of the NHPA and ARPA require consultation with Indian tribes when undertakings may affect properties of religious and/or cultural significance to the tribe. NAGPRA goes a step further and establishes tribal ownership or control of certain cultural items discovered or excavated on federal lands. Specifically the law applies to human remains and associated or unassociated funerary objects, sacred objects, and items of cultural patrimony. This statute affects cultural resource management in oil and gas leasing and development situations when any of these cultural items are encountered during archaeological excavations or in discovery during development activities.

Current Archaeological Resource Management Practices

The Bureau of Land Management has developed a series of national cultural resource management manuals, called the 8100-series, which cover all aspects of the BLM's archaeological resource management practices. These manuals include

- 8100 The Foundations for Managing Cultural Resources
- 8110 Identifying and Evaluating of Cultural Resources
- 8120 Tribal Consultation under Cultural Resource Authorizations
- H-8120-1 Guidelines for Conducting Tribal Consultation
- 8130 Planning for Cultural Resources
- 8140 Protecting Cultural Resources
- 8150 Permitting Uses of Cultural Resources
- 8160 Preserving Collections of Cultural Resources
- 8170 Interpreting Cultural Resources for the Public

Under the 1997 Programmatic Agreement (PA) among the BLM, the Advisory Council on Historic Preservation, and the National Conference of State Historic Preservation Officers, the procedures outlined in the manuals, together with state-specific protocols for administering the PA, substitute for the 36 CFR Part 800 regulation. In addition, the New Mexico BLM has released statewide guidance for fieldwork and reporting in the form of a handbook: H-8100-1, *Procedures for Performing Cultural Resource Fieldwork on Public Lands in the Area of New Mexico State BLM Responsibilities*. Together the manual series and the state handbook guide archaeological resource management practice on public lands in New Mexico. Current management practice and procedures are described below. The Field Office–level practices and procedures have been divided into those associated with planning, leasing, ground-disturbing projects, right-of-way applications, and monitoring. Planning and monitoring are the places where practice connects most clearly with the adaptive management model illustrated at the beginning of this chapter.

Planning

Field Office cultural resources staff participate in the development of long-range resource management plans (RMPs) by characterizing the archaeological resources within the management area and identifying areas within the field office's administrative responsibility that contain resources that require special management considerations. There areas may become Areas of Critical Environmental Concern (ACECs), Special Management Areas (SMAs), or Cultural Resource Management Areas (CRMAs); applications for public use of resources within ACEs, SMAs, or CRMAs are evaluated in accordance with both general guidance for protecting cultural resources and special management practices. These evaluations will result in stipulations to any use permits that may be approved. Existing RMPs and other land use plans are reviewed by field offices on a regular basis, either annually or following an established review cycle, to ensure that plans adequately meet current land use demands. RMPs that are not meeting current or anticipated management needs may be revised or amended. Recent changes in how RMPs are to be developed will now require Field Office staff to invite Native Americans to comment on, and/or participate in, the RMP drafting process. This will provide tribes with an opportunity to express any concerns they may have with the BLM's management of the planning area, and to determine whether there are any properties of traditional cultural and religious importance that should be considered in the BLM's planning effort.

The RMP process, and the land use planning process in general, is the bedrock of BLM's adaptive management strategy. The land use plan is based on an analysis that identifies current conditions and forecasts future conditions, considers potential impacts from uses and other environmental conditions, offers several management strategies to achieve desired conditions, and creates a plan for monitoring plan implementation and operation. The RMP revision or amendment process allows the BLM to examine and revise any of the "boxes" of the adaptive management model illustrated in the beginning of this chapter.

The revision or amendment process can afford cultural resources staff an opportunity to assess their understanding of the cultural resources present in their administrative area and the effects of their current management practices on those resources. This cultural resource management assessment can include consideration of any or all of the following:

- locations where cultural resource work has been conducted
- adequacy of our ability to characterize the resource population for management purposes
- evaluation of trends in impacts to resources and/or trends in development that may affect resources
- evaluation of the effectiveness of current management practices
- identification of additional information needed to improve management practices

The Carlsbad Field Office completed a resource management plan for oil and gas development in 1997. The Overall Field Office RMP is currently being amended to address the needs of special-status species, but this process is unlikely to substantially reduce the acreage open to oil and gas development. The Las Cruces District Office has just completed a major RMP revision for the area treated in the New Mexico PUMP III project.

Leasing

Field Office cultural specialists are afforded the opportunity to review proposed lease parcels as part of the internal lease development process. Prospective lease parcels are supposed to be identified to Field Office staff at least three months prior to their release to the public. In practice, however, BLM cultural resource specialists may not receive review materials until as little as one month before the proposed lease sale date. The cultural resources staff reviews the lease parcel locations and compares them with the locations of known archaeological sites, traditional cultural properties, and other resources of known Native American interest, and with the locations of special management areas such as

ACECs, SMAs, and CRMAs. The cultural resource specialists also assess the potential of the area to include significant cultural resources that are not currently known.

Potential lease lots may include as many as 80 individual, spatially separated parcels; each of these parcels must be matched to paper and electronic records of site locations, previously surveyed areas, and special management areas. Cultural resource specialists may suggest stipulations be attached to the proposed parcel leases to protect cultural resources; these suggestions are incorporated into the lease packets at the discretion of the lease preparers. Cultural resource specialists do not have the opportunity to review lease stipulations once the review packet is returned to the preparer.

The BLM has just recently issued guidance regarding Native American consultation and involvement at the lease level for energy development. In those instances where tribal consultation was insufficient during the RMP process, the Field Offices will attach as a lease stipulation a notice stating that development will not be authorized until the agency fulfills its obligations under the National Historic Preservation Act and other applicable legal authorities. The agency may also restrict development or disapprove any activity that may adversely affect cultural resources if those effects cannot be successfully avoided, minimized, or mitigated. Currently, cultural resource specialists in the Carlsbad Field Office contact Native American tribes with expressed interests in their administrative areas when lease packets are released for internal review. The tribes are advised of the potential for leasing and their comments on the proposed lease locations are solicited. As noted, however, these procedures are changing.

Exploration and Operations

When exploration proposals are submitted to the BLM, the cultural resources staff is afforded the opportunity to review them as part of the internal EA review and sign-off procedures. The proposed exploration locations are matched against paper and electronic records of recorded sites and field inventories, and the cultural resources staff person makes a determination as to whether an archaeological inventory survey is required.

For geophysical exploration projects, archaeological inventories cover the entire impact area, including receiver and source lines. Ordinarily, these projects are subjected to the same survey requirements as all other proposed land uses. Exceptions to the survey requirement follow the guidance in the New Mexico Protocol (the state-specific agreement that implements the BLM's nationwide programmatic agreement) and the H-8100 handbook. For exploration projects, exceptions to the survey requirement will normally occur only when there is prior ground disturbance or when adequate survey has previously been completed.

In addition to requiring archaeological surveys, through the efforts of BLM staff archaeologists, biologists, and other resource specialists, the southeast New Mexico field offices have begun to apply other stipulations intended to minimize the potential for surface impacts. In the Carlsbad Field Office, for example, heavy vehicles involved in exploration are expected to be outfitted with oversized balloon tires that spread the vehicle load as widely and evenly as possible.

Permit applications for rights-of-way (ROWs) and drilling locations (APDs) are circulated among the Field Office staff with check-off or sign-off cover sheets specific to each type of application. Cultural resource and other specialists fill in these cover sheets as they complete their reviews. Cultural resource staff review must include both a consideration of NEPA and a consideration of NHPA, and this dual requirement can introduce some difficulties in the internal review process, as described in the description of APDs and rights-of-way below.

ROW applications come to the cultural resources staff through the realty specialists. The realty specialists may determine that, under NEPA, a ROW application meets the requirements of a Categorical Exclusion (CX), based on their understanding of the current environmental conditions. Usually, this is the case when the application is for use of a previously granted right-of-way or road corridor. In these cases, the realty specialist assumes there has been an archaeological survey at some earlier date. The archaeologist's review of this ROW application, however, may reveal that there was no prior survey, or that the survey did not extend to the corridor width required by the present use application, or that the proposed use will disturb previously uninventoried land.

Even though the application is a CX under NEPA, the procedures to comply with Section 106 of NHPA must still be followed. Because of their responsibilities under NHPA and because they have access to more complete records regarding previous survey and the presence or absence of cultural resources in the proposed project area, cultural resources staff may find themselves contradicting realty staff communications to the ROW applicant about the need for inventory survey or monitoring during construction.

When a project comes to the cultural resources staff for review, they look first to the location, and draw on their own familiarity with the area and its resources to make an initial determination of whether or not survey is required. They support this initial determination with a check of existing paper maps, which are updated by Field Office staff, as well as with the ARMS database and existing data concerning prior survey quality and location.

APDs follow the same path through the field office as ROW applications. When the project review package is circulated to the cultural resources staff, however, it may or may not have an archaeological report attached to it because archaeological consulting firms submit their reports directly to the office. Most often, the staff must determine whether an archaeological report has been submitted by a contractor on behalf of the project sponsor/proponent and then locate the appropriate report, match it up with the project package, review the report for compliance with BLM and NHPA requirements, and determine if they can sign off on the application. Delays in this process occur when the project proponent has not contracted for an archaeological survey, when the archaeological inventory report has not been received and reviewed by the time other internal reviews of the APD have been completed, or when the archaeological inventory report fails to meet BLM requirements and must be revised, amended, or corrected.

The first problem, failure to include an archaeological report in the application package, is not uncommon, and it creates a substantial potential for delay. Cultural resources field staff may respond to this problem by contacting the proponent directly and asking them to initiate a survey; by conducting a records search to determine whether cultural resources are at risk from the proposed action; by conducting a rapid, emergency survey, especially when operations have commenced in the area; or through a combination of these actions. Failure to consider archaeology during project planning is generally a result of a lack of familiarity with federal requirements on the part of a project proponent. Field Office staff in southeast New Mexico hold annual educational programs for energy, communications, and other potential land use applicants, and it is very important that potential applicants take advantage of these educational opportunities. The second type of problem, missing archaeological survey reports, requires telephone calls or letters to the consulting firm in an attempt to locate the report or speed up its submission. The third problem, substandard inventory reports, requires written reviews that request corrections and, on occasion, repeated requests for missing or supplemental information.

It is not uncommon for cultural resource staff to find that inventory survey reports have been produced for areas that had been surveyed previously and that site records have been created for sites that were recorded previously, but were not recognized as such. Consulting archaeologists are required to review BLM records and records held by ARMS prior to initiating fieldwork, and to consult with BLM cultural resource staff before initiating fieldwork for large, complex, or out-of-the-ordinary projects. This requirement is not always met, and the resulting confusion from multiple surveys and site records can also introduce delay into the report review process. Field Office staff hold training courses for consultants on BLM standards for fieldwork and reporting and have revoked permits for consulting firms that consistently underperform.

Applications for land use permits are incomplete if they do not include a reviewed and approved archaeological inventory report. These reports must be available to the Field Office cultural resource staff before they receive the application package and review sign-off sheets and checklists. Coordinating receipt, review, and filing of cultural resource inventory reports for APDs and ROWs is a time-consuming and critical process; the potential for delay in the application review process is clear and frequently realized.

Field Office staff evaluate each project independently. Ordinarily, the decision as to whether a survey is needed is made by the cultural resource specialists. These specialists must consult a variety of records to make this determination in any particular case. Any changes in management practices or development of desktop tools that can reduce the search time for records, make records management simpler, and create the opportunity for evaluating survey needs and survey adequacy more easily will be of benefit to both BLM staff and applicants for land-use authorizations.

Monitoring

Monitoring is the other area of practice that articulates clearly with the previously presented model of adaptive management. The Field Office staff monitor the performance of the consulting archaeological firms operating in their administrative areas through field checks on projects to determine whether sites are being identified and recorded in accordance with BLM standards. In addition, Field Office staff are required to monitor up to 5% of the undertakings, once construction has been completed, to ensure site avoidance stipulations are being followed.

One of the most critical needs, in terms of closing the adaptive management loop for cultural resources, is for monitoring, evaluation, and synthesis of the data that have accumulated over the past 30 years. Data on archaeological resources and inventory surveys are contained in paper maps, electronic map-servers, electronic database summaries, and paper reports and records. At present, the feedback loop between field data and practice is limited to an evaluation as to whether a survey has been conducted in the proposed project area. Any more sophisticated evaluation is dependent on improving our ability to synthesize, evaluate, understand, and manage the paper and electronic records we have developed.

The pressures of meeting day-to-day obligations have overridden consideration of larger cultural resource management questions: Can we adequately characterize the area covered by a particular land-use application based on work in nearby or similar areas? What is the research, or educational, or recreational value of an identified resource, based on what we have learned from inventory survey or archaeological fieldwork? Should assessment of resource values be adjusted in accordance with new information? Should field practice or review practice be modified in accordance with new information? Are resources that are at risk qualitatively different from currently protected resources? Will the cumulative impacts be detrimental to the entire population of resources? Are we preserving a representative sample of materials for future benefit?

Oil and Gas Leasing and Development and the BLM

The BLM is responsible for leasing oil and gas resources on all federally owned lands, including those lands managed by other federal agencies. This includes about 564 million acres of federal minerals estate. BLM reviews and approves permits and licenses to explore, develop, and produce oil and gas and is responsible for inspecting oil and gas wells and other development-related operations and enforcing lease requirements and regulations.

Legal and Regulatory Constraints

The Mineral Leasing Act of 1920, as amended, and the Mineral Leasing Act of 1947 for acquired lands provide the statutory authority for federal oil and gas leasing. 43 CFR 3100 provides the regulatory basis for BLM to administer federal oil and gas leasing. 43 CFR 3160 authorizes BLM to issue onshore oil and gas when necessary to promote the orderly and efficient exploration, development, and production of oil and gas.

There are currently seven Onshore Orders:

- No. 1 – Approval of operations
- No. 2 – Drilling
- No. 3 – Site security
- No. 4 – Measurement of oil
- No. 5 – Measurement of gas
- No. 6 – Hydrogen sulfide operations
- No. 7 – Disposal of produced water

And two proposed orders

- No. 8 – Well Completions/Workovers/Abandonment
- No. 9 – Waste Prevention and Beneficial Use of Oil and Gas

The BLM, in partnership with the USDA Forest Service, has prepared and published *Surface Operating Standards for Oil and Gas Exploration and Development* (RMRCC 1989), also known as "The Gold Book," to provide lessees and operators with basic information about the statutory and regulatory requirements. The Gold Book provides guidance for all phases of development from geophysical exploration through drilling and production to reclamation and abandonment.

Current Oil and Gas Management Practices

Planning

Initial decisions about management of oil and gas resources are made as part of the BLM's land-use planning process. Resource Management Plans (RMPs) are developed for specific geographic areas—often BLM field office areas—and these RMPs are updated and revised on a periodic basis. One of the classes of information contained in an RMP is a categorization of land parcels that are open to oil and gas leasing, available for leasing with special stipulations, and closed to leasing. The only way that parcels can be closed to leasing is through the RMP process.

Leasing

Parcels to be offered in BLM lease sales are identified in two ways: through informal expressions of interest from potential lessees or formal pre-sale offers for noncompetitive leases of lands in expired, terminated, relinquished, or cancelled leases. Leases must have been terminated for at least a year before a pre-sale offer can be submitted. Both expressions of interest and pre-sale offers must be filed with the BLM State Office at least 17 weeks before a scheduled quarterly sale.

Information on the parcels that have been identified for the next lease sale is sent to the field offices for review at least 3 months before the sale, where they are compared with land-use plans and reviewed by the various resource specialists to identify possible resource conflicts. Any conflicts are addressed through recommendations for stipulations to be attached to the lease. The Field Office manager returns the information on the identified parcels to the State Office with stipulations attached or recommends that leasing of a parcel be deferred if additional information is needed or if a plan amendment is required.

Forty-five days prior to the sale, the State Office publishes a Notice of Competitive Lease Sale, which lists the parcels available at auction and includes information on stipulations attached to each lease. The maximum competitive lease parcel is 2,560 acres; the maximum non-competitive lease parcel size is 10,240 acres. The minimum parcel size is about 40 acres. Lease parcels may be noncontiguous, but separate parcels must be within 6 miles of one another.

Successful bidders at the auction execute a contract and pay a sale cost share, a year's rental in advance, and other fees. Parcels that are not sold during the auction are then leased to the pre-sale offeror, if one exists; otherwise they are available for noncompetitive leasing beginning the day after the lease sale and for a period of two years. Leases are good for 10 years as long as the rental is paid ($1.50 per acre for first 5 years; $2.00 per acre beginning in year 6). Leases will automatically continue after the 10-year period if drilling operations are in progress, if there is a well on the lease that produces in paying quantities, or if the lease can receive an allocation of production from an off-lease well. If a lessee fails to pay rental by a lease anniversary, and if the lease has not been drilled, the lease automatically terminates.

Lease interests are transferable—either record title interest or operating interest—but BLM must approve the transfer; a record title interest transfer must be for no less than 640 acres. Leases may be developed with one or multiple wells; spacing is determined by the State of New Mexico Oil Conservation Division. Anything that prevents a lessee from developing a leased parcel is considered a taking.

The lessee may explore and drill for, extract, remove, and dispose of oil and gas, but prior to any ground-disturbing activities, the lessee or operator must secure BLM approval and post a bond. Bonds for individual leases are at least $10,000; statewide ($25,000) or nationwide ($150,000) bonds can also be established. A change in operator for a lease requires notice to BLM with information on whose bond (operator, lessee, single lease, or state or nationwide bond) will be used. Royalties for producing wells are 12.5%.

All or part of a lease may be relinquished, but the lessee must plug any wells and reclaim disturbed areas according to BLM standards and have lease account payments up to date. Otherwise, the bond for the lease may be forfeited, and the lessee may be prohibited from leasing on federal land.

Exploration and Operations

Geophysical exploration can be carried out on most BLM land whether it has been leased or not; lessees may conduct geophysical exploration as a lease right. Geophysical operations must be bonded and approved by BLM; ground disturbance requires specific authorization. For split estate where the surface is nonfederal, no authorization from BLM is required.

Operators secure BLM approval for drilling operations through either the Notice of Staking (NOS) procedure or through an Application for Permit to Drill (APD). The APD process is more familiar to most operators and tends to be the preferred alternative in southeast New Mexico. The application consists of three parts: a downhole drilling plan, a surface use plan (covering a 600 × 600 foot area), and a safety plan. Once the APD has been reviewed by BLM for completeness, the Surface Protection staff completes an Environmental Assessment; attaches stipulations to the APD to ensure protection of surface resources, including archaeological resources; and schedules an onsite inspection. The applicant is notified within 7 working days of the completeness of the application and the onsite inspection is scheduled within 15 days.

During the onsite inspection, the BLM, the operator, and the operator's consultants examine the staked well pad, access road, and other facilities. They agree on construction standards, and the operator is advised of any deficiencies in the drilling or surface use plan either during the inspection or within 5 working days. Within 45 days after the inspection, the operator submits a completed APD with any needed revisions and an archaeological survey report if required. One of the problem areas identified by BLM cultural resource staff are flow lines that are included in an APD but, for whatever reason, are not included in the cultural resource inventory. This can be a source of delay or cause damage to unidentified archaeological sites. The approved APD is valid for 1 year.

Once the APD is approved, the operator develops the facilities and drills the well according to the submitted plans and files a report when the well is completed and another when it begins producing. Subsequent well operations require filing of Sundry Notices. Although some of the operations covered by Sundry Notices require prior approval, most do not, and most routine operations that do not involve ground disturbance require neither prior approval nor subsequent reporting.

Monitoring of Leases and Well Operations

During the APD process, the Surface Protection staff ensures that appropriate stipulations are attached to the APD. Once the APD is approved, the Environmental Protection staff and Petroleum Engineering technicians monitor compliance with those stipulations during construction and subsequent operations. During well operations, leases are inspected periodically by Petroleum Engineering technicians and occasionally by the Environmental Protection staff; the former are more focused on production-related problems, the latter on environmental issues. The schedule for regular lease inspections is established by the Surface Protection staff based on the potential for problems. High priority leases are inspected annually; the target for inspecting less problematic leases is a 3-year rotation, but in fact the actual schedule is probably closer to a 5-year rotation owing to the huge number of leases in southeast New Mexico.

Rights-of-Way

Whereas on-lease activities related to well operations are carried out under Sundry Notices, off-lease activities (powerlines, produced water lines and injection wells, tanks, etc.) require a right-of-way (ROW) approval. A Realty Specialist evaluates the ROW, establishes any needed stipulations in consultation with the resource specialists, and prepares an EA. The stipulations apply throughout the life of the ROW (generally 30 years), but no notification of construction is required after the ROW grant is made. The process from application to ROW approval generally takes 45 days.

From an environmental and cultural resource standpoint, ROWs tend to be much more problematic than leases. Leases are inspected periodically; ROWs are not. Construction activities on leases require either prior approval or at least post facto notification; neither is required for ROWs. Even the as-built locations of pipelines and other buried features within ROWs are not reported, so it is impossible to know, for example, whether previous archaeological survey will be adequate for new construction.

Abandonment/Relinquishment

If a well doesn't produce or stops producing, the operator must secure approval to abandon the well and relinquish any ROWs. Protective stipulations can be placed on the abandonment approval; BLM Environmental Protection staff inspect the reclamation and relinquishment areas prior to final approval and release of the operator's bond.

Challenges and Needs

Based on discussions among the BLM, SHPO, and members of the New Mexico PUMP III project team and on interviews with representatives of the oil and gas industry in southeastern New Mexico, we have identified challenges posed by the current approach to cultural resource and fluid mineral management as well as some things that are needed to facilitate integration of cultural resource and oil and gas management.

Cultural Resource Perspectives on Current Management Practices

The current process for gathering archaeological information and managing archaeological sites on BLM lands in southeastern New Mexico is almost entirely driven by APDs and ROWs. As a result, we lack some basic data that are necessary to a rational and cost-effective management process. We don't know if the data we have gathered are representative or if our knowledge of the archaeological record is skewed by the requirements of locating oil and gas facilities. Would block surveys be better? Are they even feasible, given the nature of oil and gas development? Large geophysical exploration projects have produced some systematic grids of survey information: Are these grids providing us with sufficiently representative data to permit us to characterize the surface archaeological record?

In areas where oil and gas wells and facilities are being developed, the "flag and avoid" approach to cultural resource management means we have garnered very little excavation data relative to the very large amount of survey data. This has left us with no real understanding of the relationship between surface manifestations and subsurface archaeological deposits. We don't have a replicable process for defining site boundaries; we don't even know how to identify meaningful site types. And we have no mechanism for evaluating the reliability and consistency in survey and recording techniques.

The limited availability of excavation data is exacerbated by the lack of synthesis of those data that are available. What have we already learned? What do we still need to learn? These questions are not mere academic exercises; the lack of data means that management decisions must be based on an inadequate understanding of the archaeological record and thus tend to be very conservative. Have we learned all we can learn from surface survey in this area? We don't know, so we continue to survey. Is this site eligible to the National Register of Historic Places? We don't have adequate excavation data to assess this issue, so most sites are considered eligible—the consequences of erring in the “not eligible” direction are much greater, and more permanent, than the consequences of erring in the “eligible” direction.

The APD- and ROW-based approach to cultural resource management means that we have no opportunity to be proactive about locating energy development away from sensitive sites, we are unable to take advantage of economies of scale, and we have no way of taking into account the long-term and cumulative impacts of energy development on the archaeological record. Anecdotal evidence indicates that well-servicing activities, which are covered under Sundry Notices on leases and are uncontrolled entirely on rights-of-way, are having a significant cumulative effect on the sites that were so carefully and effectively avoided during initial drilling and construction. Is this true? We don’t know, but if it is, we cannot address the problem using current standard procedures.

The problems created by the APD- and ROW-based approach to cultural resource management have been couched here in terms of their negative consequences for the archaeological resources, but they have negative consequences for energy development as well. Case-by-case decisions, inventory, and reporting are more time-consuming than larger scale efforts. Conservative decisions about eligibility may be causing needless avoidance of sites that, in fact, would not yield important information about the past and do not have other cultural or historical values. Operators are carefully adhering to provisions designed to avoid impacting sites during drilling and construction, yet cumulative impacts may be rendering their good faith efforts moot.

In examining cultural resource management procedures in oil and gas fields, the underlying questions that must guide our efforts are these: Do they constitute good stewardship of the archaeological resources? Are they compatible with best practices for energy development? Are they in the best public interest?

Oil and Gas Industry Perspectives on Current Management Practices

To determine how the problems associated with the APD and ROW approval processes are affecting energy development on the BLM lands in southeast New Mexico, interviews were conducted with representatives of seven oil and gas companies of varying sizes with established production histories in the area. Information identifying these companies was acquired from the BLM Carlsbad Office and the New Mexico Oil Conservation Division Offices in Artesia and Hobbs, New Mexico. Phone interviews were conducted in October and November 2004 with the following personnel, listed here with their company affiliation.

Clifton May, Regulatory Agent, Yates Petroleum Corporation
Mickey Young, District Manager, Mewbourne Oil Company
Linda Guthrie, Regulatory Specialist (Southeast NM), Devon Energy Corporation
Dan Girand, Director of Regulatory Affairs, Mack Energy Corporation
Dean Chumbley, Landman, Marbob Energy Corporation
Bob Monthei, Operations Specialist, BP Amoco
Joe Janica, President, Tierra Exploration Inc.

A questionnaire was developed to elicit the views of each company representative on the present problems with the BLM’s cultural resources requirements and any potential solutions that should be considered as a part of this study. The questionnaire was sent via email prior to the interview along with a cover letter explaining the purpose of the PUMP III study and the intent of the interview questions. After each representative reviewed the questionnaire, the phone interview was conducted.

The first question asked the respondent to identify the most important problems that arise as a result of current BLM cultural resources management procedures. There was near unanimity on the part of the respondents: the current APD review process is fraught with delays, and the perceived source of these delays is the requirements that the BLM imposes relating to the management of archaeological sites. Other comments relating to these delays included the lack of sufficient BLM archaeology staff to conduct APD reviews, the effect of frequent staff turnover on the continuity of the APD review process, and internal conflict that exists within the BLM among the reviewing specialties.

The second most commonly identified “problem” had to do with the value of the archaeological record itself. Many questioned what has been, and could ever be, learned from the archaeological record in southeastern New Mexico, which these individuals view as inconsequential. Several respondents noted the importance of the archaeological record in the northwest corner of the state to illustrate how dissimilar, and thus unimportant, archaeological sites are in the Permian Basin. “It’s not Chaco Canyon,” as one industry representative put it. The lack of appreciation for sites in the southeast was not absolute, however. Many said they were aware of some sites that they thought particularly interesting, but added that the number of these places was “just a handful.” Related to this was a common view that the archaeology of the twentieth century is so insignificant as to be unworthy of any management at all, being described by more than one respondent as “trash.” It was assumed that there are better sources of information in records and archives and that preservation of sites dating to this time period is a waste of time and energy.

At the heart of the concern over site significance is the view expressed by several respondents that the National Register criteria are not being applied in accordance with regulation under 36 CFR 60.4. Historical sites dating to the 1930s and the small lithic scatters with fire-cracked rock that are typical of the area are not eligible for listing, in their opinion. The belief is that National Register determinations for sites of this nature are not, and cannot be, justified. One respondent thought that these more common site types, with little or no value, should be managed categorically—that is, declared to be ineligible as a class so that greater attention could be devoted to protecting more worthy sites. In a related comment, another industry representative expressed the view that not all sites on the BLM lands are important, and yet observed that all sites are being given equal management consideration. This gave him the impression that the agency itself is not able to make effective management decisions because it cannot discriminate between the (few in his opinion) sites that are truly worthy of protection and the (majority in his opinion) sites that are not.

These views are bolstered by another issue, which is the observation that so much archaeological work (survey) has been done in the past, and yet so little is currently known about the archaeological record. The respondents wanted to know why additional work is needed if so little has been learned after all this effort. The expressed frustrations are understandable given the years of compliance-driven archaeology for which industry has paid. The perception among those interviews was that, instead of seeing any dividends from this investment over time in the form of reduced regulatory burdens, the companies have encountered increased requirements that make their jobs more difficult. They do not understand why the agency is treating the archaeological record as worthy of management concern, and they feel that the BLM has not made sufficient effort to explain the cultural resources requirements in terms that they can understand. The only explanation offered is that “It’s the law.” As one frustrated company representative said, “Let’s learn something,” so that the knowledge can be used to change management practices on the ground.

The second question asked the respondents how their businesses were affected by the problems identified in question one. Again, as a group the respondents expressed the concern that delays inherent in the APD process increase costs, but more importantly, disrupt the planning cycle. One industry representative explained that his company needed to produce within 120 days of staking a well pad, which means that scheduling is tight from the very beginning. In addition, delays in the APD process can result in stand-by charges for an idle drilling rig and crew of up to $8,000 per day, costs that cannot be sustained for long. More typically, delays result in decisions to switch drill locations, but when that happens, the producer must go back through the process with a new APD and the regulatory clock starts all over again. The respondents all noted that the permit approval is supposed to occur within 30 days, but all noted that it was taking longer. One respondent said that the approval time was typically between 45 and 120 days. Another noted that the 30-day time limit on permits corresponds to the legally required public notice period, saying that if permit approvals could be granted within the ideal 30-day time frame, that would solve many of the problems from their perspective (see further discussion in Chapter 9).

Questions 3 and 5 are related in that the respondents were asked how they thought the procedures should be changed and whether there was information that, if available, would make it easier for their companies to work on BLM lands. The responses to these questions, having to do with potential solutions to the problems identified here, are discussed in Chapter 9.

Question 4 asked what aspects of the permitting process the respondents thought were working well. Most had no response, reflecting a generally negative view of the whole process. A few did note that the quality of information on previously surveyed areas and the accuracy of site locations have improved at the BLM office. When asked why this was important, they said that better information gave them a clearer idea of what to expect on the ground, thereby facilitating their planning. One company representative highlighted the new statewide standards for well pad construction as an example of the BLM working in concert with the oil and gas industry to solve a problem of mutual concern. He emphasized that the new standards were based on research-driven studies, the results of which everyone could accept. While not related to the cultural resources management practices per se, this was offered as an example of a process he thought oil and gas could follow in addressing the cultural resources issues (see additional discussion in Chapter 9). Several went out of their way to say they thought the BLM staff was “just doing their jobs,” but noted that even with four archaeologists at the BLM Carlsbad office, there has been no decrease in the time it takes to process APDs and ROW applications.

The sixth question asked if there are critical points in the planning process where meeting the cultural resources requirement can be most problematic. As a follow-up question, the respondents were asked if considering cultural resources earlier in the planning process, prior to the APD stage, might be helpful in reducing conflicts. All agreed that the APD stage was a “choke point” for them, when meeting the BLM’s cultural resources requirements is most likely to cause delays owing to the presence of archaeological sites in the development area. As one industry representative noted, every time there is a problem with archaeology and a drill location has to be moved or modified, the regulatory clock starts all over again. In extreme cases, a well site will be abandoned in favor of a location that has fewer regulatory problems. It was also observed that there appears to be no coordination between the APD review process and the process that ROW applications go through. As a result, decisions can be made about the location of a pipeline that conflict with where a well pad access road will go. Both actions require that archaeology be done, with any overlapping areas surveyed twice.

As to whether the requirements could be met at an earlier stage, some agreed this would help—*if* the BLM conducted the necessary archaeological studies at its own expense. Most noted, however, that archaeological site clearance prior to the APD makes little economic sense from their perspective. This would require expending money to do the archaeology before the productive viability of an area could be demonstrated. If the well or wells are dry, then the cost of doing the archaeology just adds to their overall losses.

Several of the representatives from the larger companies said that they had conducted block surveys in areas targeted for the development of multiple well pads. Survey at this level has the advantage of assessing the regulatory liability of archaeological clearance on a large scale and can facilitate planning and development strategies while reducing the unit per acre cost of archaeology. Knowing where the sites are in relation to the planned location of well pads, access roads, pipelines, and power lines can enable a more comprehensive management strategy than is usually possible, which is why it is favored as a strategy by the BLM. Nonetheless, block surveys cost more than paying for individual well pad and ROW clearances and as such are not favored by most of the respondents over the status quo. In short, while the idea of archaeological site clearance earlier in the planning process sounds good, the respondents said that doing this is not feasible in all cases, particularly if the oil and gas industry is going to pay for it.

Follow-up questions were asked regarding the idea of using royalty relief or eco credits as a way of generating funds to do archaeological research in areas that are being developed as emergent fields. The idea is to fund the necessary studies in a manner that is decoupled from the APD/ROW approval process. This way research can be conducted on the nature and meaning of the archaeological record outside of the regulatory framework that normally drives the compliance process for individual components of emerging energy fields. The respondents were warm to this idea but questioned how it would work, noting that royalty relief, for instance, would require approval at both the federal and state levels and presents accounting difficulties. One industry representative suggested, however, that a program similar to the habitat restoration program in use on the BLM lands in Farmington might work (see further discussion in Chapter 9).

The last question asked if the respondents had any ideas as to how cultural resources management could be more effectively integrated with the way that the oil and gas industry operates. There were no ideas on better integration, and most reiterated concerns that had been expressed earlier. The BLM and the oil and gas industry have different priorities and operate on different time scales. One respondent took the view that industry is better able to react to changing conditions than the agency and that, because of this, industry's needs and the BLM's responsibilities are like a "square peg in a round hole." Several of the respondents echoed earlier comments, saying they thought that the requirements the oil and gas industry has to meet, including those relating to cultural resources, have expanded over the years, creating increasingly difficult conditions for energy development. The subtext of the whole discussion was that the oil and gas industry feels hampered by the agency. While the respondents acknowledged that the BLM has multiple responsibilities, the feeling expressed by the oil and gas industry representatives is that the APD and ROW approval processes are too cumbersome and take too long, and that archaeology is the principal source of the problem.

In general, the responses can be summed as follows.

- The APD and ROW approval processes are not operating within the BLM's 30-day turnaround period
- Delays increase costs and affect scheduling
- The value of the archaeological record is highly suspect
- The BLM treats all sites as if they are equally important, but few sites are viewed by the respondents as National Register–eligible
- Historical sites, especially those from the twentieth century, are not viewed as worthy of management concern
- The cultural resources requirements make little sense to the respondents because they have not been adequately explained or justified
- Archaeology at the APD stage is the "choke point" in lease development
- Archaeological investigation prior to the APD is not economically feasible if the oil and gas industry must pay for it
- The requirements that must be met to work on the BLM lands have increased over time
- The permit stipulations protecting archaeological sites are seen as the cause of most delays in the approval process

The "Ideal Outcome" for New Mexico PUMP III

In discussions with BLM, SHPO, industry, and the members of the New Mexico PUMP III team, we have tried to identify an "ideal" outcome for this project. Although one project clearly cannot meet all of these objectives, we view this as a long-term goal statement for cultural resource management as it concerns archaeology in southeastern New Mexico, and we will return to these points in the concluding chapter, examining the contributions of this project toward these goals.

One important outcome of this project will be a set of management recommendations for how BLM might more effectively integrate cultural resource management procedures with the need for energy development on the public lands. A quick look at the concerns raised by oil and gas industry respondents in the previous section provides a number of ideas about what is needed from the industry perspectives: faster, more predictable turnaround times; decreased regulatory burden; and mechanisms for focusing time and dollars on the most significant archaeological resources. At the same time, any proposed management changes must be compatible with BLM's legal responsibilities and its multiple-use mandate. Additionally, the proposed changes should be specific, practical, and doable. Any proposed changes should also include implementation measures and training components as appropriate, as well as improved communication with lessees and operators. Finally, the management recommendations should be tied into ongoing planning within the BLM and should consider the need for coordination between any proposed cultural resource process and other environmental review processes.

A second important outcome of NM PUMP III will be a critical look at information and information management. The "U" in PUMP III stands for "upstream." We will be looking at approaches whereby cultural resources are considered earlier in the planning process, so that BLM can make better-informed decisions and industry will have more predictability and needed information on environmental issues at the "pre-lease" phase of energy development.

We will be looking at technological solutions that will enable us to focus time and money on good preservation outcomes and expedited energy development rather than needless, time-consuming process. Possible examples of technological solutions might be an automated screening system for determining inventory needs and cultural resource sensitivity of a lease or right-of-way or electronic submissions to streamline the consultation process.

One of the products from NM PUMP III will be a set of "sensitivity" maps based on predictive models. How can we ensure that these maps will be used appropriately—for planning and evaluation of alternatives, not to "blow off" the need for survey? How can we ensure that the models and the maps are maintained, updated, and refined? How do we ensure that modeling is seen as a process rather than being treated as product?

Third, this project will result in some recommendations for how to do better archaeology in service of both compliance with historic preservation laws and better stewardship. We need to critically evaluate current inventory procedures for archaeological resources. Are we gaining the information we need for management? Are time and money being well spent? Any recommendations to change inventory procedures have to be realistic, however. While upfront survey of entire leases or other blocks of land would undoubtedly be most effective and efficient, there is no regulatory or funding mechanism to enable this to happen.

Current procedures for managing oil and gas and cultural resources have not enabled us to deal with cumulative and indirect effects on archaeological sites. What can be done to address this issue? Are there means of examining the data that can give managers better ways to anticipate which sites will be adversely affected by indirect or cumulative effects?

One of the most pressing needs in terms of our ability to manage cultural resources in southeastern New Mexico is for subsurface data. The standard "flag and avoid" approach to managing archaeological sites has left us with so little excavation data that we don't know how to assess either the integrity of sites or their information potential from surface manifestations. It is critical that we find a way of assessing the subsurface potential and the surface/subsurface relationships of more sites in this region so that management and protection can be focused on the most significant resources. And the nature and significance of the archaeological record in the region needs to be communicated to public land users and the public.

Finally, although the NM PUMP III project is using management data from BLM lands in southeast New Mexico and evaluating management practices for archaeology in oil and gas fields, ultimately we want to develop products and suggest practices that can be more widely applied—to other agencies, to other development situations, and potentially even to other kinds of cultural resources. Possible products that could lend themselves to wider applications include technical data on the sensitivity modeling attributes and process used in this project, effective approaches to inventory, mechanisms for dealing with cumulative and indirect effects, flexible approaches to compliance requirements, and "upstream" approaches for moving consideration of cultural resources earlier in project planning.

Conclusions

Cultural resources management on the BLM lands in southeastern New Mexico is largely driven by oil and gas developments that are subject to environmental laws and regulation. These laws require the BLM to consider the effects of energy development on archaeological sites, among other cultural and environmental resources, as part of the agency's multiple-use mandate. The BLM follows an adaptive management strategy to guide the agency's planning process so that, ideally, agency personnel are able to use evaluation and analysis of the results of existing management strategies to make informed decisions about future management strategies. In practice, however, this is difficult to achieve.

Years of development-driven archaeological survey and the virtual absence of excavation data have produced a wealth of information on only two dimensions of a three-dimensional phenomenon. This, combined with the lack of synthesis of these existing data, has left BLM with a limited understanding of the resources that the agency is charged with managing. For this reason, day-to-day management decisions tend to be conservative, erring on the side of "being safe," even when those decisions may not be warranted. For these and other reasons, the adaptive management process, which should enable the agency to determine if what it does is effective, lacks critical information and the ability to evaluate and adjust cultural resource and oil and gas management processes.

The BLM strives to meet its legal obligations under a large variety of land-use, environmental, and historic preservation laws. Procedures for oil and gas development on BLM lands are designed to protect a wide range of environmental resources, including archaeological sites. An important purpose of the New Mexico PUMP III project is to evaluate the efficacy of these procedures as they relate to archaeological stewardship and efficient recovery of oil and gas reserves on the public lands. In this chapter we have identified a number of concerns about archaeological stewardship under the current procedures. Archaeological sites may be avoided in the siting and construction of a well pad, for example, only to be damaged repeatedly over time by maintenance and well-servicing activities. Rights-of-way are not subject to the same level of environmental review as leases.

We have also identified a variety of impediments to efficient energy production. The review and approval processes for APDs and ROWs, for example, could be more streamlined. And the necessarily conservative approach to site eligibility has led to avoidance and protection requirements that may not be warranted by the actual significance of some sites. As well pads and development infrastructure continue to be directed away from these sites, the current level of ignorance about them is perpetuated. Without the benefit of a growing knowledge base on the archaeology of the Permian Basin, it is difficult for the agency to change its management practices in order to achieve greater efficiencies and more effective resource protection.

These problems are compounded by increasing demand for energy production on the BLM lands and the concomitant pressures on the agency to respond to APD/ROW applications in a timely manner. Staffing constraints, procedural problems internal to the BLM, and applicants who fail to submit the necessary information all contribute to a management environment that can, and does, produce delays and duplication of effort, despite the best efforts of the BLM and the oil and gas industry.

Solving the problems touched on in this chapter, and more fully described in the rest of this report, will require a more comprehensive understanding of the archaeological record as well as flexible and creative procedures whereby the effects of energy production on archaeological sites can be addressed. What is needed are both short- and long-term planning goals with an implementation strategy that has the support of the agency and the energy producers. Identifying what's wrong with the current situation and recommending changes to solve these problems are important objectives of this study.

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CHAPTER
3

Information Technology, Management of Cultural Resources, and the New Mexico Pump III Study

Tim Seaman and Eric Ingbar

The Pump III study as a whole examines how resources are managed in light of the *information* that is known about them. This chapter examines technologies that *convey information* into the practice of archaeological resources management as it is currently performed and as it might be transformed in the future. We also discuss how information technology was used in the Pump III analytical and management studies.

The term "information technology" has come to mean digital data storage, query, and display in a wide variety of ways. This meaning, however, is overly limiting in the context of cultural resource management. Cultural resource experts and managers utilize many forms of information that are not digital in any comprehensive way. These information forms include paper records and maps, traditional photographs, documentary sources, experience in the field and laboratory, and a considerable body of person-to-person communications, both formal (e.g., professional presentations) and informal (e.g., professional discourse). Although we cannot address all of these different forms of information in anything like a comprehensive fashion, it is important to remember that "information technology" in its digital sense, referred to as "IT" throughout the chapter, is only one of several important information technologies.

The link between sound information and sound management and decision-making is so well known as to be a truism. In archaeology a high value has always been placed on sound sources of information because reliable data greatly facilitate fieldwork and decision-making. For instance, archaeological fieldwork is guided by a series of questions that can often be answered by sound information:

- Where have investigations been performed already?
- What did prior investigations find?
- How reliable are the findings?

If these questions can be answered well, then the fieldworker has more secure answers to some important operational questions:

- Where does one need to look for new, undiscovered resources?
- What sorts of archaeological materials are likely to be encountered?
- What level of effort will a new investigation require?

Until recently, these questions were answered using paper maps and records. As long as these were comprehensive and up-to-date, they worked very well. Paper records, especially large-format maps, are not necessarily difficult to keep, but they are very limited in their distribution. Most paper archives of archaeological investigations and resource information are unique collections of materials that must be visited to be used. Travel costs and the time it takes to conduct research that is usually geographic in extent involving records that are filed by date (e.g., site records are filed in sequential order regardless of site location) make the use of paper archives expensive. Digital information technology addresses many of these problems because it allows records (and maps) to be retrieved in many different ways: geographically, by index number, by information attributes or content, and by combinations of these methods.

The New Mexico Cultural Resources Information System

The New Mexico Historic Preservation Division (HPD) has long been a leader in archive management, both as a paper records system and in digital information technology. The Archaeological Records Management Section (ARMS; see www.nmhistoricpreservation.org/PROGRAMS/arms.html) has maintained statewide maps and files for more than 80 years. For the past 25 years, ARMS has been automating its maps and the contents of its files into a geographic information system (GIS) and relational database management system (RDBMS) known as the New Mexico Cultural Resource Information System (NMCRIS).

NMCRIS captures initial information about investigations ("activities" in NMCRIS) and archaeological sites. These initial records are held in the system, and displayed in the web-based GIS component, until the record is received at ARMS and can be fully entered. GIS updates are done nightly from the initial records. ARMS staff perform custom data queries and aggregations of information for agencies or consultants if the information in the standard ARMS IT system does not meet their needs.

From an IT user perspective, NMCRIS contains two distinct forms of information: tabular data held within an RDBMS and spatial data (geographic boundaries, etc.). ARMS users are limited to qualified cultural resources professionals. Users can query tabular data from a text interface, enter preliminary information about investigations (activities) and sites, and generate full site records from the database without any associated imagery that may be in the paper file. Users can also employ a map interface to find, list, and see the locations of investigations (activities) and sites. Then, one can query by identifiers to find the full database record for each investigation or resource.

NMCRIS is an example of an information technology that conveys "what is known" about an area fairly rapidly. It is used by archaeological specialists in the private and public sector routinely. ARMS strives to be comprehensive in its geographic coverage of the state, with the exception of some tribal lands, and current in its data. Some of the major factors that hinder achieving this goal are:

- backlog of maps to digitize into GIS for investigations (activities)
- time lag between initial recording and receipt at ARMS for full entry and digitization
- agency offices holding onto reports with fieldwork results due to cancellation of projects after fieldwork was completed; these reports may never get to ARMS, so will never be part of NMCRIS
- lack of staff and/or funding to keep up with incoming work and cope with backlog

NMCRIS map services reliably show the location of all resources in the NMCRIS database, most of which are archaeological sites. This makes the map service very useful for planning where a proposed action should probably not be staged because known resources can be avoided using this information. However, because NMCRIS does not contain all of the investigation (activity) boundaries—"surveyed space" in NMCRIS terminology—it is not as useful for planning fieldwork, or even the need to do fieldwork, because one cannot tell where fieldwork has already been performed. Some parts of the state are fully digitized for investigation boundaries, and here one can utilize NMCRIS to identify areas of surveyed space. For many parts of New Mexico, one must perform a search by cadastral location first, then either get copies of the investigation reports revealed in this search or travel to ARMS to examine the reports and maps. In areas where NMCRIS is completely populated with sites and investigations in GIS, the map service is a tremendous tool for research, planning, and review of field reports.

ARMS is a substantial annual investment in software, hardware, and support staff. IT in cultural resource management is necessarily a complicated technological endeavor. Archaeological site records capture a wealth of information, much of which is list-like and thus requires sub-tables in order to query information reliably. Relationships between categories of information need encapsulation in the data too, adding to the intricacy of the data scheme. A table diagram of NMCRIS looks like a spider web or even a web of spider webs. The NMCRIS data model involves more than three dozen database tables, and six distinct GIS map layers. In a paper system (i.e., a paper CRIS), the researcher must track linkages between categories of information. NMCRIS's elaborate design is needed to allow IT to track these information links.

The introduction to this chapter discussed the series of questions that guide typical archaeological inquiry. NMCRIS was designed to answer many of these questions, especially those summarizing existing knowledge. NMCRIS was not designed, originally, to answer questions that include some forecast about the archaeological record. For example, NMCRIS has no inherent model display or model-building capability. This was not the intent of NMCRIS; how one uses a cultural resources IT system to answer model or summarizing questions is discussed further below.

NMCRIS Activities for the Pump III Project

ARMS entered data for all three of the study areas, updating the attributes held in the RDBMS for sites, updating site boundaries in GIS, digitizing investigations, and creating or updating the RDBMS attributes for investigations. An important part of the project was its coverage of the three one-degree blocks that run from the extreme southeast corner of New Mexico westward along New Mexico's southern boundary (i.e., 32 to 33 degrees North, 103 through 106 West).

So, the area for which NMCRIS data was created or updated was far larger than the study areas themselves.

In all, ARMS staff accomplished a huge amount of data entry into, and quality control over, the NMCRIS database established for the three study areas:

- 18,000 survey reports were entered and/or verified in the RDBMS
- 17,500 survey reports were digitized
- 1,800 sites were entered/verified in the RDBMS
- 3,500 site boundaries were digitized

The difference of 500 reports between digitization and RDBMS entry is due to 500 reports with source graphics that were either absent or too poor to digitize. The 1,800 sites given attributes were new entries in both the RDBMS and the GIS. The 3,500 other sites digitized had boundaries created or updated for them in GIS.

How NMCRIS Population Helps

Populating NMCRIS with up-to-date records in GIS and the tables is more than an archival exercise. The NMCRIS data serve two purposes in the present study and in its on-going utility.

First, the NMCRIS GIS and attribute data are useful for answering the “what and where” questions that precede archaeological inquiry. Since archaeological inquiry is almost always triggered by some proposed land use, NMCRIS records also provide a scoping capability, if the land-use proponent, or their agent, consults these records early in the planning process.

Second, the NMCRIS data system provides a foundation for model-building. In the present study, the models pertained to surface archaeology, for the most part, and its density. An important prescription of the modeling studies is that models be reevaluated and refined more or less constantly. The only financially practical way to do this is by using a cultural resources IT system that contains the model data.

Implications of PUMP III Modeling for NMCRIS

A major part of the study involved model-building to forecast where archaeological sites are likely to occur in each of the three study areas. NMCRIS provided the data for each of these model formations. The analysts creating the models found NMCRIS data complex to work with, which presented challenges to the model-building process. The modeling effort would have been impractical without NMCRIS, but it is important to realize that IT systems built on cumulative processes, like NMCRIS, may require extra effort to be used successfully in a modeling study.

For this study, the NMCRIS data required the modelers to expend more time and energy in data manipulation than they had expected. The effort required to work with NMCRIS data in the predictive modeling effort was underestimated owing to two major factors:

1. The intensity of archaeological investigation in two of the three PUMP III study areas—specifically, the high number of multiple site recordings; and
2. The underlying complexity of the NMCRIS relational database, which complicated the task of data reduction.

Little can be done to make modeling and analysis much easier with regard to the first factor. Archaeological work in oil and gas fields in the Carlsbad area has been conducted on a well-by-well basis, so that the same archaeological site may be recorded by several different surveys. In addition, archaeological site boundaries are exceedingly difficult to define owing to geomorphological factors, especially in the Loco Hills area. So, an apparent boundary between two sites may later become no boundary at all.

This combination results in an observational record that is complex. For instance, an archaeological site may be recorded several times over the years. Each set of observations is properly independent of its predecessors. We expect some consistency among them, but we cannot truly assess whether differences are owing to geomorphology (e.g., dune movement that now reveals more of a site), observer effects, and so forth. Because of this NMCRIS treats each “event” of observation as a unique record.

Predictive modeling does not cope well with multiple observations of the same phenomenon. After all, the point of most archaeological modeling efforts is not to understand how archaeological practice changed through time, but to understand how the archaeological record itself changed through time. Modeling is most practical when one treats each observational entity as static. For archaeological sites, this means deciding upon the attributes of the site once, and only once, and not treating each archaeological site field observation—each site recording—as a separate "site."

A simple thought experiment can illustrate this. Suppose the first recording of an archaeological site found 3 hearths and 8 projectile points. A second recording of the same site reports 2 hearths and 10 projectile points. Did the first recording "miss" 2 projectile points and the second recording "miss" a hearth? Or, are there really just the maximum of each count: 3 hearths and 10 projectile points? Or, are there actually 5 hearths and 18 projectile points—the sum of all observations? Because there is rarely a clear answer to this sort of question, an IT system for site records treats each as an independent record. Of course, a modeler would like to have a single "correct" answer with which to work.

With regard to the second factor, the NMCRIS data model is necessarily complex and modification has risks and costs. Each observational event is treated as a record in NMCRIS because decisions are made on a record-by-record basis, and the NMCRIS staff are in no position to reassess archaeological fieldwork years and miles distant from it. NMCRIS is as complex as it needs to be. NMCRIS was designed to enhance basic information management for cultural resources on a statewide basis. It was not designed for predictive modeling. Certainly predictive modeling is becoming an important management tool, but it would be better to consider alternatives to simplification of the NMCRIS design.

There are several alternatives to simplification. One alternative is simply to prepare better documentation of NMCRIS for prospective analysts and modelers. Analysis of relational data is not simple, and statistical approaches assume a flat data structure. This makes data reduction a critical—and often time-consuming—first step in modeling. Multiple records need to be summarized or filtered to create a single record, or analytical approaches need to be modified to take different entities into consideration. For instance, either sites with multiple components must be translated to a single proxy classification (e.g. single-component, multicomponent), or analysis must proceed using temporal components—rather than sites—as the analytical focus. Similarly, multiple feature observations can be used to classify sites (or components) by function prior to analysis. This approach still demands much from the prospective modeler, and the task of joining and processing multiple tables appropriately is left to the user, possibly leading to spurious results.

A better approach would be to create, and document, analytically useful SQL (Structured Query Language) "views" of the database. The ability to define SQL views, or virtual tables, is one of the strengths of relational databases. To the user, an SQL view looks just like a simple database table of rows and columns, even though it may be the result of joining several tables, and perhaps other manipulations. In this, a documented SQL view can provide a more coherent environment for the analyst. On the down side, using views for queries or reports may require intensive database performance tuning because complex views joining more than three or four tables can use larges amounts of system resources.

Similarly, summary tables can be maintained by a relational database and refreshed automatically at set intervals. These tables could, for example, summarize multiple site visits or Section 106 actions by selecting the most recent observations, or summarize site data by county, allowing expressions of variability based on larger populations of sites. Summary tables could be created and refreshed during periods of low use, providing a performance advantage over on-the-fly summary creation.

Perhaps the most sophisticated approach would be to implement business intelligence software such as Oracle Discoverer or Business Objects. These packages maintain structures similar to SQL views (a.k.a. End User Layers in Oracle) and summary tables in the underlying database. In addition, business intelligence products provide simple but powerful application interfaces that allow users to employ predefined views, develop new views and summaries, and export datasets in industry standard formats. These applications are built on existing system security rules in the underlying databases, yet they run over the internet and may also be set up with extensive help systems. From the user's perspective, they are readily accessible and, with some study, productive for answering questions. The disadvantage is cost. Oracle Discoverer, for example, requires additional license fees and annual support costs, and significant administrative costs would be required for setup and maintenance. Creation of different database views would also require a more intimate and continuous relationship with analysts in order to design useful views, query applications, and reports. The benefit of this technology is immense, however. The ability to simplify the NMCRIS database structure would open the database up to exploration by other, "non-traditional" users in historic preservation and cultural resource management, and so would have many other benefits for planning and research.

IT and Cultural Resource Management

Archives of information about "cultural resources" (*National Register Bulletin* 15 [National Park Service 1990]) are in transition from paper to digital formats, nationally. The creation and population of records in IT systems, now begun, won't stop. Paper records will continue to form the basis for most archives. IT enables swifter access to these records or some of the information on them. One role of information technology is simply to do what the archives always have done, only better.

While one might argue over what criteria constitute a "better" archive, there is little doubt that the ability to see map information and tabular information and to query in and between them is an improvement over purely paper records. This is especially so when determining the need for archaeological fieldwork.

IT works well for cultural resource archives as a way to enhance record-keeping and basic archival functions. IT is not the perfect solution, however. The nature of IT is such that it requires records of any sort—markings on maps, site forms, reports—be fairly consistent in format and content. Cultural resource archives accumulate information over decades. The information in the archives is inconsistent, variable in quality, and differs in content over time. That's the nature of the beast (Ingbar et al. 1999). Automating this information does not make it more consistent, better in quality, or more similar in content. It does make it more accessible. Thus, IT's first role in cultural resource management is: *make records accessible.*

IT also works well for things that are done in consistent ways. Just as inconsistent records limit the utility of IT, consistent processes lend themselves well to IT. FedEx is able to use IT intensively for package tracking because each delivery step is very consistent. In cultural resource management, the "process" is well-specified for federalized actions under Section 106. This should lend itself quite well to IT. The Wyoming component of this project reports upon CRMTracker, an information management tool that links to the fieldwork and 106 process. Most IT solutions in cultural resource management, however, have chosen to automate some of the less-consistent parts of cultural resource management. We will discuss those below under data quality issues. The consistent processes in cultural resource management tend to be the ones that relate to legal decision-making: determinations of legal status of resources, determinations of project effects on resources, tracking of on-going projects, and status of authorizations, tax credits, and other services. Thus IT's second role, as yet to be fully realized, is: *focus on consistent processes where a record of information is useful.*

As mentioned above, IT works well in consistent settings. Field recording of archaeological sites is not a consistent endeavor. Although field recording of sites is done on standardized forms, there is no standardization as to who actually makes the observations that go on the form. There are requirements as to who can lead a field crew, author a report, and so on, but the actual person in the field may be inexperienced, in a hurry, or simply careless. Ideally, the field crew leader will catch problems or inconsistencies, but this is not guaranteed. Fieldwork is just too complicated, and knowledge of archaeology (or architecture, or rock art) is too subtle a calculus to rely upon each field archaeologist being consistent with the next. Even if we achieve consistent field results starting today, IT must still make available hundreds of thousands of older records of variable content and unknown quality.

Keeping that notion in context, then, NMCRIS has done an admirable job of enforcing consistency in preserving the observations of the field researcher. The data structure captures the complexity and interrelationships among pieces of information. Yet, NMCRIS in all its intricacy can never guarantee consistent quality of information. IT does not solve this problem. IT's third role is: *to facilitate quality and consistency even though it cannot create them.*

As the present study shows, IT can aid immensely in conducting studies of cultural resources, especially distributional analyses with GIS. IT does not "do" such studies, at least as we presently use it. For example, the models formulated in this project have no "re-run" button to press in five years that will show a new model created from the additional information. At a simpler level, one might even wish for a red flagging function that reports when a new archaeological site occurs where it is not expected based upon the model. This, too, we lack. Insofar as explicit models are a means for communicating our understanding about a phenomenon, IT in cultural resource management has really not helped convey information effectively. GIS is especially well suited to this and can be used consistently to place results or forecasts on a map. IT's fourth role, then, is: *to summarize knowledge, not just observations*.

This last role of IT in cultural resource management is really the key because it aids decision-making and hence effective management. Too often, "having the data in a database" is the end in itself, whereas, in reality, it is just the start. As this study has made clear, the need for IT in cultural resource management runs throughout. The product of cultural resources IT, of CRISs and paper archives, of maps and file drawers is not the bits, bytes, tapes, disks, or file folders but the knowledge they bring forward and the new knowledge to which they may lead.

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CHAPTER

4

Experimental: The New Mexico Modeling Project

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As noted in Chapter 2, the purpose of this project is to examine current archaeological resource management practices in the oil and gas fields of southeastern New Mexico and identify ways of making those practices more efficient for energy development and more effective for cultural resource preservation. Under an adaptive management approach, we would determine whether the current practices in archaeological resource management are working by monitoring and evaluating the results of the past 30 years of resource management in the area and then adjust the management practices accordingly.

Ideally, to plan for and manage energy development and its effects on archaeological sites, we would want to know a variety of things about the archaeological record:

- How are the known archaeological sites distributed, both in general and in relation to topography and other environmental variables?
- Are sites of different types or different time periods distributed differently?
- What factors condition site visibility and integrity?
- What kinds of sites have the potential to yield important information about the past?
- Is there a surface signature that would enable us to recognize these sites?

We would also want to know a variety of things about the effects of current practices on the archaeological record:

- Are current inventory procedures adequate to ensure that sites are identified and considered in planning for development projects?
- Are avoidance stipulations on APDs and ROWs sufficient to protect archaeological resources from damage during construction?
- Are archaeological resources being impacted by well-servicing and other post-construction activities?

and on energy development:

- Is sufficient information available to potential lessees to enable them to factor in potential costs (in both time and money) of cultural resource work on lease parcels?
- Is needed archaeological information available in a timely and appropriate manner to cultural resource personnel, other resource specialists, managers, and lessees and operators?
- What are the perceived and actual costs (in both time and money) of cultural resource compliance for operators and lessees, and where in the process do those costs occur?

With this and other information about the archaeology of southeastern New Mexico and the results of current management practices on both archaeological resources and energy development, we could begin to answer some critical questions:

- How do we know which archaeological resources are truly significant?
- Are there areas where the density of archaeological resources or the significance of the resources is so great that these areas should be identified in the RMP as unsuitable for leasing?
- Are there more efficient, timely, and cost-effective ways to identify and protect archaeological resources in the course of energy development activities?

- Are there areas where archaeological survey is not needed, either because sites do not occur or because previous survey has been sufficient?
- How can we identify and monitor sites most likely to be inadvertently damaged by oil and gas development and operations?
- What process changes can we make to facilitate energy development while maintaining or improving archaeological resource management and protection?

One of the major impediments to examining and evaluating the current practices is the absence of any mechanism for synthesizing the results of previous archaeological surveys and excavations. We don't have a good characterization of the distribution, nature, visibility, integrity, or significance (in terms of the potential to yield information about the past) of the archaeological record of southeastern New Mexico. The Section 106 process, which drives most of the archaeological work related to energy development on BLM land in southeastern New Mexico, is "undertaking-specific." That is, each development project creates a stand-alone cultural resources report, and there is no provision in the law or in BLM procedures for compiling the knowledge gained thus far and adding the information from a given project to that body of knowledge. For this reason, it is very difficult to get an overall picture of the archaeological record itself, much less of the impacts of current management practices on that record. The approach to this problem of characterizing the archaeological record that was adopted by the New Mexico Pump III project was to develop sets of archaeological predictive models.

What Is Archaeological Predictive Modeling?

Predictive modeling is a set of techniques for characterizing and anticipating trends in sets of data. In archaeology, a predictive model can be defined as a "simplified set of testable hypotheses, based either on behavioral assumptions or on empirical correlations, which at a minimum attempts to predict the loci of past human activities resulting in the deposition of artifacts or alteration of the landscape" (Kohler 1988:33). Most archaeological predictive models address the basic question, "Where are sites located?" and generally they are based on correlations between environmental variables and site location. Most archaeologists who have worked for any length of time in a particular area develop an intuitive model of where sites are likely to be found, but it was only when quantitative methods became an important component of archaeological studies in the early 1970s that models began to be based on objective measures of environmental variables.

The earliest attempts to model site locations relative to environmental variables were bivariate. Site locations were associated with one environmental variable and then another. Archaeologists often made the statistical mistake of assuming that they could simply add the various bivariate studies together to form a powerful statistical statement about the types of locations favored by human settlement. The problem, however, is that environmental variables are usually not statistically independent of each other. Because the same variation in site location was being explained over and over, seemingly strong statements about site location were in actuality very weak.

Green (1973), in a study of prehistoric Mayan sites in northern British Honduras, pioneered the use of multiple linear regressions incorporating a series of environmental variables to predict the probability that a particular location would contain a site. Multiple regression, like many discrete multivariate statistical techniques, is designed to ensure that all independent variables are statistically independent of each other. Green's work demonstrated the potential of multivariate statistics in predicting site locations; it also pointed out the complexity of these studies.

By the late 1970s, archaeological predictive modeling had caught the attention of the large federal land-managing agencies. The passage of the National Historic Preservation Act (NHPA) in 1966 and the National Environmental Policy Act (NEPA) in 1969 had left these agencies struggling with mandates to identify and evaluate archaeological sites under their jurisdiction and to assess the potential effects of enormous development projects on archaeological sites. Full-scale surveys were considered economically prohibitive, and predictive models based on surveys of small samples of project areas seemed to have great potential. Large numbers of predictive models were developed the late 1970 and early 1980s (Thoms 1988), and the Bureau of Land Management (BLM) sponsored development of a comprehensive text on predictive modeling and the use of this technique in cultural resource management (Judge and Sebastian 1988).

In the late 1980s and 1990s, the field of archaeological predictive modeling was revolutionized by the advent of geographic information system (GIS) technology. A GIS is a set of related databases with the capability to capture, store, manipulate, and display geographically referenced data. Archaeologists can now acquire regional data on vegetation, soils, elevation, slope, aspect, hydrology, and climate and compare these with sites locations to model human settlement and land use behaviors. Because an entire category of environmental data (e.g., vegetation) can now be acquired from a single source, these data provide a less biased metric representation of the variable in question than data collected from multiple sources using different registration, scale, etc. Not only does GIS technology enable modelers to combine geographic data from different sources with different formats, scales, etc., the GIS can also be used to create maps that incorporate, synthesize, and combine the results of overlaying various data themes. Such maps become a product in themselves as well as a source of hypotheses about covariation among environmental attributes and cultural behavior that can be further tested (see Allen et al. 1990; Wescott and Brandon 2000).

The end product of an archaeological model is a set of probability statements, generally displayed as a map, that indicate the likelihood that an archaeological site will be found at a particular location. Such models are based on the correlation between known archaeological site locations and a variety of environmental variables, and can be easily tested and upgraded as additional sites are recorded.

There is a constant trade-off between accuracy and precision with predictive models. Accuracy refers to the success of the prediction-the number or proportion of "hits" as opposed to "misses." Precision refers to the statistical confidence we have in the predictions. To illustrate these concepts, imagine a predictive model defining three "sensitivity" areas—high, medium, and low—reflecting the likelihood of encountering archaeological sites in each area. If 85 of 100 sites fall within the medium and high sensitivity areas, the model may be said to have an accuracy of 85%. On the surface, this may appear to be a good model. If the medium and high sensitivity areas constitute 85% of the study area, however, then the only statement that can be made is that 85% of the sites fall within 85% of the study area-a model as effective as a dart throw. If we can refine the model such that the medium and high sensitivity areas represent, let's say, 50% of the study area, while maintaining the same level of predictive accuracy, then our model is much more precise.

All agencies wrestle with these issues prior to using predictive models as part of a management strategy. Agencies must accept a certain amount of risk that sites will be missed in exchange for the ability to define appropriate levels of effort to identify sites, depending on site sensitivity within a given area. For example, the Minnesota Department of Transportation, in conjunction with the Minnesota SHPO, uses a predictive model (termed Mn/Model) to determine where to inventory and what sampling fraction to use. According to the Mn/Model web site (http://www.mnmodel.dot.state.mn.us/pages/about_mnmodel.html):

> Mn/Model development began in 1995. The goal of the project was to use Geographic Information Systems (GIS) and statistical analysis to produce archaeological predictive models that could be replicated by anyone using the same data and following the same procedures. The aim was that these models be accurate enough to predict 85% of known archaeological sites without designating more than 33% of the state's area as high and medium site probability.

From a management perspective, Mn/Model has been very successful in cutting costs of cultural resource inventories and streamlining the compliance process. Archaeologists, however, still worry about the confidence regulators place on the model. Without continual testing, how do you know that the model has an accuracy rate of 85%?

Archaeologists and regulators all over the world struggle with this question. In the Netherlands, for example, predictive models have been incorporated in the planning process of several provinces (Kamermans et al. 2005:15–16). Archaeologists in that country are split about the applicability of such models. Some believe the "American" approach, which is inductive in nature and management-focused, can never lead to confident predictions because the models have no explanatory power. In contrast, the "European" approach, which is derived from the cultural landscape school, can lead to interesting ideas about how past people distributed themselves but has little applicability to practical problems of modern land development (Kamermans et al. 2005:16).

We do not believe that the fault lines in predictive modeling are geographic, but instead reflect the different intended uses of the results. In the United States, as in Europe, managers need models that allow them to make land use decisions. These models historically have been inductive and correlative in nature. Researchers focused on understanding past behavior need models with explanatory strength. They have placed their energy into models that derive predictions from propositions about human behavior; predictions which focus less on specific locations than on types of landforms or environments.

With the continuing advances in GIS software, the gulf between management and research models is narrowing. In addition to algorithms based on the general linear regression model (the statistical model of choice for inductive, management-focused modelers), most software packages include a wide array of techniques based on behavior, such as agent-based modeling, directionality analysis, and expert systems. Predictive models that rely on a combination of deductive and inductive techniques are already being developed in management contexts. We suspect that over the next decade predictive models will become quite diverse and much more powerful.

How Are Predictive Models Developed?

Predictive modeling is a term that covers a wide array of techniques, which capitalize on the empirical observation that archaeological site locations tend to be associated with particular environmental features. Mappable environmental features are treated as independent variables that either individually or in combination are associated with the dependent variable, archaeological site locations. Such techniques have been used in cultural resource management (CRM) for more than two decades (Altschul et al. 2004; Kohler 1988; Kohler and Parker 1986). Although quite variable in design, predictive models are developed following a fairly standard process (Altschul 1988, 1989, 1990; Wescott and Brandon 2000).

Models can be and often are developed intuitively, based on a researcher's experience and knowledge of the archaeology of a particular area; for example, "agricultural villages will be located on low ridges overlooking shallow drainages." And such models may be quite accurate, that is, successful at predicting the locational characteristics of agricultural villages. But we have no means of estimating their precision or knowing how likely it is that the prediction will be correct. For land use planning purposes, it is critical to know the likelihood that significant archaeological resources will be found in specific areas, and this is only possible with statistically based models. For such models, environmental variables such as elevation, slope, aspect, vegetation, geomorphology, and proximity to water are measured on interval, ordinal, or categorical scale, as appropriate, and then the scores on each variable are divided into sensitivity classes that represented relative probabilities of finding sites.

For the New Mexico Pump III project, we developed three different types of models: Boolean, weighted sensitivity, and logistic regression models. For all three types of models, we divided the study area into a grid of 30-meter-square cells and then examined correlations between site locations and particular values for a given set of environmental variables on a cell-by-cell basis. Boolean and weighted sensitivity models then overlay all the variables to create a mosaic in which areas are classified as high, medium, or low sensitivity, based on the combined sensitivity scores for all or most variables. This process is called the intersection method (BRW 1996). Regression models, the third type used for this project, evaluate the relative contribution of each variable to the predictive success of the model and focus on the most powerful predictors. By using multiple modeling approaches, we hoped to acquire both the predictive power of multivariate statistical techniques and the intuitive understanding that comes from models that examine simple correlations between dependent and independent variables.

Boolean Models

A Boolean model is perhaps the simplest of all predictive modeling techniques. Every cell of the digital study region is classified as either "site" or "non-site" based on one rule. "Sites" are defined as cells that score favorably on every environmental attribute or theme; "non-sites" contain one or more unfavorable environmental scores. For example, if 90% of all the known-site cells are located within 500 m of water, then the GIS layers for distance to streams can be transformed into a layer that has a value of 1 or 0, where 1 indicates an area within 500 m of a stream and 0 indicates an area further away. Another layer can be constructed for slope. Let's assume that 90% of the sites are located on slopes of less than 2º. The slope layer can then be transformed into a slope "likelihood" layer of 0s and 1s. The distance to water and slope layers can then be overlaid so that all cells that scored "1" on both layers are coded as "1" or likely to contain a site; all other cells are coded "0" or not likely to contain a site. Although simple, Boolean intersection models work well in areas characterized by strong spatial autocorrelation (that is, where the environmental values in a particular cell are strongly influenced by the values of neighboring cells) and where environmental variables exert an overwhelming influence on human settlement.

It is important to remember that Boolean models often have little statistical strength. The environmental variables are being treated as independent of each other and all are given the same weight in determining site sensitivity. In our example above, it is possible that prehistoric peoples selected locations solely on the basis of nearby water. Relatively flat land may be located near streams, but this environmental factor was secondary in decisions about settlement, if considered at all. Thus, by using both criteria, researchers are mistaking the correlation between environmental variables with factors involved in settlement decisions. More importantly, areas close to water, but on steeper slopes, are being coded as "unfavorable" when these areas may have been considered desirable by prehistoric people.

As with any model, the results must make sense to the researcher. The great advantage of a Boolean model is that the researcher can easily "tinker" with it. By adding and subtracting layers, great insight into settlement behavior can often be achieved.

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 cutoff 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 liberal in defining categorical states and cutoff ranges because the intersecting properties of the method have a tendency to greatly reduce the favorable zone. In our Boolean models, we chose states and cutoff ranges for each variable that would ensure that a large percentage (80–95%) of the known site cells were included in the favorable category.

Weighted Models

Weighted models, like Boolean models, are created by the intersection method, in which each environmental theme is separated into cells that are associated with archaeological sites and cells that are not. When the themes are overlaid, the areas of intersection where multiple themes contain cells associated with sites are classified as high sensitivity zones; areas where multiple themes contain cells not associated with sites are classified as low sensitivity zones. Those areas where some environmental themes are correlated with sites and some are not are considered moderate sensitivity zones.

Weighted models are more sophisticated than Boolean models in that variable states within each theme are weighted based on their correlation with known archaeological sites, and the sensitivity ranking is determined by some type of mathematical formula. For the Pump III models we divided each environmental variable into discrete states and then calculated the expected percentage of the site-associated cells that should fall within each of the states if sites were randomly distributed. If, for example, the vegetation category "Chihuahuan desert scrub" constitutes 10% of the study area and sites are randomly distributed relative to vegetation, then 10% of the cells that contain sites should be found in Chihuahuan desert scrub areas. We then determined the observed percentage of cells containing sites within each vegetative category, and where the percentage of sites observed for a category was less than the percentage expected, we assigned that category a negative value. Conversely, if the percentage observed was greater than expected, we assigned the category a positive value. The greater the deviation in either direction, the higher the weight.

After deriving similar scores for each cell for the remaining environmental themes, the weighted model summed the scores for every cell. In order to map the results of the weighted model, we grouped the weights in sensitivity categories. The assignment of weights and sensitivity classes is somewhat subjective, but this is actually an advantage of this method. Because the scores are easily manipulated, 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.

Logistic Regression Models

The problem with intersection models, whether we use weighted variables or not, is that *all* values for *all* variables become part of the model outcome when we overlay the various themes and identify the overlaps. On both theoretical and empirical grounds, we have good reason to believe that some environmental variables are more strongly correlated with human settlement behavior than are others. On a practical level, as more variables are overlaid, the complexity of the model increases at a geometric rate, often without a commensurate improvement in the end product. More sophisticated mathematical modeling techniques can reduce the complexity. Most of these techniques are based on linear regression approaches, with the most common being multilinear regression, discriminant function analysis, principal components analysis, and logistic regression (see Rose and Altschul 1988 for a description of these approaches).

Multivariate regression techniques examine the covariation among the independent (in our case, environmental) variables; only those environmental variables that independently explain sufficient variability in the dependent variable (that is, site location) become part of the regression analysis. The result of the analysis is an equation that calculates the probability that a grid cell will contain an archaeological site. The resulting probability scores are then used to create a three-dimensional isopleth map. Cells with the tallest probability "spikes" have the greatest likelihood of containing an archaeology site; cells with the lowest spikes are the least likely to contain a site.

Regression models are popular among archaeological predictive modelers because they can be quite powerful. Model "users," such as agency managers and cultural resource staff, however, tend to prefer intersection models, even though they are generally less accurate and precise. Multivariate regression models are statistically complex, and for those without advanced training in statistics, these models are difficult to understand and use. Intersection models, though less powerful, are easy to understand, and they make intuitive "sense." The best archaeological models for practical applications are those that combine the intuitive nature of intersection models with the power of multivariate statistics.

Is one kind of model "better" than the other? It depends on the intended use of the model and on the questions being asked. A logistic regression model is generally a better predictor of site location than an intersection model. If the question is, for example, whether a proposed lease is likely to contain archaeological sites, the best approach would be to overlay the lease boundaries on the surface probability map generated by a regression model. If, on the other hand, the question is what accounts for the surface distribution of sites, then developing a weighted model and running it repeatedly with different weights for the variables would be a good approach. By determining what variable weights maximize the predictive power of the weighted model, one can begin to understand what factors may have determined the nature of the archaeological landscape.

Appropriate Use of Predictive Models in Cultural Resource Management and Planning

As noted above, in the late 1970s and early 1980s, federal land managing agencies invested heavily in archaeological predictive models. Faced with the substantial costs of large, intensive archaeological surveys in anticipation of major energy development projects or broad-scale military training exercises, agency managers seized upon predictive modeling. They believed that by spending the money to create an objective and verifiable model, they could then avoid large-scale survey and instead use the predictions of the model as a substitute means for meeting the requirement to identify affected historic properties. This belief constituted a fundamental misconception about what predictive models can and cannot do, and most applications of this belief reflected a fundamental misunderstanding of the requirements of good resource stewardship under NHPA.

Within the archaeological profession there was an outcry against the misuse of predictive models as a means of "identifying" archaeological sites that would be affected by federal undertakings. The result of a predictive model is a set of probabilities that describe the *likelihood* that an archaeological site will or will not be found in a particular location. Section 106 of the NHPA, on the other hand, requires that agencies make a reasonable and good faith effort to identify *actual* historic properties, evaluate their eligibility to the National Register of Historic Places, and determine whether any of the qualities that make the property eligible to the Register will be affected by the agency's undertaking. None of these requirements can be met by consulting a sensitivity map or other representation of the results of a modeling effort and determining the probability that a site will be encountered at a particular place.

Critics of this misuse of modeling also pointed out, as Judge and Martin (1988:580) note, that "modeling is a cyclical process of ongoing refinement, rather than a one-time event, and thus models cannot be developed by outsiders and then simply 'turned over' to agency field office archaeologists for 'application.'" Equally problematic, most models were being developed for arbitrarily defined areas—the area that would be affected by a large energy-development project or the land within the boundaries of particular military installation, for example. In such models, the patterning observed in site locations can be a response to factors outside the study area and thus not controlled for in the model, which makes the model much less accurate and interpretable (Kincaid 1988:552). Additionally, Native Americans often ascribe religious and cultural values to archaeological sites. These values generally are related to esoteric knowledge and oral traditions and not necessarily correlated with features of the natural environment. Because archaeological predictive models are based on environmental variables, sites with traditional cultural values could be underrepresented or overlooked entirely by the model.

Section 106 review agencies—that is, the Advisory Council on Historic Preservation and many of the State Historic Preservation Offices—were quickly convinced of the inadequacy of predictive models as a substitute for archaeological survey, and standard on-the-ground inventories became the norm for archaeological compliance (see Fish and Kowalewski 1990). This conservative approach satisfied the concerns of preservation-minded archaeologists and the Section 106 reviewing agencies but did not really address the problems of planning for large-scale development. And ironically, this approach also failed to provide a sufficient understanding of the archaeological record on which to base good management decisions—primarily because no mechanism emerged to synthesize the results of surveys from multiple projects.

Unfortunately, when it became clear that predictive models could not be substituted for intensive surveys, many land-managers abandoned the whole concept of archaeological models. Some agencies did continue to develop and refine models, however, because they realized that there are valid and important uses for models in the Section 106 process and in federal land management in general.

Kincaid (1988:554), for example, noted that

> Perhaps the most cost-effective context for model development is within the framework of general planning by a land-managing agency or a local government. These programs can develop and sustain long-term approaches that are funded incrementally and result in cumulative and refined data bases. Such databases, and the models based on them, may take years to develop and test. The end result, however is a powerful and effective management tool.

One of the most effective and appropriate uses of predictive modeling is for project planning and project design. If Section 106 undertakings are designed from the beginning to avoid areas containing a high density of cultural resources, costly redesigns and reroutes as well as mitigation efforts can be minimized. Predictive models can also be used to structure the Section 106 identification efforts for archaeological historic properties. In some settings, land managers can use sensitivity maps to target proportionately greater survey effort in those areas most likely to contain the greatest number of the sites or the most significant sites, while surveying other areas at a lower intensity.

There is more to cultural resource management than Section 106, however. Section 110 of the NHPA, for example, requires that federal agencies establish a program to identify and evaluate historic properties under their jurisdiction and that they manage and maintain National Register–eligible properties under their jurisdiction in a way that preserves their historic qualities. Predictive models can assist land managers to meet their Section 110 obligations by informing their decisions about land uses and by enabling them to make the best use of the scarce dollars available for resource identification, stabilization, and protection.

The National Environmental Policy Act (NEPA) requires that federal agencies evaluate the impact of their actions on the "human environment," including cultural and historic resources. All federal projects require NEPA assessment at some level, but those that have the potential to cause major impacts require formal evaluation of effects and alternatives through the Environmental Assessment or Environmental Impact Statement processes. The purpose of these NEPA assessments is to enable federal agency managers to make informed decisions that consider, in an even-handed way, the environmental, cultural, and social consequences of alternative agency actions.

NEPA does not require that agencies identify all specific resources that will be impacted or that the agency acquire comprehensive, detailed data about all the alternatives that are being considered. Rather, NEPA requires that the agency have or gather sufficient data to evaluate the alternatives effectively and that those data be gathered and evaluated in a scientifically valid way. Predictive modeling, alone or combined with sample survey, is an excellent approach to NEPA compliance for archaeology. A thoroughly tested and refined predictive model can enable an agency to evaluate a wide variety of alternatives and assess their relative impacts in an impartial, scientifically sound process.

After a decade or more of being out of favor among land-managing agencies, predictive models are making a comeback. Existing models are being updated and improved, and agencies that abandoned their models after learning that they could not simply substitute models for survey are rethinking that decision. There are several reasons for this renewed interest in modeling. For one thing, despite a quarter of a century of cultural resource management work, we are still struggling with the problem of how to synthesize all the gathered data. Section 106, which drives most of the cultural resource work, is totally case-specific. We have no mechanism for taking what we learn from each individual survey or excavation project, combining that information with all the other surveys and excavations in the area, and using the synthesized data to inform future management decisions.

As the New Mexico Pump III project shows, there are areas where literally hundreds of surveys have been completed but where we know very little more about the nature and meaning of the archaeological record than we did in the beginning. Archaeological modeling enables us to combine all of the existing data and examine them for patterns of correlation or to evaluate the data against theory-based predictions. Archaeological synthesis is not only critical to our ability to interpret and explain human behavior in the past, it assists us to develop more sophisticated research and management strategies for the future.

One of the most critical needs in cultural resource management today is for better assessments of archaeological significance. As part of the Section 106 process, decisions must be made every day about the potential of archaeological sites to "yield important information" about the past. By synthesizing existing data and characterizing what is common and what is rare in the archaeological record, predictive modeling can assist with this process. Perhaps even more important, archaeological models can help us identify the things that require explanation.

The accuracy of predictive models is often given a great deal of emphasis, but it is important to note that predictive power does not correlate with archaeological importance. We might, for example, create a model that predicts archaeological site locations with an accuracy of 80% or more, which might lead managers to question the value of model refinements intended to better that accuracy by something less than the remaining 20%. In all likelihood, however, it is the remaining 20% of sites that have the greatest potential to teach us important things about the past.

These "red flag" sites (Altschul 1989, 1990), which do not fit expected distributional patterns, result from human behaviors that are beyond our predictive capabilities. These sites are, by definition, are likely to yield important information on past settlement behavior and, therefore, are likely to be eligible for listing in the National Register of Historic Places. Predictive models will not identify these sites, and archaeological inventory alone will not indicate their significance. Through a combination of modeling to identify the common, environmentally predictable patterns and inventory to identify the exceptions, however, we can identify those sites that should be the focus of our research, mitigation, and site protection efforts.

Another reason for the renewed interest in predictive modeling is the current government-wide emphasis on environmental streamlining. One of the most effective ways to streamline environmental review is to move decision-making to a point earlier in the planning process. This is a good thing for preservation of archaeological sites and other kinds of cultural resources, since more avoidance and mitigation alternatives are available at the earliest stages of planning. Because early planning takes place well before Section 106–driven resource identification has been completed, however, land-managers need a mechanism for synthesizing, manipulating, and evaluating existing data in order to make effective, well-informed cultural resource management decisions. Archaeological modeling, combined with limited identification and testing, has much to contribute to environmentally responsible streamlining efforts.

Predictive modeling should be part of a management strategy for cultural resources. Yet, it is important to recognize that modeling is not a rote exercise. For models to be useful, archaeologists with regional expertise must work together with GIS specialists and archaeostatisticians. Many examples exist of the use of inappropriate modeling techniques resulting in models on which managers have relied that are, in reality, poor predictors and make little archaeological sense.

Finally, we sometimes learn very useful information about the past and about the resources being managed when models do not work. For example, the Yuma Proving Ground (YPG) encompasses about 850,000 acres in the Sonoran Desert of southwestern Arizona. The region is located in one of the harshest desert environments in the world, receiving less than 3 inches of rain a year and subjected to summer temperatures well in excess of 100°F. Under contract to develop a predictive model for the installation, Altschul (2005) argued that environmentally based, correlative models should work well in this situation. After all, survival in this region depended on humans mapping onto a small set of environmental resources, all of which were distributed in very restricted areas. Yet, surprisingly, logistic regression and weighted models did not work well at all. Site locations were simply not correlated with environmental variables. How could this be?

The answer was not intuitively obvious, but after studying the archaeological and ethnohistoical records, Altschul realized that few people in the past actually went into this part of the desert to collect resources. Instead, they focused on the resources and established settlements along the permanent rivers of the region, the Colorado and Gila rivers. Sites in the desert were created by people traveling between the riverine settlements. To demonstrate this hypothesis, Altschul eschewed correlative models in favor of directional analysis which identified logical routes based criteria such as least effort and water availability. These routes were then correlated with the locations of known archaeological sites, and predictions were offered not only about where sites would be located but also about the types of sites that would be encountered. Altschul (2005) argued that almost all Native American resources on YPG could be attributed to a restricted set of behaviors (i.e., those associated with travel).

The management significance of this discovery is that the potential of both known and yet-to-be-recorded sites to yield important information on the past (criterion D of 36CFR60.4) could be addressed programmatically. Based on this knowledge, appropriate measures could be defined so that archaeological resources could be identified, evaluated, and treated simultaneously, greatly streamlining the compliance process. The Army is in consultation with the Arizona SHPO and tribes of the region to incorporate Altschul's suggestions into management practices.

Advances in predictive modeling, like most advances in science, are cumulative. They require that researchers apply appropriate techniques to particular questions about settlement systems. Some questions, such as where will sites be located, may only require simple techniques. As we probe deeper into past behavior, however, both to increase the accuracy of our predictions as well as to distinguish portions of the archaeological record worth saving, the questions become increasingly complex, as we will discuss in the following section of this chapter. Addressing these questions requires archaeologists to continually enlarge their predictive tool kit.

How Does Modeling Contribute to Our Understanding of the Past?

The predictive models described in this report are statistically derived techniques for anticipating probable densities of archaeological sites within three localities of southeastern New Mexico. The immediate application of this information is resource management, but predictive modeling has a much broader range of uses in archaeology. The long-range goal of archaeology as a scientific discipline is "the contribution of knowledge to objective understandings of human behavior" (Cordell et al. 1994:164). The scientific questions that interest archaeologists range from quite specific human acts at one end of the human behavioral spectrum to broad processes of cultural development and change at the other end (Cordell 1994:152). Nevertheless, most of the questions that archaeologists ask pertain not to individual behaviors or societies in general but rather to the behavior of cultural groups in given times and places. Further, the time frame of interest usually is the precontact or early historical period, although archaeologists as members of the professional anthropological community do, in fact, study modern societies to gain insight into ancient behavior and societal processes.

Archaeologists investigate past human behavior through artifacts and their attributes, architecture and other constructed features, sites and settlement patterns, the residues of cultural and economic activities, and the many ways that humans alter and interact with their physical environments. Archaeologists researching historical-period groups also may investigate the past through written records, where available and applicable. Observations concerning the formal attributes of these remains of past activities, as well as their temporal and spatial associations, are recovered primarily during the course of systematic surveys and controlled excavations. The recorded observations become archaeological data, and it is these data that are described and analyzed. Analysis usually involves the search for patterning or regularities in form, function, association, or developmental sequence. Ideally, analysis of one or a few sets of data is compared with other data sets, and patterning at larger temporal and spatial scales can be perceived from this integration and synthesis of multiple data sets.

From these higher-level studies, conceptual models are developed to account for the behaviors of interest. We accept the definition of models offered by Clarke (1968:32), who suggests that models are hypotheses or sets of hypotheses that simplify complex observations but offer a largely accurate predictive framework to account for given behaviors. For example, a researcher may want to understand why large, late, precontact village sites that housed most of a given valley's population were more-or-less evenly spaced along a particular river system. Was this spacing a result of the distribution of arable land, competition for and defense of immediate territory, or the need to locate sites within easy distance of cooperative kin, trading partners, and potential mates? The researcher would develop alternate models describing what patterns we might expect to see in the archaeological record for each of these possible explanations of village spacing—in other words, economic self-sufficiency, competition, or cooperation.

The data examined in our example might include the distribution and amount of high-quality arable land and water, the presence or absence of territorial markers (e.g., field-side houses, shrines, petroglyphs, or large areas of unoccupied land), or the similarity or dissimilarity of culinary pottery among adjacent villages. The expectations (or predictions) generated by each model would then be compared with the available data. A model would be judged successful if the fit between the researcher's expectations and the actual observed data proved to be a strong one. If the fit was found to be poor, either the postulated behavior (e.g., competition) was not, in fact, responsible for the site distribution, or the model or the data were inadequate for the test. As this example shows, archaeological models are generalizations derived from pattern-recognition studies that postulate cause-and-effect relationships among clusters of environmental and social conditions and human behaviors and test these expectations against the archaeological record.

Seen in this way, all archaeological models are predictive, but the goal of the modeling effort is not to accurately project where sites will likely occur, but rather to understand the contexts, conditions, decisions, and human actions behind those archaeological patterns. The predictive models developed for the Loco Hills, Azotea Mesa, and Otero Mesa study areas were designed to discover general patterns in human settlement relative to aspects of the physical environment and to reveal something about the subsistence activities and economic decisions behind those patterns.

Other types of human decisions and behavioral patterns—those related to demographic or ideological considerations, for example—could not be considered in these models because few of the data needed for such models have been compiled, analyzed, and interpreted. Although hundreds of artifact scatters have been located, no comprehensive study has been undertaken to classify these scatters by their various functions (e.g., short- and long-term base camps or habitations, resource procurement locales, resource processing locales). No detailed studies of functionally important or temporally sensitive artifact classes have been undertaken. No synthetic study has been undertaken to resolve chronological issues or questions of cultural affiliation. The PUMP III models focus on economic decision-making in relationship to site location because the currently available archaeological data are best suited to models of this nature.

The PUMP III models, or at least the Loco Hills and Azotea Mesa models, were moderately successful in predicting site location, which would indicate that economic decision-making was an important influence on the location of human activities in this area. But the models were even more successful in generating questions about the past and the nature of the archaeological record. In all cases, they underscored the need for focused study and data recovery in southeastern New Mexico.

Let us suppose that such studies and archaeological data recovery were actually to take place. What, then, could we expect future modeling efforts to do for us in the PUMP III study areas? How can modeling contribute to our understanding of the past? To address these questions, we have briefly described below five examples of archaeological models that used spatial referenced site data, environmental variables, and GIS technology to contribute to our understanding of past human behavior. All of the examples are regional analyses, and each was developed to account for the known distribution of archaeological sites or settlement centers.

A Model of Trade and Cross-Cultural Interaction

Archaeologist Kathleen Allen (1990) developed a model that used the demand for and direction of movement of trade goods as a predictor of settlement location and population distribution. Specifically, she wanted to understand the development of trade between native Iroquois populations and European colonizers in New York state from about AD 1600 to 1750. To do this, she used a Network Analysis module within the ARIC/INFO GIS package to simulate the outward flow of specific trade goods from historically known population centers at three periods of time: the time before major European colonization in the mid- to late 1500s, the time of the early establishment of trading posts in the early 1600s, and the mid-1700s the time by which European trading posts and forts were well established throughout the region. The major conduit for travel and trade were river valleys, and a hydrology layer in the GIS served as a proxy for trade routes. Allen used the location of known Iroquian villages and European trading posts and forts and the historical records of trade items to develop her model for the three temporal periods. She successfully replicated the broad patterns of historical-period trade, and she discovered that distribution of watercourses was more important in explaining the movement of goods and people than earlier researchers had conjectured.

A Model of Territory and Social Organization

Archaeologist Stephen Savage (1990) used geographic location theory to develop a model for the existence of a particular form of social organization in Late Archaic hunting and gathering societies in the southeastern United States. Savage's model suggests that the distribution of Late Archaic period sites in the Savannah River Valley of Georgia and South Carolina was the result of the creation of habitually used and exclusive territories by Late Archaic period hunter-gatherers. In this model, each small group (the minimal band) functioned as an independent subsistence unit connected to other groups through a large contiguous social network (the maximal band) which fulfilled mating, ritual, and defensive functions. Environmental data required to develop the model included elevation data (and one of its derivatives, terrain roughness) and hydrology. Archaeological data included site locations, site sizes, and site types based on tool and raw material variability. Savage displayed and analyzed his data with a GIS program called MAPCGI. Using a variety of spatial analysis techniques, including site catchment, nearest-neighbor, and least-cost movement analyses, as well as Thiessen polygons, Savage was able to delimit the habitual use areas (territories) of six minimum bands and estimate the population of each territory based on site size and complexity, overall population size, and the likelihood that a larger social network existed to satisfy higher-level societal functions.

A Model of Population Growth and Migration

Archaeologist Ezra Zubrow (1990) harnessed the power of GIS to simulate various models of European settlement, population growth, and migration in New York state for the interval between AD 1608 and 1810. His goal was to account for the location of settlements in the early nineteenth century and to understand the process of colonization. Also considered were the interactions of European settlers with native populations and a variety of obstacles to movement. Zubrow's methods included reconstructing the hydrological network that would have been usable for travel, establishing the locations and initial size of original populations and their rates of population growth, employing the Network Module of ARC/INFO to simulate and display the movement and distribution of migrants, and comparing the simulated results with historical records of actual examples of people moving and settling the landscape. From three initial centers along the Hudson River in eastern New York, the simulation charted the movements of colonists and their potential routes of migration. The model was run numerous times, in which each run specified different growth rates and dispersal assumptions. Through modeling and dynamic simulation, Zubrow was able to effectively model different migration patterns and sequences that accounted for the 83 known early European settlements during that two-century period. He also was able to suggest that populations moved along a larger number of watercourses and in different directions than previously realized. Finally, through the modeling exercise Zubrow came to understand much more about the factors that limited population growth and population movement during the settlement of what was then a frontier area.

A Model of Cultural Contact and Shifting Economic Priorities

Cultural anthropologist Clifford Behrens (1996:55–77) developed an economic model based on cultural ecological theory to account for the changing distribution of sites and site types in a region of the Peruvian Amazon at the end of the twentieth century. His goal was to better understand how increasing sedentism and growing market demand for products can lead to altered settlement patterns and increasingly intensive uses of land among indigenous Amazonians. The ecological effects of these human land-use practices included widespread deforestation and the reduction of biodiversity within the rainforest. Behrens used the GIS system GRASS to display and analyze classified Landsat satellite imagery (Thematic Mapper data) as a means to document developments in the Lower Pisqui River region of eastern Peru in the 1980s. The relationships between indigenous hamlets, mestizo and white villages, and various land-use categories (cropland, pasture, forest land, water, wetland, barren land) were explored with a variety of spatial techniques and statistical measures. From these exploratory data analyses, Behrens was able to construct a three-stage process model that accounted for the changes in settlement. Among the various factors were a desire on the part of natives to acquire more efficient tools and ready-made goods, to gain access to schools and health care, and to satisfy a desire to reduce travel distances to their workplaces. The effects of the changes in settlement and settlement duration were realized as shortened fallow periods for agricultural plots and cattle pasture, forest destruction, and disruption of former social and political networks. The apparent success of Behrens's methods and models in explaining the settlement patterns suggests that similar approaches could be taken to predict settlement change under similar pressures elsewhere.

A Model of Environmental Variability, Agricultural Productivity, and Food Sharing

Archaeologists Carla Van West and Timothy Kohler (1996:107–131) created a subsistence risk sensitivity model for the AD 900–1300 interval in southwestern Colorado to account for the cyclical pattern of population aggregation and dispersal that has been documented for that area. The data used in this modeling effort were developed in an earlier GIS-coordinated reconstruction by Van West (1994) of environmental variability and agricultural potential for the Mesa Verde area. Environmental variables used in the earlier study to estimate prehistoric agricultural yields were tree-ring-based reconstructions of precipitation and soil moisture, elevation information, soils data, soil productivity data, and historical crop yields by soil class. VICAR-IBIS, a mainframe raster system, and EPPL7, a PC raster system, were used to process the data. Van West and Kohler drew on discussions of risk and uncertainty in behavioral ecology and microeconomics to develop their expectations. They expressed risk sensitivity to fluctuations in crop yield as a willingness to share or horde food. They predicted that time periods when maize yields were high but characterized by significant temporal and spatial variability would be associated with risk-averse behavior, food-sharing, and the establishment and growth of aggregated settlements (villages with public architecture). In contrast, they predicted that time periods when maize yields were low but accompanied by significant temporal and spatial variability would be associated with risk-seeking behavior, defection from the system of food-sharing (hording), the break-up of villages into smaller units, and dispersal into habitable areas. Their expectations were tested by comparing their predictions to the archaeological settlement history, which is well documented for the Mesa Verde region. Their expectations were met, and they concluded that the model effort was generally successful in predicting when and where villages were likely to have been established or abandoned. Perhaps more importantly, however, Van West and Kohler were able to argue that food sharing, perhaps the most basic of all cooperative behaviors, was a likely element in the complex set of factors that led to development of sociopolitical complexity in the northern Southwest.

Conclusions

We have offered these examples of more sophisticated archaeological models to indicate what is possible with more detailed archaeological data. Although each of the models described above used different theory, methods, and analytic techniques to explore site distributions, what they have in common is data on the formal and temporal characteristics and spatial distributions of artifacts, features, and sites in the targeted region. Such knowledge can only be gained through analysis of systematically recovered archaeological materials or, in the case of historical-period remains, written records. Significant insights concerning past human behavior in southeast New Mexico will be gained only when a sufficient sample of well-documented sites and their contents has been obtained, analyzed, and interpreted. Only then will archaeologists be able to suggest which human behaviors and social processes are the most powerful predictors of settlement patterns and accurately evaluate the potential of individual archaeological sites to yield data important to this understanding of the past.

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CHAPTER

5

Results and Discussion: The Loco Hills Study Area

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The Loco Hills study area (Figure 1.2) is a rectangle covering approximately 1,200 square kilometers (460 square miles) located between the towns of Hobbs and Artesia in southeastern New Mexico. Most of the study area lies within the Pecos River valley; the river itself is about 16 kilometers (10 miles) west of the study area's western boundary.

The northeastern corner of the study area includes a small segment of The Caprock or Mescalero Ridge, which forms the eastern edge of the river valley and the western edge of the Llano Estacado (Figure 1.3). Elevations within the study area vary from about 300 meters (1,000 feet) in the southwest to 390 meters (1,300 feet) in the northeast; most of the land within the study area is less than 360 meters (1,200 feet) above mean sea level.

Much of the study area is covered by a thick sand sheet deposited some 5,000–9,000 years ago and topped with parabolic dunes that are very recent in age; in the western and southwestern portions of the study area, the sand sheet is thinner and covered with coppice dunes formed around mesquites and other shrubs. In the southwestern and south-central parts of the study area, exposures of eroded Permian-Triassic sedimentary rocks are covered with thin soils. The northeastern portion of the area lies within the Llano Estacado, which is a flat, nearly featureless landscape of eroded Ogallala caprock caliche characterized by thin soils and numerous, shallow drainage depressions and playas. Permian, Triassic, and Ogallala outcrops represent diverse geological ages and rock types and are collectively referred to here as "bedrock."

The Predictive Models

Environmental Data

In developing the Loco Hills predictive models, we began by assembling data on all types of environmental variables. Some of these variables were subsequently found to be correlated with archaeological sites; others were not. These relationships became clear during the next step in the model development process, but at this initial stage we needed to ensure that we cast our net wide enough so that the variables included in the model would, through a variety of statistical manipulations, cover as many aspects of the human decision-making process through which indigenous people placed themselves and their activities on the landscape as possible.

In compiling the environmental data for Loco Hills, we restricted our search to data that already existed in digital formats that could be converted easily 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 Loco Hills. This GIS package is a raster-based system and uses a grid of a specified size superimposed over the area in question. We chose a 10 × 10 m cell as our grid size, which generated 13,298,193 cells for the Loco Hills study area.

The environmental variables used in predictive models are best viewed as proxy variables. Humans use a complicated "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 houses or measure the exact distance to water, but they do choose land that is flat and near water. The indigenous people of Loco Hills probably did not know, much less care, at what elevation they placed their camps, but they certainly knew where the stands of black grama and tobosa grasses occurred. Elevation, though not part of the prehistoric "calculus," is strongly correlated with the vegetative communities of southeast New Mexico and thus can be used as a predictor of site location.

For environmental variables, we obtained GIS layers on elevation, vegetation, and geomorphology. Because the data relate to empirical observations (i.e., 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 (USGS; Figure 5.1). DEMs are created by interpolating between a set of points with known elevations

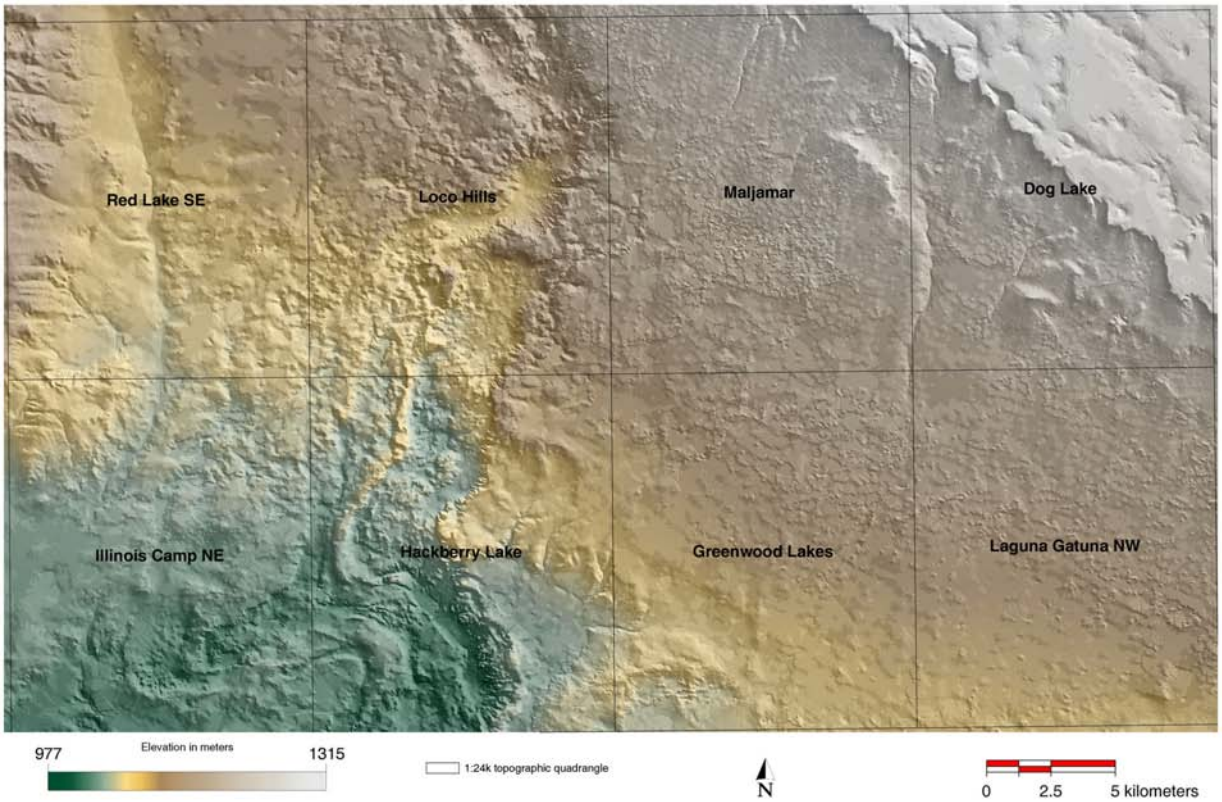

Figure 5.1. Digital elevation model (DEM) of the Loco Hills study area with USGS 7.5-minute quadrangles labeled. Note DEM extends slightly outside study area.

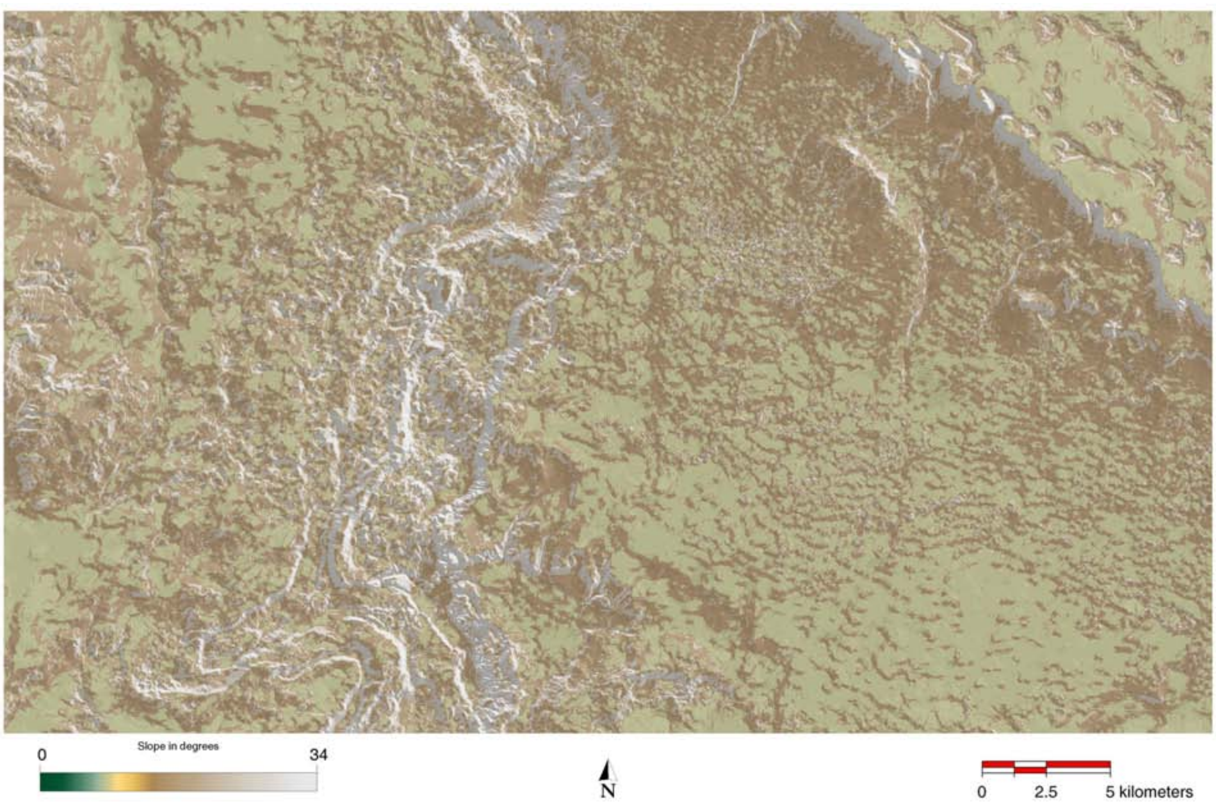

Figure 5.2. A secondary layer, slope, for the Loco Hills area; this layer was created from the DEM primary layer.

at a specified contour interval. In the case of Loco Hills, the contour interval is 40 feet.

Algorithms exist within GIS packages to transform 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. For example, to calculate the slope of a cell, IDRISI uses the elevation scores of the four cells located to the north, south, east, and west of the one in question to compute an "average" slope (Figure 5.2). Similarly, aspect, or the prevailing 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.

Distance to water themes were also created from the DEMs by calculating either the shortest distance from a cell to an interpolated blue line feature (i.e., distance to water; streams are plotted on Figure 5.3) or the shortest distance following the flattest grade (cost distance to water). The interpolated stream systems may differ from the blue topographic lines because the GIS is computing where water will flow based on slope and elevation of the DEM. This is very useful for archaeological site modeling, since most topographic blue lines show only modern drainages.

Vegetation

In addition to the environmental themes based on the DEM, we acquired a vegetation layer from the Gap Analysis Program of the USGS, which provides information on biodiversity and conservation gaps. The data are displayed as major vegetation categories, which are divided into 21 subcategories based on common descriptions of vegetation.

As Figure 5.4 shows, more than 58% of the Loco Hills study area is covered by vegetation that is categorized as broadleaf sand scrub, with another 9% being categorized as some type of desert scrub. Of the remainder, most is short-grass steppe (19%) or some type of grassland (14%). The major grass species are black grama (*Bouteloua eriopoda*) and tobosa (*Hilaria mutica*), along with various species of dropseed and sacaton (*Sporobolus* spp.). The main shrub species are creosote (*Larrea tridentate*), mesquite (both *Prosopis julifora* and *gladulosa*), and shin oak (*Quercus havardii*).

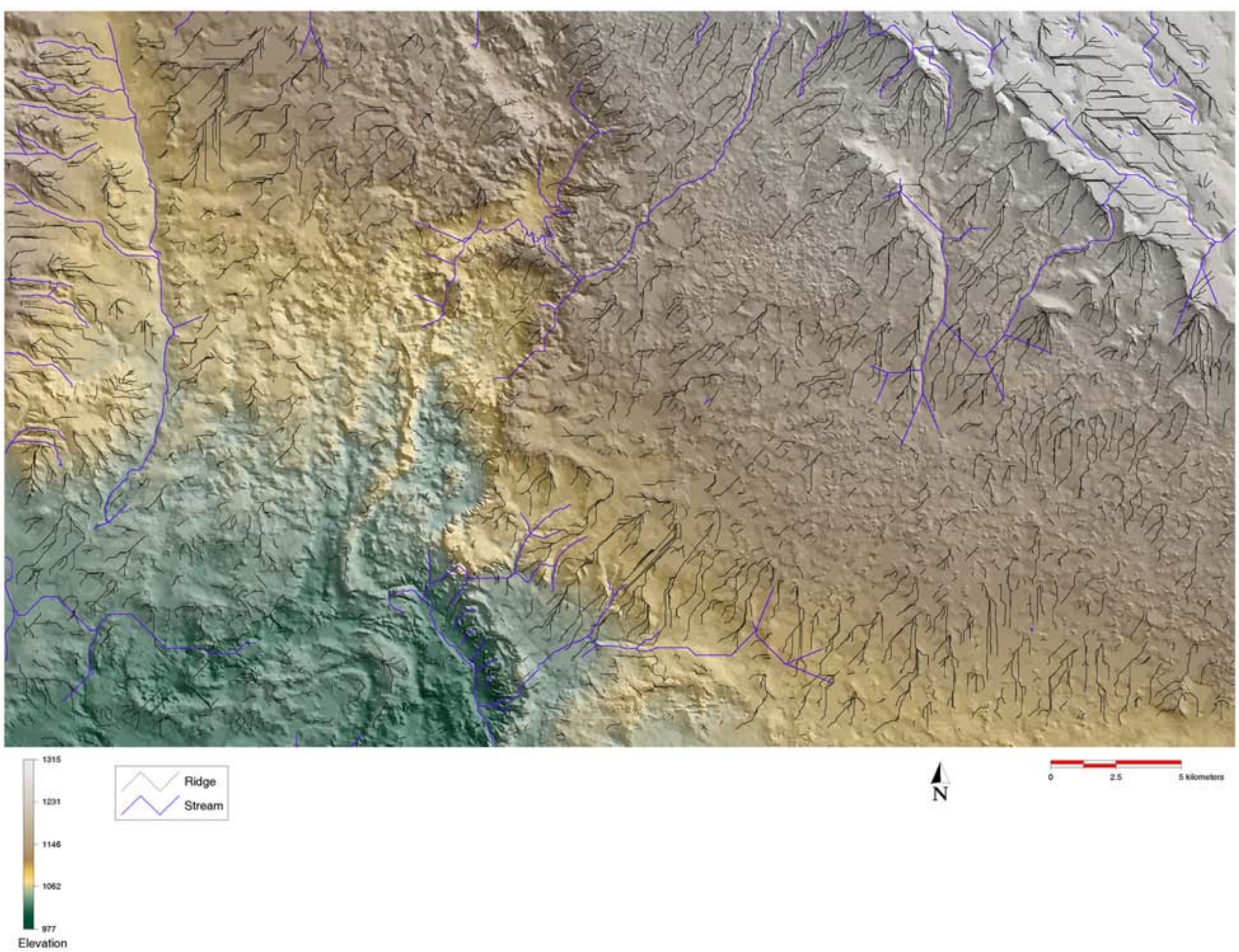

Figure 5.3. Drainages and ridges in the Loco Hills study area.

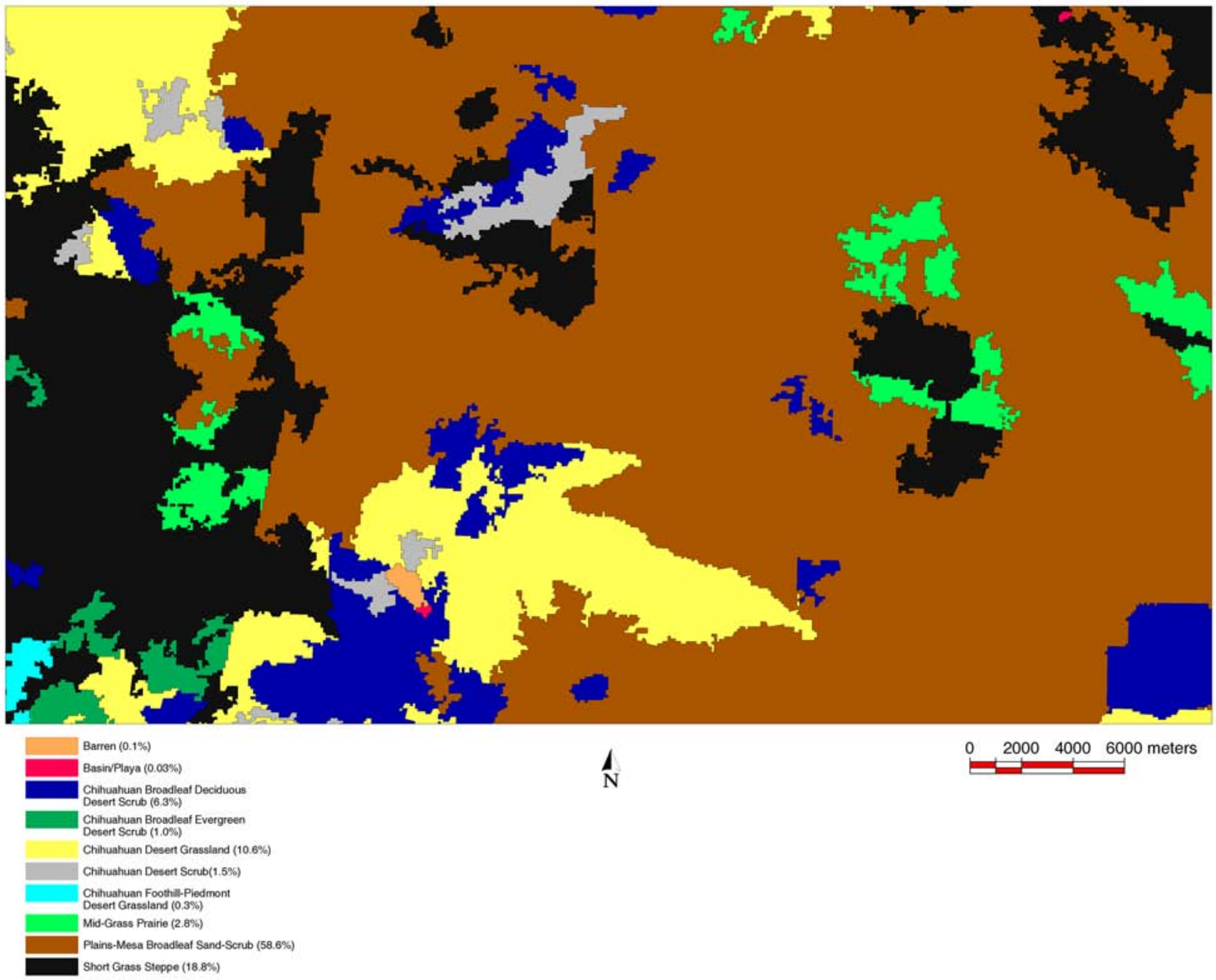

Figure 5.4. Vegetation in the Loco Hills study area

Geomorphic Data

The final category of environmental data used for the models was geomorphology data provided by Gnomon, Inc., based on maps prepared by Stephen Hall of Red Rock Geological Enterprises. The 500 square mile Loco Hills 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, South Dakota. Landforms were identified from the stereo aerial photographs using a Topcon mirror binocular stereoscope at 3× 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. For reasons of practicality, 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.

The geomorphology of the Loco Hills study area (Figure 5.5) is characterized by Permian-Triassic shales and sandstone bedrock. Because of a rare combination of geologic circumstances operating actively over the past 100,000 years (and with precursors extending back millions of years), the Loco Hills area is today dominated by an eolian sand sheet. The central portion of the Mescalero Sands is comparatively thick and young (Holocene), whereas the edges of the sand sheet are thin and old (Pleistocene). The High Plains and Caprock escarpment occur in the northeast corner of the study area. The entire landscape slopes gently to the southwest.

Where the sand sheet is thick and covered by shin oak vegetation, recent erosion has produced small parabolic dunes. The blowout areas of the dunes are colonized by plants and become filled in with new sand. Thus, if sites are present and partially exposed by erosion, they become buried again, masked from surface surveys. In contrast, the margins of the sand sheet do not have shin oak vegetation. Here recent erosion has produced mesquite coppice dunes,

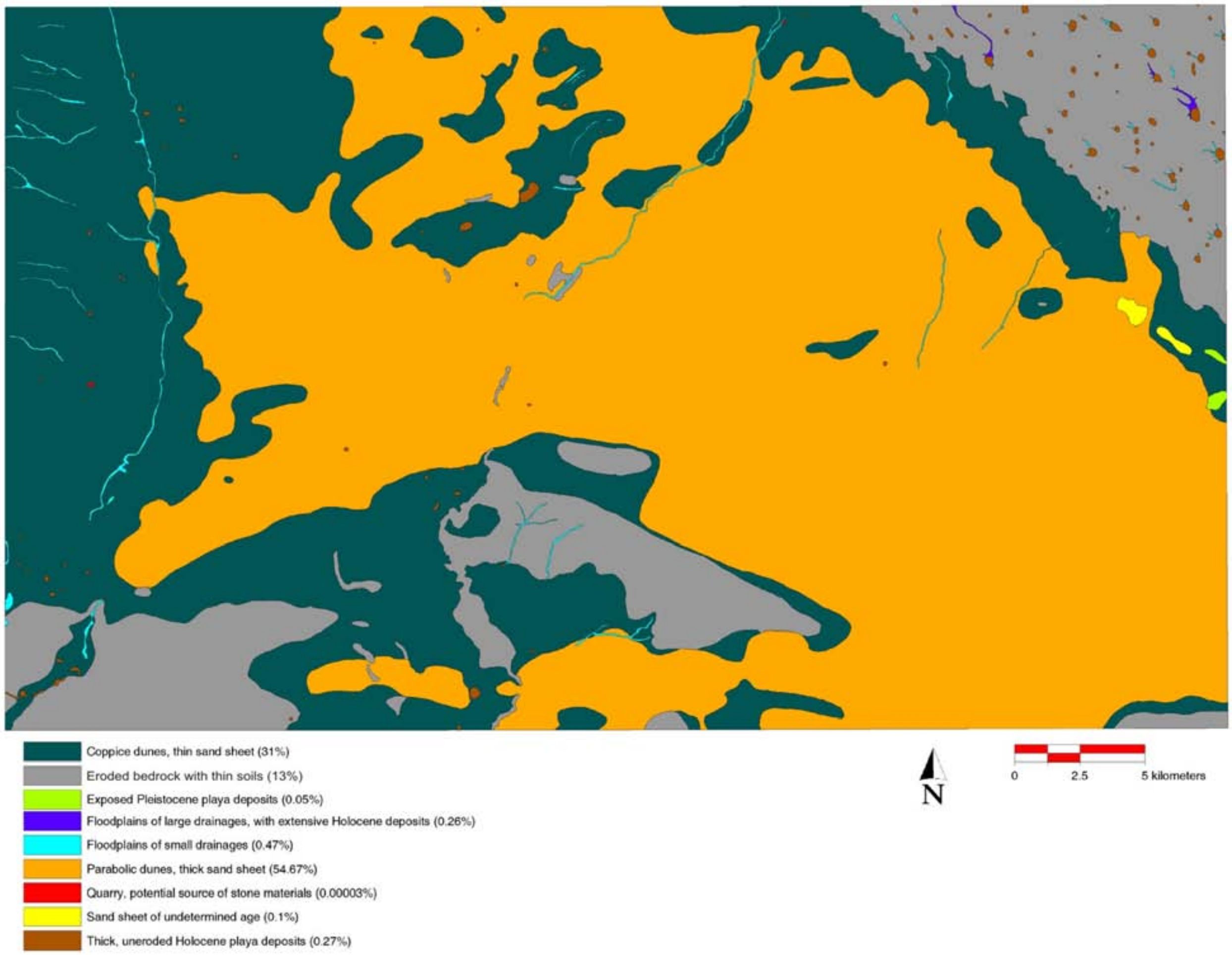

Figure 5.5. Geomorphology of the Loco Hills study area

sand hummocks that form around woody plants. Often coppice dunes are the result of desertification of former shrublands owing to land development or disturbance. The areas between the coppice dunes are severely deflated down to Pleistocene-age sand, exposing all sites that are present.

By mapping the distribution of the sand sheet and comparing it with the distribution of archaeological sites, we hoped to address both cultural and taphonomic questions: Did people choose to live on or off the sand sheet? Did they prefer the margins or the central portion? What has been the effect of recent geomorphology on the visibility of archaeological materials?

Eolian Sand. The sand sheet described above is the main geomorphic feature of the study area. The central portion of the sand sheet is comparatively thick (1 to 6+ meters) and composed of sand that accumulated about 5,000 to 9,000 years ago (Hall 2002). The thicker sand is characterized by low, shrubby shin oak (*Quercus havardii*) vegetation and has been recently deflated, forming small parabolic dunes oriented east and east-northeast.

At the margins of the sand sheet, the eolian sand cover is comparatively thin, generally less than 1 meter in thickness. The thin sand is an eroded, older, red sand that has been dated to 70,000 to 90,000 years BP by optically stimulated luminescence. As noted above, erosion in the twentieth century has formed numerous coppice dunes around the Torrey mesquite (*Prosopis glandulosa torreyana*). Archaeological sites in this setting are both highly visible and disturbed by erosion, although intact cultural features may intrude into the old red sand or may be preserved beneath some coppice dunes.

Beneath the sand sheet is a moderately well developed calcic paleosol (Mescalero paleosol) that formed on bedrock and that predates the sand sheet.

A weak A horizon soil (known as the Loco Hills soil) occurs throughout the study area. Radiocarbon ages for the soil range from 150 to 380 radiocarbon years BP. The soil likely formed in association with desert grassland vegetation during a slightly less arid period than today . The Loco Hills soil is the surface that was disturbed by deflation, resulting in parabolic and coppice dunes in the past century. The soil occurs on surfaces of all ages and may mantle sediments containing archaeological sites.

Alluvium. Stream deposits in the project area are largely hidden by recently deposited eolian sand. At various times in the past, around AD 1000, for example, surface water may have been more abundant. Although difficult to assess, all alluvial deposits and small streams were mapped with the possibility in mind that surface water was more abundant in other times.

A few deposits of terrace gravels that contain rounded caliche clasts from the nearby Ogallala Formation were mapped. It has been noted in the field that many fire-cracked rocks are actually Ogallala caliche and not caliche from the local Mescalero paleosol that underlies the sand sheet.

Playas and Small Ponds. Numerous playa lakes occur on the High Plains surface in the northeastern corner of the project area. The lakes probably originated in the Pleistocene; some have established drainages leading into them. The playas likely all contain Holocene sediments as well as deflated remnants of Pleistocene deposits. All of these playa lakes were mapped, as were the alluvial sediments in associated drainages. It seems reasonable to expect that the playas, especially the larger ones, were sources of permanent water during periods of wetter climate and higher water tables.

Throughout the Mescalero Sands are several small ponds that may be related to karst activity (in the eastern area) or the presence of depressions on the irregular surface of the sand sheet. The larger, less ephemeral ones were identified by color infrared photography and included on the geomorphology maps.

Given a slightly wetter climate and more surface water, these small playas and ponds would have been sources of water for game animals and prehistoric inhabitants.

Eroded Bedrock Surfaces. Where not mantled by Quaternary deposits, the bedrock terrain is denuded and archaeological sites have 100% visibility. These surface sites may also be severely bioturbated. Sites of all ages occur on the surface of the eroded bedrock.

In the Loco Hills study area, thick deposits of sand dunes that may cover and mask the presence of buried archaeological sites characterize much of the landscape. On the other hand, the remaining portion of the area is severely eroded and denuded, and archaeological sites are visible. The dichotomy of site visibility related to geology makes the Loco Hills area a good case study.

Archaeological Data

For the Loco Hills models, the dependent variable 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 the subject of archaeological surveys, the sites that have been recorded, and various characteristics of those sites. Ideally, we would like to have created a series of predictive models by dividing the sites into classes based on time of occupation and/or function. Unfortunately, current knowledge about the archaeological sites recorded in the Loco Hills region is not sufficient to allow us to classify sites into temporal or functional classes.

The basic distinction in the ARMS database is between artifact scatters and artifact scatters with features. Only a small set of sites has descriptive data on items such as the types of features, diagnostic artifacts, and depth of cultural deposits; presumably the other sites either lack these types of artifacts and features or they are not visible on the surface. At the time of our analysis, the ARMS data were not linked to the GIS files, so retrieving descriptive information was extremely time consuming and prone to error. Consequently, any information on site characteristics reported below was obtained by sampling the database through visual inspection of the individual records.

Although very few sites have been dated, we were able to distinguish between post-European contact and precontact sites. Because these two temporal categories represent fundamentally different cultural systems, we excluded historical period sites from the predictive models.

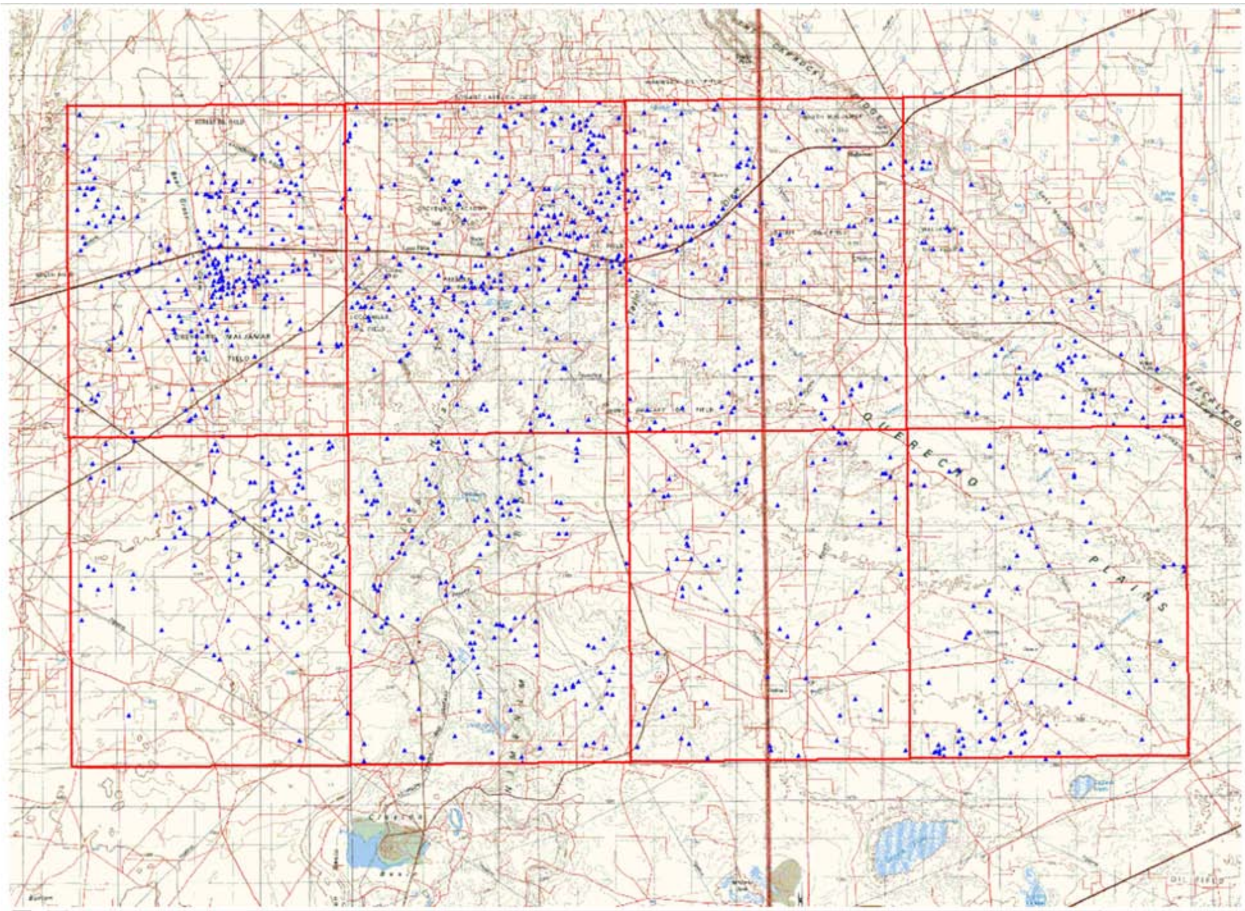

Figure 5.6. Distribution of known archaeological sites, Loco Hills study area

Site Data

The archaeological site data provided by ARMS are shown graphically in Figure 5.6. The data used in the models are in vector format, which is a geographic information system (GIS) convention that stores spatial data and databases with a corresponding point, line, or area feature. The site data were provided as polygon features, where every site is represented as an area within the GIS. Each site polygon is also linked to related information, such as area, site number, and a site description, within the vector database.

An important part of GIS data is its spatial orientation 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 (NAD 27). The UTM georeference system is common for archaeological applications, and *x* and *y* coordinates are given in meters.

The site data originally contained 1,625 polygons. It was determined that this number could be reduced to 779 polygons by combining multiple recordings of the same site. These polygons from multiple recordings overlapped each other and could be fused into one without disrupting modeling goals. The original, unmodified site data layer was also used for some analyses.

Survey Data

The archaeological survey data provided by ARMS (Figure 5.7) are polygon features, in which every survey is represented as an area within the GIS. As with the site data, 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 also georeferenced in Universal Transverse Mercator (UTM), Zone 13 grid format, using the NAD27 datum.

The survey data originally contained 5,196 polygons. For the purpose of modeling, overlapping surveys were merged to create fewer polygons. The Loco Hills boundary was then used to crop survey polygons to conform to the

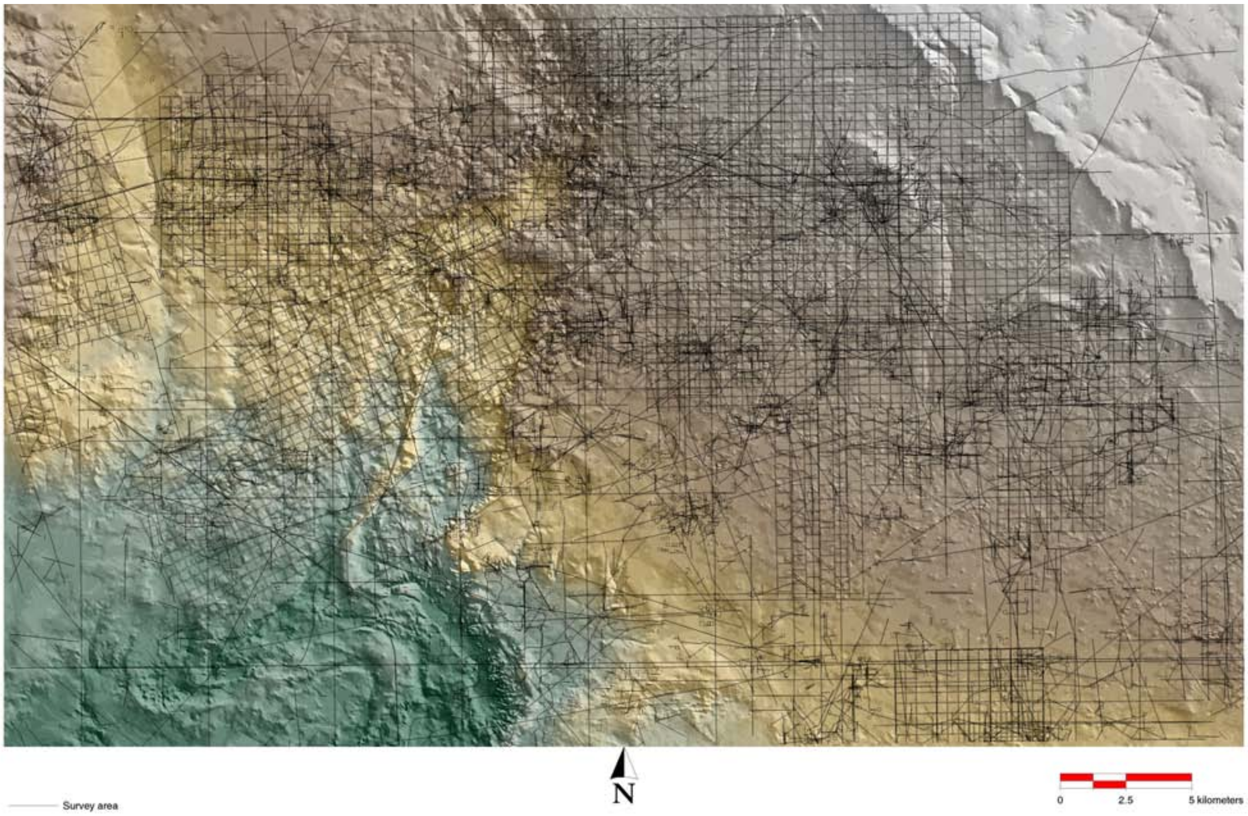

Figure 5.7. Surveys conducted in the Loco Hills study area as of 2002

rectangular study area. This process allowed us to convert the polygons into a raster format that was assigned unique values. The raster format was subsequently converted into a binary format. In binary format, every cell for all layers can be classed as surveyed (value is 1) or not surveyed (value is 0). The net result was 6,301 individual polygons comprising 5,099 individual survey episodes.

Confidence and Statistical Independence

Once the GIS layers had been assembled, each environmental theme was reviewed to determine whether the areas covered by archaeological surveys adequately represent the target environmental attributes. If coverage is adequate, we can have confidence that the association between the environmental variable and site location found in the surveyed areas mirrors their relationship in the larger study area. Although one could test for these relationships statistically, we have found that a simpler approach suffices. 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, 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.

As an example of this process, the histogram for the slope of all cells in Loco Hills (Figure 5.8) is nearly identical to that for cells that have been covered by archaeological surveys (Figure 5.9), indicating that all slopes present in Loco Hills are adequately represented by the surveyed areas.

Visual comparisons for all of the histograms displaying environmental variables in the Loco Hills study area suggested that, with one exception, the surveyed cells adequately represent the values for each of the environmental variables. The exception occurs within the geomorphology theme. Eroded bedrock covers approximately 13% of Loco Hills, but only about 7% of the archaeologically 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 bedrock that *have* been surveyed, and anecdotal evidence from archaeologists and geomorphologists indicates that, even if sites were to be found here, their integrity would be limited. Intact cultural deposits are very unlikely on this landform given the lack of soil development (see Hall 2002). Thus, even though the eroded bedrock 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).

Beyond demonstrating that the environment of the surveyed areas adequately represents the general Loco Hills 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 purportedly independent variables that are, in fact, related to each other, we calculated the pair-wise Spearman's r scores for each pair of environmental variables (Table 5.1). No r score exceeded 0.52, and all but two were below 0.4. Thus, no variable explains more than 25% of another (r^2). 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) both with and without the two most interrelated variables—elevation and cost distance to water. The logistic regression model calculated without these two variables was very close to the model calculated with all variables (comparing the two models, $r = 0.78$). Accordingly, we only present the full model below.

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. But, of course, 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 as one moves away from the Pecos Valley. Thus, knowing the slope of one cell allows one to guess within reason the slope of its neighbors.

To overcome spatial autocorrelation, we used a feature of IDRISI that places a "filter" over the Loco Hills grid. The program selects a 10% random sample of cells. The filter was applied to all environmental variables during the logistic regression; all cells for the dependent variable, site location, were included in the model calculations, however. With the filter in place, the regression equation was then applied to all cells in the study unit. No filter was used in the creation of the weighted models (see discussion of modeling techniques below).

Sensitivity Maps

There are many different types of predictive models (see discussion in Chapter 4), ranging from subjective statements about where archaeologists have found sites in a region to highly sophisticated multivariate statistical models. For Loco Hills, we used two modeling techniques: a weighted method and logistic regression. These two approaches capture both the predictive power of multivariate statistical techniques and the intuitive understanding that comes with intersection models, which examine simple correlations between dependent and independent variables.

Weighted Model

The Loco Hills weighted model can be considered a type of intersection model. Each environmental variable was divided into discrete states that were then weighted based on their correlation with known archaeological sites. For instance, the geomorphology theme was divided into nine classes as defined in Table 5.2. Based on the percentage of the study area that falls into each of the geomorphic categories, we calculated the expected percentage of the site cells that should fall within each of the nine categories if sites were randomly distributed. That is, if geomorphic class X constitutes 10% of the study area and sites are randomly distributed relative to geomorphology, then 10% 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.

Using the data presented in Table 5.2 on geomorphology as an example, we see that coppice dunes cover 31% of the study area, but 54% 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 bedrock covers 13% of the project area, but only slightly more than 1% of eroded bedrock cells contain sites. We must remember that eroded bedrock areas are underrepresented in archaeological surveys. Thus, the strong negative association between sites and eroded bedrock could 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 bedrock class –3.

We performed a similar analysis for the remaining seven environmental themes: aspect, slope, elevation, vegetation,

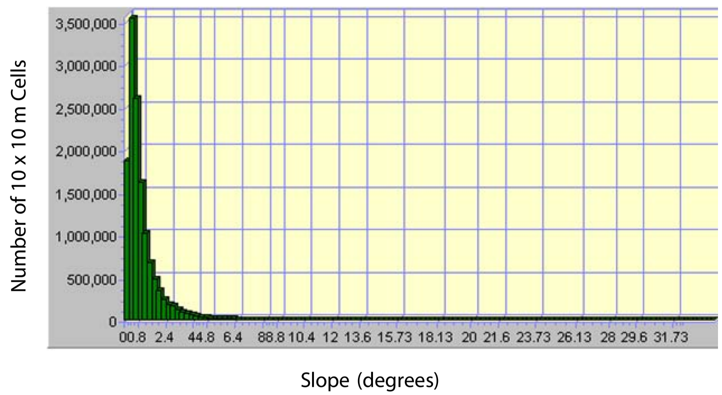

Figure 5.8. Slope values for entire Loco Hills study area (mean = 0.96º)

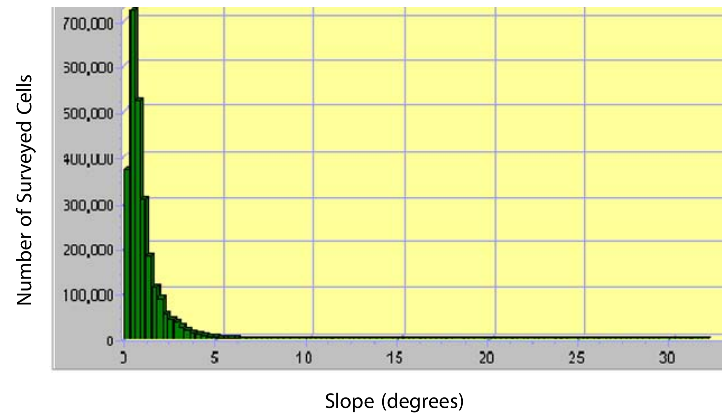

Figure 5.9. Slope values for surveyed cells within Loco Hills area (mean = 0.98º)

Table 5.1. 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

Table 5.2. 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 bedrock surface, 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

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 33. To make the results comparable with those of the logistic regression model, the possible weights were grouped to yield four sensitivity zones (Figure 5.10). Class 4 comprises those cells scoring 21–33 (excellent chance of containing a site); Class 3 contains those cells scoring between 18–21 (good chance); Class 2 contains cells scoring between 15–18 (average chance); and the cells in Class 1 had scores ranging between 0 and 15 (poor chance). Class 3 contains 45% of the cells with sites in 32% of the project area. Classes 2 through 4 combined contain 76% of cells with sites in 41% of the project area.

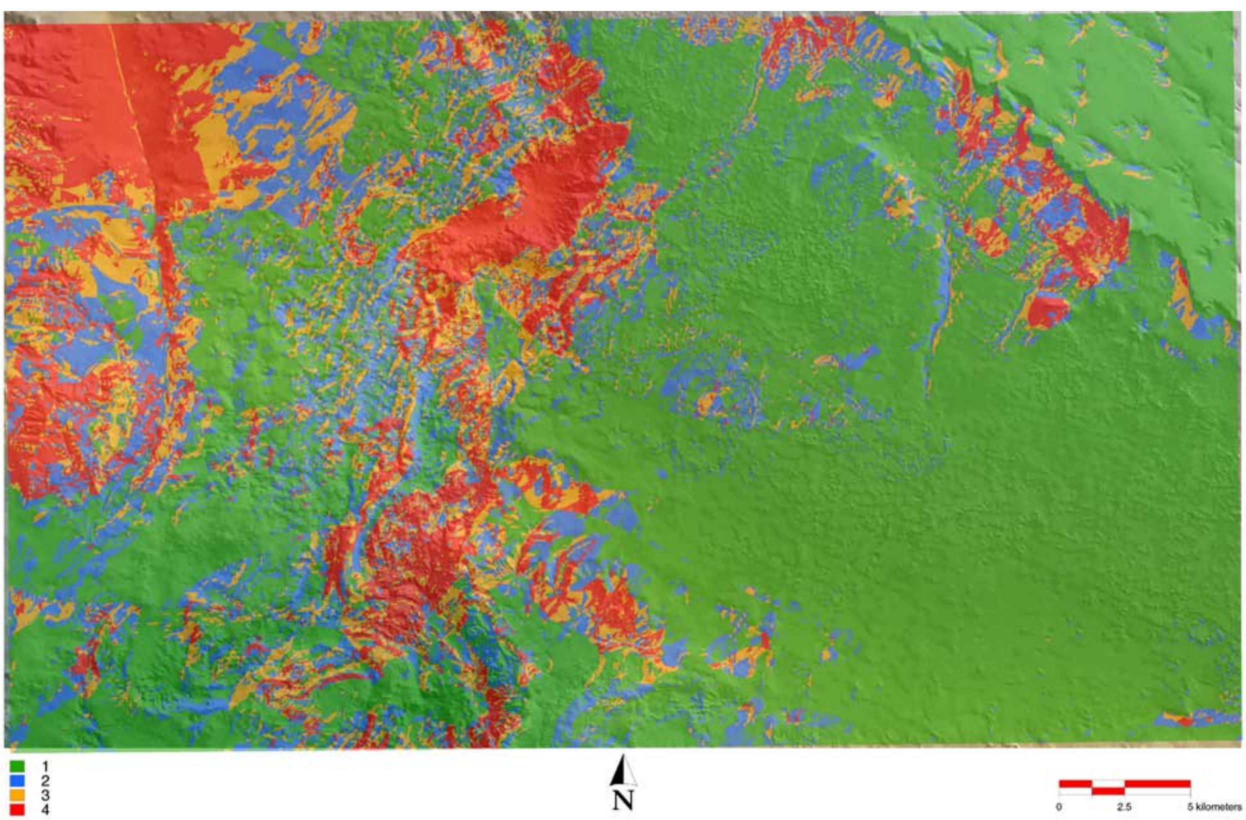

Figure 5.10. Weighted sensitivity model with 4 classes.
Portions of DEM not covered by the model are outside the boundaries of the study area.

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 the model can be re-created, and the results of those 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. We started by determining which classes have the highest proportion of cells with sites. Next, we combined the classes with the highest proportion of site cells into one class that contained minimally 65% of all cells with sites. This class was assigned a weight of 3. Of the remaining classes, we then combined those with the highest site density to account for the next 20% of site cells; this class was given a weight of 2. Finally, all remaining classes were combined and given a weight of 1. 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 models increased to 0.74.

Logistic Regression Model

As discussed in more detail in Chapter 4, regression models evaluate the covariation among the independent variables (in our case, environmental variables) and dependent variables (the location of archaeological sites). Only those environmental variables that independently explain sufficient variability in site location are used in the regression analysis. The result of the regression analysis is one or more equations that are used to calculate the probability that a cell within the study area will contain an archaeological site, and the result of the probability calculations is a probability map.

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

Logit(site) = 1.4146 + 0.545241(coppice dune) + 0.003666(cost distance to water) –0.000043(distance to quarries) – 0.000169(distance to water) – 0.005068(elevation) – 2.489208(eroded bedrock) – 0.003594(north-south aspect) – 0.217984(slope) – 1.075599(grass cover) – 0.317156(scrub) + 0.000689(east-west 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, in a logistic regression the slope coefficient is interpreted as the rate of change in the “log odds” as the independent variable changes. The magnitude of the slope coefficients, then, is not a direct reflection of the predictive strength of the independent variable. Although 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 Loco Hills model. Instead, we used the results of the weighted model to provide insight (see discussion below) 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, however, several “Pseudo R^2” statistics. Although their values can vary between 0 and 1, 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. IDRISI also 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.

Both the Pseudo R^2 and the goodness-of-fit scores of the Loco Hills model may be affected by the mismatch between the number of cells that contain sites (8,500) and those representing the environment (1,330,429). Another potential explanation relates to the substantial differences in site size. Sites in the highest sensitivity zone average 21,147 m^2 (minimum = 0.003, maximum = 2,893,597, s.d. = 143,316), whereas those in the lowest sensitivity zone are, on average, 5,029 m^2 (minimum = 26, maximum = 48,900, s.d. = 12,523). Because each raster cell is treated the same by the model, large sites are given more weight than smaller ones. It is possible, then, that the logistic regression model is skewed by the inclusion of a few very large sites.

To test this notion, we ran the model again using only one cell to represent each site. A cell near the middle of the site was selected, and the resulting equation was termed the “centroid” model. To our surprise, the result of the centroid model was very close to that of the full model (Spearman’s *r* score of 0.74). Site size, therefore, is not a major factor in determining the shape or nature of the surface probability map.

Although the Pseudo R^2 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. For the Loco Hills logistic regression model the ROC was 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.

Once we were satisfied that the logistic regression result was an accurate reflection of the relationship between site locations and environmental variables, we needed to display the calculated probabilities. For each cell, the logistic regression calculates a probability score between 0 (site less likely) and 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:

1 (0.00–0.09: poor chance of site presence);
2 (0.10–0.39: average chance of site presence);
3 (0.40–0.59: good chance of site presence); and
4 (0.60–1.00: excellent chance of site presence)

Classes 3 and 4 together contain 95% of the site cells and cover 71% of the study area. Class 4 alone contains 58% of the site cells and constitutes only 21% of the project area. A probability surface map of these scores is displayed in Figure 5.11. Probability scores could not be calculated for the thin band of cells at the top of the figure; they are shown in gray.

Comparison of the Sensitivity Models

Visually, the main difference between the weighted model and the logistic regression model is that the former contains 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 with the dependent variable of all the independent variables as a group. Some variables are weighted more

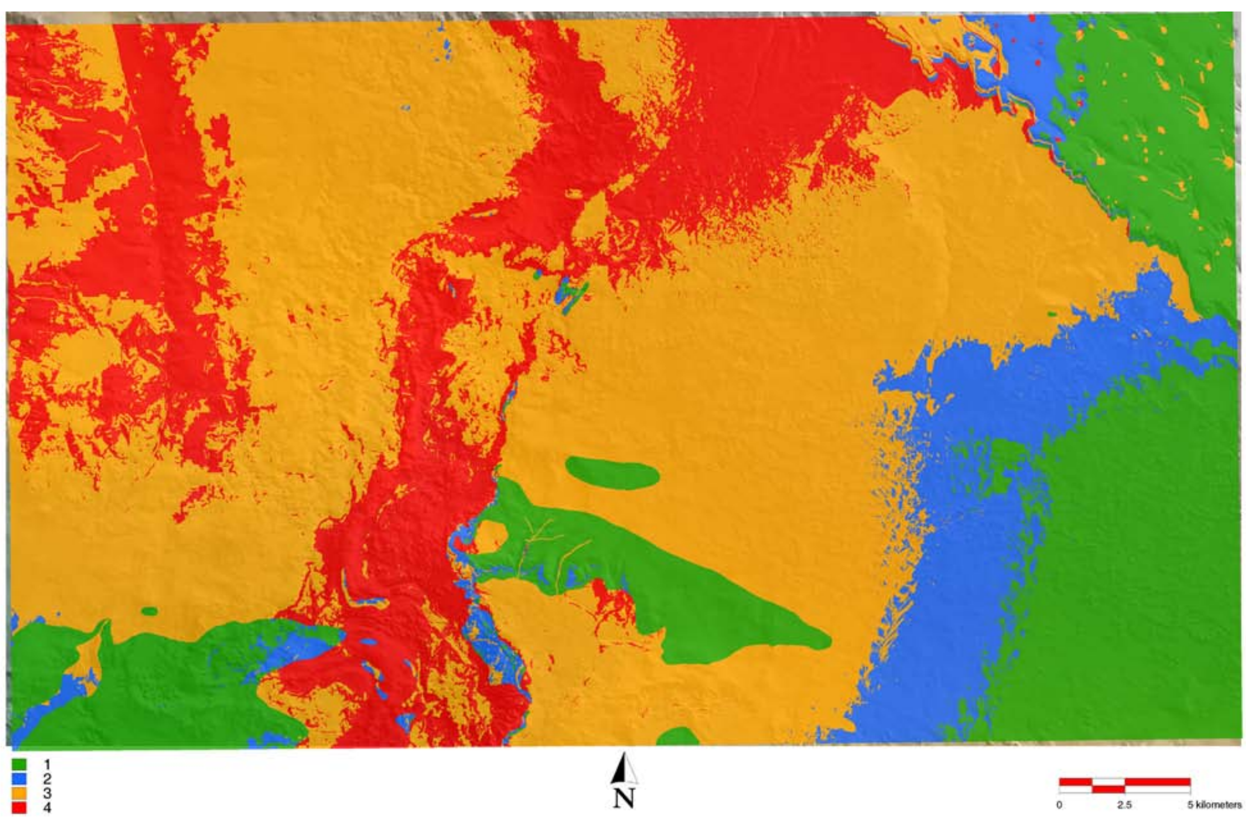

Figure 5.11. Logistic regression model with 4 classes (1–4).

than others, not because they are more important in human decisions about settlement but because they account for more of the variation in site location. Because less of the variation in site location remained to be explained by the other proxy variables, those 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 5.2) 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 1) (Figure 5.12). The logistic regression model, however, weights variables in relation to their association with the dependent variable. Parabolic dunes cover a far smaller percentage of the lowest sensitivity class in the logistic regression model (Figure 5.13) than they do in the weighted model (Figure 5.12) because logistic regression allows only the explanatory portions of environmental variables that are independent of explanatory portions of other environmental variables into the equation. Logistic regression is a much more efficient and more powerful statistic. However, because the statistical interactions between independent variables are complex, it is exceedingly difficult to isolate the association of a particular variable with site location.

The question immediately arises as to which is the better model. Ideally, we could test the models by performing a blind survey in which survey crews would be randomly assigned to high and low probability areas. Survey results could then be used to compare predicted and observed performance for each model. More important than determining which model works best is an effort to obtain a better understanding of site distribution. The common tendency for managers is to discard the model with the worst fit. Much could be learned, however, by understanding why the various models do not work and then refining them. For example, if we find that the weighted model works poorly, we might change the weights of the various variables manually to maximize its predictive power. This would be an excellent means of intuitively grasping the importance of particular variables. Such an exercise helps us begin to understand the archaeological landscape.

Instead of focusing on which model works better, it seems more profitable to discuss how and when the models can best be used for management purposes. The logistic regression model for Loco Hills is more powerful, and statistically it is a better predictor. If the proposed boundaries of a lease area are known, for example, 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 from the regression model. The weighted model, in contrast, is best used as an analytical tool to guide future research whose ultimate goal is to allow managers to make better-informed decisions. 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.

Interpreting the Results

Predictive models can effectively identify patterns or trends in settlement. Some trends are easy to spot and intuitive to grasp. In Loco Hills, bigger, more complex sites are found along watercourses in the coppice dunes (Table 5.3). These settings, which would have supported economically important grasses and attracted small mammals, would have been ideal campgrounds for hunter-gatherers. Not surprisingly, sites in the high sensitivity class are larger, have more features, more formal flaked tools, more milling implements, and deeper cultural deposits. Sites in the lowest sensitivity zone are smaller and less complicated than their counterparts in the more sensitive zones, but these tendencies are ones of degree. 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.

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. Sebastian (1989a:55–56) describes the serial foraging settlement pattern as follows:

> A strategy of serial foraging involves a small residential group that moves into the general vicinity of an abundant resource and camps there, uses the target resource and other hunted and gathered resources encountered in the general area until the target resource is gone, or until another desired resource is known to be available, and then

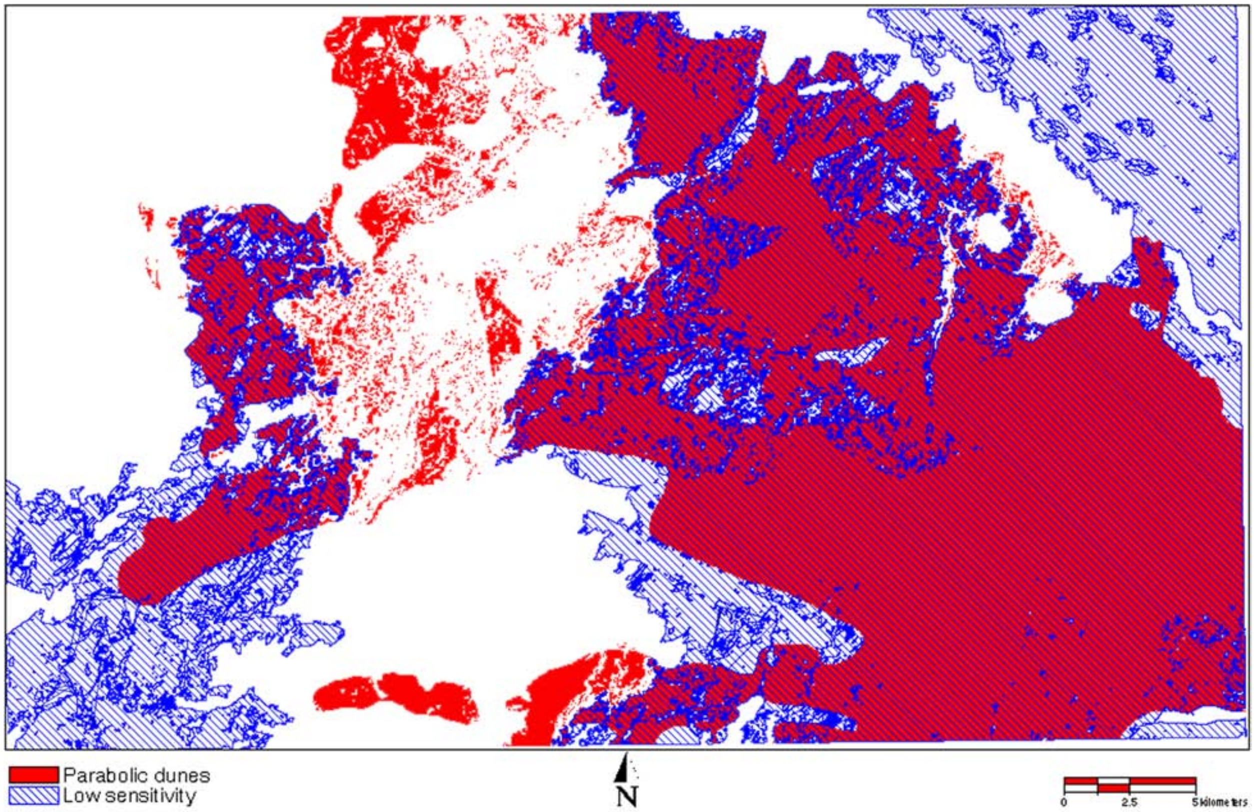

Figure 5.12. Weighted sensitivity model. Parabolic dunes cover 73% of the low sensitivity area

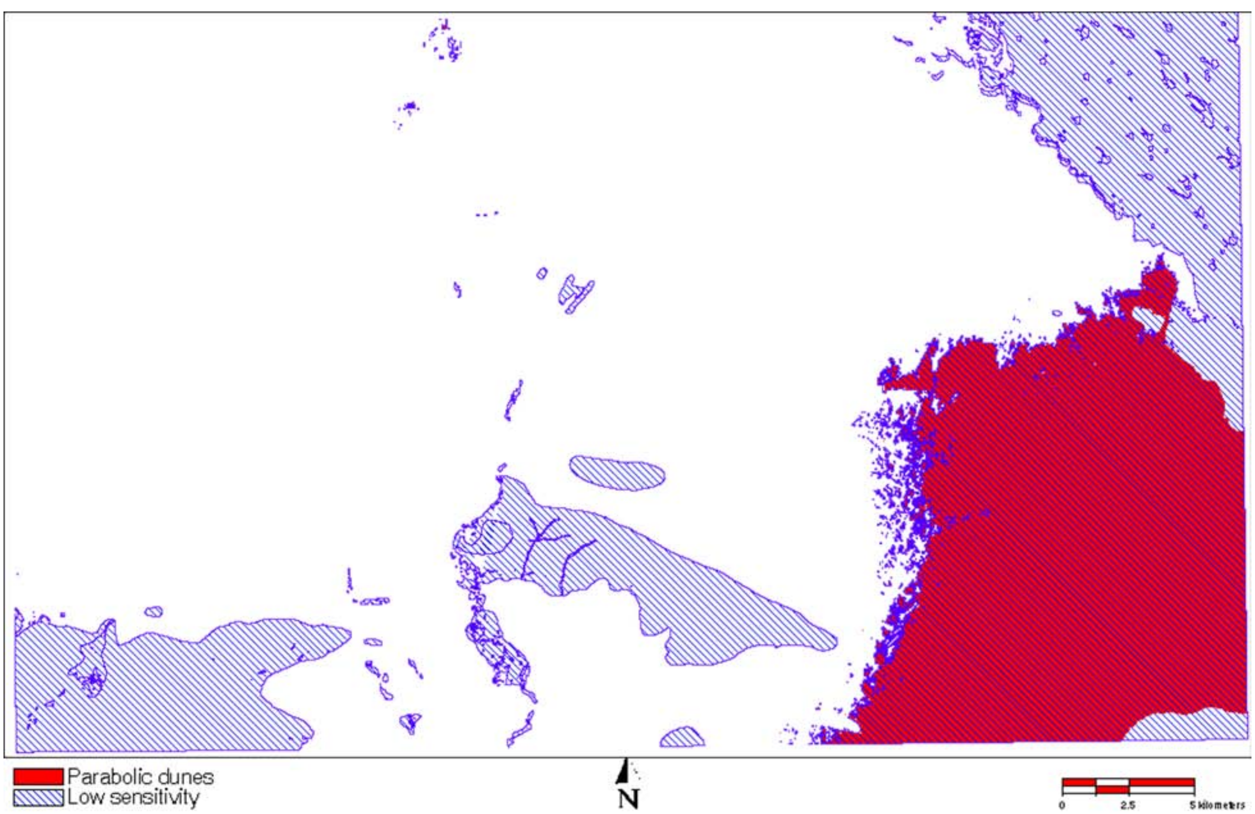

Figure 5.13. Logistic regression model. Parabolic dunes cover 53% of the low sensitivity area.

> moves on to the next scheduled procurement area. Such a strategy could be expected to create a great deal of redundancy in the archaeological record—an endless series of small, residential camps from which daily hunting-and-gathering parties move out over the surrounding landscape, returning to process and consume the acquired foods each evening. If the resources were randomly distributed, all the sites would look generally the same. But since many resources appear in the same place year after year or in some other cyclical pattern, some sites tend to be reoccupied.

Under a serial foraging model, all sites in the Loco Hills region would reflect small, mobile groups performing similar activities. Differences in site size, artifact density, and feature occurrence would not be the result of differences in the nature of group composition or site function but instead would reflect the distribution and availability of particular plant and animal resources and the resultant duration of occupation and likelihood of reoccupation. The probability surface map, under this scenario, could be viewed as a prehistoric resource use map.

During the subsequent Ceramic period, settlement may have become more complex (Sebastian 1989b:82–83). Groups practicing agriculture or focusing on intensive use of succulents or acorns may have established seasonally permanent sites, although they probably never achieved year-round permanence. These base camps would have housed larger groups who were practicing a wide range of domestic and economic activities. To guard against crop failure, these groups would have foraged far afield, gathering plants and hunting animals in the surrounding region, including Loco Hills, and creating small sites consisting primarily of artifact scatters. Alternatively, hunters-and-gatherers and agriculturalists or groups specializing in other resources may have coexisted 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 or resources suitable for intensification, with small, impermanent camps located at or near targeted wild resources.

The archaeological record of these and other possible 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 more structured base camps? Detailed surface mapping and analyses of distribution patterns of the artifacts and features could inform on these issues, although definitive answers would require data obtained via controlled excavation.

As for the relatively small sites found in the low sensitivity zones, superficially 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 limited research potential and would not be considered eligible for listing in the National Register of Historic Places under criterion d on an individual basis. Even if they are eligible as a class, it is likely that data recovery will be needed at only a few before their research potential is exhausted.

Table 5.3. Prehistoric Site Data for a Sample from High and Low Model Sensitivity Drawn from the Reclassified Logistic Regression Model

	Low Sensitivity	High Sensitivity
Number of prehistoric sites	36	101
Average site size	19,038 m^2	173,107 m^2
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 fire-cracked rock 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

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 base camps? 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 postdepositional 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 twentieth-century land use. The underlying parent sand sheets of the two types of dunes are different, 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 have 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 occurred on the sand sheets beneath the two recent landforms, we would expect to find more archaeological sites exposed on the surface within coppice dunes than in parabolic dunes.

This raises a third point about the meaning and significance of sites in low probability areas, particularly the parabolic dunes. If sites are, in fact, more rare in the parabolic dunes, and if they are more protected from erosion and thus have greater integrity, both factors would make them more likely to yield important information about the past. Low sensitivity zones should not be read to mean “not eligible to the National Register.” The relationship between sensitivity modeling and significance in cultural resource management is more complex.

Such observations beg the question, “Are the differences in the archaeological record simply due to visibility?” Examining the distribution of sites relative to the two types of dunes provides mixed results. As noted above, the two geomorphic surfaces appear similar with regard to many environmental variables. For example, the average slope for coppice dunes is 1.56º, whereas it is 1.51º for parabolic dunes. It is striking, therefore, that the two landforms diverge dramatically in their distance to water. Coppice dunes average 902 m from water; parabolic dunes are found at an average distance of 1,505 m from water.

Given the importance of water to human settlement in the region, we cannot simply dismiss the difference in site distribution between coppice and parabolic dunes as being a result of surface visibility. To determine the causes of variation in the archaeological site distribution will require more in-depth study, relying particularly on excavation data to assess issues of site function and integrity. To many, such a conclusion will be anticlimactic. Didn’t we know this already? Can’t predictive models do better than this?

We believe such questions, though common, miss the point. Predictive models like the ones presented here for Loco Hills are regional in scope. They are designed to assist in discerning large-scale relationships between archaeological sites and mappable environmental features. They are based on measurements of environmental data taken at a relatively crude scale and use archaeological data of dubious quality. Therefore, it is unreasonable to expect such models to discern anything but the most robust patterns in the distribution of archaeological sites.

Predictive models, however, can assist in tailoring excavation projects that address questions posed at finer scales. For example, it is a common refrain among archaeologists in southeast New Mexico that excavation is needed to further our understanding of issues of site function and regional chronology. But which sites need to be excavated? Most archaeologists would focus on those sites with obvious research potential, such as rockshelters with thick cultural deposits of good integrity. These are not the types of sites, however, that are found in Loco Hills. Instead, we need to focus on sites threatened by current and future development. Can these sites assist in answering regional research questions, and if so, which sites and which research questions?

It is here that predictive models can be of great utility. The Loco Hills models can assist in selecting sites from different environmental settings, such as a controlled group from coppice and parabolic dunes that will assess the nature, integrity, and ultimately, the research potential of sites in these landforms. By linking sites and their settings to regional interpretations, we can not only learn about the past but also offer managers useful information on the basis of which resource decisions can be made. If, for example, 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 area must take into account these differences. Predictive models represent one step in this research process. But they are only one step.

The failures of the past in using models often revolve around assuming models can answer fine-scale questions, such as, will this location contain a site? Models built on regional data cannot answer this question satisfactorily. Instead, models are useful because they provide a snapshot of a region and as they are refined over time, provide benchmarks that can be used to assess whether additional data are leading to a stronger correlation between environmental variables and the archaeological record. They can assist in focusing surveys and tailoring excavation projects. If viewed as part of a process whose goal is understanding and managing archaeological resources, then models are worth the time and effort needed to create them. If the expectation is that models by themselves will provide management answers, then all parties will be disappointed.

Modeling and Management

Evaluation of our predictive models demonstrated that they were reasonably successful in predicting the locations of surface-visible archaeological sites based on the correlation of site locations with a variety of environmental factors. The point of this project, however, is not prediction for its own sake, or even modeling as a means of understanding human behavior in the past. The goal of the New Mexico PUMP III project is 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 chapter 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. Chapter 9 will discuss in detail the management implications of the Loco Hills, Azotea Mesa, and Otero Mesa studies and provide recommendations for more efficient and effective cultural resource management strategies.

Model Stability

Our first approach to evaluating the effectiveness of current cultural resource management practices for Loco Hills was to address 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 collecting more archaeological data in the same ways would permit us to continue refining our model. 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 as strong a predictive model as possible based solely on environmental variables.

The predictive models developed here make the simplifying assumption that indigenous people located their activities on the landscape largely in response to the distribution of resources. If this assumption is correct, once the model stabilizes, the predictions should be fairly accurate. If the placement of activities was based primarily on cultural values, such as proximity to villages, shrines, or hostile groups, however, the model might become quite stable and still be a poor predictor of site location. It is important, therefore, to have independent sources of model verification, such as blind surveys, and potentially to develop theory-based models of settlement that explain the results prior to using the models in the management of resources.

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 accurate 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). We chose 1985 as the start date because by that time approximately 10% of the 62,875 acres covered by 2002 had been surveyed. This total had risen to 20% by 1991, 30% by 1995, and 55% by 1998.

When the models were run and mapped, we found that, visually, there was little difference among them. Figures 5.14 and 5.15 show the models based on the data available in 1986 and in 2002 data (already shown above in Figure

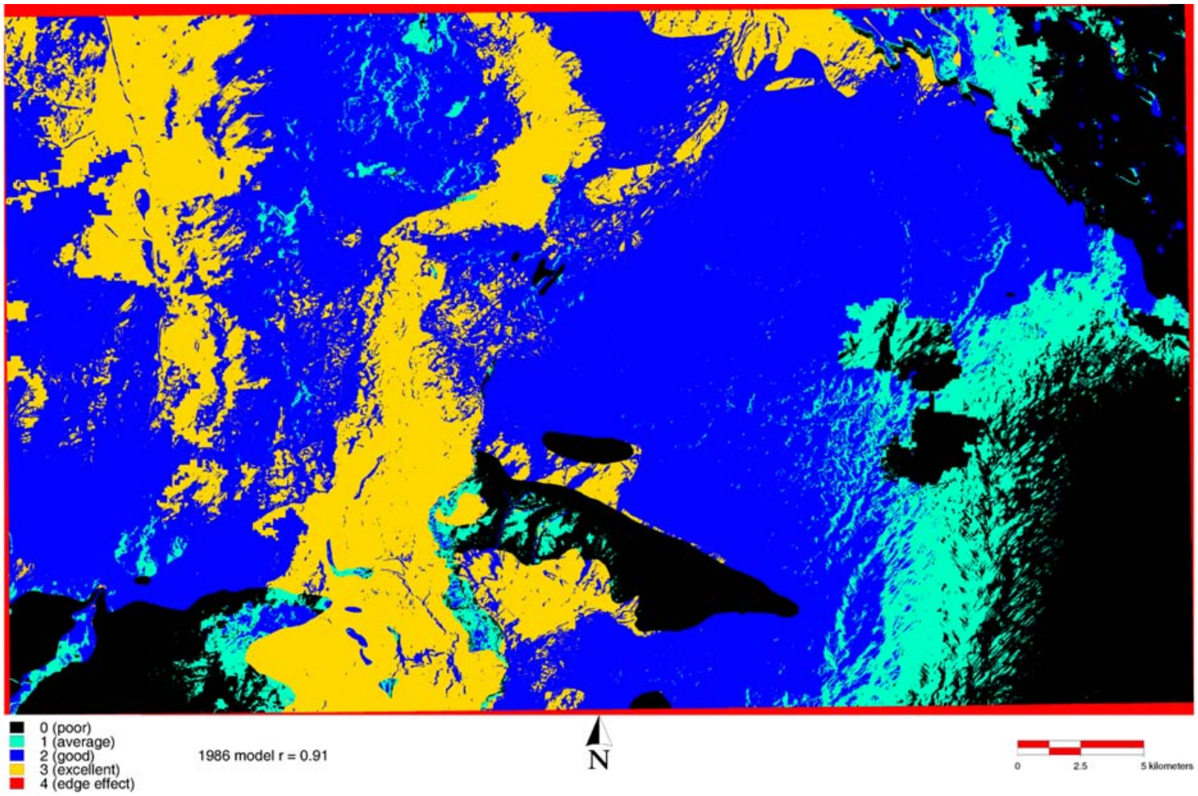

Figure 5.14. Logistic regression model created using prehistoric site data prior to 1986.
The correlation score is the relation to the 2002 model. The red areas are outside the study area.

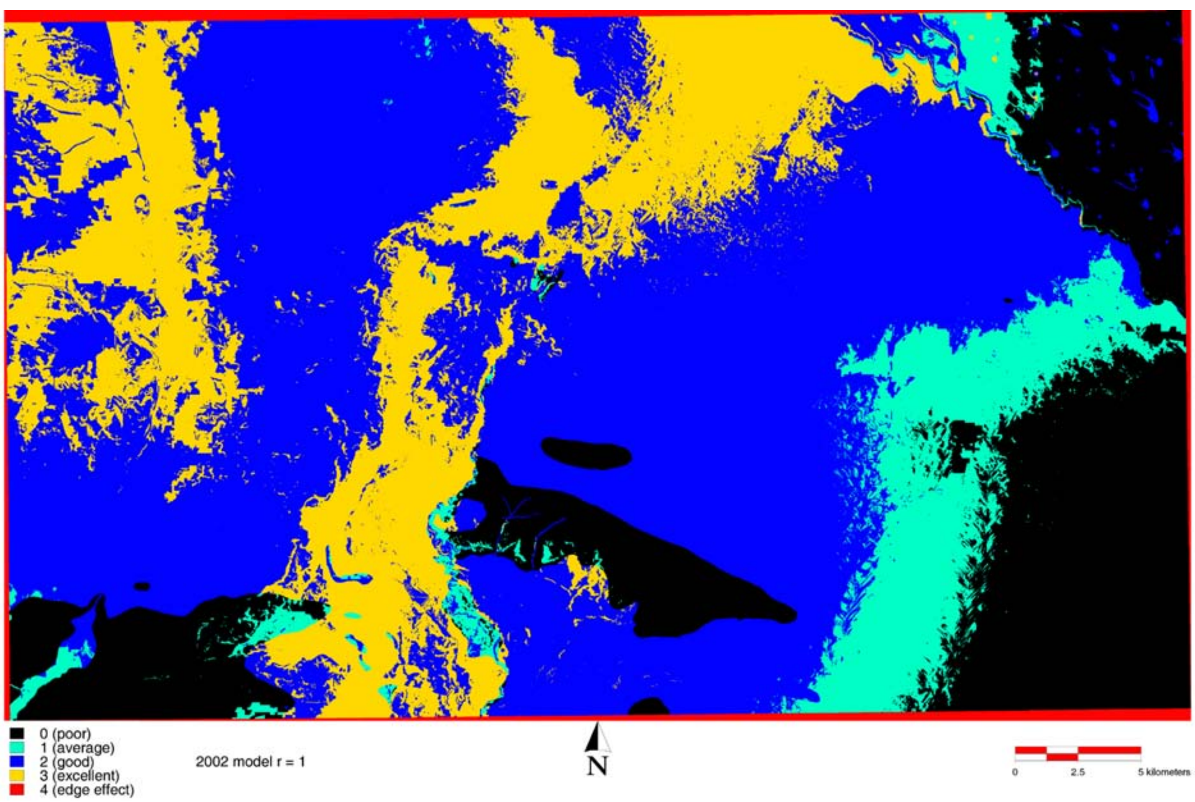

Figure 5.15. Logistic regression model created using prehistoric site data prior to 2003. The correlation score is 1 because this is the 2002 model against which the others were compared. The red areas are outside the study area.

5.11). 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 5.16 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 pattern of site locations in relation to the Loco Hills environment after only 10% of the region had been surveyed.

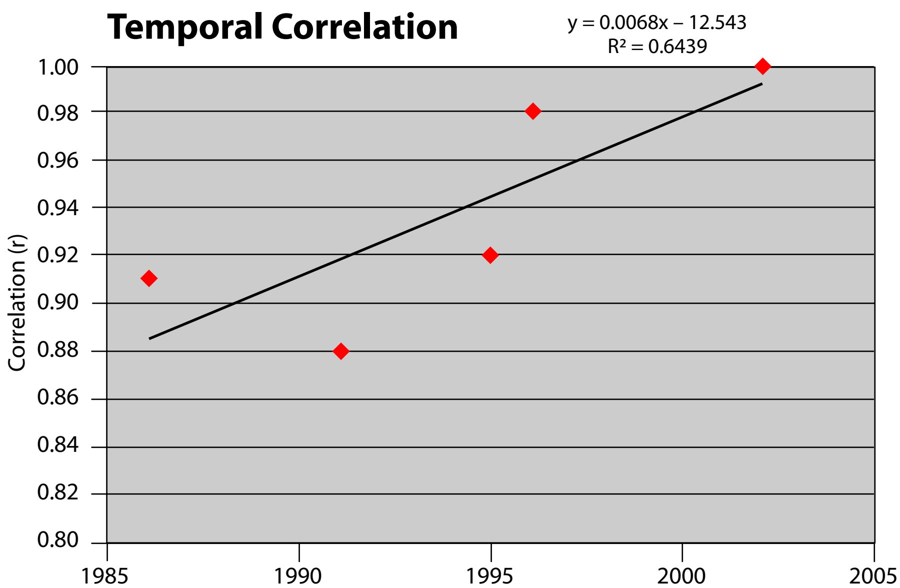

Figure 5.16. Correlation of each logistic model by year to 2002.

Inventory Reconstruction

In the previous section, we demonstrated that the structure of the logistic regression model of archaeological site location stabilized very early in the development of the Loco Hills field. Areas highly likely to contain sites could have been differentiated from those less likely 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 carrying out the same kinds of cultural resource identification efforts, and whether we would have managed either the energy development or the cultural 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 distribution relative to environmental variables are quite strong, the complexity of the statistical techniques makes it difficult for the non-statistician to assess how much faith should be placed in the results.

In this section, we provide a more intuitive and simpler means of making this assessment. Using the dates when surveys were conducted and sites were recorded, we reconstructed the history of archaeological inventory in the Loco Hills study area. Then we examined this history to determine when, in an ideal setting, we would have been able to recognize that we were not learning significantly more about site distribution.

At first glance, the inventory reconstruction seemed simple. The ARMS staff had digitized and entered associated attributed data for 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 surveyed 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% of the estimates. We then examined the annual history and determined 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.

Figures 5.17 and 5.18 demonstrate the problem. These two figures show a small portion of the study area which, though somewhat more intensively inventoried than the majority of the area, is by no means exceptional in its complexity. Figure 5.17 shows the raw data 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 portion of a site was recorded during any particular survey event. In this example, the large number of coincident boundaries is the result of one large site being repeatedly recorded to differing extents.

To circumvent 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 set. Figure 5.18 shows surveys within the same small portion of the study area, coded by year, and Figure 5.19 shows a time sequence of cumulative survey, aggregated by year, within the whole study area.

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 that was taking place each year. The magnitude

Figure 5.17. Examples of survey and recording episodes.

Figure 5.18. Example of survey coverage aggregated by year.

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 (19.25% of the study area) were actually inventoried; the 12,348-acre difference results from resurvey. More than 19 sections of land were resurveyed over the years. A quick look at Figure 5.20 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. We want to be clear. We are not suggesting that resurvey per se is a bad thing—in an active geomorphic environment like Loco Hills, purposeful resurvey is an important management tool. But resurvey should be the result of a management decision, not of an endless, uncontrolled series of inadvertent overlaps and do-overs.

Figure 5.20 graphically displays the history of survey in the Loco Hills study area with special attention to this issue of resurvey. For each year there are three bars, one representing the reported number of surveyed acres, one representing the reported acreage minus the overlapping surveys within that year, and one representing the actual new ground surveyed with all overlaps removed.

These data allowed us to calculate site density (site acres per surveyed acres) using two different methods. Method I (Figure 5.21) is based on survey as it was actually performed. In this analysis, sites that were recorded more than once

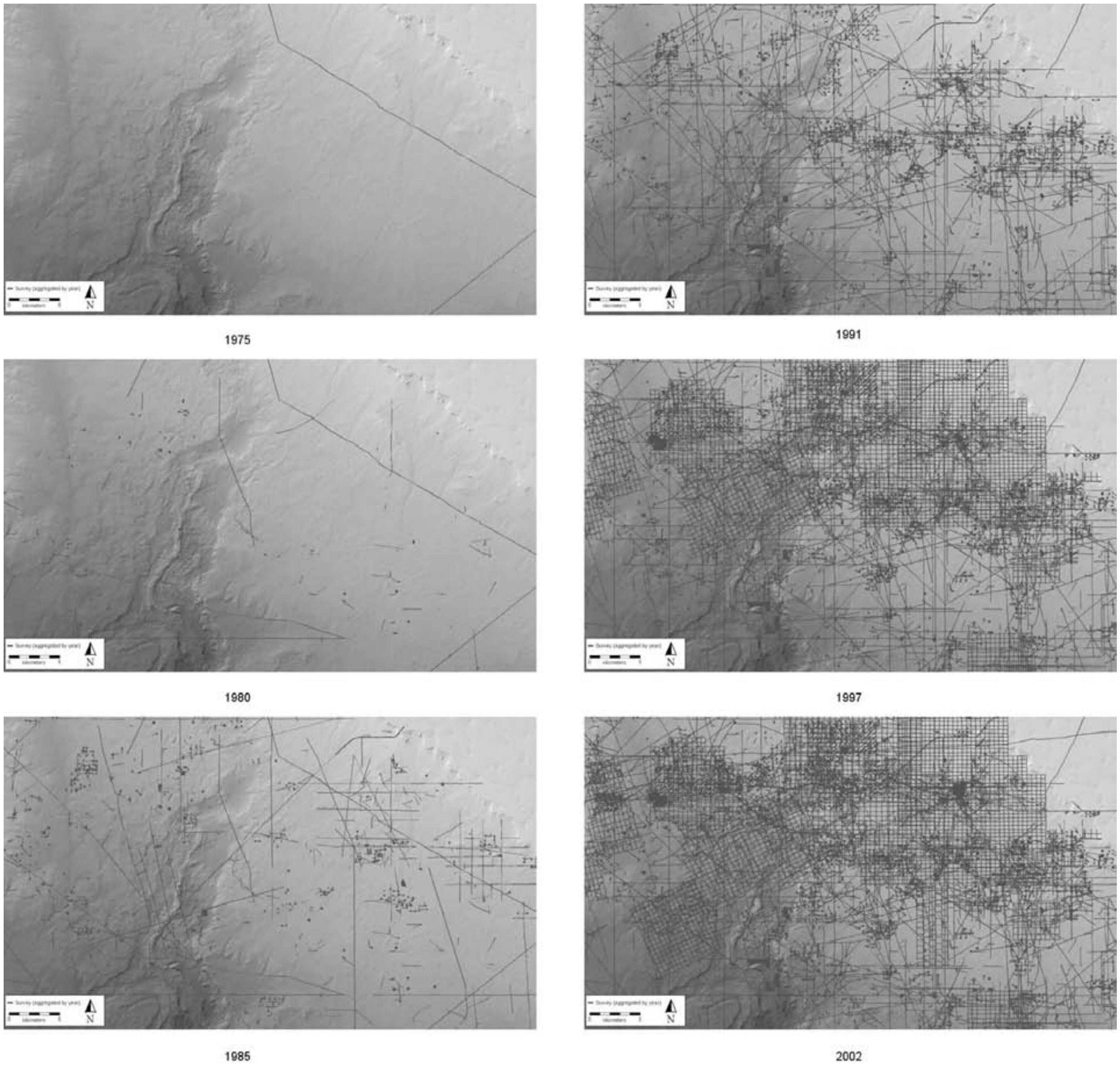

Figure 5.19. Time sequence for cumulative survey in the study area, aggregated by year.

and areas that were surveyed more than once in different years are included in the calculations for *each* year that fieldwork took place. The site density figures in Method I, therefore, are inflated. Method II (Figure 5.22) eliminates 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. It is important to note that one of the products of the overall PUMP III project is a computerized system (the pilot being developed for portions of Wyoming) that allows data to be recorded in real time. The calculation of site density as well as other similar descriptive statistics should move from Method I to Method II in the near future.

For each year represented in Figures 5.21 and 5.22, we present an annual site density and a cumulative running site density. The first bar (gray) for each year presents the site density calculated by dividing the number of site acres recorded in that year by the number of acres surveyed in that year. The second bar is cumulative density, and it is calculated by dividing the total number of site acres recorded up to the end of the year in question by the total number of acres surveyed up until that time. The second bar is shaded either light gray or black, depending on whether it falls

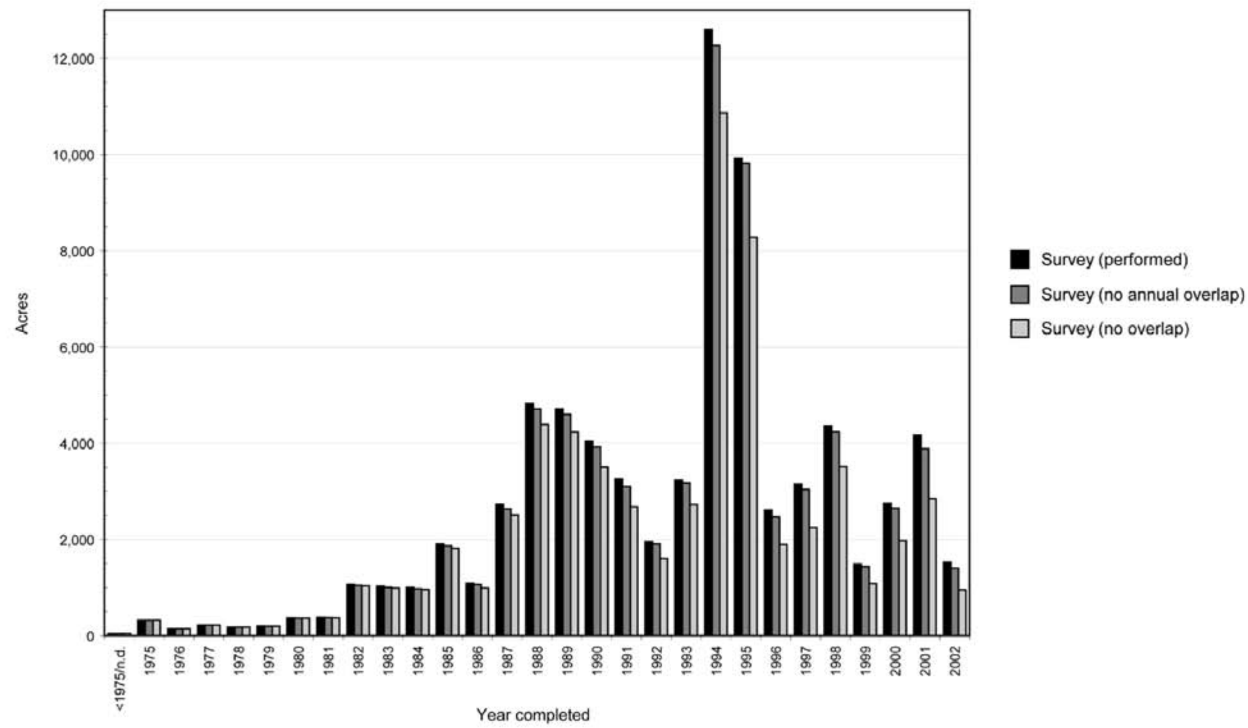

Figure 5.20. Annual survey statistics.

outside (light gray) or inside (black) the 95% confidence intervals. Visually, we expect to see fluctuations in annual density throughout the sequence, whereas the cumulative site density figure should vary early on and then stabilize as the proportion of the study area surveyed becomes larger.

The results of the annual site density analyses meet our expectations but are intriguing nonetheless. 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; it may 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% 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 of the dataset. In contrast, under Method II the running site density stabilizes much earlier, around 1984, and only falls out of the 95% confidence intervals in two of the 19 years in question.

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

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 survey locations have historically been driven by the patterns of oil and gas development.

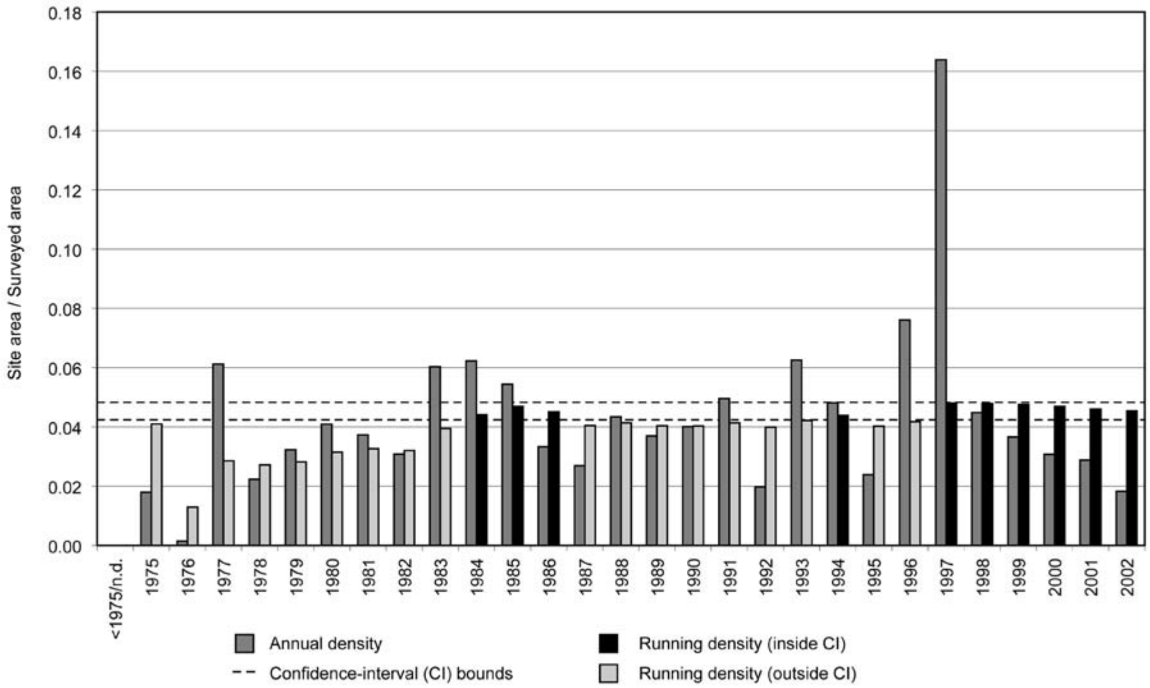

Figure 5.21. Overall site density, Method I.

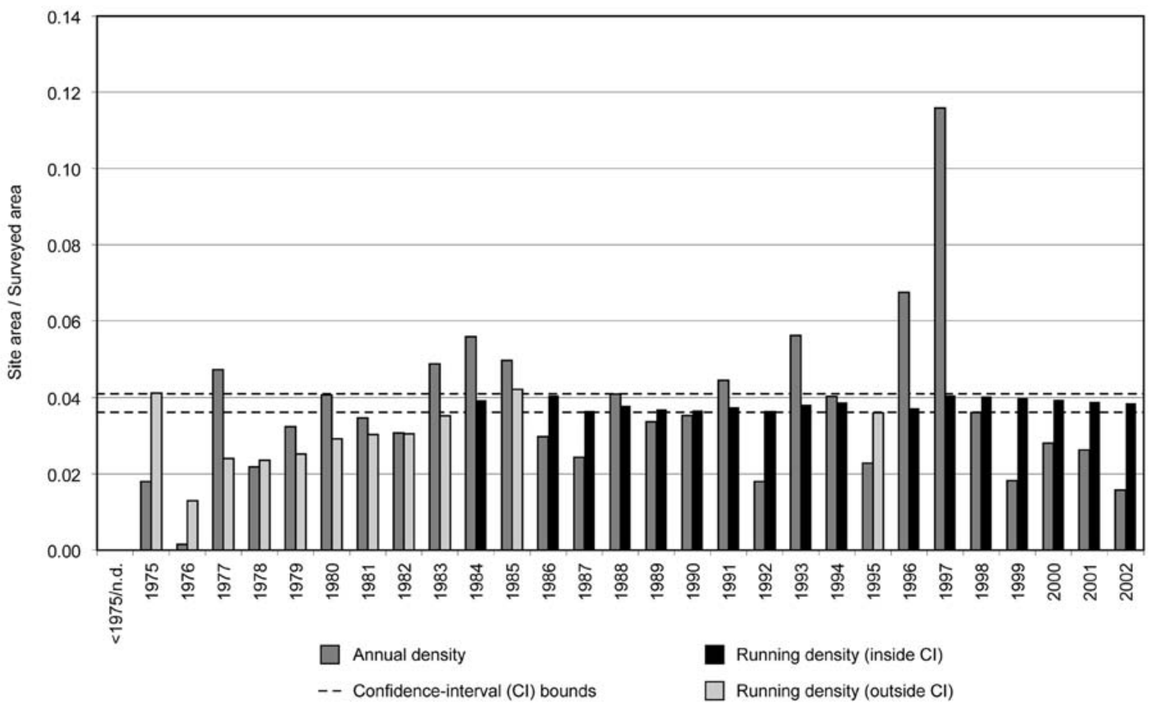

Figure 5.22. Overall site density, Method II.

The logistic regression models and site density results presented 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. Based on a visual inspection of the 2002 survey map shown in Figure 5.19, 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% 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. Thus, narrowly spaced linear surveys appear to cover more ground than was actually examined in the field.

Nonetheles, 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 virtually as much as we know now about the distribution of the surface manifestations of the archaeological record well before even the 20% level of survey coverage was reached. How is this possible? One reason is that oil and gas development is often preceded by seismic testing, which involves 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 crosscut the various environmental zones represented in the study area. Because human settlement is 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 when only a relatively small percentage of the study area had been inventoried.

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 5.21 and 5.22) 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 actually conducted, overlaps and all—and uses data on the total amount of surveyed acres and the reported number of archaeological sites. If we assume a management standard that defines "stability" as five years of stable trends, then confidence in the site density estimate would not be reached until 2003. This assessment seems reasonable given the relatively wide annual fluctuations in site density in the late 1990s. In contrast, applying the same management standard using Method II, reliable density figures would have been available by the end of 1990.

Managers could have performed the same calculations of site density as presented above in real time. Although the cumulative site density figure would change on an annual basis, it would have reached five-year stability in the early to mid 1990s. These results, 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 by the mid 1990s as we have today, despite the large amount of additional archaeological survey since that time.

Management Implications

For all the survey that has been completed in Loco Hills, our understanding of the prehistory of the region has not dramatically increased, and this is not an academic issue. Time and money are being spent on efforts that neither advance our ability to manage cultural resources nor improve our ability to balance resource protection and energy development. One of the purposes of cultural resource surveys in Loco Hills is to meet the BLM's legal obligation under Section 106 of the National Historic Preservation Act to identify historic properties that may be affected by oil and gas development, and the 5,196 surveys between 1975 and 2002 have met that need.

There is more to Section 106 than identification, however. The agency is required to determine whether properties are eligible to the National Register of Historic Places, for example. But BLM still has difficulty making this determination with any confidence, even with all the survey data from Loco Hills, so as a matter of good stewardship BLM must err on the side of calling too many sites eligible. Projects are delayed, redesigned, moved, and moved again to avoid sites that may or may not truly have the potential to yield important information. In part, the difficulty with determinations of eligibility is a result of so little effort having gone into studying the relationship between surface cultural manifestations and subsurface cultural deposits. Then, too, the absence of regional research designs or historic contexts means that property types eligible for the National Register have not been defined. Thus, we cannot readily evaluate the sites already recorded or even be certain that sufficient data are being recorded.

Equally to the point, Section 106 is not BLM's only legal mandate concerning cultural resources. Since cultural resource identification efforts are being paid for by the American people, either directly through tax dollars appropriated to the BLM or indirectly through the pass-through costs of energy products, these surveys should also be contributing new or improved management information needed to meet BLM's responsibilities under Section 110 of the National Historic Preservation Act, the National Environmental Policy Act, and other mandates. Simply finding sites, and finding the same sites over and over, is not enough. The models and inventory reconstruction suggest that elements of site distribution are known for the Loco Hills area, and could have been known for some time. In the absence of a parallel interpretive regional analysis, however, no amount of data collection will move cultural resource management forward.

Several lessons for cultural resource management in southeastern New Mexico have been suggested by the results of our inventory reconstruction and modeling efforts. First, oil and gas development, although not a random process, is conducted in a way that provides reasonable data for the creation of predictive models that associate human settlement with environmental features, especially when linear arrays of seismic tests or pipelines are producing a substantial portion of the data. Despite the appearance of the maps showing surveyed space, however, only approximately 20% of the actual ground surface within the Loco Hills study area has been surveyed.

Second, there has been a great deal of re-survey of land and re-recording of sites in the Loco Hills study area. Cumulatively, more than 75,000 acres have been surveyed, of which about 12,500 acres represent areas that have been surveyed more than once. Approximately 1,625 sites have been recorded, and of these, 508 have been recorded more than once. By any measure, the history of archaeological investigation is one of inefficiency. The overlapping nature of the development, combined with the current, case-by-case approach to inventory, makes a certain amount of duplication unavoidable, but the magnitude of the duplicated effort was surprising.

Third, 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% of the land in the Loco Hills study area had been inventoried. At approximately that point, site density analysis would have indicated that our understanding of where sites are located had stabilized, and predictive modeling would have indicated which environmental variables and values were strong predictors. Because there has been no mechanism for synthesizing previously acquired survey data, cultural resource managers neither have been able to use previous data to limit duplication of effort nor had available models and other tools to focus management and preservation efforts.

Fourth, our understanding of the past has not increased proportional to the amount of survey or the number of sites recorded. The research questions posed for southeast New Mexico prepared in the 1980s have still not been addressed (Sebastian and Larralde 1989). Our knowledge of the archaeology of Loco Hills is rudimentary. We do not know if the sites visible on the surface reflect the distribution of archaeological deposits; we are no closer to understanding prehistoric adaptation.

How might we have done things differently? An obvious answer, but a difficult one to implement, given the nature of oil and gas development, is that a systematic inventory completed prior to all development would have eliminated all duplication of survey and site recording efforts. This level of information on cultural resources is not necessary, however, for effective management. If surveyed space data and GIS or other sophisticated data management technology had been available from the beginning of development in Loco Hills, the BLM would have been able, as early as 1990, to make informed decisions as to where, within a lease or set of leases, energy-related development should be concentrated and what areas should be avoided in order to minimize both immediate and, especially, cumulative, long-term effects to cultural resources. Decisions could have been made about where archaeological inventory efforts should be intensive and where they could be less intensive, and some, though by no means all, of the overlapping, duplicative efforts could have been avoided.

These approaches would have provided both better cultural resource management and greater cost-effectiveness for oil and gas development, but they would only have eliminated duplication; they would not have answered our questions about buried sites or cultural adaptation or enabled us to make better decisions about the significance of archaeological resources. Currently, decisions about the scientific importance, and thus the National Register eligibility, of archaeological sites in southeast New Mexico are based almost entirely on surface manifestations. Given the active geomorphic setting and the relative lack of excavation data, these decisions tend to be extremely conservative: we don't know enough about the integrity and data potential of these sites to know which ones have the potential to yield important information and which ones do not.

To address these issues, we would have to drastically change our objective from simply documenting surface-visible archaeological sites and avoiding them to determining and understanding the nature and distribution of archaeological sites and deposits. We have enough information now to model basic settlement patterns. Our challenge is to build a better survey—one that will provide management information in addition to simply finding sites. We need to implement adequate subsurface testing as a standard part of site evaluation. We need to assess site formation and site destruction processes along with documenting the cultural content, so that we can determine the information potential of deposits underlying surface sites. In this way we can begin 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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CHAPTER

6

Results and Discussion: The Azotea Mesa Study Area

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The Azotea Mesa study area (Figure 1.2) is rectangle covering approximately 1,200 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 the approximate 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 Azotea Mesa study area vary from about 1,700 meters (5,600 feet) in the southwest to 950 meters (3,100 feet) in the northeast; the edge of the Pecos Valley escarpment is at about 1,200 meters (3,950 feet).

The Predictive Models

As discussed in Chapter 4, the premise of the modeling component of the Pump III project is that human behavior is patterned, and that decisions about where to locate activities on the landscape are likewise patterned. These patterns are conditioned by a variety of influences, many of them environmental. The archaeological remains of human activities should, therefore, be correlated to some degree with environmental features.

The Azotea Mesa study area does not represent an ideal setting for predictive modeling because it incorporates relatively little environmental diversity and consists mostly of eroded bedrock surfaces. Soil is thin and dissected by a braided network of small drainages that ultimately feed two larger, east-flowing washes. Much of this area would have been 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 two possibilities: If indigenous people were specifically targeting resources in the study area, they would most likely have established short-term camps at or near specifically targeted resources, exhausted those resources, and then moved on to another similarly situated camp. Alternatively, this portion of Azotea Mesa may have contained a variety of travel routes between the relatively resource-rich river valley and uplands; in this scenario, small patches of useful resources would have been exploited opportunistically by groups and individuals who were otherwise simply passing through.

Either of these alternatives would be consistent with the nature of the archaeological resources recorded during surveys that have been performed in conjunction with lease development in the Azotea Mesa oil and gas field. The vast majority of the 550 recorded archaeological sites 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 immediate management goal for this project is to determine where cultural resources are most likely to be found so that informed decisions can be made about development locations. In our modeling efforts, we have attempted 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 their predictive power is increased.

Environmental Data

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.

Elevation, for example, would not have been a factor in decisions by indigenous people about where to locate camps and other activities, but vegetative communities would have been an important factor in such decisions. Because elevation is strongly correlated with vegetative communities in southeast New Mexico, it can be used as a proxy for vegetation in models attempting to predict site location.

We began the modeling component of the Azotea Mesa study by assembling data on a variety of environmental variables that may have affected the decisions that people in the past made about where to locate their activities. 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). Predictive models are only as good as the data upon which they are based. The use of regional environmental data with crude resolution along with cultural data of variable quality means that the resulting models are not precise predictors of actual site locations, but are better viewed as indicators of regional trends in site distribution.

Once again 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 × 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. 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 6.1. As described in Chapter 5, IDRISI uses the DEM, a primary theme, to produce secondary themes, such as slope (Figure 6.2) and aspect.

Five secondary themes were developed to display the distance from a particular cell to specific environmental variables: distance to drainages, distance to ridges, distance to drainage intersections, cost distance to drainages (drainage 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 drainages and ridgelines (Figure 6.3). From this layer, the GIS then computed the shortest distance from each cell to the closest drainage or ridge line. Distances from major drainage intersections were also computed.

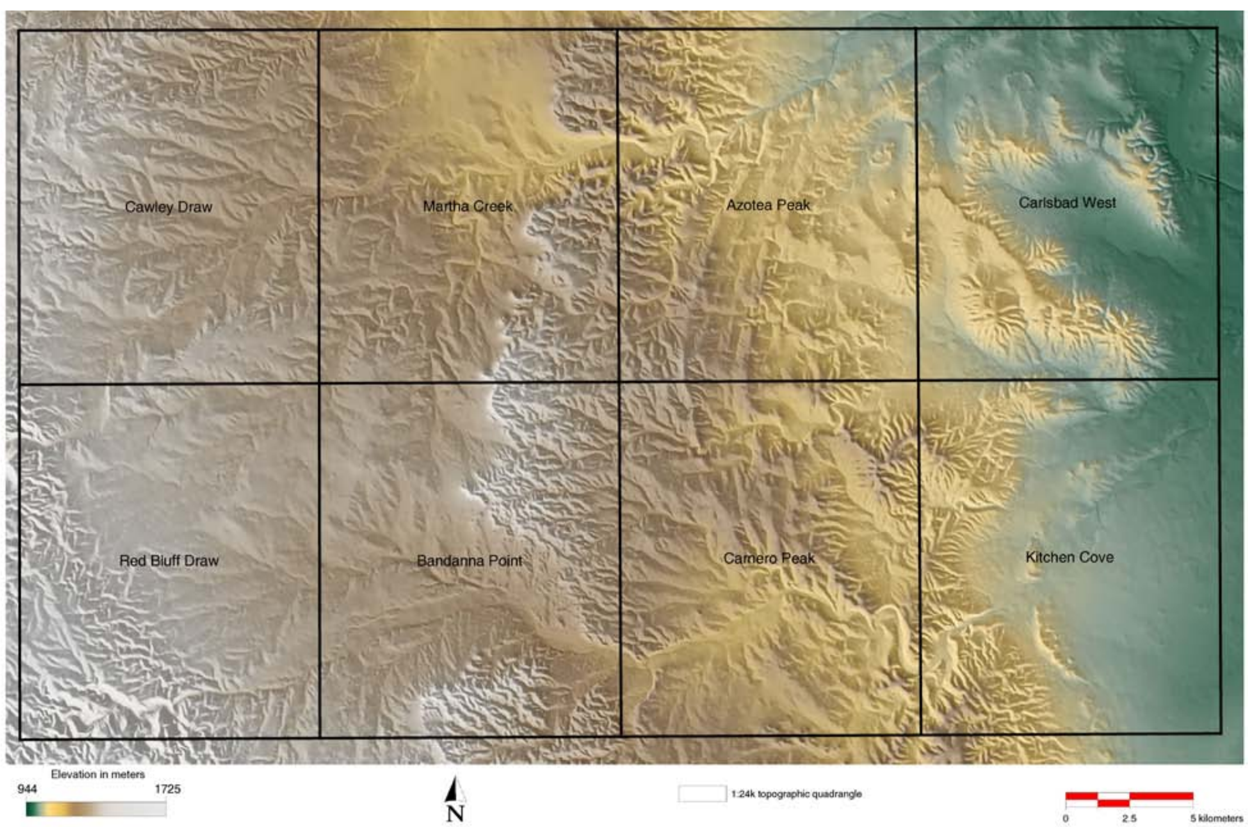

Figure 6.1. Digital elevation model (DEM) of the Azotea Mesa study area with USGS 7.5-minute quadrangles labeled. Note DEM extends slightly outside study area.

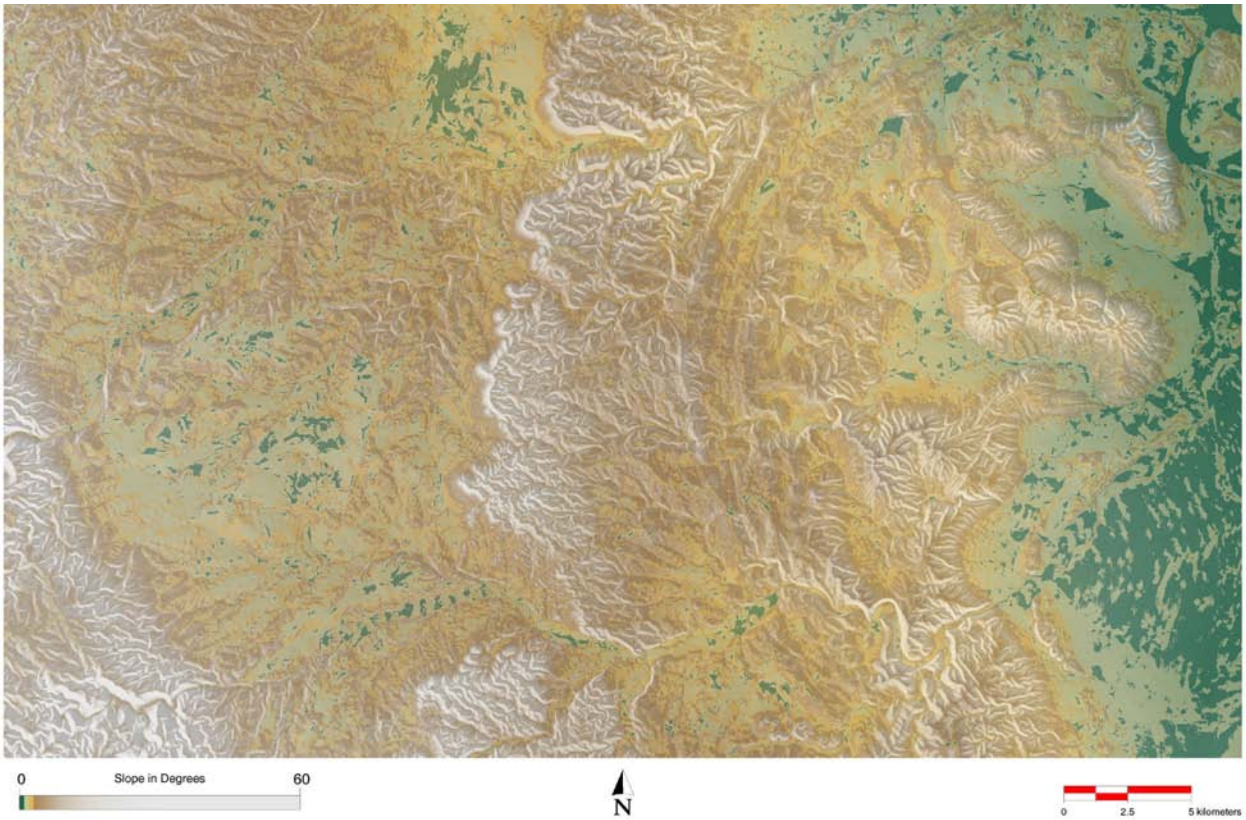

Figure 6.2. Slope in the Azotea Mesa study area.

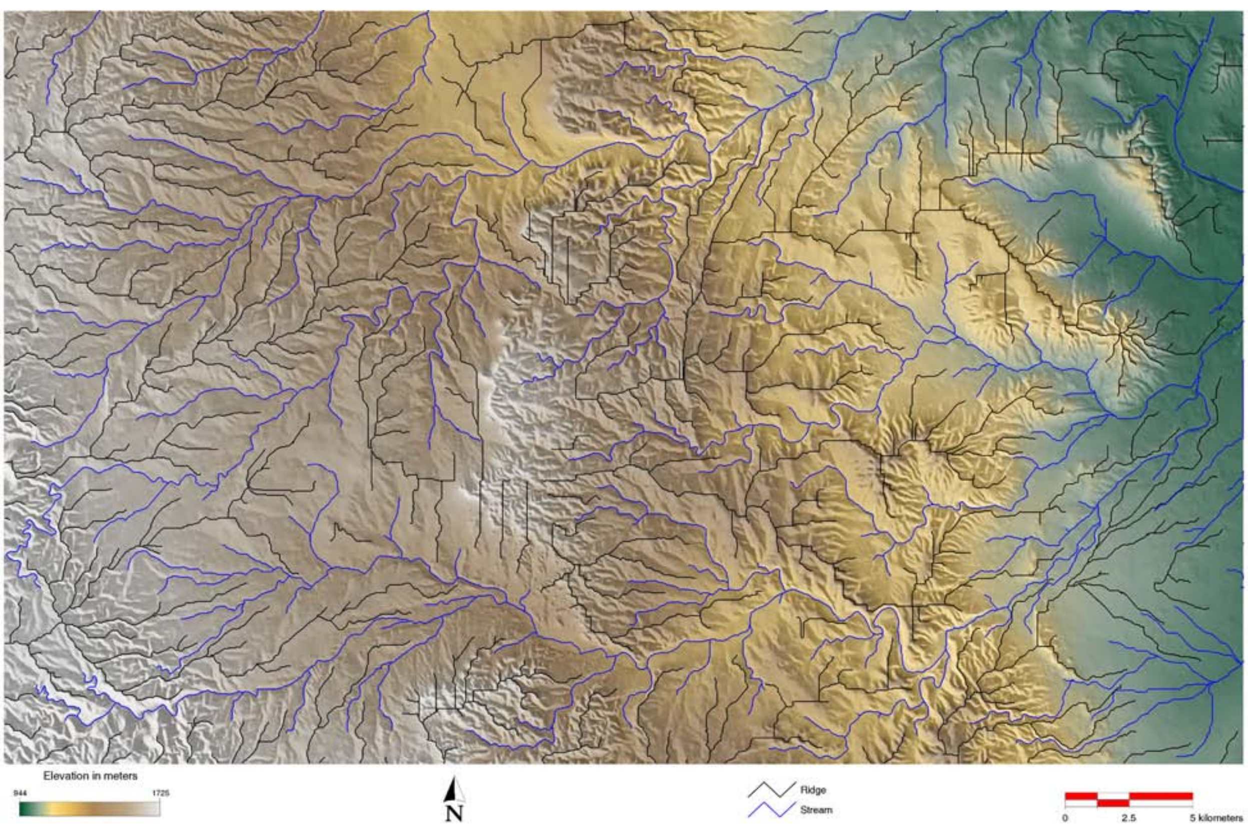

Figure 6.3.   Drainages and ridges in the Azotea Mesa study area.

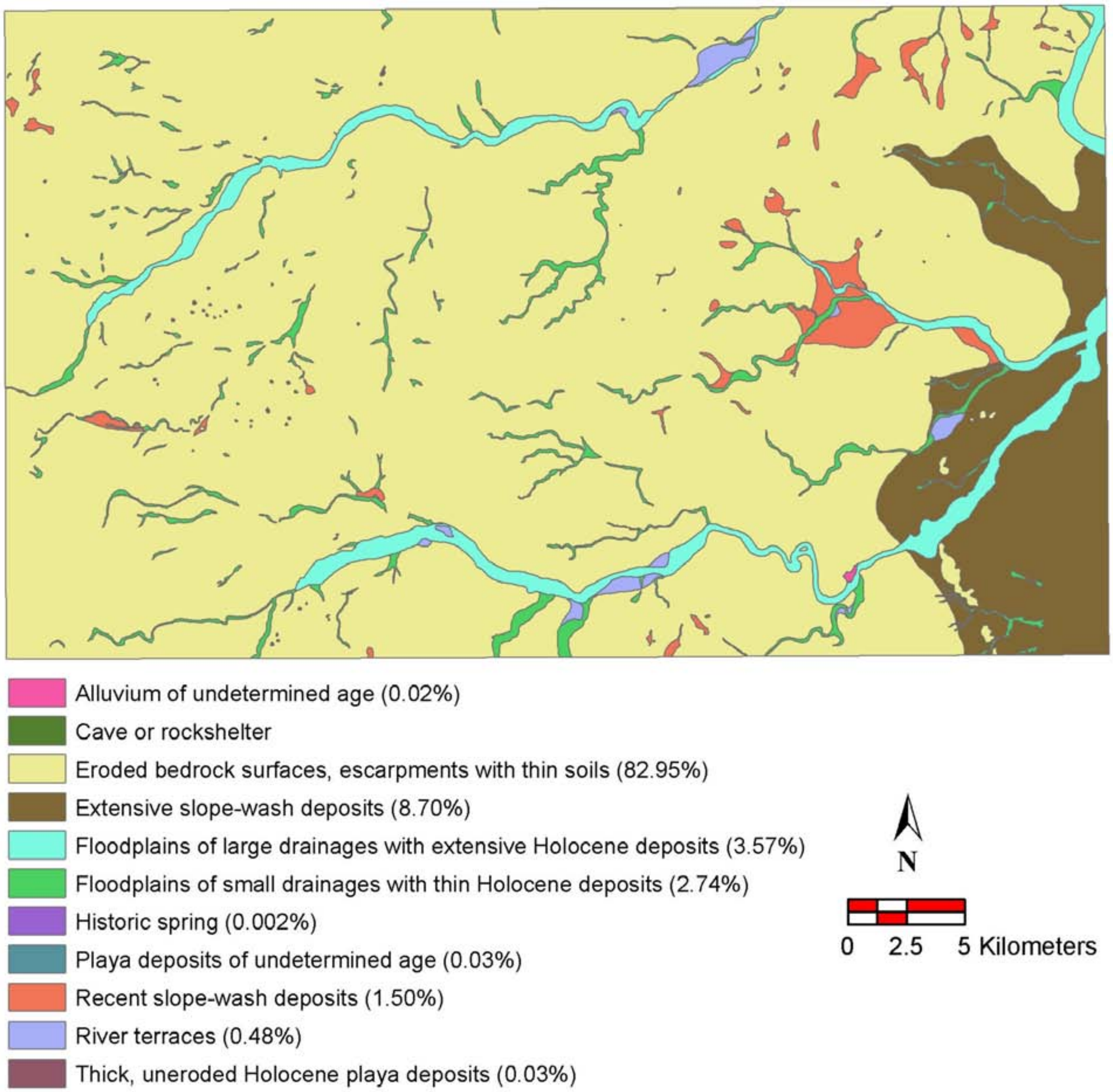

Figure 6.4. Geomorphology of the Azotea Mesa study area.

The cost distance variables use slope and distance to compute the effort required to travel between a cell and the nearest drainage or ridge line. 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.

Geomorphic Data

The geomorphology data (Figure 6.4) 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, South Dakota. Landforms were identified from the stereo aerial photographs using a Topcon mirror binocular stereoscope at 3× 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. one-tenth of an inch on topographic maps and smaller yet on the aerial photos) were not mapped.

The geomorphology of the Azotea Mesa study area 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 study area.

Eroded Bedrock Surfaces. The most prominent geomorphic characteristic of the study area is denuded limestone bedrock. The modern surface of the entire study 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 to postglacial 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, most archaeological sites away from drainages are likely to be found on the eroded surface and are not buried in soils or deposits. Thus, these sites will have near 100% visibility, although site integrity may have been impacted by erosion and other postdepositional processes.

Alluvium. The drainages 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. Although 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 are more likely to be 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 study area. The colluvium is composed of uniformly massive silt (44%), very fine sand (25%), and clay (24%) 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 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. Given the relatively recent age of the colluvium, buried sites are possible in this area.

Summary. Most of the Azotea Mesa study area is terrain characterized by denuded Permian limestone. Archaeological sites on these surfaces will have high visibility, but the integrity of artifact distributions and the preservation of features may have been impacted by erosion and other kinds of disturbance. Large and small areas of colluvium may contain buried archaeological materials, although the colluvium is likely to be strongly bioturbated, resulting in some loss of site integrity. 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 the channels and along valley margins.

Vegetation

The vegetation data (Figure 6.5) 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 on common descriptions of vegetation.

As Figure 6.5 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 is an open woodland of one-seed juniper (*Juniperus monosperma*). The gross scale at which the vegetation is mapped and the general nature of the vegetation categories do not allow us to observe or model the effects of relatively small patches of highly valued resources such as succulents or seed grasses on the location of past human activities. At best, we can only evaluate general land-use patterns related to vegetation categories.

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 the subject of 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 detailed to allow us to classify sites into temporal or functional classes. In the absence of clear temporal and functional data, we used site size to create analytical groups. This choice was based on the assumption that size could be an indicator of differences in site function, length of use, and/or the number of times a location was used. Although very

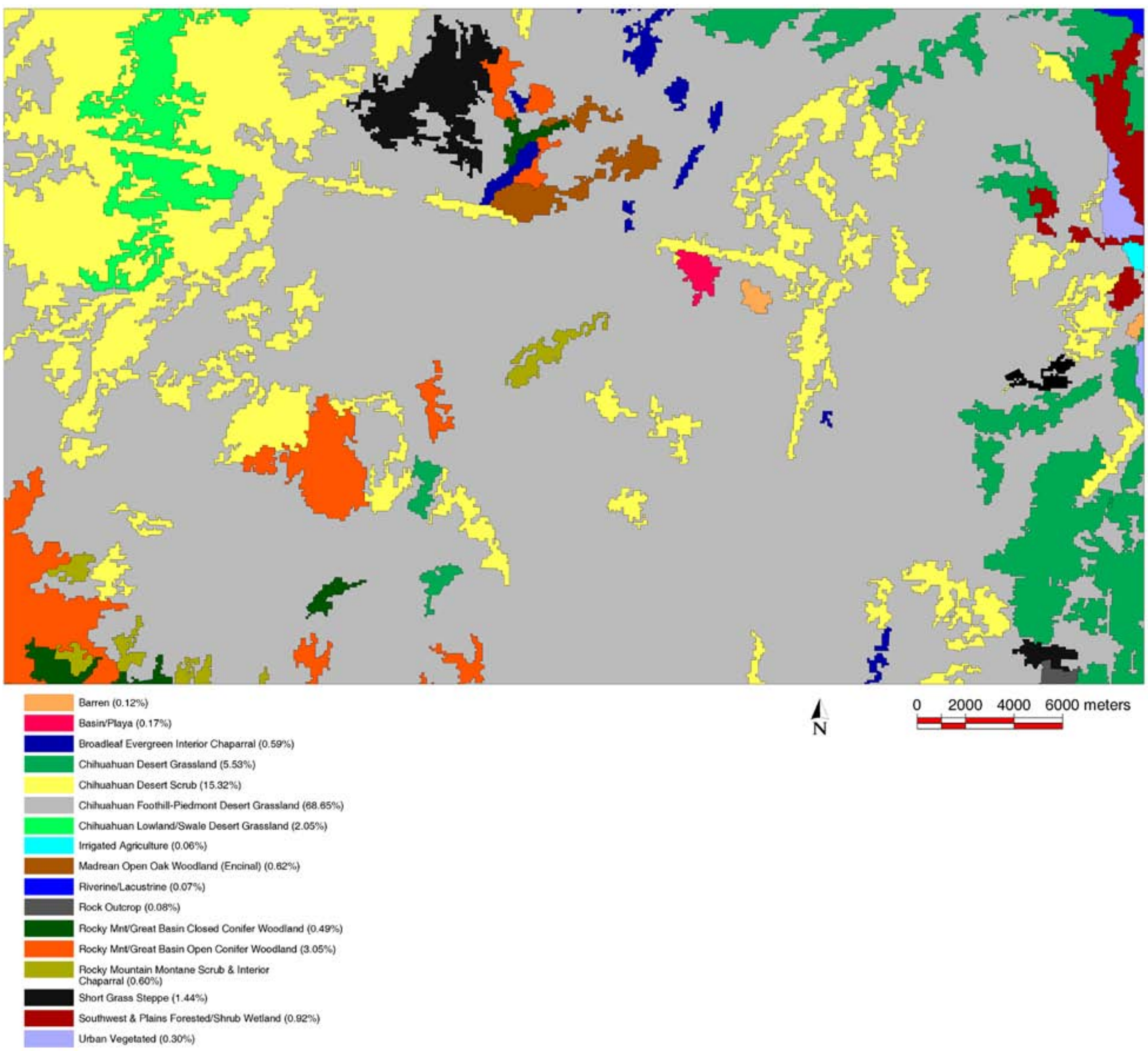

Figure 6.5. Vegetation of the Azotea Mesa study area

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, and because other sources of information are available for the later sites, we excluded postcontact period sites from the predictive models.

Site Data

The archaeological site data provided by ARMS are shown graphically in Figure 6.6. 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.

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 *x* and *y* coordinates 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, postcontact sites. The resulting 550 polygons were converted to raster format for modeling purposes. Sites were transformed into blocks of 30 × 30 m cells that encompassed each polygon. The site layer created in this fashion consisted of 12,155 cells coded with 1 when a portion of one of the sites was found in that cell and 1,610,536 cells coded with 0 when they did not contain any portion of any of the sites.

Nearly all sites in the Azotea Mesa study area data were recorded as artifact scatters. Few are described as having features, and even fewer as having 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 6.1). Ninety percent of the sites on Azotea Mesa can be classified as very small (<7 acres), with another 7% falling into the small category (8–26 acres). The sites falling into the medium class (27–60 acres) account for nearly 2.5% of the total number of sites.

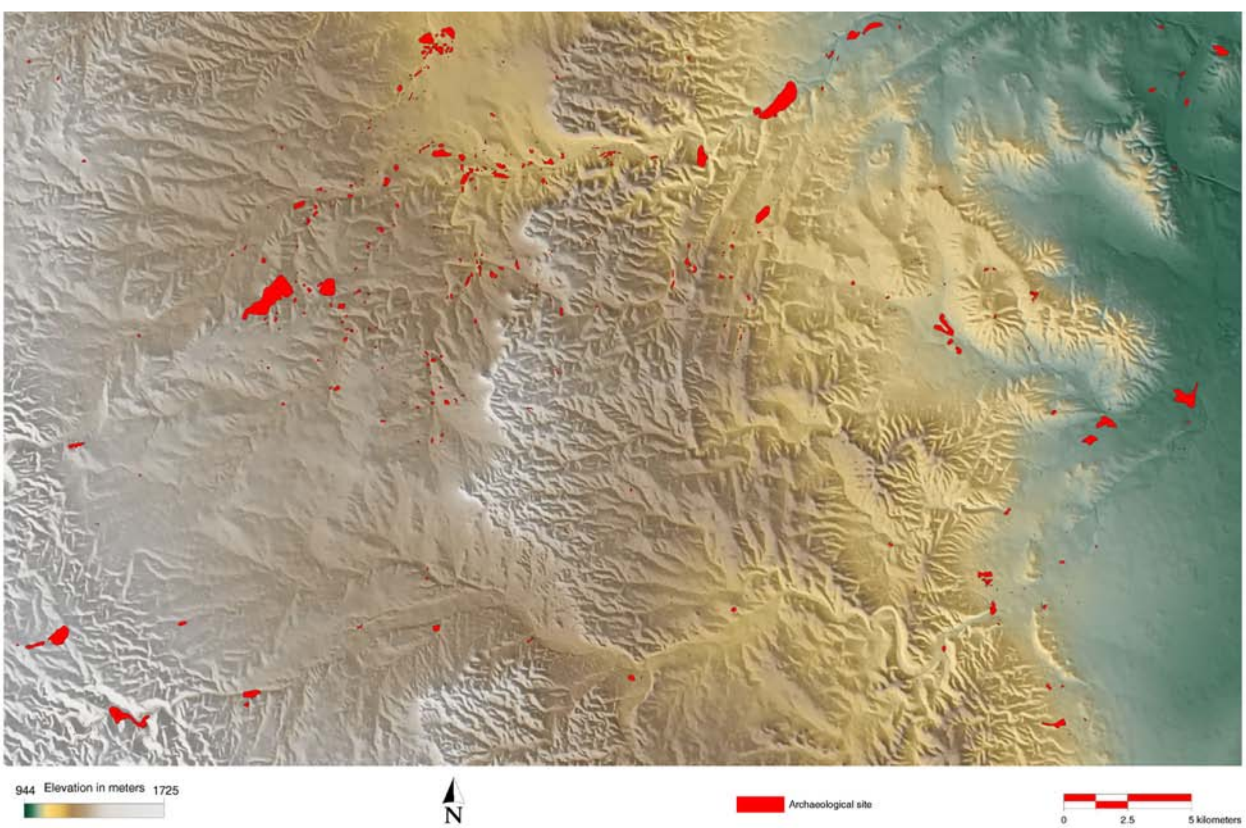

Figure 6.6. Precontact archaeological sites recorded in the Azotea Mesa study area

Very small sites represent 90% of all sites, yet they constitute less than 25% of all site cells; large and very large sites (those exceeding 61 acres), which, combined, constitute just over 1% of all sites, encompass more than 35% of all site cells. Although the “very small” site category ranges as large as 7 acres (which would cover 31 cells), the vast majority of these sites are much smaller. The average numbers of cells per site in the very small category is 5.9, or 5,310 m^2. Based on our assessment of the ARMS data, most very small sites are sparse artifact scatters.

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. 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 camp should be based on a number of factors, such as availability of potable water and flat spaces suitable for basic domestic activities. Resource procurement locations, on the other hand, should be close to the targeted resource and show less regard for factors of slope and the availability of water. Of course, other behavioral interpretations could be put forth. Our purpose here is not so much to provide an analytical interpretation as 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 initial 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.

Table 6.1. Site Classification by Size

Classification	Acres	Number of Sites	Number of Site Cells	Percentage of Site Cells	Average Number of Cells per Site
Very small	0.1–7	494	2917	24	5.9
Small	8–26	37	2188	18	59.1
Medium	27–60	13	2674	22	205.7
Large	61–100	4	1337	11	334.3
Very large	>100	2	3039	25	1,519.5
Total	N/A	550	12,155	100	22.1

Survey Data

In addition to providing 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 6.7). As with the site data, each survey polygon is linked to related information, such as area, identification number, and some basic methodological descriptions, within the vector database. The ARMS data contained information on 1,233 surveys totaling 33,960 acres.

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 locations found in the models discussed below is an accurate reflection of the relationship between environment and site locations in the larger study 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 oil and gas development; they were located without reference to environmental factors and with no attention to 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 6.7. 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 portions of the study area. It is possible, then, that strong biases exist in the sample represented by the archaeological surveys.

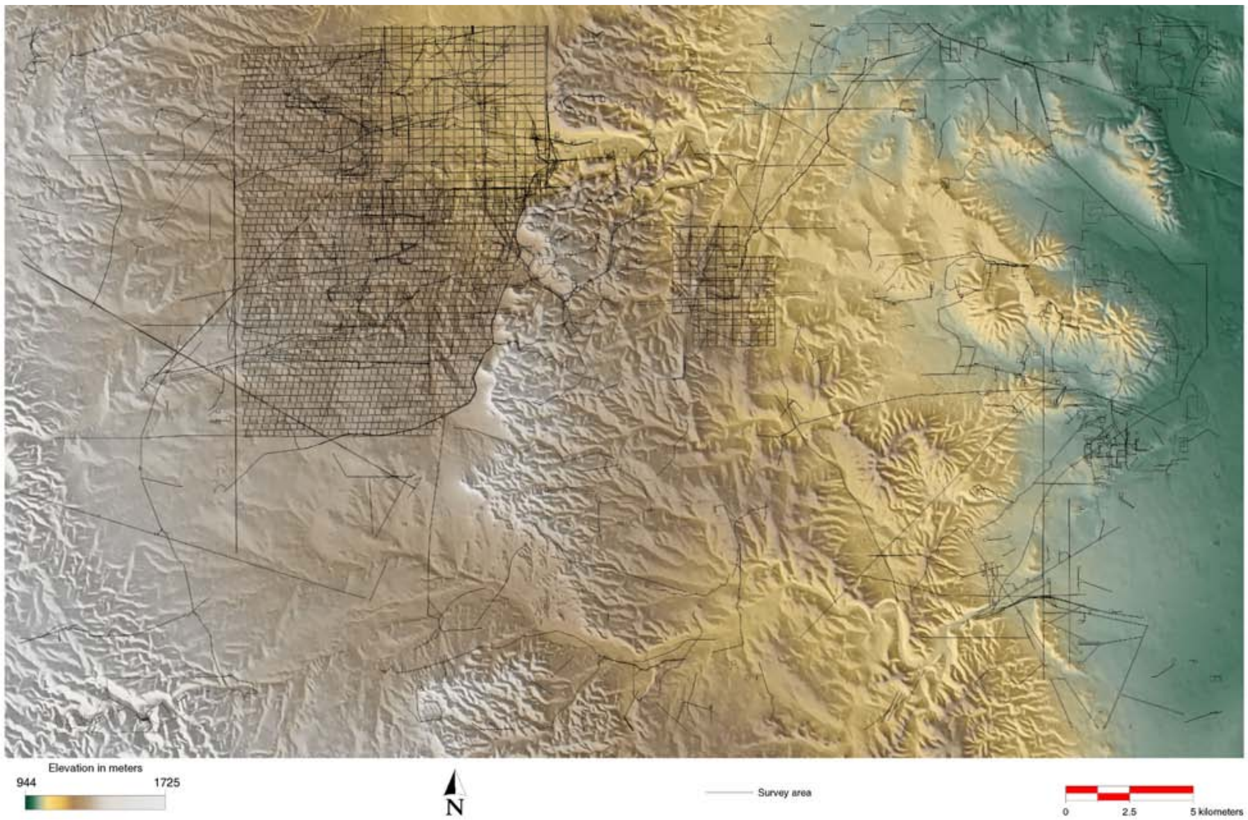

Figure 6.7. Survey data from Azotea Mesa

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 to the larger study area the relationship between environmental variables and archaeological site locations found in the surveyed areas. One approach would be to compute a difference of means test between the area surveyed and the entire GIS raster for each variable. Given the number of cells in the study area, such a test will almost assuredly show a significant difference between the population and the sample at a 0.05 or 0.001 significance level. We are less concerned, however, that the surveyed areas meet a statistical benchmark than we are with ensuring that there are no gross differences between the sample and the population. To gain this confidence, 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% 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 shown in Figure 6.8 is nearly identical to that for cells that have been covered by archaeological surveys (Figure 6.9), indicating that all slopes present in Azotea Mesa are adequately represented by the surveyed areas.

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 inclusion of independent variables that are related to each other, we used IDRISI to calculate the pair-wise Spearman's *r* scores for each set of environmental variables (Table 6.2). IDRISI takes each raster layer, which represents a single variable, and calculates a pair-wise Spearman's *r* score with all other raster layers. Because Spearman's *r* assumes variables scored on a continuous scale, the results for rank-order variables are meant more as an indication of possible variable interactions than as a meaningful score. Even with this caveat, it is instructive that 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 accepted as statistically independent. To test this conclusion further, we calculated the logistic regression model (developed and discussed below) both with and without the three most interrelated variables: slope, cost distance to drainages, and cost distance to ridges. The results of the two logistic regression models were very similar ($r = 0.92$).

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 study 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% 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. Spatial autocorrelation, then, could enter into the models because large sites contain many contiguous cells. By separating small sites as a test case, we have an independent test of the influence of spatial autocorrelation. If the models for large sites and small sites are similar then spatial autocorrelation is not a factor. Otherwise, we will need to revisit this issue.

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 drainages), 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), the layer was deemed statistically significant with reference to site distribution. The *z*-score is computed by the formula

$$z = \frac{\text{sample mean} - \text{population mean}}{\text{population standard deviation / square root of sample size}}$$

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 (cells with sites) is from the overall background environment (population). According to Kvamme (1990), the *z*-score test is better than a conventional *t*-test at identifying associations between variables. The *z*-score test is less influenced by spatial autocorrelation and more sensitive to variable association because it considers the entire study area as a population and the sites as a sample of that 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 make this evaluation process more clear. For slope, we find that the mean score for cells with larger archaeological sites (i.e., eliminating the very small site category) is 3.457º, whereas the average slope for the entire study area is 4.57º. To determine if sites really fall on less-steep 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,

$$z = (3.457 - 4.57) / (5.068 / \sqrt{9526}) = -21.43$$

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%) 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, as is the case for 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. Cells with eroded limestone *and* sites were compared with

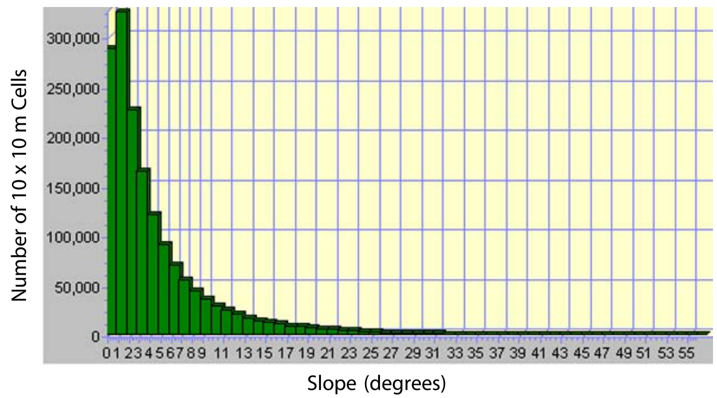

Figure 6.8. Slope values for the entire Azotea Mesa study area (mean = 4.57º)

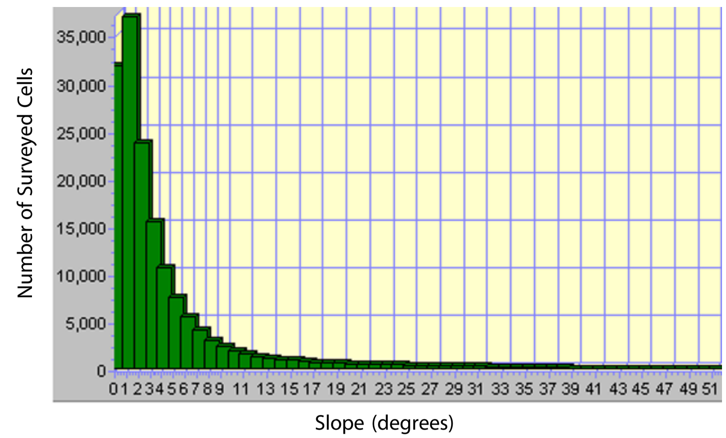

Figure 6.9. Slope values for the surveyed cells within the Azotea Mesa study area (mean = 4.39º)

Table 6.2. Pair-wise Spearman's *r* Scores for Environmental Variables

	Elevation	Geomorphology	Vegetation	Slope	Aspect	Distance to Water	Cost Distance to Water	Distance to Ridges	Cost Distance to Ridges	Distance to Drainage Intersection
Elevation	1									
Geomorphology	–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 drainage	0.19	–0.19	–0.16	0.13	0	1				
Cost distance to drainage	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	
Distance to drainage intersection	0.31	–0.18	–0.27	0.13	–0.05	0.42	0.31	–0.18	0.03	1

all cells characterized by 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 values are computed according to the following formula:

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

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% of the study area then the expected number of site cells found on eroded limestone should be 50% of the total number of site cells. Chi-square scores exceeding 124.34 at 100 degrees of freedom are significant at the 0.05 level. Using 100 degrees of freedom is extremely conservative for categorical variables. For example, the degrees of freedom for a matrix of three categorical geomorphic variables (e.g., eroded bedrock, floodplains, and river terraces) is 2 (number of categories [3] – 1). A chi-square score of 5.99, well under the score of 124.34 used here, is significant at the 0.05 level. For continuous variables, however, the degrees of freedom can be much larger than 100. We chose this figure because the probability calculations for 100 degrees of freedom are readily available. Table 6.3 presents the geomorphological variables that have significant chi-square scores.

Based on the *z*- and chi-square scores, we included 11 environmental variables in the Azotea Mesa predictive models: 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.

Table 6.3. 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	7878	257	48
Chi-square	636	219	2538

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 (see Chapter 4). 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. The weighted method and logistic regression are discussed in briefly in Chapter 5 and in more detail in Chapter 4; the Boolean model, which was not used in Loco Hills, is described briefly below and in more detail in Chapter 4.

A Boolean model is perhaps the simplest of all predictive modeling techniques. Every cell of the digital study region is classified as either “site” or “non-site” based on one rule. “Sites” are defined as cells that score favorably on every environmental variable; “non-sites” contain one or more unfavorable environmental scores. For example, if 90% of all the cells with known sites are located within 500 m of drainages and on slopes of less than 10º, then the GIS layers for distance to drainage 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 cutoff 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 cutoff ranges because the intersecting properties of the method have a tendency to greatly reduce the favorable zone. For each variable, we chose states and cutoff ranges such that a large percentage (80–95%) of the known site cells were included in the favorable category (Table 6.4).

For continuous variables, we used the variable range that contained 90% of the site cells in the smallest area. For categorical variables, states were chosen for inclusion based on their proportional significance; that is, variable states that had the highest proportion of site cells to total cells were chosen first as favorable until 90% of all site cells were included in the favorable state. This approach may seem counterintuitive because it allows some states, such as the Rocky Mountain/Great Basin Conifer vegetative community, to be considered favorable, when this area is exceedingly small and contains few site cells. Yet, proportionally, this vegetative community meets the selection criteria. To eliminate it simply because of its size would make the modeling process subjective and impossible to replicate objectively.

The sensitivity map generated by the Boolean model is presented in Figure 6.10. 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 contain cells located in areas 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.

The Boolean model was tested using the Gain Statistic (Kvamme 1988), which compares the proportion of site cells correctly located with the proportion of the model area that contains sites. The score can range from $-\infty$ 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 predict that sites would only 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 sites could be found in the future.

Table 6.4. Boolean Model Variables

Environmental Variable (favored categorical states)	Cutoff Range for Continuous Variables	% of Site Cells Contained in Favored State/Range	% of Study Area Contained in Favored State/Range
Elevation	958–1400 m	89	94
GEOMORPHOLOGY			
River terraces	—	5	0.47
Floodplains of large drainages	—	10	4
Eroded bedrock	—	67	82
Floodplains of small drainages	—	6	3
VEGETATION			
Shortgrass steppe	—	4	1
Rocky Mtn./Great Basin closed conifer	—	0.1	0.5
Chihuahuan desert scrub	—	17	15
Chihuahuan foothill-piedmont grassland	—	65	68
Distance cost to ridge	0–195	94	96
Distance from ridges	0–1180 m	96	96
Distance cost to drainage	0–170	94	89
Distance from drainages	0–1300 m	93	90
Aspect	N, S, E	91	84
Slope	0–9°	96	89
Distance from drainage intersection	0–3200m	93	92

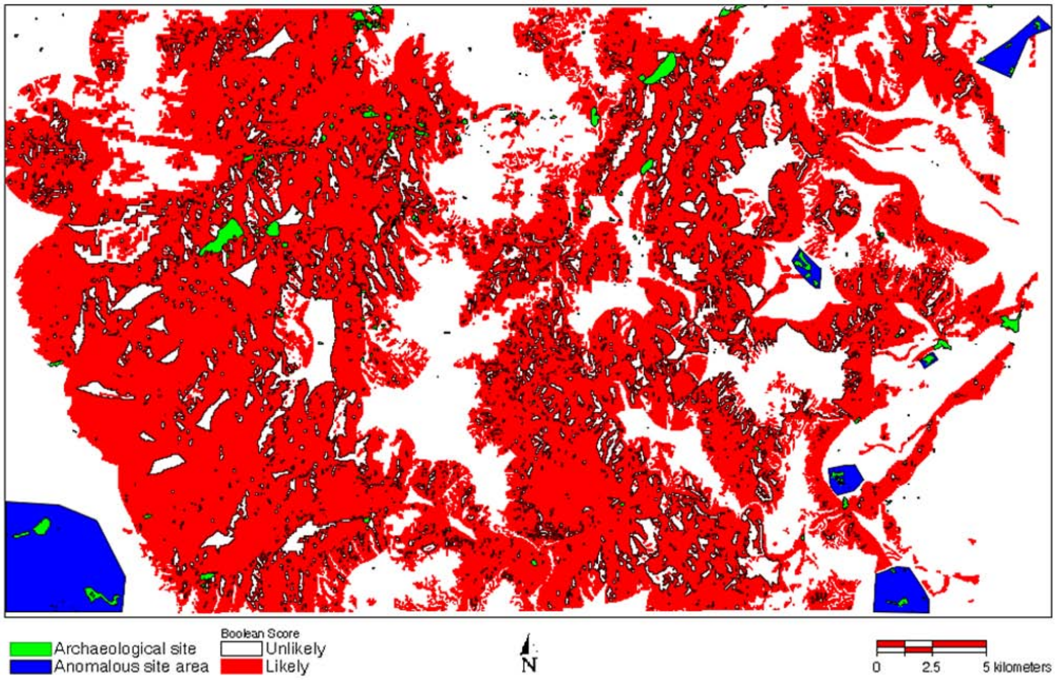

Figure 6.10. Boolean model: 0 (white) = site unlikely, 1 (red) = site likely; sites are in green, and blue polygons are sites that are not captured by the model (i.e., that occur in “unlikely” locations).

The Gain Statistic is calculated as

Gain Statistic = 1 – (proportion of model area / proportion of site cells 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 site cells 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 cell by using the Boolean model is only about 12% better than if we were to pick areas randomly.

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 the locations of the 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 6.5 lists the environmental variables, the cutoff ranges, the proportion of site cells 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.

Once the variables were weighted, the variable scores for each cell were added together. Table 6.6 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 categories that best represent site sensitivity. In this case, the four sensitivity categories were coded as poor (1), average (2), good (3), and excellent (4). A fifth category (coded 0 in Table 6.6) was disregarded because of the small size of the area it covered.

Figure 6.11 presents the sensitivity map for the weighted model with sites overlain in black. Seven sites had more than 90% of their cells fall in poor areas; these are outlined with white polygons (the size of the polygons has been enlarged to enhance visibility). 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 chapter.

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:

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% better chance of being correct than if one guesses randomly. The weighted model, then, is about 6% more accurate than the Boolean model.

We also tested the weighted model 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 that of larger sites. This suggests that small sites are located according to the same human “calculus” as larger sites. The weights in Table 6.6 make it clear that the most important factor in human settlement on Azotea Mesa involves water. Sites are found close to drainages, away from ridges, and in places where the effort to reach water was minimal (i.e., flat land near drainages). The effects of these variables are illustrated in Figure 6.11, which shows the linear and dendritic nature of site sensitivity.

Although the model accurately predicts about 70% of site locations, it is not a particularly powerful model. We need almost 40% 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 the Azotea Mesa study area 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 drainages.

Table 6.5. Weighted Model Variables

Environmental Variable	Cutoff Range for Continuous Variables	% of Site Cells Contained in State/Range	% of Study Area Contained in State/Range	Weighted Score
VEGETATION				
Rocky Mtn. closed conifer	—	0.1	0.5	0
Rocky Mtn. open conifer	—	5.27	3.01	2
Madrean open oak woodland	—	0	0.6	–1
Rocky Mtn. montane scrub	—	1.6	0.6	1
Broadleaf evergreen interior chaparral	—	0	0.6	–1
Chihuahuan desert scrub	—	17	15	2
Shortgrass steppe	—	4	1	3
Chihuahuan desert grassland	—	4.23	5.47	–1
Chihuahuan foothill-piedmont grassland	—	65	68	–3
Chihuahuan lowland/swale desert grassland	—	0	2	–2
Southwest plains forested/shrub wetland	—	0.5	0.9	0
Irrigated agriculture	—	0	0.06	0
Barren	—	0	0.1	0
Rock outcrop	—	0	0.08	0
Urban vegetated	—	0	0.3	0
Riverine/lacustrine	—	0.05	0.07	0
Basin playa	—	0	0.2	0
GEOMORPHOLOGY				
Eroded bedrock	—	67	82	–15
Floodplains of small drainages	—	6	3	3
Floodplains of large drainages	—	10	4	6
River terraces	—	5	.5	5
Alluvium	—	0	0.02	0
Thick, uneroded Holocene deposits	—	0	0.03	0
Playa deposits	—	0	0.003	0
Recent slope-wash deposits	—	3.3	1.48	2
Extensive slope-wash deposits	—	8.07	8.6	–1
Cave or rockshelter	—	0	0.0007	0
Historically recorded spring	—	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
Distance cost to ridges	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
Distance cost to drainages	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 drainages	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 drainage 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	0–9º	94.03	85.25	9
	9–17º	3.64	10.03	–6
	17–33º	2.33	3.41	–1
	>33º	0	1.31	–1

Table 6.6. Weighted Model Scores and Reclassification

Model Score	Proportion of Study Area	Proportion of Site Cells	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 to 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

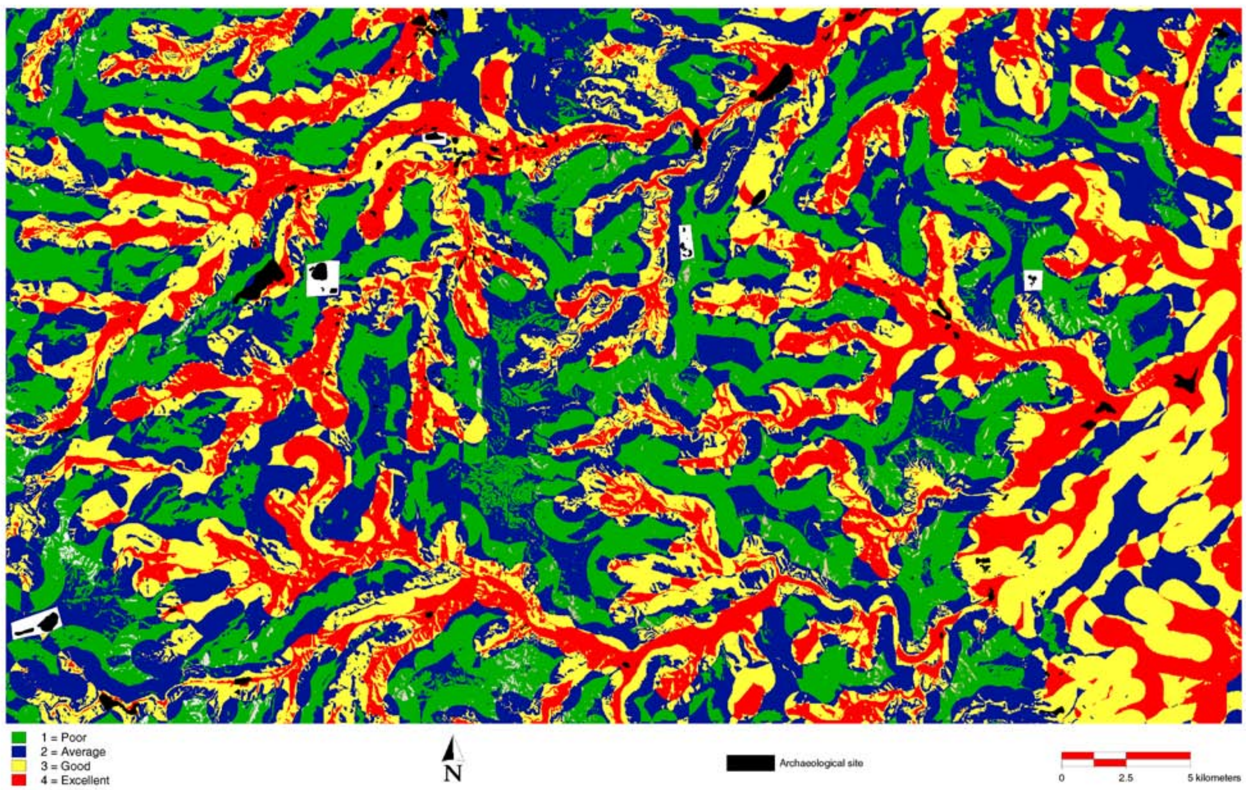

Figure 6.11. Weighted model with sites in black.
White polygons encompass recorded sites in areas modeled as poor or average candidates for site presence.

Logistic Regression Model

Logistic regression is a complex statistical technique (see Chapter 4). 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 6.7 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 drainage, 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 drainages 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 6.7. Computed Coefficients for Variables Used in the Logistic Regression Model

Variable	Coefficient	Coefficient without Aspect
Distance from drainages	–0.00122318	–0.00122661
Distance from ridges	0.00054383	0.00054599
Chihuahuan foothill-piedmont	0.07353178	0.06888962
Shortgrass steppe	1.33956144	1.30428528
Slope	–0.04192440	–0.04463399
North-facing	2.96050762	N/A
South-facing	2.57331814	N/A
East-facing	2.74273073	N/A
West-facing	2.48460818	N/A
River terraces	1.96534996	1.97969398
Extensive slope wash	0.12737117	0.13443338
Elevation	0.00201439	0.00200162
Drainage 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 activities 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 6.8 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 percentage of site cells 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. The cutoffs between the four sensitivity groups were chosen to capture the most site cells in the smallest area. There is no hard and fast rule about selecting these cutoffs, which may be changed by others to enhance different aspects of the sensitivity map.

Figure 6.12 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 classified as good or excellent has shifted from around 45% in the Boolean and weighted models to more than 60% 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.

Table 6.8. Logistic Regression Probability Scores and Reclassification Values

Probability	Percentage of Study Area	Percentage of Site Cells	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

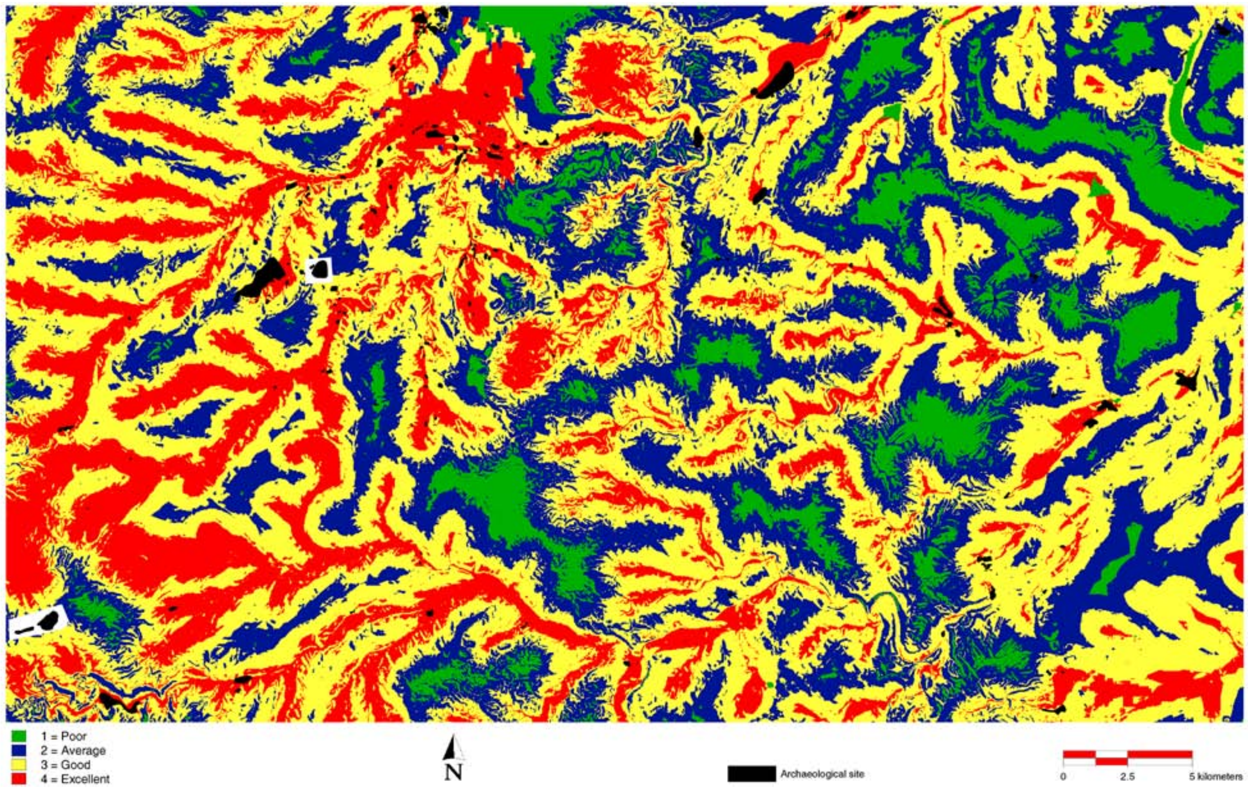

Figure 6.12. Logistic regression model with sites in black. White polygons are site areas that are in the poor or average class.

Gain = 1 – (63.34 / 85.09) = 0.26
Gain over Random = 85.09 – 63.34 = 22

The logistic regression model works slightly worse as a predictor than the weighted model (27% better than random for the weighted model versus 22% better than random for the logistic regression model). Both models, however, have about the same accuracy (22–24% better than random) in correctly classifying the independent group into sensitivity areas. Visually, both models appear to be capitalizing on the distance to drainage variable, 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 6.9. 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% 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 6.9. 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

Interpreting the Results

In our discussions of the three models presented 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 termed 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 land-use 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 6.10) and the characteristics of the set of large sites used to develop the models (Table 6.11). We then compared the environmental characteristics of red flag sites and with those of the correctly predicted sites (Table 6.12); note that because of the small sample size, these sets of sites are only compared descriptively, not statistically.

It is tempting to speculate that the predictive models reflect primarily "Mogollon" settlement patterns. This time period represents nearly 60% of the components of known time periods recorded in the ARMS database. 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 LA 130417/LA 83187.

Table 6.10. Red Flag Sites

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

Table 6.11. Sites Used to Create the Predictive Models

Time Period/ No. of components (N)		Area (Acres)	Number of Features	% of Sites with >1,000 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	39	100
	mean	22.59	19.5	
	std. dev.	0.86	21	
Middle Archaic (1)		7.23	6	0
Late Archaic (6)	N	293.13	64	50
	mean	48.86	13	
	std. dev.	36.07	11	
Unspecified Archaic (2)	N	324.78	3	50
	mean	162.388	2	
	std. dev.	214.16	1	
Mogollon (21)	N	478.68	246	33
	mean	22.79	12	
	std. dev.	18.26	11	
Protohistoric (1)		36.39	0	0
Unknown (24)	N	739.251	218	25
	mean	30.80	9	
	std. dev.	45.81	17	
All sites (53)†	N	1729.39	527	28.3
	mean	32.64	10	
	std. dev.	51.99	14	

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

Table 6.12. 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
Std. dev.	36.60	51.99
Elevation (m)		
Range	1264–1686	952–1452
Mean	1493.747	1151.976
Std. dev.	182.38	131.958
Distance from drainages (m)		
Range	880–1620	0–1197
Mean	1458.304	264.368
Std. dev.	306.337	231.065
Slope (degrees)		
Range	0–7	0–31
Mean	3.942	3.40
Std. dev.	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%)

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 groups who would have been based at residential sites elsewhere, most likely on the Pecos River. What types of activities were being carried out within the study area? The dendritic distribution of the high-probability areas in both the weighted and the regression models makes clear that these activities were focused on the drainages. Were they gathering specific plant resources along the drainage bottoms or terraces? Were the terraces or small alluvial fans from side drainages part of an agricultural strategy that emphasized use of a wide variety of field settings? Or were these drainage networks being used as routes of travel between the Guadalupe uplands and the river valley? The small size and undifferentiated surface expression of the sites in the study area would be consistent with any or all of these explanations. It will require detailed, targeted data recovery at a sample of these sites for us to begin to understand the functions of the Azotea Mesa sites within the larger settlement system or systems of which they were a part.

In contrast, the numerically rare Archaic sites occur in a very different environmental setting from that common to the Formative sites and may reflect an adaptation focused on seasonal hunting. Relative to the sites that were correctly predicted by the models, the Archaic sites are larger, located at higher elevations, and tend to be farther away from drainages. 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 or downwind of 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 drainages.

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 out potential avenues of research 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 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 chapter describes a variety of modeling approaches that we used to examine the effectiveness of current management practices and identifies some implications of the results for future management practices. Chapter 9 will provide more detailed management recommendations.

Model Stability

The logistic regression model for Azotea Mesa correctly predicted the locations of 85% 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% 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. This might be the case if, for example, the "resource" for which the study area was valued was one or more favored routes of travel.

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 this 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 (2002) data. At the end of 1982, approximately 6% of the 33,960 acres covered by 2002 had been surveyed. This total had risen to 34% by 1992, 64% by 1997, and 94% by 2000. Only 7% of the 550 currently known sites had been recorded by 1982. By 1992, 29% of the currently known sites had been recorded; by 1997, 58% of these sites had been found; and by 2000, 78% of all currently known prehistoric sites had been recorded.

Figures 6.13–6.17 show 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 6.17 differs slightly from the model displayed in Figure 6.12 in the previous section, which excluded the data from the very small sites. The Spearman's *r* score for 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 6.18). 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 6.13) reinforces this observation. Although wide fluctuations are noted in the 1982 and 1992 models, the coefficients vary little in the last three models.

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 unlikely that additional data will 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 Valley.

We suspect that the human adaptation to this environment included resources from the mountains to the west and resources 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 passed 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 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

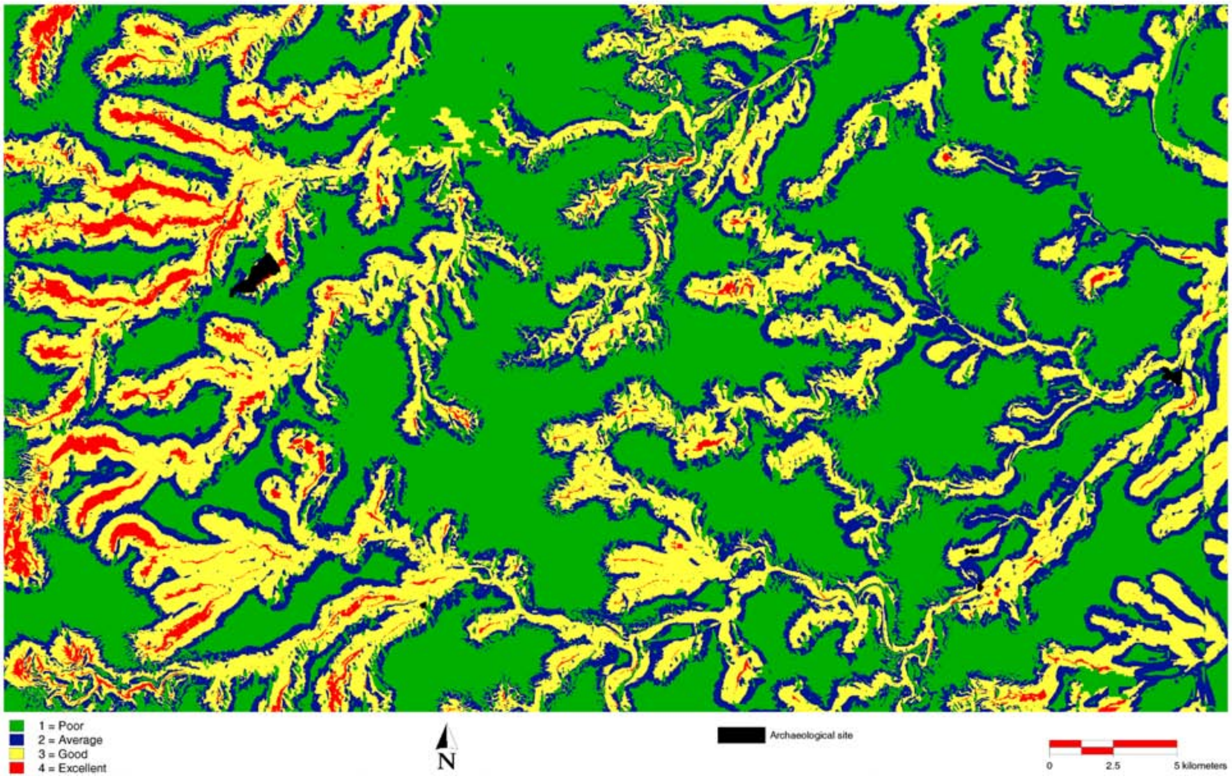

Figure 6.13. Logistic regression model created using all sites recorded through 1982.
The correlation in relation to the model based on 2002 data is 0.7.

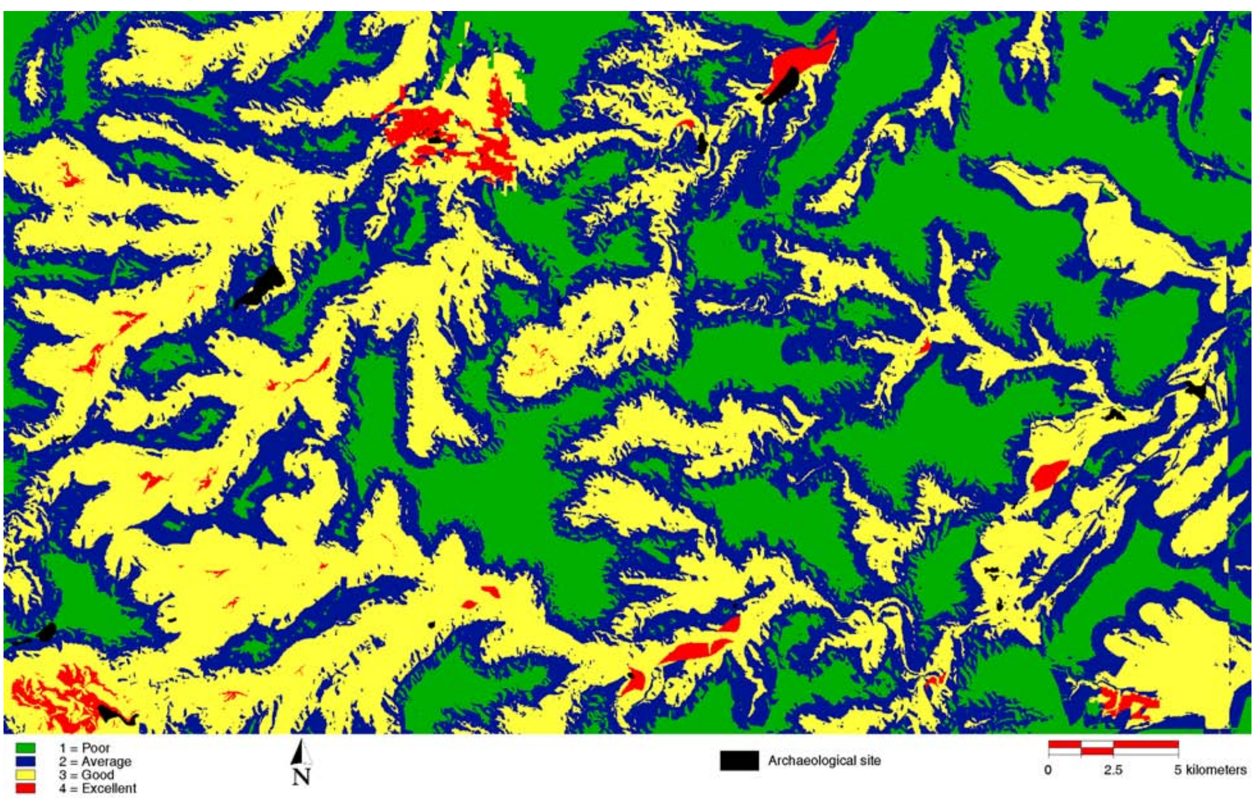

Figure 6.14. Logistic regression model created using all sites recorded through 1992.
The correlation in relation to the model based on 2002 data is 0.87.

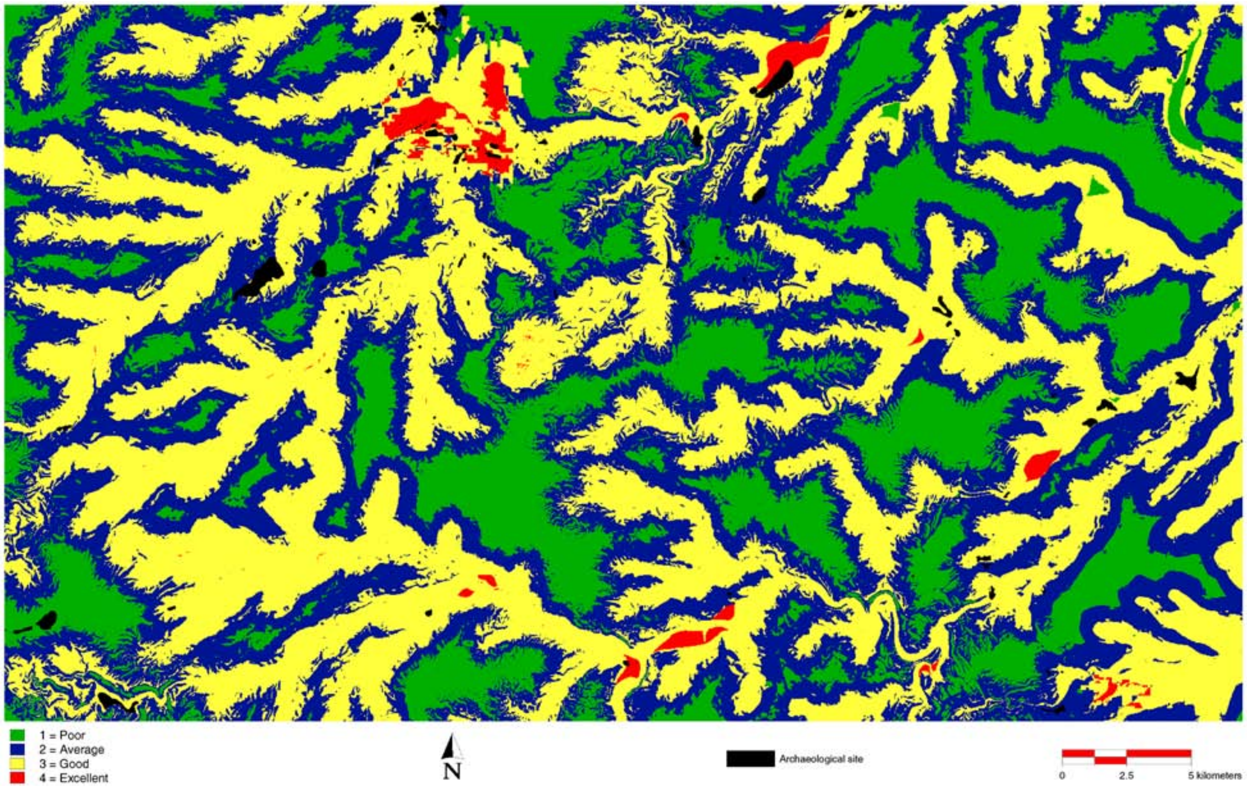

Figure 6.15 Logistic regression model created using all sites recorded through 1997.
The correlation score in relation to the model based on 2002 data is 0.995.

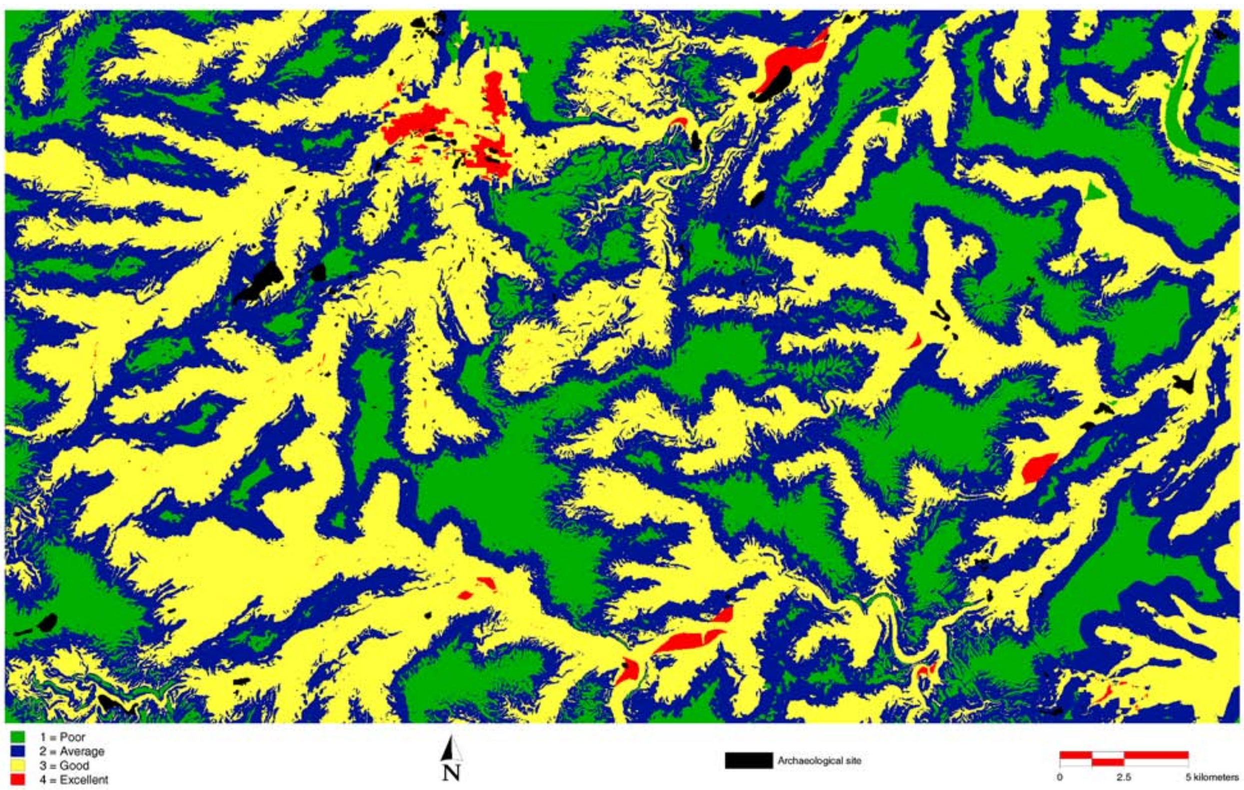

Figure 6.16. Logistic regression model created using all sites recorded through 2000.
The correlation score in relation to the model based on 2002 data is 0.999.

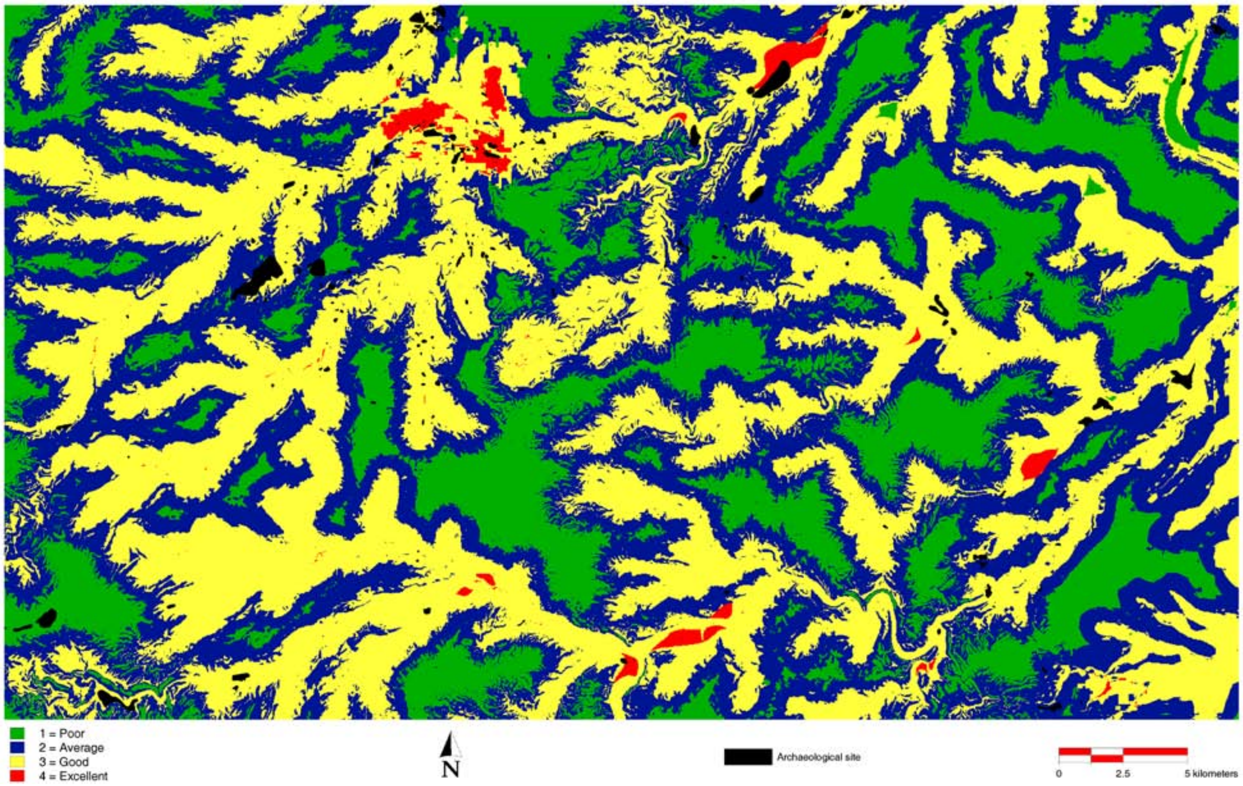

Figure 16.17. Logistic regression model created using data from all prehistoric sites recorded prior to 2002.

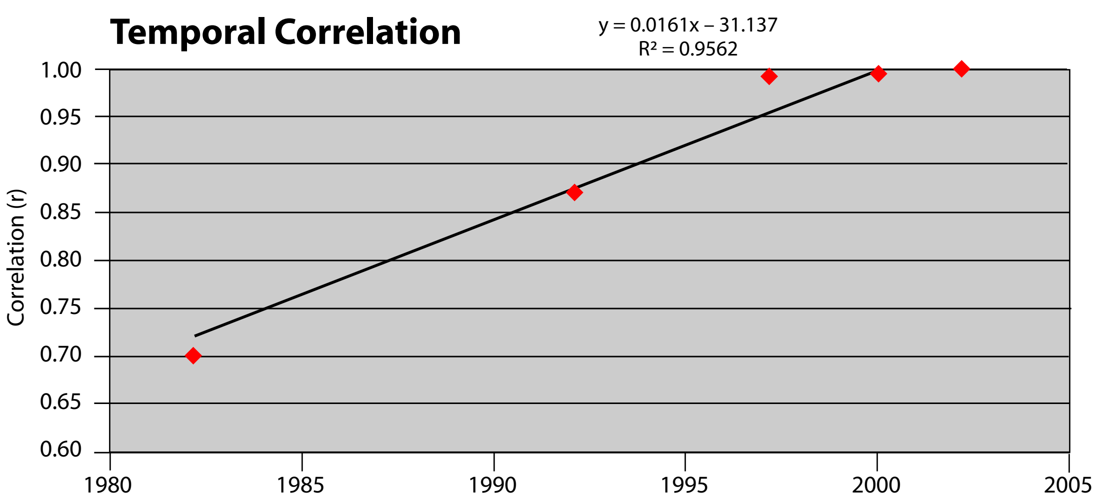

Figure 6.18. Correlation of each logistic model by year to 2002 ($r =$ 0.98).

Table 6.13. Comparison of Logistic Regression Coefficients

	1982	1992	1997	2000	2002
Distance from drainages	–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
Shortgrass steppe	–18.95510762	1.54981816	1.39244750	1.25407640	1.23422307
Slope	–0.06301770	–0.01121114	–0.04376925	–0.04645208	–0.04570684
North-facing	18.49441267	1.37578453	2.19733547	2.33641498	2.24024762
South-facing	18.46219677	0.97058514	1.77860719	1.91828232	1.82313037
East-facing	18.68033657	1.30033149	1.96868271	2.07221704	1.97888617
West-facing	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 drainage intersections	0.00014312	–0.00031192	–0.00009975	–0.00013687	–0.00013192

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 drainage 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 just barely cuts through the northeastern 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 drainage in order 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, concentrating 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 indirect 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 regional archaeological 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 (Chapter 5), 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 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% of the estimates. We then examined the annual history to determine when the running site density began to fall consistently 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 that are unavoidable in a large regional data base with contributions by a wide variety of researchers—the same site being recorded more than 10 km away from itself, recording episodes tied to surveys that were nowhere in the vicinity, etc. 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 data base as a 30 m diameter circle.

Figure 6.19 illustrates some of the 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.

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 6.20 shows surveys within the same small portion of the study area, coded by year, and Figure 6.21 shows a time sequence of cumulative survey, aggregated by year, within the whole study area.

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 6.20 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. We do not mean to imply that resurvey, per se, is a bad thing; decisions to resurvey an area or re-record a site when there are reasons to do so are important management choices. The resurvey and re-recording documented here were generally not the result of a management decision, however. Rather, these duplicative efforts were the result of a case-by-case approach to inventory driven by the pattern of oil and gas development and not by cultural resource management needs.

Figure 6.22 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.

These data allow us to calculate site density using two different methods. Method I (Figure 6.23) 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. Site density for a particular year is calculated by dividing the number of "site" acres by the total number of acres surveyed in that year. The site density figures calculated using Method I are, therefore, inflated. Method II (Figure 6.24) eliminated

Figure 6.19. Examples of survey and recording episodes.

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 unplanned survey overlaps or inadvertent site re-recording.

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% 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.

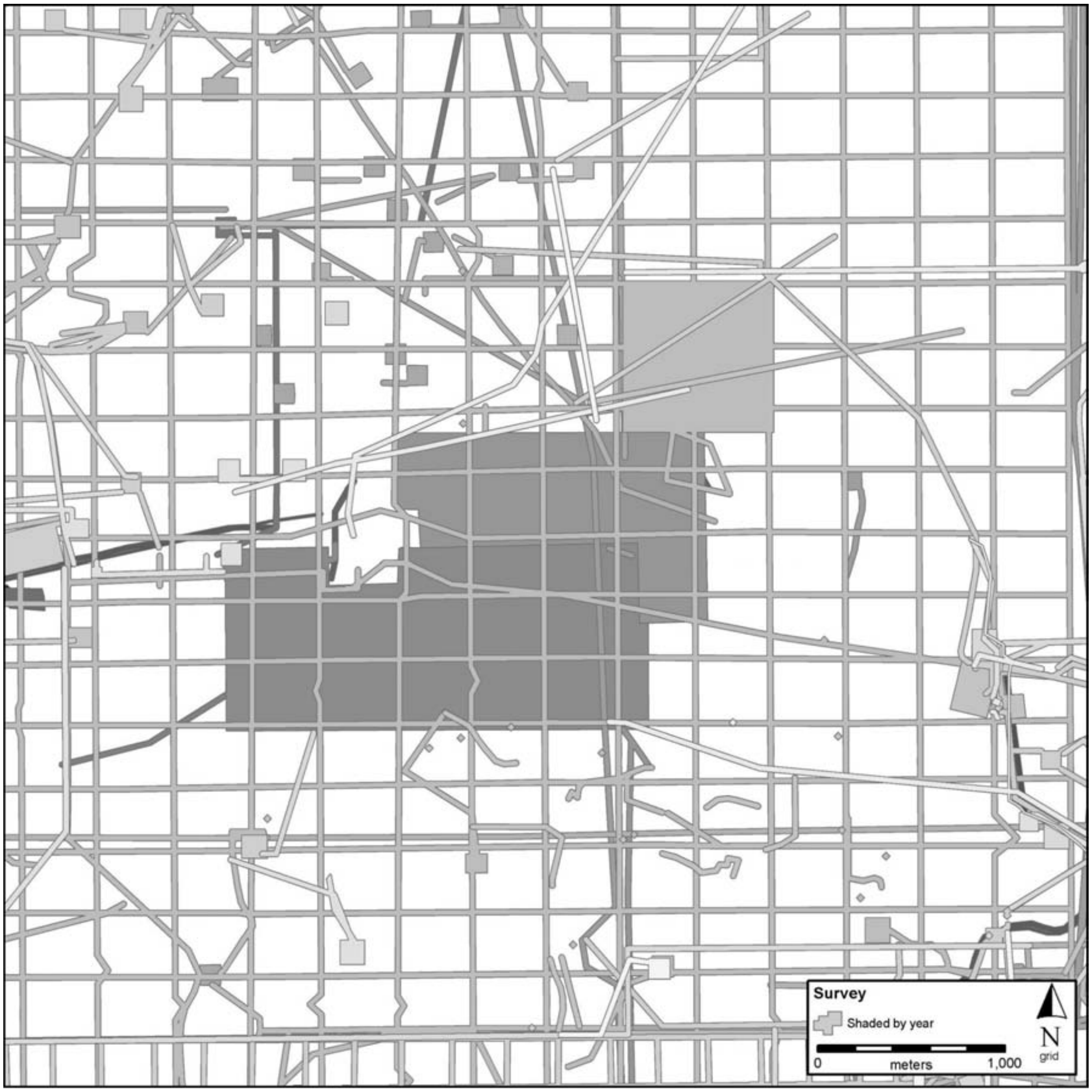

Figure 6.20. Example of survey coverage aggregated by year.

Management Implications

In some ways our findings for Azotea Mesa are like those for the Loco Hills study area. As was the case with Loco Hills, we found that on Azotea Mesa oil and gas development, although 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 a great deal of resurvey 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, however, some observations that are particular to Azotea Mesa. One clear lesson learned is that just 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 and acquire some level of functional information about the archaeological sites

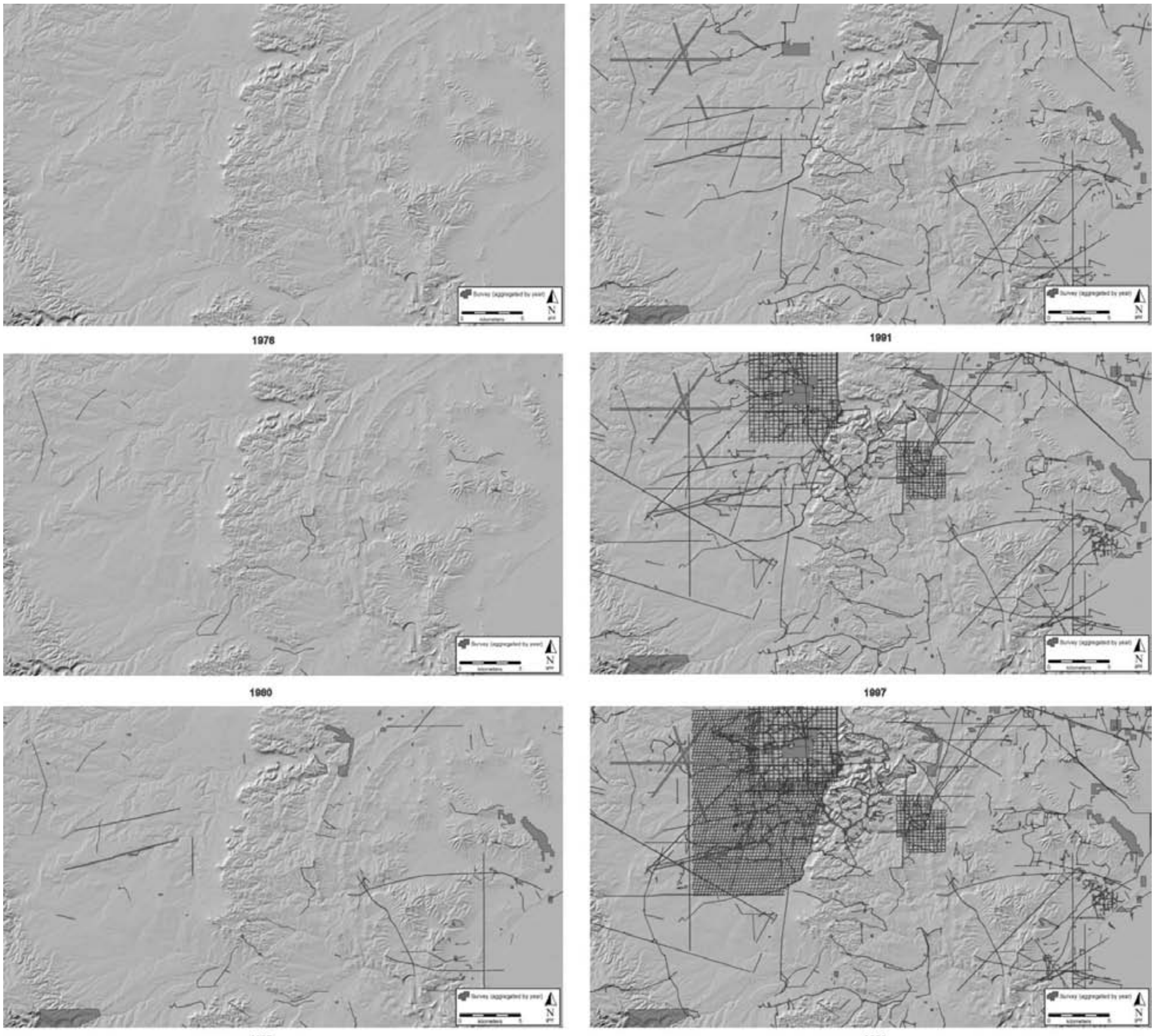

Figure 6.21. Time sequence for cumulative survey in the study area, aggregated by year.

in the area. Human use of the region clearly extends beyond the oil and gas lease areas. By focusing solely on the study area, we do not have a large 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. Likewise, the sites within the Azotea Mesa study area were part of larger settlement systems, and without functional information about these sites, it is not possible for us to understand their significance within those larger systems.

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 conclusion 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, possibly in small, mobile groups that exploited locally available resources and then left, or as travelers following a favored route from the river to the uplands, or possibly even as part-time agriculturalists establishing opportunistic fields at favorable locations to capture runoff. What we don't know is which one or ones of these strategies they were pursuing, where they came from and where they went, how use of this area changed through time, and whether the structure of use changed as a result of organizational changes at a larger scale.

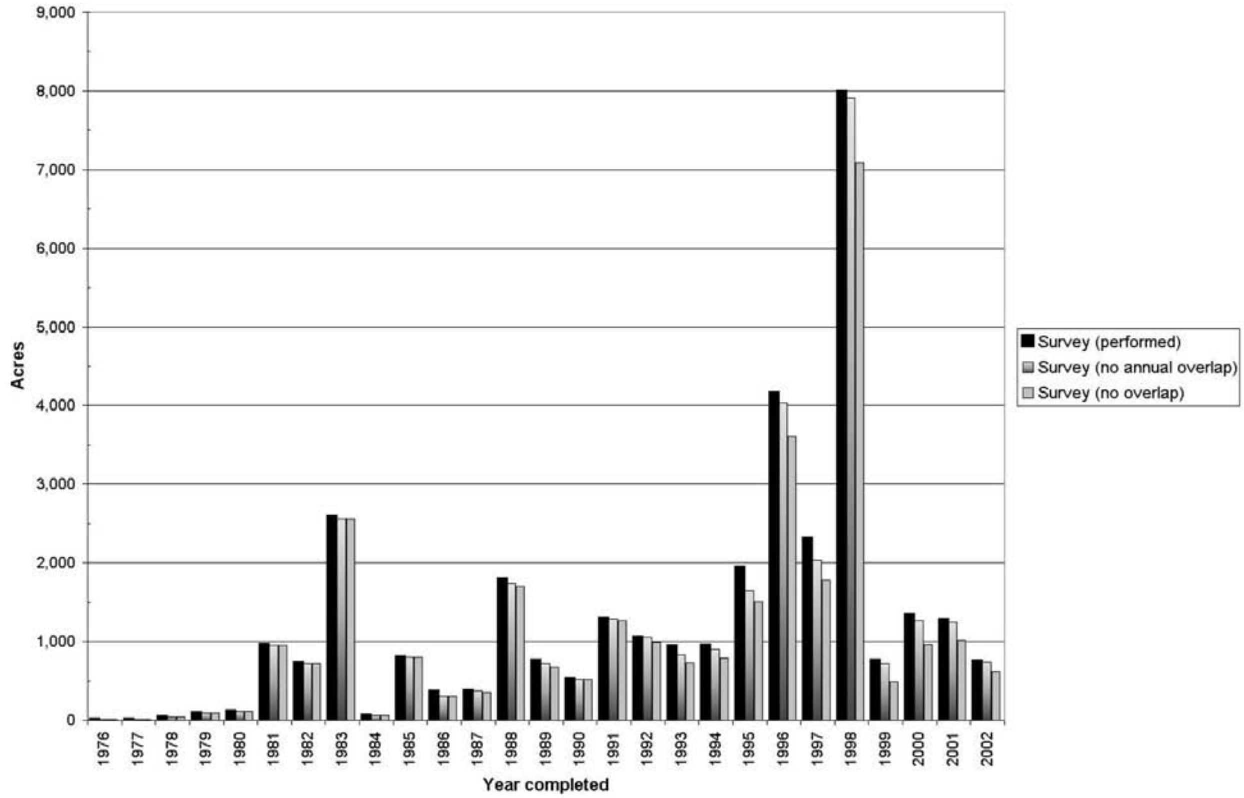

Figure 6.22. Annual survey statistics.

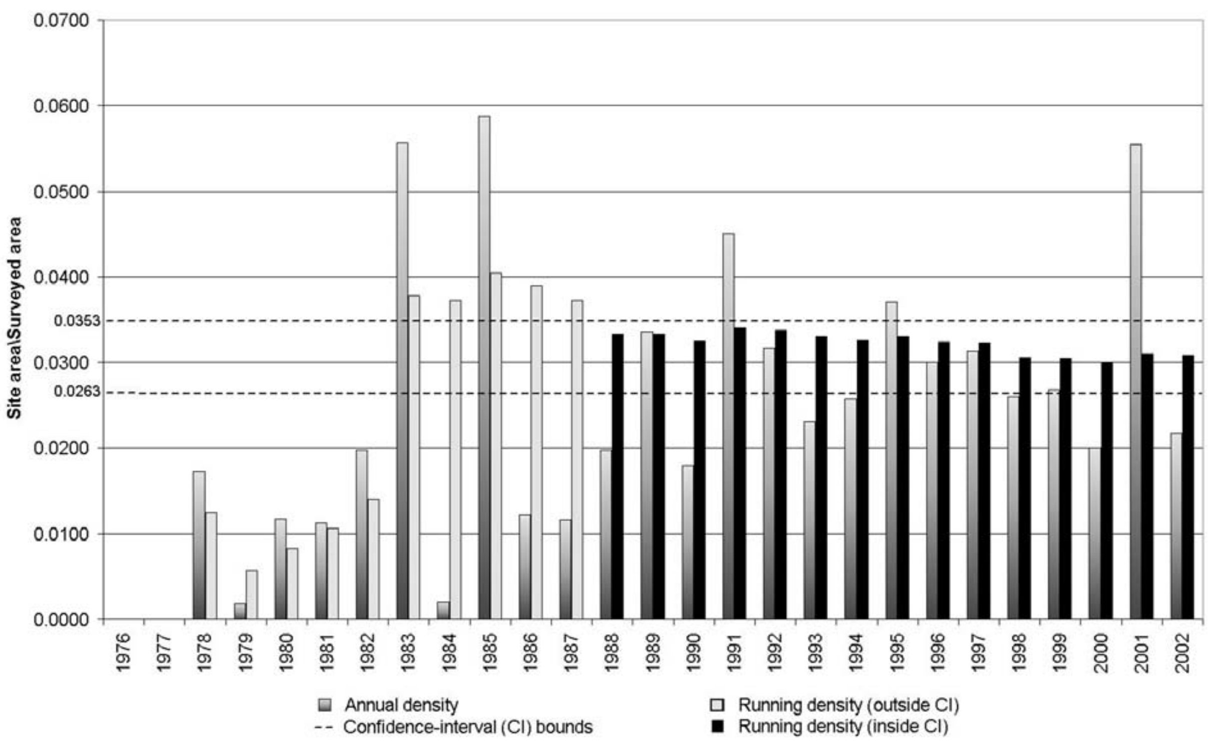

Figure 6.23. Overall site density, Method I.

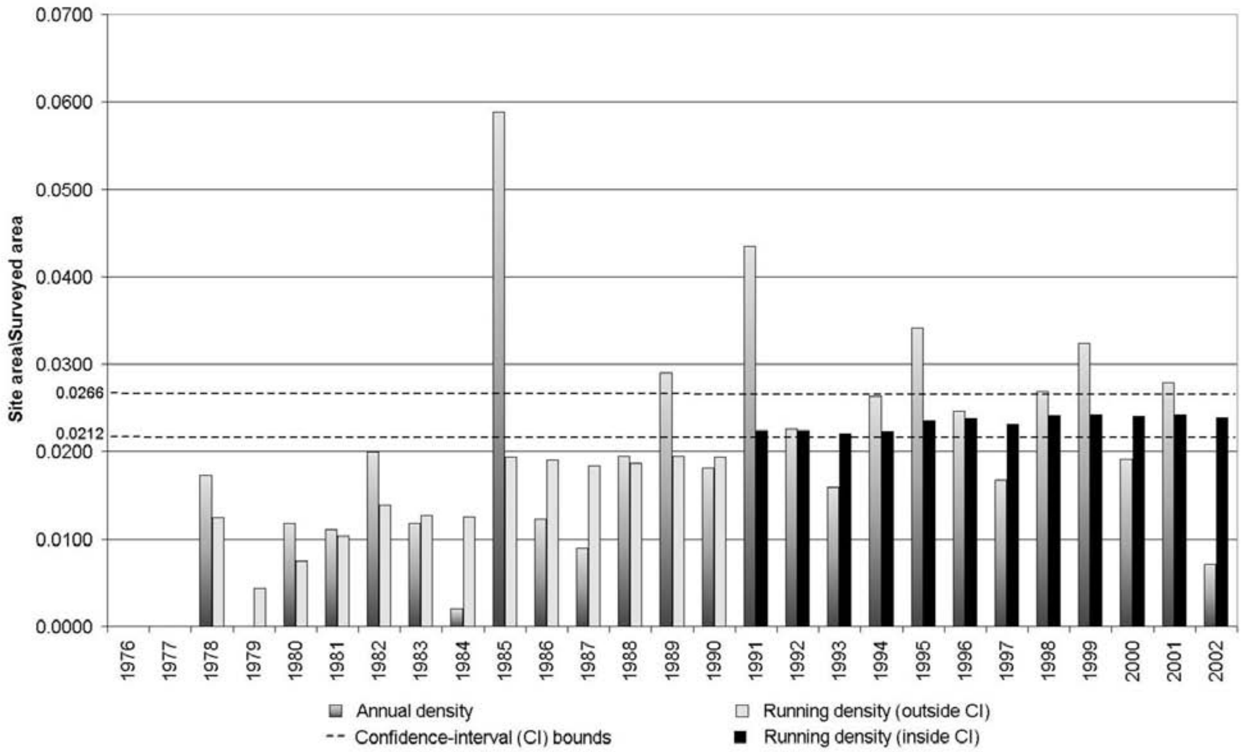

Figure 6.24. Overall site density, Method II.

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 for resources other than travel routes? Was simple floodwater agriculture possible, and was it practiced here? 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 environmental and settlement picture, however, it may be difficult to gain sufficient 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 small sites with large boundaries will compensate for large sites recorded as points. 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.

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CHAPTER

7

Results and Discussion: The Otero Mesa Study Area

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The Otero Mesa study area is located in Otero County on the southern border of New Mexico, northeast of El Paso, Texas, and southwest of the Guadalupe Mountains (Figure 1.2). The region in which our study area falls is generally referred to as "greater Otero Mesa" since it includes not only the landform of Otero Mesa, but a wedge of rugged canyon country that constitutes the southernmost extension of the Sacramento Mountains, as well as the Cornudas Mountains, and the Salt Basin, a large internal drainage basin that lies between the Guadalupe and Brokeoff Mountains on the east and Otero Mesa proper on the west. Generally the term "mesa" refers to an erosional feature, a flat-topped expanse of land demarcated by steep eroded edges, but Otero Mesa is actually a horst, an elevated block of land separated by faults from the Tularosa Basin to the west and the Salt Basin to the east.

Originally the Otero Mesa study area was planned as a rectangle of eight 7.5-minute quadrangles like the Loco Hills and Azotea Mesa study areas. In order to increase the environmental diversity for modeling purposes, however, and to include the locations currently leased for oil and gas exploration, the study area was redesigned as two separate blocks comprising a total of eleven quadrangles (Figure 7.1).

The Predictive Models

Otero Mesa presents a classic problem in predictive modeling: the region has received little archaeological attention. The predictive model, therefore, is based on limited information, much of which is dated and of suspect quality. The models for Loco Hills and Azotea Mesa have shown, however, that the relationship between site locations and environmental attributes can be discerned with surprisingly limited data. As we have seen, predictive models always yield results. The question of overriding concern to managers and archaeologists alike is, "How much confidence can we have in these results?" In large part the answer lies in our ability to assess model performance statistically. But perhaps just as important as objective measures is our subjective assessment of whether the model mimics our perception of how humans would have placed themselves on the landscape. In essence, we must be assured that the models not only work, but also make sense.

The eastern Otero Mesa study unit encompasses four quadrangles or 65,400 hectares (253 square miles), and the western study unit covers seven quadrangles, or 114,443 hectares (440 square miles). The two study units reflect different physiographic areas. The eastern unit encompasses the closed drainage basin of Crow Flats and the western unit consists largely of rolling desert grasslands. Only 0.4% of the eastern unit has been surveyed and 20 sites have been recorded, representing both postcontact and prehistoric time periods. The western unit is one of the better-studied areas of Otero Mesa. Here, 3.0% of the unit has been surveyed and 83 prehistoric and historical sites have been recorded.

As with Loco Hills and Azotea Mesa, the predictive models created for Otero Mesa are correlative models (see discussion in Chapter 4), which examine correlations between archaeological site locations and environmental features. The modeling process began with a compilation of available data on the environment and archaeology of Otero Mesa. We restricted our search to data 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 Otero Mesa. This GIS package is a raster-based system, which uses a grid of a specified size superimposed over the area in question. We chose a 10 × 10 m cell as our grid size, which generated 6,185,909 cells for the eastern study unit and 10,827,725 cells for the western study unit.

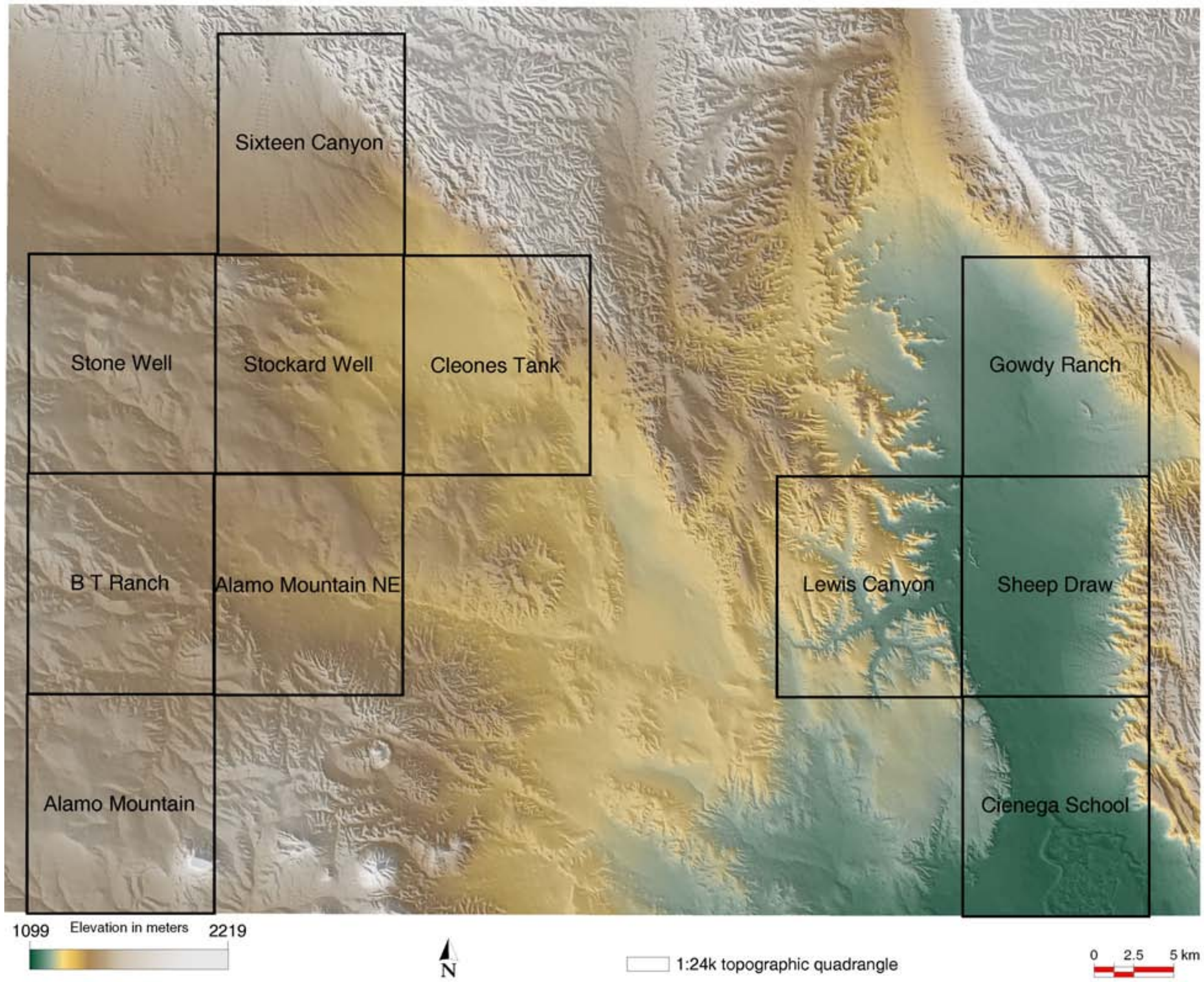

Figure 7.1. Digital elevation model of Otero Mesa and location of eastern and western study units with USGS 7.5-minute quadrangles labeled.

Environmental Data

As with Loco Hills and Azotea Mesa, the first step was to assemble data on a variety of environmental characteristics of Otero Mesa. We obtained GIS layers on elevation, vegetation, and geomorphology. The elevation theme is a digital elevation model (DEM; Figure 7.1) created by the United States Geological Survey. In the case of Otero Mesa, the contour interval is 20 feet. In many cases, DEMs serve as the primary data theme from which secondary themes, such as slope (Figure 7.2) and aspect, are created.

A data layer for major streams and ridgelines was also created using the DEM as a primary data layer (Figure 7.3). Once streams and ridges are defined, distance and cost surfaces can be computed from them. The GIS uses the streams and ridges as points of origins and can determine the distance or cost of travel to any cell in the study area. Cost is an estimation of the expenditure of energy required when traveling from a source, such as a stream or a ridgeline. Cost can be computed a number of ways: we could sum the slope values, slope squared values, or the square root slope values for each cell traversed. That is, the GIS could begin at cells coded as streams and sum the cost of crossing each cell encountered when traveling away from those sources. If, for example, the two cells to the east of a stream cell have slope values of 4 and 9, then the cost value for the second cell would be 13 if the slope values are summed, 97 if the slope values are squared, and 5 if the square roots of the slope values are summed. If the terrain is flatter, then the cost to reach the second cell would be less. Cost surfaces can be used to determine whether locations are easier or more difficult to access in relation to the surrounding landscape, but they do not necessarily identify actual travel routes used by people in the past.

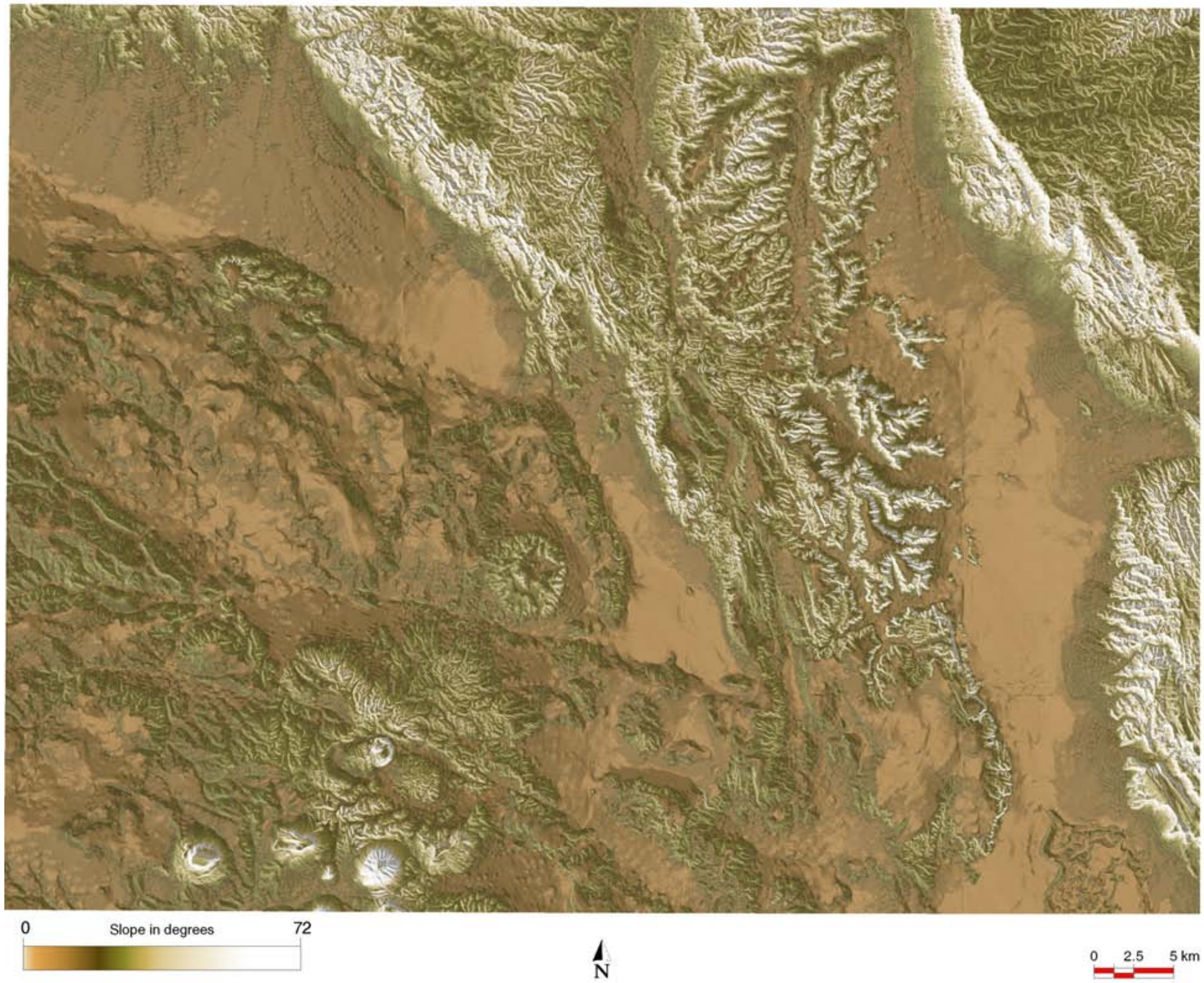

Figure 7.2. Slopes in the Otero Mesa study area.

To determine which cost value to use, we computed one-sample means tests for the three methods outlined above for the eastern study area (Tables 7.1 and 7.2). All three methods yield statistically significant results, though squaring the slope values yields a non-intuitive result—that sites are located at higher cost distances from streams than non-sites. For purposes of this study we chose to calculate cost distance using the slope value itself, without any transformation.

Geomorphology

The geomorphology data were provided by Gnomon, Inc., based on maps prepared by Steve Hall of Red Rock Geological Enterprises. The Otero 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, South Dakota. Landforms were identified from the stereo aerial photographs using a Topcon mirror binocular stereoscope at 3× 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. one-tenth of an inch on topographic maps and smaller yet on the aerial photos) were not mapped.

The geomorphology of the Otero Mesa study area (Figure 7.4) is characterized by limestone bedrock composed of the Yeso and San Andreas formations (Permian) with broad areas of colluvial-alluvial-lacustrine deposits. Eolian and playa deposits occur in the Salt Basin in the eastern study unit. Large and small alluvial fans occur at the mouths of small canyons that are eroded into Permian limestone bedrock.

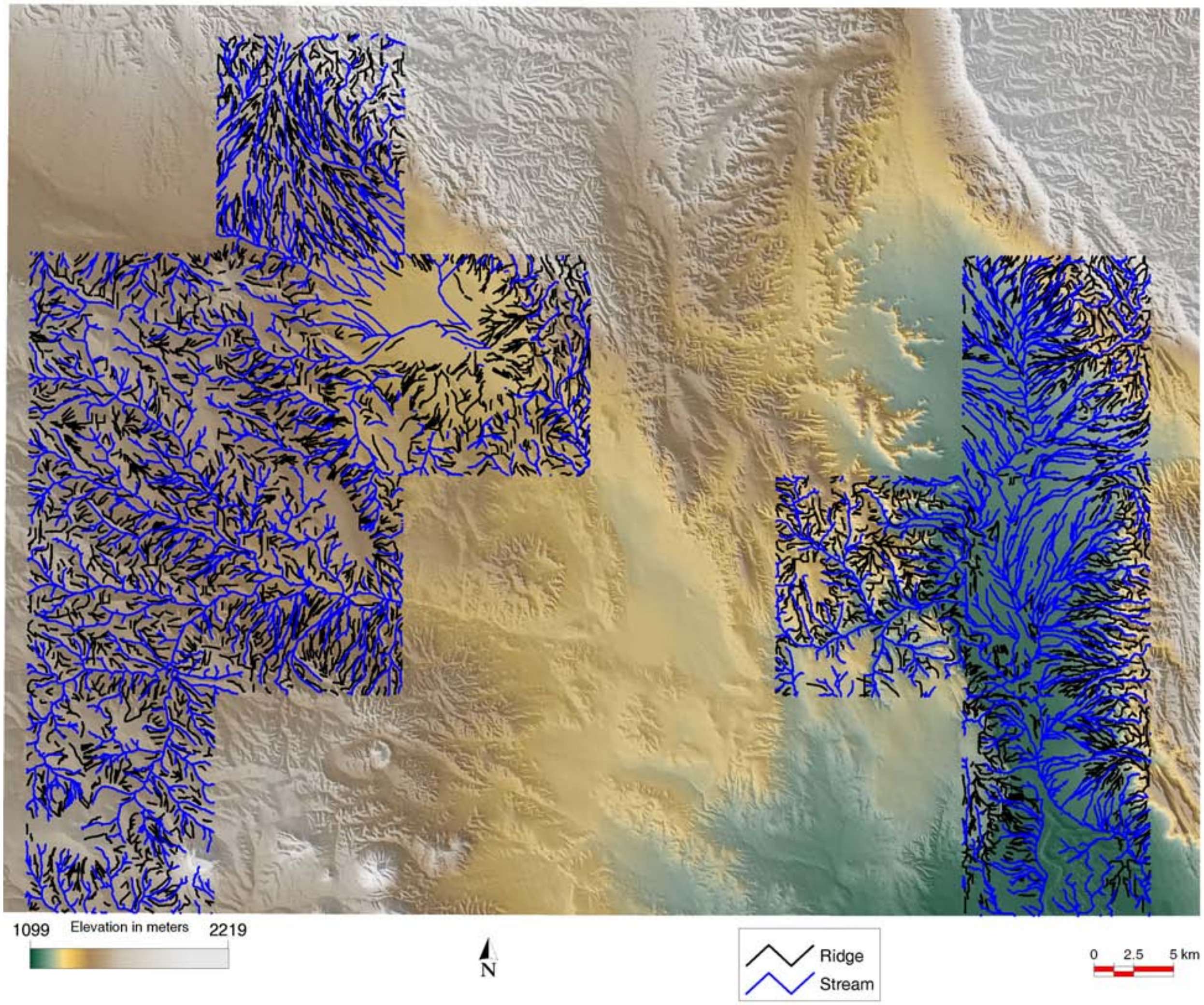

Figure 7.3. Drainages and ridges in the Otero Mesa study area.

Table 7.1. Descriptive statistics on slope values for the Eastern Otero Mesa Study Unit and for Sites within the Eastern Study Unit

	Slope Cost Surface from Streams	Slope Squared Cost Surface from Streams	Slope Square Root Cost Surface from Streams
Eastern Study Unit			
mean	84.18	1085.39	29.56
std. dev.	171.67	3114.42	47.44
range	0–1809.96	0–38,846.66	0–425.11
Sites			
mean	94.59	149.32	56.87
std. dev.	64.93	154.43	40.99
range	0–224.02	0–1679.75	0–138.42

Table 7.2. One-Sample Means Test for the Eastern Study Unit

Cost Distance from Streams	Means Test	Significance Assessment
for slope itself	Z = (94.59 – 84.18) / (175 / √3164) = 32.39	Yes; site cells tend to have higher cost distances than non-site cells
for slope squared	Z = (149.32 – 1085.39) / (3114.42 / √3164) = –16.91	Yes; site cells tend to have lower cost distances than non-site cells
for slope square root	Z = (56.87 – 29.56) / (47.44 / √3164) = 32.38	Yes; site cells tend to have higher cost distances than non-site cells

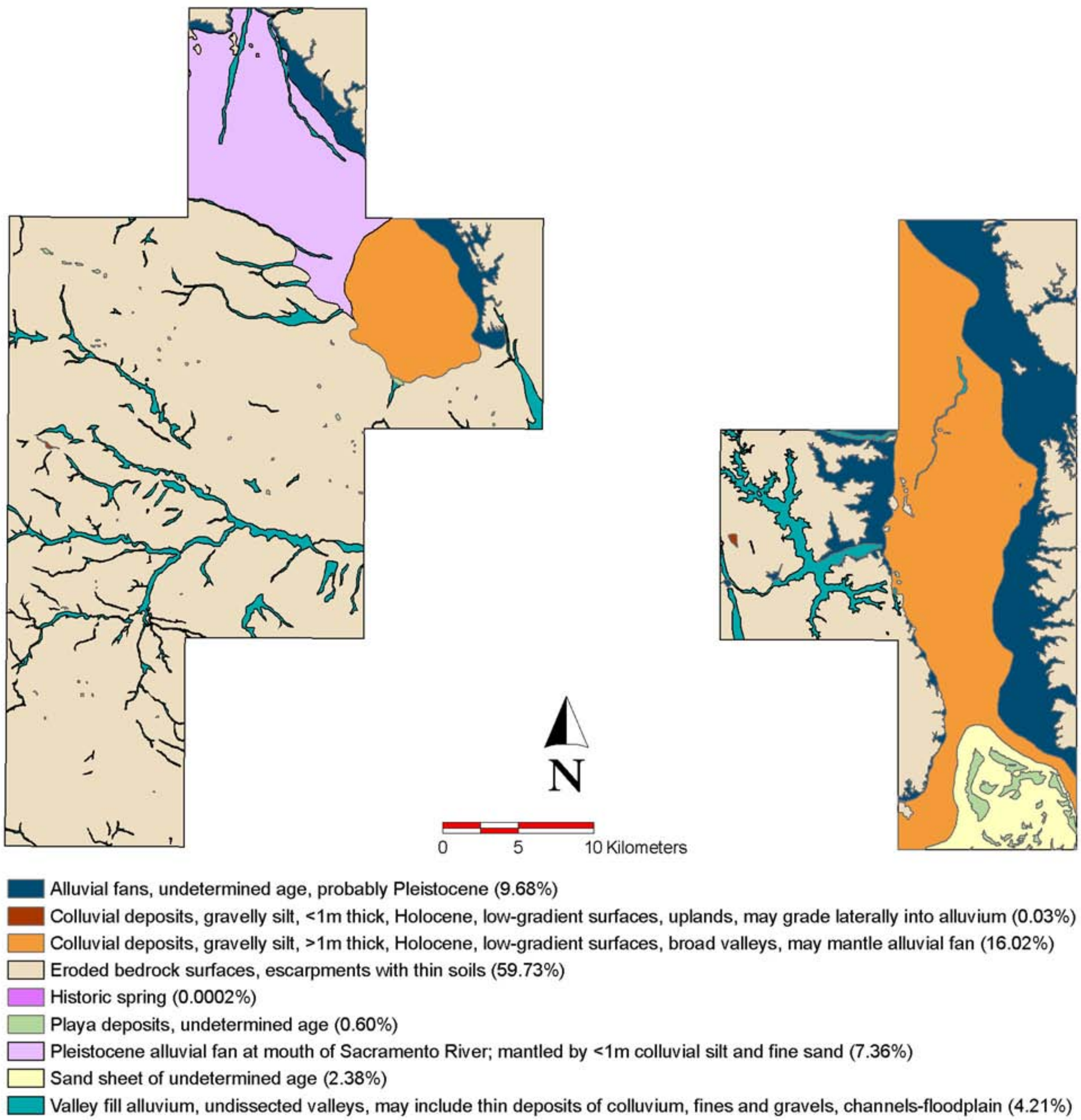

Figure 7.4. Geomorphology of the Otero Mesa study units.

Eroded bedrock surfaces. Most of the project area is classified as eroded limestone bedrock. Soils and geomorphic deposits are generally absent. If an ancient (Pleistocene) soil was present on the limestone hills and low-relief limestone mountains, it is gone now.

Archaeological sites located on areas of exposed limestone bedrock will be highly visible. These sites may have poor integrity, however, as deposits at the sites may be compromised by bioturbation, potentially destroying any original site stratigraphy.

Broad areas of low relief that are underlain by Permian limestone may have a mantle of recent colluvial sand and silt that is comparatively thin, generally less than 0.5 m in thickness. The absence of soil development indicates a recent age of the sandy silt. Archaeological sites may be partly buried by the colluvial mantle.

Alluvium. A few ephemeral streams with thin alluvial deposits occur in the area. Streams that originate in canyons cut into limestone bedrock may have alluvial deposits of considerable thickness, especially at the mouths of small canyons where alluvial fans have formed. The age of the thicker alluvium appears to be largely pre-Holocene, however, so archaeological sites are likely to occur on the present-day surface of the alluvial fill or at shallow depth.

Alluvial fans. Alluvial fans form broad, sloping surfaces along limestone escarpments. Where exposed, the fans are composed of gravels, some of which are cemented by carbonates, indicating a pre-Holocene age. Archaeological sites may be found on the surfaces of these old alluvial fans. Site integrity may be low, however, owing to postoccupational bioturbation.

Deposits at Salt Basin. The Salt Basin in the southern portion of the eastern study unit is a down-faulted graben with playas and associated eolian deposits. The playas are characterized by saline water, and their deposits are evaporites of late Pleistocene age. Along the margins of the playas are gypsiferous eolian sands of Holocene age. Extensive archaeological deposits buried in the sheet sand/coppice dunes along the eastern flank of the Salt Basin have recently been recorded (Tim Kearns, Western Cultural Resources Management, Farmington, NM, personal communication 2004). These data were not available for this study, however.

Summary. Denuded limestone and thin colluvial-alluvial deposits characterize a large proportion of the Otero Mesa study area. Archaeological sites in these settings will be highly visible, although site integrity may be affected by post-occupation bioturbation. Thin alluvial deposits associated with small ephemeral streams may also incorporate archaeological sites. Some thicker alluvial deposits at the mouths of canyons may be older, and sites will likely occur at the present-day surface. The eolian sands along the eastern margins of the Salt Basin are now known to contain buried archaeological sites as well.

Vegetation

The vegetation data (Figure 7.5) 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 on common descriptions of vegetation.

As Figure 7.5 shows, most of the vegetation in the study area is Chihuahuan desert scrub, dominated by creosotebrush (*Larrea tridentata*), with substantial areas of Chihuahuan foothill-piedmont desert grasslands along the western edges of the western study unit and the eastern edges of the eastern study unit. The central and southern portions of the eastern study unit are dominated by Chihuahuan lowland desert grasslands. The grasslands are characterized by several species of grama grass (*Bouteloua* sp.) and by alkali sacaton (*Sporobolus airoides*) and various other species of dropseed (*Sporobolus* sp.), as well as a variety of forbs.

Archaeological Data

As with the Loco Hills and Azotea Mesa predictive models, the next step for the Otero Mesa models was to examine the dependent variable, the presence or absence of archaeological sites dating prior to European contact. 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 the subject of archaeological surveys, the sites that have been recorded, and various characteristics of those sites. As with Loco Hills and Azotea Mesa, the ARMS data were accepted at face value and no fieldwork or additional archival investigations were completed.

Ideally, we would have created predictive models for each site class and/or temporal period. With only 95 total sites (78 in the western study unit and 17 in the eastern study unit), however, we were forced to combine all site data for each

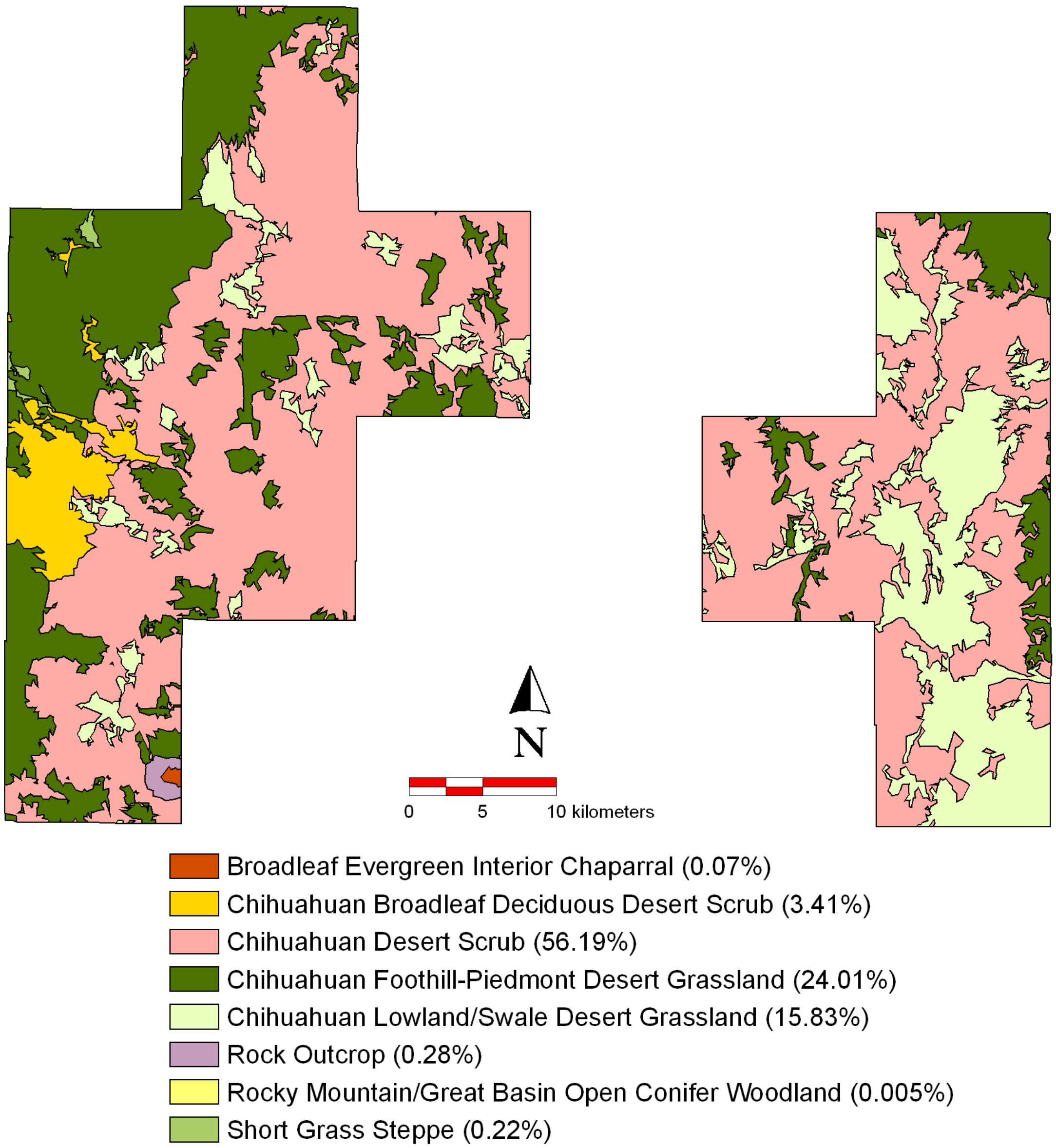

Figure 7.5. Vegetation of the Otero Mesa study units.

study area. The small sample even precluded us from distinguishing sites based on size as we did for Azotea Mesa. As before, we were able to separate historical from precontact components and exclude the former from the models. The site data, while sparse, did allow for statistical analysis; the necessity of combining all the site data did, however, impose limitations on the predictive value of the modeling as discussed below.

Site Data

The archaeological site data provided by ARMS are shown graphically in Figure 7.6. The site data were provided as polygon features, with each site polygon linked to available information, such as area, site number, and a site description.

An important part of GIS data is its spatial orientation 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. The UTM georeference system is common for archaeological applications, and *x* and *y* coordinates are given in meters.

The GIS site data layer contains 324 polygons overall for Otero Mesa. This number is reduced to 103 when only our eastern and western study units are included. Eight of these sites date exclusively to the historical period, leaving 95 polygons to be used in the creation of the predictive models.

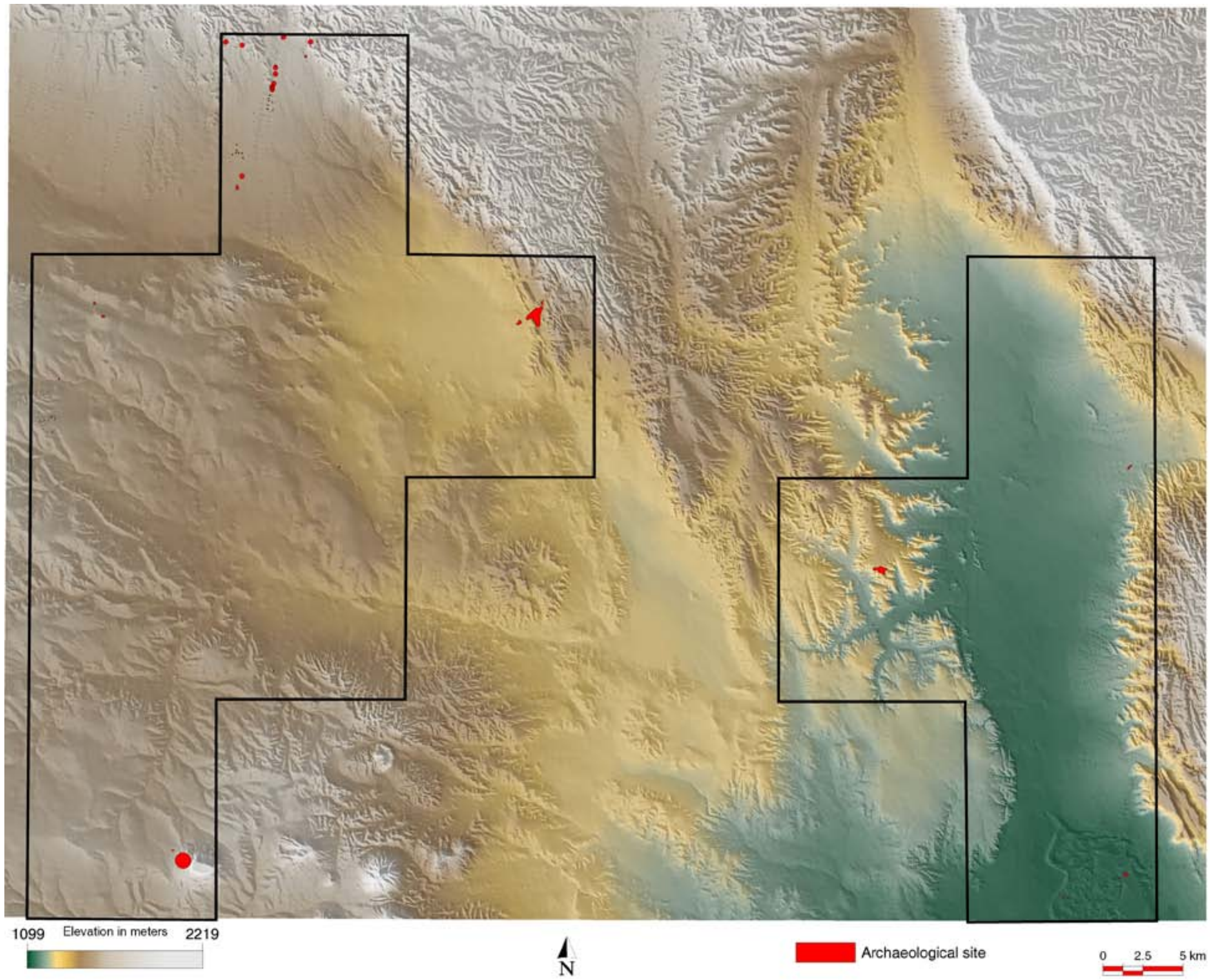

Figure 7.6. Prehistoric sites in the Otero Mesa study units (n = 95).

Survey Data
The survey data originally contained 143 polygons. For the purposes of our analysis, the survey data were clipped to only those surveyed areas falling within the boundaries of the two study areas, as shown in Figure 7.7. This resulted in a total of 119 polygons. As the figure shows, surveys have been rare in the east; the western unit's survey coverage is slightly better, but it is still largely unknown. As with the site data, the survey polygons were linked to information on the nature and year of the survey. These data were used to develop the survey histories presented later in this chapter.

Evaluating the Data
As a general rule, predictive modelers warn that unless 10% of each possible value for each environmental variable has been surveyed for archaeological sites, it is best to eliminate that variable from consideration. The problem with Otero Mesa, however, is that none of the values for any of the environmental variables meet this criterion. Although stopping at this point would probably have been prudent, we were committed to performing the modeling exercise. We tried to gain confidence in our ability to use the outcome of our modeling effort by comparing the Otero Mesa study areas with those at Loco Hills and Azotea Mesa. We reasoned that if the environments were roughly comparable, then even though the Otero Mesa region is poorly studied, we might be able to use the modeling results at least heuristically. Unfortunately, as shown in Table 7.3, the environments are not similar. We proceed with the Otero Mesa model despite the data limitations, but we urge extreme skepticism about the meaningfulness of the results.

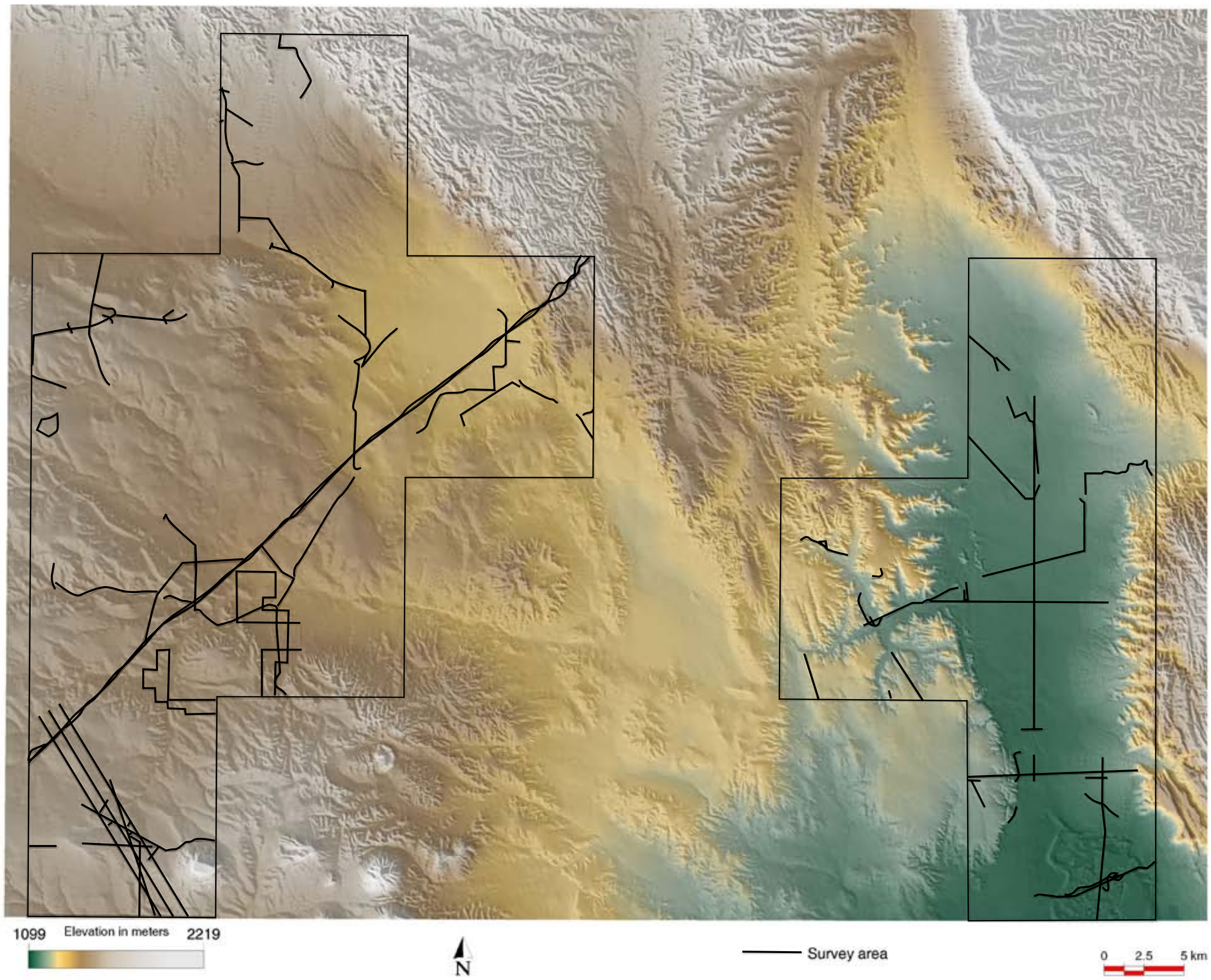

Figure 7.7. Archaeological surveys within the Otero Mesa study units.

The Association between Environmental Variables and Site Location

Two statistical testing methods were employed to test environmental data layers for significance in relation to site location. Continuous layers such as slope and elevation were tested using a one-sample means test. Categorical variables such as geomorphology and vegetation were evaluated using chi-square tests.

One-Sample Means Test. A one-sample means test can be conducted with GIS data by treating the environment of the archaeological site locations as a sample of the environmental background (total population), and testing the difference between the sample and population means. Because so little of Otero Mesa has been surveyed, we were concerned that the surveyed areas might not be representative of the entire environment. To test this possibility, we also calculated the one-sample means test by treating the surveyed area (rather than the entire study area) as the environmental background.

The means test is conducted by computing a z-score as described in Chapter 6. If the difference is significant at the 0.05 level ($z > 1.96$), then the sample (in this case, archaeological sites) is unique and does not follow a normal distribution with relation to the background environment. Such a result would suggest that the sites are located within specific environmental niches rather than being randomly distributed throughout the study area.

In our models of Loco Hills and Azotea Mesa, we used site cells as the unit of analysis, so the sample size was not the number of sites but rather the number of pixels coded as sites. In his review of the draft technical summary of Otero Mesa, Keith Kintigh pointed out that the use of site cells as opposed to sites had the effect of inflating the *z*-scores and chi-square scores, making it easier to obtain a significant relationship between site cell locations and environmental features. In his review comments, Kintigh noted that:

> Particularly with respect to environmental variables, a chi-square test or for that matter the means test assumes that the observations are independent. Because of spatial autocorrelation, the observations for multiple cells for a single site are manifestly not independent observations.

There is no easy solution to this problem. The predictive model being developed predicts site cells, not sites. We do, however, recognize that by splitting sites into large numbers of cells we have inflated the chi-square and *z*-scores. To address this problem, we calculated the scores for Otero Mesa using both site cells and sites as the unit of analysis. To establish the environmental measurement for a site on each environmental variable, we had the GIS average the scores for that variable from the constituent site cells.

A second problem pointed out by Kintigh was the use of all cells in the study area to represent the environmental background as opposed to only those cells that had been surveyed. Using the entire study area provides the best representation of the environmental features of the region, but Kintigh is correct in pointing out that we can only measure the association between environmental variables and site location for areas that we have surveyed. If we were to use surveyed areas only in a situation like Otero Mesa, where survey coverage is limited and many environmental variables have been underrepresented, the results would be problematic. To evaluate this issue, for Otero Mesa we calculated the associational tests independently, using first the entire study area and then the surveyed areas only to represent the environmental background.

The one-sample means test results that show a significant relationship between site location and environmental variables are presented in Tables 7.4 and 7.5 for the eastern and western study units, respectively. The tables present first the results for tests that used the entire study area as the population (Column 2) and then the results for tests that used only surveyed areas as the population (Column 3).

In both the east and west study units, sites appear to be found in counterintuitive locations—away from stream intersections and at higher elevations. Other relationships appear when site cells are used (as opposed to whole sites), but these are likely to be the result of the large numbers of cells inflating the results, as discussed above. Most of these relationships between site cells and environmental variables vanish when polygons are used to represent sites, suggesting that these relationships are weak or nonexistent.

Table 7.3. Average Environmental Scores for Each Study Area

	Loco Hills	Azotea Mesa	Otero Mesa West	Otero Mesa East
Elevation (m) mean ± s.d.	1,121 ± 70	1,198 ± 144	1, 468 ± 91	1,207 ± 105
Geomorphology†	Parabolic dunes, 55% Coppice dunes, 13% Eroded bedrock, 13%	Eroded limestone, 83% Extensive slope-wash deposits, 9% Floodplains of large drainages, 4%	Eroded bedrock, 75% Pleistocene alluvial fan at mouth of Sacramento River, 12% Holocene colluvial deposits, gravelly silt >1 m thick, 4%	Holocene colluvial deposits, gravelly silt >1 m thick, 33% Eroded bedrock, 32% Alluvial fans of undetermined age, 22%
Vegetation†	Chihuahuan desert grassland, 59% Chihuahuan desert scrub, 19% Broadleaf evergreen interior chaparral, 11%	Chihuahuan foothill-piedmont desert grassland, 69% Chihuahuan desert scrub, 15% Chihuahuan desert grassland, 6%	Chihuahuan Desert scrub, 56% Chihuahuan foothill-piedmont desert grassland, 32% Chihuahuan lowland/swale desert grassland, 6%	Chihuahuan Desert scrub, 57% Chihuahuan lowland/swale desert grassland, 34% Chihuahuan foothill-piedmont desert grassland, 9%
Distance to water (m) mean ± s.d.	1,967 ± 1,694	636 ± 478	209 ± 212	284 ± 324
Survey coverage (% of total area)	19%	10%	3%	0.4%
Prehistoric sites				
Number of polygons	779	550	78	17
Acreage (range)	0.01–890.95	0.15–313.82	0.05–193	0.17–56.03
Acreage (mean ± s.d.)	7.14 ± 41.1	4.62 ± 19.22	7.94 ± 28.48	4.85 ± 13.52

† Top three geomorphology and vegetation categories by area are reported with percent of total study area represented.

Table 7.4. One-Sample Means Test for Continuous Variables of the Eastern Study Unit, Listed in Order of Significance

GIS layer	Means test using study area as population	Means test using survey areas as population	Variable assessment
DISTANCE FROM STREAM INTERSECTIONS			
cells	$Z = (932.86 – 606.37) / (355.77 / \sqrt{3164}) = 51.62$	$Z = (932.86 – 2362.55) / (1775.18 / \sqrt{3164}) = –45.3$	Cells: Site cells are located further from stream intersections than non site cells when the entire study area is considered. However, when only cells from survey areas are considered, site cells are found to be statistically closer than non site cells to stream intersections.
polygons	$Z = (507.375 – 606.37) / (355.77 / \sqrt{17}) = –1.15$	$Z = (507.38 – 2362.55) / (1775.18 / \sqrt{17}) = –4.31$	Polygons: Sites are not found to be statistically associated with stream intersections when the entire study area is considered. Sites are statistically closer to stream intersections when only areas that have been surveyed are considered.
DISTANCE FROM STREAMS			
cells	$Z = (343.66 – 209.02) / (171.67 / \sqrt{3164}) = 44.12$	$Z = (343.66 – 324.4) / (256.46 / \sqrt{3164}) = 4.22$	Cells: Site cells are located further from streams than non site cells when the entire study area and when only areas that have been surveyed are considered.
polygons	$Z = (209.46 – 209.02) / (171.67 / \sqrt{17}) = 0.01$	$Z = (209.46 – 324.4) / (256.46 / \sqrt{17}) = –1.85$	Polygons: Sites are not found to be statistically associated with streams.
ELEVATION			
cells	$Z = (1284.11 – 1207.22) / (104.74 / \sqrt{3164}) = 41.29$	$Z = (1284.11 – 1234.55) / (457.52 / \sqrt{3164}) = 6.09$	Cells: Site cells are located at higher elevations than non site cells when the entire study area and when only areas that have been surveyed are considered.
polygons	$Z = (1158.98 – 1207.22) / (104.74 / \sqrt{17}) = –1.90$	$Z = (1158.98 – 1234.55) / (457.52 / \sqrt{17}) = –0.68$	Polygons: Sites are not found to be statistically associated with elevation.
COST DISTANCE FROM STREAMS			
cells	$Z = (94.59 – 84.18) / (175 / \sqrt{3164}) = 32.39$	$Z = (94.59 – 170.62) / (234.75 / \sqrt{3164}) = –18.22$	Cells: Site cells have higher cost distance to streams than non site cells when the entire study area is considered. However, site cells have lower cost distance to streams when only the surveyed areas are considered.
polygons	$Z = (17.72 – 84.18) / (175 / \sqrt{17}) = –1.57$	$Z = (17.72 – 170.62) / (234.75 / \sqrt{17}) = –2.69$	Polygons: Sites have lower cost distance to streams when both the entire study area and only areas that have been surveyed are considered.
DISTANCE FROM RIDGES			
cells	$Z = (141.67 – 314.58) / (371.95 / \sqrt{3164}) = –26.15$	$Z = (141.67 – 1682.56) / (1583.6 / \sqrt{3164}) = –54.73$	Cells: Site cells are closer to ridges than non site cells when the entire study area and when only areas that have been surveyed are considered.
polygons	$Z = (340.75 – 314.58) / (371.95 / \sqrt{17}) = 0.29$	$Z = (340.75 – 1682.56) / (1583.6 / \sqrt{17}) = –3.49$	Polygons: Sites are not statistically associated with distance to ridges when the entire study area is considered. Sites are closer to ridges when only surveyed areas are considered.
COST DISTANCE FROM RIDGES			
cells	$Z = (15.20 – 48.87) / (96.92 / \sqrt{3164}) = –19.6$	$Z = (15.20 – 142.94) / (220.96 / \sqrt{3164}) = –32.52$	Cells. Site cells have lower cost distances to ridges than non site cells when the entire study area and when only areas that have been surveyed are considered.
polygons	$Z = (14.71 – 48.87) / (96.92 / \sqrt{17}) = –1.45$	$Z = (14.71 – 142.94) / (220.96 / \sqrt{17}) = –2.39$	Polygons: Sites are not statistically associated with cost distance to ridges when the entire study area is considered. Sites have lower cost distance to ridges than non sites when only surveyed areas are considered.
SLOPE			
cells	$Z = (2.69 – 4.99) / (8.58 / \sqrt{3164}) = –15.08$	$Z = (2.69 – 4.99) / (8.62 / \sqrt{3164}) = –15.01$	Cells: Site cells are located on flatter slopes than non site cells when the entire study area and when only areas that have been surveyed are considered.
polygons	$Z = (2.07 – 4.99) / (8.58 / \sqrt{17}) = –1.40$	$Z = (2.07 – 4.99) / (8.62 / \sqrt{17}) = –1.40$	Polygons: Sites are not found to be statistically associated with slope.

Table 7.5. One-Sample Means Test for Continuous Variables of the Western Study Unit, Listed in Order of Significance

GIS layer	Means test using study area as population	Means test using survey areas as population	Variable assessment
Cost distance from ridges			Cells: Site cells have higher cost distance to ridges than non site cells when the entire study area and only areas that have been surveyed are considered. Polygons: Sites are not statistically associated with cost distance to ridges.
cells	$Z = (192.94 - 38.91) / (108.45 / \sqrt{22777}) = 214.35$	$Z = (192.94 - 41.52) / (78.56 / \sqrt{22777}) = 290.89$	
polygons	$Z = (34.54 - 38.91) / (108.45 / \sqrt{78}) = -0.36$	$Z = (34.54 - 41.52) / (78.56 / \sqrt{78}) = -0.78$	
Slope			Cells: Site cells are located on steeper slopes than non site cells when the entire study area and when only areas that have been surveyed are considered. Polygons: Sites are not found to be statistically associated with slope.
cells	$Z = (6.94 - 2.57) / (4.56 / \sqrt{22777}) = 144.63$	$Z = (6.94 - 2.21) / (3.06 / \sqrt{22777}) = 233.29$	
polygons	$Z = (2.26 - 2.57) / (4.56 / \sqrt{78})) = -0.6$	$Z = (2.26 - 2.21) / (3.06 / \sqrt{78}) = 0.14$	
Elevation			Cells: Site cells are located at higher elevations than non site cells when the entire study area and when only areas that have been surveyed are considered. Polygons: Sites are located at higher elevations than non sites when the entire study area and when only areas that have been surveyed are considered.
cells	$Z = (1551.85 - 1467.88) / (91.25 / \sqrt{22777}) = 138.88$	$Z = (1551.85 - 1496.21) / (35.83 / \sqrt{22777}) = 234.36$	
polygons	$Z = (1535.52 - 1467.88) / (91.25 / \sqrt{78}) = 6.55$	$Z = (1535.52 - 1496.21) / (35.83 / \sqrt{78}) = 9.69$	
Cost distance from streams			Cells: Site cells have higher cost distance to streams than non site cells when the entire study area and when only the surveyed areas are considered. Polygons: Sites are not found to be statistically associated with cost distance to streams.
cells	$Z = (118.39 - 48.98) / (113.7 / \sqrt{22777}) = 92.13$	$Z = (118.39 - 44.85) / (64.11 / \sqrt{22777}) = 173.12$	
polygons	$Z = (42.91 - 48.98) / (113.7 / \sqrt{78}) = -0.47$	$Z = (42.91 - 44.85) / (64.11 / \sqrt{78}) = -0.27$	
Distance from stream intersections			Cells: Site cells are located further from stream intersections than non site cells when the entire study area and when only cells from survey areas are considered. Polygons: Sites are located further from stream intersections than non sites when the entire study area and when only cells from survey areas are considered.
cells	$Z = (806.12 - 675.75) / (450.91 / \sqrt{22777}) = 43.64$	$Z = (806.12 - 336.9) / (695.74 / \sqrt{22777}) = 101.78$	
polygons	$Z = (820.92 - 675.75) / (450.91 / \sqrt{78}) = 2.84$	$Z = (820.92 - 336.9) / (695.74 / \sqrt{78}) = 6.14$	
Distance from streams			Cells: Site cells are located closer to streams than non site cells when the entire study area and when only areas that have been surveyed are considered. Polygons: Sites are located closer to streams than non sites when the entire study area and when only areas that have been surveyed are considered.
cells	$Z = (224.54 - 283.59) / (270.73 / \sqrt{22777}) = -32.92$	$Z = (224.54 - 336.9) / (688.86 / \sqrt{22777}) = -24.62$	
polygons	$Z = (215.63 - 283.59) / (270.73 / \sqrt{78}) = -2.21$	$Z = (215.63 - 336.9) / (688.86 / \sqrt{78}) = -1.55$	
Distance from ridges			Cells: Site cells are farther away from ridges than non site cells when the entire study area is considered. However, site cells are closer to ridges than non site cells when only areas that have been surveyed are considered. Polygons: Sites are not statistically associated with distance to ridges.
cells	$Z = (265.43 - 236.18) / (231.13 / \sqrt{22777}) = 19.1$	$Z = (265.43 - 321.24) / (717.01 / \sqrt{22777}) = -11.75$	
polygons	$Z = (227.34 - 236.18) / (231.13 / \sqrt{78}) = -0.34$	$Z = (227.34 - 321.24) / (717.01 / \sqrt{78}) = -1.16$	

Categorical Chi-Square Goodness-of-Fit Test. The categorical variables—aspect, geomorphology, and vegetation—were tested for significance using a chi-square test at the 0.05 critical value level. The test assesses each environmental layer for significant differences between expected numbers of archaeological sites (if placement is random with respect to that variable) and observed numbers numbers of sites. The chi-square value is calculated using the formula provided in Chapter 6. For example, if a category covers 50% of the study area then the expected number of site cells should be 50% of the total site cells. The number actually observed is computed using the GIS to determine the actual number of site cells within the category. If an expected score is less than 5 then that category is combined with others until a value of 5 or greater is reached, thereby meeting statistical requirements of the test.

The degree of freedom (df) for these matrices is defined as the number of columns minus one multiplied by the number of rows minus one. We defined chi-square scores over 9.488 as indicative of a nonrandom relationship between site location and aspect variables, for example (df = 4), whereas for geomorphic variables we used a chi-square score of 14.067 (df = 7). In both cases, scores of more than the cutoff value occur less than 5 times in 100 as a result of chance alone. The highest score for each category is reported in bold in the accompanying tables to facilitate comparison of testing results between variables.

We determined the chi-square score for site polygons by transferring the data to TNTmipps GIS software. TNTmipps enabled us to transform raster statistics to vector data. One problem with this algorithm is that it handles the typology of polygons by dividing overlapping polygons into separate shapes and counting the resultant pieces as extra areas, thus increasing the site polygon count. For this reason, the number of polygons evaluated in this test is larger than the actual number of sites—20 for the eastern study unit (rather than 17) and 83 for the western study unit (rather than 78).

The results of the chi-square tests for significant association with aspect are presented in Tables 7.6 and 7.7. In the eastern study unit, site cells tend to be open to the south and east in greater proportions than expected; in the western study unit, site cells are mostly oriented to the west. In both areas, northern exposure occurs less often than expected. None of these associations, however, is significant when the unit of analysis switches from site cells to site polygons.

For geomorphology (Tables 7.8 and 7.9), the chi-square results are consistent with those for the one-sample means test. Site cells and sites in the eastern study unit are found on bedrock; site cells, but not sites, are also found in significant numbers on sand sheets but not on alluvium. Such conditions are found away from water and on elevated surfaces. In the western study unit, sites are found on almost the opposite landforms. Here, site cells and sites tend to be located on alluvial fan deposits and valley alluvium. Sites in the west are less often found on eroded bedrock. In both units, site cells and sites are rare on colluvial deposits. Though prehistoric peoples may have avoided these surfaces, it is also possible that the absence of sites is a result of postdepositional processes that have buried precontact cultural materials. The presence of archaeological deposits buried under shallow colluvial soils is indicated by recent, as yet

Table 7.6. Chi-Square Tests for Significant Association with Aspect in the Eastern Study Unit

	North (315–360°, 0–45°)	East (45–135°)	South (135–225°)	West (225–315°)	No Slope Direction
Background percentage	11.86	21.27	34.61	30.01	2.25
Survey percentage	16.03	40.49	29.69	13.73	0.06
Site cells	208	830	1743	365	19
Site polygons	3	5	7	5	0
Background cells expected	375.37	673.2	1095.41	949.82	71.21
Background site polygons expected	2.37	4.25	6.92	6.00	0.45
	(combine with east)				(combine with west)
Survey site cells expected	507.35	1281.51	939.69	434.55	71.21
Survey site polygons expected	3.21	8.1	5.94	2.75	0.01
	(combine with west)				(combine with west)
Background site cell P^2	74.63	36.52	**382.85**	360.08	38.28
Background site polygon P^2	(combined with east)	0.17	0.001	**0.33**	(combined with west)
Survey site cell P^2	176.62	159.08	**686.72**	11.13	38.28
Survey site polygon P^2	(combined with west)	1.19	0.19	**2.03**	(combined with west)
Survey coverage %	0.01	0.35	0.5	0.22	0.12

Background site cell P^2 = 74.62 + 36.52 + 382.85 + 360.08 + 38.28 = 892.35
Background site polygon P^2 = 0.17 + 0.001 + 0.33 = 0.501
Survey site cell P^2 = 176.62 + 159.08 + 686.72 + 11.13 + 38.28 = 1071.83
Survey site polygon P^2 = 1.19 + 0.19 + 2.03 = 3.41

Table 7.7. Chi-Square Tests for Significant Association with Aspect in the Western Study Unit

	North (315–360°, 0–45°)	East (45–135°)	South (135–225°)	West (225–315°)	No Slope Direction
Background percentage	23.77	30.83	30.31	14.79	0.25
Survey percentage	27.93	31.83	31.68	8.56	0
Site cells	2580	1453	6988	11757	0
Site polygons	22	18	31	13	0
Background site cells expected	5414.09	7022.46	6904.01	3368.72	56.94
Background site polygons expected	19.97	25.9	25.46	12.42	0.21
					(combined with west)
Survey site cells expected	6361.90	7250.24	7216.07	1949.80	0
Survey site polygons expected	23.46	26.74	26.61	7.19	0
Background site cell P^2	1483.55	4416.8	1.03	**20887.23**	56.95
Background site polygons P^2	0.21	**2.41**	1.21	0.01	(combined with west)
Survey site cell P^2	2248.19	4635.43	7.21	**49328.74**	
Survey site polygons P^2	0.09	2.86	0.72	**4.69**	0
Survey coverage %	0.42	1.57	1.38	1.4	0.77

Background site cell P^2 = 1,483.55 + 4,416.8 + 1.03 + 20,887.23 + 56.95 = 26,845.56
Background site polygon P^2 = 0.21 + 2.41 + 1.21 + 0.01 = 3.84
Survey site cell P^2 = 2248.19 + 4635.43 + 7.21 + 49328.74 = 56219.57
Survey site polygon P^2 = 0.09 + 2.86 + 0.72 + 4.69 = 8.36

Table 7.8. Chi-Square Tests for Significant Association with Geomorphic Units in the Eastern Study Unit

	Eroded bedrock	Sand sheet	Valley fill alluvium	Alluvial fans	Playa deposits	Colluvial deposits <1 m thick	Colluvial deposits >1 m thick
Background percentage	32.29	6.49	3.88	22.23	1.44	0.05	33.62
Survey percentage	74.62	0	11.03	14.35	0	0	0
Site cells	2153	569	28	324	0	0	85
Site polygons	2	5	2	5	0	0	6
Background site cells expected	1020.04	205.02	122.57	702.25	45.49	1.58	1062.06
Background site polygons expected	6.46	1.30†	0.78†	4.45	0.29†	0.01†	0
Survey site cells expected	2357.25	0	348.44	453.32	0	0	0
Survey site polygons expected	14.92	0	2.21	2.87	0	0	0
Background site cell P^2	**1258.38**	646.19	72.97	203.74	45.49	1.58	898.86
Background site polygon P^2	3.08	†	†	0.49	†	†	**6**
Survey site cell P^2	17.7	**569**	294.69	36.89	0	0	85
Survey site polygon P^2	**11.19**	†	†	3.91	†	†	6
Survey coverage %	0.24	0.14	0.3	0.07	0	0	0.004

Background site cell P^2 = 1258.38 + 646.19 + 72.97 + 203.74 + 45.49 + 1.58 + 898.86 = 3127.21
Background site polygon P^2 = 3.08 + 0.49 + 6 = 9.57
Survey site cell P^2 = 17.7 + 569 + 294.69 + 36.89 + 85 = 1003.28
Survey site polygon P^2 = 11.19 + 3.91 + 6 = 21.1

† Cells combined with Alluvial fans

Table 7.9. Chi-Square Tests for Significant Association with Geomorphic Units in the Western Study Unit

	Eroded bedrock	Historically known spring	Valley fill alluvium	Alluvial fans	Playa deposits	Colluvial deposits <1 m thick	Colluvial deposits >1 m thick	Pleistocene alluvial fan*
Background percentage	75.42	0.0003	4.4	2.52	0.11	0.02	5.97	11.56
Survey percentage	91.85	0	7.83	0	0.009	0.11	0	0.20
Site cells	10960	37	2923	59514	0	0	0	2904
Site polygons	49	0	15	2	0	0	0	18
Background site cells expected	17179.17	0.07	1002.23	574	25.06	4.56	1359.85	2633.14
Background site polygons expected	63.35	0†	3.7	2.12†	0.09†	0.02†	50.15	9.71
Survey site cells expected	20921.59	0.07†	1002.23	0	2.05‡	25.06	1359.85	2633.14
Survey site polygons expected	77.15	0†	6.58	0	0.008†	0.09†	0	0.17†
Background site cell P^2	2251.45	19483.21	3681.15	**50425.78**	25.06	4.56	1359.85	27.86
Background site polygon P^2	3.25	†	20.66	†	†	†	**50.15**	7.08
Survey site cell P^2	4743.10	†	3823.79	**5954**	‡	25.06	1359.85	27.86
Survey site polygon P^2	10.27	†	**99.83**	†	†	†	0	†
Survey coverage %	1.55	100	2.26	2.18	0.1	9.09	0	0

Background site cell P^2 = 2251.45 + 19483.21 + 3681.15 + 50425.78 + 25.06 + 4.56 + 1359.85 + 27.86 = 77258.92

Background site polygon P^2 = 3.25 + 20.66 + 50.15 + 7.08 = 81.14

Survey site cell P^2 = 4743.1 + 3823.79 + 5954 + 25.06 + 1359.85 + 27.86 = 15933.66

Survey site polygon P^2 = 10.27 + 99.83 = 110.1

* mouth of Sacramento River

† Cells combined with Valley fill alluvium

‡ Cells combined with Colluvial deposits <1 m thick

unreported fieldwork within the eastern study unit (Tim Kearns, personal communication). This underscores the difficultly of modeling the relationship between site location and landforms in the absence of sufficient site and survey data.

The results of the chi-square tests for significant association with vegetation units are presented in Tables 7.10 and 7.11. In order to meet the statistical assumptions of the chi-square test, many of the vegetative communities needed to be combined. In the east, we found significant associations between site cells and cells coded for Chihuahan desert scrub, Chihuahuan foothill/piedmont, and Chihuahuan lowland/swale, though no significant relationships emerged when site polygons were used. In the west, a variety of "combined" environmental zones were related at significant levels to both site cells and site polygons.

Statistical Independence

In the preceding section, we often remarked that the relationship between site locations and one environmental theme was similar to that found with another theme. Such results are expected because environmental variables are closely related to one another. Plants of a particular vegetative community will occur only on well-watered, well-drained soils, for example. Conversely, areas devoid of vegetation generally lack soils or water or both—an exposed rock surface, for example.

While the interrelationship between environmental variables is expected, it also violates a fundamental assumption of most statistical tests: that the independent variables used in the analysis are statistically independent of one another. Complete independence is rare in the social sciences. Modelers of real world situations, therefore, accept that there are problems of interdependence and concentrate on understanding the statistical effect of interrelationships of independent variables on model predictions.

In general, violations of the independence assumption lead to an overstating of the predictive power of the statistical model. Intuitively, such a result makes sense. Assume, for example, that a specific vegetative community is found only on a particular geomorphic landform. If both variables are included in the model without accounting for the interrelationship, the predictive power of the model will likely be overstated.

To guard against including supposedly independent variables that are, in fact, related to each other, for each study area we calculated the pair-wise Spearman's r between each pair of those environmental variables that were measured on a continuous scale (Tables 7.12 and 7.13). Any r score that exceeded 0.5 was noted, and the pair of variables was examined. The one with the weaker relationship to site location was removed before model development.

Table 7.10. Chi-Square Tests for Significant Association with Vegetation Units in the Eastern Study Unit

	Rky Mtn/Great Basin open conifer	Chihuahuan Desert scrub	Chihuahuan foothill-piedmont	Chihuahuan lowland/swale
Background percentage	0.01	57.01	9.44	33.53
Survey percentage	0	83.62	6.33	10.05
Site cells	0	442	21	2702
Site polygons	0	7	1	12
Background site cells expected	0.32	1804.37	298.78	1061.22
Background site polygons expected	0.002†	11.4	1.89†	6.71
Survey site cells expected	0	2646.57	200.34	318.08
Survey site polygons expected	0	16.72	1.27†	2.01†
Background site cell χ^2	0.32	1028.64	258.25	**2536.85**
Background site polygon χ^2	0†	1.70	0†	**2.25**
Survey site cell χ^2	0	1836.39	160.51	**17866.81**
Survey site polygon χ^2	0	0	†	†
Survey coverage %	0	0.15	0.07	0.03

Background site cell χ^2 = 0.32 + 1028.64 + 258.25 + 2536.85 = 3824.06
Background site polygon χ^2 = 1.70 + 2.25 = 3.95
Survey site cell χ^2 = 1836.39 + 160.51 + 17866.81 = 19863.71
Survey site polygon χ^2 = 0

† Cells combined with Chihuahuan Desert scrub

Table 7.11. Chi-Square Tests for Significant Association with Vegetation Units in the Western Study Unit

	Broadleaf evergreen	Chihuahuan Desert scrub	Chihuahuan broadleaf deciduous	Short-grass steppe	Chihuahuan foothill-piedmont	Chihuahuan lowland/swale	Rock outcrop
Background percentage	0.1	55.77	5.36	0.34	32.35	5.65	0.43
Survey percentage	6.16	64.35	0	1.31	16.47	11.70	0
Site cells	0	8952	6	34	7198	68	6520
Site polygons	0	17	1	5	60	0	1
Background site cells expected	22.78	12703.29	1220.9	77.45	7368.68	1286.96	97.95
Background site polygons expected	0.084†	46.85	4.50‡	0.28‡	27.17	4.75	0.36*
Survey site cells expected	1403.12	14657.64	0†	298.39	3751.54	2665.03	0*
Survey site polygons expected	5.17	54.05	0†	1.10‡	60	0	1*
Background site cell P^2	22.78	1107.76	1208.93	24.38	3.95	1154.55	421058.97
Background site polygon P^2	†	19.09	‡	‡	36.29	3.31	*
Survey site cell P^2	1403.12	2219.42	†	233.86	3166.19	5774.68	*
Survey site polygon P^2	5.17	24.04	†	‡	167.92	9.02	*
Survey coverage %	0	1.47	1.48	5.08	0.65	2.63	13.95

Background site cell $P^2 = 22.78 + 1107.76 + 1208.93 + 24.38 + 3.95 + 1154.55 + 421058.97 = 424581.32$

Background site polygon $P^2 = 19.09 + 36.29 + 3.31 = 58.69$

Survey site cell $P^2 = 1403.12 + 2219.42 + 233.86 + 3166.19 + 5774.68 = 12797.27$

Survey site polygon $P^2 = 5.17 + 24.04 + 167.92 + 9.02 = 206.15$

† Cells combined with Chihuahuan Desert scrub
‡ Cells combined with Chihuahuan foothill-piedmont desert grassland
* Cells combined with Chihuahuan lowland/swale desert grassland

Table 7.12. Pair-wise Spearman's *r* Scores for Eastern Study Unit Environmental Variables Measured on a Continuous Scale

	Elev.	Geo.	Veg.	Slope	Aspect	Dist. from streams	Cost dist. from streams	Dist. to ridges	Cost dist. from ridges	Dist. from stream inters.
Elevation	1									
Geomorphology	—	1								
Vegetation	—	—	1							
Slope	—	—	—	1						
Aspect	—	—	—	—	1					
Distance from streams	0.24	—	—	—	—	1				
Cost distance from streams	**0.69**	—	—	—	—	0.45	1			
Distance to ridges	–0.3	—	—	—	0	–0.09	–0.23	1		
Cost distance from ridges	**0.54**	—	—	—	0.03	0.08	0.5	–0.09	1	
Dist from stream intersection	0.22	—	—	—	0.04	0.44	0.28	–0.07	0.14	1

Table 7.13. Pair-wise Spearman's Scores for Western Study Unit Environmental Variables Measured on a Continous Scale

	Elev.	Geo.	Veg.	Slope	Aspect	Dist. from streams	Cost dist. from streams	Dist. to ridges	Cost dist. from ridges	Dist. from stream inters.
Elevation					1					
Geomorphology	—					1				
Vegetation	—	–0.05					1			
Slope	—	—	—				1			
Aspect	—	0.01	—	–0.75			1			
Distance from streams	–0.01	0.09	—	0.03	—			1		
Cost distance from streams	0.16	–0.15	—	—	—	0.21	1			
Distance to ridges	0.02	0.09	—	—	—	0.01	–0.05	1		
Cost distance from ridges	0.17	–0.11	—	—	—	0	**0.5**	0.29	1	
Distance from stream intersection	–0.01	0.09	—	—	—	**0.62**	0.25	–0.03	0.11	1

Selection of Independent Variables

The foregoing sections describe our evaluation of the statistical association between environmental variables and the targeted cultural variables as well as the degree of statistical independence between environmental variables. Based on these analyses, we chose a set of environmental variables to serve as the independent variables in the predictive models (Table 7.14). Although we would have preferred to have each independent variable strongly correlated with site locations, as defined by sites cells and polygons, such a selection criterion would have left us with few variables. We strongly suspect that it is the lack of survey on Otero Mesa, and not cultural behavior, that explains the weak relationships. In selecting independent variables we were guided by the results of the statistical tests, but we also used the knowledge gained from the better studied locales of Loco Hills and Azotea Mesa.

Table 7.14. Environmental Variables Used for Modeling the Study Units

Section	Environmental Variables Used in Model
East	Elevation, geomorphology, vegetation, slope, aspect, distance from streams, distance from ridges, and distance from stream intersections
West	Geomorphology, vegetation, slope, aspect, distance from streams*, distance from ridges, and cost distance from ridges

* Distance from streams was chosen rather than the distance from stream intersections layer because distance from streams is more likely to have affected human behavior.

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 Otero Mesa, we used the same three modeling techniques that were employed at Azotea Mesa: Boolean intersection, weighted method, and logistic regression. All three allow the use of variables measured on different scales, although the first two require that data measured on interval scales be transformed into data measured on ordinal or nominal scales. In our previous technical summaries, we have described each of the methods. The reader is referred to Chapter 4 for a description of these modeling methods.

Boolean Model

The first step in creating a Boolean model is to define the states that are favorable for human settlement for each environmental variable. For categorical variables, this step consists simply of defining the appropriate environmental features, such as eroded bedrock or historically known springs. For continuous variables we need to define a break point, or cutoff range, for each variable that distinguishes cells likely to contain sites (e.g., sites located between 1,103 and 1,360 m above sea level) from those that probably do not (e.g., above 1,360 or below 1,103 m above sea level). In Boolean models, it is preferable to be generous with categorical states and cutoff ranges because the intersecting properties of the method have a tendency to greatly reduce the favorable zone. For each variable, we chose states and cutoff ranges so that a large percentage (90–100%) of the known site cells were included in the favorable category (Tables 7.15 and 7.16).

The Boolean model for the western study unit is presented in Figure 7.8 and the model for the eastern study unit in Figure 7.9. The locations of sites used to develop the model are shown in green. The blue polygons represent anomalies, site areas that are not correctly predicted by the model. For the Boolean model, 11 sites were misidentified; 8 sites were correctly identified. Two of these sites were misidentified by the other two modeling techniques as well. These two sites, along with other sites with anomalous locations, will be discussed later in this chapter.

Each Boolean model was tested using the Gain Statistic. This statistic is discussed in Chapter 4; for more detail, the reader is referred to the original source (Kvamme 1988).

Gain Statistic = 1 – (proportion of model area / proportion of sites correctly located)
East Gain = 1 – (0.31/0.81) = 0.62

A gain score of 0.62 indicates a relatively good model. To measure exactly how good a predictor the model is, we calculate the model's performance relative to a random predictor by applying the equation,

Gain over random = proportion of site cells correctly located – proportion of model
East gain over random = 0.81 – 0.31 = 0.5

From this score, our chance of locating an archaeological site by using the Boolean model is 50% better than if we randomly pick areas.

West Gain = 1 – (0.56/0.87) = 0.36

A gain score of 0.36 for the west study unit indicates a decent model. To measure exactly how strong, we calculated the model's performance relative to a random predictor:

West gain over random = 0.87 – 0.56 = 0.31

From this score, our chance of locating an archaeological site using the Boolean model is 31% better than if we randomly pick areas.

Table 7.15. Boolean Model Variables for the Eastern Study Unit

	Cutoff range for continuous variables	% of site cells contained in favored state/range	% of study unit contained in favored state/range
Elevation	1103–1360m	100	91
GEOMORPHOLOGY			
Alluvial fans	—	26	3
Historically recorded spring	—	0.2	0.0003
Eroded bedrock	—	48	75
Pleistocene alluvial deposits at mouth of Sacramento River	—	13	12
Valley fill alluvium	—	13	4
VEGETATION			
Rock outcrop	—	29	0.43
Chihuahuan foothill-piedmont	—	32	32
Chihuahuan Desert scrub	—	39	56
ASPECT	—	17	15
North	315–361°, 0–45°	11	24
South	135–225°	31	30
West	225–315°	52	15
Slope	0–27°	95	99
Distance from streams	0–600 m	100	97
Distance from ridges	0–425 m	95	77
Distance from stream intersections	0–1308 m	95	96

Table 7.16. Boolean Model Variables for the Western Study Unit

	Cutoff range for continuous variables	% of site cells contained in favored state/range	% of study unit contained in favored state/range
GEOMORPHOLOGY			
Eroded bedrock	—	68	32
Sand sheet	—	18	6
Alluvial fans	—	10	22
VEGETATION			
Chihuahuan lowland/swale	—	85	34
Chihuahuan Desert scrub	—	14	57
ASPECT	—	17	15
East	45–135°	26	21
South	135–225°	55	35
West	225–315°	12	30
Slope	0–27°	100	95
Distance from streams	0–910 m	100	97
Distance from ridges	0–751 m	95	96
Cost distance to ridge	0–1484	100	99

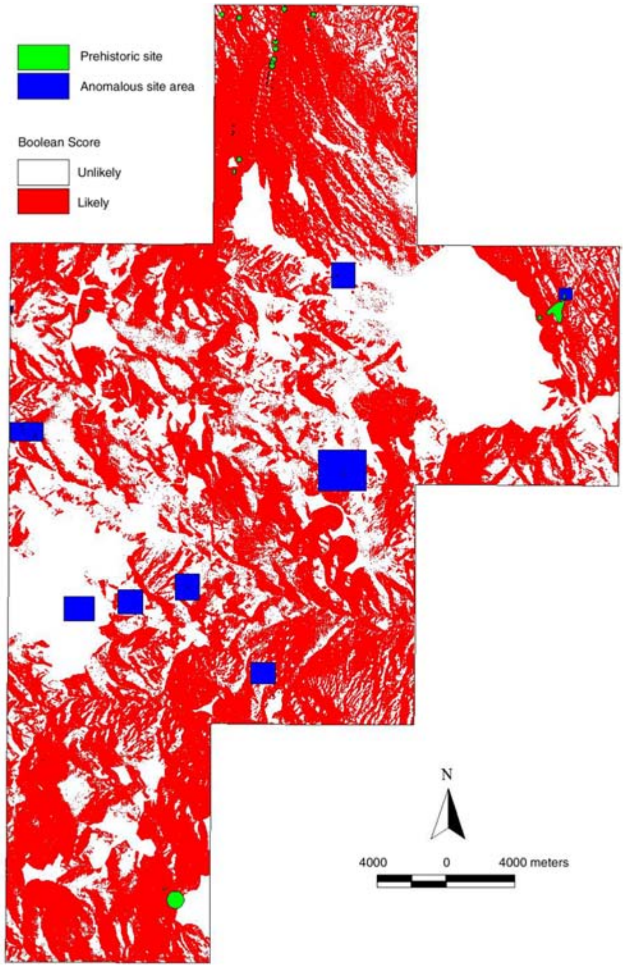

Figure 7.8. Western study unit Boolean model. Sites are in green, and blue polygons are sites that are not captured by the model.

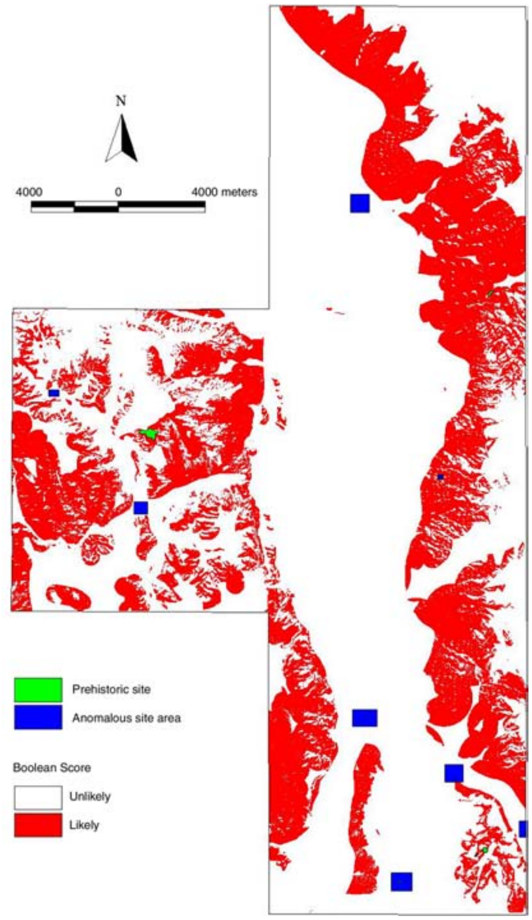

Figure 7.9. Eastern study unit Boolean model. Sites are in green, and blue polygons are sites that are not captured by the model.

The Boolean model for the western study unit portrays an environment generally favorable to site location, with three "holes" marking unfavorable locations. Comparisons with Figures 7.4 and 7.5 help to explain much of this pattern. The large "hole" in the eastern part of the western study unit marks the location of a large, contiguous deposit of colluvium that appears either to have been avoided by the indigenous inhabitants or to be masking any traces of their activities.

The large "hole" along the western edge marks the location of a unique vegetation community for this study area: Chihuahuan broadleaf deciduous desert scrub. Because this vegetation community provides few edible resources and makes travel difficult, it is possible that this "hole" is real—that the area was avoided by indigenous inhabitants. There has only been one archaeological survey within this area, however, and three of the anomalous sites indicated in Figure 7.8 are from that survey. So the apparent "hole" could also be the result of limited survey and the fact that this vegetation community is massed here and occurs nowhere else in the study unit.

The third "hole" is Alamo Mountain, located in the southeast corner of the western study unit. This is the location of a very large, multicomponent, historical stage station/Jornada Mogollon site (LA 9076) situated in a unique vegetation zone "rock outcrop," which is likely to have unduly influenced the models. Because the Boolean model gives equal credence to all environmental variables and because the rock outcrop vegetation zone is small and localized, the Boolean model is not as affected by the skewed correlation between the rock outcrop vegetation zone and site locations as are the other two models. The Boolean model, probably appropriately, classifies this area as unfavorable owing to slope, aspect, etc.

Although the western Boolean model points to environmental attributes avoided by humans, it does not provide great insight into settings favored for use or settlement. The poor predictive power of this model is reflected in the low Gain score.

The eastern Boolean model is clearly heavily influenced by the large expanse of colluvial deposits in the northeastern arm of the Salt Basin, which runs north/south through the center of this study area. As in the western study unit, archaeological surveys on this colluvium indicate an absence of sites or at least of surface-visible sites. The most interesting aspect of this map is the cluster of "anomalous" sites in the southernmost block of the study unit. This area, like both the zone of deciduous desert scrub and Alamo Mountain in the western study unit, is a unique environment relative to the rest of the study unit.

This Alkali Lakes area of sand sheet deposits and playas would intuitively appear to have been a relatively attractive zone for indigenous peoples—as the cluster of "anomalous" sites affirms. We coded the area as "site unlikely" for the Boolean model, however, because the percentage of site cells in the region is about the same as the percentage of area surveyed. This would, in part, account for the relatively weak predictive power of the eastern Boolean model as reflected in the Gain score. As previously mentioned, however, recent archaeological investigations along the eastern margin of the Salt Basin suggests a more extensive use of this area by human populations in the past than previous surveys have indicated. It is interesting to note that neither the weighted nor the regression models classify this area as unfavorable.

The Weighted Model

The weighted model is a more sophisticated intersection modeling technique than the Boolean method. Each variable is divided into categorical states that are then weighted in terms of the strength of their relationship with archaeological site location. For Otero 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 for each of these categories. By subtracting the percentage representation of each categorical variable in the environment from the percentage of site coverage, we derived weights, rounded to the nearest integer value, that vary from –215 to 301 for the eastern study unit and −132 to 151 for the western study unit. Negative weights indicate that humans tended to avoid these environmental features in locating their activities, whereas positive weights suggest the opposite.

Tables 7.17 and 7.18 list the environmental variables for each study area, the cutoff ranges, the percentage of site cells 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 score for each variable that was used to construct the weighted model.

Once the variables were weighted, the variable scores for each cell were added together. Tables 7.19 and 7.20 present the results in relation to the area and the percentage 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).

Figures 7.10 and 7.11 present the weighted models with sites overlain in black. In the eastern study unit, 10 sites fell in average or poor areas, whereas 40 sites fell in average or poor areas in the western study unit; these sites are outlined with white polygons on both maps. Sites that fall into poor areas throughout each model are discussed later; however, it is apparent that very small sites are the most likely to be predicted incorrectly.

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.

East Gain = 1 – (0.43/0.88) = 0.51
East gain over random = 0.88 – 0.43 = 0.45

The weighted model allows us to predict archaeological site locations in the eastern study unit with about a 45% better chance of being correct than if we guessed randomly.

West Gain = 1 – (0.25/0.87) = 0.71
West gain over random = 0.87 – 0.25 = 0.62

The weighted model allows us to predict archaeological site locations in the western study unti with about a 62% better chance of being correct than if we guessed randomly.

A comparison of the images of the weighted models and the Boolean models is striking. Gone from the weighted models are the large, unfavorable "holes" or generalized favorable areas. Based on the Gain statistics, the western weighted model clearly outperforms the eastern weighted model and both Boolean models, though the fact that nearly half the sites lie in unfavorable settings is disconcerting. We are hopeful that this latter situation will improve when the model is rerun without the heavy weight currently being given to the "rock outcrop" vegetation community, as discussed below.

Table 7.17. Weighted Model Variables for the Eastern Study Unit

	Cutoff range for continuous variables	Percentage of site cells contained in state/range	Percentage of study area contained in state/range	Weighted score
VEGETATION				
Rky.Mtn/Great Basin open conifer	—	0	0.01	0
Chihuahuan Desert scrub	—	13.97	57.3	–43
Chihuahuan foothill-piedmont grassland	—	0.7	9.49	–9
Chihuahuan lowland/swale desert grassland	—	85.37	33.67	52
GEOMORPHOLOGY	—	0	0.6	–1
Eroded bedrock surface	—	68.03	32.23	36
Sand sheet	—	17.98	6.47	12
Valley fill alluvium	—	0.88	3.88	–3
Alluvial fans	—	10.24	22.2	–12
Playa deposits	—	0	1.44	–1
Colluvial deposits <1 m thick	—	0	0.05	0
Colluvial deposits >1 m thick	—	0	33.59	–34
ASPECT	—	0	0.1	0
North-facing	315–360°,0 –45°	6.57	11.86	–5
East-facing	45–135°	26.22	21.26	5
South-facing	135–225°	55.07	34.58	20
West-facing	225–315°	11.34	30	–19
ELEVATION	<1104 m	0	2.30	–2
	1104–1112 m	19.4	7.44	12
	1112–1270 m	12.13	70.02	–58
	1270–1359 m	68.47	12.96	56
	>1359 m	0	7.28	–7
	0–5°	86.1	75.57	11
SLOPE	5–15°	12.67	10.57	2
	15–27°	1.23	9.15	–8
	>27°	0	4.71	–5
DISTANCE FROM STREAMS	0–70 m	5.12	24.17	–19
	70–300 m	24.42	50.26	–26
	300–600 m	70.46	22.19	48
	>600 m	0	3.38	–3
DISTANCE FROM STREAM INTERSECTIONS	<150 m	0	6.59	–7
	150–335 m	2.84	18.93	–16
	335–805 m	27.33	48.05	–21
	805–1385 m	69.83	23.34	46
	>1385 m	0	3.09	–3
DISTANCE FROM RIDGES	0–170 m	80.22	48.47	32
	170–420 m	14.53	27.92	–13
	420–1415 m	5.24	20.88	–16
	>1415 m	0	2.73	–3

One of the noticeable features of the western study unit weighted model is the classification of the dissected upland remnants of the Sacramento Mountains, which run through the northeast corner of the study area, as excellent. This same tendency to classify dissected upland terrain as excellent is observable near the southern edge of the southeastern block of the study unit and near the corner where the northern and northwestern blocks come together. These are the only other places in the study area where dissected upland terrain is found. This pattern is very clear and, thankfully, is unlikely to be affected by the Alamo Mountain "rock outcrop" vegetation zone problem. The near absence of surveys in these dissected areas makes it difficult to know, however, whether this pattern is real or is a reflection of the presence of one large site cluster in this environmental setting in the eastern block of the study unit, or both. The classification of the dissected upland areas as excellent is consistent with settlement data from the Guadalupe Mountains and elsewhere (Tim Kearns, Western Cultural Resources Management, Farmington, NM, personal communication 2004). Presumably, this setting offers more diverse biotic and abiotic resources and is better watered and sheltered than much of the other areas.

Table 7.18. Weighted Model Variables for the Western Study Unit

	Cutoff range for continuous variables	Percentage of site cells contained in state/range	Percentage of study area contained in state/range	Weighted score
VEGETATION				
Broadleaf interior chaparral	—	0	0.1	0
Chihuahuan Desert scrub	—	39.3	55.77	–17
Chihuahuan broadleaf deciduous desert scrub	—	0.03	5.36	–5
Short-grass steppe	—	0.15	0.34	0
Chihuahuan foothill-piedmont desert grassland		31.6	32.35	–1
Chihuahuan lowland/swale desert grassland	—	0.3	5.65	–5
Rock outcrop	—	28.63	0.43	28
GEOMORPHOLOGY				
Eroded bedrock surface	—	48.12	75.42	–27
Valley fill alluvium	—	12.83	4.4	8
Alluvial fans	—	26.14	2.52	24
Playa deposits	—	0	0.11	0
Colluvial deposits <1 m thick	—	0	0.02	0
Colluvial deposits >1 m thick	—	0	5.97	–6
Historically known spring	—	37	0.003	37
Pleistocene alluvial fan of Sacramento River	—	12.75	11.56	1
ASPECT				
North-facing	315–360°,0–45°	11.33	23.77	–12
East-facing	45–135°	6.38	30.83	–24
South-facing	135–225°	30.68	30.31	0
West-facing	225–315°	51.62	14.79	37
SLOPE	0–6°	62.29	91.36	–29
	6–29°	33.81	7.9	26
	>29°	3.91	0.74	3
DISTANCE FROM STREAMS	0–400 m	80.65	76.66	4
	400–600 m	15.48	14.46	1
	>600 m	3.87	8.88	–5
COST DISTANCE FROM RIDGES	0–155	70.33	96.14	–26
	155–660	17.5	3.36	14
	>660	12.17	0.5	12
DISTANCE FROM RIDGES	0–75 m	23.99	23.97	0
	75–150 m	16.55	20.15	–4
	150–1130 m	59.46	54.04	5
	>1130 m	0	1.11	–1

A second notable feature of the western weighted model is the classification of a large swath of alluvium in the western half of the northern block as good or excellent. As Figure 7.4 shows, all of the northern block except for the dissected uplands in the northeast corner is mapped as alluvium. A comparison with Figure 7.5 makes it clear that the weighted model classifies only the portion of the alluvium that lies in the desert grassland vegetation zone as good or excellent. The portion of the alluvium that lies in the desert scrub vegetation zone is classified as average. It is very possible that this pattern is a true reflection of precontact resource use in the area; grasslands may have provided more usable resources and easier travel and camping terrain in the past than the desert scrub vegetative zone. It is also important to note, however, that there has been no archaeological survey in the desert scrub portion of the alluvium, whereas a number of surveys have been completed in the grasslands portion. This apparent pattern warrants additional research and modeling efforts in the future.

The third notable feature of the western weighted model is a clear result of the LA 9076 problem at Alamo Mountain in the southeastern corner of the southern block. The model outcome is skewed by what is almost certainly a major over-representation of the size of the Jornada Mogollon component at that site. By the very nature of the way that weighted models are derived, the apparent association of a very large number of site cells with the unique vegetation zone "rock outcrop" has caused the model to classify this zone as excellent.

Table 7.19. Weighted Model Scores and Reclassification for the Eastern Study Unit

Model Score	Percentage of Study Area	Percentage of Site Cells	Reclassification
–215 to –165	5.85	0.16	1
–165 to –115	14.44	6.41	2
–115 to –75	15.85	1.74	2
–75 to –25	20.66	3.41	2
–25 to 25	16.78	1.93	3
25–65	10.86	0.88	3
65–115	8.62	2.53	3
115–165	5.06	10.65	4
165–205	1.42	11.66	4
205–255	0.36	18.61	4
255–301	0.08	42.02	4

Table 7.20. Weighted Model Scores and Reclassification for the Western Study Unit

Model Score	Percentage of Study Area	Percentage of Site Cells	Reclassification
–132 to –107	15.98	1.44	1
–107 to –82	42.18	4.34	2
–82 to –57	17.19	7.38	2
–57 to –32	16.94	26.99	3
–32 to –7	3.22	12.73	3
–7 to 18	2.92	18.43	3
18–43	0.92	7.51	4
43–68	0.52	5.44	4
68–93	0.11	15.59	4
93–118	0.02	0.04	4
118–143	0.00005	0.02	4
143–151	0.0002	0.01	4

Like the eastern Boolean model, the weighted model for the eastern study unit portrays the upland dissected areas along the eastern and western margins as good or excellent and the central lowland colluvium as average or poor. The major difference between the weighted and Boolean models for the eastern study unit is that the weighted model classifies the sand sheet and playa environment of the Alkali Lakes area in the southern block as good to excellent whereas the Boolean model classified it as unfavorable.

It is very intriguing that both the eastern and western weighted models classify dissected uplands as high probability zones for archaeological sites. It is notable that, despite limited survey, clusters of sites have been found in the dissected uplands at the southern end of the Sacramento Mountains in both our eastern and western study units. For this reason, we think it likely that the good to excellent scores in the weighted models reflect an actual preference among indigenous people for locating activities in the dissected uplands, at least those of the Sacramento uplift. Given the complete absence of survey data from the other dissected upland zones in the two study units—the lower slopes of the Guadalupe and Brokeoff Mountains in the eastern study unit and the dissected zone north of the Cornudas Mountains in the western unit—we cannot yet determine whether these uplands were favored zones as well. This is one of the future research and modeling issues that will need to be addressed for greater Otero Mesa.

Logistic Regression Model

Logistic regression is a complex statistical technique (see discussion in Chapter 4). The results of models based on logistic regression are not easily interpreted. Yet, the great advantage that logistic regression has over other modeling techniques is its 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.

One difficulty with the logistic regression for Otero Mesa is the irregular shape of the two study areas. Irregularly shaped rasters cannot be incorporated directly into many of IDRISI's raster manipulation algorithms. For the logistic

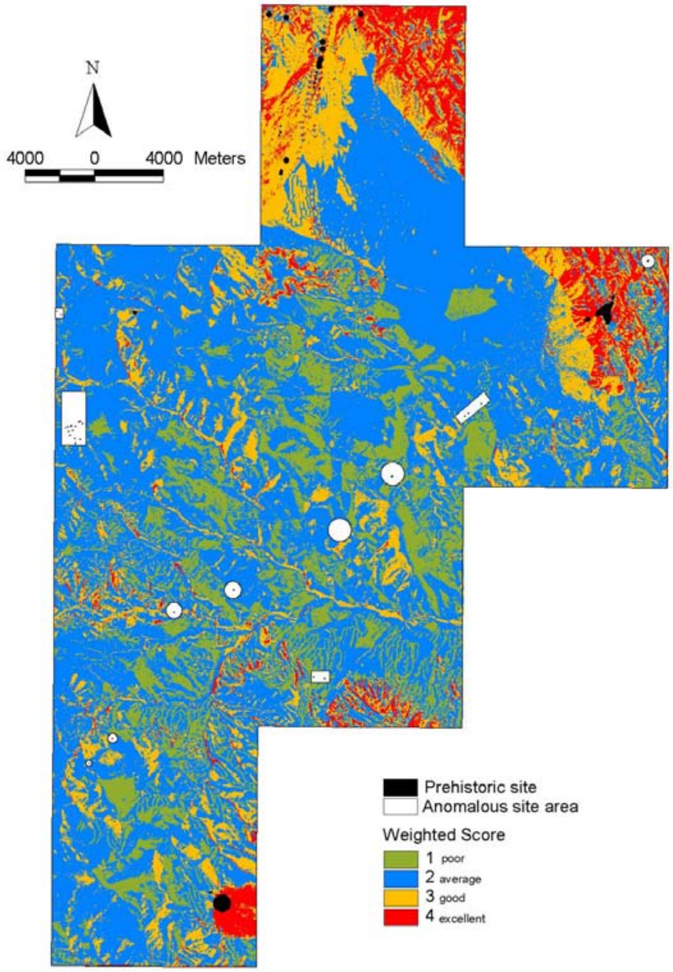

Figure 7.10. Western study unit weighted model.

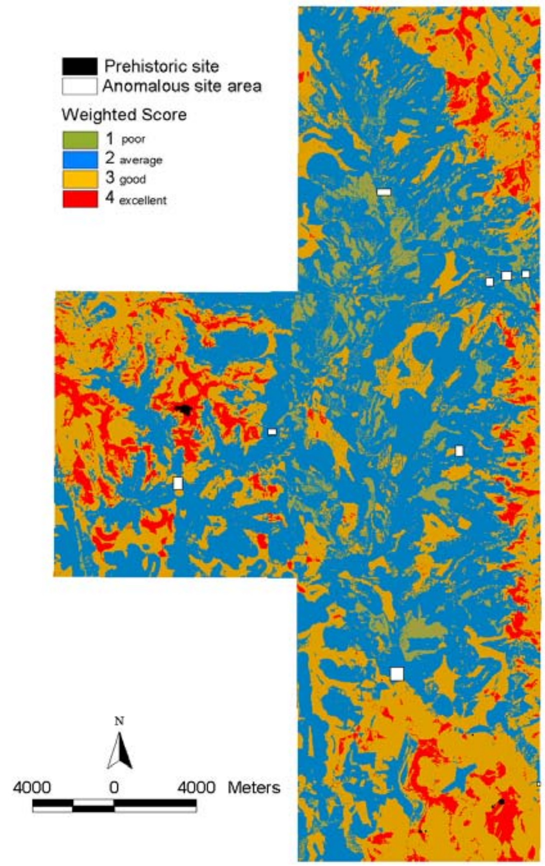

Figure 7.11. Eastern study unit weighted model.

regression function, the algorithm creates a rectangle that encompasses not only the study area, but also outside areas needed to complete the rectangle. For example, the eastern study unit is shaped like a T tilted on its side. The algorithm creates a rectangle by filling the northwest and southwest quadrangles with cells coded as null values on each variable. IDRISI ignores the null values in producing the logistic regression equation, but the program computes a logistic score for each cell in the rectangle. To produce the model image, we clipped the portion of the rectangle outside the study area and eliminated these scores from further consideration.

Tables 7.21 and 7.22 present 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. For example, the coefficient for distance from streams in Table 7.21 is only slightly negative (–0.001), whereas eroded bedrock has a relatively large positive coefficient (2.14642). But these coefficients are not comparable. Distance from streams in Otero Mesa varies from zero to thousands of meters. The regression coefficient, then, is multiplied by numbers varying from zero to very large. A cell can only have two scores for a categorical variable, such as eroded bedrock (0 or 1), which is then multiplied by a coefficient that takes into account the restricted range of the variable. When examining logistic regression coefficients, it is important to compare variables measured on the same scale with each other.

In examining the tables of regression coefficients, the differences between the two study units are evident. In the east, the most important categorical variables are the Chihuahuan foothill-piedmont and Chihuahuan lowland/swale vegetative communities, with the sand sheet and eroded bedrock geomorphic variables being a distant second in statistical importance. In the west, geomorphology assumes a more equal, if not slightly more dominant, statistical position for categorical variables. Thick colluvial deposits and the Chihuahuan broadleaf deciduous vegetative community are the

Table 7.21. Computed Coefficients for Variables Used in the Logistic Regression Model for the Eastern Study Unit

Variable	Coefficient
Eroded bedrock	2.14642
Colluvial deposits >1 m thick	–1.80939
Alluvial fans	0.05042
Sand sheet	2.934188
Chihuahuan foothill-piedmont	–5.7748496
Chihuahuan lowland/swale	4.5608234
South-facing aspect	0.68843053
West-facing aspect	0.253798944
Elevation	0.01430186
Slope	–0.14297992
Distance from Streams	–0.00115654
Distance from Stream Intersections	0.00185916
Distance from Ridges	–0.00234531

Table 7.22. Computed Coefficients for Variables Used in the Logistic Regression Model for the Western Study Unit

Variable	Coefficient
Eroded bedrock	–1.86807250
Alluvial fans	1.24345371
Colluvial deposits >1 m thick	–16.96504835
Chihuahuan broadleaf deciduous	–16.51966538
Rock outcrop	6.25818135
Chihuahuan lowland/swale	–3.18205604
West-facing aspect	1.3662265
East-facing aspect	–0.68437538
Slope	0.00957143
Distance from Streams	–0.00161888
Cost Distance to Ridges	0.00129103
Distance from Ridges	–0.00362474

most important categorical variables followed at a distance by rock outcrops and further still, the Chihuahuan lowland/swale vegetative community.

This is another point at which it is important to note that the apparent significance of the vegetation category "rock outcrop" is the result of a substantial overestimation of site size for a single site component located in this vegetation category. With the exception of the area immediately around Alamo Mountain (noted in the discussion of the modeling results below), we do not believe that this problem had a major impact on the modeling results as mapped in Figure 7.13.

Tables 7.23 and 7.24 present the reclassification values for the two study units. The results have been collapsed into ten 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.

Figures 7.12 and 7.13 show the outcome of the logistic regression models after the reclassification. For the eastern section, eight sites fall into the poor to average category compared with ten sites in the weighted model. The sites that are found in anomalous settings are almost identical in both models (see below). In the western section the number of sites located in poor or average areas is 40, which is the same number and generally represents the same sites as were located in poor or average areas in the weighted model. The amount of land classified as good or excellent, however, has shifted from around 25% in the weighted models to 34% in the logistic regression model. These shifts are reflected in the relatively low gain and gain-over-random scores.

East Gain = 1 – (44.88/91.58) = 0.51
East gain over random = 91.58 – 44.88 = 46.7

West Gain = 1 – (34/90.26) = 0.62
West gain over random = 90.26 – 34 = 56.26

Table 7.23. Logistic Regression Probability Scores and Reclassification Values for the Eastern Study Unit

Probability	Percentage of Study Area	Percentage of Site Cells	Reclassification
0–10	0	0.19	1
11–20	0.02	0	1
21–30	1.04	0	1
31–40	7.19	0.66	2
41–50	17.2	0.32	2
51–60	29.67	7.27	2
61–70	30	2.69	3
71–80	12.67	14.38	3
81–90	2.03	15.36	4
91–100	0.18	59.15	4

Table 7.24. Logistic Regression Probability Scores and Reclassification Values for the Western Study Unit

Probability	Percentage of Study Area	Percentage of Site Cells	Reclassification
0–10	0	0	0
11–20	3.01	0	1
21–30	8.31	0.03	1
31–40	0	0	1
41–50	0.05	0	1
51–60	4.28	0.58	2
61–70	50.34	9.15	2
71–80	31.01	31.95	3
81–90	2.87	33.70	3
91–100	0.14	24.61	4

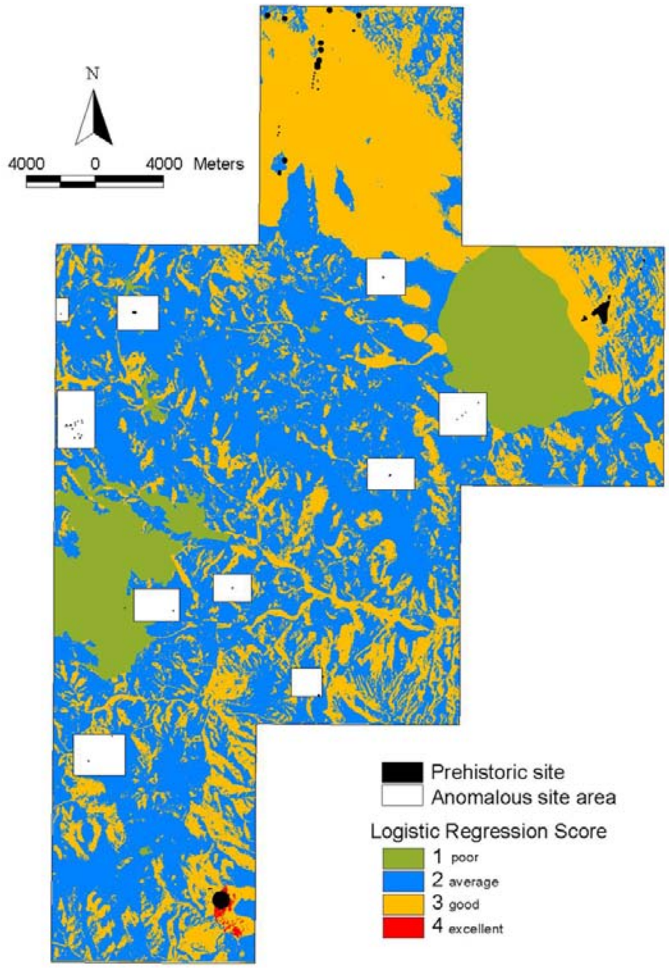

Figure 7.12. Logistic regression model for western study unit.

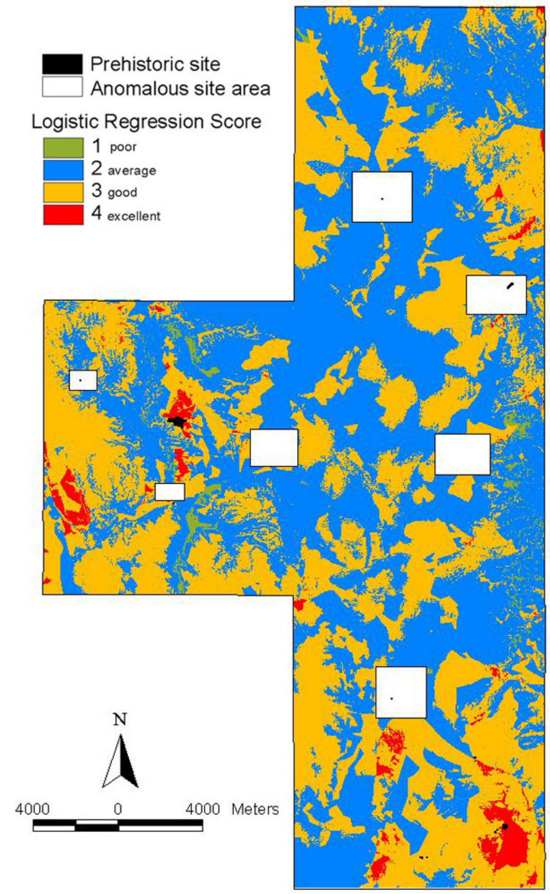

Figure 7.13. Logistic regression model for eastern study unit.

The eastern logistical regression model works almost exactly as well as the eastern weighted model (47% better than random for the logistic regression model versus 45% better than random for the weighted model). The western logistic regression model, however, works slightly worse as a predictor than the weighted model for the same unit (56% better than random for the logistic regression model versus 62% better than random for the weighted model).

Figures 7.12 and 7.13 give rise to several interesting observations. First, the two large "holes" of unfavorable environmental settings noted in the Boolean model reappear in the logistic regression model for the western study unit. They are associated with a large area of colluvium in the eastern block of the study unit and an environmentally unique area of broadleaf deciduous desert scrub along the western edge.

The second observation is that, once again, the skewing effect of the very large, multicomponent site at Alamo Mountain is apparent in the high probability classification of the area in the southeastern corner of the western study unit. Decreasing the number of cells covered by the precontact component of this site could reduce the sensitivity of this area.

Third, the regression model classifies the entire expanse of alluvial deposits in the northern block of the western study unit as good, whereas the weighted model classified only the grasslands portion of the alluvium favorably. A comparison of the vegetation map (Figure 7.5) with the sensitivity maps from all three modeling techniques gives the impression that desert grassland vs. desert scrub vegetation was not an important factor in determining the location of precontact human activities.

The fourth observation is that the regression models, like the Boolean and weighted models, classify the wedge of the southern Sacramento Mountain uplift, which extends between and into the edges of the two study units, as good to excellent. But unlike the weighted models, the regression models do not generalize this favorable classification to all dissected uplands. This is especially noticeable along the eastern edge of the eastern study unit. Although Figure 7.12

makes it appear that the portion of the Sacramento uplands in the western study unit is not as favorable to site location as the portion in the eastern study unit, this is most likely a function of different cutoff points having been used for the reclassification of the probability scores for the two study units (see Tables 7.23 and 7.24).

The fifth observation is that the eastern regression model, like the eastern weighted model, classifies the Alkali Lakes at the southern end of the study area as a good to excellent location for encountering the remains of the human activities. The two most robust patterns produced by the Otero Mesa models, and thus the ones most likely to be a reflection of precontact human behavior, are the high favorability scores for the southern Sacramento uplift and for the Alkali Lakes. These will be addressed in the interpretations offered in the next section of this chapter.

Interpreting the Results

The performance of the predictive models is compared in Table 7.25. The weighted model for the western section scores the highest Gain Statistic because it provides the smallest sensitive area relative to the number of sites correctly identified. The logistic regression models, however, are statistically more robust. They accurately placed, on average, about 91% of the site cells, a gain of about five percentage points over the other models.

Sites that have been located in "poor" or "average" areas have been noted above in the discussions of the model outcomes; those sites located in poor or average areas that are common to at least two models are shown in Table 7.26. Altschul (1990) has argued that sites in anomalous settings, which he terms "red flags," often provide insight into prehistoric settlement and the inner workings of predictive models. General information about these anomalous sites, as provided by ARMS, is listed in the table. The environmental setting and size characteristics of the red flag, or incorrectly predicted sites and those of the correctly predicted sites are compared in Table 7.27.

The large number of anomalous sites is the best indicator that the models are poor predictors, which is not surprising given the very limited amount of archaeological data available. The fact that nearly half the sites in each study unit are found in poor or average sensitivity locations does not bode well for use of these models to guide management decisions. But not all anomalous sites are equal. The models correctly predict the large sites, a plus for managers because these sites are the most costly in terms of time and money. Examining Table 7.26, we are struck by the nondescript nature of the red flag sites. We presume that most of these sites were limited activity areas; it is possible that the models are poor predictors only of places where people went to gather specific plants or hunt particular animals, and not of all sites.

The models may be much better at portraying the regional settlement structure. In the modeling results are patterns indicating that the indigenous, precontact occupants of the greater Otero Mesa area were focusing their activities in three very different areas: the broad expanse of alluvium in the northern block of the western study unit, the sand sheet and playa environment of Alkali Lakes in the southern block of the eastern study unit, and the southernmost end of the Sacramento Mountain uplift, which forms a wedge of dissected upland between and extending into the edges of the two study units.

The alluvium in the northern block of the western study unit has been laid down by two major drainages—the Sacramento River and Chatfield Canyon—as well as a series of smaller canyons in the uplift across the northwest of the block. All of these sources of runoff from different parts of the Sacramento Mountains would have made this a favorable location for wild resources and potentially for simple floodwater farming during periods of better-than-average rainfall.

The Alkali Lakes area would have been especially favorable during Paleoindian and early Archaic times, but the presence or intermittent presence of water and playa-associated faunal resources would have made this area a locus for human activities during many periods in the past.

Table 7.25. Comparison of the predictive models

Model	Percentage of area that is good or excellent	Percentage of site cells classified as good or excellent	Gain score	Gain over random chance
Boolean East	31	81	0.62	0.50
Boolean West	56	87	0.36	0.31
Weighted East	43	88	0.51	0.45
Weighted West	25	87	0.71	0.62
Logistic regression east	45	92	0.51	0.47
Logistic regression west	34	90	0.62	0.56

Table 7.26. “Red Flag” Sites

ARMS Site Number (LA)	Area (Acres)	Features	Artifacts
EASTERN UNIT			
14736	1.017	0	<1000
26922	0.174	1 (hearth)	<1000
45889	0.174	1 (hearth)	Unknown
45891	0.175	1	Unknown
45899	0.175	1 (hearth)	Unknown
46138	0.175	0	Unknown
49281	0.174	1 (hearth)	Unknown
49282	7.685	1 (ring midden)	Unknown
54963	0.537	1 (burned rock midden)	Unknown
WESTERN UNIT			
56759	0.175	1 (ring midden)	Unknown
56760	0.175	1 (ring midden)	<10
65457	0.634	None	<100
72840	1.392	1 (hearth)	<1000
87907	0.175	1 (FCR concentration)	<100
107586	0.174	None	<10
107587	0.175	None	<10
107589	1.598	None	<10
107590	0.174	None	<10
107592	0.175	None	<10
107593	0.175	None	<10
107594	0.175	None	<10
117031	0.049	None	<10
117032	0.049	None	<10
117034	0.198	None	<10
117037	0.049	None	Unknown
120882	0.175	None	<10
120883	0.174	None	<10
120884	0.174	None	<10
120885	0.174	None	<10
120886	0.174	None	<10
120887	0.174	None	<10
120888	0.174	None	<10
120889	0.174	None	<10
120890	0.174	None	<10
120891	0.174	None	<10
120892	0.174	None	<10
120893	0.174	None	<10
120894	0.174	None	<10
120895	0.174	None	<10
120896	0.174	None	<10
120897	0.174	None	<10
120898	0.174	None	<10
120899	0.174	None	<10
120900	0.174	None	<10
120901	0.174	None	<10
120902	0.174	None	<10
120903	0.174	None	<10
120904	0.174	None	<10

Table 7.27. Comparison of Red Flags and Correctly Predicted Sites

	East Red Flag	West Red Flag	East Correctly Predicted	West Correctly Predicted
Site Area (in acres)				
range	0.2–8	0.05–7	0.2–56	0.2–193
mean	1	0.4	9	16
std. dev.	2.5	1	19	39
Elevation (m)				
range	1110–1274	1340–1556	1104–1358	1333–1877
mean	1197	1469	1297	1553
std. dev.	421	76	101	138
Distance from Streams (m)				
range	30–381	10–612	0–594	0–910
mean	98	264	379	224
std. dev.	52	242	112	185
Slope (degrees)				
range	0–10	0–4	0–27	0–57
mean	2	2	3	7
std. dev.	3	1	3	9
Aspect				
largest percentage	South (70%)	East (49%)	West (52%)	South (53%)
second largest percentage	West (19%)	North (31%)	South (31%)	West (29%)
Geomorphology				
largest percentage	Alluvial fans (80%)	Eroded bedrock (83%)	Eroded bedrock (78%)	Eroded bedrock (48%)
second largest percentage	Colluvial deposits >1 m thick (13%)	Valley fill alluvium (9%)	Sand sheet (21%)	Alluvial fans (27%)

The nature of precontact human use of the dissected uplands of the southern Sacramento uplift cannot be projected based on what we know now. We have evidence to indicate that this was a favored zone. Additional survey and modeling to verify this pattern, and additional research to determine the nature of human uses and the resources on which they were focused, should be a priority for the future.

The places where sites are *not* found or predicted to be found by the models are perhaps just as informative about human behavior in the study areas as the places where sites *are* found or predicted. The large expanses of colluvium mapped in Figure 7.4 are conspicuous in this regard. Either the areas of colluvium did not get a high score in the site-location "calculus" of the indigenous people in this area, or activities were sited there but the colluvium is masking the presence of buried sites. This is an issue to which we will return in the management section below.

It is readily apparent from Figure 7.7 that the most extensively surveyed area covered by the models is the southern three blocks of the western study unit. Yet a quick comparison with Figure 7.6 reveals the virtual absence of sites recorded during these surveys. From an anthropological standpoint, this isn't surprising. The area is flat, away from the drainage network, and on eroded bedrock surfaces; the availability of resources in this area is likely to have been very limited. From a management standpoint, as will be discussed below, this tantalizing evidence that there may be marked differences in archaeological site densities in the different environments of greater Otero Mesa offers the promise of some important management opportunities.

Only additional survey will provide data to test the accuracy of the models and our interpretations. We did, however, evaluate the effect of the big sites on the models by re-analyzing the data for the western study unit after diminishing the influence of site size. Using a module in ArcView, we divided the sites into three classes—small, medium and large—based on natural breaks in the range of site sizes (Table 7.28). We then determined the mean number of cells for each site. Ten percent of the mean number of cells was then chosen as the number of cells to represent each site in the class. Through an ArcView extension, a random selection of cells was chosen for each site. All sites had at least one cell selected. Because most small sites are represented by fewer than four cells, this process over-represented small sites when a new logistic regression model was generated using this data set. The results of the "sample" logistic regression model are compared with those of the "full" model in Table 7.29 and Figure 7.14.

The largest differences occur in the nominal data, particularly in the thick colluvial deposits and the Chihuahuan broadleaf deciduous areas. The effects of these variables are depressed, which can be seen in the favorability maps as a decrease in the size of the unfavorable zones. The impact of the site size issue for the multicomponent site at Alamo

Table 7.28. Site Classes for the Western Study Unit, Otero Mesa

	Site Classes		
	Small	Medium	Large
Site size (m²)	199.5-27437.5	27437.5-71454	71454-781064
Number of sites	63	13	2
Mean number of cells	4	67	799
Number of random points generated per site	1	7	80

Table 7.29. Comparison of Coefficients for Variables Used in the Original Western Logistic Regression Model and the Random Site Sample Model

Variable	Full Model Coefficient	Sample Model Coefficient
Eroded bedrock	–1.86807250	–1.4487918
Alluvial fans	1.24345371	1.46807467
Colluvial deposits >1 m thick	–16.96504835	–2.37375768
Chihuahuan broadleaf deciduous	–16.51966538	–1.95976601
Rock outcrop	6.25818135	5.67053689
Chihuahuan lowland/swale	–3.18205604	–1.73397543
West-facing aspect	1.3662265	0.97048214
East-facing aspect	–0.68437538	–0.42596248
Slope	0.00957143	0.00903231
Distance from streams	–0.00161888	–0.00154771
Cost distance from ridges	0.00129103	0.00097066
Distance from ridges	–0.00362474	–0.00307946

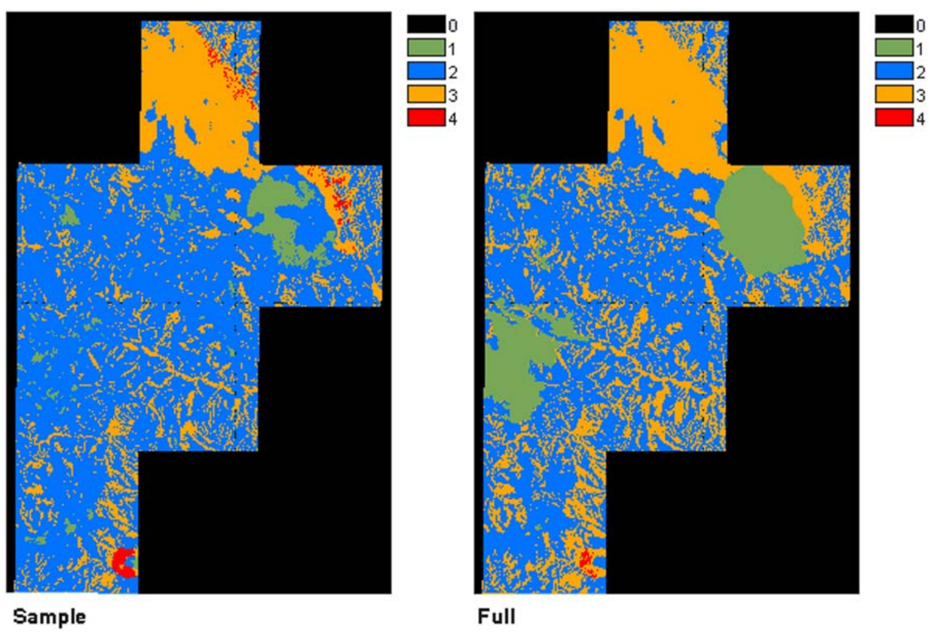

Figure 7.14. Comparison of the sample and full logistic regression favorability maps for the western study unit. Black areas (0) are outside the study area.

Mountain is also apparent in the differences between these maps. In most other ways, however, the two models are quite similar and show the same settlement trends. Overall, the similarity of the models is striking; statistically, the models are relatively close with a pair-wise Spearman's *r* score of 0.76. The inference we draw, therefore, is that while site size is an overriding influence in the models, it is not masking settlement trends.

There is no question but that the predictive models for Otero Mesa are based on inadequate data. We expect that future work will greatly refine certain aspects of the relationship between the environment of Otero Mesa and past human settlement. We do, however, believe that the models accurately portray broad settlement trends. In assessing the modeling results, it is important to remember that the models in the eastern and western study units were developed independently. Different environmental variables dominate the models in the two study units. Even so, the complex calculus that past humans used to place themselves on the landscape, a calculus that thus far eludes us, appears to have subsumed regional environmental differences into a broader perception of settlement and land use.

Inventory Reconstruction

Unlike Loco Hills (Chapter 5) and Azotea Mesa (Chapter 6), Otero Mesa has an archaeological record that is relatively unexplored. It may seem foolhardy, then, to perform the same type of inventory reconstruction for the Otero Mesa study area as was presented in the preceding chapters. Although we acknowledge the data deficiencies, we thought that the reconstruction of survey history might still provide some insights. Given the extremely limited survey coverage, our expectation was that the annual computations of site density for Otero Mesa should fluctuate widely. But what if they do not? What should managers and archaeologists infer from such results?

As we did for the Loco Hills and Azotea Mesa study areas, we used the dates when surveys were concluded and sites were recorded to reconstruct the history of archaeological inventory on Otero Mesa. Using the digitized data provided by ARMS, we associated surveys with the year in which they were completed and sites with the completion year of the survey 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 2000 was an accurate estimate of site density within the entire Otero 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 2000 figure, which captured 95% of the estimates. We then examined the annual history to determine if and when during the history of archaeological survey in the area the running site density began to fall consistently within the confidence intervals.

Although we encountered many of the same issues of resurvey and data quality previously identified during the Loco Hills and Azotea Mesa studies, the dearth of survey in the Otero Mesa study area actually lessens the impact of these problems. Still, some areas had been surveyed multiple times and some sites had been re-recorded, sometimes within the same year. The problem of "site boundaries," with the polygons consisting of arbitrary buffers around map points, is present in the data set from Otero Mesa as it was for the other study areas. As in the other areas, some site boundaries seem to be randomly sized and inconsistent with the written site descriptions.

Figure 7.15 illustrates some of the overlap and re-recording problems. 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.

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 7.16 shows surveys within a small portion of the study area, coded by year, along with the aggregated site boundaries (note the large, arbitrary circle "boundary"). Figure 7.17 shows a time sequence of cumulative survey, aggregated by year, within the whole study area.

After aggregating the data, we found that the process of estimating site density on an annual basis was only slightly complicated by the amount of resurvey and the concomitant re-recording of sites. Between 1976 and 2000, surveys in the study area covered 7,820 acres, but only 7,638 acres of ground were actually inventoried; the 182-acre difference results from resurvey. This is clearly a minor matter compared with the Loco Hills and Azotea Mesa results. Far less actual survey has been performed: approximately 1.7% of the entire Otero Mesa study area has been inventoried, and the percentage of resurvey included in the inventory figure is only approximately 2.3%. Despite the limited nature of the resurvey problem, we analyzed the Otero Mesa inventory history using both "survey as performed" data and "survey with overlap omitted" data in order to ensure that the results would be consistent with the Loco Hills and Azotea Mesa studies.

Figure 7.15. Examples of survey and recording episodes.

Figure 7.18 graphically displays the history of survey in the Otero Mesa study area with special attention to this issue of resurvey. For each year there are three bars, one that represents the reported number of surveyed acres, one that represents the reported acreage minus the overlapping surveys that occurred within that same year, and one that represents the actual new ground surveyed with all overlaps removed.

These data allow us to calculate site density using the two different methods developed for the Loco Hills and Azotea Mesa study areas. Method I (Figure 7.19) is 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 that the fieldwork took place. The site density figures calculated using Method I are, therefore, inflated. Method II (Figure 7.20) eliminates survey overlap and site re-recording, providing a slightly more accurate estimate of site density. In short, Method I calculates site density as this information would have been available to managers under existing survey strategies, whereas Method II provides the density figures that would have been available in an ideal world where there were no survey overlaps or site re-recording.

The trend in running site density figures is far from clear in this study. Site density stabilizes at about 0.0051 under Method I and 0.0052 under Method II. Running density for both methods initially falls in the 95% confidence intervals in 1980, then again from 1986 to 1991, and 1996 to 2000. The peak in site density in 1996 is responsible for substantially raising the running density. The sites portrayed in Figure 7.15 are largely responsible for this phenomenon; these extensive sites were recorded twice in the same year by two different surveys, thus effectively doubling their representation in the site density statistic. Although this is a minor discrepancy in acreage when compared with the Loco Hills and Azotea Mesa studies, it is over represented because of the extremely small sample size.

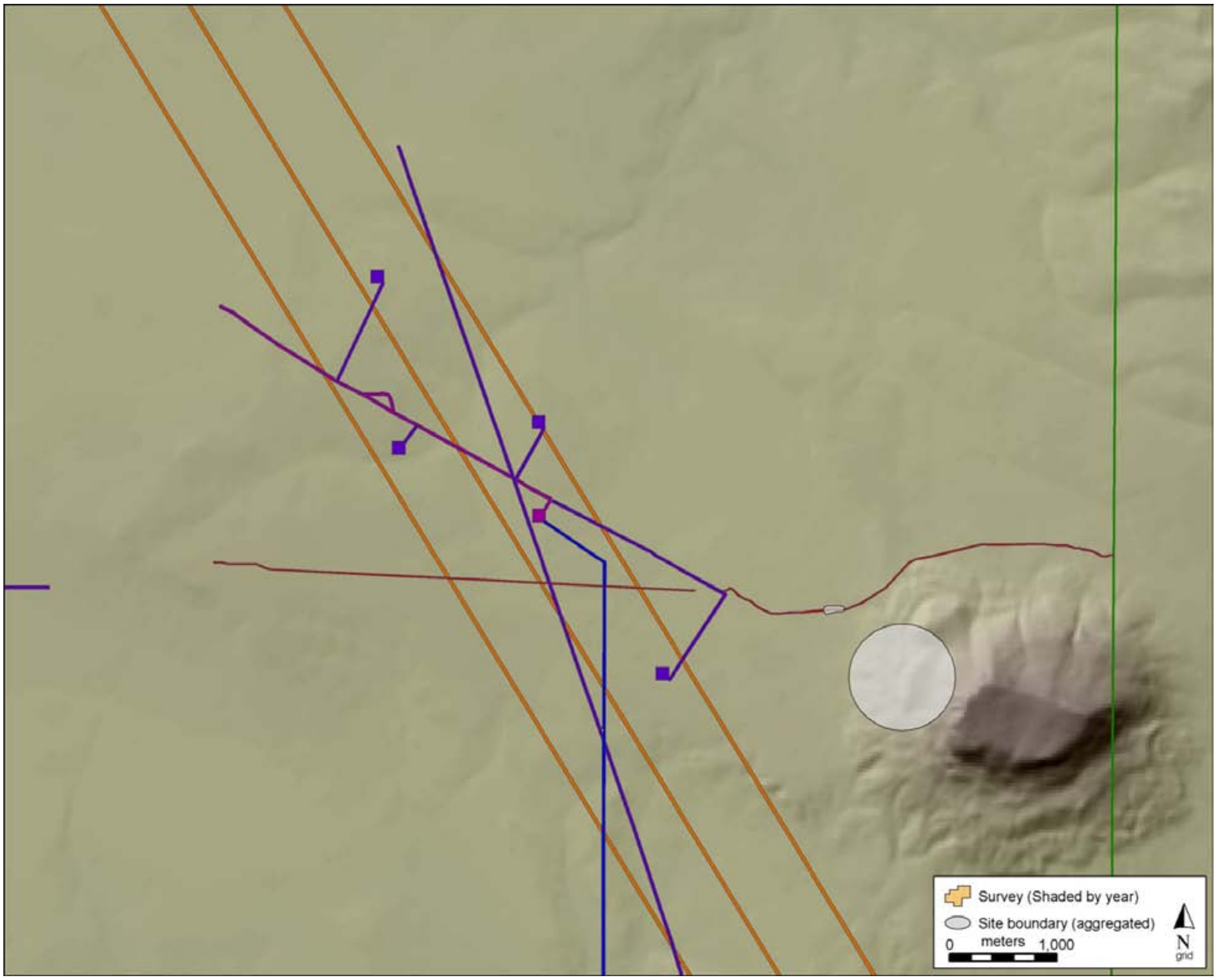

Figure 7.16. Example of survey coverage aggregated by year.

Although the running site density on Otero Mesa appears to be quite stable, we believe that such an inference in unwarranted. The wide fluctuations in the annual site density figures are telling a different story, one in which our perception of the archaeology of Otero Mesa is constantly changing.

Conclusions

Because they are based on very limited data, the archaeological site location models of Otero Mesa are poor predictors. Yet, we believe that they have some utility for both managers and archaeologists. The models point out areas that are likely to contain sites and areas where site density is apparently quite low. For all their shortcomings, both the eastern and the western study area models identify some similar trends, which gives us greater confidence in them than we might otherwise have. Moreover, a comparison of models developed using full and sampled data sets indicates that the results of the two modeling efforts are very similar.

The models from Otero Mesa cannot be used to tell us exactly where we will find sites, but they can be used to guide us as to where we should look for sites. The models can also give us some general guidance about conditions that should be placed on oil and gas exploration. The models all point to the uplifted, dissected regions of greater Otero Mesa, and especially the southernmost extension of the Sacramento Mountain uplift, as likely places for archaeological sites. The models also identify the Alkali Lakes region in the southern part of the eastern study unit and the alluvium of the northern block of the western study unit as higher-probability areas for cultural resources. Since Alkali Lakes is

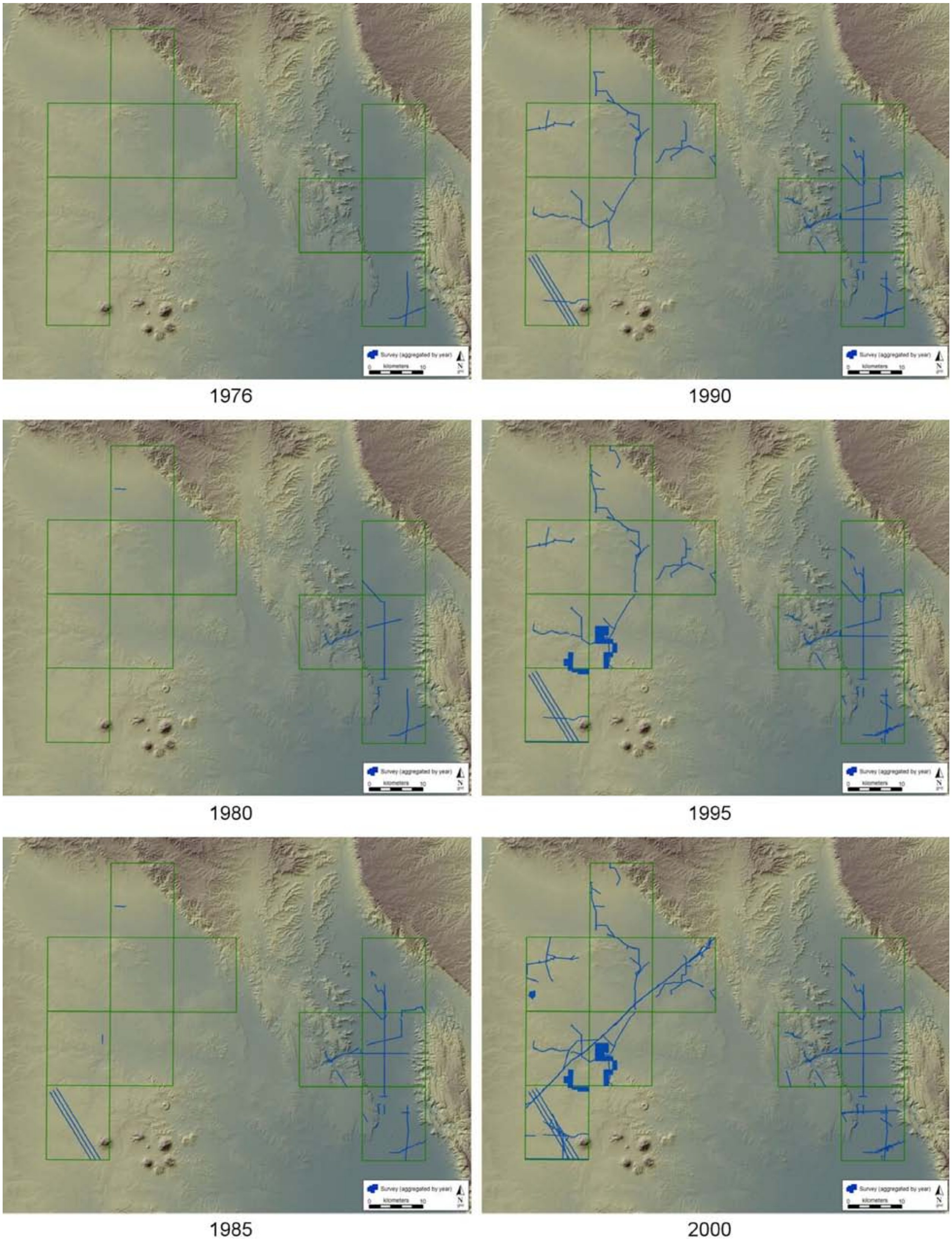

Figure 7.17. Time sequence for cumulative survey in the study area, aggregated by year.

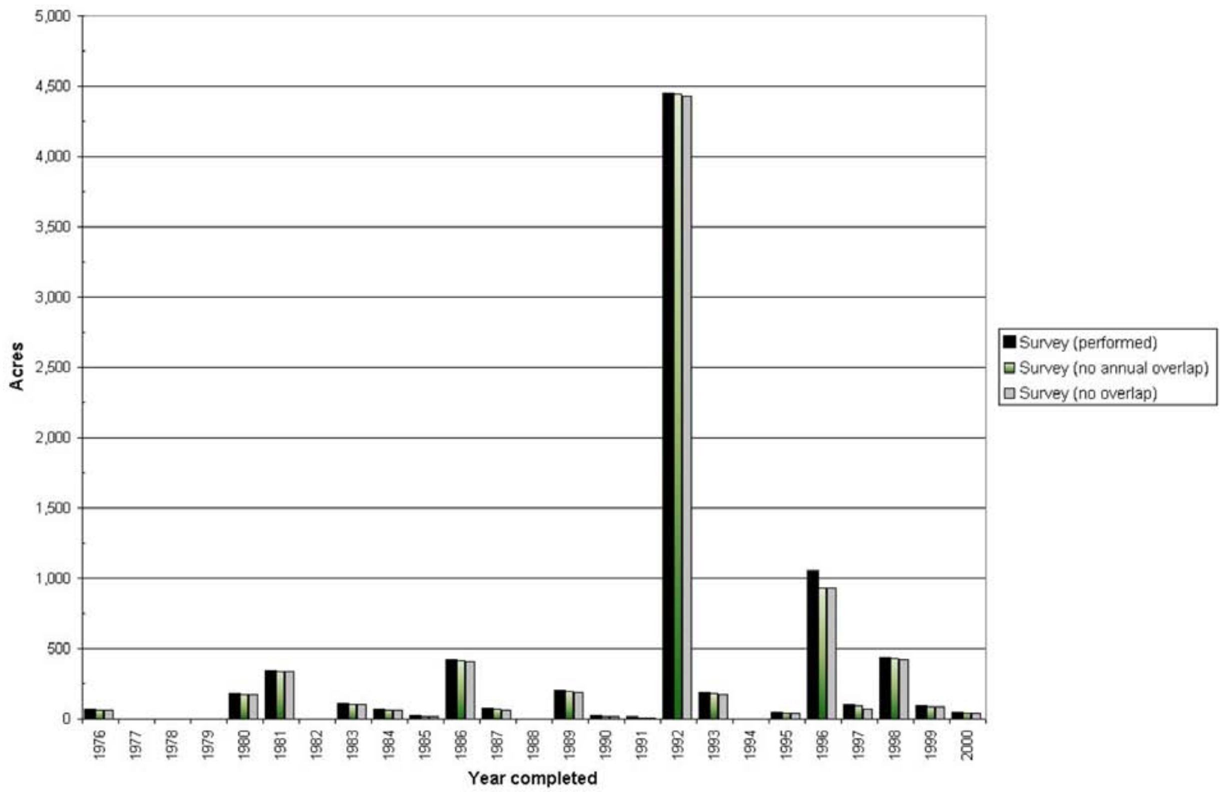

Figure 7.18. Annual survey statistics.

already managed as an Area of Critical Environmental Concern by BLM for its waterfowl, shorebird nesting sites, rare plants, and ecological diversity values, there may be important management opportunities for cultural resource management in this area as well.

Whereas the uplifted, dissected areas of Otero Mesa are predicted to contain sites, the models predict that few sites will be found during surface survey in colluviated areas. While it is possible that humans avoided these areas, it is also possible that the model results have less to do with the correlation between environment and human land use than with visibility of the archaeological record, a possibility that seems to be supported by recent archaeological work in the area. Buried sites are frequently found in colluvial settings, and surface survey may not be sufficient to identify historic properties that would be affected by oil and gas development activities in some areas. Subsurface testing, possibly shovel tests or use of shallow probes, may be needed to identify shallowly buried sites in colluvium and should be required as part of inventories until BLM can determine whether such sites are likely to exist.

Archaeologists need to confirm and explain the patterns suggested by these preliminary models, and the archaeological record needs to be more fully characterized: What types of sites are found in the high potential locations? What activities took place here in the past? What was the full range of human activities in the greater Otero Mesa area and how were all of these activities distributed on the landscape? At the very least, managers need to be aware of the potential high-density and low-density areas in order to develop appropriate inventory strategies. At the same time, potential lessees can be forewarned about the likelihood of additional costs and constraints and develop their own human calculus about the resource costs and benefits to be found in the Otero Mesa landscape.

Finally, we recommend that the BLM continue the predictive modeling process for Otero Mesa. The current models indicate that there may be fairly strong patterns of high density and low density areas for archaeological sites, but that our understanding of site density has not yet stabilized. If additional survey and additional modeling refine these patterns and provide us with greater confidence in their validity, the opportunities for innovative management of cultural resources during future oil and gas development in the greater Otero Mesa area will be greatly enhanced.

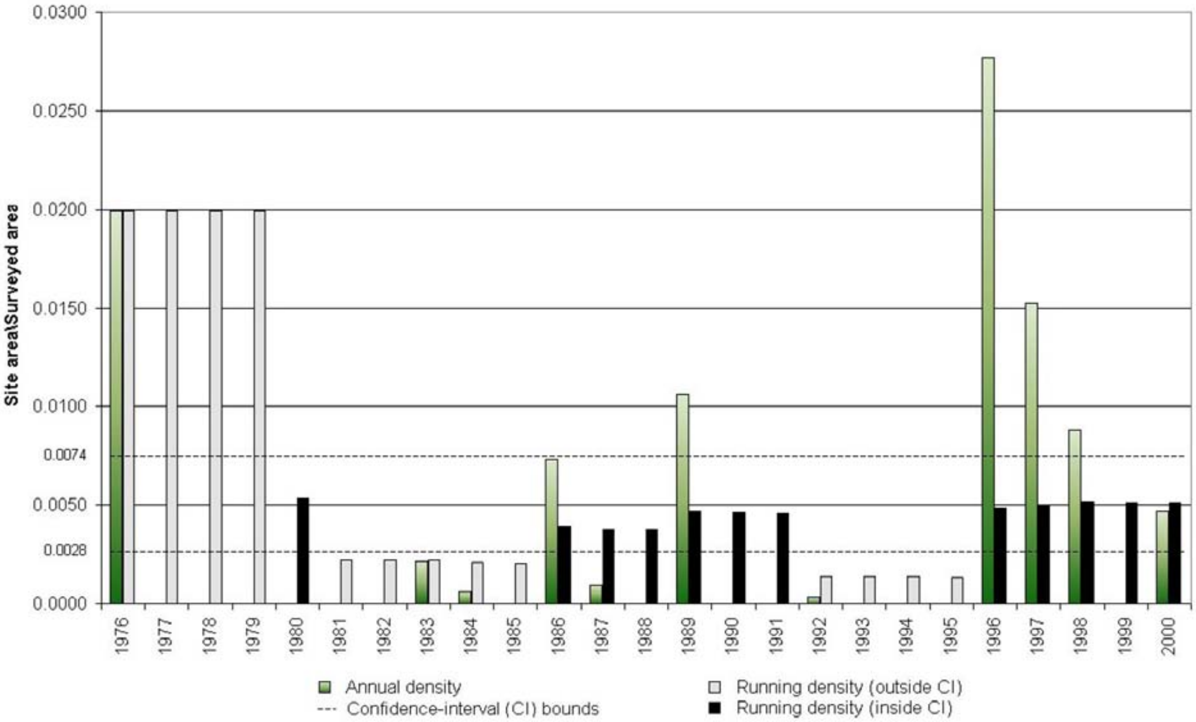

Figure 7.19. Overall site density, Method I.

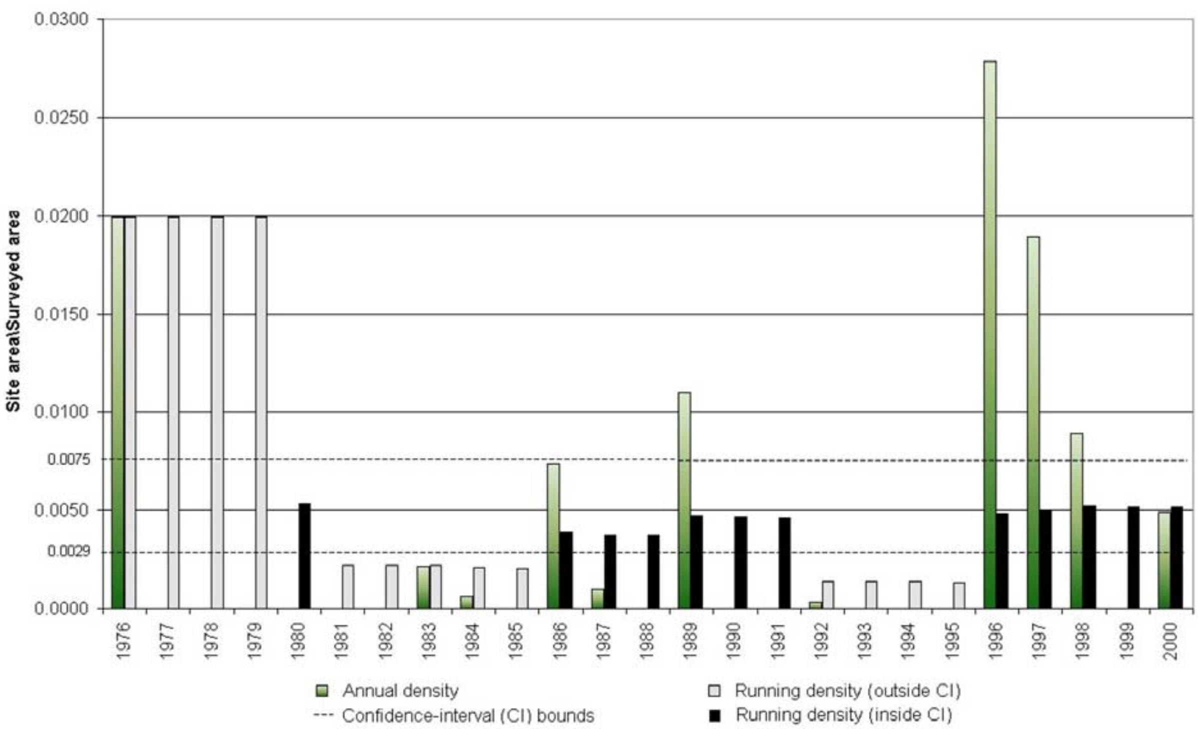

Figure 7.20. Overall site density, Method II.

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CHAPTER

8

Historical Period Land Use on Otero Mesa

Scott Thompson

As noted in Chapter 1, much of the historical landscape within the Loco Hills and Azotea Mesa study areas has been irrevocably altered by modern development—roads, communities, and especially in Loco Hills, oil and gas development. Otero Mesa, however, has seen very little in the way of modern development and still retains many of the subtle physical traces of early Euroamerican settlement and land use. For this reason, we have provided this chapter of baseline information on the Euroamerican culture history and resources of the Otero Mesa study area. This chapter will provide general information about the kinds of historical resources that may be encountered if oil and gas development takes place in this area, and a context for interpreting and evaluating the significance of those resources.

Archival Research Methods

In March and April 2004, project personnel visited or contacted the following institutions and repositories to identify and evaluate sources documenting the period of occupation and use of lands within the Otero Mesa project area: Alamogordo Public Library; Bureau of Land Management (BLM) Office, Las Cruces; Directorate of the Environment, U.S. Army Air Defense Artillery Center, Fort Bliss, Texas; New Mexico State Land Office, Santa Fe; New Mexico State University Library, Rio Grande Historical Collections, and Special Collections, Las Cruces; Tularosa Basin Historical Society, Alamogordo; U.S. Army Corps of Engineers, New Mexico Real Estate Office, Albuquerque; and the University of Arizona Main Library and Special Collections, Tucson.

During the course of archival research a variety of textual and nontextual documents, comprising both primary and secondary sources, was evaluated for information content and significance. Relevant sources were copied, compiled, verified, and analyzed. From the documents reviewed and data collected, information was gleaned regarding the general history of the study area and surrounding vicinity as well as a history of settlement and land tenure. The records search was the first step in determining the locations of cultural resources in the study area.

At the BLM office in Las Cruces, we studied the General Land Office (GLO) survey plat maps of the Otero Mesa study area spanning the years 1885–1939. The locations of historic buildings, structures, and water storage and conveyance features were geo-referenced and overlaid onto the eleven U.S. Geological Survey (USGS) 7.5-minute-series topographic maps illustrating the project area. In addition to reviewing documentary materials on file at the aforementioned facilities, SRI obtained the GLO files of patented homesteads within the project area from the BLM web site (http://www.glorecords.blm.gov/). These records provide specific information on patented claims, including the names of patentees, the year the patents were received, the authority under which the claims were patented (e.g., Homestead Act, Enlarged Homestead Act, Stock Raising Homestead Act), total number of acres per patented claim, and the legal descriptions for the claims. Locational information for the homestead parcels was digitized and transferred onto USGS topographic maps of the study area.

The records search was by no means exhaustive. Further research in the form of oral history interviews with local personages and examining Otero County deed and land records could furnish additional information concerning the occupation and use of lands on Otero Mesa. Specifically, oral history interviews with longtime residents could explore in detail the farming and ranching activities from the viewpoints of those who engaged in them.

Historical Overview of Exploration and Settlement on Otero Mesa

As described in Chapters 1 and 7, Otero Mesa lies in Otero County in south-central New Mexico (Figure 1.2). Otero Mesa encompasses 1.2 million acres of Chihuahuan Desert grassland and extends from the Hueco Mountains on the west to the Guadalupe Mountains on the east, and from approximately the Texas–New Mexico border north to the

Sacramento Mountains (Figure 1.3). For most of the historical period, both Native Americans and Euroamericans treated this region as a place to pass through on the way to somewhere else or as one to avoid altogether.

Very little has been written about the history of Otero Mesa; much more information is available about the neighboring Tularosa Basin, owing to the basin's mineral resources and the earlier and more extensive Euroamerican settlement of that area. The Tularosa Basin adjoins Otero Mesa on the west and is approximately 150 miles long and 60 miles wide, encompassing an area of 6,000 square miles. It is bordered on the north by the Sierra Oscura range and the Chupadera Plateau, on the east by the Sacramento Mountains, and by the San Andres and Organ Mountains on the west. The Jarilla, Franklin, and Hueco Mountain ranges border the Tularosa Basin to the south (Schneider-Hector 1993:3).

To create a framework for understanding Euroamerican settlement, land tenure, and historical resources on Otero Mesa, we can examine the culture history of the Tularosa Basin, which has similar climatic and landscape characteristics as well as having experienced similar historical processes. Both regions have dry, harsh, marginal environments that militated against historical period settlement. Semi-nomadic Native American groups such as the Manso, Suma, and Mescalero Apache used the lands of the Tularosa Basin and Otero Mesa for hunting and gathering food, but they did not establish permanent or long-term settlements in these forbidding landscapes. Rather, their base camps were located near reliable water sources in the surrounding mountain ranges and in the Rio Grande Valley. During the Spanish and Mexican periods and the early years of the American period, the Tularosa Basin/Otero Mesa region was seen as less than desirable owing to the lack of water and to the Apache presence. Only after the Apaches were settled onto reservations did significant settlement occur here (Faunce 2000:4–5, 23).

The Spanish Colonial Period

Between 1581 and 1583, two Spanish expeditions entered what is now south-central New Mexico through the pass between the Franklin Mountains and the Sierra de Juárez that later became known as El Paso del Norte. The first expedition, under the command of Captain Francisco Sanchez Chamuscado, paralleled the Rio Grande in search of gold and converts to Christianity. In 1583, Don Antonio de Espejo led a group of two priests and 15 soldiers north of El Paso del Norte along the Rio Grande. Accounts of the journey indicate the group did not enter the Tularosa Basin owing to a lack of water and to their perception that the region held nothing of value. Espejo's group was interested in finding a route around the inhospitable area to other regions rich in resources.

In 1595, King Philip II of Spain commissioned Juan de Oñate to conquer and settle the northern territories of New Spain. Oñate claimed the territory for the Spanish crown in 1598, establishing settlements near the Indian pueblos of Acoma, Isleta, Soccoro, and Santo Domingo, and subsequently founded the Spanish villages of Española, Santa Fe, and Bernalillo. Oñate's expedition avoided the Tularosa Basin altogether (Faunce 2000:27–28). Consequently, when the colonial government established the Camino Real, or Royal Highway, to connect the settlements of the northern frontier to Mexico City, the route lay well to the west of the Tularosa Basin and Otero Mesa (Schneider-Hector 1993:32).

During the Spanish colonial period the Tularosa Basin and the entire south-central region of present-day New Mexico were perceived as a wasteland with little to offer in the way of resources. Interest in the area was minimized even further by the Apache presence in the Organ and Sacramento Mountains. Instead, Spanish settlement centered in and around Santa Fe and along the Rio Grande, where farms tended to dominate the rural landscape (Culbert 1941:155). The first documented use of the Tularosa Basin by the Spaniards was in 1647 when the Salt Trail was established to exploit substantial salt deposits in the region. Initially, the trail extended north from the silver mining districts of Durango, Mexico, through El Paso del Norte (present-day El Paso, Texas), along the eastern edge of the Organ Mountains to Lake Lucero, an ephemeral lake on the present-day White Sands National Monument located due west of Alamogordo. In 1691, the Spaniards discovered additional salt deposits in the eastern Tularosa Basin. The Salt Trail between El Paso and the basin deposits was abandoned in 1862, after a superior source was discovered near Guadalupe Peak in Texas (Faunce 2000:23–24; Sonnichsen 1960:7).

Apart from extracting salt from deposits within the basin, Spanish activity in the area consisted largely of punitive expeditions against the Apaches. Throughout the eighteenth century, the Spanish military responded to Apache depredations by launching several campaigns to flush the raiders out of their mountain strongholds and recover stolen property. In 1786, Bernardo de Gálvez, the viceroy of New Spain, instituted a policy of continuous military harassment coupled with a promise of kind treatment and supplies if the hostile bands would agree to live in peace. By waging vigorous campaigns against the Apache, the Spaniards hoped to make peace more appealing than war. Those who sued for peace had to agree to remain within a bounded area. In return for their "settled" lifestyle, they received rations from the colonial government. This dependency system was costly for the Spanish crown, but it brought peace to the northern frontier throughout the remainder of the Colonial period. From 1793 to 1821, the region experienced relative peace as only a few raiding Apache bands required action on the part of the frontier garrisons (Faunce 2000:28–35; Hawthorne 1994:12).

The Mexican Period

After Mexico won its independence from Spain in 1821, the new government dismantled the pacification system that paid the Apaches for peace, and the Indians began raiding once again. The Salt Trail continued to be used to transport salt from the Tularosa Basin south to El Paso and on to the mining districts of Chihuahua and Durango (Faunce 2000:40–41). Like its predecessor, the Mexican government looked upon south-central New Mexico as an inhospitable area offering nothing of value other than the salt deposits that continued to be mined. The absence of reliable water sources and the presence of the Apache in the nearby mountains continued to discourage Euroamerican settlement.

The first commercial use of the Tularosa Basin other than for salt mining involved the construction and operation of a water-powered sawmill on the Tularosa River, processing timber from the Sacramento Mountains. According to Sale et al. (1996), this took place in 1845 and mill workers cut vigas, or beams, for use in the construction of a church in El Paso. Three trips were made to transport the cut lumber to El Paso, and on the first trip they were attacked by a band of Mescalero Apaches (Sale et al. 1996:22). In contrast to this account of a short-lived commercial activity, Sonnichsen's Tularosa (1960:10) refers to a sawmill operation on the river "which had supplied timber for churches and other buildings up and down the Rio Grande since before the year 1800." Whatever the actual dates of the sawmill's operation, it constituted the first documented non-Native American settlement in the region.

As it had during the colonial period, the Apache presence in the region deterred exploration and settlement of the Tularosa Basin and Otero Mesa during the Mexican period. Those who ventured into the region either traveled along the Salt Trail or were in pursuit of Apache raiders and stolen livestock. According to Faunce (2000:43), some grazing of livestock occurred in the area along the present-day New Mexico–Texas border during the Mexican period, but it was not until the United States gained control of the territory that large numbers of Euroamerican miners and settlers moved into the region.

The American Period

In May 1846, the United States went to war with Mexico over the annexation of Texas and President James Polk's interest in the Mexican territory of California. After U.S. troops seized Mexico City in September 1847, representatives of the two countries signed the Treaty of Guadalupe-Hidalgo, which Congress ratified in March of the following year. Under the terms of the treaty, Mexico recognized the United States' claim to Texas and ceded the territories of California and New Mexico. Along with the acquisition of this huge expanse of territory, the U.S. government inherited the Apache problem.

Shortly after acquiring the territory of New Mexico, the United States established military posts to protect settlements and began to explore and map the region. The first documented foray into the Tularosa Basin by U.S. military forces occurred in 1849 when a small contingent entered the basin in pursuit of Apache raiders (Sale et al. 1996:22). That same year, several U.S. Army expeditions traveled either through or around the basin. In their respective reports they commented on the abundant grasslands east and north of El Paso and determined that the area would be suitable for grazing livestock if sufficient water could be secured (Faunce 2000:51).

In September 1849, Capt. Randolph B. Marcy came to New Mexico territory under a directive to establish a route from Fort Smith, Arkansas, to New Mexico and California. On the return trip to Fort Smith, Marcy's party entered the Tularosa Basin from the west, seeking a southern route from Santa Fe to Fort Smith. Marcy relied on a local guide to lead his expedition through the territory east of the Organ Mountains. Shortly after Marcy's expedition, Lt. William F. Smith and a small escort surveyed the Sacramento Mountains on the east side of the basin in search of a practicable wagon route. Traveling from the military post at El Paso, the party headed north on the Salt Trail along the eastern slope of the Organ Mountains before turning east toward the Sacramentos. Smith's reconnaissance concluded that the rugged terrain was unsuitable for a wagon road (Schneider-Hector 1993:5, 39–41).

In 1857, the Butterfield Overland Mail established a route through southern New Mexico following a portion of the trail blazed by Captain Marcy eight years earlier. The stageline was organized by John Butterfield of Utica, New York, in response to increasing demand for improved and regular communication between the eastern states and the western territories and California (Conkling and Conkling 1947). Westbound travelers crossed into New Mexico from Texas just west of the Guadalupe Mountains and passed through the Otero Mesa region near the subsequent and now-deserted settlement of Orange (established in 1904) before reaching the station at Cornudas de los Alamos (Figure 8.1). Passenger Waterman L. Ormsby, Jr., who traveled the entire route from Missouri to San Francisco in 1858, provided the following description of the stagestop at Cornudas:

> There is quite a large station here, and we procured a fresh team and a side driver and set out for Waco Tanks [Hueco, meaning "hollow" or "trough" in Spanish], thirty-six miles distant [cited in Greene 1994:74].

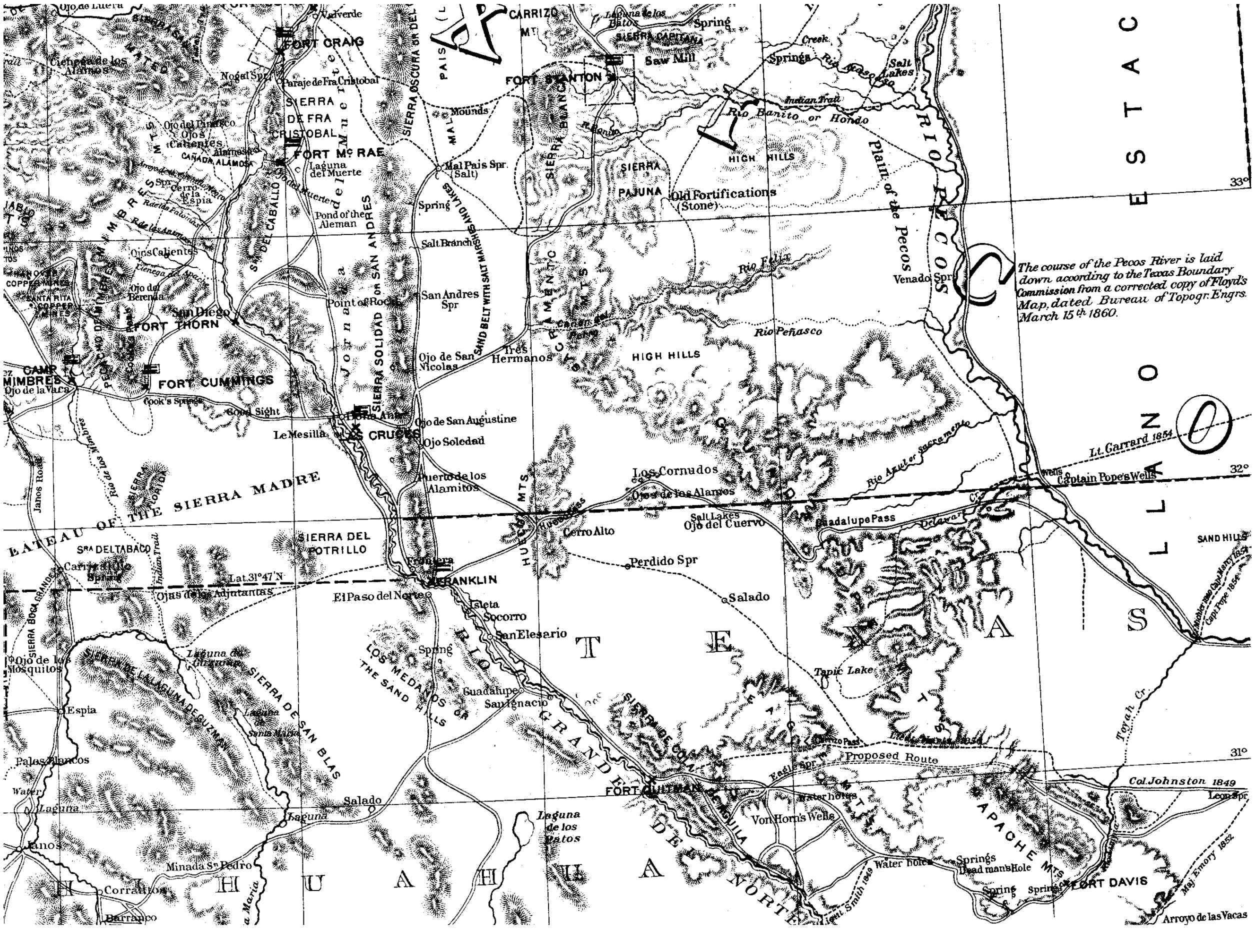

Figure 8.1. Portion of 1864 map of the Military Department of New Mexico by Capt. Allen Anderson, Fifth U.S. Infantry (accompanying report of Brig. Gen. J. H. Carleton, U.S. Army Series I, Vol. LXVIII; reproduced from Gerow 1996).

From Cornudas de los Alamos the trail continued about 16 miles in a generally westerly direction to the station at Ojos de los Alamos (Figure 8.2), also known as Cottonwood Springs. Situated one-half mile from a perennial spring, the station house was large and both exterior and interior walls were built of stone and adobe (Greene 1994:75). Upon leaving Ojos de los Alamos, the stagecoaches headed west and then dipped south across the border into Texas for a stop at Hueco Tanks before reaching El Paso.

The Butterfield Overland Company operated successfully until the outbreak of the Civil War when the United States government canceled the contract and rerouted the mail through the central states. During its period of operation, the stageline moved passengers, mail, and light cargo, serving as the primary and sometimes only means of transportation before the railroads connected the New Mexico territory to the east and west. Even after the Butterfield Company abandoned the line, the route continued to be used by emigrants, freighters, and the military (Conkling and Conkling 1947; Faunce 2000:56: Greene 1994:74–75, 182).

Raiding by Apache bands continued throughout the 1860s, and the military launched several campaigns against the raiders during that period (Faunce 2000:57). By the early 1870s, conflict with the Apaches had begun to lessen, and several bands had settled near Fort Stanton (established in 1855) in the Sacramento Mountains. On May 29, 1873, President Ulysses S. Grant established, by executive order, the Mescalero Apache Indian Reservation (Hawthorne 1994:14; Mehren 1969:68). Over the next decade there were sporadic outbreaks of violence, but in general, the era of Apache raids was over. By the mid-1880s, with the reservation system firmly in place, farmers and ranchers began moving into the region.

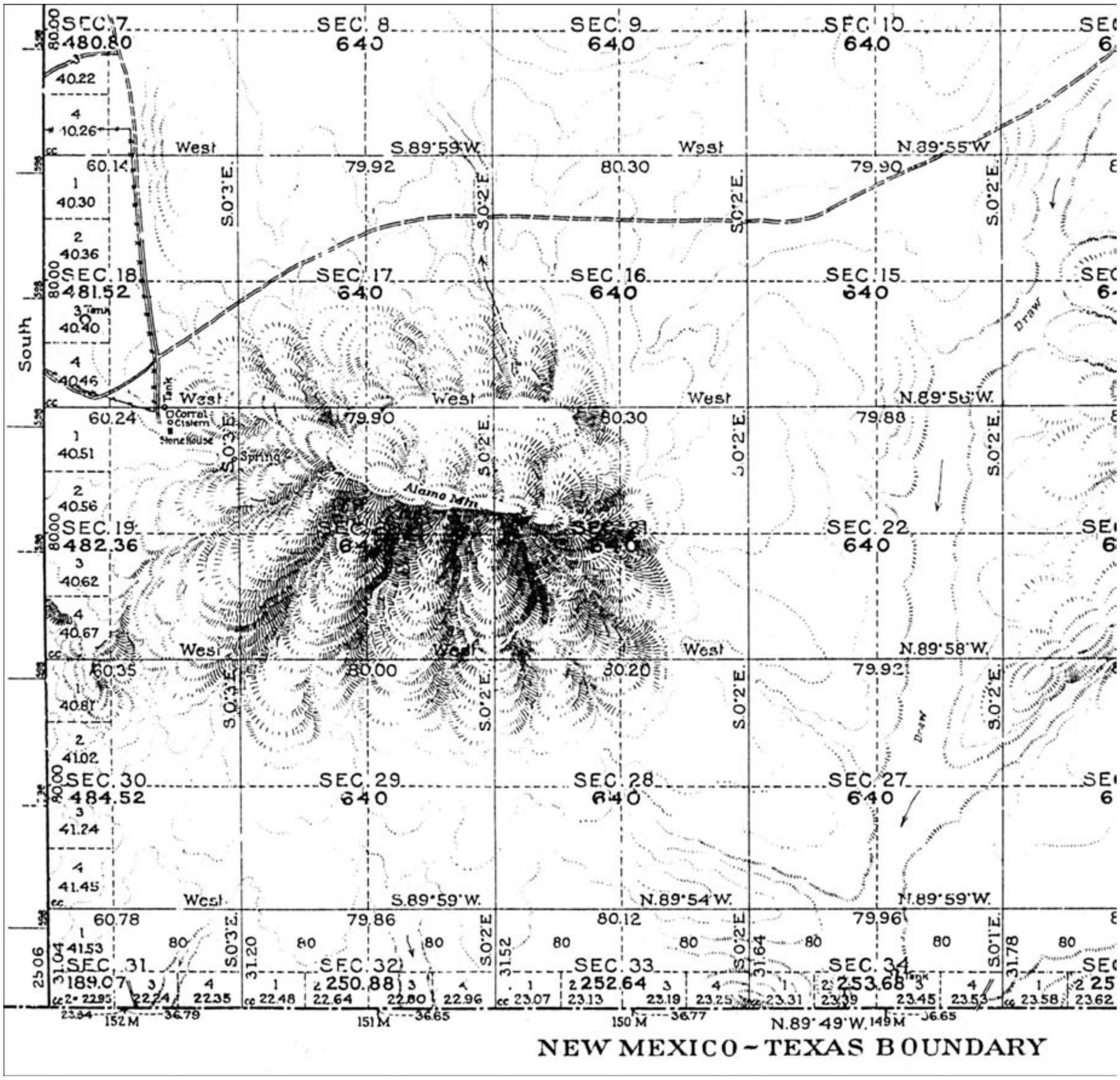

Figure 8.2. 1926 GLO survey plat of Township 26 South, Range 13 East indicating the location of the Ojos de los Alamos stagestop on the Butterfield trail (GLO 1926).

Farming

The first non–Native American settlers in present-day Otero County arrived in the 1860s. In 1862, Hispanic pioneers who had been forced by repeated floods of the Rio Grande to abandon their homes and fields in the Mesilla Valley established the community of Tularosa on the Tularosa River at the western base of the Sacramento Mountains. They planted fields of vegetables and grain as well as fruit orchards on the outskirts of town and diverted water from the river to irrigate their crops. This was not the first attempt to settle the area. Two years before, a small group of farmers had cleared fields and planted crops but were driven out by the Apaches before the first harvest. A year after Tularosa was founded, another group of Hispanic emigrants, this time from the flood-ravaged Socorro area on the Rio Grande, established a colony beside La Luz Creek, 15 miles south of Tularosa. Because of the village's proximity to Apache camps in the nearby Sacramento Mountains, the residents of La Luz built an adobe fortress for defense. They also built a community ditch to irrigate fields planted with corn and wheat, and they raised small herds of cattle, sheep, and goats as well (Hawthorne 1994:14–15; Schneider-Hector 1993:42; Sonnichsen 1960:11; Townsend and McDonald 1999:95–96). An abundant supply of water and the U.S. military presence at Fort Stanton enabled these communities to grow and prosper.

Ranching

The majority of the lands in the Tularosa Basin were unsuitable for farming owing to the lack of water, but the vast expanses of grasslands in the basin and on Otero Mesa to the east attracted ranchers from Texas, where years of drought and overgrazing had limited their opportunities. Stockraising had been one of the primary industries in New Mexico since Juan de Oñate introduced the first breeding stock of cattle and sheep in the late sixteenth century. Spanish ranchers found a market for their cattle and sheep in the mining camps of Nueva Vizcaya, in what today are the states of Chihuahua and Durango, Mexico. Cattle ranching began its climb to prominence during the 1850s, however, when the U.S. government established military garrisons across the territory in response to increased raiding by the Apache and other nomadic Indian tribes. The ranchers benefited not only from the protection offered by the military presence but also from the new market as these installations required a steady supply of beef to feed the troops (Simmons 1988:7–9; Townsend and McDonald 1999:121).

With the confinement of the nomadic Indian tribes on reservations and the near extinction of the great buffalo herds on the high plains of eastern New Mexico, the way was paved for cattlemen to drive their herds into the territory and establish ranches on the open range. By the 1880s, stockraising was the dominant economic activity in Otero County (Lowery and Gibbs 1999:39). Census figures for 1880 report 400,000 head of cattle and 5,000,000 sheep in the territory. Bust followed the boom years of the early 1880s. Nationwide, cattle prices dropped between 1884 and 1891, and severe droughts devastated the industry in 1903–1904 and 1907–1908 (Simmons 1988:11–12). The industry recovered as ranch operations became more efficient by improving breeds, sinking wells and building windmills. Federal policies established grazing districts, leases, and fees to regulate the ranchers' access to public lands.

During the period of the open range, ranchers' herds grazed on the public domain and relied on natural water sources. In 1934, Congress passed the Taylor Grazing Act to regulate grazing on federal land. Under the provisions of the act, the Grazing Service (later the BLM) of the Department of the Interior divided federal land into grazing districts and issued permits in order to manage livestock grazing within each district. This ended the open range system. Ranchers adapted to these new requirements and made improvements to leased public lands by constructing wells, windmills, and stock tanks. Such improvements, however, had to be authorized by the Grazing Service (Hawthorne-Tagg 1997:31–32).

By the outbreak of World War II, cow-calf operations were the most common ranch type in the state. These operations sold young animals and only retained breedingstock. The war created an expanded demand for beef, as ranchers contracted with the government to supply meat to military installations. During the war years (1942–1945) New Mexico ranches marketed a half-million head of cattle annually (Simmons 1988:12–13). Throughout the twentieth century, New Mexico's cattle ranching industry experienced periods of success and decline, but it has survived into the twenty-first century as a viable business enterprise. Several studies provide an extensive history of ranching in the Tularosa Basin (e.g., Faunce 2000; Hawthorne 1994; Hawthorne-Tagg 1997), so only a summary is presented in the following paragraphs.

Owing to the scarcity of water, the majority of basin and mesa lands proved more suitable for grazing livestock than for growing crops. Ranchers began moving their herds into what is now Otero County during the 1860s and early 1870s. Most of the ranchers were from Texas. They were attracted by the region's vast expanse of public domain land that was suitable for year-round grazing. Typically, ranchers resided on deeded land, where they maintained their ranch headquarters, but claimed range rights to the best water sources on the public domain where they grazed their livestock (Hawthorne-Tagg 1997:29–30).

Perhaps the most prominent Texas rancher to emigrate to the Tularosa Basin was Oliver M. Lee. He established his headquarters near Dog Canyon in the Sacramento Mountains in 1884. Over the years Lee expanded his holdings and gained control over valuable water sources in the basin and on Otero Mesa. His extensive system of wells, pipelines, and stock tanks allowed his herds to survive periods of drought that ruined other ranchers in the area (Faunce 1997:69). At one point, Lee controlled approximately one million acres of deeded land and open range, stretching from the Sacramento Mountains south to the Texas border (Townsend and McDonald 1999:127).

Public domain and state land constitute the vast majority of lands on Otero Mesa, although there are pockets of privately owned land, most of which are used for ranching. Private holdings are generally located at or near a water source. Ranchers built earthen stock tanks to collect water from natural drainage channels, or placed pipelines in areas where there was little or no surface runoff. Wells were drilled to supply water to metal stock tanks. According to Faunce (2000:281–282), well depths on Otero Mesa typically reached 1,200 to 1,500 feet. Even at these depths, wells did not always produce large amounts of water. Between 1935 and 1936, the Civilian Conservation Corps constructed earthen stock tanks and maintained existing tanks on federal land to benefit both the ranchers and the local economy (Faunce 2000:173). Today's ranchers graze their herds on state lands leased from the New Mexico State Land Office and on federal lands through the BLM.

Railroad

The Otero Mesa study area has always been slightly removed from the state's early transportation system. During the Spanish and Mexican periods, the major north-south transportation routes were the Camino Real and the Salt Trail, both of which bypassed the study area to the west. A wagon road extending north from El Paso through the Tularosa Basin connected Fort Bliss and Fort Stanton and was frequented by soldiers traveling between the posts or in pursuit of Apaches. Beginning in 1857, the Butterfield Overland Mail route passed through a portion of the study area. This route generally followed the trail established by Captain Marcy in 1849. The Apache threat that delayed Euroamerican settlement of the Otero Mesa and Tularosa Basin likely slowed the development of major transportation routes through the region. In May 1881, after the confinement of the Apache on reservations, the Southern Pacific Railroad reached El Paso from New Mexico. Shortly thereafter plans were initiated to extend a railroad line from El Paso north through the Tularosa Basin to the coal deposits at White Oaks; however, a series of setbacks delayed construction for 16 years (Myrick 1970:58, 66–72).

South-central New Mexico remained relatively isolated until 1898. At that time, the El Paso and Northeastern Railway was extended from El Paso 85 miles north to the newly founded town of Alamogordo at the western base of the Sacramento Mountains. Alamogordo served as the headquarters of the railroad, with offices, machine shops, and a company hospital. The railroad built a line east into the Sacramento Mountains to tap the rich timber resources. Work also commenced to extend the railroad north of Alamogordo to Carrizozo and the coal fields of the Capitan Mountains. By 1902, the El Paso and Northeastern reached Santa Rosa, where it met the Rock Island Line (Myrick 1970:71–77).

The railroad brought major changes to the Tularosa Basin by connecting the region to larger markets and encouraging settlement. Area ranchers could now drive their herds to the nearest siding for shipment to national markets. Within days of the line reaching Alamogordo, prospective farmers filed homestead claims on 4,000 acres of federal land in the vicinity of the newly established town (Faunce 2000:76). Alamogordo and the surrounding communities grew at a rapid pace, and on January 30, 1899, the territorial legislature created Otero County from parts of Doña Ana, Lincoln, and Socorro counties. The county is named after Miguel A. Otero, the territorial governor at the time (Coan 1925:572). The railroad was initially built to exploit the region's coal and timber resources, but it also had a significant impact on settlement of the basin and surrounding areas. The railroad launched an era of economic development by providing relatively easy and inexpensive access to national markets. Mines and ranches also now had outlets for their products and a ready source of necessary supplies.

Mining

Apart from farming and ranching, mining was the other major economic pursuit that historically characterized south-central New Mexico. The first group to extract mineral resources from what is now Otero County was probably the Apaches, who surface-mined turquoise in the Jarilla Mountains. Around 1841, the Refugio Mine was established in the Organ Mountains, an area known for its silver deposits since the Spanish colonial era. During the 1880s, mining began in earnest in the Jarilla Mountains with the discovery of copper, gold, silver, and iron deposits. By 1883 a number of mining operations were in full swing, including the St. Louis United Copper Company which was extracting ore from seven mining claims (Faunce 2000:85, 91).

The completion of the El Paso and Northeastern Railroad in 1898 led to increases in mining activity in the Jarillas by improving access to the area and opening markets for mineral products. A gold rush started in 1905 in the Jarillas when a prospector from Alamogordo found a large gold nugget. As more people arrived to capitalize on the mineral resources, land and town development followed. In November 1905, the South West Smelting and Refining Company laid out lots and streets at Jarilla Junction. The company also constructed a smelter for processing ore, eliminating the need to ship the ore to El Paso. In April 1906, the burgeoning community changed the name of the mining town from Jarilla Junction to Orogrande (Spanish for "Big Gold"). To facilitate growth and secure a dependable water source for the smelter and the town, the South West Smelting and Refining Company constructed a 27-mile water pipeline from the Sacramento River to Orogrande. The community grew rapidly, and by 1907 it had more than one hundred buildings, including a school, hospital, pharmacy, church, cement block factory, bank, two saloons, a water company, and headquarters for many mining companies. Prosperity did not last long once the minerals started to play out. In 1908 the South West Smelting and Refining Company abandoned the smelter, and shortly thereafter the company went bankrupt. Iron mining followed the earlier gold and copper booms but declining iron prices in the 1920s forced many of these mines to close (Faunce 2000:92–95; Townsend and McDonald 1999:83–89).

Oil and Gas Exploration

In 1919, mineralogists and geologists discovered Pennsylvania-series fossils in the Sacramento Mountains and Tularosa Basin and thick, porous sand beneath the basin floor. Both discoveries indicated the presence of oil deposits below the surface. Once word spread of these discoveries, oil companies from California and nearby states flocked to New Mexico. This flurry of activity attracted ranchers and homesteaders, eager to get rich from the subsurface resources. By April 1919, more than 5,000 mineral claims for oil and gas exploration had been filed in the Tularosa Basin. Several local oil and gas exploration companies formed, including the Alamogordo Shale and Oil Company and Cox Oil Company, The latter was organized by W. W. Cox, a local rancher. In October, the Cox Oil Company prepared to drill its first well. Cox never struck oil. He and his shareholders lost their investments and Cox subsequently went bankrupt. By the early 1920s, few companies had struck oil. The oil craze had a significant impact on the basin and surrounding areas as speculators, ranchers, and homesteaders invested and then lost a great deal of time and money (Faunce 2000:97–100).

Military

In the mid-1930s, with the specter of war looming over Europe, the U.S. Congress enacted legislation to maintain its policy of isolation and neutrality. By the fall of 1939, Germany invaded Poland and an all-out war was raging in China. These events forced the United States to abandon neutrality and begin a massive buildup of its air, land, and sea forces. As the nation prepared for war in Europe, the Army Air Corps expanded dramatically. This expansion incorporated three major tasks: the production of aircraft, the recruiting and training of personnel, and the acquisition of land for the construction of airfields and training facilities (Cate and Williams 1983:104–105). Vast expanses of inexpensive desert land and weather suitable for flying year-round attracted military planners to the Southwest.

The Tularosa Basin, with its sparse population; vast, unencumbered airspace; and large amount of public land, was an ideal location for a military training facility. In 1942, the federal government began withdrawing public lands and condemning ranches and homesteads for the purpose of establishing the Alamogordo Bombing and Gunnery Range. As part of the land withdrawal the government suspended grazing permits, denying area ranchers access to grazing lands. Construction of Alamogordo Army Air Field, located immediately west of Alamogordo, began in 1942. Throughout the war the base served as a training facility for British pilots and American bomber crews. On July 16, 1945, the first atomic bomb was detonated at the Trinity site in the northern part of the range (Hawthorne 1994:23). The Alamogordo Bombing and Gunnery Range and Alamogordo Army Air Field were subsequently integrated into the White Sands Proving Grounds (now known as the White Sands Missile Range) at the end of the war. Alamogordo Army Air Field was renamed Holloman Air Force Base in 1947 and officially separated from the proving grounds (Lowery and Gibbs 1999:1). During the ensuing years the U.S. Air Force and Army acquired large tracts of both improved and undeveloped land to accommodate the testing and training needs of their respective forces. Military testing and training have supplanted stockraising as the primary use of the basin.

A Historical Perspective on American Period Settlement and Land Tenure in the Otero Mesa Study Area

In 1880, the study area and much of the south-central portion of the New Mexico Territory was unplatted (Cram 1880). The nearest communities were San Augustine to the west (near the Organ Mountains) and La Luz and Tularosa to the north. The earliest evidence of Euroamerican settlement in the study area appears on GLO survey plats published in 1885. In March–April 1884, a survey of the township lines and subdivisions of Township 24 South, Range 12 East (New Mexico Principal Meridian) noted a ranch in the southeast quarter of Section 29 (GLO 1885a). A survey of Township 25 South, Range 12 East, performed during the same time period, recorded a ranch in the southwest quarter of Section 10 (Figure 8.3) (GLO 1885b). Both locations are labeled “Ranch,” with no other information on the plat map or in the surveyor’s notes. Later GLO surveys encompassing the Otero Mesa study area recorded ranches, farmsteads, and houses. These settlements likely represent legitimate homestead claims, deeded or patented land, or squatter activity. In her study of historical settlement of Holloman AFB, Hawthorne (1994:185) suggests squatters on public land in the Tularosa Basin did not file their claims because of the distance to the nearest land office in Las Cruces, more than 70 miles away. This was probably also the case for Otero Mesa. For example, the 1912 GLO survey plat for Township 22 South, Range 13 East depicts the “Trammell’s” farmstead (GLO 1912b). Adrian A. Trammell moved his family to Otero Mesa around 1898, yet he did not patent a homestead until January 11, 1919 (Faunce 1997:98; GLO 1919). How the settlers in the study area acquired their land is poorly understood and requires further research.

As noted above, the first substantial wave of settlers arrived in the southern Tularosa Basin in 1898 and filed homestead claims totaling 4,000 acres to the south and west of Alamogordo (Faunce 2000:76). Under the provisions of

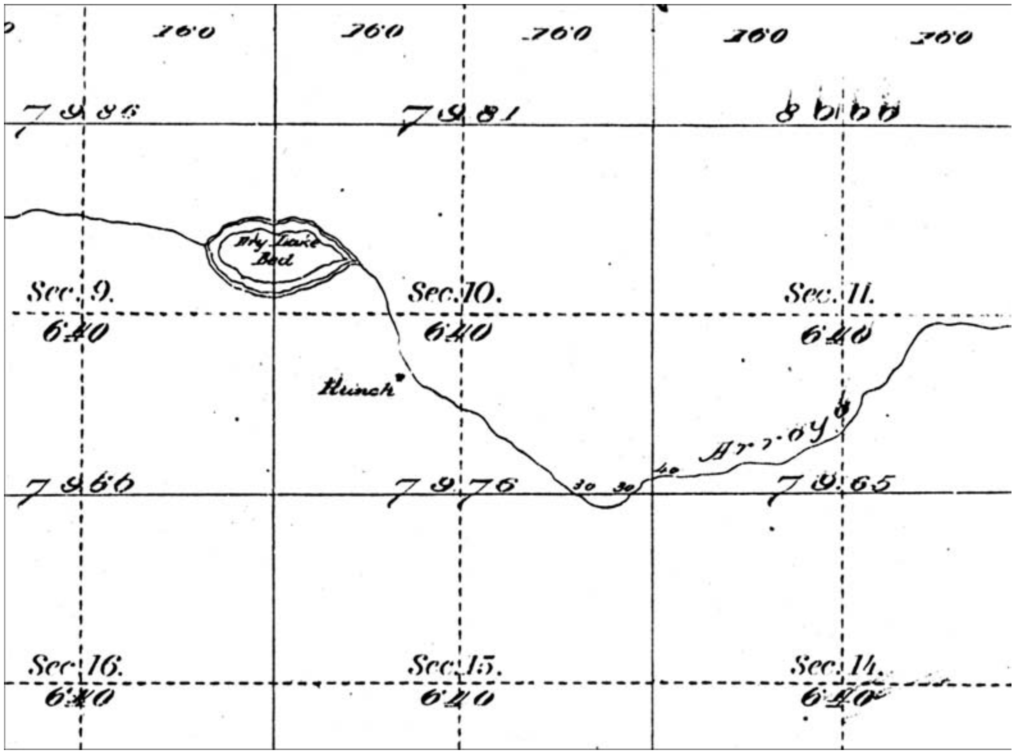

Figure 8.3. 1885 GLO survey plat of Township 25 South, Range 12 East (GLO 1885b).

the Homestead Act of 1862, U.S. citizens (or resident aliens who declared their intention of becoming U.S. citizens) could acquire up to 160 acres of free land, provided they resided on the land continuously for five years and cultivated a portion of the land in the final four years. At the end of the five-year period, and upon fulfilling the settlement requirements, claimants made final proof and received a patent for their land (Stein 1990:4). The earliest record of a patented homestead claim in the study area is 1914. On January 29 of that year Emma Kaler patented 160 acres in Township 22 South, Range 13 East, Sections 14 and 15 (GLO 1914).

Significant changes to the homestead law occurred in 1909 when Congress passed the Enlarged Homestead Act, also known as the Dry Farming Homestead Act. Most land in the western United States was too arid for growing highly water-dependent crops, but proponents of the act believed that by employing dry farming techniques the land could be productive. Successful dry farming required an annual rainfall of more than 10 inches, emphasizing the cultivation of drought-tolerant crops, plowing deeply in the fall, and harrowing the soil during fallow periods to help it retain moisture. Under the provisions of the act, each claimant received up to 320 acres of non-irrigable, non-mineral land (land for which the federal government retains rights to subsurface mineral deposits) that required five years of continuous residence and a graduated scale of cultivation before a patent was issued. Congress, in an effort to promote the settlement of public land, reduced the five-year residency requirement to three years in 1912 (Layton 1988:21; Stein 1990:5).

Evidence of farming within the study area is depicted on a GLO survey plat filed in 1912 (Figure 8.4) (GLO 1912b). Three cultivated fields and several flood ditches (presumably used for diverting seasonal floodwater from the normally dry Sacramento River) are shown on the portion of the township that lies in the study area. Two of the fields are clearly associated with the residences of Don Porter and Adrian A. Trammell, located in Sections 14 and 21, respectively. Both Trammell and Porter were enumerated in the 1910 census. Trammell gave his occupation as "farmer" and Porter, who was enumerated with the family of John A. Prather as a hired hand, listed "horse trainer" as his occupation (U.S. Bureau of the Census 1910a). The 1920 census lists Trammell as "farmer." Porter's name does not appear in either the 1920 or 1930 censuses (U.S. Bureau of the Census 1920a, 1930a). Several small farming operations were underway in the vicinity of Orange, New Mexico, located in Township 26 South, Range 18 East (Figure 8.5) (GLO 1912a). Dry farming on the marginal lands of south-central New Mexico was a risky endeavor. Extended periods of droughts during the 1920s and 1930s effectively ended dry farming in Otero County, and farmers either sold their land to ranchers in the area or relinquished their homestead claims to the government (Townsend and McDonald 1999:104).

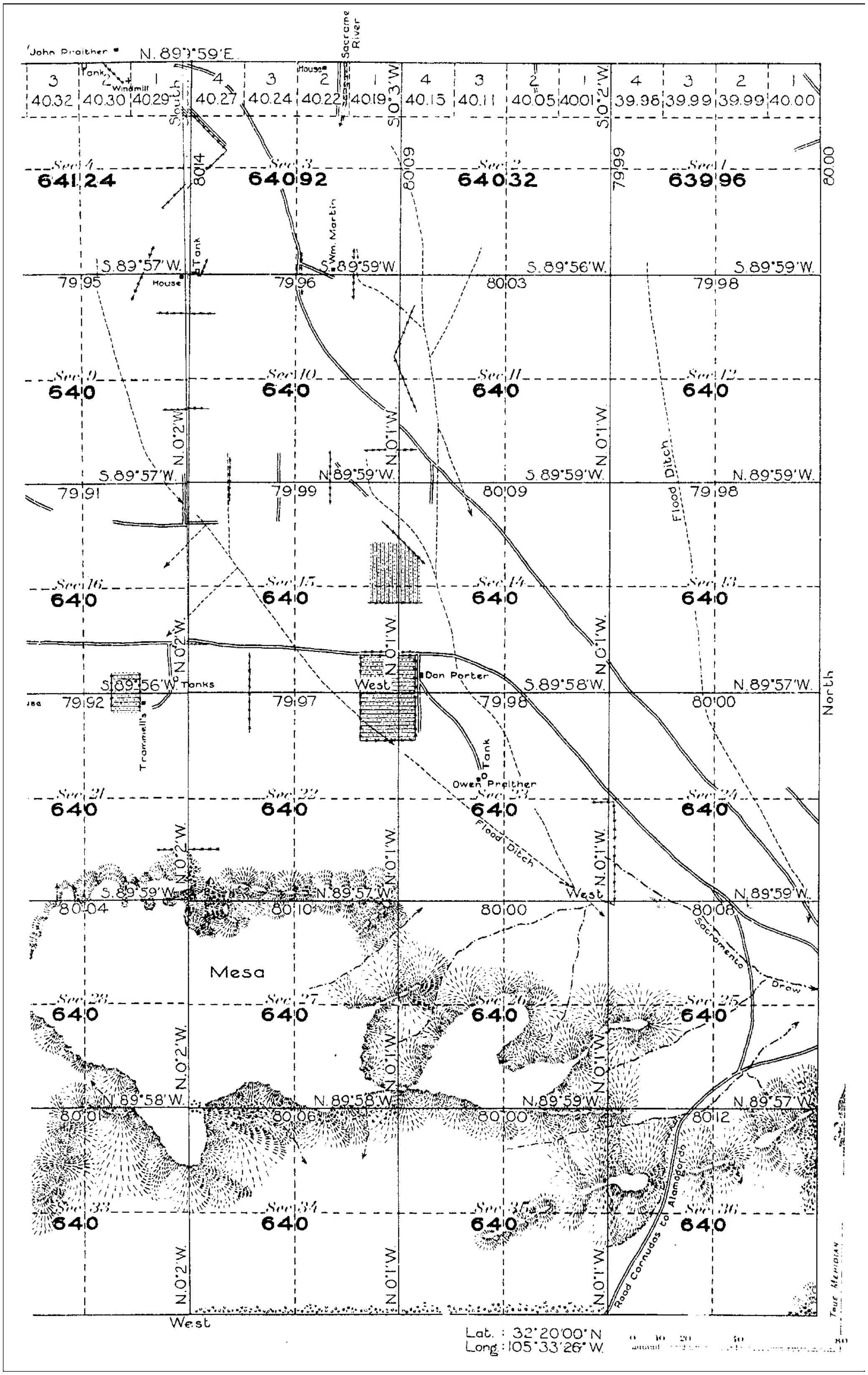

Figure 8.4. 1912 GLO survey plat of Township 22 South, Range 13 East depicting cultivated fields and floodwater ditches in study area (GLO 1912b).

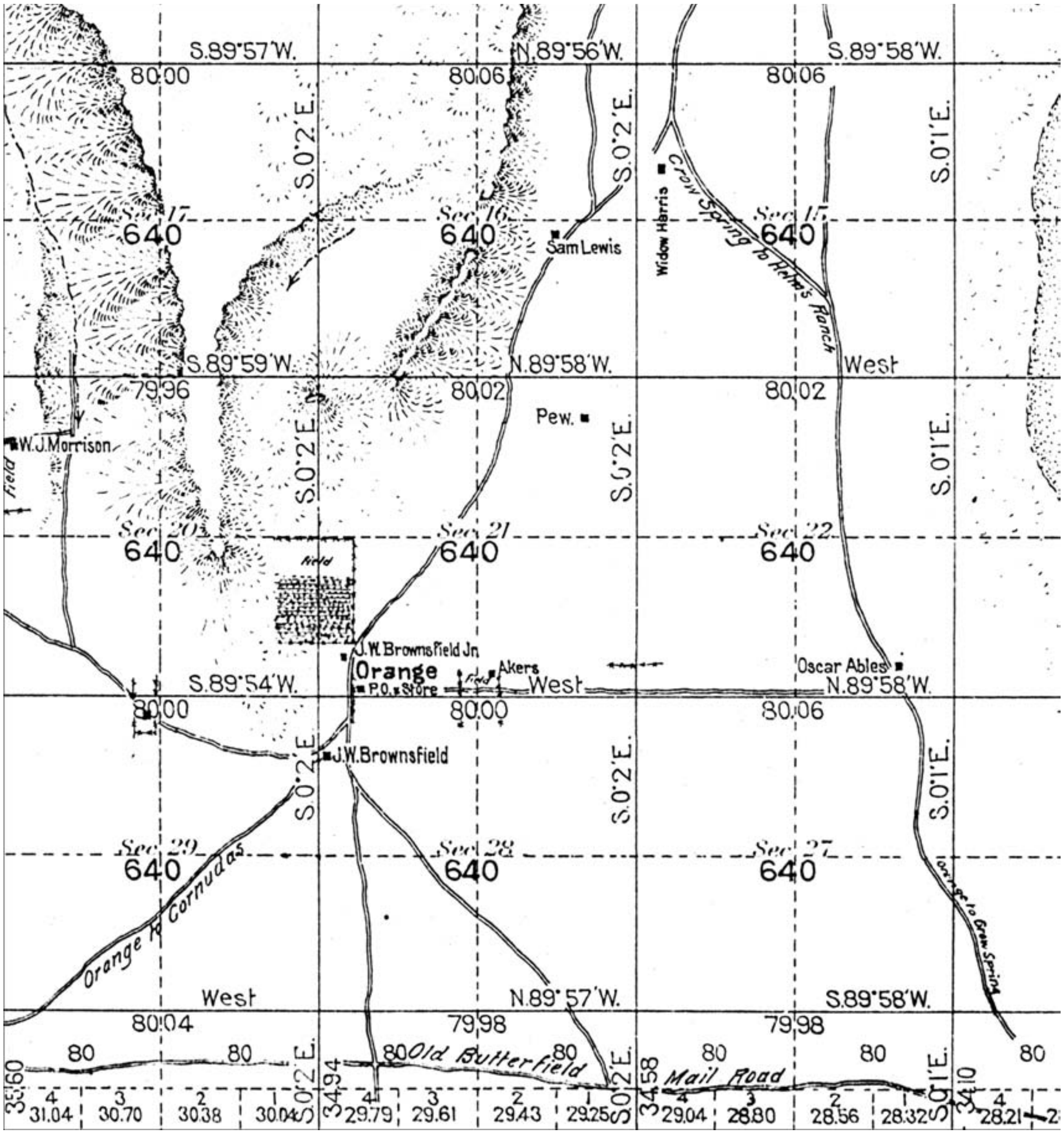

Figure 8.5. 1912 GLO survey plat of Township 26 South, Range 18 East. Note the route of the Butterfield Overland Mail shown at the bottom (GLO 1912a).

In 1916 Congress passed another homestead law, the Stock Raising Homestead Act, to promote the settlement of non-irrigable and non-mineral remnant lands with no commercial timber. The act (also known as the Grazing Homestead Act) provided for homesteads of 640 acres on land valued primarily for grazing livestock and producing forage crops. While claimants did not have to cultivate the land, the act required improvements of $1.25 per acre before a patent was issued (Layton 1988:61). Both the Enlarged Homestead and Stock Raising Homestead Acts altered the landscape in Otero County by allowing settlers to claim larger parcels of land.

The Prather family is representative of those who emigrated to Otero Mesa to try their hands at farming and ranching. John Ellis Prather abandoned his farm in Van Zandt County, Texas, in 1884, after a devastating drought. The family traveled by train and wagon to New Mexico where they homesteaded 160 acres on the Agua Chiquita River in the Sacramento Mountains. Around 1898, John E. Prather and his wife, Mattie Browning Prather, moved to the area on Otero Mesa where the Sacramento River empties into the flat lands. They dry farmed, relying on a combination of rainfall and floodwater diverted from the Sacramento River. Other farmers by the names of Grisak, Langford, Martin, Trammell, and Van Winkle also homesteaded this area, known as “the flats” (Tularosa Basin Historical Society 1981:387–388).

John E. Prather's sons—Samuel (Tink), John A., and Owen—preferred ranching to farming and soon amassed their own land and livestock (Tularosa Basin Historical Society 1981:388). Shortly after settling on the flats, the Prathers purchased homesteads from those who failed to prove up their claims (Faunce 2000:223). Like other successful ranchers in the area, they bought up land both to increase their holdings and to obtain additional, reliable water sources for their herds. By the 1950s, John A. Prather's ranch encompassed 4,000 acres of deeded land and 20,000 acres of leased federal and state land. He mainly raised horses and mules, both of which require less water and forage than cattle (Faunce 2000:308; Tularosa Basin Historical Society 1981:389). In 1956, the U.S. Army, as part of its plan to expand the McGregor Guided Missile Range, attempted to purchase Prather's deeded land and grazing leases. Prather refused to sell and the federal government proceeded to condemn his land. After three years of trying to evict Prather, and much negative publicity, the Army settled with Prather, giving him $106,985 for his property and a lifetime lease on his ranch house and 15 surrounding acres. Prather died in 1965 and is buried on his ranch, which is now part of McGregor Range (Faunce 1997:125).

Several farming and ranch communities sprang up in the study area, each with its own post office. Between June 1898 and May 1900, a post office distributed mail in the area known as Crow Flat. The now-abandoned town of Orange, located less than 2 miles north of the New Mexico–Texas border, maintained a post office from May 19, 1904, to May 29, 1925 (Julyan 1996:250). Around 1912, the post office was housed in a store located on the east side of the road connecting Orange to the community of Weed in the Sacramento Mountains (GLO 1912a). To the northwest of Orange, in the area settled by the Prathers and Trammels, the Lulu Post Office served the community between August 22, 1913, and August 31, 1923. The settlement known as Cienega was located in the southeast part of Otero County, approximately four miles north of the New Mexico–Texas border. A post office was established on March 31, 1927, and later discontinued on February 28, 1942 (Tularosa Basin Historical Society 1985:xi).

During the late nineteenth and early twentieth centuries, school-age children in the diffusely populated region were educated by their parents, or in the case of families with the financial means, by private teachers who worked for wages as well as room and board (Tularosa Basin Historical Society 1981:388). The Otero County Board of Education established public schools in the communities of Orange and Lulu around 1920, possibly earlier. Orange was designated as District 19 and Lulu District 20 (Figure 8.6) (Otero County Board of Education 1921). In the spring of 1921, District 19 had an enrollment of 22 students. The following is a description of the District 19 school written by the school's students.

> Our school house is located in a valley; on the west are low hills and on the east are the beautiful Guadalupe Mountains. The winters here are warm and pleasant except for an occasional snowstorm which lasts only a few days.
>
> We have a large playground with a well and pump in the southeast corner. The school building is a one story adobe building. The outside is pebble-dashed and the inside is plastered. The ceiling is painted a light green.
>
> The room is heated by a large stove in the center of the room, and is lighted and ventilated by large double windows. There are three rows of double seats.
>
> We have a set of reference books, several supplementary books, maps, a globe and a new unabridged dictionary.
>
> We have an organ and have opening exercises every morning. On the different holidays we have some splendid programs. The house was beautifully decorated at Christmas and the tree and program were enjoyed. There is a Sunday school each Sunday.
>
> We are proud of our little school and would be glad to have anyone visit it and let us show what we are doing [Otero County Board of Education 1921:30–31].

Families in District 20 sent their children to the school at Lulu. The community was situated in the upper center of Township 22 South, Range 13 East along the road that extended southeast to Orange (see Figure 8.4). Mrs. J. R. McMurrough served as teacher for the 1920–1921 school year with a total enrollment of 12 students (Otero County Board of Education 1921:32). Little is known about the communities of Orange and Lulu. Further archival and oral historical research may yield valuable information on these now-abandoned villages.

Analysis of Census Records

Archival research included the review of decennial census records for the years 1910, 1920, and 1930. Settlers on lands within the Otero Mesa study area were enumerated in Precincts 12 and 14. Precinct 12 covered the eastern portion of the Otero Mesa study area and included the settlement of Orange and part of Alamo (Guadalupe) National Forest. Precinct 14 incorporated the western portion of the study area, including Lulu and part of Alamo (Sacramento) National Forest.

The 1910 New Mexico Territorial Census enumerated 176 residents in Precinct 12, and 184 in Precinct 14 (U.S. Bureau of the Census 1910b). E. O. Brownfield, the enumerator for both precincts, recorded the road between Pinon

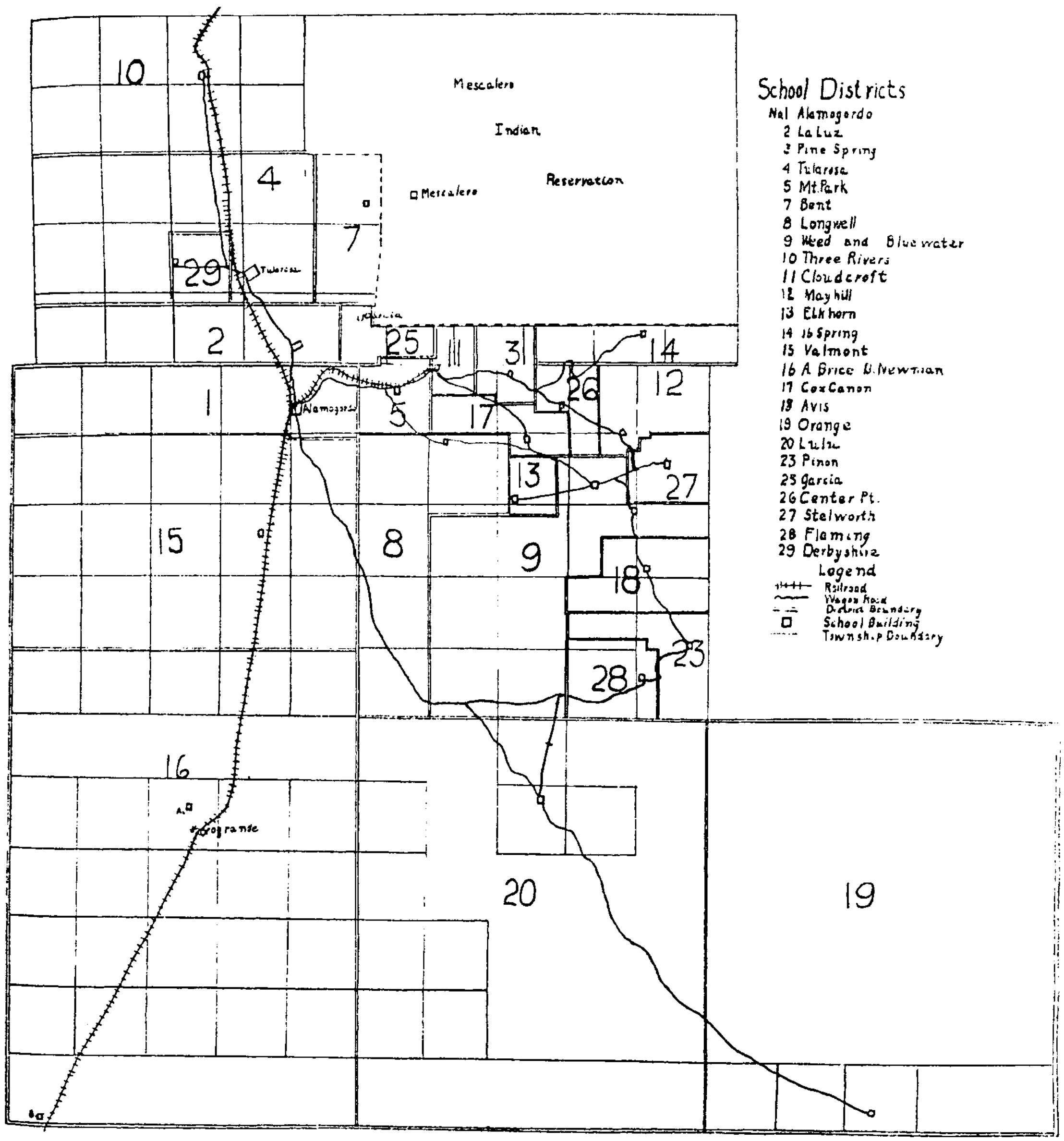

Figure 8.6. Map of Otero County school districts (Otero County Board of Education 1921:12).

and Orange as the general location of those counted in Precinct 12, and the Sacramento River Road as the at-large address of those enumerated in Precinct 14 (U.S. Bureau of the Census 1910a, 1910c). Sixty-four of the 176 residents in Precinct 12 were employed, with 44 engaged in ranching. Of those 44, 27 owned their ranching operations. Only three farmers were listed in the precinct (U.S. Bureau of the Census 1910c). In Precinct 14, 59 of 186 were employed, with 30 engaged in ranching. Another 16 gave their occupation as "farmer" (U.S. Bureau of the Census 1910a). Other occupations in Precincts 12 and 14 included a store merchant, freighter, two teachers for private families, several well drillers, horse tamers, carpenters, and general laborers (U.S. Bureau of the Census 1910a, 1910c).

By 1920, 153 people resided in Precinct 12. Sixty-three were employed and 38 of those were engaged in ranching (21 ranch owners/operators; 17 ranch hands). None was involved in commercial farming. Two teachers were enumerated; one taught on a ranch, the other at the Orange School (U.S. Bureau of the Census 1920b). Census figures for Precinct 14 dropped dramatically from 186 in 1910 to 80 in 1920. Among the 40 who were employed, 38 were engaged in ranching. Interestingly, the ranch laborers (35) far outnumbered the ranch owners (3). Census records listed the remaining two individuals as a farmer and a public school teacher (U.S. Bureau of the Census 1920a).

The 1930 census recorded 51 residents in Precinct 12, a significant drop from the 153 enumerated 10 years earlier. Of the 18 who gave their occupational status, all were engaged in ranching, with 12 ranch owners and 6 laborers (U.S. Bureau of the Census 1930b). Only 25 residents were enumerated in Precinct 14, with seven in ranching. Of particular note is that one of the ranchers raised sheep (U.S. Bureau of the Census 1930a).

Both farming and ranching were difficult endeavors, requiring the acquisition and effective management of water. As stated previously, farming on Otero Mesa with its dry, harsh climate proved difficult at best. Homesteaders likely had a false perception of the land, believing there was enough water for successful dry farming. This is supported by an analysis of the census records for Precincts 12 and 14, as the number of farmers diminished over the years. By 1930, the census records no longer document farming activity (U.S. Bureau of the Census 1930a, 1930b). Ranching proved to be the dominant and enduring economic activity on Otero Mesa, largely because it was easier to graze livestock than grow crops with a limited amount of water. Ranching on the Otero Mesa was still a challenge and many ranches failed, as evidenced by the census figures for the period 1910–1930. For example, census records for 1910 indicate there were 27 independent ranchers in Precinct 12. By 1920, the number of ranchers had dropped slightly to 21. Ten years later the number had dwindled to 12. For the same time period, the number of ranch laborers in Precinct 12 diminished from 26 in 1920 to only 6 in 1930 (U.S. Bureau of the Census 1910c, 1920b, 1930b). This suggests decreases in herd size within the area. Successful ranchers developed wells, stock tanks, and pipelines to control scarce water resources.

General Land Office Transactions in the Study Area

To document Otero Mesa settlement patterns, SRI searched the GLO files at the Las Cruces BLMoffice and accessed the BLM's Internet database of GLO records (http://www.glorecords.blm.gov/). The GLO records search encompassed all lands within the Otero Mesa study area, as depicted on current USGS 7.5-minute-series topographic maps.

Table 8.1 summarizes the results of this research and lists the completed GLO transactions in the study area. The parcel distribution covered by these transactions is depicted on maps in the Appendix. It should be noted that only successful claims and cash sales are included in the table and on the corresponding maps. The maps also represent only the earliest claimant for a parcel and do not reflect later ownership of parcels.

The 56 transactions in Table 8.1 span the years 1914–1969, with an unequal distribution by decade (1910–1919, *n* = 13; 1920–1929, 23; 1930–1939, 14; 1940–1949, 0; 1950–1959, 1; 1960–1969, 5). Of the 56 transactions, five were cash sales, five were obtained under the Desert Land Act, one was an exchange for National Forest land, one was a private land claim, 14 were homestead patents, 13 were obtained under the Enlarged Homestead Act, and 17 were authorized under the Stock Raising Homestead Act. The settlement distribution is fairly uneven throughout the study area. The largest concentration of parcels is in the area known as Crow Flat (near the former town of Orange), located in Townships 25 and 26 South, Range 18 East (Cienega School, New Mexico, 7.5-minute quadrangle). The largest land transaction consists of several noncontiguous parcels comprising 13,193 acres patented by the Otero Investment Company. (Oliver M. Lee, a powerful rancher and businessman, teamed with El Paso banker James G. McNary to form the Otero Investment Company in 1930 as a means to acquire the struggling Circle Cross Cattle Company.) In 1936, the Otero Investment Company received a legal land patent to 62,013 acres, of which 13,193 lie within the study area ([Faunce 1997:70; GLO 1936].). Table 8.1 is a composite of land ownership and does not provide a complete picture of settlement for the period 1914–1969.

In addition to the GLO transactions, SRI consulted GLO survey plats filed between 1885 and 1939. The locations of constructed features (e.g., buildings, fields, water storage and conveyance features, and other structures) depicted on the GLO survey plats were digitized and overlaid onto current USGS topographic maps (see Appendix). Tables 8.2 and 8.3 present the data obtained from the GLO plats.

Summary

A review of GLO survey plats, records of patented claims, and census figures indicate a sizeable number of ranchers and homesteaders settled in the study area, with the period of greatest settlement occurring around 1900–1930. The focus for survival in this arid region has always been on water and the ability to secure and manage an adequate supply. Struggling to carve out a livelihood in the dry climate of Otero Mesa, settlers modified the landscape with buildings, fence lines, water control features, and other structures. Stockraising operations dominated the landscape on Otero Mesa, although periods of boom and bust caused some ranching operations to fail. Despite these hardships, some ranchers succeeded and ranching remains the primary economic activity on Otero Mesa.

Table 8.1. GLO Transactions in the Project Area

Map†	Claimant	Year	Entry Type	Acres	T_S	R_E	Section	Aliquot
1	Akers, John F.	1920	H	160	26	18	21	SE
2	Akers, Joseph W.	1921	HE	320	26	18	22	SE
2	Akers, Joseph W.	1921	HE		26	18	23	W½SW
2	Akers, Joseph W.	1921	HE		26	18	26	NWNW
2	Akers, Joseph W.	1921	HE		26	18	27	NENE
3	Akers, Quincy E., and Quincy E. Flynn	1920	HE	320	26	18	23	SESW
3	Akers, Quincy E., and Quincy E. Flynn	1920	HE		26	18	26	S½NW, NENW, SW
4	Beaman, Watson Moses	1924	HS	640	26	18	1	
5	Brownfield, Edward O.	1917	H	160	26	18	21	SW
5	Brownfield, Edward O.	1921	H	160	26	18	20	S½SE, NESE, SENE
6	Brownfield, James W.	1919	H	160	26	18	28	NW
6	Brownfield, James W.	1921	H	160	26	18	28	SW
7	Cavender, James B., and Maude Cavender	1921	HE	320	26	18	28	E½
8	Coffelt, Elijah H.	1919	HE	320	26	18	15	SW
8	Coffelt, Elijah H.	1919	HE		26	18	22	NW
9	Cope, Tolbert H.	1914	C	160	26	18	22	SW
10	Duggar, Bryce	1969	P	2,318	24	13	1	
10	Duggar, Bryce	1969	P		24	14	5	SWSW
10	Duggar, Bryce	1969	P		24	14	7	
10	Duggar, Bryce	1969	P		24	14	9	
10	Duggar, Bryce	1969	P		24	14	15	W½
11	Gentry, Frank	1956	C	40	26	18	29	NENE
12	Goforth, Ola N.	1914	H	160	22	13	15	SWNE, SENW, NESW, NWSE
13	Goodwin, Tommy	1916	C	160	26	18	10	SW
14	Harris, Mary J.	1916	H	160	26	18	10	NE
15	Hinds, Earl	1930	HE	240	26	18	11	W½W½
15	Hinds, Earl	1930	HE		26	18	14	W½NW
16	Hutchins, W. C.	1965	D	320	26	18	3	NE, E½NW, NESW, NWSE
17	Jeffers, Elvira	1921	D	280	26	18	29	NW, W½NE, SENE
18	Jones, Margaret M.	1917	D	320	26	18	29	S½
19	Justis, Victor H.	1920	HE	320	26	18	27	S½NE, SE
19	Justis, Victor H.	1920	HE		26	18	34	N½NE
19	Justis, Victor H.	1926	HS	234.72	26	18	27	NWNE
19	Justis, Victor H.	1926	HS		26	18	34	N½NW; Lots 1, 2, 3, 4
20	Kaler, Emma	1914	H	160	22	13	14	SWNW, NWSW
20	Kaler, Emma	1914	H		22	13	15	SENE, NESE
21	Kitchens, Drue	1933	HS	640.33	25	18	1	SW, S½NW; Lots 3, 4
21	Kitchens, Drue	1933	HS		25	18	12	N½
22	Lee, Curtis A.	1937	HE	320	23	15	17	SW
22	Lee, Curtis A.	1937	HE		23	15	18	SE

Table 8.1. continued—

Map†	Claimant	Year	Entry Type	Acres	T_S	R_E	Section	Aliquot
23	Lewis, Annie M.	1933	HS	550.2	24	19	18	E½, E½W½; Lots 1, 2, 3, 4
24	Lewis, David C.	1932	HS	640	25	18	21	E½
24	Lewis, David C.	1932	HS		25	18	22	W½
25	Lewis, I. Dempson	1929	HS	640	25	18	26	W½
25	Lewis, I. Dempson	1929	HS		25	18	27	E½
26	Lewis, Ira D.	1932	HS	639.48	24	18	1	S½, S½N½; Lots 1, 2, 3, 4
27	Lewis, James H.	1936	H	160	23	18	29	NW
28	Lewis, Martin	1936	HS	640	25	18	13	S½
28	Lewis, Martin	1936	HS		25	18	24	N½
29	Lewis, Martin V.	1936	HS	640	25	18	25	S½, NE
29	Lewis, Martin V.	1936	HS		25	18	26	SE
30	Lewis, Ollief A.	1920	HE	320	26	18	21	N½
30	Lewis, Ollief A.	1931	HS	320	25	18	14	SESW, SWSE
30	Lewis, Ollief A.	1931	HS		25	18	23	SE, W½NE
31	McArron, Earl E.	1921	HE	278.08	26	18	33	N½N½; Lots 1, 2, 3, 4
32	Mooney, Ala, and Logan D. Mooney	1920	H	160	26	18	27	NW
33	Niland, John M.	1922	H	160	26	18	3	NESE, S½SE, SESW
34	Otero Investment Company	1936	EF	13,193	22	13	22	SW, S½NW
34	Otero Investment Company	1936	EF		22	13	23	W½SW, SESW
34	Otero Investment Company	1936	EF		22	13	25	
34	Otero Investment Company	1936	EF		22	13	26	
34	Otero Investment Company	1936	EF		22	13	27	NE, E½SE
34	Otero Investment Company	1936	EF		22	13	35	
34	Otero Investment Company	1936	EF		23	13	3	SE, S½NE, S½SW, NESW, Lot 1
34	Otero Investment Company	1936	EF		23	13	4	S½SW
34	Otero Investment Company	1936	EF		23	13	5	S½, SWNW
34	Otero Investment Company	1936	EF		24	13	28	
34	Otero Investment Company	1936	EF		24	13	29	
34	Otero Investment Company	1936	EF		24	13	31	E½, E½W½
34	Otero Investment Company	1936	EF		24	13	33	
34	Otero Investment Company	1936	EF		25	13	3	S½, S½N½, Lots 1, 2, 3, 4
34	Otero Investment Company	1936	EF		25	13	4	S½, S½N½, Lots 1, 2, 3, 4
34	Otero Investment Company	1936	EF		25	13	5	S½, S½N½, Lots 1, 2, 3, 4
34	Otero Investment Company	1936	EF		25	13	6	SE, S½NE, Lots 1, 2, 3, 4, 5, 6
34	Otero Investment Company	1936	EF		25	13	7	E½, Lots 1, 2, 3, 4
34	Otero Investment Company	1936	EF		25	13	8	
34	Otero Investment Company	1936	EF		25	13	9	
34	Otero Investment Company	1936	EF		25	13	10	
34	Otero Investment Company	1936	EF		25	13	15	
34	Otero Investment Company	1936	EF		25	13	17	

Table 8.1. continued—

Map†	Claimant	Year	Entry Type	Acres	T_S	R_E	Section	Aliquot
34	Otero Investment Company	1936	EF		25	13	18	E½, Lots 1, 2, 3, 4
34	Otero Investment Company	1936	EF		25	17	7	E½, E½W½, Lots 1, 2, 3, 4
34	Otero Investment Company	1936	EF		25	17	18	E½, E½W½, Lots 1, 2, 3, 4
35	Prather, Jack E.	1936	HS	629	22	13	19	E½, E½W½; Lots 1, 2, 3, 4
36	Prather, John E.	1916	C	160.59	22	13	4	S½NE; Lots 1, 2
37	Prather, Owen W.	1917	HE	320	22	13	14	SWSW
37	Prather, Owen W.	1917	HE		22	13	15	S½SE
37	Prather, Owen W.	1917	HE		22	13	22	N½NE
37	Prather, Owen W.	1917	HE		22	13	23	W½NW, SENW
37	Prather, Owen W.	1927	HS	320	22	13	23	SE, NESW
37	Prather, Owen W.	1927	HS		22	13	24	W½SW, SESW
38	Robertson, Stella Cleone	1937	HS	640	23	15	15	SE
38	Robertson, Stella Cleone	1937	HS		23	15	22	NE, E½SE
38	Robertson, Stella Cleone	1937	HS		23	15	23	W½SW
38	Robertson, Stella Cleone	1937	HS		23	15	26	W½NW
38	Robertson, Stella Cleone	1937	HS		23	15	27	E½NE
39	Shipley, Harold	1966	D	320	25	18	13	NW
39	Shipley, Harold	1966	D		25	18	14	NE
40	Silbas, Amado	1923	H	160	22	13	15	S½SW
40	Silbas, Amado	1923	H		22	13	22	N½NW
41	Smith, Charles B.	1924	HE	320	25	18	24	S½
41	Smith, Charles B.	1928	HS	320	25	18	25	NW
41	Smith, Charles B.	1928	HS		25	18	26	NE
42	Stockard, James W.	1924	H	144.52	24	14	5	NENE, NWNE, NENW
42	Stockard, James W.	1924	HS	488.68	24	14	5	SE, S½N½, N½SW, SESW; Lot 4
43	Trammell, Adrian A.	1919	HE	320	22	13	16	E½
43	Trammell, Adrian A.	1936	HS	320	22	13	21	E½
44	Trammell, Augusta A.	1918	H	320	22	13	16	S½SW
44	Trammell, Augusta A.	1918	H		22	13	17	SE, S½NE (outside project area)
45	Walker, Vernon W.	1967	C	2.5	23	19	33	SWSESWSE
46	Warren, Jerry A.	1963	D	240	25	18	27	NW, N½SW
47	White, Elijah	1920	HE	320	22	13	8	NE (outside project area)
47	White, Elijah	1920	HE		22	13	9	NW
48	Woods, William H.	1927	HS	640	24	18	20	S½
48	Woods, William H.	1927	HS		24	18	29	N½

Key: C = cash sale; D = Desert Land Act; EF = Exchange-Forest Service Special Act (40 Stat. 1204); P = private land claim; H = Homestead Act; HE = Enlarged Homestead Act; HS = Stock Raising Homestead Act

† Refers to the land claims represented on the maps found in the Appendix.

Table 8.2. Buildings and Cultivated Fields as Depicted on General Land Office Survey Plats, 1885–1926

Map†	Feature Name on Map	Feature Type	T_S	R_E	Section	GLO Date
1	Akers	Building	26	18	21	1912
2	Orange Post Office and store	Building	26	18	21	1912
3	Field	Field	26	18	21	1912
4	Field	Field	26	18	20, 21	1912
5	J. W. Brownsfield, Jr.	Building	26	18	21	1912
6	J. W. Brownsfield	Building	26	18	28	1912
7	Sam Lewis	Building	26	18	16	1912
8	Pew	Building	26	18	21	1912
9	Widow Harris	Building	26	18	15	1912
10	Oscar Ables (sic)	Building	26	18	23	1912
11	Turney	Building	26	18	3	1912
12	Field	Field	26	18	3	1912
13	House	Building	25	18	35	1921
14	House	Building	25	18	25	1921
15	House (SE¼)	Building	25	18	24	1921
16	House	Building	25	18	12	1921
17	Ranch house	Building	25	18	8	1921
18	Ranch house (NE¼)	Building	25	18	21	1921
19	Ranch house (SE¼)	Building	25	18	21	1921
20	M. Lewis	Building	24	17	27	1921
21	Wood's Ranch	Building	24	18	29	1921
22	Sam Lewis	Building	24	19	18	1921
23	P. H. Walde	Building	22	14	30	1912
24	Chester Stephens	Building	22	14	4	1912
25	F. Williams	Building	23	12	23	1919
26	House	Building	24	13	35	1921
27	Vacant house	Building	24	13	10	1921
28	Ranch	Building	24	13	32	1921
29	Stone house	Building	26	13	19	1926
30	Corral	Corral	26	13	19	1926
31	Ranch	Building	25	12	10	1885
32	Ranch	Building	24	12	29	1885
33	Don Porter	Building	22	13	14	1912
34	Owen Prather	Building	22	13	23	1912
35		Field	22	13	14, 15	1912
36		Field	22	13	14, 15, 22, 23	1912
37	Trammell's	Building	22	13	21	1912
38	Field	Field	22	13	16, 21	1912
39		Building	25	17	5	1921
40	House	Building	22	13	9	1912
41	House	Building	22	13	3	1912
42	William Martin	Building	22	13	3	1912
43	House (NW¼)	Building	25	18	24	1921
44	House	Building	24	14	28	1920

† Refers to the historic features depicted on the maps found in the Appendix.

Table 8.3. Water Storage and Conveyance Features as Depicted on General Land Office Survey Plats, 1885–1927

Map†	Feature Name on Map	Feature Type	T_S	R_E	Section	GLO Date
1		Windmill	25	18	35	1921
2		Well	25	18	35	1921
3	Tank	Tank	24	17	6	1921
4	Wood's Ranch	Well	24	18	29	1921
5	Wood's Ranch	Windmill	24	18	29	1921
6	Windmill	Windmill	24	18	11	1921
7		Well	24	18	11	1921
8	Windmill	Windmill	24	18	36	1921
9	Windmill	Windmill	24	18	36	1921
10	Sam Lewis	Windmill	24	19	18	1921
11	Windmill and well	Windmill, well	23	18	9	1927
12	Windmill and well	Windmill, well	23	18	22	1927
13	Tank	Tank	23	12	16	1919
14	Jernigan windmill	Windmill	24	13	35	1921
15	Dirt tanks	Tank	24	13	26	1921
16	Tank	Tank	26	13	18	1926
17	Tank	Tank	26	13	19	1926
18	Cistern	Cistern	26	13	19	1926
21	Tank	Tank	22	12	25	1919
23	Dry surface tank	Tank	26	12	32	1926
24	Tank	Tank	24	14	29	1920
25	Windmill	Windmill	24	14	28	1920
27	Well	Well	24	14	5	1920
28	Tank	Tank	25	17	11	1921
29	Tank	Tank	25	17	12	1921
30	Tank	Tank	25	13	14	1926
31	Dry Lake Bed	Tank	25	12	10	1885
32	Tank	Tank	22	13	16	1912
33	Tank	Tank	22	13	3	1912
34	Windmill	Windmill	22	13	4	1912
35	Tank	Windmill	22	13	4	1912

† Refers to the historic features depicted on the maps found in the Appendix.

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CHAPTER

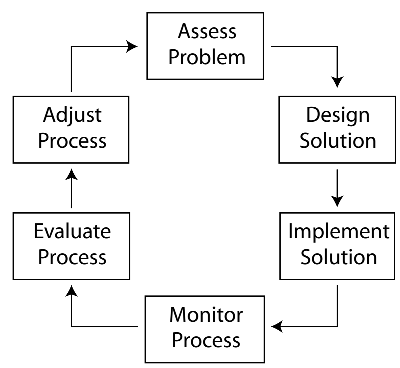
9

Conclusions and Management Recommendations

Lynne Sebastian, Eric Ingbar, and David W. Cushman

In Chapter 2 we introduced the concept of adaptive management, which can be defined as *a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs*. As noted in that chapter, one of the problems faced by BLM managers and cultural resource staff in southeastern New Mexico is that the sheer volume of oil and gas development has created a situation in which management of cultural resources is stuck at the *implement solution* step in this process. At current staffing levels, simply keeping up with the flood of applications for permits to drill, rights-of-way, and other exploration and development actions is so time-consuming that there is little opportunity to monitor and evaluate the results of current practices, much less design adjustments to that process.

The New Mexico Pump III project is an initial effort to determine what the results of current practices have been, both for cultural resource management and for oil and gas development, to evaluate those results, and to propose adjustments. Chapter 2 described the current process for cultural resource management and oil and gas leasing and development in southeast New Mexico and identified areas where the current process is viewed as problematic within the BLM and by stakeholders in both the historic preservation and oil and gas communities. Chapters 5, 6, and 7 presented and evaluated current data on cultural resource management in three study areas—the mature oil and gas field of Loco Hills, the developing field of Azotea Mesa, and the proposed field of Otero Mesa—and provided information and management tools that will be used to support process evaluations and proposed adjustments described in this chapter.



In developing the management recommendations offered in this chapter we were guided by two principles. The first principle is **balance** between the need for energy development on the public lands and the stewardship and multiple-use mandates of public land management agencies. The National Environmental Policy Act and the National Historic Preservation Act use the following virtually identical words in describing the balanced approach envisioned by Congress:

NEPA says:
It is the continuing policy of the Federal Government . . . to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans.

NHPA says:
It shall be the policy of the Federal Government . . . to foster conditions under which our modern society and our prehistoric and historic resources can exist in productive harmony and fulfill the social, economic, and other requirements of present and future generations.

The second principle governing our recommendations is **feasibility**. There are many management strategies that would greatly facilitate planning for and management of archaeological resources in oil and gas fields. The ideal situation would be one in which all archaeological sites in a prospective field would be identified and evaluated for eligibility to the National Register before the first lease sale was even planned. Under this dream scenario, a Resource Management Plan (RMP) amendment would then be completed to provide protection for the most significant sites and perhaps for a representative sample of all site types. Then a data recovery program would be completed to recover information from a scientifically valid sample of the remaining sites in the proposed development field, and the results would be reported in detail, including a broad education and public outreach component.

Once these efforts were completed, historic preservation compliance for leasing, exploration, and development within the entire field would consist simply of ensuring avoidance of the protected sample of sites and possibly monitoring of ground disturbance in areas where buried archaeological sites were likely to be present. This idyllic approach would be, by far, the most effective and efficient means of managing archaeological resources in oil and gas fields, but it ain't gonna happen. BLM has neither the personnel nor the funding to survey large tracts of the public lands and carry out extensive excavations to prepare the way for private energy development. The oil and gas industry's exploration and development actions are driven by constantly changing market forces, geophysical information, and production data. This makes broad-scale, up-front investment in cultural resource investigations uneconomical and impractical for the industry, especially given the short time frames within which many decisions must be made.

Faced with an ideal scenario that is unachievable, we have tried to focus in this chapter on achievable changes that could largely be carried out with existing federal funding and personnel and would be compatible with the economic realities of the oil and gas industry. Our recommendations must also be consistent with BLM's statutory and regulatory responsibilities and move cultural resource management in southeast New Mexico toward the goals outlined by BLM and the various stakeholders who were interviewed for this project.

These are serious constraints on our ability to formulate "adjustments" to the existing management process that would truly make a difference; something has to give. And that "something" is preconceptions about *shoulds, oughts,* and *can'ts* as well as inflexible, *"we've always done it this way"* attitudes. If we are going to adaptively manage cultural resources and energy development in a less-than-perfect world, all of the participants in this process have to recognize the limitations and accept practical rather than ideal strategies.

The need for change is undeniable. In the mid 1980s, one of us (Sebastian) was the senior researcher on the first published synthesis of the archaeology of what was then called the Roswell District of the New Mexico BLM (Sebastian and Larralde 1989). Nearly 20 years have passed since the research was completed, and we know very little more about the archaeological record of that area than we did in 1987, despite the fact that as of this writing 18,158 additional surveys have been completed. Thousands of sites have been minimally recorded and, based on surface evidence, considered eligible to the National Register and avoided by initial construction, sometimes at substantial cost and delay. Unknown numbers of these sites have subsequently been destroyed or degraded by the intensity of later activities on leases and rights-of-way. Despite all the time and effort and money spent, we are still not able to make well-informed decisions about the integrity or significance of archaeological sites in this area, and we have not learned important and exciting things about our nation's heritage that we can share with the American people. If anything, we are in an information deficit; not only are we not learning anything new in support of either better management or better science from the work that we are doing, we are losing information from the cumulative, long-term effects of intensive development.

Some of the "adjustments" in BLM's cultural resource management process for oil and gas fields that are proposed in this chapter will seem very radical—with good reason. They ***are*** radical, and necessarily so. The alternative is that for another 20 years we continue doing the same things that we have done for the past 20, giving us the opportunity to know less and less about more and more oil and gas fields. Section 106 of the National Historic Preservation Act has enormous potential for flexibility and creative approaches. There is a desperate need to tap into that potential in the oil and gas development areas of southeast New Mexico if we ever hope to have effective stewardship, informed management decisions, and productive harmony between the needs of our modern society and the remains of our ancient ones.

In the following sections of this chapter we first offer an evaluation of the problems that have arisen from the current management process and recommend adjustments to the process. Then we suggest specific strategies to improve management within the Loco Hills, Azotea Mesa, and Otero Mesa fields. Some of these recommendations could stand alone and be implemented independently of the others. Most of the recommendations, however, are interdependent, a package of trade-offs designed to improve resource management while facilitating multiple use. Finally, we address mechanisms for applying the insights gained from this project in the future and for ensuring that a true adaptive management cycle continues to inform cultural resource management decisions.

Managing Cultural Resources in Oil & Gas Fields

Management recommendations for archaeological resources in oil and gas fields must take into account the needs and goals of both the BLM and industry. Industry is looking for ways to maximize the predictability of the regulatory process and minimize the costs in time and money. BLM is trying to acquire adequate information on which to base management decisions, meet its legal obligations, and maintain and enhance resource values under its multiple-use mandate. The following observations about shortcomings of the current process and recommendations for adjustments are organized by the phases of energy development. It is important to note once again that this discussion addresses only archaeological sites that are or may be eligible to the National Register of Historic Places because of their potential to yield important information about the past. Management for other values associated with such sites is not addressed here.

Planning and Leasing

One of BLM's most important needs is cultural resource information for broad-scale planning, up to and including planning at the RMP level. The New Mexico PUMP III project, which includes digitization of surveyed space over a broad area and development of predictive models and sensitivity maps for three sizeable study areas, provides a strong basis on which to build and expand the needed information.

Recommendation 1: Expand the Loco Hills and Azotea Mesa models to cover as much as possible of current and likely lease areas—all of the data needed are already available except geomorphology. A project currently underway by the Office of Contract Archeology (OCA) at the University of New Mexico is, among other things, developing 1:500,000-scale geomorphology information for southeast New Mexico. This information should be used to plan a more detailed mapping project, and BLM should seek funding to complete finer-scale mapping and expand and maintain the current models. Possible funding sources might include future Department of Energy PUMP grants and, if the models are used to target, streamline, and improve the compliance process as suggested below, the oil and gas industry itself.

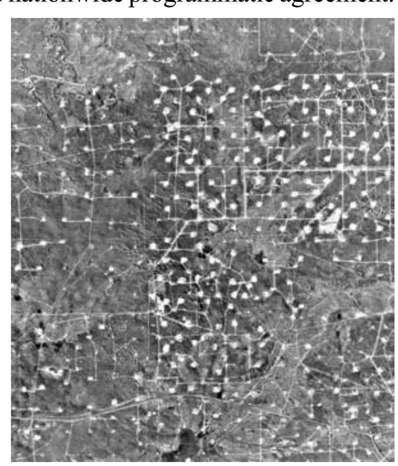
The archaeological sensitivity maps from such a project could be used by BLM as the basis for RMP revisions, including identification of areas unsuitable for leasing; planning for road, pipeline, and utility corridors within oil and gas fields; and a broader-scale approach to NEPA compliance, as discussed below. Surface protection specialists, working with cultural resource staff, could use these data to plan their schedule of leases to inspect. Cultural resource specialists could use these data in a wide variety of ways specified in later recommendations.

Recommendation 2: Make the sensitivity maps developed in the PUMP III project (and the expanded maps described in Recommendation 1) available to landmen, lessees, and operators in the BLM Public Room or other venue, such as the online access tool developed for the Wyoming component of this project. The Cultural Resources Information Summary Program (CRISP) is a web browser–based tool that makes sensitivity maps and summaries of cultural resources information available to land use proponents and nonspecialists in cultural resources. CRISP is specifically aimed at the audiences that use the BLM Public Rooms.

The oil and gas industry could use this archaeological sensitivity information to evaluate potential leases and to plan developments on current leases. An important component of this effort would be a commitment on BLM's part to maintaining, reevaluating, and updating the models. This could best be accomplished if model revision were linked to a specific planning cycle already in use within BLM.

Recommendation 3: BLM needs to inform its management strategies by compiling basic archaeological data from subsurface contexts. We have recorded at least minimal surface information from thousands of sites, but without data from controlled excavations and detailed study of the recovered materials we cannot ascribe a function or temporal period or cultural affiliation to most of these sites or understand the general relationship between surface archaeological manifestations and subsurface deposits in this area. A better understanding of all these things is critical to determining the significance of and appropriate management strategies for the archaeological record of southeastern New Mexico.

Although relatively little archaeological excavation has been done in southeastern New Mexico compared with other oil-and-gas-producing areas in the state, some important work has been done. BLM should give high priority to funding a compilation and synthesis of all available excavation data from the region, perhaps using the joint outreach, education, and data synthesis funds identified in the state protocol implementing the nationwide programmatic agreement. This project should specifically include provisions for creation and dissemination of a popular summary of the results and of other educational materials.



Recommendation 4: Both cultural resource management and oil and gas development can be better served if NEPA compliance is moved "upstream" to the planning and leasing phases of energy development. Currently, NEPA compliance for oil and gas explorations and operations on BLM land in southeastern New Mexico is carried out on an APD-by-APD and ROW-by-ROW basis. This is problematic for a number of reasons, but the most serious is the near impossibility of effectively considering cumulative impacts at this scale. To illustrate this point, we have reproduced the aerial photo of a portion of Loco Hills from Chapter 2 here. Almost certainly, every one of the individual well pads, roads, powerlines, pipelines, and other features visible in this photo was classified under NEPA as a Categorical Exclusion or analyzed through an Environmental

Assessment and found to have no significant impact. Yet can there be any doubt that, in the aggregate, field development at this level of intensity has had a significant impact on the quality of the natural and cultural environment?

BLM needs to find a way to carry out NEPA compliance for oil and gas development at a broader scale—minimally at the level of the lease, preferably at the level of some much larger natural or developmental unit. For example, the previously referenced OCA project will include identification of logical environmental units based on physiographic characteristics. These units would provide an appropriate scale for considering both cultural and natural resources. Only through such broader-scale NEPA analysis can cumulative impacts be effectively addressed and appropriate mitigation measures devised. We recommend that BLM put together a small working group of people with extensive NEPA experience to explore ways of broadening the context of NEPA compliance in southeastern New Mexico.

It is important to note in regard to the problem of cumulative impacts on cultural resources from intensive oil and gas development that two of the BLM's national cultural resource program goals are: "to ensure that proposed land uses initiated or authorized by the BLM avoid inadvertent damage to federal and non-federal cultural resources" and "to protect and preserve in place representative examples of the full array of cultural resources on public lands for the benefit of scientific use and public use by present and future generations." Preservation of a representative sample of sites within a planning unit could be one of the mitigation measures considered for ongoing impacts from intensive development.

Not only would broadening the scale of NEPA compliance lead to more effective archaeological resource management, it could also be designed to solve coordination problems between realty specialists and cultural resource staff for rights-of-way that are Categorical Exclusions (CXs) under NEPA (see discussion in Chapter 2). Improved coordination should reduce or even eliminate at least one of the problems of nonconcurrent, delayed, or conflicting reviews that were identified during interviews with the oil and gas industry representatives. One possibility that should be examined is programmatic NEPA assessments that predefine issues such as levels of effort and evaluation of impacts for whole resource categories. If BLM convenes a NEPA working group, establishing a protocol for coordination of NEPA and Section 106 compliance for CX rights-of-way should be the group's first priority.

BLM's Instruction Memorandum No. 2005-247 of 9/30/2006 spells out additional categorical exclusions established under Section 390 of the Energy Policy Act of 2005. One of the new exclusions created in the statute is specific to rights-of-way, and another exclusion speaks to small disturbance areas within larger NEPA-analyzed developed fields. As of this writing, it is unclear how BLM will implement all of the measures in the Energy Policy Act. What is clear, however, is that some measures in the Act make possible, and even encourage, implementation of some of the recommendations made here.

Oil and Gas Exploration and Operations

The results of the PUMP III studies and our interviews with BLM staff and stakeholders identified four areas of concern relative to archaeological resource management and oil and gas exploration and operations: level of effort to identify archaeological resources; decisions about the eligibility of identified sites to the National Register of Historic Places; processing of APDs and ROW applications; and monitoring and protection of "avoided" archaeological sites. The first two concerns are addressed together in the next section, the other two separately below.

Identification and Evaluation of Archaeological Sites

The regulation implementing Section 106 of the National Historic Preservation Act requires that federal agencies "make a reasonable and good faith effort to carry out appropriate identification" of historic properties that may be affected by their undertakings, and notes that they should take into account (among other things) "the likely nature and location of historic properties within the area of potential effects" in deciding what that level of effort should be (36 CFR 800.4[b][1]). The regulation further defines a historic property as a "prehistoric or historic district, site, building, structure, or object included in, or eligible for inclusion in, the National Register of Historic Places" (36 CFR 800.16[l][1]).

For the past 30 years the archaeological component of this requirement has been met in southeastern New Mexico by carrying out intensive pedestrian survey of the area of potential effects for virtually every project. This approach has the advantage of being simple, straightforward, and predictable. It also has a number of disadvantages, however. As Chapters 5, 6, and 7 of this report show, this approach has led to an astonishing amount of resurvey of the same pieces of ground and re-recording of the same sites. With modern GIS technology and with the data on surveyed space in this area now being available in NMCRIS as a result of the PUMP III project, some of this resurvey and re-recording could be eliminated, but given the constant overlap of project areas in heavily developed fields, it is often more cost effective simply to survey the whole project area rather than try to establish on the ground which pieces have been surveyed and which have not.

Another disadvantage of this approach to identifying historic properties is that what we are actually *identifying* are the locations of archaeological artifacts and features. In southeast New Mexico, we have no real context within which to determine whether those artifacts and features indicate the presence of *historic properties* (that is, sites eligible to the National Register) or not. Two of the authors of this chapter (Sebastian and Cushman) spent years of our professional lives as Section 106 reviewers in the New Mexico Historic Preservation Division. Both of us, at one time or another, were assigned to review submissions from the BLM Roswell and Carlsbad Offices, and between us we reviewed thousands of survey reports and site forms.

For all the years before our tenure at SHPO, sites in the oil patch of southeast New Mexico had been found, minimally recorded, and avoided; found, minimally recorded, and avoided; found, minimally recorded, and avoided. The result? An immense archaeological record whose potential to yield important information about the past was untested and unknown. Faced with the extremely limited information on the significance of this archaeological record, we, like the reviewers before us and those since, had no real alternative but to err on the side of caution. The archaeological record is finite and nonrenewable. If we decide, without any scientific basis, that a site is not eligible and it is destroyed, there is no going back if we learn later that, in fact, it did have the potential to yield important information about the past. So we continued the conservative approach of considering a large proportion of the sites to be eligible—because we had no basis for saying that they weren't—and agreeing that they should be avoided.

This, of course, leaves us with several problems. (1) Our lack of information about the significance of the archaeological record in this area is self-perpetuating; we never gain any more information on which to base decisions about eligibility, so we have to keep making the same conservative decisions over and over. (2) Money and time are, without any doubt, being spent on redesigning projects or even abandoning projects to avoid archaeological sites that would not be found eligible to the National Register if we had enough information to truly evaluate them. (3) As more and more projects and more and more conservatively evaluated sites are packed into mature development fields, avoidance becomes increasingly difficult and redesigns increasing common. (4) Ironically we are not even really protecting these avoided sites in any long-term sense; "avoidance" means that the site is not directly affected by initial construction. Long-term operations within leases and rights-of-way are constantly degrading all those carefully "avoided" sites. As one BLM Surface Protection Specialist said during an interview, "If you think we're preserving sites by avoiding them, you're fooling yourselves."

How, then, can we make better decisions about good faith efforts to identify historic properties, determine the eligibility of archaeological sites, and generate requirements to avoid archaeological remains, while at the same time doing a better job of preserving truly significant sites? We don't have much information about the subsurface nature of the archaeological record in southeast New Mexico, but we have a huge amount of information about the surface manifestations. And thanks to this DOE-funded study, we have some of the tools that we need to begin using that surface information to make tough decisions about allocating effort for acquiring additional inventory data vs. other needed data.

Recommendation 5: In areas for which predictive models have been developed and for which it has been demonstrated that model outcomes and site density projections have stabilized (as described in Chapters 5, 6, and 7), BLM should use that information, in conjunction with geomorphic information about potential for surface visibility and NMCRIS information about intensity of previous survey, to make decisions about the need for survey in anticipation of future projects.

The Wyoming component of this project created a framework similar to that proposed above. The likelihood of buried archaeological sites was assessed systematically across the Wyoming study area. This map (available on-line through the CRISP tool described above) and the observed incidence of inventory have become important tools for cultural resource managers when they decide whether a survey is required.

In Wyoming, at present, the decision-making is on a case-by-case basis. Here, we advocate going a step further and creating a decision matrix that would be programmatic in its use. The basis of the matrix is the forecast surface occurrence of cultural resources, site visibility (and the likelihood of encountering buried sites), and existing adequate inventory for cultural resources. The specific matrix should be designed by BLM in consultation with SHPO and the archaeological community. Once the matrix is in place and an electronic interface has been set up, oil and gas lessees and operators would be able to input locational information and get immediate feedback for planning as well as specific information about cultural resource requirements for a specific development project.

Just as a heuristic, we might imagine a matrix that would look something like this:

	Projected Site Density from Predictive Model		
	High	Medium	Low
Surface visibility			
high			
low			
Surveyed acreage in surrounding square mile			
>10%			
<10%			

The "surface visibility" values indicate the likelihood that an area contains buried sites—in "high surface visibility" areas, the potential for buried sites is small and if sites occur in that area, they will generally be visible on the surface. For this example, outcomes might be set in the matrix design as:

For all projects, avoid known sites AND

If site density = high
- and surface visibility = high
  - and previous survey <10% = pedestrian survey
  - and previous survey >10% = every 5th project,† pedestrian survey
- and surface visibility low
  - and previous survey <10% = sample backhoe trench
  - and previous survey >10% = sample backhoe trench

If site density = medium
- and surface visibility = high
  - and previous survey <10% = every 5th project, pedestrian survey
  - and previous survey >10% = every 10th project, pedestrian survey
- and surface visibility = low
  - and previous survey <10% = every 5th project, sample backhoe trench
  - and previous survey >10% = every 10th project, sample backhoe trench

If site density = low
- and surface visibility = high
  - and previous survey <10% = every 10th project, pedestrian survey
  - and previous survey >10% = every 15th project, pedestrian survey
- and surface visibility = low
  - and previous survey <10% = every 10th project, sample backhoe trench
  - and previous survey >10% = every 15th project, sample backhoe trench

† The electronic interface would include a counter to identify the 5th or 10th or whatever project registered in a particular matrix category

Again, this matrix and these outcomes are not specific recommendations—they are simply designed to convey the concept. And before our industry partners break out the champagne and the historic preservation crowd breaks out the tar and feathers, we hasten to point out that there is one more important component to this suggestion. The point of this triage approach to *identifying historic properties* is to move from the current total focus on *identifying* and to gather data needed to make informed decisions about which identified sites are *historic properties,* that is, properties eligible to the National Register.

The needed data have to do with potential for entirely buried sites, age of soils and other sediments, the relationship between surface manifestations and subsurface content of sites, site integrity, and detailed information on site function, age, and other archaeological research domains. Some of these data would be acquired through a program of backhoe trenching in lieu of surface survey in areas of low surface visibility. The trenches would be monitored by professional archaeologists who would record both stratigraphic and archaeological data (note that this may require that BLM provide some training for permittees). The trenching/monitoring program would be designed to be similar in cost to what conventional archaeological survey would have been for the project.

The rest of the needed data can only be acquired through archaeological excavation, which brings us to:

Recommendation 6: BLM should implement a scientifically designed program of testing of archaeological sites within the areas covered by current (or expanded) archaeological models. This testing program should be based on the data needs, research questions, and excavation strategies being identified as part of the previously mentioned BLM-sponsored OCA research project. The testing program would be funded through cultural resource assessments paid by oil and gas operators on a project-by-project basis for those projects which were not selected for either survey or trenching during the matrix evaluation explained under Recommendation 5. The assessment would be equal to the average cost of a standard pedestrian survey for a project of the appropriate type and would be placed in a restricted fund that could only be used for the testing program. Another potential source of funding for these efforts is the provision in Section 365 of the Energy Policy Act of 2005 allowing use of rental receipts from leases for costs of coordinating and processing oil and gas use authorizations.

Now, before our industry partners resort to the tar and feathers and the historic preservation crowd joins them, let's think about the implications here.

First, from the industry perspective:

- The overall cost to industry of "doing archaeology" should stay the same.
- For projects that "win the lottery" and are not required to do either survey or trenching, there would be a substantial time saving. (We also have suggestions below about time savings for projects that are selected for survey or trenching.)
- A subset of the money being spent to "do archaeology" would actually go toward learning about the past and about the value of the archaeological record. The testing program could (and should) be set up to include periodic summaries written for a public audience, school programs and curriculum materials, museum exhibits, etc.
- Over time, as our understanding of the true information potential of archaeological sites in southeastern New Mexico increases, there will almost certainly be fewer sites that require avoidance, making siting of wells and other developments easier rather than increasingly difficult.

And from the historic preservation perspective:

- BLM will still be able to meet its regulatory requirement to make a reasonable and good faith effort to identify historic properties that may be affected by oil and gas developments that it authorizes.
- Determinations of eligibility can be based on a scientifically valid, three-dimensional understanding of the significance of the archaeological record rather than on surface manifestations alone.
- BLM cultural resource managers will have the information needed to identify and preserve a representative sample of significant archaeological sites for long-term research, education, and heritage tourism
- BLM will have the information needed to explain the significance and value of the archaeological heritage of southeastern New Mexico in a way that engenders support for preservation and research among public land users and the local communities.

Will archaeological sites be damaged or destroyed as a result of the triage approach advocated above? Without question, sites will be lost. But sites are being damaged or destroyed now, and we don't even know enough to decide whether they are mundane scatters of debitage and burned caliche or a key piece of the puzzle of the past that should have been protected at all costs.

The alternative to a radical approach such as that proposed above is to continue with business as usual. As noted above, in the 18 years since Sebastian finished her research for the Roswell BLM District overview (Sebastian and Larralde 1989), 18,158 archaeological surveys have been conducted within that study area. At an average of, say, $500 per survey, more than $9 million has been spent to find, minimally record, and sort of avoid 13,296 archaeological sites of unknown significance and meaning. Surely we can do better.

Processing of APDs and Right-of-Way Grants

Processing of APDs was identified by both industry representatives and BLM cultural resource staff as being prone to archaeology-related delays. According to cultural resource staff, these delays are of three types: (1) An applicant who is unfamiliar with the APD process fails to have an archaeological survey done before submitting the application. (2) The archaeological survey has been done but the report isn't submitted with the application. (3) The archaeological survey has been done and the report accompanies the application, but the report has missing or substandard information.

Right-of-way grant applications also experience delays of these three types, plus as described in Chapter 2 and noted above, there are coordination problems within BLM for ROWs that are Categorical Exclusions under NEPA but require full compliance under Section 106. We have suggested above that BLM convene a working group of BLM staff with substantial NEPA experience to brainstorm solutions to the NEPA/Section 106 coordination problem and other NEPA-related issues. Here we focus on the three problems identified in the previous paragraph.

Recommendation 7: The question of how best to inform applicants for land-use authorizations about cultural resource requirements is one that should be resolved through advice from industry representatives. They understand the needs, mindset, information flow, and culture of their colleagues better than any of us on the outside. An informal working group of industry representatives should be asked for advice about how BLM can most effectively prevent problems of the first type. Above, we suggested that a matrix-based approach could be useful. This could be automated, perhaps best with a map-like interface, so that project proponents, potential lessees, and managers have an early opportunity to find out cultural resource requirements.

Recommendation 8: Although missing and incomplete survey reports are problems in their own right, what is needed to process an APD or ROW application is information about the outcome of the survey, not the physical report per se. Consider developing an immediate post-fieldwork electronic submission form for the critical information needed to process an APD or ROW application. Applications could then be approved based on the electronic submission, with the full report to follow. Again, work with industry advisors to design a system for ensuring that the reports would, in fact, follow in a timely fashion. If this recommendation is implemented, it will be important for BLM cultural resource staff, in consultation with NMSHPO, to establish criteria for determining when expedited approval might not be appropriate.

The Wyoming component of this project has elaborated upon an existing SHPO-BLM tool called CRMTracker that follows the cultural resource investigation process from its inception through the decision-making process to the paper archive itself. This system could serve as a model for eliminating much of the current paper submittal prior to decision-making. Currently in Wyoming, paper reports are still passed between agencies, and decisions are recorded in CRMTracker. Wyoming BLM and Wyoming SHPO are presently discussing eliminating the use of paper documents during the decision phases for no effect and no adverse effect projects. Paper documents would still be the permanent record, but basic critical information would be provided through and decisions would be based on the electronic system.

Recommendation 9: For negative surveys, allow the electronic submission to serve as the report. The development currently underway of a paper "NMCRIS Investigative Abstract Form," which serves in lieu of a negative survey report, could be expanded to all electronic submission. What is gained, in terms of management or understanding or preservation of the archaeological record, from the generation of hundreds of boilerplate-filled negative survey reports? Again, the CRMTracker system discussed briefly above could be useful in implementing this recommendation.

Recommendation 10: In exchange for the time applicants save by having APDs and ROW grants approved on the basis of the electronic submissions and for the money applicants save by having the electronic submissions stand as the full report for negative surveys, BLM should increase site evaluation requirements for those surveys that do encounter archaeological sites. These requirements might include in-field analysis of artifacts, trowel-testing of features, and shovel-testing or other forms of subsurface evaluation where approriate. In this report we have identified the need for subsurface testing and excavation to gather data to allow us to make better-informed determinations of eligibility. We need to collect commensurate data from newly recorded surface sites in order to apply the insights gained from excavations.

Improving Protection of Avoided Sites

A number of structural aspects of the BLM environmental program allow the activities that currently cause most of the damage to archaeological sites that have supposedly been avoided to slip through the cracks. For example, leases, APDs, and construction get most of the environmental attention, and as a result, these are not the activities that are causing most of the site preservation problems. On-lease activities carried out under sundry notices are uncontrolled, as are most post-construction activities on rights-of-way. For the latter, however, the problem is exacerbated because ROWs are not monitored in the way that leases are.

Recommendation 11: BLM should work toward the creation of development corridors, placed in areas identified by the models as exhibiting low site sensitivity. These corridors could be used for pipelines and power lines serving multiple leases. If some acceptable arrangement for sharing facilities can be developed and brokered by BLM, this should provide cost and time savings for lease operators as well as providing better protection for cultural resources. The Energy Policy Act of 2005 contemplates establishing formal corridors for intense study and scrutiny. Our recommendation is feasible, regardless of the legislation, but we think the legislation gives it added momentum.

Recommendation 12: For unitized leases, site sensitivity information from the models should be emphasized as a factor in locating all development.

Recommendation 13: BLM should work toward providing the same levels of monitoring for rights-of-way as are currently applied to leases, at least in high and medium site sensitivity areas.

Recommendation 14: In establishing their priorities for leases to monitor each year, Surface Protection Specialists should include the presence of known sites or, for pre–Section 106 era developments, leases with high or medium site sensitivity among the selection criteria. Training for Surface Protection Specialists in use of the models and sensitivity maps and in evaluating impacts to archaeological sites might be included in implementation of this recommendation.

Recommendation 15: BLM should convene a summit with industry to develop strategies for avoiding or at least limiting the damage to "avoided" archaeological sites that is being caused by well-servicing operations.

Specific Recommendations for the New Mexico Pump III Study Areas

The management implications of our work in each of the PUMP III study areas are detailed in Chapters 5, 6, and 7. Specific management recommendations for Loco Hills, Azotea Mesa, and Otero Mesa are offered below.

Loco Hills

Recommendation 16: If there is any willingness to consider the whole approach of survey-requirement matrices, subsurface trenching, archaeological testing, and the accompanying trade-offs, as described in Recommendations 5 and 6, Loco Hills is the place to start. As well spacing and other development becomes denser and denser in Loco Hills, avoidance of sites becomes increasingly problematic, and the need to determine which sites actually have the potential to yield important information and which don't becomes increasingly critical.

Azotea Mesa

Recommendation 1 dealt with the importance of expanding the PUMP III models to cover more of the current and projected oil and gas development areas in southeast New Mexico. Azotea Mesa would be an excellent place to start.

Recommendation 17: The Azotea Mesa model should be expanded not only to cover adjacent oil and gas development areas, but also to incorporate representative segments of the surrounding environmental zones to which it is likely to have had close functional ties—that is, the slopes of the Guadalupe Mountains and the Pecos River valley.

Recommendation 18: There has, in the past, been discussion of a "pooled mitigation" approach in portions of Azotea Mesa wherein a sample of archaeological sites would be excavated and subsequent development on the designated leases could be carried out without avoidance or further mitigation of effects to archaeological sites. BLM should continue to pursue this possibility as one means to gain high-quality information about the subsurface archaeology of this study area.

Otero Mesa

Of our three study areas, the undeveloped field of Otero Mesa offers the greatest potential for innovative management approaches, especially given BLM's decision to require unitization in response to other resources' sensitivities. Because of the limited previous survey in this study area, however, we also have the least secure basis for management decisions.

Recommendation 19: BLM should seek funding to carry out targeted surveys to test and refine the predictive model. Are the apparent high-, medium-, and low-sensitivity patterns real? If so, they offer some real possibilities for future management decisions.

Recommendation 20: Based on the results of the recommended survey, refine the model and make the resulting site sensitivity data available to prospective lessees to encourage pre-sale offers and expressions of interest for lease parcels in low sensitivity areas.

Recommendation 21: For unitized leases, make location of common facilities (power lines, pipelines, roads) in low sensitivity areas a Condition of Approval.

Recommendation 22: For seismic projects in the areas of recent colluvium, require a program of sample trenching to test for buried sites (rather than traditional surface survey) as the mechanism for identifying potentially affected historic properties.

Adaptive Management and the Future in Southeastern New Mexico

One reaction we received from colleagues who were told about this project was "Oh, another one of those shelf studies." Shelf studies are documents of great initial interest that then fall out of favor (and out of use) to languish in a bookcase. We began our discussion in this chapter with diagrams that illustrated the cycle of adaptive management. We noted that management efforts tend to get stuck at "implement solution." Projects become shelf studies because they get stuck in the implementation phase. Sometimes the solution continues to be implemented without regard to continuing effectiveness; other times the solution being implemented is no longer seen as relevant to the situation at hand, so it is discarded (i.e., shelved). Sometimes, this starts a search for a new solution (ignoring earlier work). In other cases, no new cycle of adaptive management ensues, and implementation becomes idiosyncratic. In this section, we suggest ways to keep adaptive management approaches cycling in both this southeast New Mexico study area and elsewhere.

Another reaction that we received when contacting people about this project was "we really need to get this cultural resource management thing fixed." Above, we described some of the problem area within the "cultural resource management thing"; it is important to note that there will never be just one set of repairs. The recommendations in this chapter address cultural resource problems in oil and gas settings as we see them now. Even if we were to fix all of the problems that we see today, tomorrow's problems may be different from today's. Management is a process—adaptation happens over time as conditions vary. Successful management should yield meaningful cultural resource investigations and preservation actions. How do we keep monitoring, evaluating, and adjusting the operation of cultural resource management so as to continually identify new problems and address them? That is the question we focus on in the rest of this section.

Creating a Culture of Adaptive Management

BLM Field Offices in active oil and gas development areas are extraordinarily busy workplaces. Staff have little time to do anything but apply current work procedures. Applying new procedures and approaches appears risky: at least doing what worked in the past has predictable demands and outcomes. Trying something new could result in an increase in workload (e.g., what if the SHPO rejects our plan and it has to be rewritten?). In short, there is a deeply conservative streak in the approach to cultural resources with little organizational support and few resources for real innovation.

The problems we found in our study could be solved without changing the "culture" of management itself, but this would accomplish a short-term change: a single loop of the adaptive management cycle. Long-term problem solving for cultural resources will require a change from the tedious safety of a focus on work *process* to a focus on achieving cultural resource management *products* and *outcomes* through innovation (for ideas on this subject see Sebastian 2005).

Time savings have to come from the existing work days of Field Office staff. Above, we have suggested several ways in which desk work can be reduced and in some cases eliminated. Most suggestions focus on simplifying reporting on negative inventories and no effect projects, and eliminating unneeded paperwork. Management must then task the staff to use this newly-minted time for adaptive management activities (rather than simply filling the time with more of the same work load).

Training is critical if any change in approach is desired. Overall, agency staff are well-trained in national policies and procedures. Yet, only over time does staff gain the professional archaeological and managerial experience to be really effective in their jobs. The amount of time that this takes is variable, but it could certainly be made shorter through training. Training in using new tools is equally important. We have emphasized the value of model-based approaches and programmatic strategies—but models and information systems require training to be used correctly.

Creating the time to do this more outcome-oriented (as opposed to process-oriented) work does not actually get adaptive management done. Field staff in oil and gas offices need to be encouraged to adapt their own approaches, knowledge, and professionalism over time. One way is to make "management planning" a work accomplishment. Even something as simple as periodically reviewing the site records that do not "match" the existing site occurrence models should be credited in a staffer's work effort.

This study had the luxury of funding support to do research and consider how to do management differently. Agency staff do not have such support. The single greatest step toward a culture of adaptive management could be designation of at least 5% of a senior cultural resources staff person's time each year to be spent in evaluating and improving the ways in which the Field Office does cultural resource management. Some framework and guidance for their work would be essential and should probably come from a national-level group of cultural resource experts within the agency. In the case of BLM, this expert body is the Preservation Board. The role of the larger body of experts is to seek examples from the field level and to disseminate information on successful (and unsuccessful) strategies and tactics from different Field Offices.

Putting Products in Place

Creating the time for agency professionals to change management approaches does not put the new management tools in place. Many of the suggestions we have made involve changing aspects of how archaeology is done on the public lands. Having the time to do things differently is not enough; time must be accompanied by the wherewithal as well. For example, one of the findings at the start of our work on the overall Pump III project was that relatively few BLM cultural resource specialists were comfortable using geographic information systems (GIS) software on a daily basis. Almost every one of them felt that GIS was a useful tool; they just did not have the time to learn it or to use it.

Some of the products of this project, which we think should be put in place for future use are:

- Models of site likelihood in each study area
- Geomorphology maps showing Holocene deposits
- Much-improved GIS and database information on projects and resources

Field staff, field managers, landmen, and lessees need to be introduced to these tools as appropriate, and then they need to truly use them. Many of these tools are (or can be) on-line systems. Other "products" have been cited above too: tools that eliminate paperwork, save time, and simply make current work go faster. Some of these "products" are procedural changes, others are virtual or physical things like software, maps, and documents. In any case, the initial steps are (1) to decide which of the many recommendations and tools created during this study have highest value now; (2) to train people in their use and enable that use; (3) to evaluate the gains (or losses) in quarterly or six-month increments.

Perhaps an example will make this more clear. When the CRMTracker tool was first introduced to the Wyoming BLM, an eight-week period was allotted for comment. Despite everyone agreeing to test the system in those eight weeks, only one person did. What happened? First, it was too hard to use without more training. Second, everyone agreed to make this effort just as the summer field season began—the busiest part of their professional year. Third, there was no negative outcome for not testing the tool. Finding the software confusing but lacking the time to learn it, and facing no penalty for not using it, most people did the obvious thing: they just did not bother. Now that the system has been in use for over a year, it has been possible to gather useful evaluations from its users: they know what helps their work and what is inessential or even a hindrance. Two years after the initial introduction of CRMTracker, the Wyoming component of the Pump III project is in a position to build a better management tool.

Introduction of new tools and new work processes will take persistence and some multi-year commitments by all parties. Adaptive approaches to cultural resources will take time to yield results, and patience is going to be a virtue. This does not mean, however, that some progress cannot happen immediately. Several of our recommendations, streamlining the reports for negative field inventories, for example, could be implemented quickly with relatively minor amendments to the New Mexico protocol for Section 106 compliance. Another example might be reporting of no effect and no adverse effect projects in electronic form to be followed by the paper report. Other changes simply involve some training and familiarization: the maps of potential site density are readily understood after a brief explanation and can be made available in agency GIS systems quite swiftly.

Keeping the Cycle Going

How do we ensure that, at least for cultural resources, adaptive management will become a cycle as intended rather than swinging around the dial and getting stuck at "implement" again? Our suggestions above include making more information about cultural resources available early in the lease/development timeline, making cultural resource management decisions in a larger framework of regional knowledge, and broadening the definition of appropriate identification and mitigation.

These procedural changes are great places to start the cycle of adaptive management, which must then be kept dynamic. Starting this cycle requires:

- Managerial sponsorship
- Negotiation with preservation partners
- Training of appropriate staff, stakeholders
- Use of new processes
- Formal evaluation of the benefits and drawbacks of new processes
- "Tweaking" process or replacing it

This is the cycle discussed at the start of this chapter. We think a key component of starting the cycle and keeping it going is managerial sponsorship. Sponsorship is active support (not just permission) to try new tactics, perhaps to take on "risky" activities under current perceptions, and to take the work time to effect change. The other points above follow from sponsorship and cannot occur without it. For the BLM, in its current organization, the managerial sponsorship may best be sought at something like the statewide leadership meetings held by the BLM State Director.

Our recommendations involve the use of many technical products: information tools like database systems and automated maps, geomorphological studies, archaeological studies, and predictive models. The evolutionary nature of information technology and scientific inquiry (geomorphology, archaeology) is well known, as are the concomitant needs for maintenance and investment. What is less often recognized is the need to continually test and maintain the models as well as the technical systems and data. The "shelf study" syndrome alluded to above is very common with predictive models. Models fall out of use because new data are not used to test them and reaffirm confidence in the model, or model predictions are found to be at odds with new data. Or both things happen at different times. Either way, a basically sound model may be discarded for lack of "maintenance."

For the models generated by the New Mexico Pump III project, we think that the information technology framework already present in the NMCRIS system could be developed into a continuous testing tool for the models presented in this study. How would this work? With a modest amount of funding, NMCRIS could be augmented to update simple model statistics as new inventories in the study areas are reported. Information on the current (at time of model development or revision) values for those statistics and information on the updated values would be available to managers, CRM staff, and researchers interested in monitoring model performance. The automated system could be programmed to constantly compare current statistics for the existing model with the updated statistics, and to automatically notify senior BLM cultural resources staff of any changes in the statistics that exceed parameters established in the program.

On a regular basis (quarterly, semi-annually) and/or when notified by NMCRIS that model statistics have gone out of the established range, the designated BLM cultural resources staff members would then evaluate the model itself and determine whether revisions to the model and the density maps are needed. Simple revisions could potentially be done in partnership between BLM and ARMS; more complicated reworking of the model might require a contractor. The key point here is that no one has to "rebuild" the model forecasts tediously: much of the work and the calculations will already have been done by the NMCRIS program.

There is more to maintaining these models than monitoring them for out-of-range statistics on the existing variables, however. We would hope that new information and new *kinds* of information will accumulate. In addition to assessing and updating the performance of the current models, BLM staff or outside contractors should periodically evaluate available information and determine how to keep existing predictors useful and accurate or create new or finer-grained predictors. Currently, for example, the models lump all precontact archaeological sites together because the data are insufficient to permit us to divide most sites into functional or temporal categories. As in-field artifact analysis, subsurface testing, and data recovery take place in the future, it is likely that we will be able to categorize many more sites based on their surface manifestations. Finally, in addition to updating and upgrading the existing models with new data and new kinds of data, BLM staff or contractors need to evaluate alternative modeling approaches that can, for example, incorporate social variables or test theoretical predictions.

The Future

In the tradition of a good adaptive management approach, we have come back to the point where we began this chapter—to the need for feasible approaches to achieving a better balance between the need for energy development on the public lands and the stewardship and multiple-use mandates under which BLM operates. The future of cultural resource management in southeast New Mexico can be more of the same, or it can move in some vital new directions. All of the recommendations made above could be implemented in large part through a reallocation of existing resources of time, money, and personnel. What is needed is leadership, a willingness to accept radical change, and a shift from focusing on rote compliance process to focusing on preservation outcomes, public benefit, true resource management, and good public policy.

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List of Acronyms

ACEC – Area of Critical Environmental Concern

APD – Application for Permit to Drill

ARMS – Archaeological Records Management Section (of NMHPD)

ARPA – Archeological Resources Protection Act

BLM – Bureau of Land Management

CRM – Cultural Resource Management

CRMA – Cultural Resource Management Area

CRISP – Cultural Resources Information Summary Program

CX – Categorical Exclusion (under NEPA)

DEM – digital elevation model

EA – Environmental Assessment (under NEPA)

EIS – Environmental Impact Statement (under NEPA)

FLPMA – Federal Land Policy Management Act of 1976

FONSI – Finding of No Significant Impact (under NEPA)

GAP – the US Geological Survey's Gap Analysis Program on protecting biodiversity

GIS – Geographic Information System

GLO – General Land Office

IDRISI – is not an acronym! Idrisi was an important medieval cartographer and geographer, and the geographic analysis software package used in this project was named after him.

IT – information technology

NAGPRA – Native American Graves Protection and Repatriation Act of 1990

NEPA – National Environmental Policy Act of 1969

NHPA – National Historic Preservation Act of 1966

NMCRIS – New Mexico Cultural Resource Information System

NMHPD – New Mexico State Historic Preservation Division

NMSHPO – New Mexico State Historic Preservation Office or Officer

NOS – Notice of Staking

OCA – Office of Contract Archeology (at the University of New Mexico)

PA – programmatic agreement (under NHPA)

PUMP – Preferred Upstream Management Practices

RDBMS – relational database management system

RMP – Resource Management Plan

ROW – right-of-way

SHPO – State Historic Preservation Office or Officer

SMA – Special Management Area

SQL – Structured Query Language

USDA – US Department of Agriculture

UTM – Universal Transverse Mercator

WYSHPO – Wyoming State Historic Preservation Office or Officer

APPENDIX

GLO Transactions and Historic Features Documented for Otero Mesa Project Area

May 2004: Statistical Research, Inc.

A.1. Otero Mesa Project Area (East)
A.2. Alamo Mountain Quadrangle
A.3. Alamo Mountain NE Quadrangle
A.4. B T Ranch Quadrangle
A.5. Cienega School Quadrangle
A.6. Cleones Tank Quadrangle
A.7. Gowdy Ranch Quadrangle
A.8. Lewis Canyon Quadrangle
A.9. Sheep Draw Quadrangle
A.10. Sixteen Canyon Quadrangle

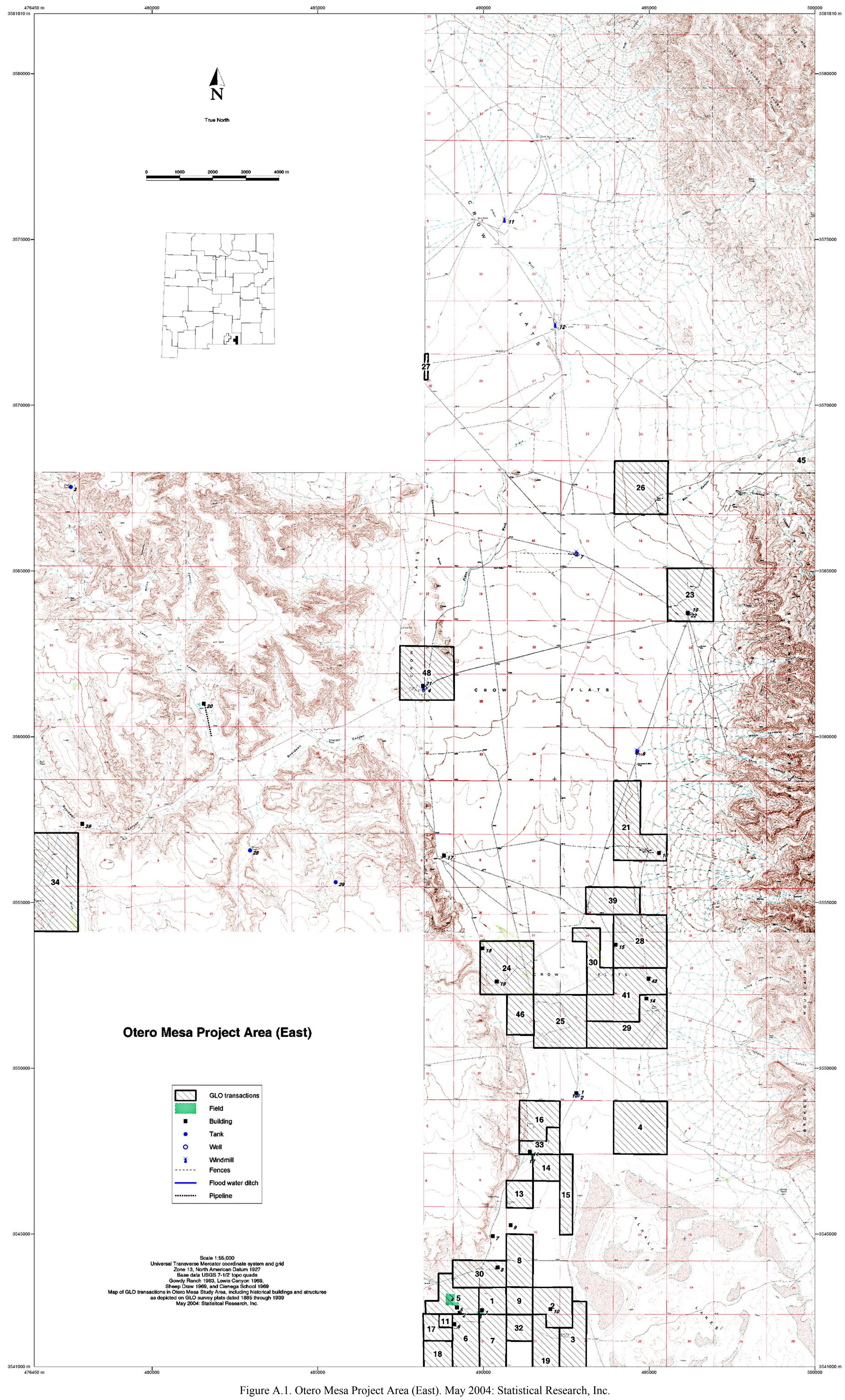
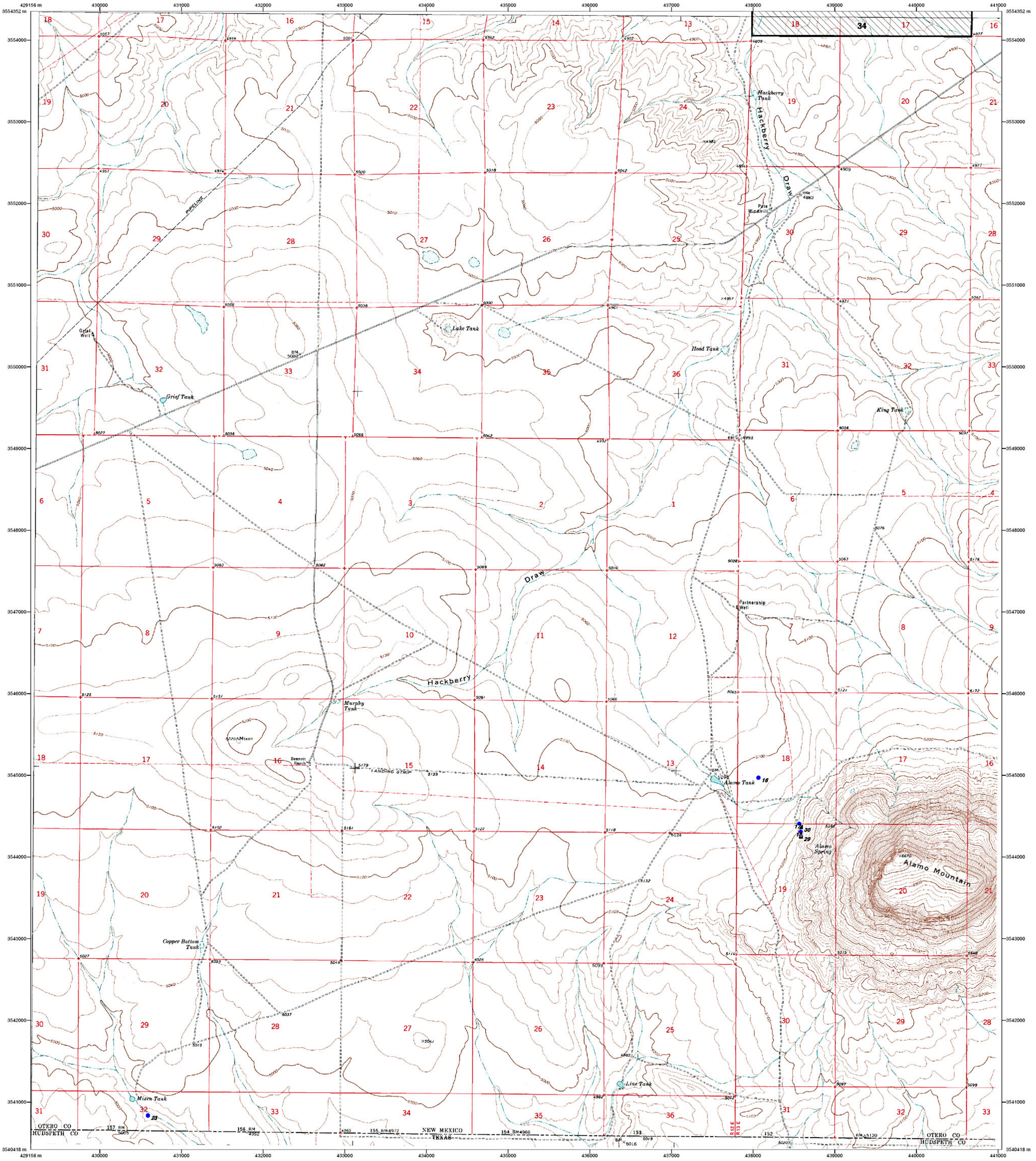
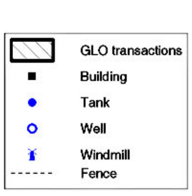


Figure A.1. Otero Mesa Project Area (East). May 2004: Statistical Research, Inc.



Alamo Mtn Quadrangle



Scale 1:24,000
Universal Transverse Mercator coordinate system and grid
Zone 13, North American Datum 1927
Base data USGS 7-1/2' topo quad, Alamo Mountain 1975
GLO transactions in Otero Mesa Study area, including historical buildings and structures as depicted on GLO survey plats dated 1885 through 1939
May 2004: Statistical Research, Inc.

Figure A.2. Alamo Mountain Quadrangle. May 2004: Statistical Research, Inc.

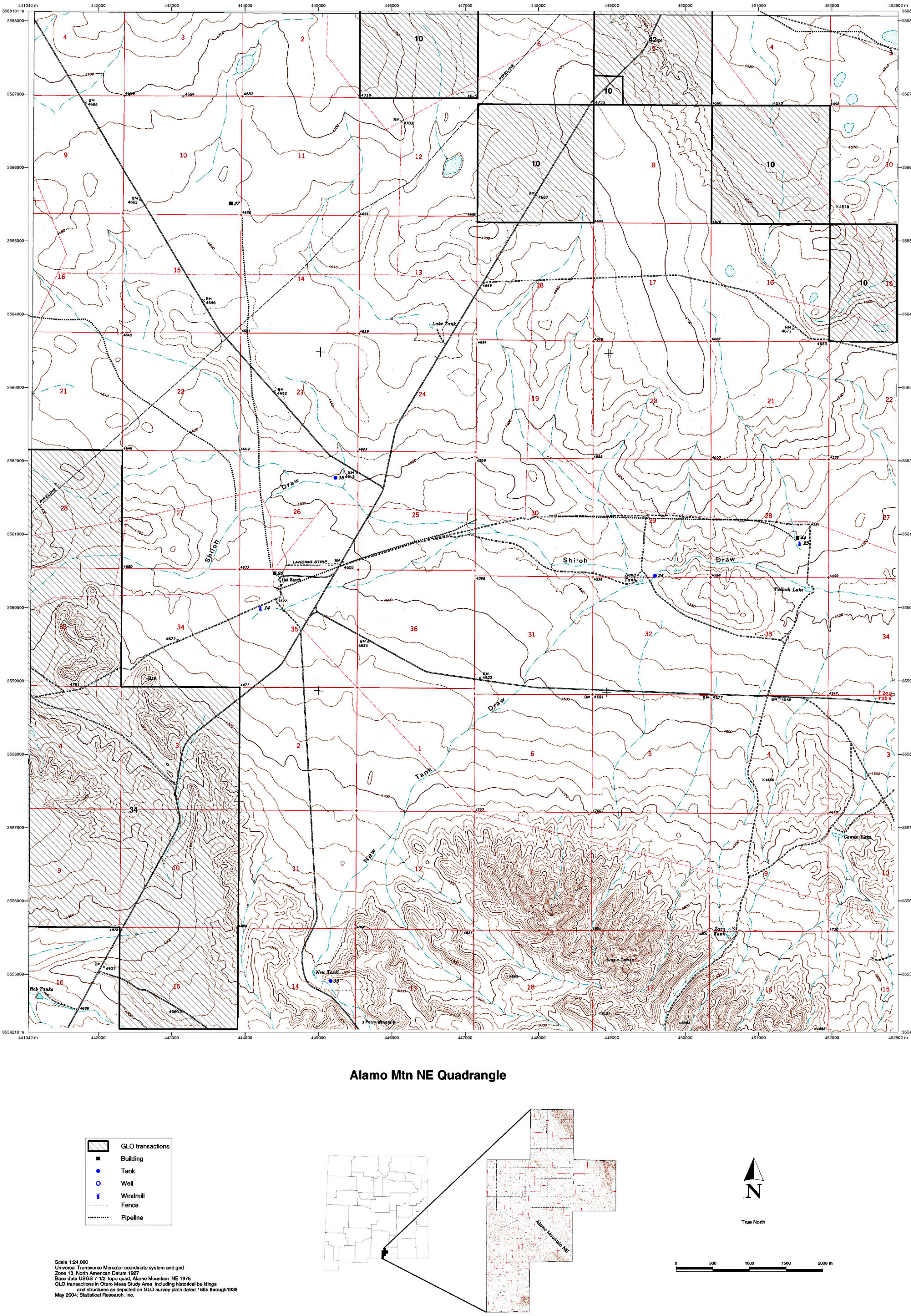
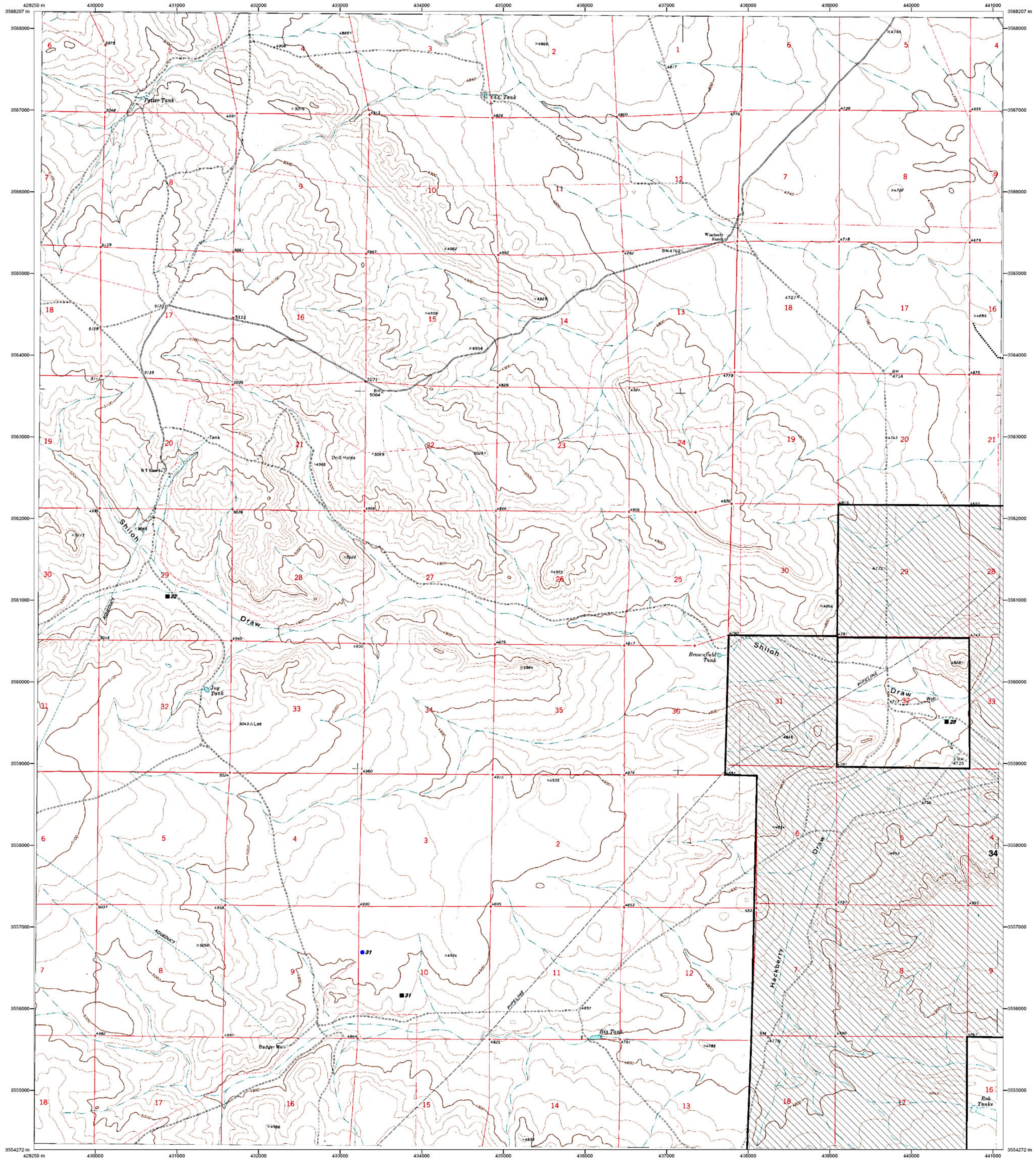


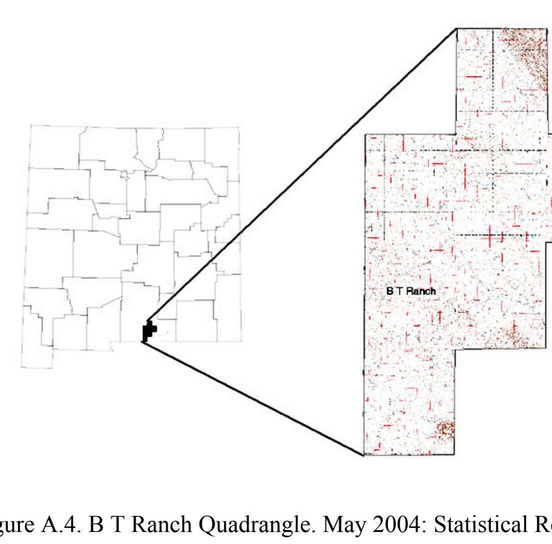
Figure A.3. Alamo Mountain NE Quadrangle. May 2004: Statistical Research, Inc.



B T Ranch Quadrangle

GLO transactions
Building
Tank
Well
Windmill
Pipeline

Scale 1:24,000
Universal Transverse Mercator coordinate system and grid
Zone 13, North American Datum 1927
Base data USGS 7-1/2' topo quad, B T Ranch 1975
GLO transactions in Otero Mesa Study Area, including buildings and structures as depicted on GLO survey plats dated 1885 through 1939
May 2004: Statistical Research, Inc.



N
True North

0 500 1000 1500 2000 m

Figure A.4. B T Ranch Quadrangle. May 2004: Statistical Research, Inc.

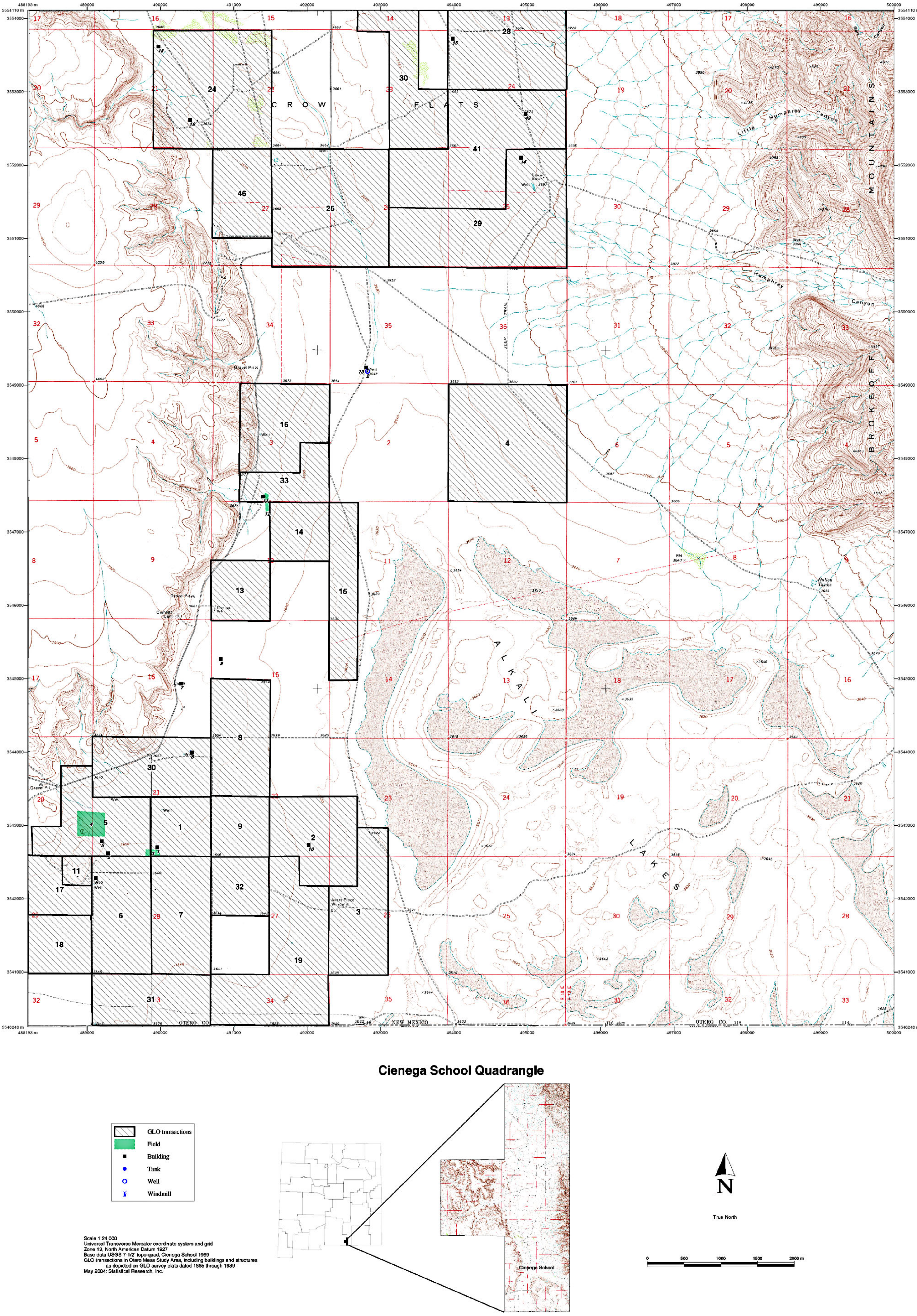


Figure A.5. Cienega School Quadrangle. May 2004: Statistical Research, Inc.

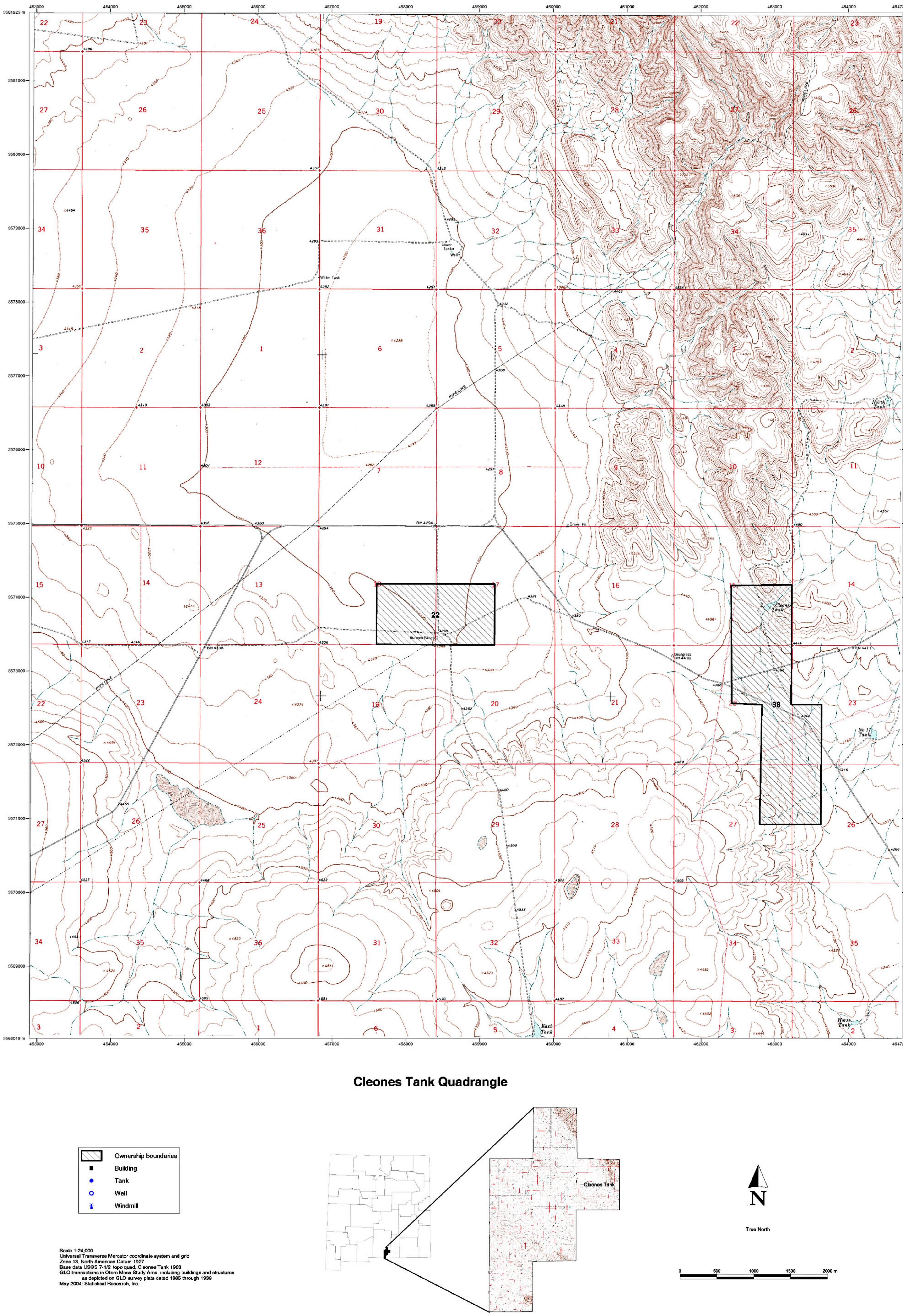


Figure A.6. Cleones Tank Quadrangle. May 2004: Statistical Research, Inc.

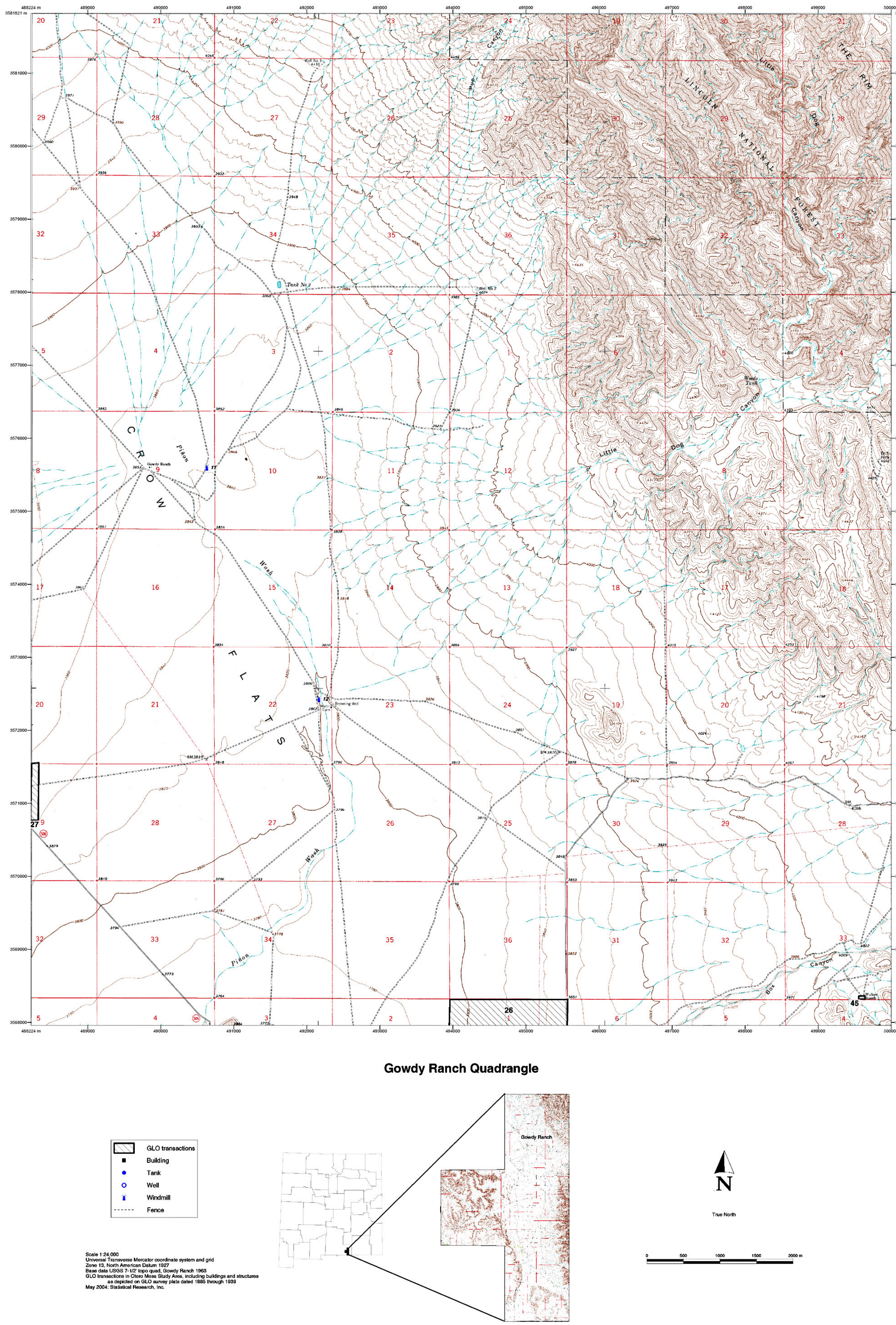
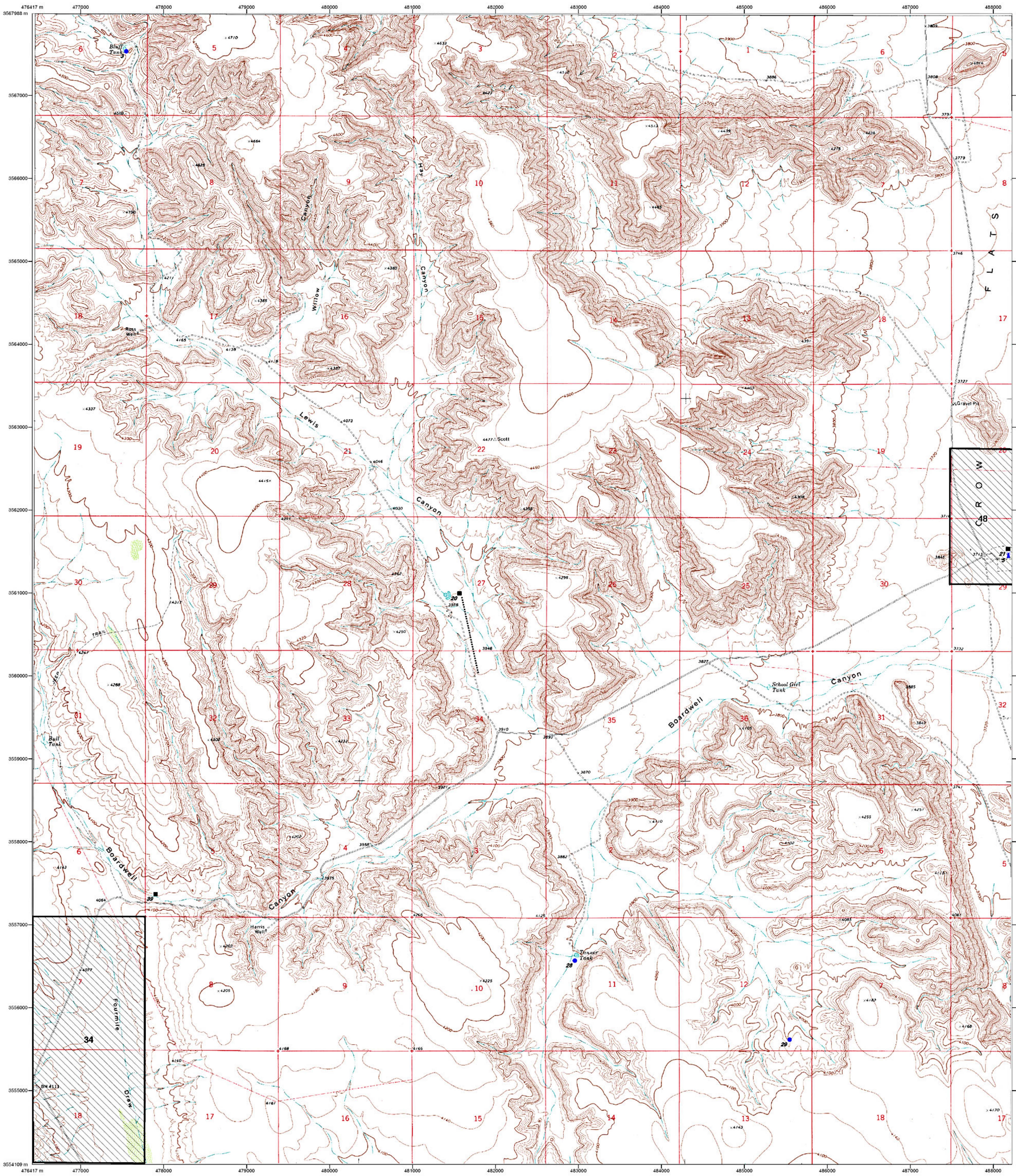


Figure A.7. Gowdy Ranch Quadrangle. May 2004: Statistical Research, Inc.



Lewis Canyon Quadrangle

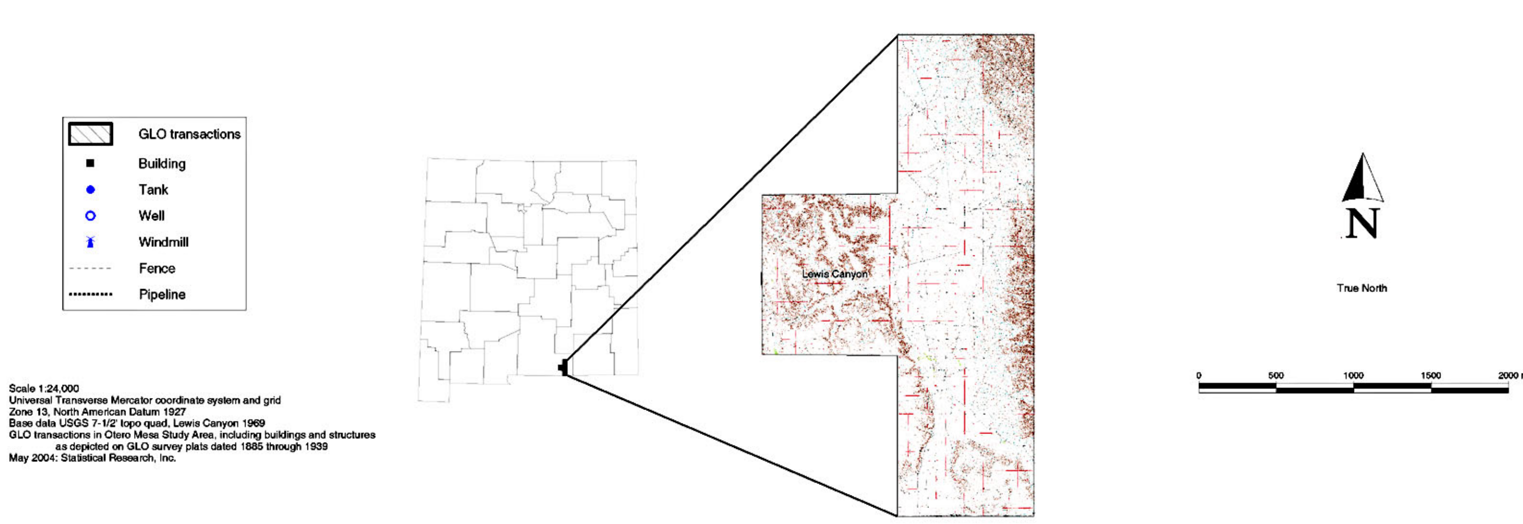


Figure A.8. Lewis Canyon Quadrangle. May 2004: Statistical Research, Inc.

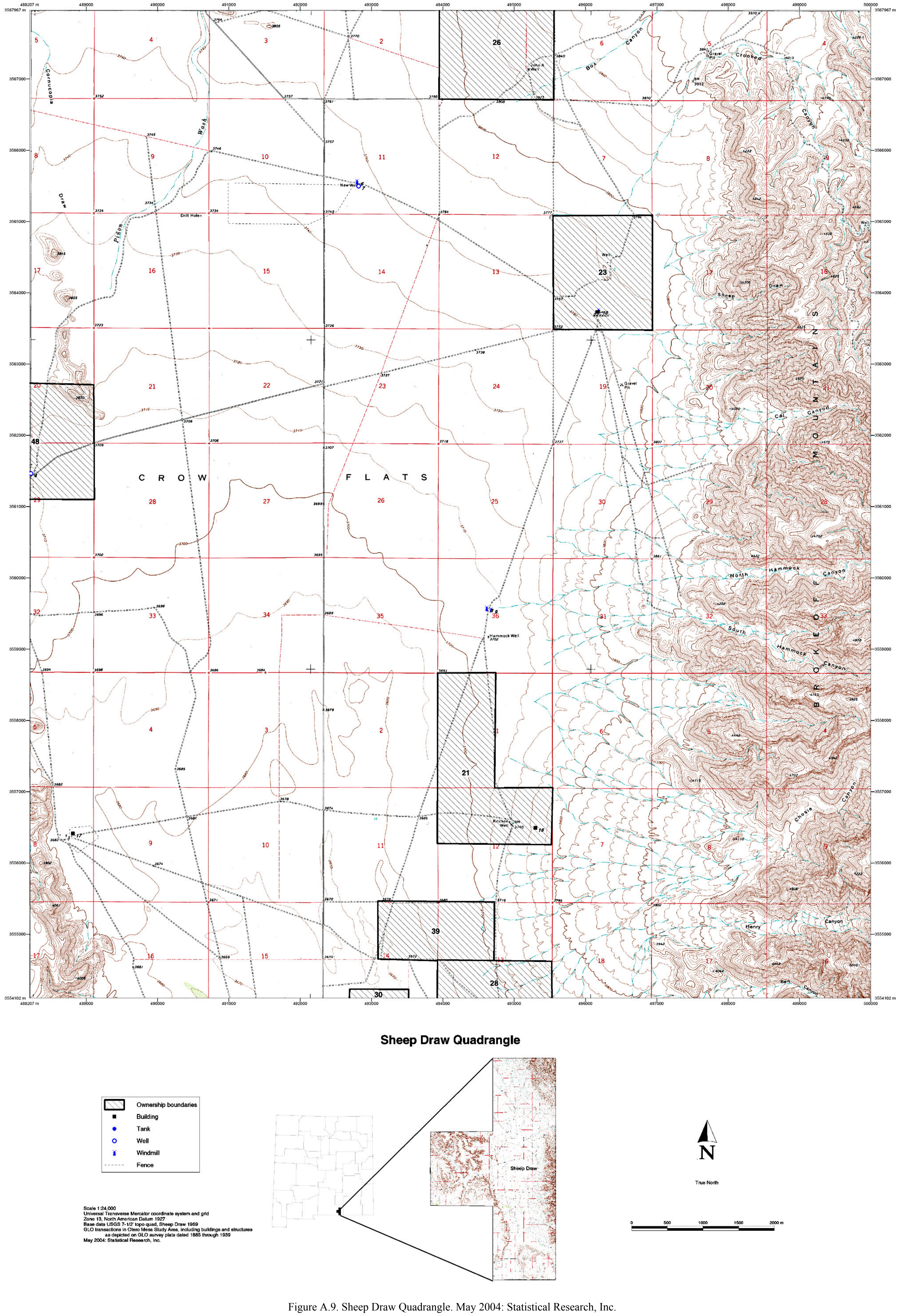
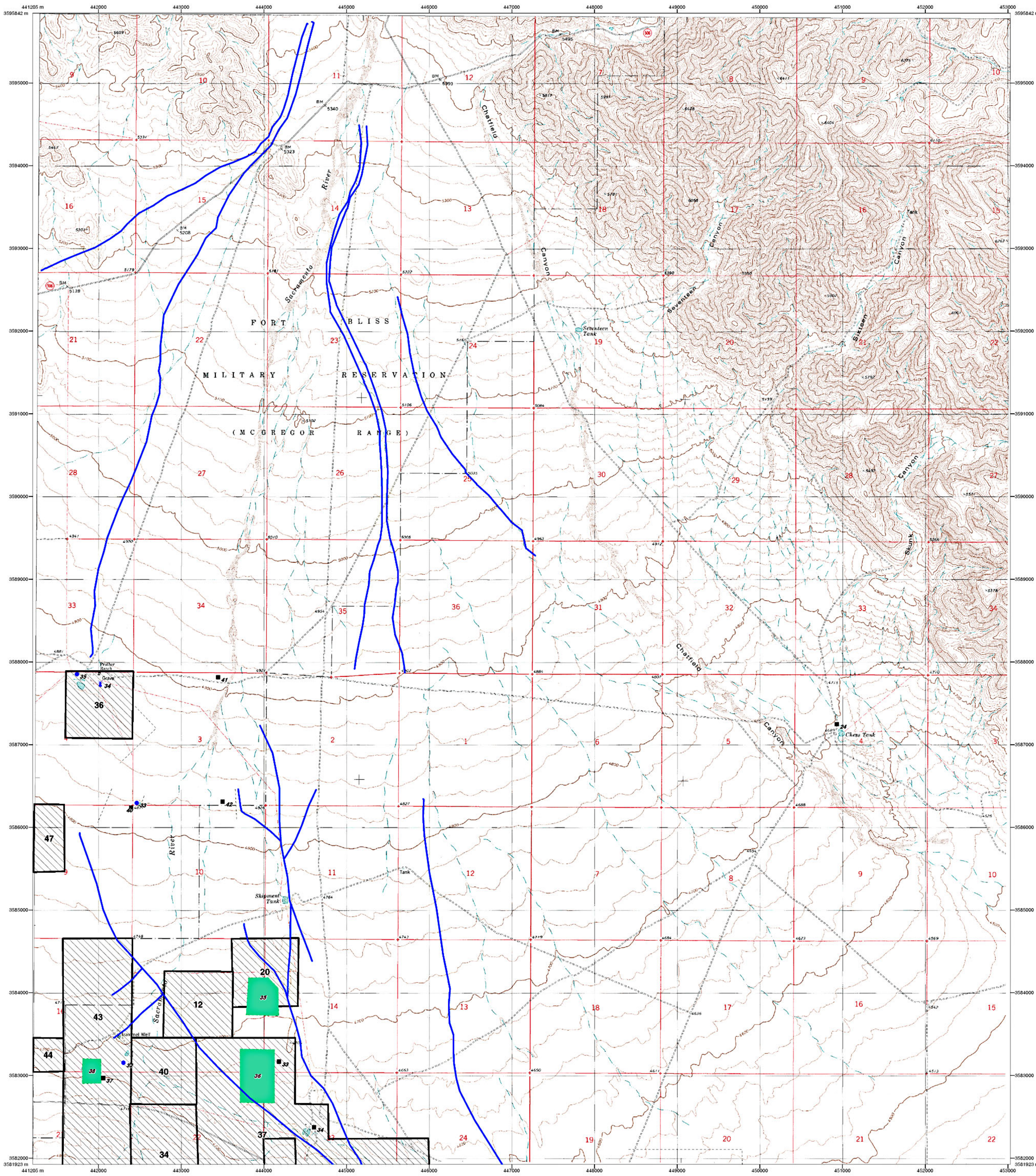
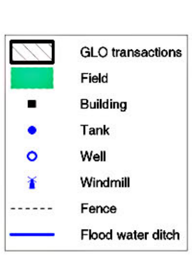
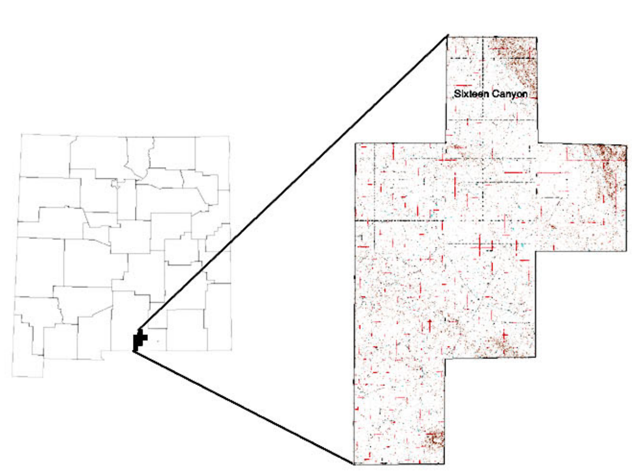


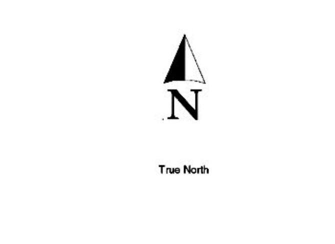
Figure A.9. Sheep Draw Quadrangle. May 2004: Statistical Research, Inc.



Sixteen Canyon Quadrangle







Scale 1:24,000
Universal Transverse Mercator coordinate system and grid
Zone 13, North American Datum 1927
Base data USGS 7-1/2' topo quad, Sixteen Canyon 1980
GLO transactions in Otero Mesa Study Area, including buildings and structures
as depicted on GLO survey plats dated 1885 through 1939
May 2004: Statistical Research, Inc.

Figure A.10. Sixteen Canyon Quadrangle. May 2004: Statistical Research, Inc.