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

Semi-Annual Technical Progress Report

July 1, 2004 – December 31, 2004

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# DISCLAIMER

# ABSTRACT

This report contains a summary of activities of Gnomon, Inc. (Gnomon) and five subcontractors that have taken place during the second six months of 2004 (July1, 2004 – December 31, 2004) under the DOE-NETL cooperative agreement: *Adaptive Management and Planning Models for Cultural Resources in Oil & Gas Fields in New Mexico and Wyoming*, DE-FC26-02NT15445. Although Gnomon and all five subcontractors completed tasks during these six months, most of the technical experimental work was conducted by the subcontractors SRI Foundation (SRIF) and William Eckerle of Western GeoArch Research (WGR).

***SRIF*** created a sensitivity model for the Otero Mesa area of southeastern New Mexico that rates areas as having a very good chance, a good chance, or a very poor chance of containing cultural resource sites. SRIF suggested that the results of the sensitivity model might influence possible changes in cultural resource management (CRM) practices in the Otero Mesa area of southeastern New Mexico.

***William Eckerle*** created sensitivity models to predict the probability of discovering buried cultural resources in the Powder River and Tongue River basins of Wyoming and made suggestions as to how these models might change how cultural resource managers conduct business in the Powder River and Tongue River basins in Wyoming.

These two technical reports each have sections for TITLE PAGE, DISCLAIMER, ABSTRACT, TABLE OF CONTENTS, LIST OF GRAPHICAL MATERIALS, INTRODUCTION, EXECUTIVE SUMMARY, EXPERIMENTAL, RESULTS AND DISCUSSION, CONCLUSION, AND REFERENCES. They are included in this semi-annual summary in their entirety as Appendix A (*The Otero Mesa Technical Summary*) and Appendix B (*Archaeological Burial Model: Powder River and Tongue River Hydrological Basins, Wyoming*). They both will be incorporated into our final report for DOE after we receive feedback from peer reviewers.

***Gnomon*** revised and delivered the Cultural Resources Management Tracker (CRM Tracker) to Wyoming SHPO, and they are now using it. There will be a description of this application and a manual on how to use it in the final report.

Gnomon also created an application to be used by cultural resource managers and contractors, BLM, and representatives of the oil and gas industry. It is a web-based desktop tool to search areas within the Wyoming study area to see where cultural resource inventories have already been done and to see the sensitivity models created by William Eckerle. These models should help managers determine which areas have the highest probability of having buried cultural resources. The name of this tool is the Cultural Resources Information Summary Program, or CRISP. A full description of the application and a manual on how to use the application will be included in the final report to DOE.

***Wyoming SHPO*** continued to add more data to the master GIS database for the Wyoming study area and started writing the final report for the Wyoming part of the DOE PUMP III project.

***The Archaeological Records Management Section (ARMS)*** of New Mexico Historic Preservation Division (NMHPD) continued to enter data for cultural resource sites and surveys into the master GIS database for the New Mexico study areas.

# TABLE OF CONTENTS

# EXECUTIVE SUMMARY

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

**Gnomon Activities**

Gnomon continued oversight of the entire project and in addition worked on these components of the final products:

1. Modified some of the models in the Wyoming report at the request of the primary author.
2. Reviewed Otero Mesa report and Wyoming sensitivity studies report before sending them out for peer review.
3. Modified and installed the CRM Tracker for use in Wyoming.
4. Created and tested the Cultural Resources Information Summary Program (CRISP) for Wyoming.
5. Wrote the training manual for the CRISP tool.

**Wyoming Activities**

***Wyoming State Historic Preservation Office (WYSHPO)*** continued to enter cultural resource data into a master database and to create Geographical Information System (GIS) data to link to the database. All projects have been digitized for all eight counties. A total of 38,200 inventory spatial entities have been created for the study area. An additional 4,924 inventory areas were added during the last six months. The project has currently exceeded the estimated inventory creation records of 9,329 projects. A total of 46,456 sites have been digitized, with an addition of 2,357 sites being added during this six-month period. A total of 16,634 sites have been encoded into the extensive site attribute database. Project staff reviewed and encoded 3,933 new sites and additional site information was incorporated from the "CROW" project conducted by the University of Wyoming. The dataset was used to test the geomorphic models. Mary Hopkins of WYSHPO and Eric Ingbar of Gnomon started writing the final report for the Wyoming part of the project.

A project meeting was held in Laramie on September 23, 2004, in conjunction with the fall meeting of the Wyoming Association of Professional Archaeologists and the Frison Institute Lecture on the campus of the University of Wyoming.

***William Eckerle of Western GeoArch Research (WGR)*** completed his work on the geomorphology of the Power River Basin of Wyoming. His draft of a sensitivity study for the Wyoming study area was sent out for peer review in December. His protocol handbook summarizing fieldwork documentation was sent out for peer review along with the sensitivity study.

The sensitivity models described in the report predicating the likelihood of encountering buried cultural resources concluded:

1. Very high archaeological landscape sensitivity zones are situated primarily along the floodplains and low terraces of low gradient, basin alluvial valleys with lesser areas of eolian sand.
2. High sensitivity zones occur on low slopes, exhibit thick accumulations of surficial sediment, lack evidence for mature soils, and contain little large and small gravel.
3. The moderate sensitivity zone consists of areas that did not fall into the very high, high, low, and very low zones. As such, they either have a "moderate" or an "unpredicted" sensitivity.
4. Areas predicted to have low archaeological landscape sensitivity include areas with a thin mantle of sediment, steep slope, and coarse-grained texture. As well, this zone is mostly mantled by surface soils that are of questionable Holocene-age.
5. Areas at the lowest extreme of the sensitivity scale are within the very low sensitivity zone. Included are large areas of non-soil land such as badlands, gravel pits, rock outcrops, etc.; areas containing soil types thought to be too old to engulf any intact and buried cultural material; depth to bedrock is very shallow; slopes are very steep; and/or gravel comprises the largest proportion of the soil component. Generally speaking, much of this zone is situated on steep slopes in mountainous areas.

Cultural resource management recommendations for the different sensitivity zones include:

1. In the very high sensitivity zones earth-disturbing construction activities should only occur under the most controlled circumstances, including a pre-construction archaeological inventory, and monitoring of construction activity, or at a minimum post-disturbance (pre-refill or pre-regrade) inspection.
2. In the high zones, monitoring of construction activity or at a minimum post-disturbance (pre-refill or pre-regrade) inspection should be considered.
3. In the moderate zones some areas of sensitive sediments will be situated within areas mapped as moderate. State Soil Geographic (STATSGO) Database lumps small areas of higher and lower sensitivity in with the moderate class, especially within the basin portion of the project area. In areas where the Soil Survey Geographic (SSURGO) Database mapping is lacking, common sense use of the sensitivity outline by professional archaeologists can help discriminate areas of higher sensitivity from areas of lower sensitivity. On-site, geoarchaeological evaluations might help discriminate these areas from larger portions of the moderate zone that might be less sensitive. Post-disturbance (pre-refill or pre-regrade) inspection should be considered in all moderate areas.
4. In the low zones agency and consulting archaeologists should make an effort to identify smaller areas of higher sensitivity within this zone. The protocol handbook presented in Appendix A is designed to assist in identifying these areas.

5. In the very low zone as with the low zone, agency and project archaeologists should attempt to identify smaller areas of higher sensitivity within these zones. Only at these specially identified areas are open trench inspection and other monitoring recommended.

**New Mexico Activities**

***The Archaeological Records Management Section (ARMS)*** of the New Mexico Historic Preservation Division (NMHPD) continued to enter data for cultural resource sites and surveys into a master database for the New Mexico study areas. After ARMS delivered extracts of these data for Loco Hills, Azotea Mesa, and Otero Mesa to SRIF in 2003, they moved on to work on three one-degree lat/long blocks of 64 quads each to extend the area where they have good data in southeastern New Mexico. During these last six months, they completed the third one-degree lat/long block of 64 quads (32105), then focused on the backlog of incoming new reports from the BLM that had built up, but were set aside while data were being compiled for the sensitivity models. Approximately 1,000 new reports were entered, attributed, and digitized into the database.

The final numbers of data entered by ARMS for the PUMP III project are:

| | |
|---|---|
| Number of survey reports attributed | 18,000 |
| Number of surveys digitized | 17,500 (the disparity between these numbers is the result of reports that had inadequate or no source graphics) |
| Number of sites attributed | 1,800 |
| Number of site boundaries digitized | 5,300 |

***Stephen Hall of Red Rock Geological Enterprises (RRGE)*** completed his section of the New Mexico report that described the geomorphology in the New Mexico study areas and how he gathered his data.

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

The data used to create the sensitivity model included:

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

SRIF concluded that because the results are based on very limited data, the archaeological site location models of Otero Mesa are poor predictors, but they can guide us as to where we should look for sites:

1. Uplifted, dissected regions of greater Otero Mesa, and especially the southernmost extension of the Sacramento Mountain uplift

2. Alkali Lakes region in the southern part of the eastern study area and the alluvium of the northern block of the western study area

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. Buried sites are frequently found in colluvial settings. This result of the models indicates that 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.

The report makes several recommendations for cultural resource management in the Otero Mesa area of New Mexico:

1. 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.

2. 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.

3. BLM should 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.

***SRIF*** also continued to work on the remainder of the final report for the New Mexico component of the DOE PUMP III project. In October and November they contacted seven different organizations involved in oil and gas exploration in the southwest and interviewed representatives for the management section of the report.

# EXPERIMENTAL NEW MEXICO

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

IDRISI GIS software installed on standard desktop computers.

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

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

***Experimental and Operating Data Used to Complete the Sensitivity Mode l for the Otero Mesa Study Area***

See Appendix A

# EXPERIMENTAL WYOMING

***Experimental Apparatus Used to Complete the Sensitivity Model for the Powder River Study Area in Wyoming***

ESRI ArcGIS 9.0 GIS software installed on standard desktop computers

***Experimental and Operating Data Used to Complete the Sensitivity Model for the Powder River Study Area in Wyoming***

See Appendix B

# EXPERIMENTAL GNOMON

***Experimental Apparatus Used to Complete the CRM Tracker and CRISP tool for the Wyoming Study Area***

CRM Tracker was created using Java script writing on Apache Tom Cat. It uses an SQL Server database.

The CRISP tool was created using ESRI ArcIMS 9.0, ESRI MapObjects 2.2, and ASP.NET

***Experimental and Operating Data Used to Complete the Sensitivity Model for the Powder River Study Area in Wyoming***

See Appendix B

# RESULTS AND DISCUSSION

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

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

There have been no major problems encountered and all parties have been able to meet their deadlines on time and within budget. Below is a summary by participant of what has been accomplished and what each hopes to accomplish in the next three (3) months.

**Gnomon, Inc.**

Added new data to the data library.

Revised and delivered CRM Tracker to WYSHPO.

Assisted WYSHPO with data automation problems.

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

Reviewed and edited sensitivity models developed by William Eckerle (WGR) to predict zones where buried cultural resources would likely be found. Sent this report out for peer review in December.

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

Continued to develop the lease/APD desktop information tool. It is a web-based application that can be used by cultural resource managers and consultants, BLM, and oil and gas industry managers. The application is called Cultural Resources Information Summary Program (CRISP). Gnomon led a demonstration of the revised CRISP tool for WYSHPO, who provided feedback for further modifications and improvements. Gnomon has put the application on line and is now getting user feedback from WYSHPO for further improvements.

Gnomon is writing a user manual for the CRISP tool that will be included with the final DOE report.

Gnomon has created the skeleton outline for the final New Mexico and Wyoming reports, and is making sure that the style guide and DOE formatting requirements are met.

Submitted required reports on time to DOE.

Held the second technical meeting in Albuquerque, New Mexico for all participants and ollaborators in September 2004.

Gnomon is writing parts of the final Wyoming report and New Mexico report.

**Western GeoArch Research**

Completed the *Archaeological Burial Model: Powder River and Tongue River Hydrological Basins, Wyoming* report. Worked with Gnomon to edit it and prepare it for peer review.

See **RESULTS AND DISCUSSION** section of the report in Appendix B.

**Red Rock Geological Enterprises**

Completed Chapter 6 for the final New Mexico report. This chapter describes how the geomorphology in the New Mexico study areas were analyzed and submitted to SRIF to be used for their models.

**New Mexico Historic Preservation Division**

Completed entering all cultural resource data for the New Mexico study areas. During these last six months, they completed the third one-degree lat/long block of 64 quads (32105), then focused on the backlog of incoming new reports from the BLM that had built up, but were set aside while data were being compiled for the sensitivity models. Approximately 1,000 new reports were entered, attributed, and digitized into the database.

The final numbers of data entered by ARMS for the PUMP III project are:

Number of survey reports attributed 18,000
Number of surveys digitized 17,500 (the disparity between these numbers is the result of reports that had inadequate or no source graphics)
Number of sites attributed 1,800
Number of site boundaries digitized 5,300

**Wyoming State Historic Preservation Office**

Completed entering all cultural resource data for the Wyoming study area. A total of 46,456 sites have been digitized, with an addition of 2,357 sites being added during this six-month period. A total of 16,634 sites have been encoded into the extensive site attribute database. Project staff reviewed and encoded 3,933 new sites and additional site information was incorporated from the "CROW" project conducted by the University of Wyoming. The dataset was used to test the geomorphic models. Mary Hopkins of WYSHPO and Eric Ingbar of Gnomon started writing the final report for the Wyoming part of the project.

**SRI Foundation**

Published and sent for peer review the *Otero Mesa Technical Summary.* See **RESULTS AND DISCUSSION** section of the report in Appendix A.

Continued to write additional chapters for the final New Mexico component of the DOE report.

Interviewed representatives from seven oil and gas industry organizations to gather information for the management section of the final report.

# CONCLUSION

Gnomon and its five (5) subcontractors continue to work together as a team to complete the DOE PUMP III project. The major accomplishment in the last six (6) months is the completion of *The Otero Mesa Technical Summary,* the *Archaeological Burial Model: Powder River and Tongue River Hydrological Basins, Wyoming* report, the CRM Tracker application, and the CRISP application. WYSHPO and ARMS have completed entering all data into their GIS databases for the study areas. SRIF has completed most of the New Mexico report, and WYSHPO and Gnomon have almost completed the Wyoming report.

See Appendix A and Appendix B for the **CONCLUSIONS** for each of the technical reports completed during this time period.

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

**TO BE ACCOMPLISHED January 1 – June 30, 2005**

**Gnomon and SRIF** – complete the final New Mexico report, send out for peer review, incorporate edits and submit to DOE as part of the final report.

**William Eckerle** – incorporate suggestions from peer reviewers for Wyoming sensitivity models report.

**Gnomon and WYSHPO** – complete the final Wyoming report, send out for peer review, incorporate changes and submit final report to DOE.

**Gnomon**

1. Complete the CRISP application and user manual and incorporate into final DOE report. Install the application for use by WYSHPO, Wyoming cultural resource managers and contractors, and Wyoming BLM offices.
2. Complete the final report for DOE, which includes the New Mexico study area, the Wyoming study area, and appendices.

# REFERENCES

See Appendix A (*The Otero Mesa Technical Summary*), page A-60 and Appendix B (*Archaeological Burial Model: Powder River and Tongue River Hydrological Basins, Wyoming*), page B-77 for references.

# APPENDIX A

# The Otero Mesa Technical Summary

**Appendix A for Semi-Annual Technical Report**

**July 1, 2004 – December 31, 2004**

by

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

December 2004

**Adaptive Management and Planning Models for Cultural Resources in Oil and Gas Fields**

**(DOE PUMP III)**

DOE Award Number: DE-FC26-02NT15445, Task 6

Submitting Organization:
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# ABSTRACT

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 State Historic Preservation Division,
- a geomorphology study for each of the three study areas,
- predictive models of archaeological site locations based on correlation with environmental variables for each of three study areas,
- inventory simulations to reconstruct the history and evaluate the effectiveness of archaeological survey within each of the study areas, and management recommendations for more predictable, efficient cultural resource compliance processes for oil and gas development as well as better management of cultural resources on the public lands.

This technical summary contains a brief characterization of Otero Mesa, one of the three study areas in New Mexico. The report describes the Otero Mesa environment; describes the predictive models and the inventory reconstruction analysis; and discusses the implications of the modeling and reconstruction analysis for management of cultural resources on Otero Mesa for future oil and gas leasing.

This report will be integrated with two previous technical reports (Loco Hills and Azotea Mesa) in the final report delivered to DOE. The final report will provide much more detailed management recommendations based on the results of the three technical summaries.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# Introduction

In 2002, Gnomon, Inc., was awarded a contract from the U.S. Department of Energy for a project entitled, *Adaptive Management and Planning Models for Cultural Resources in Oil and Gas Fields*. This project, funded through DOE's *Preferred Upstream Management Practices (PUMP)* grant program, is examining cultural resource management practices in two major oil and gas producing areas, southeastern New Mexico and the Powder River Basin of Wyoming, with the purpose of identifying more effective management practices and developing information technology tools to facilitate those practices.

Gnomon, Inc., in partnership with the Wyoming State Historic Preservation Office and William Eckerle of Western GeoArch Research, is completing the Wyoming portion of the project. SRI Foundation, in partnership with the New Mexico Historic Preservation Division, Statistical Research, Inc., and Stephen Hall of Red Rock Geological Enterprises, is carrying out the New Mexico component.

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 State Historic Preservation Division,
- a geomorphology study for each of the three study areas,
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- inventory simulations to reconstruct the history and evaluate the effectiveness of archaeological survey within each of the study areas, and
- management recommendations for more predictable, efficient cultural resource compliance processes for oil and gas development as well as better management of cultural resources on the public lands.

The New Mexico project area encompasses much of the current and projected areas of oil and gas development on the public lands in the New Mexico portion of the Permian Basin. The three detailed study areas (Figure 1) were chosen because they represent a heavily developed oil and gas field (Loco Hills), a currently developing field (Azotea Mesa), and a potential field (Otero Mesa) that is the subject of a recent land use plan by the Bureau of Land Management (BLM). 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 effective management strategies for future developments.

This technical summary is an interim product of the New Mexico Pump III project. In order to ensure that the technical products of this effort— that is, the predictive models and inventory reconstructions—will be of the highest quality, technical summaries are being produced for each study area and submitted for initial peer review. A management recommendations summary document will also be circulated for initial peer review. Ultimately, all of the pieces of the various technical and management summaries will be folded into a draft technical report that will be circulated for broader peer review prior to development of the final project report.

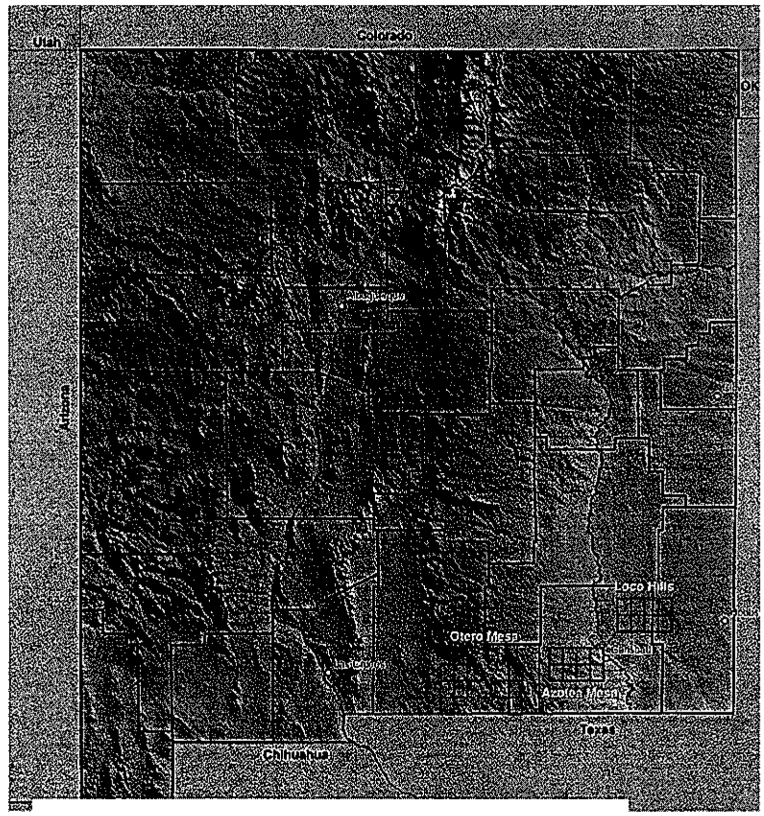

**Figure 1. Location of the three study areas**

In 2003 SRI Foundation prepared the technical summary for the Loco Hills study area (Altschul et al. 2003). That document provided substantial background information on the New Mexico Pump III project, as well as detailed information on the paleoenvironment and culture history of the project area. Earlier this year, SRI Foundation prepared and disseminated a technical summary for the Azotea Mesa study area (Altschul et al. 2004). The detailed information from the Loco Hills technical summary was not repeated in the Azotea Mesa summary and will not be repeated here; the reader is referred to Altschul et al. (2003) for any needed background.

This technical summary contains a brief characterization of the Otero Mesa environment, detailed discussion of the predictive models and the inventory reconstruction analysis, and a brief discussion of the implications of the modeling and reconstruction analysis for management of cultural resources on Otero Mesa for future oil and gas leasing. The final report for the project, which will be produced in the late fall of 2004, will provide much more detailed management recommendations based on the results of the three technical summaries.

# Executive Summary

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 State Historic Preservation Division,
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SRIF concluded that because the results in this report are based on very limited data, the archaeological site location models of Otero Mesa are poor predictors, but they can guide us as to where we should look for sites:

1. Uplifted, dissected regions of greater Otero Mesa, and especially the southernmost extension of the Sacramento Mountain uplift

2. Alkali Lakes region in the southern part of the eastern study area and the alluvium of the northern block of the western study area

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. Buried sites are frequently found in colluvial settings. This result of the models indicates that 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.

The report makes several recommendations for cultural resource management in the Otero Mesa area of New Mexico:

1. Archaeologists need to confirm and explain the patterns suggested by these preliminary models, and the archaeological record needs to be more fully characterized.

2. 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.

3. BLM should continue the predictive modeling process for Otero Mesa.

This report will be integrated with two previous technical reports (Loco Hills and Azotea Mesa) in the final report delivered to DOE. The final report will provide much more detailed management recommendations based on the results of the three technical summaries.

# EXPERIMENTAL

## Experimental and Operating Data

### Location and Topography

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). The region in which our study areas fall is generally referred to "greater Otero Mesa," since it includes not only the landform of Otero Mesa, but a wedge of rugged canyon country that comprises the southernmost extension of the Sacramento Mountains, 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 physically separate blocks comprising eleven quadrangles (Figure 2).

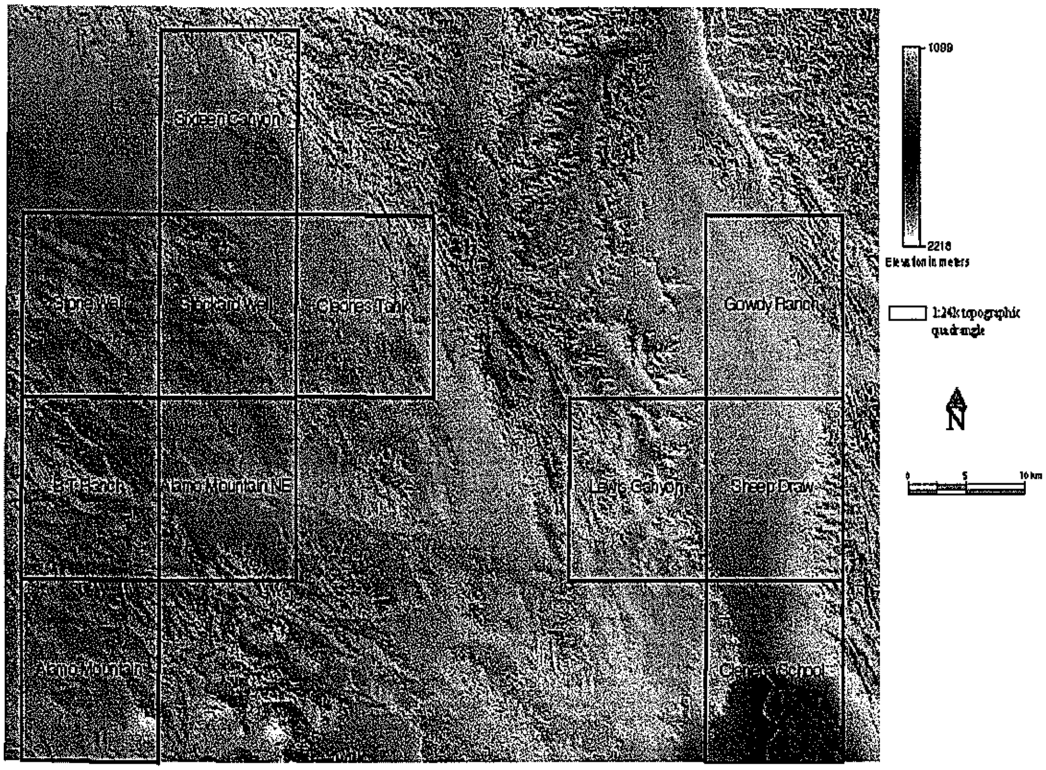



**Figure 2. Otero Mesa terrain and location of eastern and western study areas. Named blocks are 1:24,000 topographic quadrangles.**

In the western study area, elevations range from 1300 meters (4265 feet) in the easternmost block to over 1900 meters (6230 feet) in the far northeast corner. The southernmost block of this study area includes Alamo Mountain, an isolated peak rising to over 1900 meters (6230 feet) above surrounding terrain that is less than 1600 meters (5250 feet) in elevation. The eastern study area is generally lower in elevation, with the central and southern portions being approximately 1100 meters (3600 feet), rising slightly to about 1300 meters (4265 feet) in the west and sharply to 1800 meters (5900 feet) on the lower slopes of the Guadalupe Mountains at the northeast corner and to1400 meters (4590 feet) in the Brokeoff Mountains along the eastern edge of the study area.

The western study area consists mostly of rolling desert grasslands, with rugged higher-elevation canyon country in the eastern and northeastern most parts of the area. In the north, this study area receives runoff from Chatfield Canyon and from the Sacramento River. Both drainages flow south out of the Sacramento Mountains. The southern portion of the western study area receives runoff from Otero Mesa through Shiloh Draw. All of these drainages end in the northwestern arm of the Salt Basin, which lies between the western and eastern study areas.

The eastern study area consists largely of Crow Flats, the northeastern arm of the Salt Basin, which lies between the canyon country remnants of the Sacramento Mountains on the west and the Guadalupe and Brokeoff Mountains to the east. Crow Flats receives runoff from the Sacramento Mountains through Piñon Creek in the north, and runoff from the Guadalupe and Brokeoff Mountains through Big Dog and Humphrey Canyons on the east and southeast. To the south of Crow Flats and in the southernmost part of the eastern study area lie a series of playas called Alkali Lakes.

## Geomorphology

The geomorphology of the Otero Mesa study area (Figure 3) 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 area. Large and small alluvial fans occur at the mouths of small canyons that are eroded into Permian limestone bedrock.

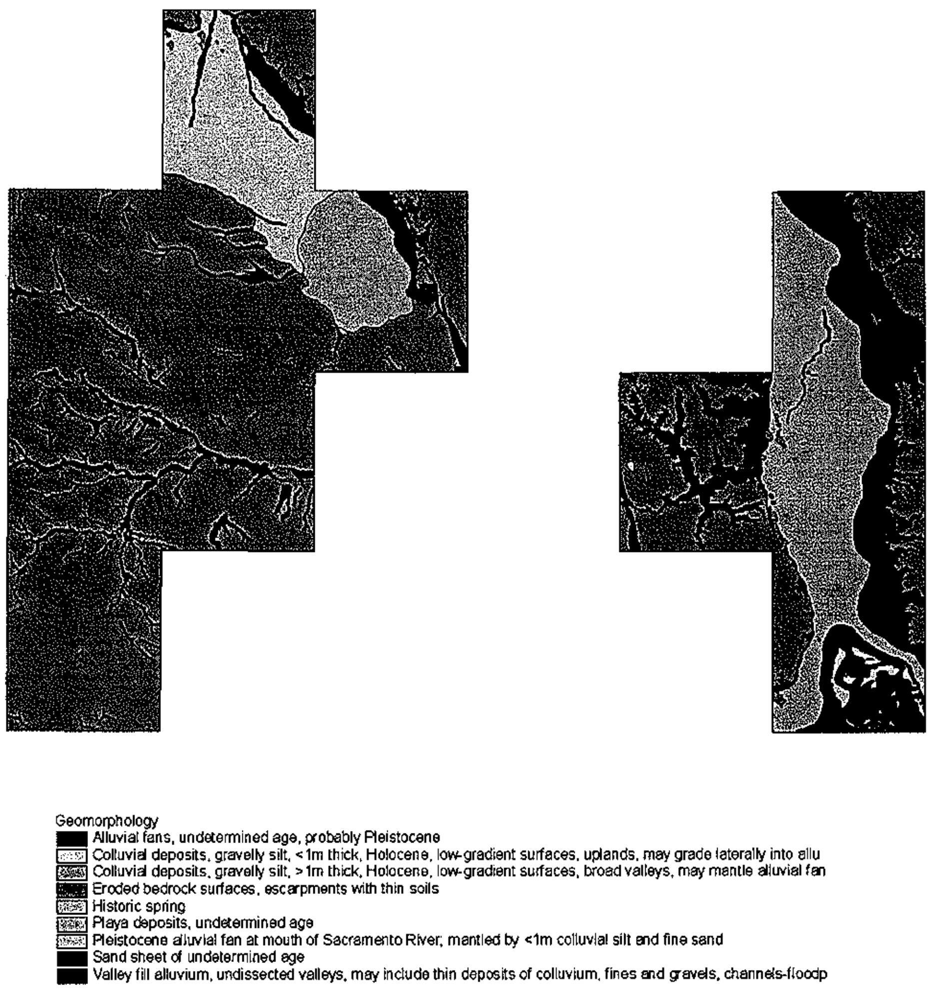



**Figure 3. Geomorphology of the Otero Mesa study area**

***Eroded bedrock surfaces.*** Most of the project area is eroded limestone bedrock. Soils and geomorphic deposits are generally absent from the denuded limestone surfaces. 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 have 100 percent visibility. 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 meter 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 will be found on the surfaces of these old alluvial fans. Site integrity may be low, however, owing to post-occupation bioturbation.

***Deposits at Salt Basin.*** The Salt Basin in the southern portion of the eastern study area 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. Archaeological sites may be buried in the sand sheet.

***Summary.*** Denuded limestone and thin colluvial-alluvial deposits characterize a large proportion of the Otero Mesa study area. Archaeological sites in these settings will have 100 percent visibility although site integrity will be low owing to 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 recent eolian sands in the Salt Basin may contain buried archaeological sites.

## Climate

The climate in south-central New Mexico is semi-arid with hot summers and mild winters. During the reporting period 1914-2004 at Orogrande, the nearest weather station, the average high temperature in July was 96 degrees F, although daytime temperatures over 100 degrees are very common. The highest recorded temperature was 116 degrees in 1934. Over the recording period, the average high temperature in both December and January was 58 degrees F with an average low of 27 degrees F, although daytime temperatures in the 60s and even 70s and nighttime temperatures in the teens are not uncommon. The frost-free season averages nearly 200 days per year.

Average annual precipitation varies substantially with elevation. Over the period 1914–2004, the average in Orogrande was 10 inches per year, with most of the precipitation falling in July, August, and September. Since the recording station lies at an elevation of 1300 meters (4300 feet), the higher elevations of the Otero Mesa study areas are likely to receive slightly more precipitation than this figure in an average year, particularly winter precipitation for which the main source of moisture is Pacific storm systems. These storm systems tend to be captured by the Guadalupe and Brokeoff Mountains along the eastern edge of the study area and drop much of their moisture before passing on to the east. The primary source of summer precipitation, on the other hand, 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. A combination of high evaporation rates and frequent strong winds, especially in the spring, contribute to the aridity of the climate and the xeric nature of the vegetation.

## Vegetation

As Figure 4 shows, most of the vegetation in the study area is Chihuahuan desert scrub, dominated by creosotebrush (*Larrea tridentate*), with substantial areas of Chihuahuan foothill-piedmont desert grasslands along the western edges of the western study area and the eastern edges of the eastern study area. The central and southern portions of the eastern study area are dominated by Chihuahuan lowland desert grasslands. The grasslands are characterized by several species of grama grass (*Bouteloua sp.*) and by alkali scacaton (*Sporobolus wrightii*) and various other species of dropseed (*Sporobolus sp.*), as well as a variety of forbs.

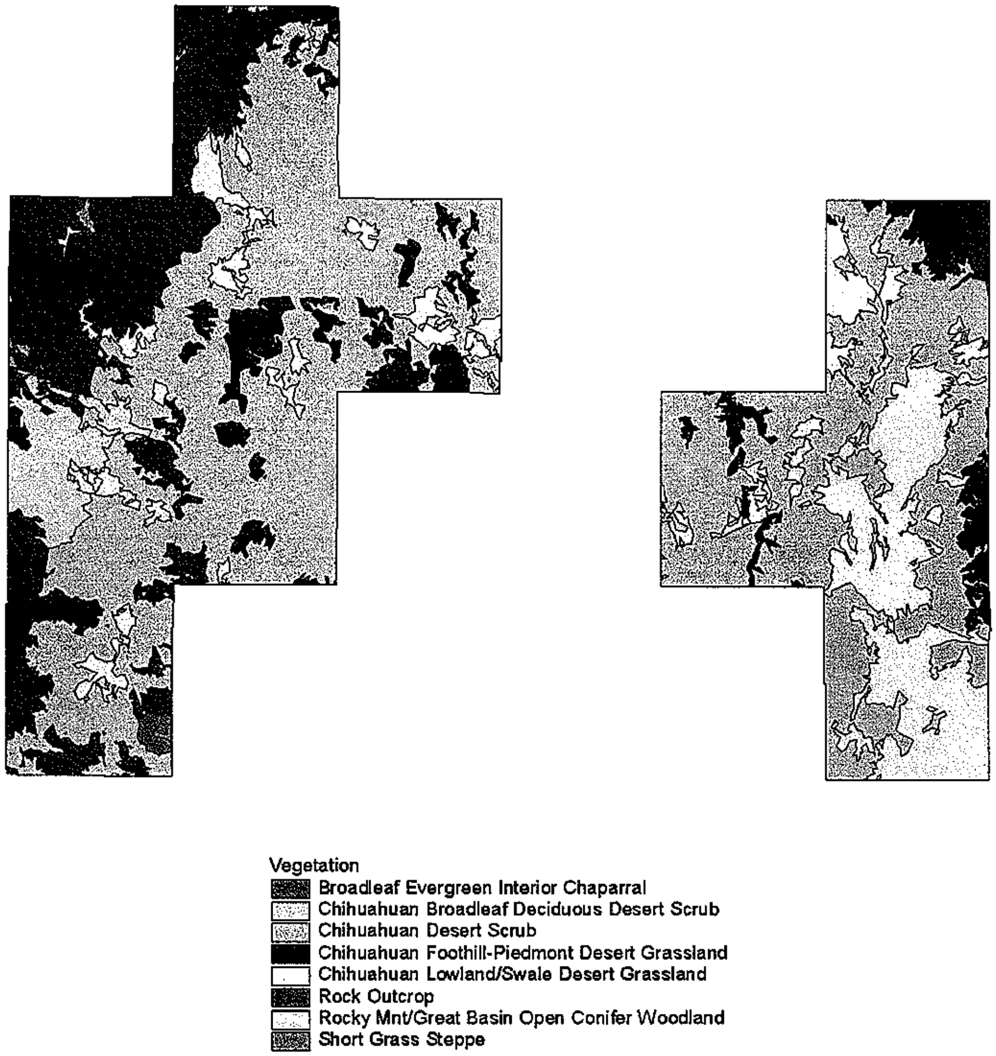



**Figure 4. Vegetation of the Otero Mesa study area**

## Predictive Models

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

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 area encompasses 4 quadrangles or 65,400 hectares (253 square miles), and the western study area covers 7 quadrangles, or 114,443 hectares (440 square miles). The two study areas reflect different physiographic units. The eastern area encompasses the closed drainage basin of Crow Flats and the western area consists largely of rolling desert grasslands. Only 0.4 percent of the eastern area has been surveyed and 20 sites have been recorded. The western area comprises one of the better-studied areas of Otero Mesa. Here, 3.0 percent of the area has been surveyed and 83 sites have been recorded.

As with Loco Hills and Azotea Mesa, the predictive models created for Otero Mesa are correlative models (see discussion in Altschul et al. 2003), which examine correlations between archaeological site locations and environmental features. The modeling process begins 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 that 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, and uses a grid of a specified size superimposed over the area in question. We chose a 10-by-10-meter 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.

## 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. Some of these environmental variables might be correlated with archaeological sites; others might not. Unlike a deductively based model, such as an optimal foraging model, we posit no predefined associations between particular aspects of the environment and human behavior. We only assert that the environment is correlated with human settlement. By casting our net wide enough, we believe that a sufficient number of environmental variables will be included in the model so that the relationship between the physical landscape and human decisions about where to settle will be captured.

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 house or measure the exact distance to water, but they do choose land that is flat and near water. The indigenous people of Otero Mesa probably did not know, much less care, at what elevation they placed their camps, but they certainly knew where the most abundant grasses occurred or where the best observation points could be located. Elevation is strongly correlated with the vegetative communities of southeast New Mexico, and thus, even though elevation would not have been a conscious part of the prehistoric "calculus," this variable can be used as a predictor of site location.

By measuring the strength of the statistical relationship between a particular environmental attribute and site location we may gain insight into this calculus. At a later stage, we could test our insight through the creation of deductively based models. Although such a step is beyond the scope of this project, it is important to recognize that our ultimate goal is to understand the past, not simply to retrodict it.

We obtained GIS layers on elevation, vegetation, and geomorphology. Because the data relate to empirical observations (e.g., someone actually measured the elevation of some of the points in the project area), these layers are termed primary themes. It is important to point out that in GIS, the designation "primary theme" does not mean that the score of *each* cell was derived from an empirical observation, only that the interpolation is based on source data. For example, the elevation theme is a digital elevation model (DEM; Figure 2) 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 Otero Mesa, the contour interval is 20 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). Similarly, aspect, or the prevailing exposure of a 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.


**Figure 5. Slopes for Otero Mesa; scale represents 0-72 degrees of slope**

A data layer for major streams and ridgelines was also created by using the DEM as a primary data layer (Figure 6). 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 so that it 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 is computed by summing slope squared values for each cell traversed. For instance, the GIS will start at cells coded as a stream and sum the cost of crossing each cell encountered when traveling away from that source. So if two cells to the east of a stream cell have a slope squared value of 50 and 55, then the cost value for the second cell would be 105. If the terrain is flatter, then the cost to reach the second cell would be less. Costs 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.

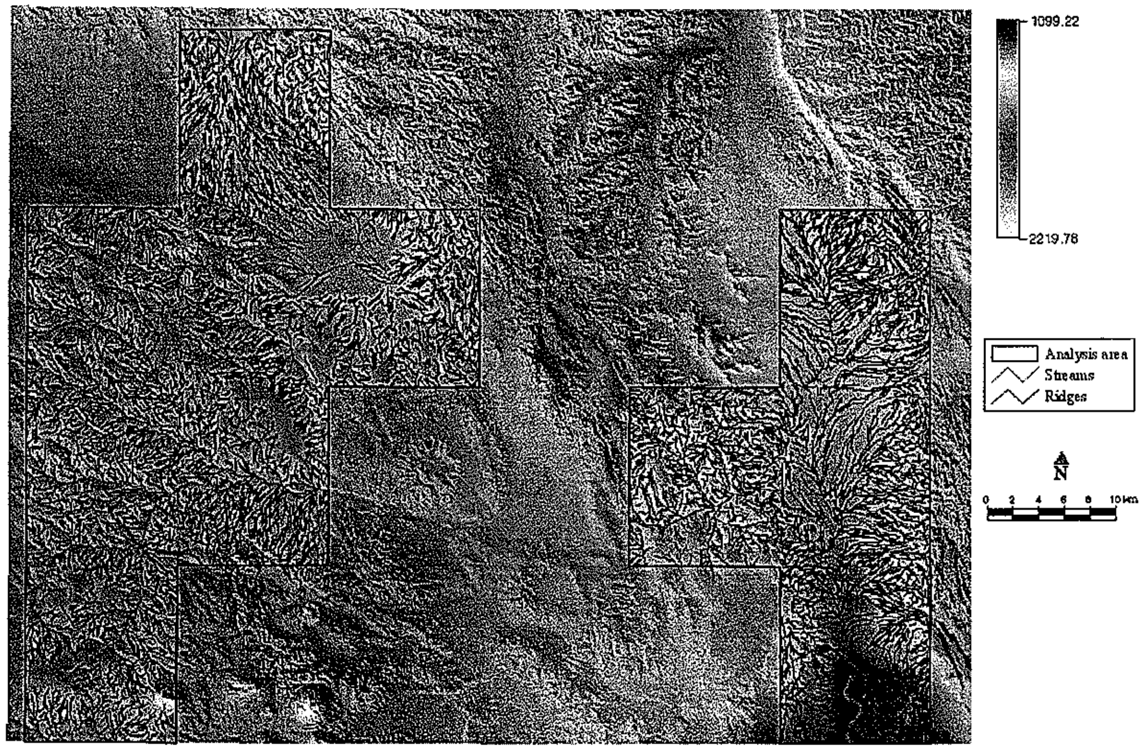



**Figure 6. Streams and ridges for Otero Mesa**

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

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

## 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 precontact archaeological sites. Archaeological data were obtained from the New Mexico Historic Preservation Division's Archaeological Records Management System (ARMS).

ARMS provides data on areas that have been subject to archaeological surveys, the sites that have been recorded, and various characteristics of those sites.

Ideally, we would have created predictive models for each site class and/or temporal period. With only 106 total sites, however, we were forced to combine all site data for each 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-period from precontact components and exclude the former from the models.

***Site Data.*** The archaeological site data provided by ARMS are shown graphically in Figure 7. 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, in which 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, but not every field contains data.

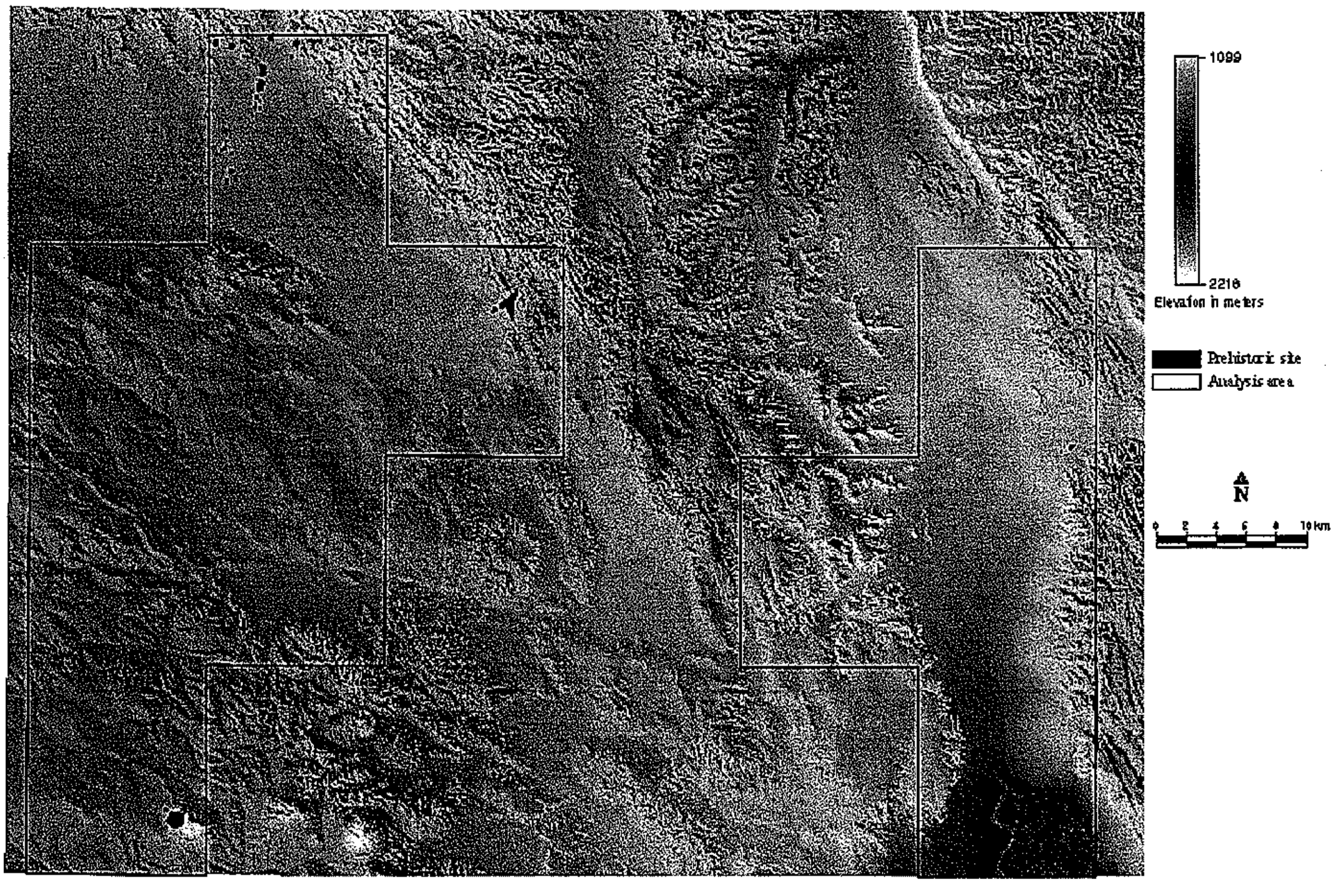



**Figure 7. Prehistoric sites for the Otero Mesa study areas (n=103)**

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 measurements in the x and y 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 areas are included. Eleven of these sites date exclusively to the historical-period, leaving 95 polygons to be used in the creation of the predictive models.

***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 8. This resulted in a total of 119 polygons. As Figure 8 shows, surveys have been rare in the east; the western area is slightly better covered, but still largely unknown. 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 technical summary.

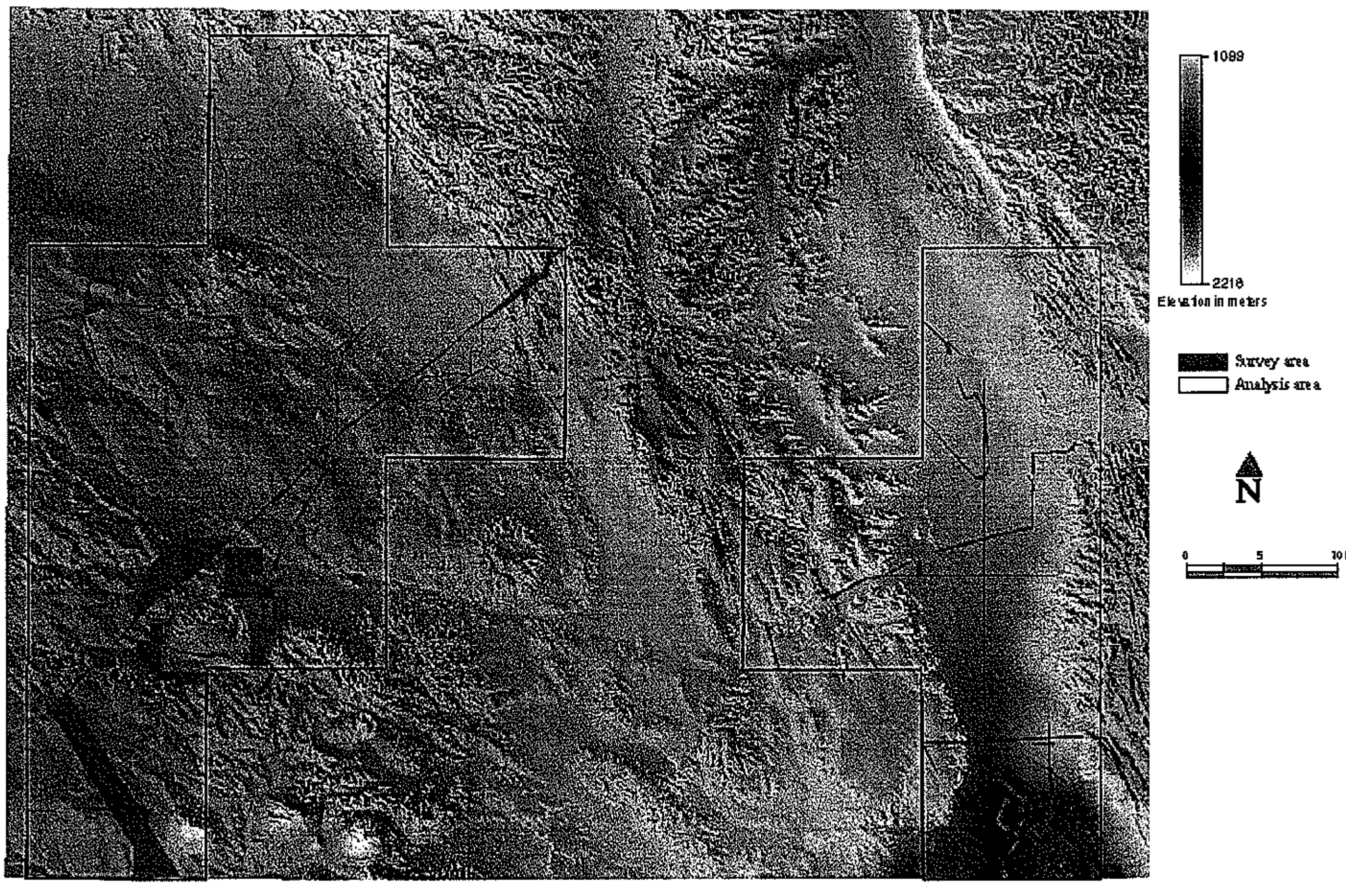



**Figure 8. Archaeological surveys within the Otero Mesa study areas**

## Data Reduction

### Evaluating the Data

As a general rule, predictive modelers warn that unless 10 percent of an 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 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 1, 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.

**Table 1. Average environmental scores for each study region**

| | ***Loco Hills*** | ***Azotea Mesa*** | ***Otero Mesa West*** | ***Otero Mesa East*** |
|---|---|---|---|---|
| Elevation (mean & standard deviation) | Mean= 1121m<br>Std.dev= 70m | Mean= 1198 m<br>Std.dev= 144 m | Mean= 1468m<br>Std. Dev= 91m | Mean= 1207m<br>Std. Dev= 105m |
| Geomorphology (Top 3 largest in area) | Parabolic dunes 55%<br>Coppice dunes 13%<br>Eroded limestone 13% | Eroded limestone 83%<br>Extensive slope-wash deposits 9%<br>Floodplains of large drainages 4% | Eroded bedrock surfaces= 75%<br>Pleistocene alluvial fan at mouth of Sacramento River= 12%<br>Colluvial deposits, gravelly silt >1m thick Holocene= 4% | Colluvial deposits, gravelly silt >1m thick Holocene= 33%<br>Eroded bedrock surfaces= 32%<br>Alluvial fans undetermined age= 22% |
| Vegetation (Top 3 largest in area) | Chihuahuan desert grassland 59%<br>Chihuahuan desert scrub 19%<br>Broadleaf evergreen interior chaparral 11% | Chihuahuan foothill-piedmont desert grassland 69%<br>Chihuahuan desert scrub 15%<br>Chihuahuan desert grassland 6% | Chihuahuan Desert Scrub= 56%<br>Chihuahuan foothill-piedmont desert grassland= 32%<br>Chihuahuan lowland/swale desert grassland= 6% | Chihuahuan Desert Scrub= 57%<br>Chihuahuan lowland/swale desert grassland= 34%<br>Chihuahuan foothill-piedmont desert grassland= 9% |
| Distance to water (mean and standard deviation) | Mean= 1967m<br>Std.dev= 1694m | Mean= 636m<br>Std.dev= 478m | Mean= 209m<br>Std.dev= 212m | Mean= 284m<br>Std.dev= 324m |
| Survey Coverage (percent of total area) | 19% | 10% | 2.5% | 0.4% |
| Prehistoric sites | Polygons= 779<br>Range acres=0.01-890.95<br>Mean size= 7.14 acres<br>std. dev= 41.1 acres | Polygons= 550<br>Range acres= 0.15-313.82<br>Mean size= 4.62 acres<br>std. Dev= 19.22 acres | Polygons= 78<br>Range acres=0.05-193<br>Mean size= 7.94acres<br>std. dev= 28.48 acres | Polygons= 17<br>Range acres= 0.17-56.03<br>Mean size= 4.85 acres<br>std. dev= 13.52 acres |

## The Association between Environmental Variables and Site Location

Two statistical testing methods were employed to test environmental data layers for significance with 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 tested using chi-squared tests.

***One-Sample Means Test.*** A one-sample means test can be conducted with GIS data by treating the archaeological site locations as a sample of the environmental background (total population), and testing the difference between the sample and population means. If the difference is significant at the 0.05 level, 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.

The means test is conducted by first computing a z-score as follows

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

Critical value at 0.05 significance = 1.96

The one-sample means test results that show a significant relationship between site location and environmental variables for the eastern and western study units are presented in Tables 2 and 3, respectively. In the east, sites are located in counterintuitive locations, away from streams and at high elevations. To the west, sites are located closer to streams, but still on elevated positions.

**Table 2. One-sample means test for continuous variables of the eastern study area, listed in order of significance**

| GIS layer | Means test | Significant |
|---|---|---|
| Distance from stream intersections | Z= (932.86-606.37)/[ (355.77/√3164)]= 51.62 | Yes; site cells are located further from stream intersections than non site cells |
| Distance from streams | Z= (343.66-209.02)/[ (171.67/√3164)]= 44.12 | Yes; site cells are located further from stream than non site cells |
| Elevation | Z= (1284.11-1207.22)/[(104.74/√3164)]=41.29 | Yes; site cells are located at higher elevations than non site cells |
| Cost distance from streams | Z= (94.59-4.18)/[(175/√3164)]= 32.39 | Yes; site cells have higher cost distances than non site cells |
| Distance from ridges | Z= (141.67-314.58)/[371.95/√3164)]= -26.15 | Yes; site cells are located closer to ridges than non site cells |
| Cost distance from ridges | Z= (15.20-48.87)/[ (96.92/√3164)]= -19.6 | Yes; site cells have lower cost distances than non site cells |
| Slope | Z= (2.69-4.99)/[(8.58/√3164)]= -15.08 | Yes; site cells are located on flatter slopes than non site cells |

**Table 3. One-sample means test for continuous variables of the western study area, listed in order of significance**

| GIS layer | Means test | Significant |
|---|---|---|
| Cost distance from ridges | Z= (192.94-38.91)/[ 108.45/√22777)]= 214.35 | Yes; site cells have a higher cost distance from ridges than non site cells |
| Slope | Z= (6.94-2.57)/[4.56/√22777)]= 144.63 | Yes; site cells are located on steeper slopes than non site cells |
| Elevation | Z= (1551.85-1467.88)/[( 91.25/√22777)]= 138.88 | Yes; site cells are located at higher elevations than non site cells |
| Cost distance from streams | Z= (118.39-48.98)/[( 113.7/√22777)]= 92.13 | Yes; site cells have higher cost distances than non site cells |
| Distance from stream intersections | Z= (806.12-675.75)/[ ( 450.91/√22777)]= 43.64 | Yes; site cells are located further from stream intersections than non site cells |
| Distance from streams | Z= (224.54-283.59)/[270.73/√22777)]=-32.92 | Yes; site cells are located closer to streams than non site cells |
| Distance from ridges | Z= (265.43-236.18)/[ 231.13/√22777)]= 19.1 | Yes; site cells are located further from ridges than non site cells |

***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 compares expected archaeological site numbers with observed site numbers and assesses each environmental layer for significance. The distribution is tested by the formula

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

where O is the observed number of sites in each layer category and E is the expected number of sites, based on the area of each category. For example, if a category covers 50 percent of the study area then the expected number of site cells should be 50 percent of the total site cells. O is computed using GIS to determine the actual number of site cells within the category. We defined chi-square scores over 124.342 as indicative of a nonrandom relationship between site location and environmental features. In matrices that exhibit 100 degrees of freedom, scores above 124.342 occur fewer than 5 times in 100 as a result of chance alone. Although the degrees of freedom in the Otero Mesa study areas are quite a bit larger than 100, we use this number as a cut off for convenience. Published probability tables generally stop at 100 degrees of freedom.

The results of the chi-square tests for significant association with aspect are presented in Tables 4 and 5.

**Table 4. Chi-square tests for significant association with aspect in the eastern study area**

| *Aspect* | *North (315-360°, 0-45°)* | *East (45-135°)* | *South (135-225°)* | *West (225-315°)* | *No slope direction* |
|---|---|---|---|---|---|
| Percentage | 11.86 | 21.27 | 34.61 | 30.01 | 2.25 |
| Site cells | 208 | 830 | 1743 | 365 | 19 |
| Expected | 375.37 | 673.2 | 1095.41 | 949.82 | 71.21 |
| Chi-square | 74.62 | 36.52 | 382.85 | 360.08 | 38.28 |
| Survey Coverage % | 0.01 | 0.35 | 0.5 | 0.22 | 0.12 |

Total Chi-square= 74.62+36.52+382.85+360.08+38.28= 892.35 Significant

**Table 5. Chi-square tests for significant association with aspect in the western study area**

| *Aspect* | *North (315-360°, 0-45°)* | *East (45-135°)* | *South (135-225°)* | *West (225-315°)* | *No slope direction* |
|---|---|---|---|---|---|
| Percentage | 23.77 | 30.83 | 30.31 | 14.79 | 0.25 |
| Site cells | 2580 | 1453 | 6988 | 11757 | 0 |
| Expected | 5414.09 | 7022.15 | 6903.71 | 3368.72 | 56.94 |
| Chi-square | 1483.55 | 4416.8 | 1.03 | 20887.23 | 56.95 |
| Survey coverage % | 0.42 | 1.57 | 1.38 | 1.4 | 0.77 |

Total Chi-square= 1,483.55+4,416.8+1.03+20,887.23+56.95= 26,845.56 Significant

In the eastern study area, sites tend to be oriented to the south and east in greater proportions than expected; in the western study area, sites are mostly oriented to the west. In both areas, northern exposure occurs less often than expected.

The results of the chi-square tests for significant association with geomorphic units are presented in Tables 6 and 7.

**Table 6. Chi-square tests for significant association with geomorphic units in the eastern study area**

| *Geomorphology* | *Eroded bedrock* | *Sand sheet* | *Valley fill alluvium* | *Alluvial fans* |
|---|---|---|---|---|
| Percentage | 32.29 | 6.49 | 3.88 | 22.23 |
| Site cells | 2153 | 569 | 28 | 324 |
| Expected | 1020.04 | 205.02 | 122.57 | 702.25 |
| Chi-square | 1258.38 | 646.19 | 72.97 | 203.74 |
| Survey coverage % | 0.24 | 0.14 | 0.3 | 0.07 |

| *Geomorphology (Continued)* | *Playa deposits* | *Colluvial deposits <1m thick* | *Colluvial deposits >1m thick* |
|---|---|---|---|
| Percentage | 1.44 | 0.05 | 33.62 |
| Site cells | 0 | 0 | 85 |
| Expected | 45.49 | 1.58 | 1062.06 |
| Chi-square | 45.49 | 1.58 | 898.86 |
| Survey coverage % | 0 | 0 | 0.004 |

Total Chi-square= 1258.38+646.19+72.97+203.74+45.49+1.58+898.86= 3127.21 Significant

**Table 7. Chi-square tests for significant association with geomorphic units in the western study area**

| *Geomorphology* | *Eroded bedrock* | *Historic spring* | *Valley fill alluvium* | *Alluvial fans* |
|---|---|---|---|---|
| Percentage | 75.42 | 0.0003 | 4.4 | 2.52 |
| Site cells | 10960 | 37 | 2923 | 5954 |
| Expected | 17179.17 | 0.07 | 1002.23 | 574 |
| Chi-square | 2251.45 | 19483.21 | 3681.15 | 50425.78 |
| Survey coverage % | 1.55 | 100 | 2.26 | 2.18 |

| *Geomorphology (Continued)* | *Playa deposits* | *Colluvial deposits <1m thick* | *Colluvial deposits >1m thick* | *Pleistocene alluvial fan mouth of Sacramento river* |
|---|---|---|---|---|
| Percentage | 0.11 | 0.02 | 5.97 | 11.56 |
| Site cells | 0 | 0 | 0 | 2904 |
| Expected | 25.06 | 4.56 | 1359.85 | 2633.14 |
| Chi-square | 25.06 | 4.56 | 1359.85 | 27.86 |
| Survey coverage % | 0.1 | 9.09 | 0 | 0 |

Total Chi-square= 2251.45+19483.21+3681.15+50425.78+25.06+4.56+1359.85+27.86= 77258.92 Significant

The chi-square results of the geomorphology are consistent with those for the one-sample means test. Sites in the eastern study area are found on bedrock and sand sheets and avoid alluvium. Such conditions are found away from water and on elevated surfaces. In the western study area, sites are found on almost the opposite landforms. Here, 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 areas, 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 post-depositional processes that have buried precontact-aged cultural materials.

The results of the chi-square tests for significant association with vegetation units are presented in Tables 8 and 9.

**Table 8. Chi-square tests for significant association with vegetation units in the eastern study area**

| *Vegetation* | *Rky Mtn/Great Basin Open Conifer* | *Chihuahuan Desert scrub* | *Chihuahuan foothill-piedmont* | *Chihuahuan lowland/swale* |
|---|---|---|---|---|
| Percentage | 0.01 | 57.01 | 9.44 | 33.53 |
| Site cells | 0 | 442 | 21 | 2702 |
| Expected | 0.32 | 1804.37 | 298.78 | 1061.22 |
| Chi-square | 0.32 | 1028.64 | 258.25 | 2536.85 |
| Survey coverage % | 0 | 0.15 | 0.07 | 0.03 |

Total Chi-square= 0.32+1028.64+258.25+2536.85= 3824.06 Significant

**Table 9. Chi-square tests for significant association with vegetation units in the western study area**

| *Vegetation* | *Broadleaf Evergreen* | *Chihuahuan Desert scrub* | *Chihuahuan broadleaf deciduous* | *Short Grass Steppe* |
|---|---|---|---|---|
| Percentage | 0.1 | 55.77 | 5.36 | 0.34 |
| Site cells | 0 | 8952 | 6 | 34 |
| Expected | 22.78 | 12703.29 | 1220.9 | 77.45 |
| Chi-square | 22.78 | 1107.76 | 1208.93 | 24.38 |
| Survey coverage % | 0 | 1.47 | 1.48 | 5.08 |

| *Vegetation (Continued)* | *Chihuahuan foothill-piedmont* | *Chihuahuan lowland/swale* | *Rock Outcrop* |
|---|---|---|---|
| Percentage | 32.35 | 5.65 | 0.43 |
| Site cells | 7198 | 68 | 6520 |
| Expected | 7368.68 | 1286.96 | 97.95 |
| Chi-square | 3.95 | 1154.55 | 421058.97 |
| Survey coverage % | 0.65 | 2.63 | 13.95 |

Total Chi-square= 22.78+1107.76+1208.93+24.38+3.95+1154.55+421058.97= 424581.32 Significant

**Table 9. Chi-square tests for significant association with vegetation units in the western study area**

| *Vegetation* | *Broadleaf Evergreen* | *Chihuahuan Desert scrub* | *Chihuahuan broadleaf deciduous* | *Short Grass Steppe* |
|---|---|---|---|---|
| Percentage | 0.1 | 55.77 | 5.36 | 0.34 |
| Site cells | 0 | 8952 | 6 | 34 |
| Expected | 22.78 | 12703.29 | 1220.9 | 77.45 |
| Chi-square | 22.78 | 1107.76 | 1208.93 | 24.38 |
| Survey coverage % | 0 | 1.47 | 1.48 | 5.08 |

| *Vegetation (Continued)* | *Chihuahuan foothill-piedmont* | *Chihuahuan lowland/swale* | *Rock Outcrop* |
|---|---|---|---|
| Percentage | 32.35 | 5.65 | 0.43 |
| Site cells | 7198 | 68 | 6520 |
| Expected | 7368.68 | 1286.96 | 97.95 |
| Chi-square | 3.95 | 1154.55 | 421058.97 |
| Survey coverage % | 0.65 | 2.63 | 13.95 |

Total Chi-square= 22.78+1107.76+1208.93+24.38+3.95+1154.55+421058.97= 424581.32 Significant

Editorial Note: This is one of those scenarios that you hope never happens, but often does when dealing with large regional archaeological databases. We were within hours of sending this draft technical summary out for peer review when we discovered a glitch in the data. The problem came to light as we were checking the Chi-square tables against the text discussions of the trends indicated by this statistical test of association between environmental variables and site locations. Table 9 indicates that, overwhelmingly, sites in the western study area tend to be located in the *vegetation* community "rock outcrop." An examination of Figure 4, the vegetation map, makes it clear that this can't be true; only the very small area of Alamo Mountain is coded "rock outcrop" on that map. We failed to notice this inconsistency initially because on the geomorphology map (Figure 3) "eroded bedrock" is, in fact, the most common *geomorphic* unit in the western study area.

This would not have been a problem, however, except for the unlucky coincidence that by far the largest site in the western study area is located in the "rock outcrop" vegetation community. This multicomponent site, LA 9076, is known by various names, including the Alamo Mountain site, the Alamo Springs stage station, Alamos wells, Cottonwood springs, and the Ojos de los Alamos station. The historical component includes a rock building, corral, cemetery, and cistern associated with the stage station. The Jornada Mogollon component includes lithic, ceramic, and faunal remains, as well as petroglyphs and a mescal pit. Unfortunately, ARMS data do not provide separate sizes for the two components, but it is likely that the very large size of the site, which has badly skewed the data on the association between *prehistoric* sites and vegetation communities, is in fact an attribute of the *historical* period site.

We have no first-hand knowledge of this site. Consequently, all we can do is make arbitrary decisions about the size of the site. For example, we can re-run the models after eliminating 10 percent, 30 percent, and 50 percent of the site pixels. We will re-run all the models before the final report, of course, but need advice as to the actual size of this site from reviewers with regional knowledge.

We don't think the inaccuracy in site size for LA 9076 had a major impact on the models as presented here, particularly the regression model. Indeed a sample regression model vs. full regression model exercise discussed below supports this position. LA 9076 appears to be one of the more complex sites in the region. Even reduced in size, it will, and should, have an impact on the shape of the model in the southern portion of the western study area.

As stated above, such glitches are unfortunately common in databases such as ARMS. Indeed, this is probably not the only such error on Otero Mesa. As long as these problems are not systematic (e.g., the same sized artifact scatters are all recorded as being twice as large in the northern part of the study area as they are in the southern part of the study area), predictive models should be able to compensate for the problems. Regional trends in site location should not be affected, though, as we have stated before, pinpoint accuracy is not to be expected from predictive models.

## 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 either 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 and geography. 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 overstating 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, we calculated the pair-wise Spearman's $r$ between each pair of environmental variables for each study area (Tables 10 and 11). 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 from model development. Table 12 lists the variables that were kept for modeling for each study area.

**Table 10. Pair-wise Spearman's *r* scores for eastern study area environmental variables**

| | Elev. | Geomor-phology | Veg | Slope | Aspect | Dist from streams | Cost dist from streams | Dist from ridges | Cost ridges | Dist strm int |
|---|---|---|---|---|---|---|---|---|---|---|
| **Elevation** | 1 | | | | | | | | | |
| **Geomorphology** | -0.63 | 1 | | | | | | | | |
| **Vegetation** | -0.06 | 0.21 | 1 | | | | | | | |
| **Slope** | 0.4 | -0.59 | -0.01 | 1 | | | | | | |
| **Aspect** | -0.96 | -0.02 | 0 | 0.02 | 1 | | | | | |
| **Distance from streams** | 0.24 | -0.33 | -0.05 | 0.2 | -0.03 | 1 | | | | |
| **Cost distance from streams** | **0.69** | -0.54 | 0.02 | **0.71** | 0.03 | 0.45 | 1 | | | |
| **Distance to ridges** | -0.3 | 0.22 | 0.22 | -0.24 | 0 | -0.09 | -0.23 | 1 | | |
| **Cost distance from ridges** | **0.54** | -0.5 | 0.02 | **0.75** | 0.03 | 0.08 | 0.5 | -0.09 | 1 | |
| **Dist from stream int** | 0.22 | -0.25 | -0.04 | 0.17 | 0.04 | 0.44 | 0.28 | -0.07 | 0.14 | 1 |

**Table 11. Pair-wise Spearman's *r* scores for western study area environmental variables**

| | Elev. | Geomor-phology | Veg | Slope | Aspect | Dist from streams | Cost dist from streams | Dist from ridges | Cost ridges | Dist strm int |
|---|---|---|---|---|---|---|---|---|---|---|
| **Elevation** | 1 | | | | | | | | | |
| **Geomorphology** | -0.02 | 1 | | | | | | | | |
| **Vegetation** | 0.01 | -0.05 | 1 | | | | | | | |
| **Slope** | **0.79** | -0.11 | 0.06 | 1 | | | | | | |
| **Aspect** | -0.99 | 0.01 | 0.01 | -0.75 | 1 | | | | | |
| **Distance from streams** | -0.01 | 0.09 | -0.02 | 0.03 | 0 | 1 | | | | |
| **Cost distance from streams** | 0.16 | -0.15 | 0.09 | **0.59** | -0.12 | 0.21 | 1 | | | |
| **Distance from ridges** | 0.02 | 0.09 | 0.06 | 0 | -0.02 | 0.01 | -0.05 | 1 | | |
| **Cost distance from ridges** | 0.17 | -0.11 | 0.22 | 0.49 | -0.13 | 0 | **0.5** | 0.29 | 1 | |
| **Dist from stream int** | -0.01 | 0.09 | -0.02 | 0.11 | 0 | **0.62** | 0.25 | -0.03 | 0.11 | 1 |

**Table 12. Environmental variables used for modeling the study areas**

| 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 over distance from stream intersections because the distance from streams layer is more likely to have affected human behavior.

## Sensitivity Maps

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 the Loco Hills technical summary (Altschul et al. 2003) for a description of the weighted method and logistic regression; a synopsis of the Boolean intersection method is provided in the Azotea Mesa technical summary (Altschul et al. 2004).

***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 historic springs. For continuous variables we need to define a break point, or cut-off range, for each variable that distinguishes cells likely to contain sites (e.g., sites located between 1103 and 1360 m above sea level) from those that probably do not (e.g., above 1360 or below 1103 m above sea level). In Boolean models, it is preferable to be generous with categorical states and cut-off ranges because the intersecting properties of the method have a tendency to greatly reduce the favorable zone. For each variable, we chose states and cut-off ranges so that a large percentage (90-100 percent) of the known site cells were included in the favorable category (Tables 13 and 14).

**Table 13. Boolean model variables for the eastern study area**

| Environmental Variable (favored categorical states) | Cut-off 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 | N/A | 26 | 3 |
| Historic Spring | N/A | 0.2 | 0.0003 |
| Eroded Bedrock | N/A | 48 | 75 |
| Pleistocene alluvial deposits at mouth of Sacramento River | N/A | 13 | 12 |
| Valley Fill Alluvium | N/A | 13 | 4 |
| **Vegetation** | | | |
| Rock outcrop | N/A | 29 | 0.43 |
| Chihuahuan foothill-piedmont | N/A | 32 | 32 |
| Chihuahuan Desert Scrub | N/A | 39 | 56 |
| **Aspect** | N/A | 17 | 15 |
| North | 315-361; 0-45$^0$ | 11 | 24 |
| South | 135-225$^0$ | 31 | 30 |
| West | 225-315$^0$ | 52 | 15 |
| **Slope** | 0-27$^0$ | 95 | 99 |
| **Distance from streams** | 0-600m | 100 | 97 |
| **Distance from ridges** | 0-425m | 95 | 77 |
| **Distance from stream intersections** | 0-1308m | 95 | 96 |

**Table 14. Boolean model variables for the western study area**

| Environmental Variable (favored categorical states) | Cut-off range for continuous variables | % of site cells contained in favored state/range | % of study unit contained in favored state/range |
|---|---|---|---|
| **Geomorphology** | | | |
| Eroded bedrock | N/A | 68 | 32 |
| Sand sheet | N/A | 18 | 6 |
| Alluvial Fans | N/A | 10 | 22 |
| **Vegetation** | | | |
| Chihuahuan lowland/swale | N/A | 85 | 34 |
| Chihuahuan Desert Scrub | N/A | 14 | 57 |
| **Aspect** | N/A | 17 | 15 |
| East | 45-135$^0$ | 26 | 21 |
| South | 135-225$^0$ | 55 | 35 |
| West | 225-315$^0$ | 12 | 30 |
| **Slope** | 0-27$^0$ | 100 | 95 |
| **Distance from streams** | 0-910m | 100 | 97 |
| **Distance from ridges** | 0-751m | 95 | 96 |
| **Cost Distance from Ridges** | 0-1484 | 100 | 99 |

The Boolean model for the eastern study area is presented in Figure 9 and the model for the western study area in Figure 10. 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. 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 technical summary.

Each Boolean model was tested using the Gain Statistic. This statistic was discussed in the Azotea Mesa technical summary (Altschul et al. 2004); for more detail, the reader is referred to the original source (Kvamme 1988).

The Gain Statistic is calculated as,

East 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 strong model. To measure exactly how strong, we calculated the model's performance relative to a random predictor by applying the equation,

East Gain over random = Proportion of site cells correctly located- proportion of model
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 percent better than if we randomly pick areas.

West Gain Statistic = 1- (proportion of model area / proportion of sites correctly located)
West Gain= 1-(0.56/0.87) = 0.36

A gain score of 0.36 indicates a decent model. To measure exactly how strong, we calculated the model's performance relative to a random predictor by applying the equation,

West Gain over random = Proportion of site cells correctly located- proportion of model
Gain over random = 0.87-0.56= 0.31

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

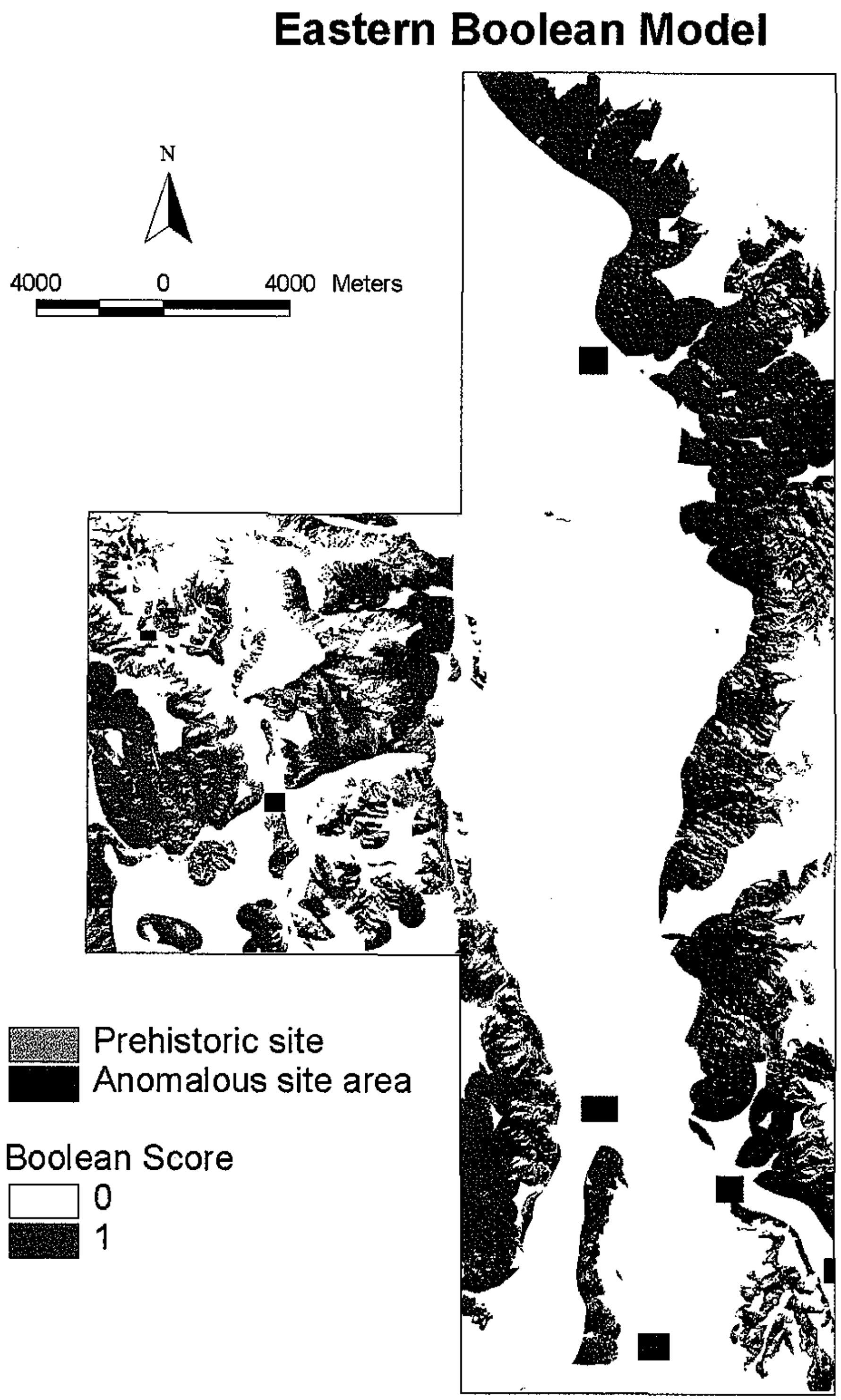



**Figure 9. Eastern study area Boolean model: Red (1) = site likely, white (0) = site unlikely, blue (squares) = sites missed, green (polygons) = sites**

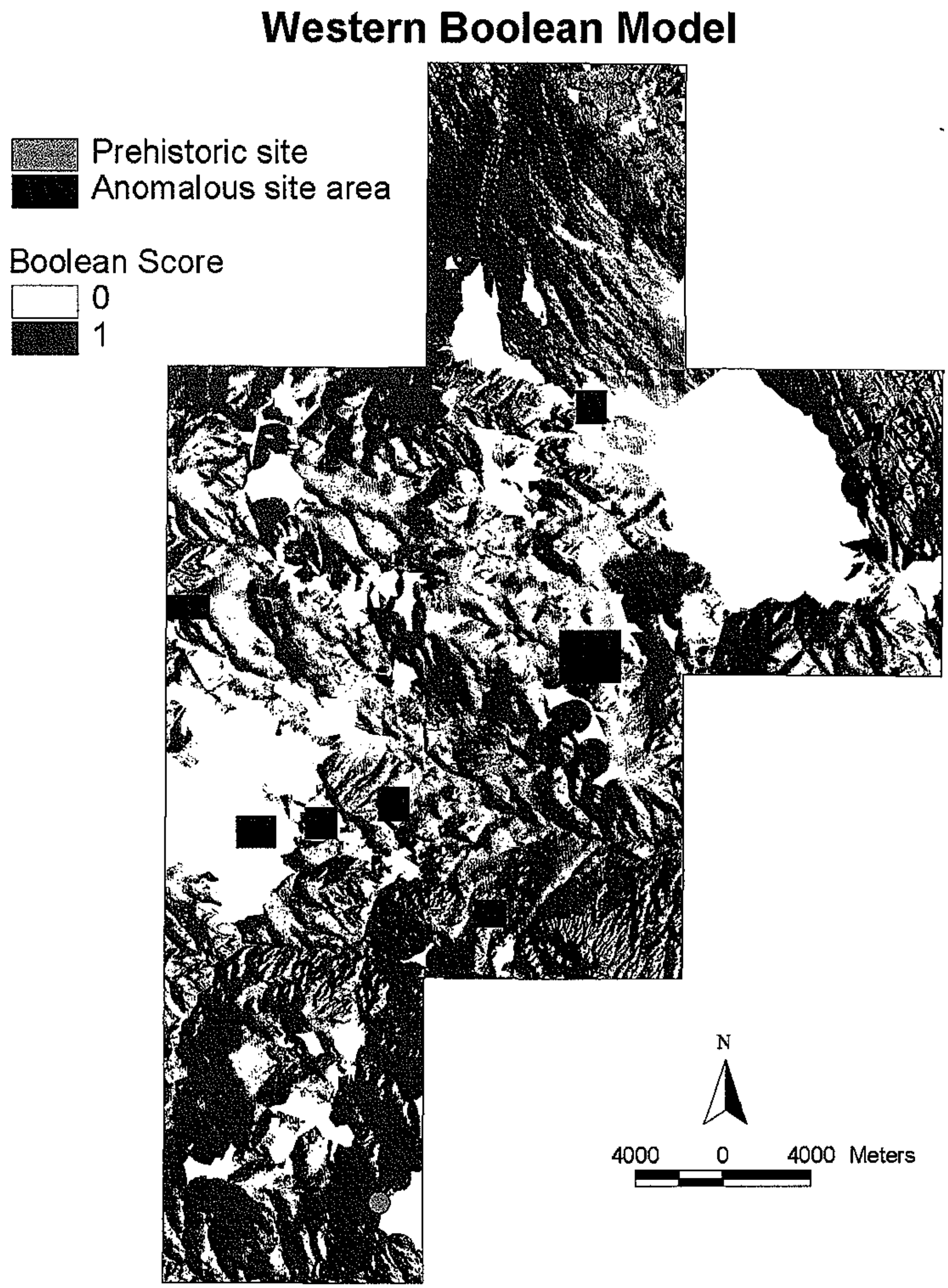



**Figure 10. Western study area Boolean model: Red (1) = site likely, white (0) = site unlikely, blue (squares) = sites missed, green (polygons) = sites**

The Boolean model for the western study area portrays an environment generally favorable to site location, with three "holes" marking unfavorable locations. Comparisons with Figures 3 and 4 above help to explain much of this pattern. The large "hole" in the eastern part of the study area 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 site indicated in figure 10 are from the 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 area.

The third "hole" is Alamo Mountain, located in the southeast corner of the study area. This is the location of the very large multicomponent historical stage station/Jornada Mogollon site situated in the 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 the other two models are. 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 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 area, 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 area. This area, like both the zone of deciduous desert scrub and Alamo Mountain in the western study area, is a unique environment relative to the rest of the study area. This Alkali Lakes area of sand sheet deposits and playas appears, based on the very limited survey, to actually have been a relatively attractive zone for indigenous peoples – as the cluster of "anomalous" sites affirms. The fact that this environmental zone is massed in one location and does not occur elsewhere in the study area seems to predispose the Boolean model to classify it as unfavorable; the weighted and regression models do not classify this area as unfavorable. This would, in part, account for the poor predictive power of the eastern Boolean model as reflected in the Gain score.

***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 by virtue 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 to 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 –215 to 301 for the eastern study area and -132 to 151 for the western study area. Negative weights indicate that humans tended to avoid these environment features in establishing sites, whereas positive weights suggest just the opposite.

Tables 15 and 16 list the environmental variables for each study area, the cut-off 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 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 17 and 18 present the results in relation to the area and the proportion of site cells associated with various score ranges. The final step was to reclassify the scores into four states that best represent site sensitivity. In this case, the four sensitivity states were coded as poor (1), average (2), good (3), and excellent (4).

Figures 11 and 12 present the weighted models with sites overlain in black. In the eastern study area, 10 sites fell in average or poor areas, while 40 sites fell in average or poor areas in the western study area; 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 problematic for the models.

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.

**Table 15. Weighted model variables for the eastern study area**

| Environmental Variable | Cut-off range for continuous variables | Proportion of site cells contained in state/range | Proportion of study area contained in state/range | Weighted score |
|---|---|---|---|---|
| **Vegetation** | N/A | | | |
| Rky.Mtn/Great Basin open conifer | N/A | 0 | 0.01 | 0 |
| Chihuahuan Desert Scrub | N/A | 13.97 | 57.3 | -43 |
| Chihuahuan Foothill-Piedmont grassland | N/A | 0.7 | 9.49 | -9 |
| Chihuahuan Lowland/Swale desert grassland | N/A | 85.37 | 33.67 | 52 |
| **Geomorphology** | N/A | 0 | 0.6 | -1 |
| Eroded Bedrock Surface | N/A | 68.03 | 32.23 | 36 |
| Sand sheet | N/A | 17.98 | 6.47 | 12 |
| Valley Fill Alluvium | N/A | 0.88 | 3.88 | -3 |
| Alluvial Fans | N/A | 10.24 | 22.2 | -12 |
| Playa Deposits | N/A | 0 | 1.44 | -1 |
| Colluvial Deposits<1m | N/A | 0 | 0.05 | 0 |
| Colluvial Deposits>1m | N/A | 0 | 33.59 | -34 |
| **Aspect** | N/A | 0 | 0.1 | 0 |
| North | 315-360$^0$;0 -45$^0$ | 6.57 | 11.86 | -5 |
| East | 45-135$^0$ | 26.22 | 21.26 | 5 |
| South | 135-225$^0$ | 55.07 | 34.58 | 20 |
| West | 225-315$^0$ | 11.34 | 30 | -19 |
| **Elevation** | <1104m | 0 | 2.30 | -2 |
| | 1104-1112m | 19.4 | 7.44 | 12 |
| | 1112-1270m | 12.13 | 70.02 | -58 |
| | 1270-1359m | 68.47 | 12.96 | 56 |
| | >1359m | 0 | 7.28 | -7 |
| | 0-5$^0$ | 86.1 | 75.57 | 11 |
| **Slope** | 5-15$^0$ | 12.67 | 10.57 | 2 |
| | 15-27$^0$ | 1.23 | 9.15 | -8 |
| | >27$^0$ | 0 | 4.71 | -5 |
| **Distance from Streams** | 0-70m | 5.12 | 24.17 | -19 |
| | 70-300m | 24.42 | 50.26 | -26 |
| | 300-600m | 70.46 | 22.19 | 48 |
| | >600m | 0 | 3.38 | -3 |
| **Distance from Stream Intersections** | <150m | 0 | 6.59 | -7 |
| | 150-335m | 2.84 | 18.93 | -16 |
| | 335-805m | 27.33 | 48.05 | -21 |
| | 805-1385m | 69.83 | 23.34 | 46 |
| | >1385m | 0 | 3.09 | -3 |
| **Distance from Ridges** | 0-170m | 80.22 | 48.47 | 32 |
| | 170-420m | 14.53 | 27.92 | -13 |
| | 420-1415m | 5.24 | 20.88 | -16 |
| | >1415 | 0 | 2.73 | -3 |

## Table 16. Weighted model variables for the western study area

| Environmental Variable | Cut-off range for continuous variables | Proportion of site cells contained in state/range | Proportion of study area contained in state/range | Weighted score |
|---|---|---|---|---|
| **Vegetation** | N/A | | | |
| Broadleaf Interior Chaparral | N/A | 0 | 0.1 | 0 |
| Chihuahuan Desert Scrub | N/A | 39.3 | 55.77 | -17 |
| Chihuahuan Broadleaf Deciduous Desert Scrub | N/A | 0.03 | 5.36 | -5 |
| Short Grass Steppe | N/A | 0.15 | 0.34 | 0 |
| Chihuahuan Foothill-Piedmont Desert Grassland | | 31.6 | 32.35 | -1 |
| Chihuahuan Lowland/Swale Desert Grassland | N/A | 0.3 | 5.65 | -5 |
| Rock Outcrop | N/A | 28.63 | 0.43 | 28 |
| **Geomorphology** | N/A | | | |
| Eroded Bedrock Surface | N/A | 48.12 | 75.42 | -27 |
| Valley Fill Alluvium | N/A | 12.83 | 4.4 | 8 |
| Alluvial Fans | N/A | 26.14 | 2.52 | 24 |
| Playa Deposits | N/A | 0 | 0.11 | 0 |
| Colluvial Deposits<1m | N/A | 0 | 0.02 | 0 |
| Colluvial Deposits>1m | N/A | 0 | 5.97 | -6 |
| Historic Spring | N/A | 37 | 0.003 | 37 |
| Pleistocene Alluvial Fan of Sacramento River | N/A | 12.75 | 11.56 | 1 |
| **Aspect** | N/A | | | |
| North | $315\text{-}360^0$;$0\text{-}45^0$ | 11.33 | 23.77 | -12 |
| East | $45\text{-}135^0$ | 6.38 | 30.83 | -24 |
| South | $135\text{-}225^0$ | 30.68 | 30.31 | 0 |
| West | $225\text{-}315^0$ | 51.62 | 14.79 | 37 |
| **Slope** | $0\text{-}6^0$ | 62.29 | 91.36 | -29 |
| | $6\text{-}29^0$ | 33.81 | 7.9 | 26 |
| | $>29^0$ | 3.91 | 0.74 | 3 |
| **Distance from Streams** | 0-400m | 80.65 | 76.66 | 4 |
| | 400-600m | 15.48 | 14.46 | 1 |
| | >600m | 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** | 0-75m | 23.99 | 23.97 | 0 |
| | 75-150m | 16.55 | 20.15 | -4 |
| | 150-1130m | 59.46 | 54.04 | 5 |
| | >1130 | 0 | 1.11 | -1 |

Table 17. Weighted model scores and reclassification for eastern study area

| Model Score | Proportion of Study Area | Proportion 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 |
| -25-25 | 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 18. Weighted model scores and reclassification for western study area

| Model Score | Proportion of Study Area | Proportion 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 |
| -32-7 | 3.22 | 12.73 | 3 |
| -7-18 | 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 |

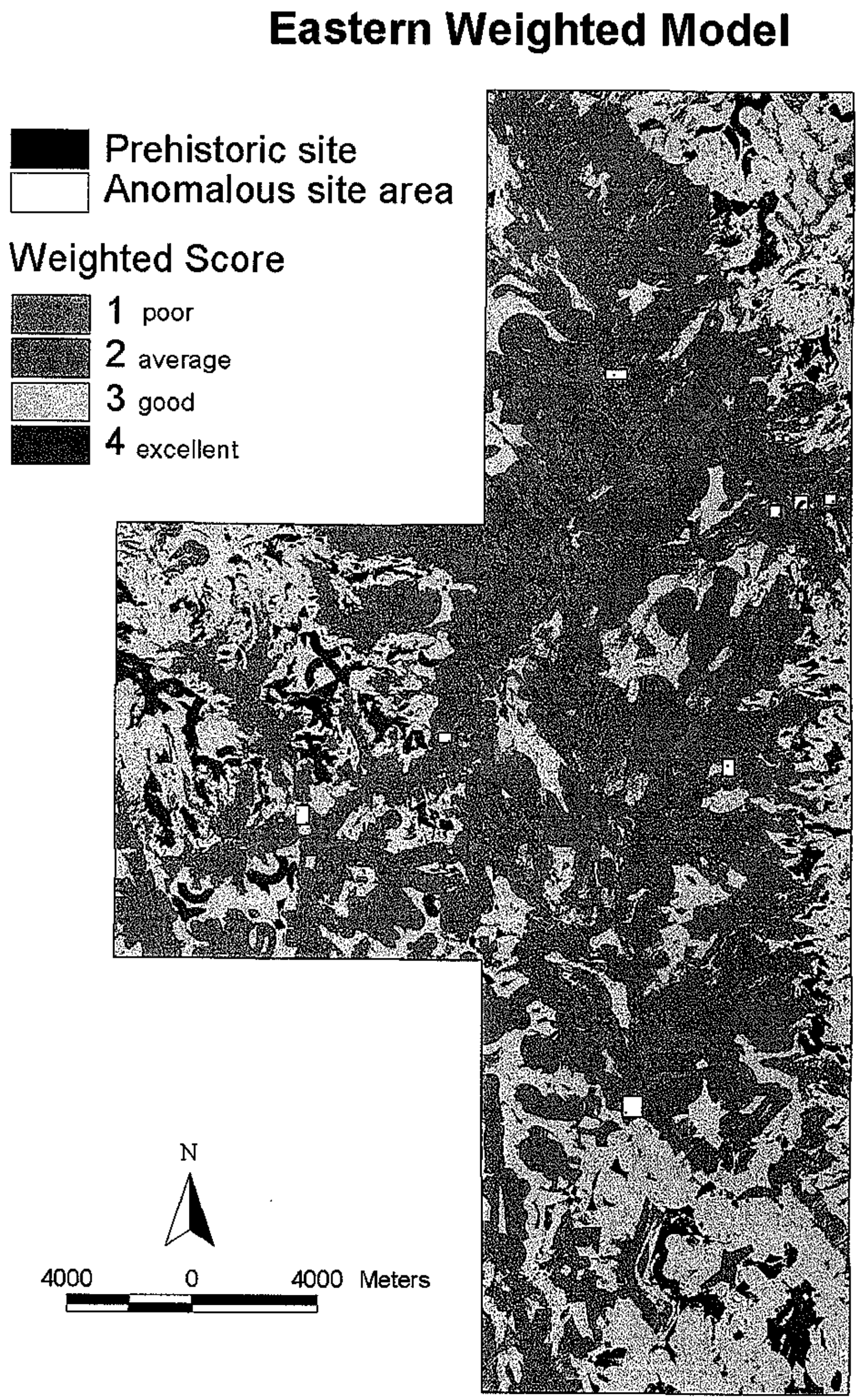



**Figure 11. Eastern study area weighted model**

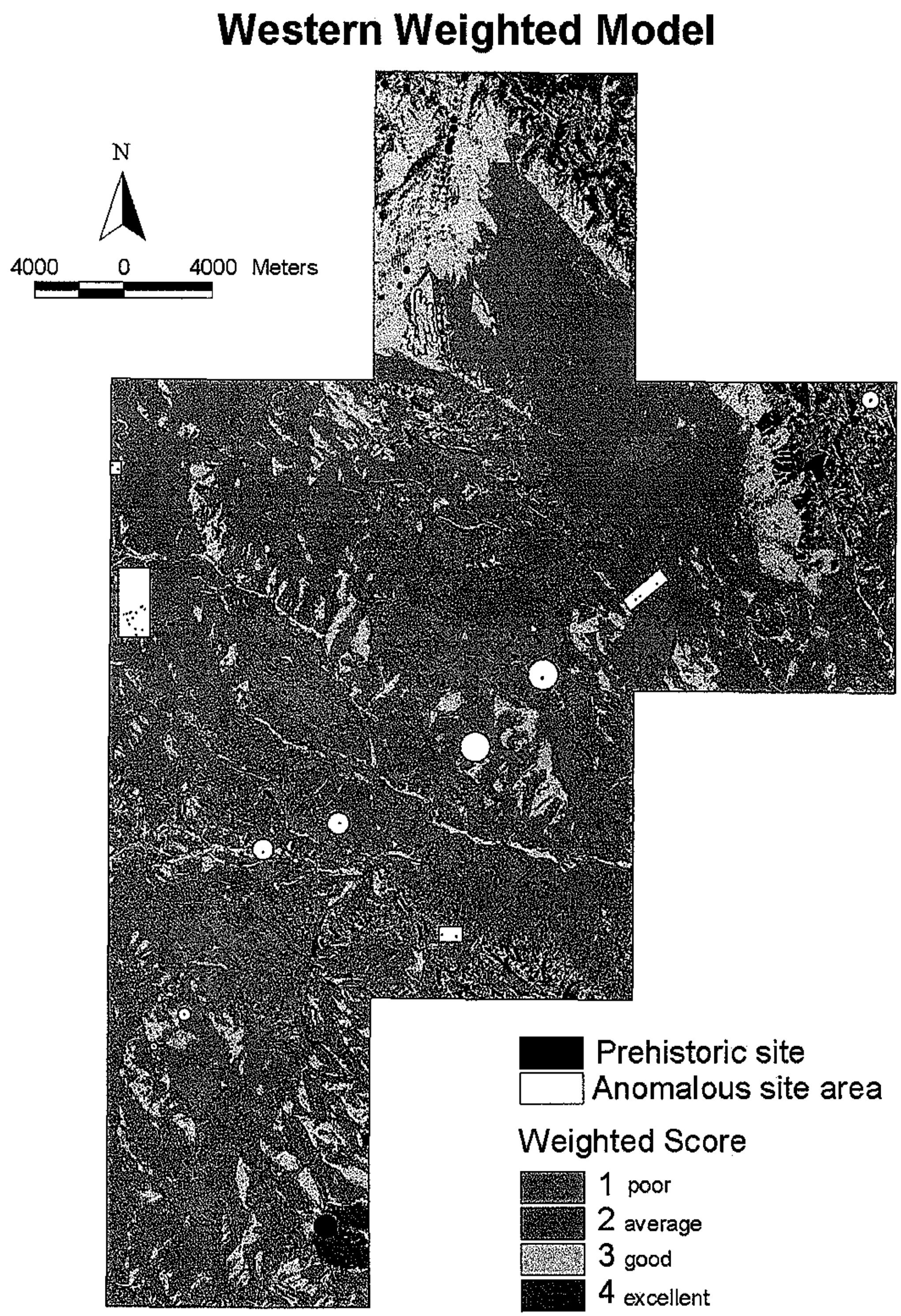



**Figure 12. Western study area weighted model**

Gain Statistic Eastern Section = 1- (proportion of model area / proportion of sites correctly located)
Gain= 1-(0.43/0.88) = 0.51

Gain over random = Proportion of sites correctly located- proportion of model
Gain over random = 0.88-0.43= 0.45

The weighted model allows one to predict archaeological site locations with about a 45 percent better chance of being correct than if one guesses randomly.

Gain Statistic Western Section = 1- (proportion of model area / proportion of sites correctly located)
Gain= 1-(0.25/0.87) = 0.71

Gain over random = Proportion of sites correctly located- proportion of model
Gain over random = 0.87-0.25= 0.62

The weighted model allows one to predict archaeological site locations with about a 62 percent better chance of being correct than if one guesses 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.

One of the noticeable features of the western study area 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 area and near the corner where the northern block and the northwestern block 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 area or both.

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 3 shows, all of the northern block except for the dissected uplands in the northeast corner is mapped as alluvium. A comparison with Figure 4 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 provide more usable resources and easier travel and camping terrain than the desert scrub. It is also important to note, however, that there has been no archaeological survey in the desert scrub portion of the alluvium, while 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 map 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. We don't expect major changes in the rest of the sensitivity map for the western study area when the model is rerun to correct this problem, but we are hopeful that a somewhat smaller proportion of sites will be classified as being in unfavorable settings once the correction is made.

Like the eastern Boolean model, the weighted model for the eastern study area 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 area 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 areas. For this reason, we think it likely that the good to excellent scores in the weighted models reflect an actual preference among indigenous populations in the area for siting 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 areas – the lower slopes of the Guadalupe and Brokeoff Mountains in the eastern study area and the dissected zone north of the Cornudas Mountains in the western area – we cannot yet determine whether these uplands were actually 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 Altschul et al. [2003]). 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. Irregular-shaped rasters can not be incorporated directly into many of IDRISI's raster manipulation algorithms. For the logistic regression function, the algorithm creates a rectangle that encompasses not only the study area, but 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 19 and 20 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 19 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 areas 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 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 14.

**Table 19. Computed coefficients for variables used in the logistic regression model for the eastern study area**

| Variable | Coefficient |
|---|---|
| Eroded Bedrock | 2.14642 |
| Colluvium >1m thick | -1.80939 |
| Alluvial Fans | 0.05042 |
| Sand Sheet | 2.934188 |
| Chihuahuan Foothill-Piedmont | -5.7748496 |
| Chihuahuan Lowland/Swale | 4.5608234 |
| South Aspect | 0.68843053 |
| West Aspect | 0.253798944 |
| Elevation | 0.01430186 |
| Slope | -0.14297992 |
| Distance from Streams | -0.00115654 |
| Distance from Streams Intersections | 0.00185916 |
| Distance from Ridges | -0.00234531 |

**Table 20. Computed coefficients for variables used in the logistic regression model for the western study area**

| Variable | Coefficient |
|---|---|
| Eroded Bedrock | -1.86807250 |
| Alluvial Fans | 1.24345371 |
| Colluvial Deposits>1m | -16.96504835 |
| Chihuahuan Broadleaf Deciduous | -16.51966538 |
| Rock Outcrop | 6.25818135 |
| Chihuahuan Lowland/Swale | -3.18205604 |
| West Aspect | 1.3662265 |
| East Aspect | -0.68437538 |
| Slope | 0.00957143 |
| Distance from Streams | -0.00161888 |
| Cost Distance from Ridges | 0.00129103 |
| Distance from Ridges | -0.00362474 |

Tables 21 and 22 present the reclassification values for each section. The results have been collapsed into 10 probability classes, with details presented on the size of the area captured by each probability class and the proportions of sites found in each class. The probability classes were then reclassified into four groups – poor (1), average (2), good (3), and excellent (4) – in terms of their site sensitivity.

**Table 21. Logistic regression probability scores and reclassification values for the eastern study area**

| Probability | Proportion of Study Area | Proportion 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 22. Logistic regression probability scores and reclassification values for the western study area**

| Probability | Proportion of Study Area | Proportion 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 |

Figures 13 and 14 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 to 10 in the weighted model. The sites that are found in anomalous settings are almost identical between the 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 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 percent in the weighted models to 34 percent in the logistic regression model. These shifts are reflected in the relatively low Gain and Gain-over-random scores.

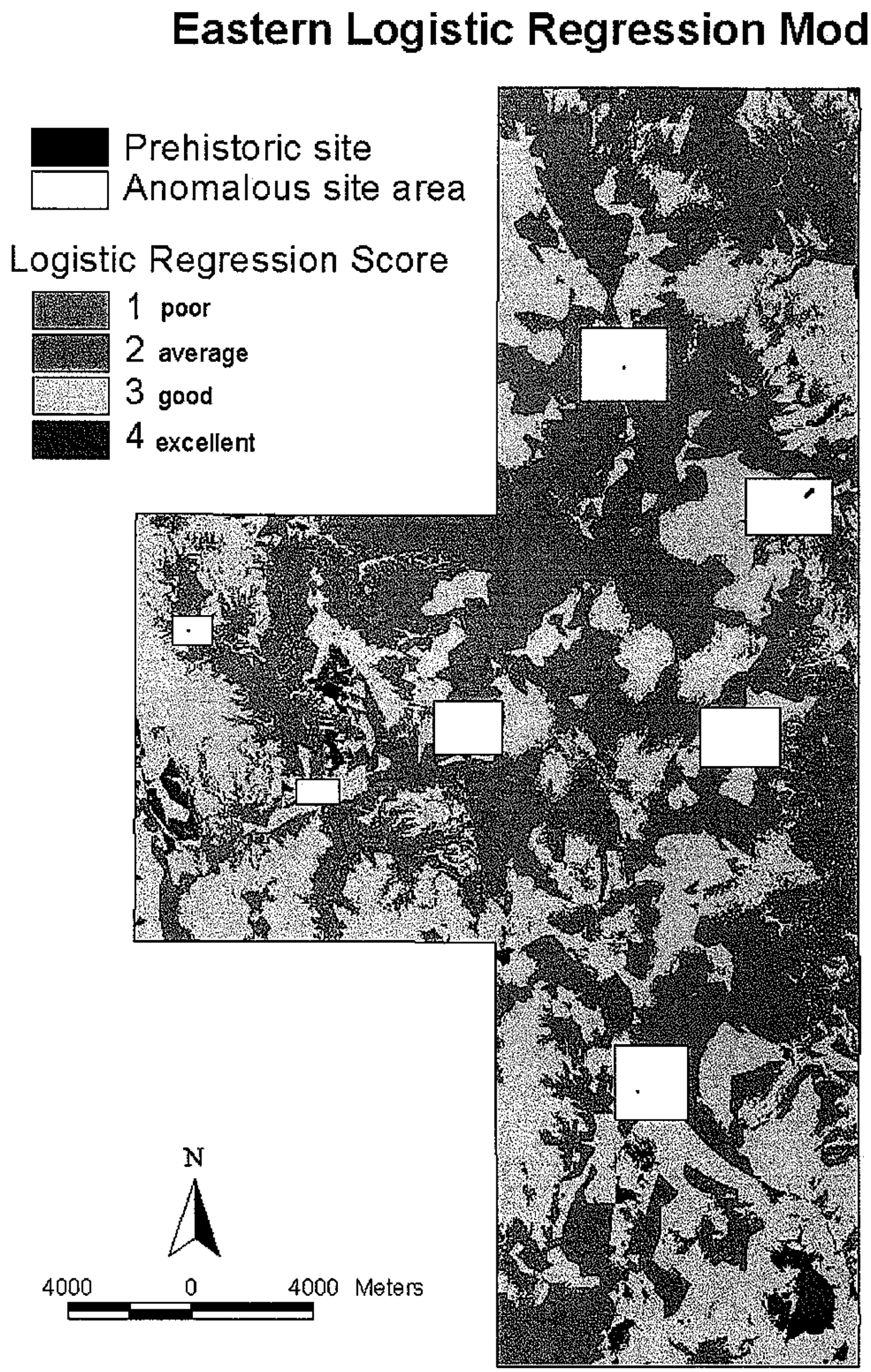



**Figure 13. Logistic regression model for eastern study unit**

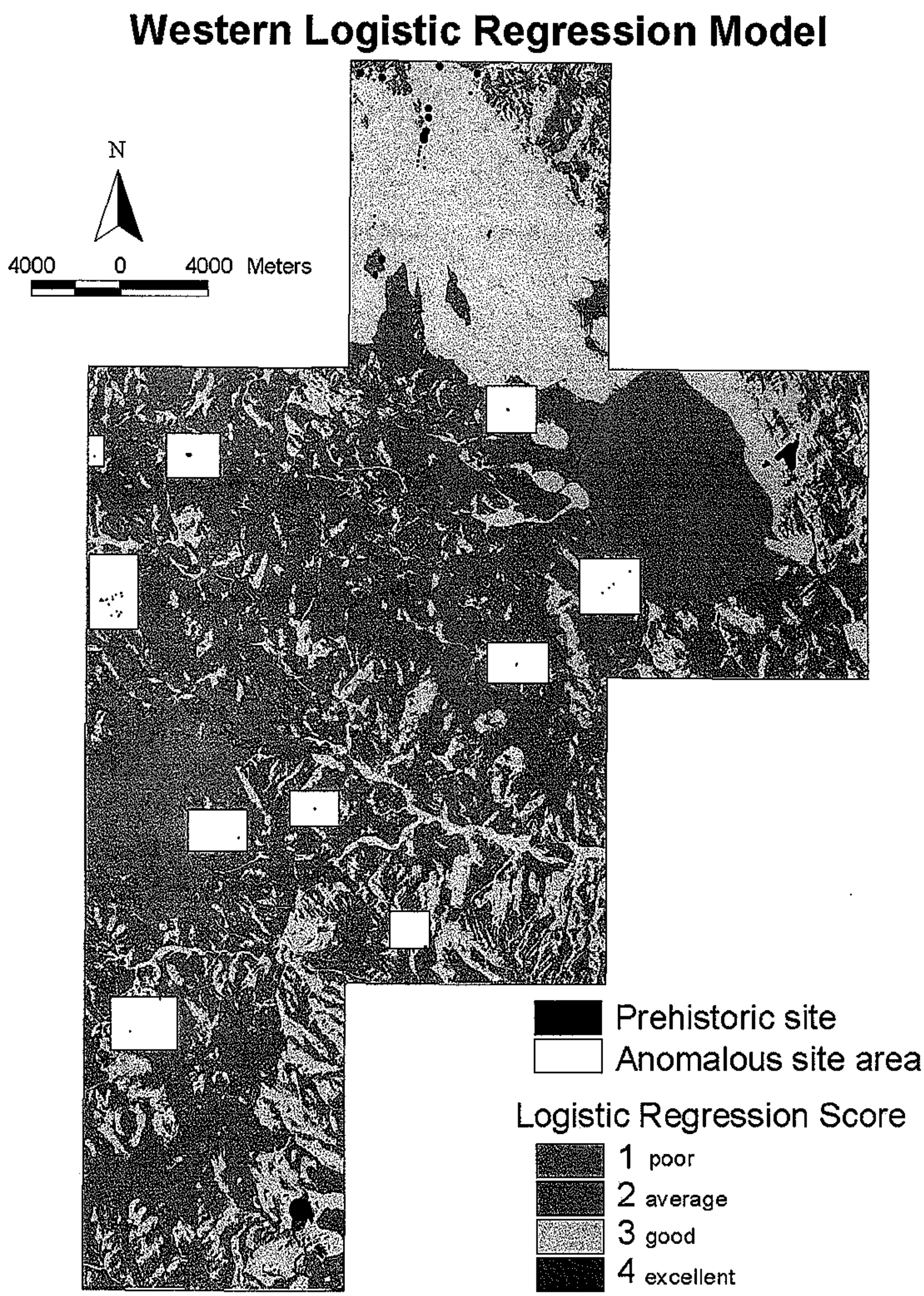



**Figure 14. Logistic regression model for western study unit**

Eastern Gain = 1- (Proportion of model area / Proportion of correctly identified sites)
Gain = 1-(44.88/91.58) = 0.51

Gain over random = Proportion of correctly identified sites – Proportion of model
Gain over random = 91.58-44.88 = 46.7

Western Gain
Gain = 1-(34/90.26)= 0.62
Gain over random = 90.26-34= 56.26

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

Examination of Figures 13 and 14 gives rise to several interesting observations. First, the two large "holes" of unfavorable environmental settings noted in the Boolean model re-appear in the logistic regression model for the western study area. These are associated with a large area of colluvium in the eastern block of the study area 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 multi-component site at Alamo Mountain is apparent in the high probability classification of the area in the southeastern corner of the southern block of the western study area. Decreasing the size of this site may reduce the sensitivity of the area, though it is appears doubtful that such changes will reverberate throughout the rest of the study area.

Third, the regression model classifies the entire expanse of alluvial deposits in the northern block of the western study area as good, while the weighted model classified only the grasslands portion of the alluvium favorably. A comparison of the vegetation map (Figure 4) 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 areas, as good to excellent. But the regression models do not generalize this favorable classification to all dissected uplands as the weighted models do. This is especially noticeable along the eastern edge of the eastern study area. Although Figure 14 makes it appear that the portion of the Sacramento uplands in the western study area is not as favorable to site location as the portion in the eastern study area, this is most likely a function of different cutoff points having been used for the reclassification of the probability scores for the two study areas (see Tables 22 and 23). When the maps are redone for the final report, the reclassifications will be adjusted to make the results more comparable between study areas.

The fifth observation is that the eastern regression model, like the eastern weighted model, classifies the Alkali Lakes area at the southern end of the study area as a good to excellent area for encountering the remains of the human activities. The two most robust patterns produced by the Otero Mesa models, and thus the ones most like 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 later in this technical summary.

# RESULTS AND DISCUSSION

## Interpreting the Results

The performance of the predictive models is compared in Table 23. The weighted model for the western section scores the highest on the Gain Statistic score 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 percent of the site cells, a gain of about five percentage points on the other models.

**Table 23. 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 | 0.5 |
| 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 |

Sites that have been located in "poor" or "average" areas have been noted in the discussions of the model outcomes above; those sites located in poor or average areas that are common to at least two models are shown in Table 24. Altschul (1990) has argued that sites in anomalous settings often provide insight into prehistoric settlement and the inner workings of predictive models. General information about these sites, termed "red flags," provided by ARMS is listed in the table.

**Table 24. "Red flag" sites**

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

The environmental and size characteristics of the red flag, or incorrectly predicted sites, and the correctly predicted sites are compared in Table 25.

**Table 25. Comparison of red flags and correctly predicted sites**

| Variable | 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 |
| Standard Deviation | 2.5 | 1 | 19 | 39 |
| **Elevation m** (range) | 1110-1274 | 1340-1556 | 1104-1358 | 1333-1877 |
| Mean | 1197 | 1469 | 1297 | 1553 |
| Standard Deviation | 421 | 76 | 101 | 138 |
| **Distance from streams m** (range) | 30-381 | 10-612 | 0-594 | 0-910 |
| Mean | 98 | 264 | 379 | 224 |
| Standard Deviation | 52 | 242 | 112 | 185 |
| **Slope degrees** (range) | 0-10 | 0-4 | 0-27 | 0-57 |
| Mean | 2 | 2 | 3 | 7 |
| Standard Deviation | 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>1m (13%) | Valley Fill Alluvium (9%) | Sand sheet (21%) | Alluvial Fans (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 available archaeological data. 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 24, 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 only poor predictors of places where people went to gather specific plants or hunt particular animals.

The models may be much better, however, at portraying the regional settlement structure. In the modeling results we have patterns that indicate the indigenous occupants of the great 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 area, the sand sheet and playa environment of Alkali Lakes in the southern block of the eastern study area, and the southernmost end of the Sacramento Mountain uplift, which forms wedge of dissected upland between and extending into the edges of the two study areas.

The alluvium in the northern block of the western study area 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 in many periods in the past.

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 modeling to verify this pattern and 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 3 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, possibly, 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 8 that the most extensively surveyed area covered by the models is the southern three blocks of the western study area. Yet a quick comparison with Figure 7 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 draining 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 promise for some interesting 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 26). 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

**Table 26. Site classes for the western study unit, Otero Mesa**

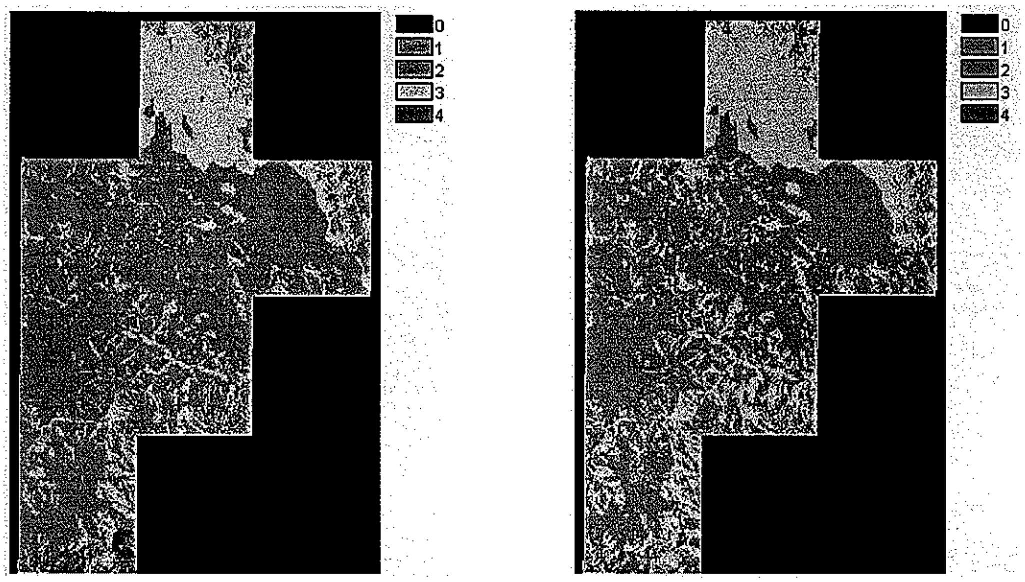
| Site Size | # of sites | Mean # of cells | # Random points generated/site |
|---|---|---|---|
| 199.5-27437.5 | 63 | 4 | 1 |
| 27437.5-71454 | 13 | 67 | 7 |
| 71454-781064 | 2 | 799 | 80 |

extension, a random selection of cells was selected 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 as a new logistic regression model was generated using this data set. The results of the "sample" logistic regression model are compared with the "full" model in Table 27 and in Figure 15.

**Table 27. 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>1m | -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 Aspect | 1.3662265 | 0.97048214 |
| East 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 |

The largest differences occur in the nominal data, particularly in the thick colluvial deposits and the Chihuahuan broadleaf deciduous layers. 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 Mountain is also apparent in the differences between these maps. In most other ways, however, the two models are quite similar and show the exact 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 site size is an overriding influence in the models, but it is not masking settlement trends.




**Sample** **Full**

**Figure 15. Comparison of the sample and full logistic regression favorability maps**

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 area were developed independently. Different environmental variables dominate the models in the two study areas. Even so, the complex calculus that past humans used to place themselves on the landscape, a calculus that so far eludes us, appears to have subsumed regional environmental differences into a larger perception of settlement and land use.

## Modeling and Management

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

## Inventory Reconstruction

Unlike Loco Hills and Azotea Mesa, 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 previous technical summaries. 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 in the Otero Mesa study areas. 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 percent 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 consistently fall 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 areas 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" for which the polygons consist 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 16 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.

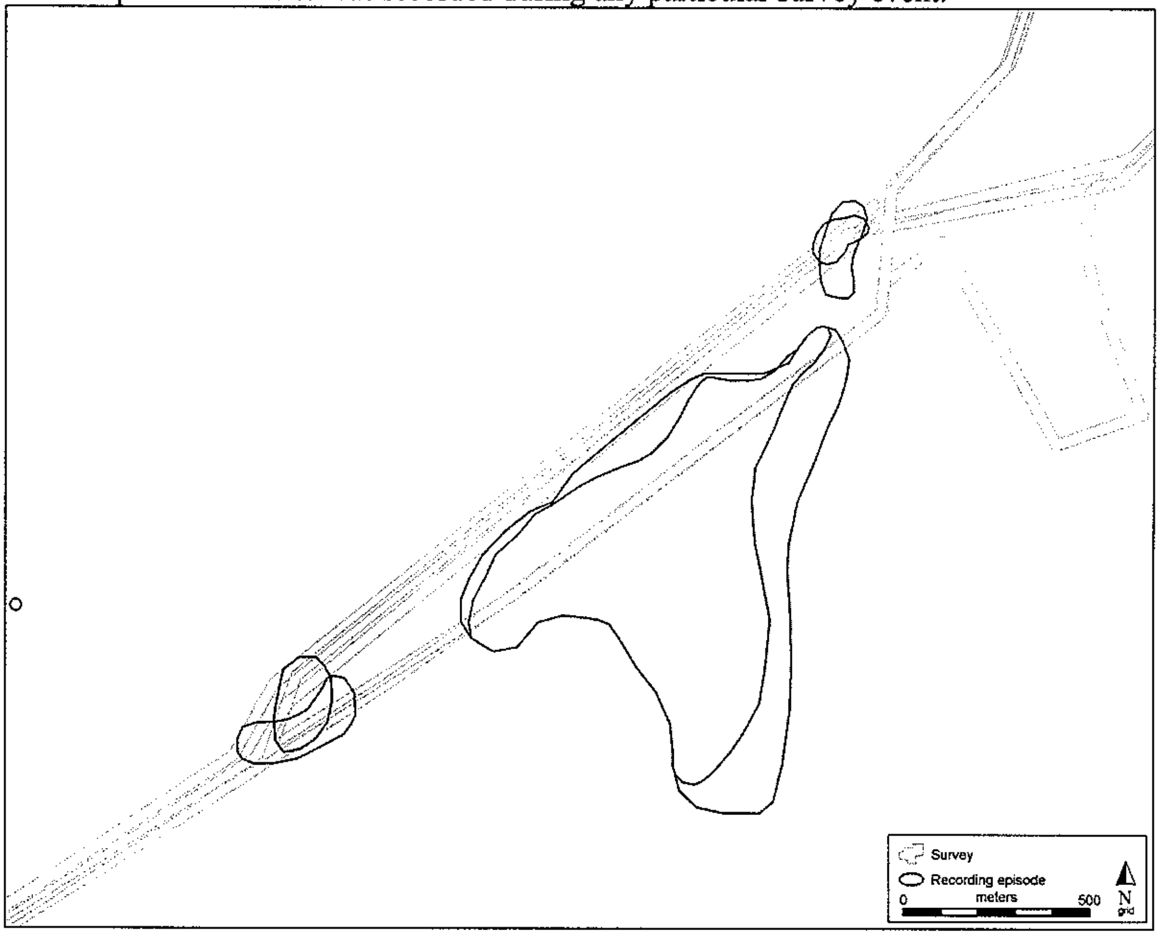



**Figure 16. Examples of survey and recording episodes**

To compensate for these problems, we aggregated the data by year. All surveys and site recording episodes were assigned to the year in which field activity concluded, as reflected in the ARMS data. Figure 17 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 18 shows a time sequence of cumulative survey, aggregated by year, within the whole study area.

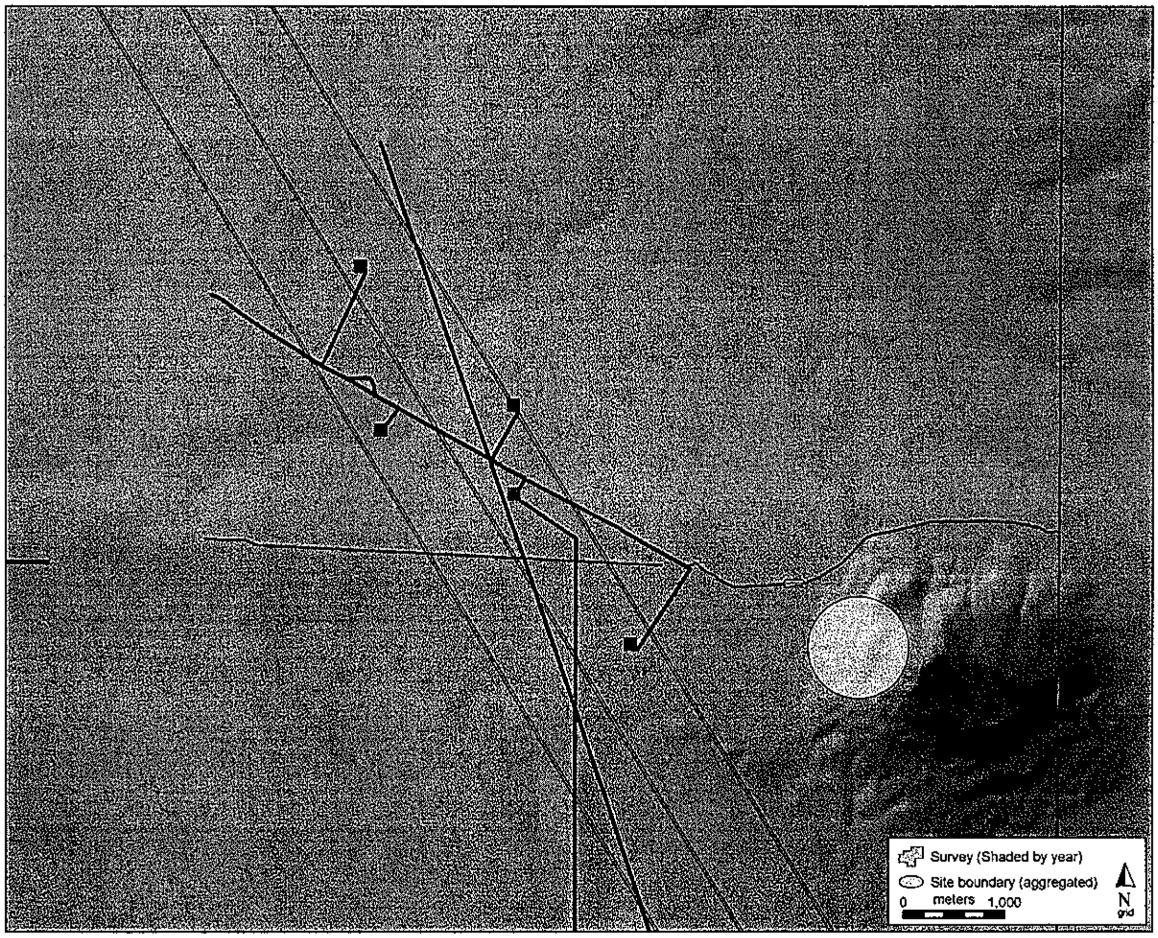



**Figure 17. Example of survey coverage aggregated by year**

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 percent of the study areas has been inventoried, and the percentage of resurvey included in the inventory figure is only approximately 2.3 percent. 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 prior studies.

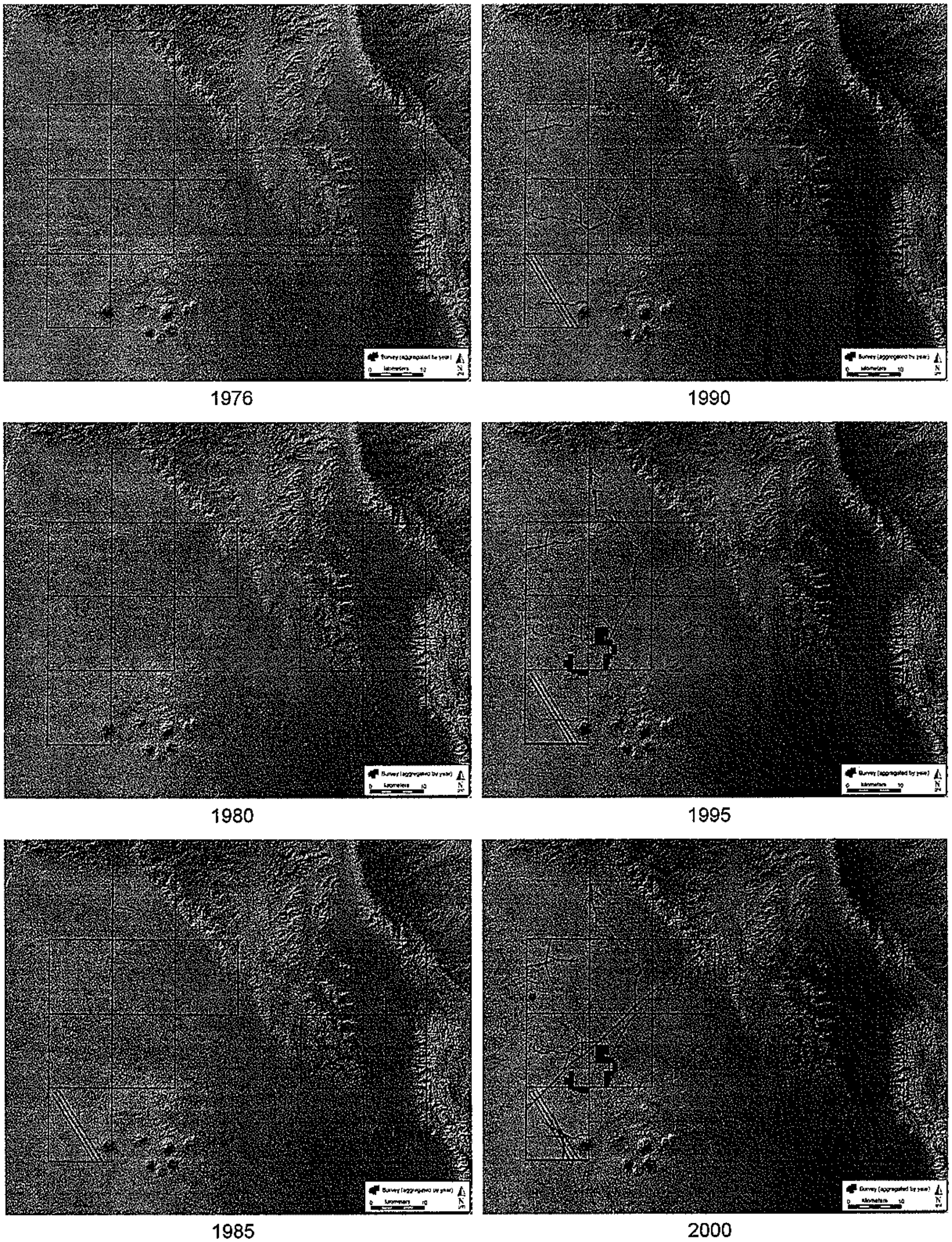



**Figure 18. Time sequence for cumulative survey in the study area, aggregated by year**

Figure 19 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 which represents the reported number of surveyed acres, one which represents the reported acreage minus the overlapping surveys that occurred within that same year, and one which represents the actual new ground surveyed with all overlaps removed.

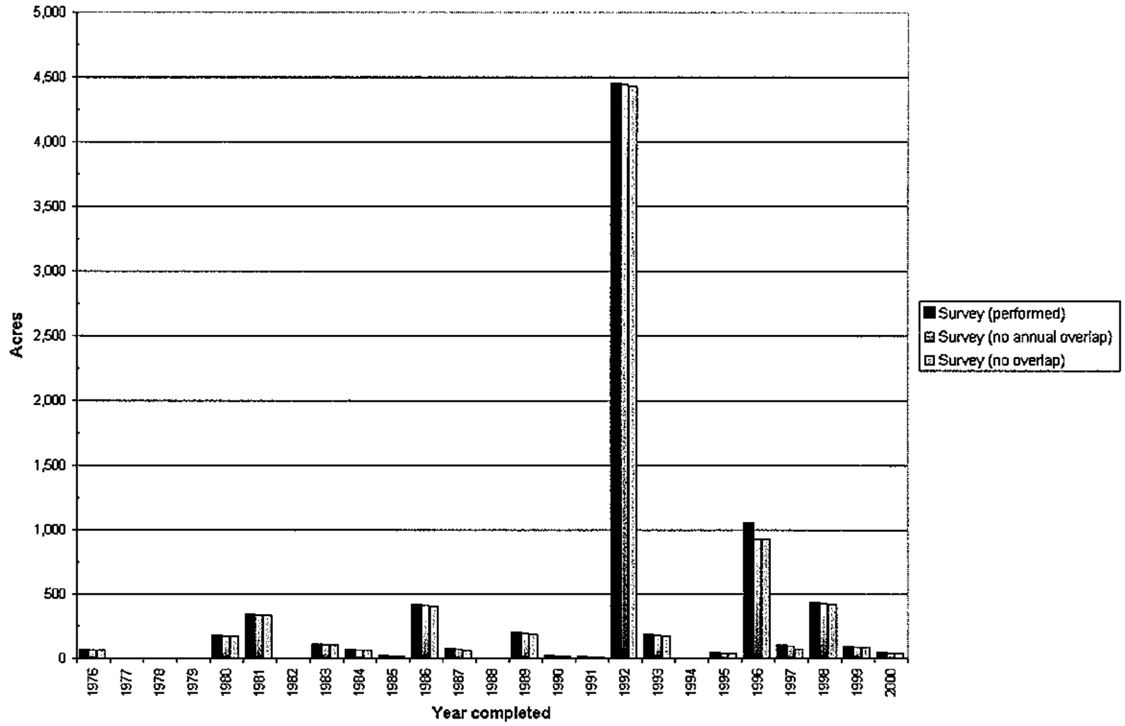



**Figure 19. Annual survey statistics**

These data allow us to calculate site density using the two different methods developed for the previous technical summaries. Method I (Figure 20) 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 21) 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.

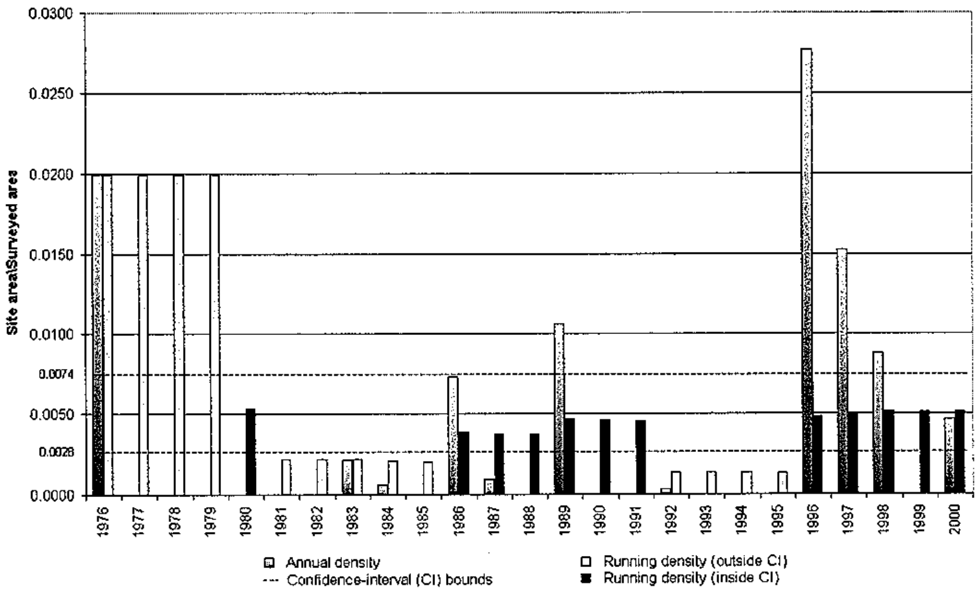



**Figure 20. Overall site density, Method I**

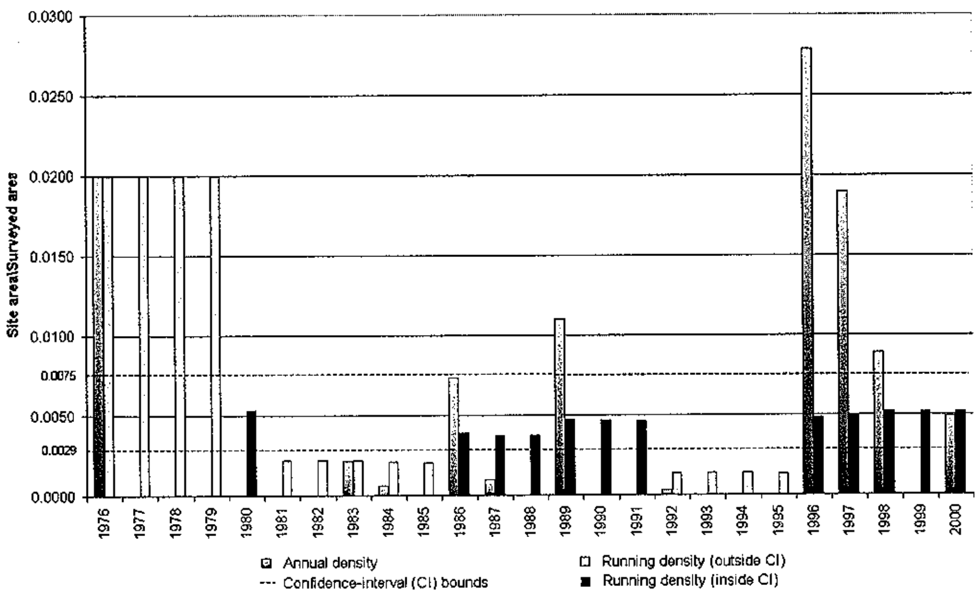



**Figure 21. Overall site density, Method II**

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 percent confidence intervals in 1980, then again from 1986-1991, and 1996-2000. The peak in site density in 1996 is responsible for substantially raising the running density. The sites portrayed in Figure 16 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.

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.

# CONCLUSION

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 area and the alluvium of the northern block of the western study area as higher probability areas for cultural resources. Since Alkali Lakes is 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. Buried sites are frequently found in colluvial settings. This result of the models indicates that 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.

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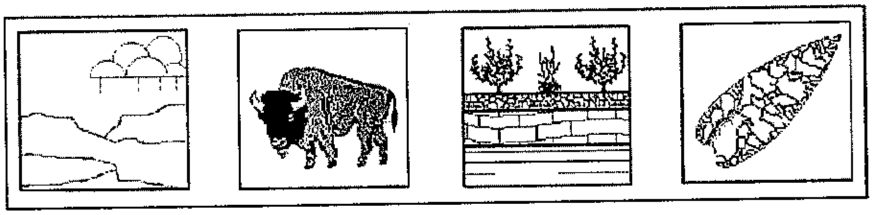
## APPENDIX B



# Archaeological Burial Model: Powder River and Tongue River Hydrological Basins, Wyoming

**Appendix B for Semi-Annual Technical Report**

**July 1, 2004 – December 31, 2004**

by

William Eckerle, Sasha Taddie, Judson Finley, Rebecca Hanna, Mary Hopkins, and Eric Ingbar

December 2004

**Adaptive Management and Planning Models for Cultural Resources in Oil and Gas Fields**

DOE Award Number: DE-FC26-02NT15445, Task 10

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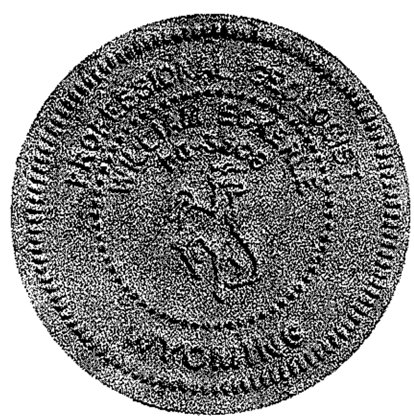

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## ACKNOWLEDGMENTS

Sasha Taddie acted as GIS specialist, wrote portions of the methodology, and produced the graphics for this report. He also prepared accompanying digital products. Judson Finley co-authored the Protocol Handbook (Appendix A), parts of the report, performed drafting, and assisted with report editing. Rebecca Hanna co-authored the conclusions and authored the summary section, as well as assisted in editing and report compilation. Mary Hopkins and Eric Ingbar assisted in evaluating the model. Reese Tietje and Mike Drews, of Gnomon, Inc., assisted with model creation. Darlene Cobbey, Aaron Geery, Peggy Robinson, and Marissa Taddie helped edit and compile the report. William Eckerle conducted field reconnaissance, determined model parameters, authored or co-authored portions of this report, and is responsible for any errors or omissions.

# ABSTRACT

The Wyoming component of the Pump III project includes:

1. Digitization of archaeological survey and site location information for the entire northeastern corner of Wyoming. These records are available through the Wyoming SHPO Cultural Records Office (WYCRO);
2. Predictive modeling of locations where the geology is suitable for the burial of prehistoric archaeological sites within the hydrological Powder River and Tongue River basins;
3. Recommendations for the use of the risk model by potential categories of users to facilitate more predictable, efficient cultural resource compliance processes for oil and gas development, as well as better management of cultural resources.

The second and third items listed above are the subject of this technical report, which will be incorporated into the final Wyoming report as Chapter 4.

The sensitivity models described in this report are based on geological features. They can be used to predict the likelihood of encountering buried cultural resources in various zones within the study area in Wyoming.

This information can be used in cultural resource management by recommending different inventory processes for different sensitivity zones. This should make the leasing process more predictable and cost efficient.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# INTRODUCTION

## Project Purpose

In 2002, Gnomon, Inc., was awarded a contract from the U.S. Department of Energy (DOE) for a project entitled, *Adaptive Management and Planning Models for Cultural Resources in Oil and Gas Fields*. This project is primarily funded by the DOE under the Preferred Upstream Management Practices (PUMP III) cooperative agreement program. The project examines cultural resource management practices in two major oil and gas producing areas, the Powder River Basin in northeast Wyoming, and southeastern New Mexico, with the purpose of identifying more effective management practices and developing information technology tools within an adaptive management paradigm to facilitate those practices.

The adaptive management paradigm process model facilitates self-correction and continual improvement (Figure 1). Within the context of the PUMP III cooperative agreement, adaptive management refers to implementing a self-corrective process to minimize management conflicts between cultural resources and oil and gas extraction on federal land.

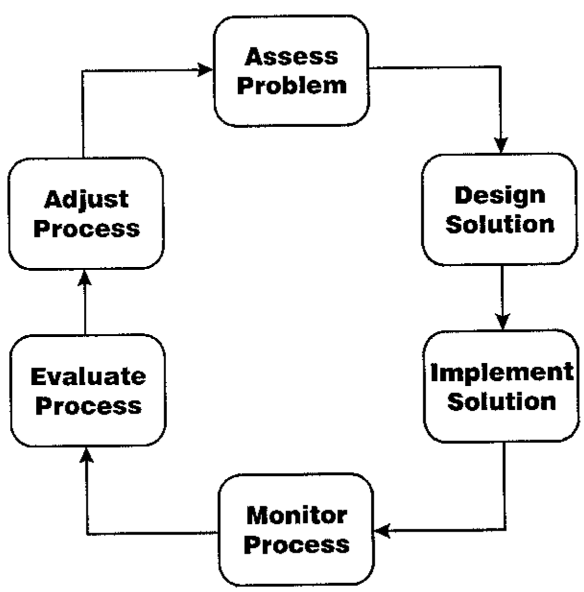


**Figure 1. Adaptive Management Flow Chart**

SRI Foundation (SRIF), in partnership with the New Mexico Historic Preservation Division (HPD), and Stephen Hall of Red Rock Geological Enterprises, completed the New Mexico component. Gnomon, Inc., in partnership with the Wyoming State Historic Preservation Office (SHPO), and Western GeoArch Research, completed the Wyoming portion of the project.

The Wyoming component of the Pump III project includes:

1. Digitization of archaeological survey and site location information for the entire northeastern corner of Wyoming. These records are available through the Wyoming SHPO Cultural Records Office (WYCRO);
2. Predictive modeling of locations where the geology is suitable for the burial of prehistoric archaeological sites within the hydrological Powder River and Tongue River basins;
3. Recommendations for the use of the risk model by potential categories of users to facilitate more predictable, efficient cultural resource compliance processes for oil and gas development, as well as better management of cultural resources.

The second and third items listed above are the subject of this chapter. Expanded development of energy resources in northeastern Wyoming brings with it the risk that archaeological sites are inadvertently damaged. Sites containing buried, intact, and well-preserved, archaeological material are some of the most scientifically important cultural resources within the project area. In point of fact, they contain all categories of data that contribute to the significance of surface sites, as well as a number of categories of contributory data that surface sites lack. From this standpoint, the level of management effort buried sites receive should be in proportion to their scientific importance. However, these site types are difficult to manage because stakeholders often have a poor understanding of the geological and soil processes that led to the burial and preservation of the site. This leads to faulty prediction of which sites have potential for preserved and intact subsurface cultural materials. This lack of understanding means some sites are subjected to more investigation than is warranted given the data categories they contain while other subsurface cultural levels remain undiscovered until they are destroyed or are unearthed during construction activity. These outcomes lead to unexpected development costs from construction and production delays, as well as loss of valuable scientific information.

Having identified the potential problem, this report presents a geoarchaeological model that predicts the location of deposits that might contain buried and intact archaeological material. This model informs the user who wants to know if a particular known site is located within an area where the burial of subsurface cultural material is possible. Likewise, the model informs the user that certain landscapes have the geological qualities conducive to site burial. If applied properly, this burial model will lead to more efficient management of cultural resources so that both resource preservation and energy extraction are facilitated.

The proposed model will need to be implemented within the Section106 process by land management agencies in order to achieve its potential. In anticipation of this implementation, we suggest how to monitor, evaluate, and adjust the model so that it might fulfill its function under changing development scenarios.

This model is specific to the Wyoming portion of the hydrological Powder River and Tongue River basins (Figure 2), where the geology is suitable for buried and preserved archaeological sites. In principal, however, similar models can be constructed for any area. Four components are used to construct the model: (1) field reconnaissance; (2) literature review; (3) data acquisition; and (4) Geographic Information System (GIS) visualization. Field reconnaissance was conducted in Campbell, Johnson, Natrona, and Sheridan counties, Wyoming, April 26-30 and May 5-7, 2003.

# EXECUTIVE SUMMARY

The sensitivity models described in this report predicating the likelihood of encountering buried cultural resources in the Powder River and Tongue River basins of Wyoming concluded:

1. Very high archaeological landscape sensitivity zones are situated primarily along the floodplains and low terraces of low gradient, basin alluvial valleys with lesser areas of eolian sand.
2. High sensitivity zones occur on low slopes, exhibit thick accumulations of surficial sediment, lack evidence for mature soils, and contain little large and small gravel.
3. The moderate sensitivity zone consists of areas that did not fall into the very high, high, low, and very low zones. As such, they either have a "moderate" or an "unpredicted" sensitivity.
4. Areas predicted to have low archaeological landscape sensitivity include areas with a thin mantle of sediment, steep slope, and coarse-grained texture. As well, this zone is mostly mantled by surface soils that are of questionable Holocene-age.
5. Areas at the lowest extreme of the sensitivity scale are within the very low sensitivity zone. Included are large areas of non-soil land such as badlands, gravel pits, rock outcrops, etc.; areas containing soil types thought to be too old to engulf any intact and buried cultural material; depth to bedrock is very shallow; slopes are very steep; and/or gravel comprises the largest proportion of the soil component. Generally speaking, much of this zone is situated on steep slopes in mountainous areas.

Cultural resource management recommendations for the different sensitivity zones include:

1. In the very high sensitivity zones earth-disturbing construction activities should only occur under the most controlled circumstances, including a pre-construction archaeological inventory, and monitoring of construction activity, or at a minimum post-disturbance (pre-refill or pre-regrade) inspection.

2. In the high zones, monitoring of construction activity or at a minimum post-disturbance (pre-refill or pre-regrade) inspection should be considered.

3. In the moderate zones some areas of sensitive sediments will be situated within areas mapped as moderate. State Soil Geographic (STATSGO) Database lumps small areas of higher and lower sensitivity in with the moderate class, especially within the basin portion of the project area. In areas where the Soil Survey Geographic (SSURGO) Database mapping is lacking, common sense use of the sensitivity outline by professional archaeologists can help discriminate areas of higher sensitivity from areas of lower sensitivity. On-site, geoarchaeological evaluations might help discriminate these areas from larger portions of the moderate zone that might be less sensitive. Post-disturbance (pre-refill or pre-regrade) inspection should be considered in all moderate areas.

This report concludes that it would be beneficial to continue to refine these models as new information becomes available.

# EXPERIMENTAL

### Experimental and Operating Data

**Burial Model Framework**

A systematic attempt to model and map the spatial location of deposits that might contain preserved, buried sites has not been undertaken until now. However, a number of informative geoarchaeological studies have been conducted and provide valuable background information. John Albanese has investigated numerous sites in the Powder River Basin (Albanese 2000) and authored several regional summaries. This work has been supplemented by the soils studies of Richard Reider (Reider 1990). Much of their work has been conducted as part of archaeological research undertaken by Dr. George Frison, University of Wyoming. As well, archaeological

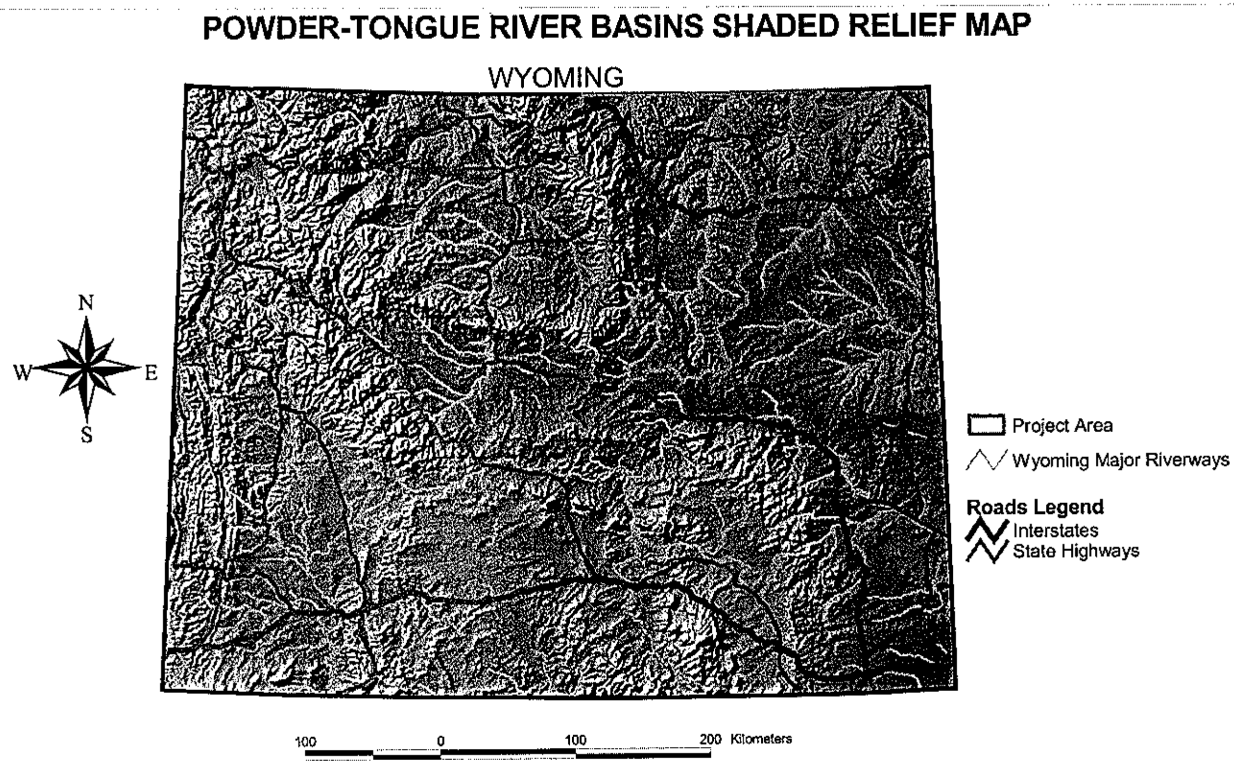


**Figure 2. Map of the project area illustrating its location in the Powder River and Tongue River basins, northeastern Wyoming**

burial models (landscape sensitivity frameworks) have been developed and successfully applied to other areas of Wyoming (Eckerle and Taddie 1997; Eckerle et al. 1999; Eckerle et al. 2000) as well as areas in Nevada (Drews et al. 2004).

The modeling framework presented in this report is based on the assumption that intact cultural resources (from a National Register of Historic Places [NRHP] perspective) are found in geological strata that were deposited since the end of the last Ice Age. As used here, the date for this event is 14,000 radiocarbon years ago. As well, archaeological materials that accumulated within moderate to low energy depositional environments are likely to have been buried close to where prehistoric peoples used and discarded them. Also many of these depositional environments buried cultural occupations deeply enough to have escaped the effects of long-term surface and near-surface disturbance processes, thus maintaining stratigraphic and behavioral integrity. Buried prehistoric archaeological sites with high stratigraphic integrity are extremely important from many perspectives; however, such sites are difficult to manage and expensive to treat under Section 106 of the National Historic Preservation Act (NHPA). These factors form the rationale for constructing a model specifically designed to assist in predicting areas where these types of sites might occur.

The model divides the landscape into archaeological site burial sensitivity categories ranked in a continuum from very high, high, moderate, low, to very low sensitivity. These sensitivity categories reflect the potential of a landscape to contain buried and relatively intact occupation strata, which exhibit both contextual and associational integrity. Modern earth-disturbing activities put any buried and intact sites at risk of the loss of scientific information and thus, data that might contribute to the sites' National Register of Historic Places eligibility. Following from the model predictions, buried sites in these locations are likely to contain perishable archaeological residues, such as bone and charcoal, which are rare and valuable remains useful in archaeological interpretation.

Geological landform and soils data are used in GIS to create multiple, overlaying map images that illustrate the burial sensitivity of areas specific to the project area. Digital data used in the GIS are available in multiple forms: geological data are from the Wyoming Surficial Geology Map (Case et al. 1998); soils data are available at the state level from the National Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) database (Soil Conservation Service 1994); and soils data are also available at the county level from the NRCS Soil Survey Geographic (SSURGO) database (Natural Resources Conservation Service 1998, 1999, 2000, 2002a, 2002b, 2003a, 2003b; United States Forest Service 1999).

Ultimately, modeled data can be used as the basis for informing and guiding individual, project-specific management decisions at the 1:250,000 (STATSGO) scale or, where available, at a 1:24,000 (SSURGO) scale (see qualifications below). Land managers can use this information to anticipate areas of archaeological compliance concern, while developers can use it to project the costs of development in targeted and alternative areas. Cultural resource management firms can use this information in the planning stages of their Section 106 consultations; their field archaeologists can make practical use of the model to better understand the geoarchaeological settings where they are likely to discover significant, buried archaeological sites. A field protocol handbook manual (see Appendix A) accompanies this report. It is designed for use by four categories of users: (1) agencies; (2) industry; (3) cultural resource consultants; and (4) field archaeologists. This is a practical, condensed guide that informs users of the logic behind the model, as well as how they might implement it given their varying needs.

## DESCRIPTION OF PROJECT AREA

### Modern Environment

***Hydrography***. The project area encompasses the Wyoming portion of the Powder River and Tongue River hydrological basins (Figure 3). Both drainages are tributaries to the Yellowstone River. Bounding drainage basins include the North Platte River to the south, Cheyenne River to the southeast, Belle Fourche to the east, Little Missouri to the northeast, Little Bighorn River to the north, Bighorn River to the west, and Sweetwater River to the southwest.

The Tongue River heads in the Bighorn Mountains near Burgess Junction and flows northeastward into Montana. Major tributaries are (from north to south with associated headwaters elevations): North Tongue River (3,098 m [10,164 ft]), South Tongue River (3,300 m [10,827 ft]), Goose Creek (3,528 m [11,575 ft]), Little Goose Creek (3,600 m [11,811 ft]), and Piney Creek, which heads on Cloud Peak (4,014 m [13,169 ft]), the highest peak in the Bighorn Mountains. The Tongue River crosses the Wyoming State line at an elevation of 1,061 m (3,481 ft).

Major northeast-flowing tributaries of the Powder River also head in the Bighorn Mountains and their foothills. They include (from north to south with associated headwaters elevations): Clear Creek (3,744 m [12,283 ft]), Crazy Woman Creek (3,218 m [10,558 ft]), North Fork of the Powder River (3,216 m [10,551 ft]), Middle Fork of the Powder River (2,659 m [8,724 ft]), and South Fork of the Powder River (2,513 m [8,245 ft]). Northwest-flowing tributaries head at much lower elevations and include (from north to south): Little Powder River (1,390 m [4,560 ft]), Wild Horse Creek (1,330 m [4,364 ft]), and Salt Creek (1,686 m [5,531 ft]). The elevation of the Powder River as it leaves Wyoming is near (1,037 m) 3,402 ft.

Structural and lithologic controls affect the drainage patterns of the basin (Albanese 1990). Areas underlain by permeable substrates are dominated by low to medium density drainages. Some shallow, internally drained basins are water collection areas. Drainage basin extent for the Tongue River basin is 13,980 $km^2$ (5,398 $mi^2$) and 34,160 $km^2$ (13,189 $mi^2$) for the Powder River (Zelt et al. 1999). Together, the Powder River and Tongue River drainage basins encompass an area approximately 48,140 $km^2$ (18,587 $mi^2$).

***Geology***. The project area includes part of the physiographic Powder River Basin (Figure 2) and adjacent Bighorn Mountains. This basin is a structural and depositional depression formed from the downward displacement of Paleozoic and Mesozoic sedimentary rocks associated with the Laramide Orogeny, where many sedimentary strata are offset in relationship to adjacent, uplifted areas (Thornbury 1965). The axis of the basin plunges gently to the northwest (Zelt et al. 1999). Major structural features bound the Powder River Basin including the Pryor-Bighorn-Casper Arch to the west, Laramie Range-Hartville Uplift to the south, Bear Lodge-Black Hills to the east, and Miles City Arch to the north. Traditionally, the Powder River Basin is divided into two parts based on surface drainage. The western Powder River Basin (WPRB) includes the Powder River and Tongue River hydrological basins, whereas the eastern Powder River Basin (EPRB) is drained by the Cheyenne, Belle Fourche, and Little Missouri rivers. Thus, the western Powder River structural basin, along with the portion of the Bighorn Mountains drained by the Powder and Tongue rivers, correspond to the project area discussed in this report.

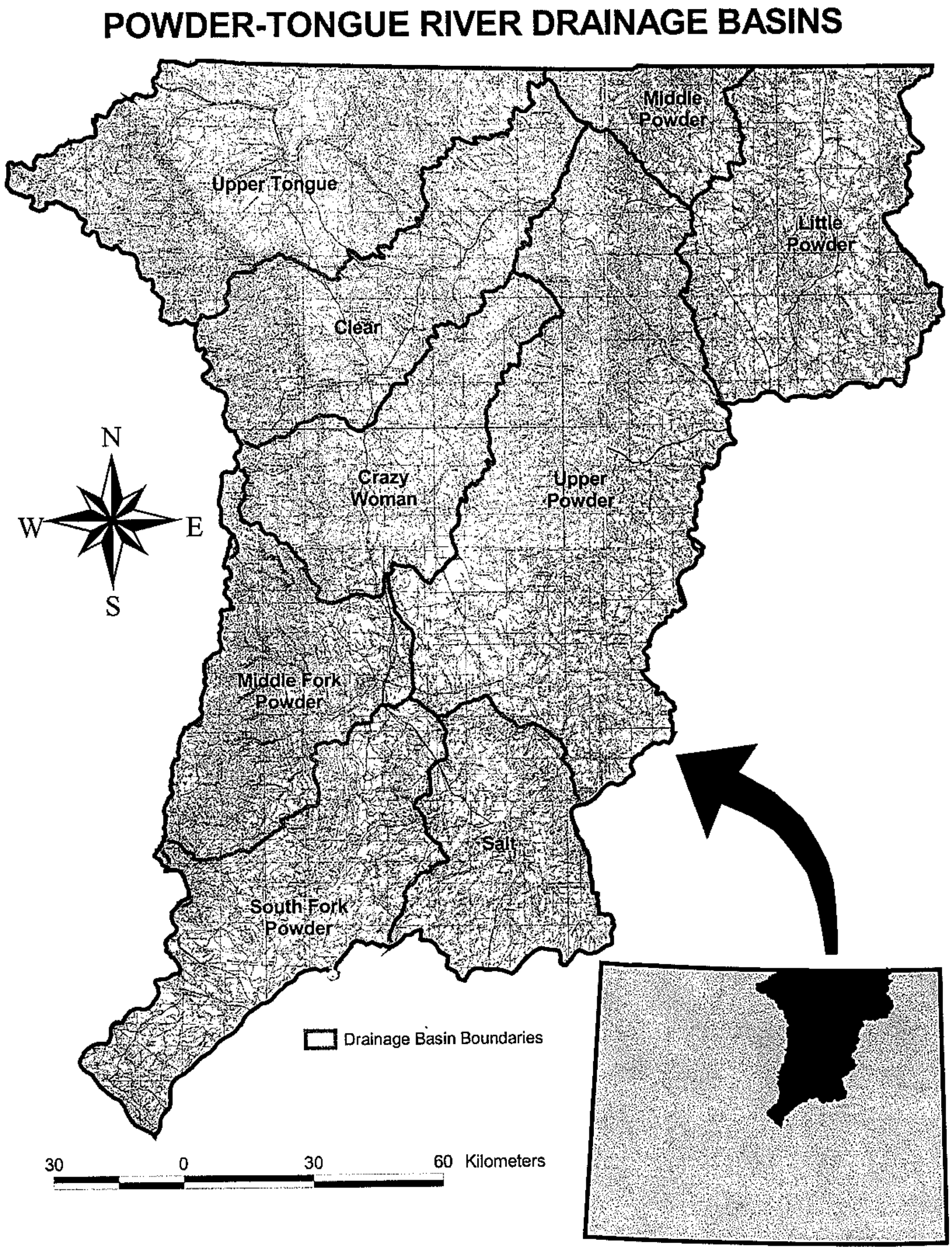


**Figure 3. Map illustrating the extent of the Powder River and Tongue River hydrological sub-basins in northeastern Wyoming**

The Bighorn Mountains, the most prominent landform visible to the west of the Powder River Basin, formed during the Late Cretaceous and Tertiary Periods, and like the nearby Black Hills, are cored by Precambrian basement rocks. Unlike other Laramide uplifts in Wyoming, thrust faults are present on both the west and east sides of the range (Lageson and Spearing 1988). Additionally, two cross-cutting faults divide the range into three blocks: the first fault trends northeast-southwest near Tongue River Canyon, and the second trends east-west nearly parallel to Tensleep Canyon. During the Laramide Orogeny, the north block was thrust southwest over the Bighorn Basin along the Big Trails fault, the middle block moved eastward over the Powder River Basin, and the south block was shoved west over the Five Springs thrust fault (Lageson and Spearing 1988).

Bedrock of the project area is illustrated in Figure 4. Crystalline granitic rocks core the Bighorn Mountains, while Paleozoic and Mesozoic sandstones, limestones, and dolomites dip steeply down the eastern flank of the Bighorns into the Powder River Basin (Love and Christiansen 1985). The heavily glaciated resistant core is exposed in the middle portion of the Bighorn Mountains, which Tertiary erosion has plainated into two erosional surfaces, the Summit and Subsummit surfaces, respectively. The sub-summit surface was erosionally modified into a distinctive, "biscuitboard" shape (in plan view) by Pleistocene glaciation (Thornbury 1965). Cretaceous sandstone and shale crop out in the belt of foothills along the eastern flank of the Bighorns. Conglomerates shed as alluvial fans from the youthful Bighorn Range interfinger with the Eocene Wasatch Formation at many places along the foothills (Lageson and Spearing 1988).

The basin areas are underlain by pre-Cenozoic-age rocks, which were downwarped during the Laramide Orogeny to form a basin. This basin filled with sediment from the adjacent uplands until late Miocene or early Pliocene times when regional uplift initiated a period of basin degradation (Mears et al. 1991). The most common formations encountered formed during the basin filling cycle include (from oldest to youngest): (1) Paleocene Fort Union Formation (Tullock, Lebo, and Tongue River members); (2) Eocene Wasatch Formation (Moncrief and Kingsbury Conglomerate members); and (3) Oligocene White River Formation (Love and Christiansen 1985) (Figure 5). Coal beds are common in Cretaceous through early Tertiary units

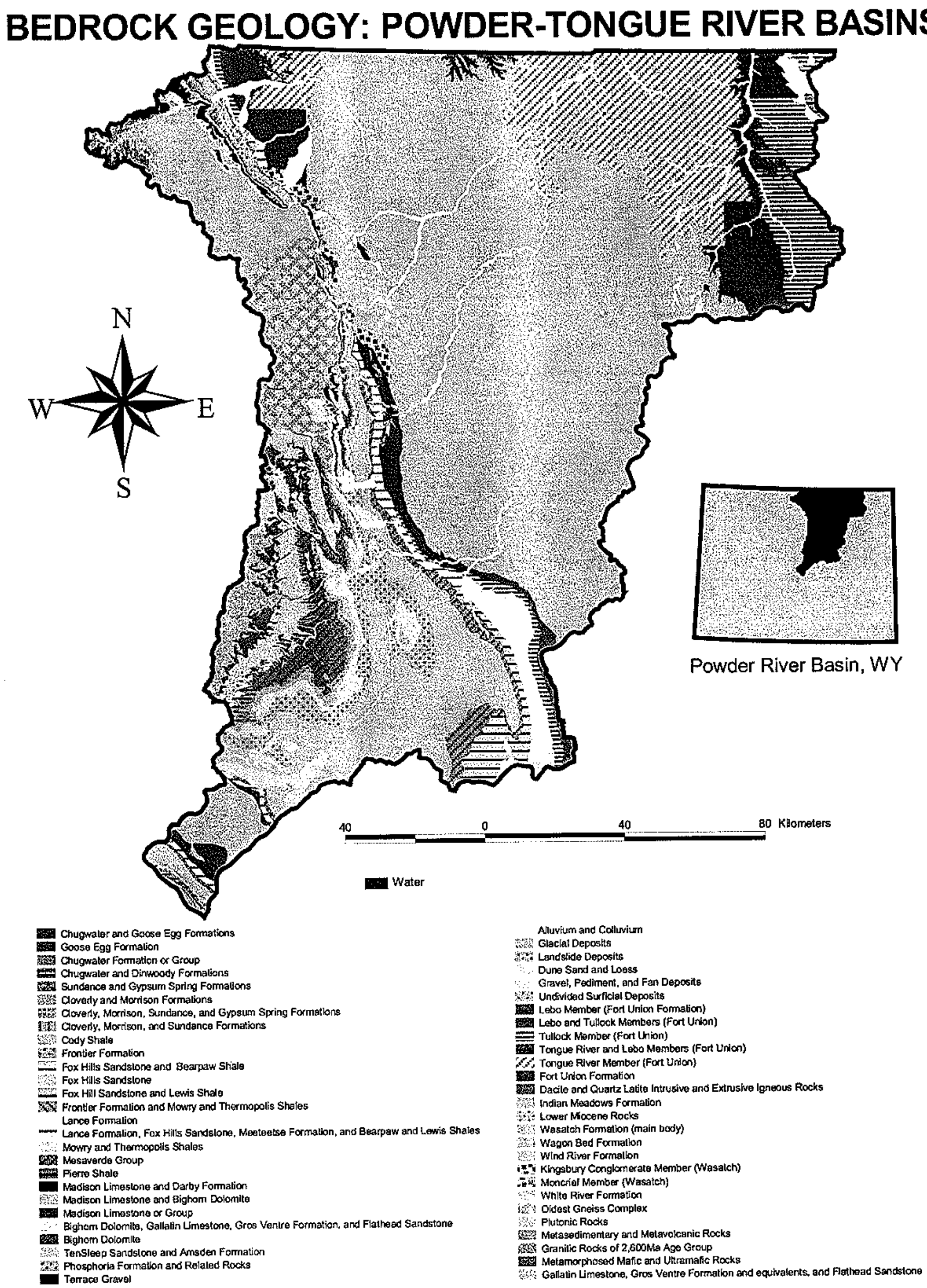


**Figure 4. Project area bedrock geology**

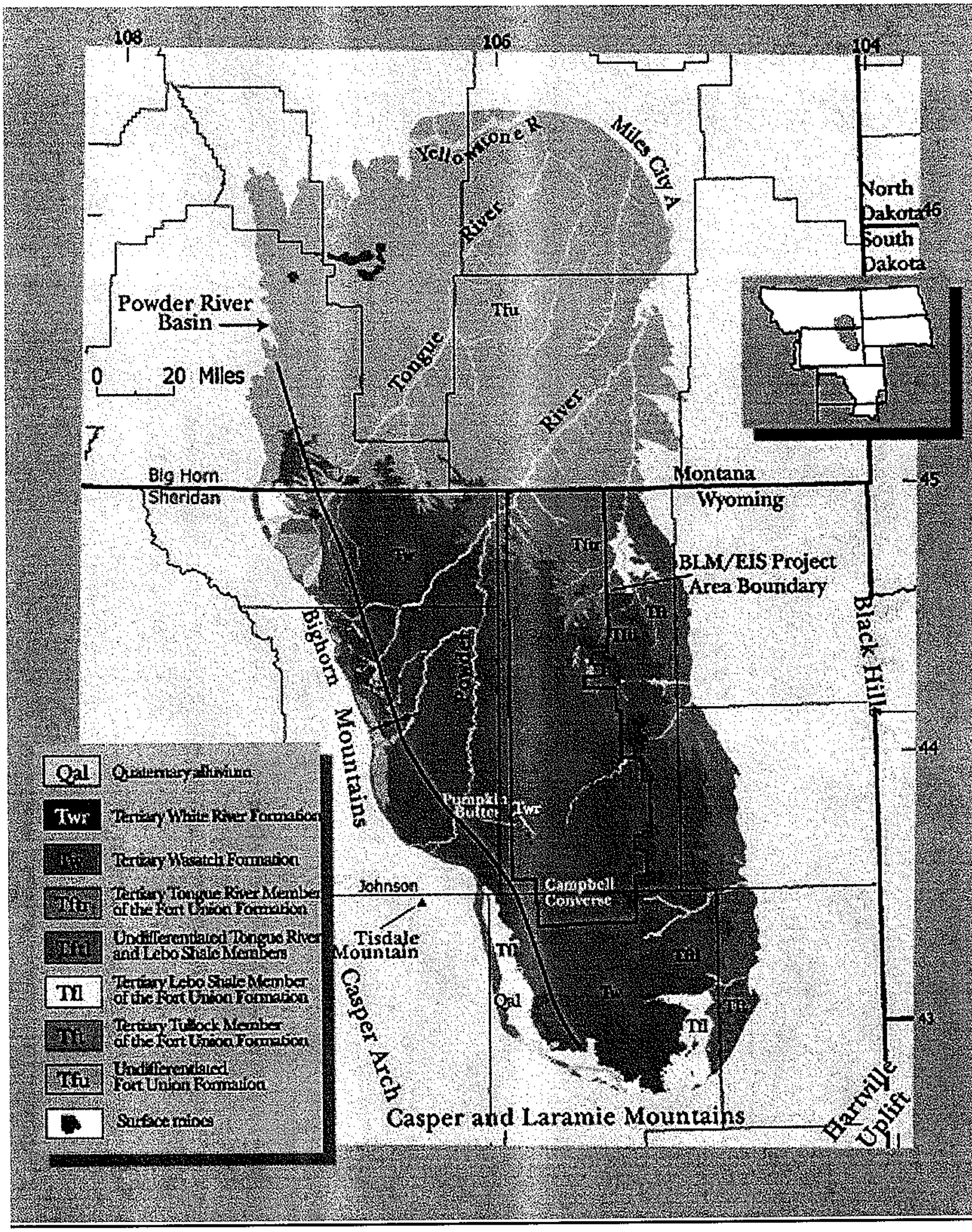


**Figure 5. Tertiary bedrock geology of the Powder River and Tongue River basins showing axis of Powder River structural basin**

and lightning-induced ignition of the coal seams has resulted in baked sediments, clinker beds, and pyro-karst collapse features. Quaternary gravel capped and plainated benches occur near the foot of the Bighorn Mountains, and Quaternary alluvium occupies river valleys in the basin.

Eastern-flowing streams draining into the Powder River Basin carry sediments derived mostly from granite, limestone, and dolomite. Stream valley alluvium is the predominant type of Quaternary deposit along the flanks of the mountains (Hunt 1986). Basin-area drainages erode and carry sediments derived from younger, mostly sandstone and shale, rocks.

***Soils.*** Soils of the project area are illustrated in Figure 6. Soils along the foothills-basin margin reflect a relatively moist precipitation regime (Kronenberger et al. 1977). Most of the soils receive enough precipitation to support the vegetation necessary for the development of humic A horizons. Areas of hard, resistant bedrock are mantled by thin, weakly formed soils (Lithic Ustic Torriorthents). Soils on soft, easily eroded bedrock are thick but only weakly horizonated (Ustic Torriorthents). More geomorphically stable locations exhibit soils with weathered and structured B horizons (Camborthids). Landscapes that have remained relatively uneroded for the longest period of time contain soils with clay-enriched B horizons (Ustollic Haplargids). Soil temperature regimes are generally frigid in the northwest and mesic in the remainder of the basin. Soil moisture regimes range from aquic along perennial streams to aridic in the drier portions of the basin.

***Vegetation.*** Porter (1962) indicates that vegetation zonation in Wyoming is dependent on elevation. Küchler (1966) delineated various zones of potential vegetation in the project area. A west-to-east transect from the crest of the Bighorn Mountains out into the basin yields the following vegetation types: (1) Alpine meadow along the crest of the range; (2) Western spruce-fir forest on the upper montane slopes; (3) Douglas fir forest on the lower mountain slopes; (4) grama-needlegrass-wheatgrass grassland in the western basin; and (5) sagebrush steppe along the incised river breaks. As well, an area of eastern Ponderosa forest is present between the Tongue and Powder rivers.

# POWDER-TONGUE RIVER BASINS CLASSIFIED SOILS MAP

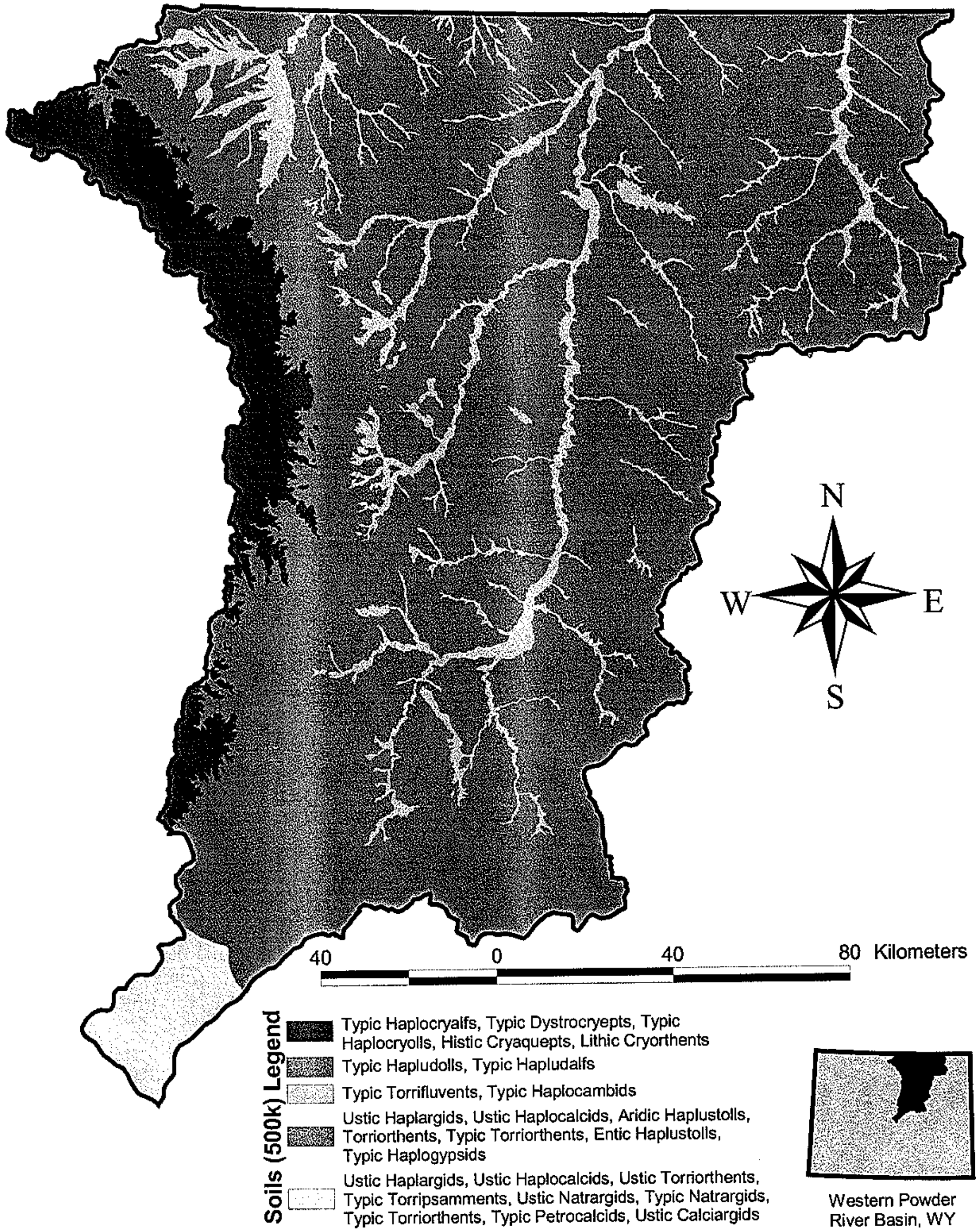


**Figure 6. Map (1:500,000) illustrating the distribution and composition of soil-map units classified by soil taxon groups**

***Climate.*** Climate of the study area is continental and characterized by cold winters and warm summers. Precipitation is distributed throughout the year and varies by elevation. Mountains are cold and moist whereas the basin is warmer and drier. In the high mountains the average maximum January temperature is -4.4° C (24° F; all temperatures are monthly means) and the average maximum July temperature is 22.2° C (72° F) (National Oceanic and Atmospheric Administration 1985). Minimum temperatures for January and July are -17.8° C (0° F) and 2.2° C (36° F), respectively (National Oceanic and Atmospheric Administration 1985). Temperatures in the basin vary but are colder in the winter due to the intrusion of cold continental air masses.

Maximum basin January temperature is 2.2° C (36° F) and the average maximum July temperature is 31.1° C (88° F). Minimum basin temperatures for January and July are -17.8° C (0° F) and 11.1° C (52° F), respectively (National Oceanic and Atmospheric Administration 1985). Average precipitation varies from 76.2 cm (30 in) in the high mountains to 35.6 cm (14 in) in the basins (Soil Conservation Service 1983). Most of the precipitation falls in the spring, and winds typically arrive from the northwest (Martner 1986).

***Present and Historic Wildlife.*** Some of the fauna found within the area were important to prehistoric peoples. Various avian species are sagebrush specialists, with the sage grouse being an example. Big game species such as wapiti, mule deer, whitetail deer, and pronghorn are found in the area. Bison, grizzly bear, and wolf were present prehistorically. Smaller species include jackrabbits, cottontail rabbits, various rodents, coyote, mountain lion, badger, and bobcat (Soil Conservation Service n.d.).

## METHODOLOGICAL ASSUMPTIONS

The purpose of the modeling is to more effectively manage buried prehistoric sites. In order to accomplish this, it is important that archaeologists understand the types of site formation and destruction processes that act to create and destroy buried sites. This section discusses common site formation and destruction processes as they affect sites, and provides a basis for evaluating the types of landscape settings deposits that are conducive to the burial and preservation of sites.

It is also important that concerned parties understand how various types of erosion can influence the discovery process for buried sites.

Archaeological materials originate within a behavioral context as objects used and produced by people. After the objects are lost, discarded, or abandoned, they enter the archaeological record. The archaeological record is valuable to modern society, in part, because archaeological science can derive information about history, lifestyles, and cultural processes that influenced the people who produced the objects now categorized as artifacts and archaeological features. One of the realities of archaeology is that when artifacts are found as close as possible to the original positions where they were lost, discarded, or abandoned, the archaeologist is able to learn much more than if the artifacts were moved from their original positions sometime between their abandonment and when the archaeologist recovers them. Various cultural and natural processes can move the artifacts from their original positions and these processes make it more difficult to extract information about the original behavior of the people who left them. A discussion of pertinent site formation and destruction processes is presented here. The following categories are summarized, which generally follow Gifford (1978): occupation trampling, post-occupational (preburial) dispersal, burial dispersal, and post-burial turbation.

### Occupation Trampling

The magnitude of occupation trampling (treading and scuffing) varies with respect to substrate texture, occupation traffic intensity (Schiffer 1987), and moisture content (Deal 1985). Experimental studies indicate that an occupation trample zone (or "churn zone") is formed in loose substrates. Well-sorted sands produce the thickest occupation trample zone that ranges from 5-16 cm (2-6 in) in thickness (Table 1) (Gifford-Gonzalez et al. 1985; Stockton 1973). Loamy sand will develop a 3-8 cm (1-3 in) trample zone (Villa and Courtin 1983), whereas loams produce almost no occupation trample zone (Gifford-Gonzalez et al. 1985). Clayey sediments, likewise, require extremely high levels of traffic or saturation before any occupation trample zone is produced (Eckerle, unpublished field observations). Pedestrian traffic on cobble or larger size clasts will not produce a trample zone at all (Hughes and Lampert 1977).

Occupation trample zones can be viewed as both a positive and a negative aspect of site formation. Occupation trample zone development on a soft substrate has the effect of blurring the occupational record of finely stratified and reoccupied sites (Hughes and Lampert 1977; Villa 1982). The positive aspect of occupation trample zones is that their formation quickly hides artifacts and makes them unavailable for site cleaning and secondary refuse disposal (Schiffer 1987). In addition, items are much easier to lose in soft substrates (Schiffer 1987). As a result there is a higher potential for discriminating areas of high primary-discard (lodges, hearth activity areas, etc.) from those of low primary-discard. Additionally, scuffage (horizontal artifact dispersal due to foot traffic) is minimal on loose substrates because items are less likely to skid.

The most important aspect of trample zones is that their thickness, as predicted by the substrate texture, can be used as a baseline for comparing the thickness of actual occupation zones. If the thickness of an actual occupation zone is much thinner than predicted, then that occupation zone is probably stratigraphically truncated. On the other hand, if the thickness is much thicker than predicted then either the zone is a specialized feature (hearth, house pit) or it is over-thickened as a result of reoccupation under an aggradational depositional regime. Truncated and over-thickened trample zones suggest some loss of site integrity.

**Table 1. Occupation churn zone thickness and predicted archaeological implications**

| SOIL TEXTURE | COMMON DEPOSITIONAL ENVIRONMENT | CHURN ZONE ( in cm) | HORIZONTAL SCUFFING | EASE OF CLEANING | IDENTIFY ACTIVITIES | IDENTIFY DOMESTIC AREAS |
|---|---|---|---|---|---|---|
| sand | eolian dunes, well-sorted fluvial sands | 5-16 | low | low | high | low |
| loamy sand | some slope deposits and alluvium | 3-8 | moderate | moderate | moderate | moderate |
| sandy loam and finer | overbank deposits, lacustrine deposits, and most slope deposits | <5 | high | high | low | high |

## Post-Occupational Dispersal

Post-occupational (but preburial) dispersal can alter the contextual integrity of surface archaeological materials. In general, soft substrates tend to hold onto artifacts after they have settled into the surface (Wandsnider 1988). Additional trampling by animals, slope processes, and eolian movement are the major categories of post-occupational dispersal. However, trampling by animals, even in environments with high populations of hoofed ungulates, is a slow process (Gifford and Behrensmeyer 1976).

Slope wash and colluviation are two common processes that transport surface artifacts. The process of colluviation occurs commonly on relatively steep (>15 percent) slopes (Rick 1976). Colluviation is gravity-driven transport in which heavier and denser materials move further down slope than lighter, less dense items (Rick 1976). Slope wash, on the other hand, involves transport in a sheet flow layer of water during storms (Butzer 1982; Reineck and Singh 1980). It can occur on low angle slopes, especially if vegetation is sparse and infiltration levels are low. This type of transport follows hydrodynamic rules in that smaller, less dense material is transported the furthest down slope.

Eolian transport of surface artifacts can occur whenever wind shear exceeds the hold of gravity (Bagnold 1941). This can be a major source of dispersal for small artifacts unless they quickly become buried (Wandsnider 1988). Eolian transport is not confined to dune fields but can occur whenever wind conditions are suitable. It is most effective on locations with minimal vegetation cover.

## Burial Dispersal

Artifact dispersal occurs in most depositional environments (Butzer 1982). An exception to this is eolian silt (loess) environments. Lack of dispersal in loess is the result of a low surface wind shear (because vegetation is usually present) also causing low impact energy of silt particles. Many surface sites on flat, vegetated surfaces are eventually, albeit slowly, buried by silt. Other depositional environments can be ranked into two categories of potential burial dispersal. The relatively low energy category includes alluvial overbank, sheet flow (including slope wash), and eolian sand environments. The high-energy category includes alluvial channel, debris flow, and colluvial depositional environments. For most water and air entrained sediments, artifact movement is a function of size and density (Gifford and Behrensmeyer 1976). Frison et al. (1988) propose a simple rule-of-thumb for determining the depositional dispersal of buried lithic artifacts. This rule states that any artifacts smaller than the break off point for the coarsest 10 percent of a sediment sample (finer than the 90th percentile) were probably moved during burial.

**Post-Burial Dispersal**

A wide range of processes can act to disperse archaeological residues after burial. Erosion and subsequent redeposition can produce a secondary deposit that contains no contextual integrity (Butzer 1982; Schiffer 1987). Many other dispersal processes are possible (Butzer 1982; Schiffer 1987; Wood and Johnson 1978), including soil formation, bioturbation (including insect and rodent burrowing [Paton et al. 1995]), plant growth (including tree tip-out), and turbation from repeated ground freezing (frost heave).

The discussions of site formation and destruction processes suggest that many factors, especially geological and soil process can degrade archaeological sites. This necessitates thorough, project-specific descriptions of surficial geology and soils.

**Factors Affecting Site Discovery: Plan View Versus Profile**

The archaeological record, as a landscape phenomenon, has both horizontal and vertical components. Human occupations deposit artifacts and features in horizontal distributions across the landscape. In time, they may become buried, adding a vertical component to the archaeological record. Archaeological survey is designed to discover horizontal distributions. Thus, buried sites often remain undiscovered until earth-moving activities occur during development. Alluvial settings are ideal for the formation and preservation of vertical deposits, but, as Albanese (1978) noted, relatively few buried sites in the Powder River Basin have been discovered in such contexts, when compared to other areas in Wyoming despite the frequent presence of cutbanks that expose appropriate sediment. He accounted the rarity of buried sites by the fact that streams destroy many sites over time. Alternatively, it is notable that discovery of buried sites is difficult in alluvial settings compared with their upland counterparts. An experienced field archaeologist is simply less likely to discover eroding cultural material at the base of a cutbank than on flat or rolling landscapes. Surface occupations and the horizontal degradation of buried occupations leave artifacts behind as a horizontal lag deposit. Whereas artifacts that erode out of arroyo walls are generally flushed downstream during subsequent flood events, thus, failing to accumulate to any significant surface density below the cutbank. A site exposed in cross-section rather than plan view logically makes fewer artifacts visible for discovery, further reducing the probability that buried sites will be discovered during survey.

Pedestrian archaeological surface inventory (survey) involves walking the landscape looking for artifacts. Generally artifacts with a long axis of 2 cm are visible for 2 m on either side of the archaeologist. For example, suppose a circle of 2 m in radius (125,600 $cm^2$) representing an archaeological site (activity area) contains 100 artifacts (flakes), all about 2 x 2 x 0.2 cm in size. The total area of artifacts is 400 $cm^2$. The ratio of the site area to the flake area is 314:1. From the center of the circle all 100 artifacts are visible. Now, take a string line 1 mm in diameter and randomly transect the site (plan view) circle. The probability of encountering a single flake along the 1 mm stream line can be calculated as:

$$Pr\ (\text{flake}) = 400/125600 = 0.003$$

and that for not encountering a flake as:

$$Pr\ (\text{no flake}) = 125200/125600 = 0.997.$$

This action is equivalent to viewing artifacts exposed in a cutbank. Base rate probabilities of encountering a single flake exposed in a cutbank are around 0.3 percent, so 99.7 percent of the time no artifact will be encountered.

Note that artifacts are usually exposed on edge in a buried context. If a 1-m deep trench were excavated through the 2 m wide buried occupation (100 cm x 200 cm = 20,000 $cm^2$) to expose the artifact-laden (400 total artifacts) surface in profile, at best, one or two flakes might be encountered (on edge; 2(2cm x 0.2 cm)= 0.08 $cm^2$). In that instance, the ratio of site area to flake area increases to 250,000:1 (20,000 cm2 / 0.08 $cm^{2)}$. It is easy to see why site areas exposed in arroyo walls are difficult to identify in profile. In fact, it is a wonder that buried sites are ever found in cutbanks through visual inspection.

Typically, it is the presence of generally rarer, larger indications such as culturally stained carbonaceous sediment, large animal bone, or the presence of fire-cracked rock that give the location of buried sites away. In any case, since most surface sites are flake scatters, it is difficult to evaluate the frequency of buried versus surface sites from archaeological inventory data. From this perspective, the Powder River Basin is a problematic setting to locate buried sites as opposed to the rolling dunal landscapes in the Wyoming Basin. Buried sites in the latter are easily found by observing artifacts in plan view at the base of dunes and then identifying the highest elevation on the dune slope at which artifacts appear. This highest elevation often marks the position of an eroding zone of cultural material.

## PATTERNING OF SURFACE GEOLOGY AND SOILS IN THE PROJECT AREA

The patterning of deposits and soils in the project area is complex but structured (Hallberg et al. 1999; Hallberg et al. 2000a, Hallberg et al. 2000b; Love and Christiansen 1985; USGS 1994). Bedrock formed during a long history of structural and depositional events, but surficial sediments were derived from bedrock and were redeposited in the relatively recent geological past (Case et al. 1998; Hunt 1986). Soils result from the interaction of soil formation factors such as parent material, surficial deposits, climate, topography, vegetation, and the duration of soil formation (Jenny 1941; Soil Conservation Service 1994).

## Surface Mapping Categories

Several important surficial regimes (Case et al. 1998) are described in the following section (Figure 7): alluvial fans, valley alluvium, exposed bedrock, bench deposits, clinker, terrace deposits, dissected terraces, shallow terrace deposits, eolian sand, glacial deposits, grus, landslides, playas, residuum, and slope wash and colluvium. Each category is described using standard U.S. Geological Survey (USGS) geologic map terms, and common soil types are summarized from NRCS maps and reports. Soils types found on each surficial unit are characterized by visually overlaying 250k soils mapping over the surficial geology map. Some of these landforms are illustrated on Figure 8. The surficial geology map and the visual associations observed when overlaying the soils maps are used to identify the types of landscapes, deposits, and soils that are important to the model building undertaken in this report. The surficial geology map was not used as a digital database in the model compilation.

***Alluvial Fans.*** Alluvial fans (Figure 7) are poorly sorted deposits that form in moderate to high-energy depositional environments at the mouths of drainages. Sometimes fans from separate, adjacent drainages coalesce into a fan-apron. Other fans merge laterally with slope wash. Fans, while generally subdued, occur in several locations within the project area, including the mouths of mountain canyons, and within the basin where side streams flow into a main stream. Fans that occur at the mouths of mountain canyons are debris-flow dominated, and include material derived from intrusive igneous rocks as well as Paleozoic and Mesozoic bedrock. Soils formed on this type of fan are relatively old and well developed, containing humic surface horizons as well as thick, clay-enriched B horizons (Argiustolls, Paleustolls, Argiborolls). Fans formed within the basin contain some debris flows, but also a high percentage of intermittent stream overbank sediment and slope wash. They also include more sediment derived from locally occurring Tertiary bedrock sources. Basin fans have less organic matter in their A horizons. They are younger and generally possess less well-developed B horizons (Ustorthents, Torrifluvents, Ustifluvents, Torriorthents, Haplargids, Calciorthids, Camborthids). Dissected alluvial fans are mapped separately from non-dissected fans, but are otherwise similar.

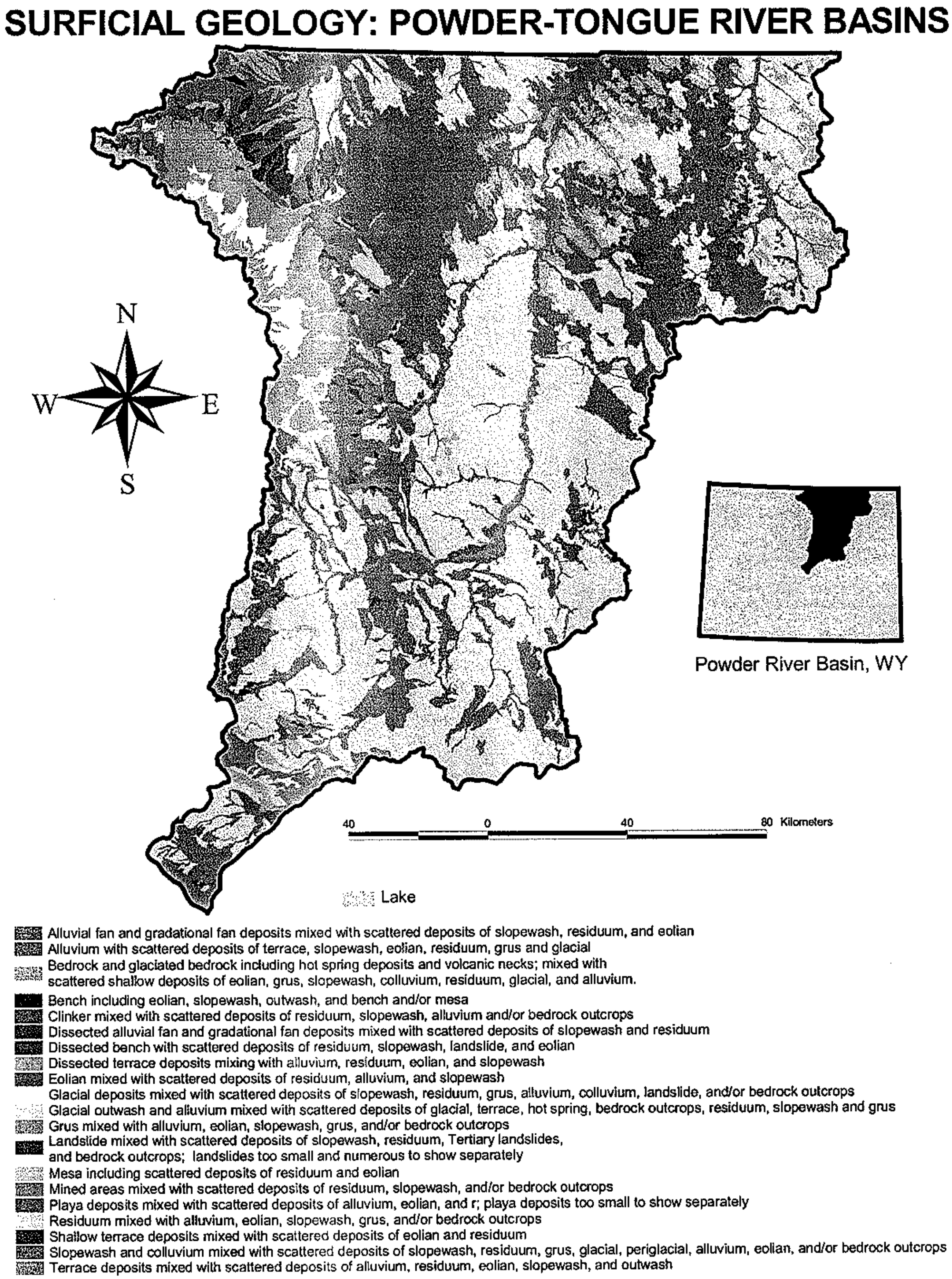


**Figure 7. Surface geology map of the Powder River and Tongue River basins illustrating the distribution of major landforms and depositional environments**

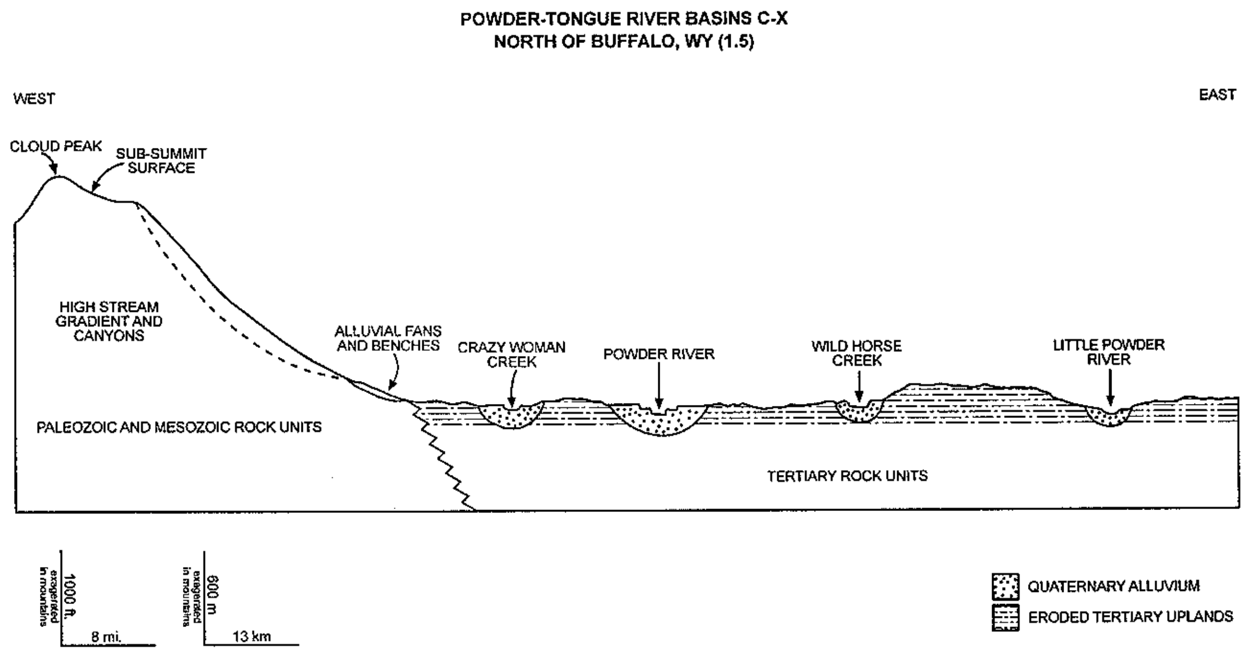


**Figure 8. Schematic cross section of the study area illustrating topography, surface geology, and soil relationships**

***Valley Alluvium.*** Alluvium occurs in valleys and contains post-glacial (less than 14,000 years old) sediment (Albanese 1990). Included in this category are channel and overbank sediments which grade laterally into slope wash and post-glacial alluvial fan deposits along the valley margins. Mapped areas of alluvium are found mostly in the foothills and the basins proper, in active and former floodplains. Much of the alluvium in the mountains is mapped as minor components of larger stratigraphic units. The few units that were mapped separately in the mountains have soil with well-developed A horizons (Cryoborolls) or clay-enriched B horizons (Cryoboralfs). In the basins, soils with some clay accumulation in their B horizons (Haplargids, Argiustolls, Natrargids) occur on slightly higher terraces while more poorly horizonated soils (Torrifluvents, Torriorthents, Ustifluvents) are common on lower terraces and floodplains.

***Exposed Bedrock.*** Areas of exposed bedrock and glaciated bedrock have hard rock that is exposed at the ground surface or rock that may only be covered by a thin zone of residuum or surficial deposits. These areas occur in several settings, including the steep eastern slope of the Bighorns, dissected uplands in the basin, and alpine areas that were scoured by glaciers. In glaciated areas, older soils with clay accumulation in their B horizons (Cryoboralfs) are common, as are soils lacking well-developed B horizons (Cryoborolls, Cryumbrepts). Soils on the bedrock areas in the basins are sensitive to slope position with more well-developed soils (Haplargids) occurring on flat areas, and less well-developed soils (Torriorthents, Haploborolls) on steeper slopes.

***Bench Deposit.*** Bench deposits are gravel-capped, isolated remnants of old river valleys and stand at the elevations of former basin floors. They are formed by topographic inversion whereby gravel-armored valleys erode slower than the surrounding softer (non-gravelly) bedrock, resulting in elevated, flat-topped features that are often dissected into several isolated planar remnants. Only one non-dissected bench is mapped in the project area; however, soil evidence suggests that other deposits might have been included within this map unit. Typically, well-developed soils occur on benches; however, the mixed variety of soil types (Torrifluvents, Ustifluvents, Argiustolls, Paleustolls, Haplargids, Torriorthents) present on the mapped areas suggests that some of the landforms may have a different origin. Dissected benches are slightly more common and have similar characteristics.

***Clinker.*** Areas mapped as clinker are situated on geologic formations that contain coal, primarily the Fort Union and Wasatch formations. The clinker is formed from the heat alteration of lithic impurities when coal beds burn. It consists of altered non-coal rocks (sandstone, shale, mudstone) that are lensed within or adjacent to the burning coal seam. Areas of clinker are common in the basin and its presence is often an indication that bedrock is close to the surface. Like bedrock areas, flat areas have soils with well-developed B horizons (Argiustolls, Haplargids) while steeper areas have thinner and poorly horizonated soils (Torriorthents).

***Terrace Deposits.*** Terrace deposits are present in some areas, both in the mountains and the basin. They are mapped adjacent to valley deposits along perennial streams on relatively flat-lying landforms. Some of these are probably too high above stream level or have too well-developed soils (Paleustolls) to be Holocene terraces. Many others have poor horizon development (Torrifluvents, Torriorthents, Ustifluvents) and might be Holocene-age. Still others have soils that are moderately developed (Haplargids, Natrargids, Argiustolls) and might be Holocene occurrences.

***Dissected Terrace Deposits.*** Dissected terrace deposits occur in the project area and are found adjacent to and slightly higher in elevation than post-glacial valley alluvium. They have a similar range of soil types as the terrace deposits (Argiustolls, Paleustolls, Torrifluvents, Ustifluvents, Haplargids, Camborthids, Natrargids), along with the potential range in ages. Dissected terrace deposits occur at the foot of the Bighorn Mountains as well as throughout the basin.

***Shallow Terrace Deposits.*** A few areas with shallow terrace deposits are mapped on intermittent tributaries of the Powder River in the vicinity of Kaycee, Wyoming. These occur in a setting underlain by a variety of Mesozoic and Tertiary rocks. Soil types are varied (Torriorthents, Natrargids, Haplargids) and range in age from Late Pleistocene to Holocene.

***Eolian Sand.*** Eolian sand occurs in the project area, although it is not as common as in the adjacent areas of the Wyoming Basin to the west and south. Mapped areas of eolian sand are most common near the head of the South Fork of the Powder River and the head of Casper Creek, north of the Powder River, Wyoming. These areas consist of mostly stabilized dunes and sandy interdune areas. The majority are downwind of the easily eroded Wind River Formation. Soils vary from poorly horizonated recent sands (Torripsamments) to buried or stabilized middle Holocene sands capped with clay-enriched B horizon (Haplargids).

***Glacial Deposits.*** Areas mapped as glacial deposits occur in the high mountains along the western margin of the project area. They are common at the base of the higher peaks in the Bighorn Mountains and in stream valleys draining these areas. Deposits consist primarily of till, which is a mixture of sand and gravel within a matrix of mud. These deposits are derived from Precambrian gneiss and granite. The sediment was transported by glaciers and emplaced in morainal deposits. Soils consist of well-developed mountain types with clay-enriched B horizons (Cryoboralfs), as well as some less well-developed types (Cryoborolls, Cryumbrepts). A single area of glacial outwash is mapped on a tributary of Big Goose Creek in the high mountains. The surface soils in this map unit are classified as Cryoboralfs, with clay accumulation present in the B horizon.

***Grus.*** In some areas of the high mountains, granitic rocks are exposed at the surface. Intercrystalline weathering of these granitic rocks has produced a grus deposit consisting of loose individual crystals derived from the granite. Grus is essentially a regolith that is formed into the upper part of the granite. It is most common in the northwestern portion of the project area. Predominant soil formation consists of clay-enriched B horizons (Cryoboralfs) with smaller areas of less developed soils that have organic accumulation in the A horizon (Cryoborolls).

***Landslides.*** Landslide deposits are mapped in a variety of areas, but generally occur directly downhill from steep slopes. Landslides have occurred on the flank of the Bighorn Mountains where large sections of Paleozoic bedrock have detached and fallen. Several landslide deposits also occur in the extreme southern part of the project area in an area where deformed Mesozoic rocks are overlain by Tertiary deposits. Only a few landslide deposits occur in the basin. One such area where they occur is around the flat-topped mesas named Pumpkin Buttes. The mesas are erosional remnants capped by the Tertiary White River Formation.

Soil formation on landslides in the project area is variable and relates primarily to local climate and age of the landslide deposit. In both the mountains and basins, some landslides have clay-enriched B horizons (Cryoboralfs, Paleborolls, Paleustolls, and Argiborolls in the mountains, and Haplargids in the basins), whereas less well-developed soils occur elsewhere (Cryoborolls in the mountains, and Torriorthents in both the mountains and basins).

***Playas.*** Two playas, which are internally-drained seasonal lakes, are mapped in the project area. One playa occurs on the divide between the Little Powder River and Donkey Creek, near Moorcroft, Wyoming, in an area underlain by Fort Union Formation rocks. It has soils characterized by clay accumulation in the B horizon as well as less well-developed soils (Torriorthents). The other playa is in the sand hills area on the South Fork of the Powder River north of Powder River, Wyoming. It is underlain by Cody Shale, and soils exhibit evidence of clay accumulation in the B horizon (Haplargids). These playas probably contain Holocene-age lacustrine sediments.

***Residuum.*** Residuum consists of bedrock that is weathered in place. Areas mapped as residuum are very common in the project area, and occur on a variety of rocks such as Mesozoic bedrock in the foothills and Tertiary bedrock in the basin. Soil formation in most areas is controlled primarily by slope with well-developed basin soils (Haplargids) on flatter areas and poorly developed soils (Torriorthents) on slopes. Well-developed soils (Argiustolls and Paleustolls) predominate on more stable areas within the foothills.

***Slope Wash and Colluvium.*** A large portion of the project area is mapped as slope wash and colluvium. Deposition of this material occurs by overland flow and rill fill during runoff events. Some debris flows and intermittent stream sediments are also present. The unit occurs in both the basins and the mountains. Generally, it is found on gently to moderately sloping ground. Most occurrences are probably Holocene-age, which is reflected by soil formation at these locations. In the mountains, soil formation is predominantly limited to humus accumulation in the A horizon (Cryoborolls), and only a few areas of slope wash have weathered (Cryochrepts) or clay-enriched (Cryoboralfs) B horizons. In the basins, poorly-developed soils (Torriorthents) are common although soils with weathered (Camborthids) or clay-enriched (Haplargids) B horizons also occur.

## VALLEY BOTTOM DEPOSITS

As identified on the surficial geology map, post-glacial valley alluvium and alluvial terraces are common surficial deposit within the project area. In addition, alluvial processes deposit large volumes of sediment in a low-to-moderate energy regime and so are conducive to the preservation of buried archaeological sites. Because of the potential of alluvium to preserve buried archaeological remains, deposits found in and adjacent to valley bottoms are investigated in more detail.

**Powder River Basin Alluvial Model**

The Powder River Basin is a classic landscape for understanding the Late Quaternary history of alluvial valleys in western North America. Leopold and Miller's (1954) seminal work set the stage for decades of subsequent investigation (e.g., Albanese 1990). These previous studies are very important for understanding how valley bottom locations fit into our sensitivity and burial model, which is discussed in detail below.

A considerable amount of work has been done to decipher the alluvial history of Quaternary river valleys in the Powder River Basin. Initial investigations were performed by Leopold and Miller (1954) and Haynes and Grey (1965). Subsequent testing of the model was conducted by a variety of investigators, but especially Albanese (1990). Mears et al. (1991) provide a review of some of these studies. The results of these investigations are discussed here and are used to help derive a valley bottom sensitivity model later in this chapter.

***The Leopold and Miller Model.*** Leopold and Miller recognize strong patterning in the geomorphic relationships of Late Quaternary river valleys within the Powder River Basin. They designate three inner-valley terraces (from lowest to highest): (1) Lightning (1.2-2.1 m [4-7 ft]); (2) Moorcroft (2.4-3.7 m [8-12 ft]); and (3) Kaycee (6-15.2 m [20-50 ft]). Leopold and Miller also propose that these terraces are underlain by a predictable set of sediments they designate as geologic formations. Deposits associated with the youngest Lightning terrace (the Lightning Formation) are composed of fine-textured overbank alluvium. The Kaycee Formation is composed of mixed slope wash and alluvium underlying the Moorcroft terrace, and also forms the uppermost bed on the Kaycee terrace. Leopold and Miller identify a "modern" soil with a "columnar" structure on the Kaycee terrace tread that formed into Kaycee Formation alluvium. The Ucross Formation, a recent (post-Wisconsin) pebbly gravel, underlies the Kaycee formation within the Kaycee terrace. They observe a well-developed calcium carbonate enriched paleosol that formed in the upper 2-3 ft of the Ucross formation; where the Ucross was absent this soil occurs in underlying sediment. Finally, the Arvada Formation, the oldest Late Quaternary deposit observed, is a weathered, periglacially modified, limonitic stained, cobbly gravel containing the remains of extinct late Pleistocene fauna. Arvada sediments fill deeply cut channels on the valley floors and overlie a bedrock strath under the Kaycee terrace.

Based on the relationships between the terraces and deposits, Leopold and Miller reconstruct a sequence of erosional and depositional events that they correlate with extant alluvial chronologies in the western U.S. During the early 1950s, these chronologies were calibrated, predominantly, with relative dates (mostly archaeologically derived) supplemented by a handful of dendrochronological and radiocarbon dates (Libby).

Leopold and Miller propose the following alluvial sequence for the Powder River Basin (Figure 9; Table 2) (Leopold and Miller 1954). The history of the alluvial sequence begins with cutting a relatively wide valley floor into bedrock. This took place at some unspecified time, presumably during the Pleistocene, and was followed by deposition of the Arvada Formation onto the valley floor. Subsequently, an inner valley was entrenched into this Arvada "floodplain", an event that occurred during the Late Wisconsin. This was followed by aggradation of floodplain gravel up to and possibly overtopping the former Arvada floodplain. An indeterminate interval of chemical weathering (i.e., redoximorphic processes) took place, resulting in limonitic staining within the Arvada gravel. Renewed deposition occurred with aggradation of finer textured gravel at canyon mouths near the mountains, and sand aggradation predominating further into the basin. This resulted in the deposition of the post-glacial-age Ucross formation, which is correlated to the early Paleoindian period based on the presence of extinct megafauna associated with Folsom-Plainview artifact associations. Then an erosional cycle removed part of the Ucross formation, partially rescouring Arvada-filled channels. Following this was the formation of a well-developed, calcium carbonate enriched paleosol into the Ucross Formation. Leopold and Miller correlate this soil formation with the Altithermal interval. Deposition of slope wash and alluvium of the Kaycee Formation followed. These deposits are associated with the presence of modern fauna and an age estimate of late Paleoindian to 4000 years before present (B.P.) is postulated. Erosion followed the deposition of the Kaycee Formation, during which the Kaycee Formation was incised down to the Moorcroft floodplain. Stabilization occurred at the Moorcroft strath or floodplain, an event that is correlated to approximately 2500-1000 years B.P.

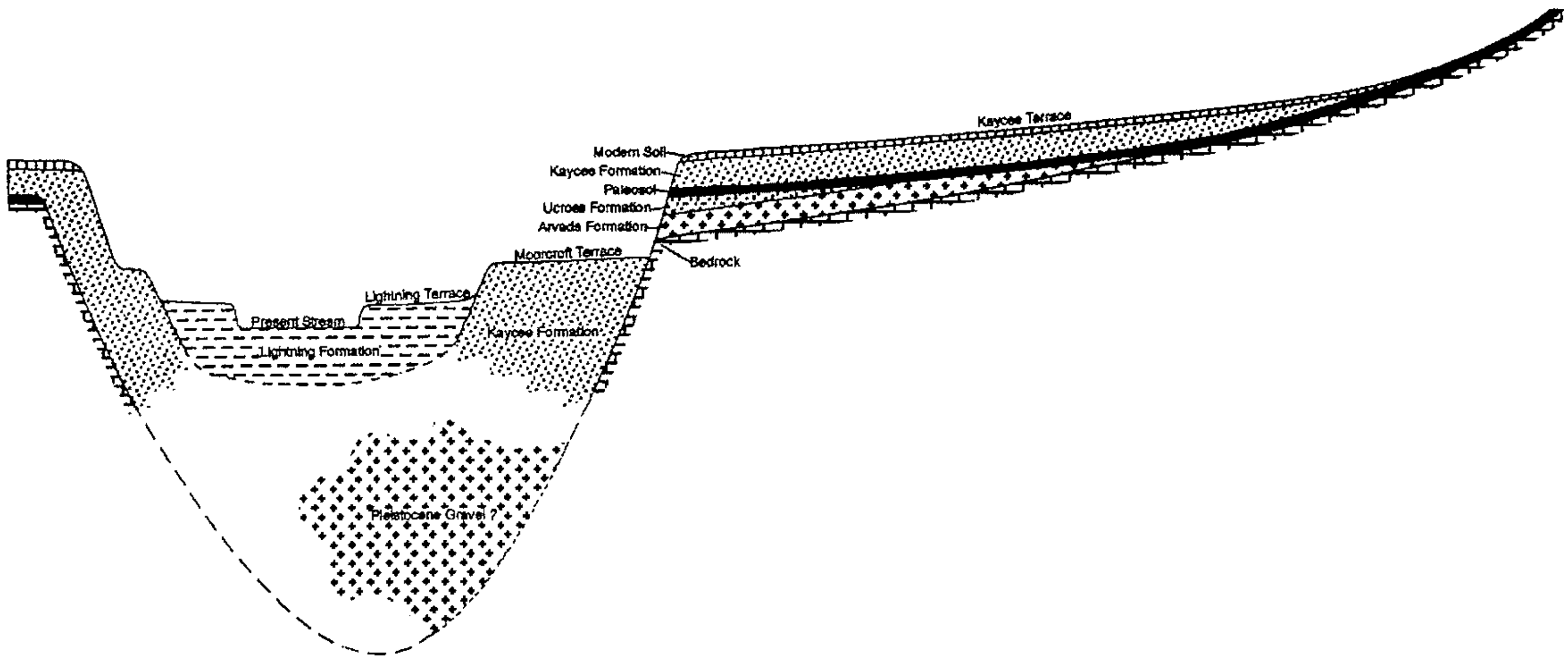


**Figure 9. Schematic cross section of typical Powder River and Tongue River basins stream valley illustrating relationships between Late Quaternary alluvial deposits and landforms**

## Table 2. Summary of Leopold and Miller (1954) alluvial model for the Powder River Basin

| Formation/Post-depositional Modification | Landform or Parent Material | Depositional, Environmental, or Pedogenic Regime | Deposit/Soil Characteristics | Age Indicators and/or Proposed Age |
|---|---|---|---|---|
| 1. Unconformity on Tertiary bedrock | | | | Tertiary |
| 2. Basal gravel | Fill underlying Recent channels | Fluvial channel | Gravel | Pleistocene |
| 3. Unconformity | | | | |
| 4. Arvada Fm. (very rare) | Deposit on cut bedrock strath | Fluvial channel | Gravel and gravelly sand | Extinct fauna |
| 5. Weathering - poor drainage on bedrock and lower part of gravel | Formed into bedrock | Possible perched drainage | Red iron staining on gravel (but not lower parts of wedges) | Evidence for iron mobilization |
| 6. Evidence for periglacial conditions on bedrock | Bedrock | Periglacial | Periglacial wedges | Pleistocene |
| 7. Possible erosional unconformity | | | | |
| 8. Ucross Fm. | Deposit overlying Arvada Fm. on bedrock strath | Channel and floodplain | Fine gravel with silt in upper part and redeposited, red-stained Arvada clasts | Anathermal |
| 9. Calcareous Soil | Formed into Ucross and sometimes into Arvada Fm. | Calcification | Carbonate mottling and rinds | Altithermal |
| 10. Erosion removes much calcareous soil | | | | |
| 11. Kaycee Fm. | Deposit overlying Ucross and forming Kaycee fill terrace | Slope grading into alluvium along valley axis | Generally silty with lenses of sand and gravel | Post-Altithermal, no extinct fauna |
| 12. Surface soil on Kaycee Fm. | Non-deposition/ non-erosion of Kaycee terrace tread | B horizon formation | Columnar or cloddy B horizon with some $CaCO_3$ | Post-Altithermal |
| 13. Channel incision cutting to Moorcroft surface | Incised into Kaycee alluvium | Occasional deposits | | Post-Altithermal - no flakes on this surface? |
| 14. Renewed channel incision | Continued incision into Kaycee alluvium | No deposits | None | During or slightly before Historic era |
| 15. Lightning Fm. | Fill terrace inset into Kaycee Fm. | Alluvium | Silty, fine or medium sand; lenses of fine gravel and coarse sand | Historic era |

After 800 years B.P., erosion and entrenchment reoccurred below the Moorcroft tread, producing the Moorcroft terrace. This was followed by overbank aggradation on the Lightning floodplain sometime around or after 800 years B.P. Finally, entrenchment of the modern channel occurred, resulting in the formation of the Lightning terrace tread.

Leopold and Miller (1954) conclude that the reconstructed alluvial sequence resulted from regional climatic events. Although subsequent work by Schumm (1981) indicates that alluvial sequences are affected by factors other than climate, some aspects of the Leopold and Miller model remain viable.

***The Alluvial Sequence in the Eastern Powder River Basin.*** Albanese (1990; 1984; 1978; Albanese and Wilson 1974) spent several decades and continues an ongoing effort to test and evaluate Leopold and Miller's model, especially as it pertains to the eastern Powder River Basin.

He makes several important observations:

1. Terraces in the eastern Powder River Basin are not always underlain by the age of sediments predicted by the Leopold and Miller model.
2. Local processes can lead to local terrace sequences.
3. The number of terraces present at any particular location varies by stream order.

As well, Albanese reports that at some locations the Kaycee correlative is capped by overbank alluvium which contains dates as young as 1580 ± 20 B.P. This suggests continued aggradation at some locations on the Kaycee floodplain, long after the date for its incision proposed by Leopold and Miller.

***Significance of Alluvial Models for the Present Project.*** Complexities of alluvial system dynamics are well known and have been adequately described elsewhere (Schumm 1973, 1981; Schumm and Brakenridge 1987; Schumm and Hadley 1957; Wolman and Leopold 1957). For the present study there are two significant aspects of the Albanese (1990) and Leopold and Miller (1954) alluvial models. First, is the presence of a textural contrast between potential archaeological bearing deposits (latest Pleistocene and Holocene) and older Pleistocene deposits

(>14,000 B.P) (Porter et al. 1983). Both Albanese (1990) and Leopold and Miller (1954) indicate that this contact can be identified by a distinct break in grain size (Hunt 1953). Typically, older Pleistocene gravel deposits (>14,000 B.P.) underlie Holocene sand and silt near the mountains and grade into coarse Pleistocene sand which underlies Holocene silt and clay in the interior basin. In addition, both Albanese (1990) and Leopold and Miller (1954), note that non-gravelly, valley fill younger than 14,000 years old is present in most valleys. Finally, both studies agree that the upper part of this post-glacial era valley fill underlies the highest Holocene-age terrace (the Kaycee). Although the Kaycee tread is referred to as an alluvial terrace, it should be noted that as the tread rises, the surface transitions from an alluvial terrace to a slope wash-deposited footslope. The wedge of slope wash thins laterally as the valley wall becomes steeper, whereupon weathered bedrock and colluvium begin to crop out and eventually predominate on the back slope.

Here, we use points of agreement between the alluvial models to delimit the width of non-gravelly valley fill, including alluvium and slope wash, along the watercourses in the project area. Other details of the alluvial models are not pertinent to the burial model. Our purpose is to provide as much specificity to the location of Holocene alluvial fills as possible and to characterize the sedimentary geometry of post-glacial-era deposits. Specific occurrences of fine-textured valley fill are important to delineate since stream valleys are known to contain Holocene alluvium deposited within a low depositional energy regime, and these settings are likely to preserve archaeological sites. Thus, we use existing alluvial models (Leopold and Miller 1954; Albanese 1990) to predict the relative width of fine textured Holocene alluvial and slope wash deposits within the valleys of the project area.

## Data Reduction

### SENSITIVITY MODELING OF VALLEY BOTTOM DEPOSITS

Valley bottom deposits are modeled using the height above stream of the highest portion of the highest Holocene terrace (Kaycee) as derived from the literature and field reconnaissance (Appendix B). Width of valley deposits is calculated from contours on 1:24,000 topographic maps. The position of the valley fill is mapped onto a digital version of the stream courses (hydrography). This process is discussed more fully below.

## Management and Planning Stream Buffers

A 1:100,000 (100k), digital hydrography dataset is used to model the width of valley bottom deposits (Wyoming Gap Analysis 1996). Examination of USGS 1:100,000 scale topographic maps indicate the presence of various permanent and intermittent stream channels in the project area (Figure 10). The topographic variability of the mountain and basin areas requires treating drainages in the respective areas differently. The mountains consist of rugged peaks with high gradient streams, a sub-summit surface (plateau) that has relatively low gradient streams, and a steep mountain front consisting again of high gradient streams. By contrast, the basins have much less diversity in gradient. Because of this contrast in topography we used gradient to classify stream segments within the mountains, whereas, we used stream order for basin streams. In both cases, stream channels serve as the centerline for defining valley fill (here referred to as stream buffers). Buffering proceeds through a number of stages as discussed below.

***Stream Buffering Using Sample Streams.*** The mountain-basin distinction is based on the break in slope at the base of the mountains as observed on topographic maps. The elevation used to reflect this break is different for the Bighorn Mountains versus the Rattlesnake Hills (1900 m [6232 ft] versus 2000 m [6560 ft], respectively). Everything below these elevations, for their respective areas, are automatically grouped into the basin areas.

We estimate the height of the highest post-glacial valley fill for each gradient or stream order class. Since a footslope grades to and merges with the highest alluvial terrace within most valleys, we estimate the upper height of this footslope. This is the elevation above stream level where the footslope pinches out on bedrock on the upper part of the footslope. Height of valley fill is calculated from: (1) survey of the literature; (2) observations acquired during field reconnaissance; and (3) inspection of landforms on topographic maps. Reconnaissance indicated that there were very few instances where Ice Age gravel terraces stood above post-glacial era fine-textured terraces. Thus, for many stream gradient or stream order classes it was a simple matter to identify upper terrace/footslope tread on 1:24,000 topographic maps. Maximum height of post-glacial fill (upper elevation footslope grading to highest fine textured terrace) for basin streams used in this report is: Stream Order 6 = 24.38 m (80 ft), Stream Order 5 = 21.34 m (70 ft), Stream Order 4 = 18.29 m (60 ft), Stream Order 3 = 15.24 m (50 ft), Stream Order 2 = 12.19 m (40 ft), and Stream Order 1 = 9.14 m (30 ft); whereas for mountain streams: 0-2.5 percent Gradient = 12.19 m (40 ft), 2.5-5 percent Gradient = 12.19 m (40 ft), 5-10 percent Gradient = 6.10 m (20 ft), and 10-100 percent Gradient = 3.96 m (13 ft).

Height above the stream is then projected cross-valley to the valley walls to establish the width of various stream order and stream gradient classes. For this exercise we select stream gradient and stream order segments from a variety of sub-basins within the project attempting to sample diverse stream types. Identifying the intersection of any topographic contour line with the stream channel on USGS 24k topographic maps provides a reference point for projecting the height of valley fill. At each intersection, a line is drawn from the stream-contour line intersection in an upslope direction (perpendicular to the stream channel) until the required elevation above stream shoreline is interpolated. The longest line segment (stream-right or stream-left) is chosen to represent the half-valley width of the valley fill. When half-valley widths are determined for all sample streams, the measurements for each stream order or stream gradient class are summed and averaged. The half valley width is then used as the value to create a buffer (corridor) along each stream class within the digital hydrographic dataset (1:100,000) using the GIS software.

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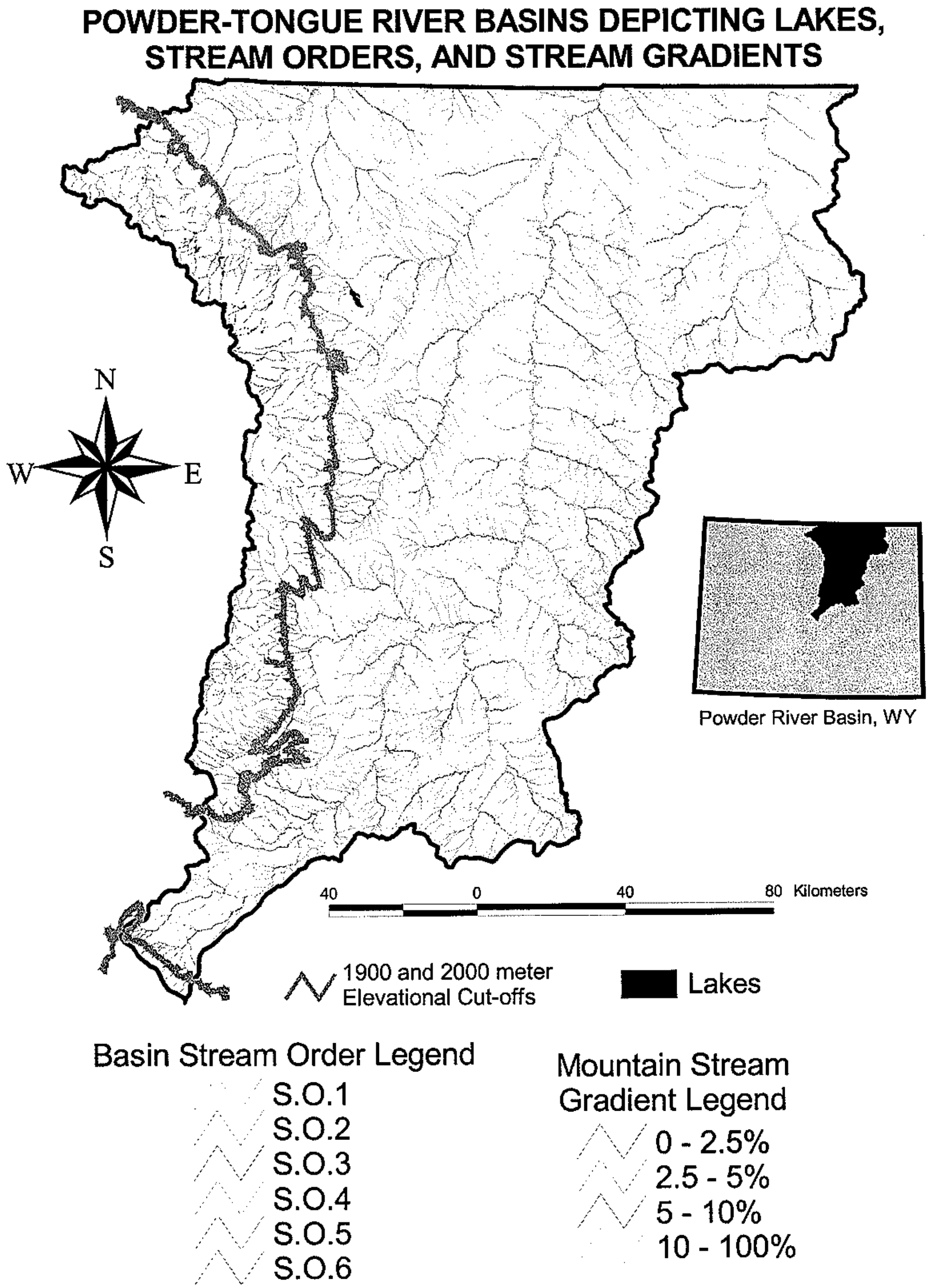


**Figure 10. Map of the Powder River and Tongue River basins drainage network showing stream orders, gradient classes, and lakes**

Next, the buffers or corridors, representing the width of post-glacial valley fill, are overlain on a sample of 24k USGS topographic maps. The buffer width is then examined visually to see if it encompasses the valley width. Buffer width is then judgmentally adjusted in width in a consistent way for each gradient or stream order class so as to encompass the valley bottom width at the 1:24,000 scale.

Natural lakes are also buffered because they generally are situated in low slope depositional basins and usually in stream valleys. Like stream valleys, lakes generally have a toe slope that grades to their shoreline. A GIS dataset containing the lakeshore boundaries was procured (Wyoming Gap Analysis 1996). All lakes within the mountain regions are included, and also one lake within the basin region, Lake De Smet, is included. Although the latter is now dammed, a natural lake preceded the reservoir. Most of the other lakes situated in the basin are reservoirs that are not treated as lakes. Also, mountain reservoirs are buffered to their existing shorelines since many reservoirs in the mountains are dammed and inundated prehistoric lakes.

## STREAM BUFFER MODELS: MANAGEMENT AND ANALYTICAL

***Management Stream Valley Buffers.*** The map resulting from the analysis described above is termed the "management" stream buffer map (Figure 11). It is designed for use as non-technical management dataset in the sensitivity models we construct later in this report, as it provides an estimate of valley fill, which strongly favors a site preservation goal. The map is constructed to illustrate the maximum extent of post-glacial valley fill at scales of 1:100,000 or smaller. A considerable amount visual checking and judgmental readjusting of the buffer width was conducted in this way to make the map as useful as possible at the 24k scale. We achieved a satisfactory level of success; however, no warranty is made for the accuracy of the stream buffers at a scale of greater than 1:100,000.

***Analytical Stream Valley Buffers.*** We developed an "analytical" stream buffer map that removes portions of the management buffer. In this buffer, we remove areas adjacent to valley fill that are included within the management map but which have streams with steep gradients or steep valley walls. We constructed this map for the purpose of testing the buffering method using site data from the Wyoming Cultural Records Office (WYCRO). The "steep area" cutoff is any area with a slope greater than 10 percent. Therefore, areas within the management buffer which contain a slope greater than 10 percent are excluded from the buffered streams areas. Removal of the steep areas results in the elimination bedrock-cut valley walls from the buffers, as well as some stream segments that are too steep to have consistently preserved occupation zones from the ravages of burial disturbance.

**POWDER-TONGUE RIVER BASINS: MANAGEMENT VS. ANALYTICAL STREAM BUFFERS**

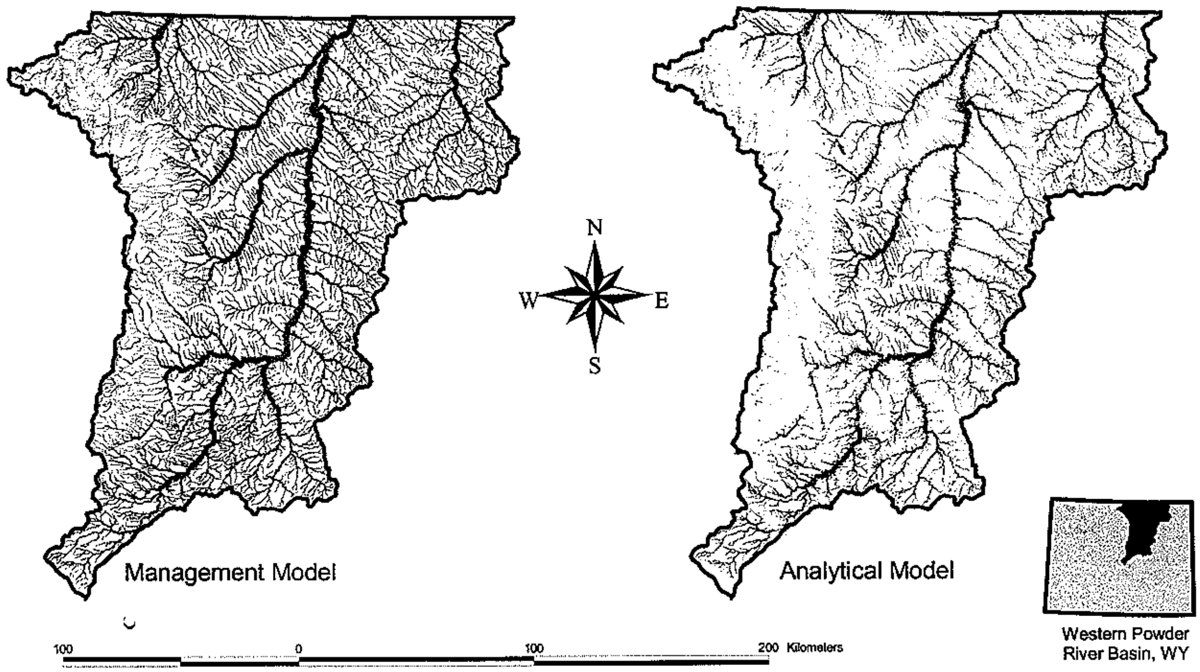


**Figure 11. Map illustrating stream buffers created for the Powder River and Tongue River basins risk-sensitivity model**

Steep areas were identified using a 30-m digital elevation model (DEM) grid to create a slope map for our project area. The slope map was divided into two zones: areas with 10 percent or greater slope and areas with less than 10 percent slope.

A stream layer was developed to use in conjunction with the slope map. To create this dataset, vector streams were split into segments approximately 250 m (820 ft) in length. This provided a good balance between detail and size. Larger segments did not reveal short, steep sections, while smaller segments made the dataset too complex. The elevations for the beginning and ending nodes of each segment were added using the 30-m elevation grid. Change in elevation along with length was used to calculate the gradient of each segment. Those segments with 10 percent or greater gradients were removed from the dataset.

The remaining segments were buffered based on stream order as described above for the management buffers. The buffers were then converted to a 30-m grid and adjacent areas with a 10 percent or greater slope were subtracted from the buffers. The resulting valley bottom buffers have slopes less than 10 percent. Small areas were removed by running a majority filter on the resulting grid twice. That grid was converted back into polygons and further filtered by removing all polygons less than 10,000 $m^2$ (107,639 $ft^2$) area. In addition, any non-buffer "island" polygons within the buffers that are less than 30,000 $m^2$ (322,917 $ft^2$) in area were removed. Finally, lakes were added back into the model. These manipulations reduced the complexity of the dataset while retaining its salient characteristics. The "analytical" stream buffer model (illustrated in Figure 11) is ultimately incorporated along with non-valley areas into the Archaeological Landscape Sensitivity Model using both STATSGO and SSURGO data, which is discussed in more detail below.

## SENSITIVITY MODELING FOR NON-VALLEY LOCATIONS

Modeling the alluvial valleys comprises one part of the model we present here. Non-valley locations are modeled using a different method. Here, we outline a methodology for subdividing the non-valley portion of the project area into zones, which are more or less likely to contain depositional settings conducive to preservation of buried and relatively intact prehistoric occupations. This is accomplished by: (1) estimating if the depositional energy regime of the sediment which buried the site is low enough to preserve the site during burial, (2) considering post-burial site formation and destruction factors that might have affected the contextual integrity of the site, and (3) assessing if the age of the deposits is within the range of human occupation (<12,000 years old).

Thus, sediments that are either too old or were deposited within a high-energy depositional regime, or were subject to high levels of post-burial site destruction are predicted to have very low or low sensitivity. Conversely, sediments that are younger than 12,000 radiocarbon years old, were deposited within lower energy depositional environments, and have not been subject to extensive site destruction processes, are more likely to contain prehistoric cultural occupations that possess stratigraphic and behavioral integrity. Landscapes possessing characteristics conducive to site preservation are considered to be more "sensitive" (at greater risk) from the perspective of site burial potential.

Spatial variation in the intensity of site destruction processes across the landscape is primarily a function of depositional environment. This variation is controlled by slope, transport energy, and resultant sediment. Artifact dispersal occurs in most depositional environments (Butzer 1982), though an exception to this is eolian silt (loess) environments. Lack of significant burial dispersal in loess is the result of a low surface wind shear (because vegetation is usually present) and the low impact energy of the silt particles. Many surface sites on flat, vegetated surfaces are eventually, albeit slowly, covered with a shallow mantel of loess. As mentioned in the methodology section above, other common depositional environments can be ranked into two categories of potential burial dispersal. A relatively low to moderate energy category includes alluvial overbank, sheetflow (including slope wash), and eolian sand environments. The moderate-to- high-energy category would include alluvial channel, debris flow, and colluvial depositional environments. For most water and air entrained sediments, artifact movement is a function of their size and density (Gifford and Behrensmeyer 1976).

The considerations discussed above, allow the construction of a model that classifies the landscape in terms of its archaeological sensitivity. This model is used to predict the spatial occurrence of sediment younger than 12,000 years B.P. at non-valley locations. It also predicts locations where site formation processes might better preserve significant archaeological resources (very high and high archaeological landscape sensitivity). Favorable locations are mapped and differentiated from locations with surface sediments older than 12,000 B.P. and/or with little potential to preserve reasonably intact archaeological sites (very low and low archaeological landscape sensitivity).

NRCS soil maps are used to help classify the relevant depositional and site formation criteria. Individual soil map units are the smallest spatial unit used in the analysis. Map unit descriptions acquired from the NRCS contain information on the soil taxon, sediment type, and landform type within each map unit. Early attempts to classify archaeological sensitivity utilized a manual, light table, approach to superimpose taxon, deposit type, and landscape characteristics to determine archaeological landscape sensitivity (Eckerle 1989). A GIS approach is used in this project to simplify the process of assigning archaeological sensitivity to soil map units.

**Scale of Soil Map Data**

Several scales of soils mapping (1:24,000, 1:250,000) are utilized in this project. Coverage at 1:24,000 is incomplete (Figure 12). County level mapping (1:24,000; SSURGO) is used where possible. SSURGO mapping is available for southern Campbell, southern Johnson, Natrona, Sheridan, as well as the small portions of Washakie, Converse, and Crook counties within the project area. Bighorn National Forest soils mapping is available from the United States Forest Service (1999), and provides nearly identical spatial geometry as would be provided by SSURGO. Unfortunately, the southern part of Johnson County is not available in a digital format and was omitted from the 24k analysis. To adjust for the lack of coverage in the areas lacking digital 24k mapping, we supplemented the SSURGO data with multi-county NRCS soils mapping (STATSGO; 1:250,000).

**Data Acquistion**

Both 250k (STATSGO) and 24k (SSURGO) scale soil mapping data was extracted from NRCS sources and entered into a custom Microsoft Access database designed for sensitivity modeling. Population of the database required two primary data sources: (1) hard copies of NRCS soil surveys for individual survey areas (mostly defined by county), and (2) a digital Soil Survey database. For the hard copy surveys, all attribute values are taken from the survey, including series descriptions. Three areas of the NRCS soil surveys are primarily used: (1) the map unit number description section, (2) the soil series description section, and (3) the engineering table appendix.

Series name, parent material, landform, precipitation, slope, and percent composition are all extracted directly from the map unit description section of the soil survey reports. Depth to bedrock, percent coarse sediment >2.0 mm (0.08 in), and range site are all extracted directly from the soil series description section of the soil survey reports. Great group taxon names are

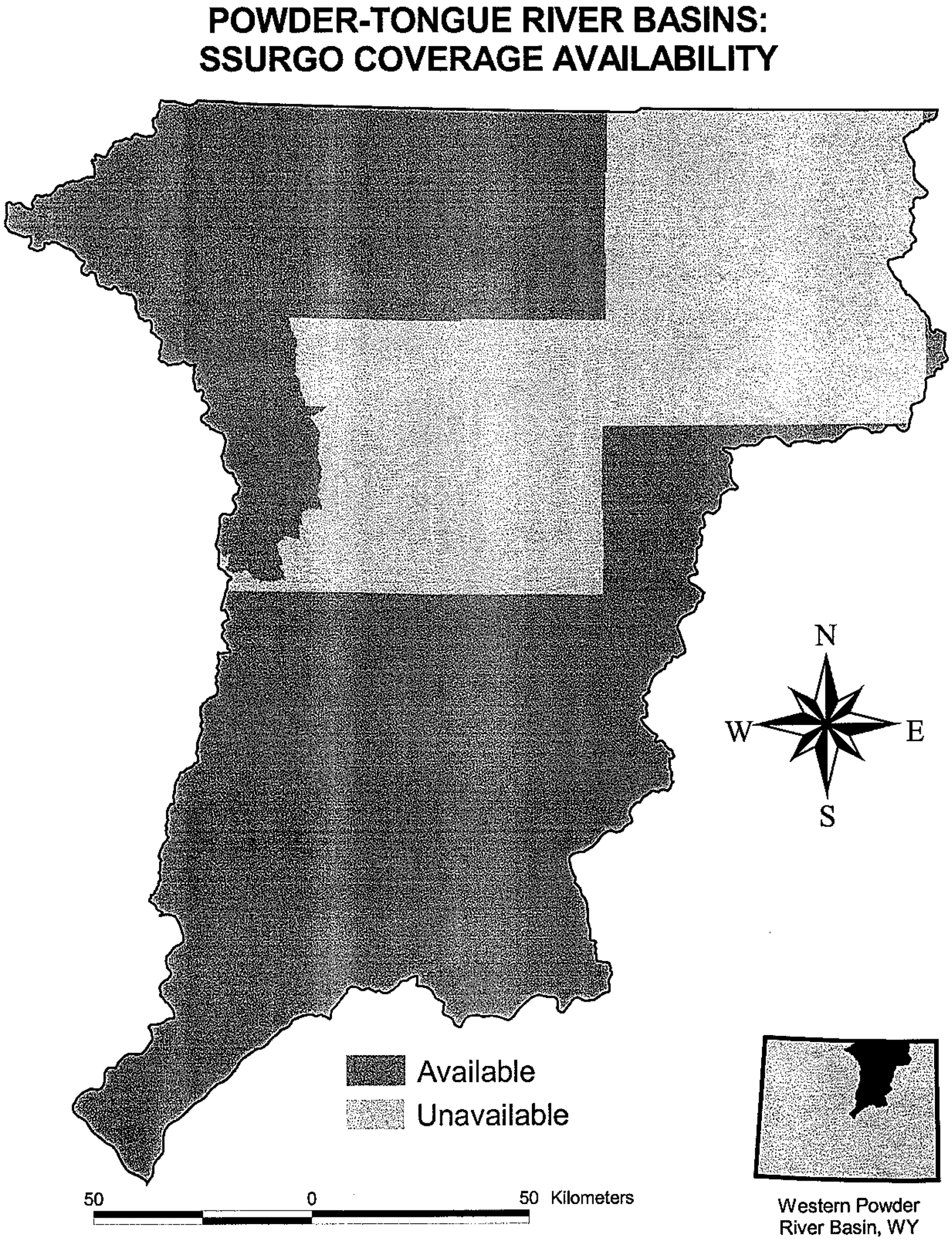


**Figure 12. Soils mapping availability for SSURGO (1:24,000 base soil mapping) soils data**

from the Classification of the Soils table contained within the soil survey reports. Percent gravel >7.6 cm (3.0 in) are all taken directly from the Engineering Index Properties table contained within the soil survey reports. For soil survey areas that did not have a hard copy soil report, we used a digital database provided by the NRCS. Unfortunately, this digital database did not contain all of the data provided by hard-copy series descriptions, thus we had to use the Official Soil Survey Descriptions (http://soils.usda.gov/technical/classification/osd/index.html) provided by the NRCS to supplement the digital information. These descriptions are virtually identical to the ones provided within the soil survey reports, however they are more generalized to the entire geographic range where an individual soil series occurs.

**Sensitivity Considerations**

The goal of the archaeological landscape sensitivity model is to use the soils mapping, surficial geology, and alluvial valley information to help predict the location of sediments that are the right age and type to contain significant buried archaeological sites. Soils mapping generates information on a number of variables relevant to this goal. For this analysis the following variables were tabulated from the NRCS soil mapping data: (1) map unit number; (2) depth to bedrock; (3) slope; (4) soil taxonomic classification; (5) landform; (6) deposit type; (7) percent gravel; and (8) percent coarse gravel.

The sensitivity analysis systematically followed rules presented in a sensitivity outline (presented below) using the criteria provided therein. Each step was done separately and saved to an ArcView shapefile. The shapefiles were then either intersected with each other, or added to the final intersection, based on the individual criterion and its operator (i.e., AND/OR). A discussion of each of the variables follows.

**NRCS Data Categories**

***Map Units.*** Soil map units delineate areas of similar soils. Map units consist of a single series, an association composed of two series, or a complex of three or more soil series. The soil map units are described in the following NRCS county soil survey reports and related SSURGO digital soils data: Soil Survey of Crook County, Wyoming (Elwonger 1983); Soil Survey of Bighorn National Forest (Nesser 1986); Soil Survey of Natrona County, Wyoming (Malnor and Arnold 1997); Soil Survey of Sheridan County, Wyoming (Lupcho 1998); Soil Survey of Washakie County, Wyoming (Liams 1983); Soil Survey of Converse County, Wyoming (Reckner, 1986); Soil Survey of Johnson County, Wyoming, Southern Part (Stephens 1975); and SSURGO data for Campbell County, Southern part (National Resource Conservation Service 1998). County surveys were clipped to the project area so not all areas of the listed counties are included. Some of the important variables extracted from the map unit descriptions are described below.

***Depth to Bedrock.*** Depth to bedrock is used to estimate the potential for a sedimentary mantle over bedrock, which would protect and preserve archaeological deposits. Sedimentary environments aggrading at a moderate to rapid rate generally offer a better chance of site preservation than do sites that form a soil surface for many thousands of years. Exceptions are made, however, for high-energy depositional regimes transporting gravel size material, as destruction of archaeological context is likely to have occurred. Other depositional environments often allow differentiation of multiple occupations, especially when sterile sediment occurs between the occupation zones. Perishables, including charcoal and butchered animal bone, are more likely to be preserved in aggradational environments, than in environments where little aggradation is occurring and the perishables are exposed to the elements or destructive soil horizons.

***Slope.*** Slope steepness characterization provides one measure of depositional energy. Steeper slopes occur in colluvial and mass wasting environments as well as mountainous alluvial channel environments. More moderate slopes occur in slope wash environments and moderate gradient stream channels, while low slope characterizes floodplains.

***Soil Taxonomic Classification.*** The taxonomic classification of the principal surface soil(s) in each map unit is tabulated. These are listed to the family or great group level of classification. Implicit in the classification are soil features that have genetic and chronological significance (Soil Survey Staff 1975), and thus provide insight to where sediment younger than 12,000 years old is located. Both the regional and local studies (Birkeland 1999; Birkeland et al. 1991; Reider and Karlstrom 1987; Reider 1983; Reider 1980; Albanese 1991; Albanese 2000; Eckerle 1986a) suggest that a general, time-dependent sequence of horizon development can be identified and includes from youngest to oldest: A (surface organic accumulation); Bw (oxidation or weak structural development); Bt and Bk (clay accumulation and calcium carbonate accumulation, respectively); K (very well-developed calcium carbonate accumulation); and Bym (very strongly developed gypsum accumulation). In terms of the taxonomic classes present in our study area, a relevant sequence would be as follows from youngest to oldest: (1) Orthents and Fluvents; (2) Camborthids at the great group level, and calcic and argic variants at the family level of other great groups; (3) Argids and Calciorthids; and (4) Paleargids and Paleorthids. A tentative age estimate for these taxonomic groupings is: (1) <1,000 year B.P.; (2) 1,000 to 10,000 years B.P.; (3) 10,000 to100,000 years B.P.; and (4) >100,000 years B.P. These estimates can be used to calculate the age of the deposits on which a soil is formed. We use these estimates to identify soils that are unlikely or questionably formed on Holocene-age sediment.

***Landform.*** Landform is a good indicator of depositional setting. Good potential depositional settings for archaeological sites are often found in floodplains, low (overbank) terraces, inset alluvial fans, and footslopes. Some areas such as badlands, rock outcrops, and cliffs contain no significant soil mantel and are poor settings for the potential preservation of buried archaeological materials with integrity. The NRCS maps these areas as non-soil areas. Landform was specifically used to help identify the locations of eolian sand sediment forming sand dunes.

***Deposit Type.*** Parent material characterizations in the NRCS data provide an estimate of both the depositional energy regime and depth of burial. Like landform, we used deposit type (eolian sand) to help identify dune fields and to informally cross-check other categories to assure that they compared favorably to sensitive deposit types. Depositional settings most likely to contain sites with good integrity are floodplain deposits, low angle alluvial fan deposits, and slope wash deposits. In contrast, locations not likely to preserve site integrity include residuum, regolith, channel gravel, and talus. Analysis of deposit type was supplemented by the use of a digital map of Wyoming surficial deposits (Case et al. 1998).

***Gravel.*** Percent gravel (clasts >2 mm) is tabulated for the soils. Percent gravel for each horizon within each soil series is presented as a range of values from which the median percent is selected to represent the series. This variable provides a good proxy measure for the energy regime of the deposit.

***Cobbles and Boulders.*** The content of cobbles and boulders (clasts >7.6 cm) present in each map unit is tabulated. The maximum percentage for each soil series is weighted according to percent that the soil series comprises of the total map unit. Rock outcrop and/or bedrock are considered to contain 100 percent fragments >7.6 cm. For this size of sedimentary clasts the weighted averages for each soil series is derived and then all the component series are averaged to get a representative figure for the map unit as a whole.

## ARCHAEOLOGICAL LANDSCAPE SENSITIVITY OUTLINE

The criteria discussed above are used to construct rules that are used to categorize sensitivity classes. These rules are outlined to facilitate the intersection and reclassification of the soil map units into archaeological landscape sensitivity areas. GIS tools are used to classify and display the sensitivity criteria into sensitivity areas using the rules specified in the outline. The process used to generate the final sensitivity areas is analogous to classifying each sensitivity criteria, displaying the classification on a transparent map, and then overlaying all the transparent maps on a light table and outlining the intersection of all the similarly classified criteria.

The analysis involved identifying the sensitivity zones in a sequential manner based on what we determined to be the most clear-cut and reliable characteristics. Class boundaries were confined by the distribution of data within particular variables and between several variables. The overall goal in determining various percent cut-off figures used in the outline was to find some balance in the relative distributions of the various sensitivity classes while at the same time not violate the theoretical and methodological precepts outlined earlier in this report. This involves a certain amount of subjectivity, which is tempered by geoarchaeological experience. Once an area (NRCS map unit) was assigned to a particular sensitivity zone, it was excluded from further analysis. The sensitivity zones are classified as very high, high, very low, and low. Remaining areas are classified as moderate. Manual inspection of post-classification variables/values suggests that the moderate category is transitional between high and low with regards to sensitivity criteria. A soil component generally means a soil series and some adjustments were needed to accommodate both the STATSGO and the SSURGO databases specified below. Note that the term "inclusion" refers to a soil series that is present in a map unit, but which composes a very low proportion of the map unit. Inclusions were excluded from the analysis.

**STATSGO/SSURGO Sensitivity Outline**

1. VERY HIGH SENSITIVITY AREAS meet the following criteria:
   a) are defined as "very high sensitivity" on the stream valley model (stream buffer model), or;
   b) contain a soil component where the parent material is eolian sand (only used for STATSGO), or;
   c) contain Soil Series (Decolney, Dwyer, Hawkstone, Hiland, Moskee, Orpha, Ryan Park, Tullock, Valent, Vonalee, Whiteriver) that are formed in eolian sand, or sand dunes, and the sum of the included soil components compose 30 percent for STATSGO, 50 percent for SSURGO, or more (≥30/≥50) of the map unit.

2. HIGH SENSITIVITY AREAS meet the following criteria:
   a) contain Soil Series (Decolney, Dwyer, Hawkstone, Hiland, Moskee, Orpha, Ryan Park, Tullock, Valent, Vonalee, Whiteriver) that are formed in eolian sand, or sand dunes, and the sum of the included soil components compose less than 30 percent for STATSGO, 50 percent for SSURGO, (<30/<50) of the map unit, or;
   b) contain a soil component where the depth to bedrock is 40 in or more (≥40), and the sum of the included soil components compose 30 percent or more (≥30) of the map unit, and;
   c) contain a soil component where the minimum slope is 10 percent or less (≥10) (excluding inclusions), and;
   d) contain a soil component where clasts 3 in or greater in diameter compose less than 3 percent (<3) by volume of the soil matrix (excluding inclusions), and;

e) contain a soil component where clasts 2 mm or greater compose 14 percent or less (≥14) by volume of the soil matrix (excluding inclusions), and the sum of the included soil components compose 50 percent or more (≥50) of the map unit, and;

f) contain a soil component having a likely Holocene-age soil taxon (Camborthids, Cryaquolls, Cryoborolls, Cryochrepts, Cryorthents, Cryumbrepts, Fluvaquents, Haploborolls, Haplocambids, Haplustepts, Haplustolls, Torrifluvents, Torriorthents, Torripsamments, Ustifluvents, Ustipsamments, Ustochrepts, Ustorthents), and the sum of the included soil components compose 25 percent or more (≥25) of the map unit.

3. VERY LOW SENSITIVITY AREAS meet the following criteria:

a) are made up of non-soil land including badlands, cirque land, colluvial land, gravel pits, gullied land, pits, dumps, rock land, rock outcrop, rubble land, shale outcrop, shale rock land, water, and the sum of the included non-soil land compose 75 percent or more (≥75) of the map unit, or;

~~b)~~ contain a soil component having a very unlikely Holocene-age soil taxon (Paleargids, Paleborolls, Paleustalfs, Paleustolls), and the sum of the included soil components composes 75 percent or more (≥ 75) of the map unit, or;

~~c)~~ contain soil components where the depth to bedrock is 25 in or less (≥ 25) (excluding inclusions), and the sum of the included soil components compose 30 percent or more (≥ 30) of the map unit, and;

d) contain a soil component where the average slope is 20 percent or more (≥ 20), and;

e) contain a soil component where clasts 3 in or greater in diameter compose 7 percent or more (≥ 7) by volume of the soil matrix, and;

f) contain a soil component where clasts 2 mm or greater compose 40 percent or more (≥ 40) by volume of the soil matrix, and the sum of the included soil components compose 25 percent or more (≥ 25) of the map unit.

4. LOW SENSITIVITY AREAS meet all of the following criteria:

a) are made up of non-soil land including badlands, cirque land, colluvial land, gravel pits, gullied land, pits, dumps, rock land, rock outcrop, rubble land, shale outcrop, shale rock land, water, and the sum of the included non-soil land compose 55 percent or more (≥ 55) of the map unit, or;

b) contains a soil component where the depth to bedrock is 35 in or less (≥ 35) (excluding inclusions), and the sum of the included soil components compose 30 percent or more (≥ 30) of the map unit, and;
c) contains a soil component where the average slope is 15 percent or more (≥ 15), and;
d) contains a soil component where clasts 3 in or greater in diameter compose 3 percent or more (≥ 3) by volume of the soil matrix, and;
e) contains a soil component where clasts 2 mm or greater compose 30 percent or more (≥ 30) by volume of the soil matrix, and the sum of the included soil components compose 10 percent or more (≥ 10), and;
f) contains a soil component having a questionable Holocene-age soil taxon (Argiaquolls, Argiborolls, Argiustolls, Calciargids, Calciborolls, Calciorthids, Cryoboralfs, Eutroboralfs, Gypsiorthids, Haplustalfs), and the sum of the included soil components compose 25 percent or more (≥25) of the map unit.

5. MODERATE SENSITIVITY AREAS
   a) Since the process is subtractive, moderate sensitivity constitutes the areas that remain after the previous operations have occurred, i.e., after the previous sensitivity areas have been delineated.

# RESULTS AND DISCUSSION

This project presents two sensitivity maps for the study area, one derived from 1:250,000 base mapping using STATSGO data (Figure 13), and the other derived from 1:24,000 base mapping using SSURGO data (Figure 14). Both maps contain stream buffering that is constructed at a scale of 1:100,000. Figure 13 presents sensitivity maps using STATSGO data for both the management and analytical stream buffer models. Likewise, Figure 14 presents sensitivity maps using SSURGO data for both the management and analytical stream buffer models. Figure 15 presents a comparison of the two maps using the management stream buffers. The STATSGO map is included because digital SSURGO coverage is incomplete for parts of the study area. Areas lacking SSURGO soil map northern Campbell County and southern Johnson County. The STATSGO map should be viewed coverage include at a scale no larger than 1:250,000, whereas the SSURGO map, excluding stream buffers, is appropriate for viewing the sensitivity classes at a scale no larger 1:24,000. Stream buffer data are accurate at a scale of 1:100,000. Note that some effort was made with the 1:100,000 stream buffer data to make it useful at a scale of 1:24,000. We feel that this process was relatively successful, but no warranty is made. The STATSGO sensitivity map (Figure 13) uses the same attributes and values as the SSURGO sensitivity map (Figure 14), with some minor exceptions noted in the outline presented above. A similar comparison is presented for the analytical maps in Figure 15.

The sensitivity classification system ranks areas according to potential geological conditions that favor buried site preservation (Table 3). Zones rated as very high and high predict locations where conditions are favorable for: (1) retention of archaeological behavioral-spatial context; (2) preservation of perishable archaeological materials (bone and charcoal); and (3) stratigraphic separation of archaeological occupation zones. The very high sensitivity reflects the distributions of landscapes of previous known important burial contexts, eolian sand and valley alluvium, respectively. Otherwise, the very high and high might be viewed as similar in terms of their management implications. Moderate, low, and very low sensitivity classes predict areas where there is a lessened chance of buried site preservation Caution is warranted as the sensitivity model only predicts where site preservation conditions might be favorable, and not locations that may have been attractive to human activity. Note that there are some special considerations concerning the use of the moderate category, especially within the STATSGO model (discussed below).

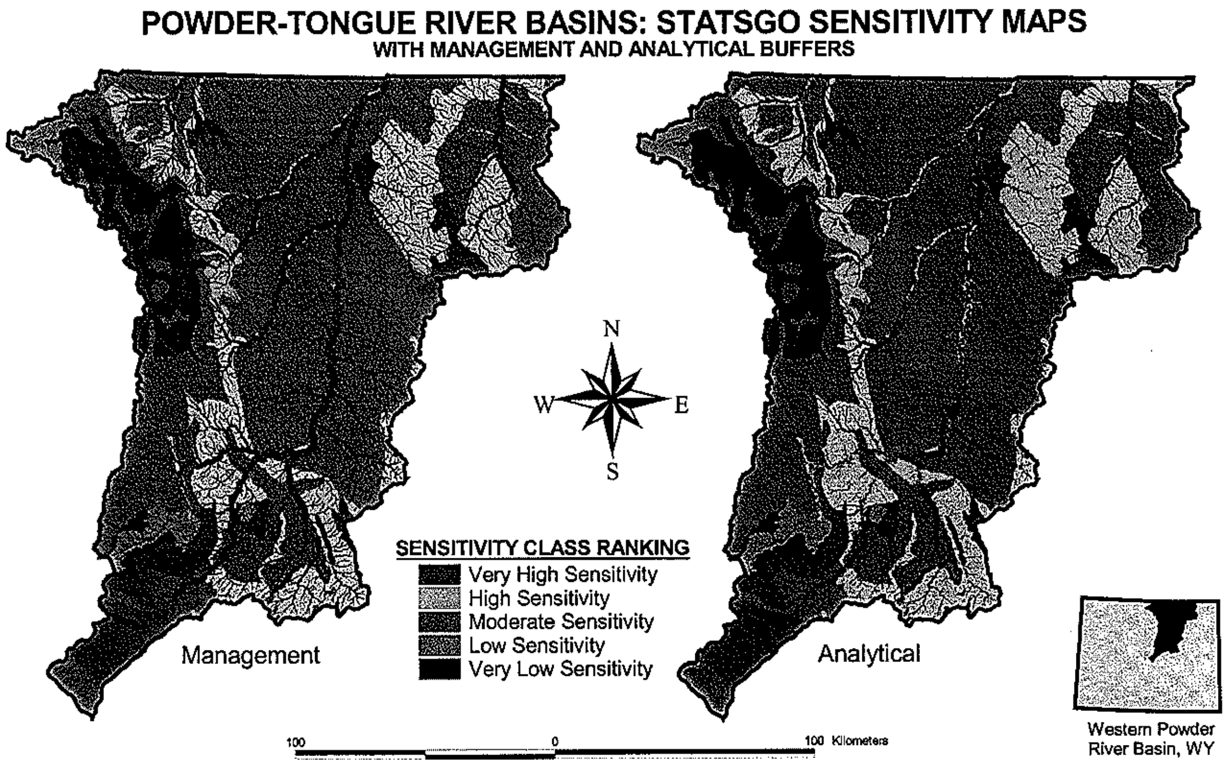


**Figure 13. Sensitivity map based on STATSO (1:250,000 base soil mapping) and stream buffers**

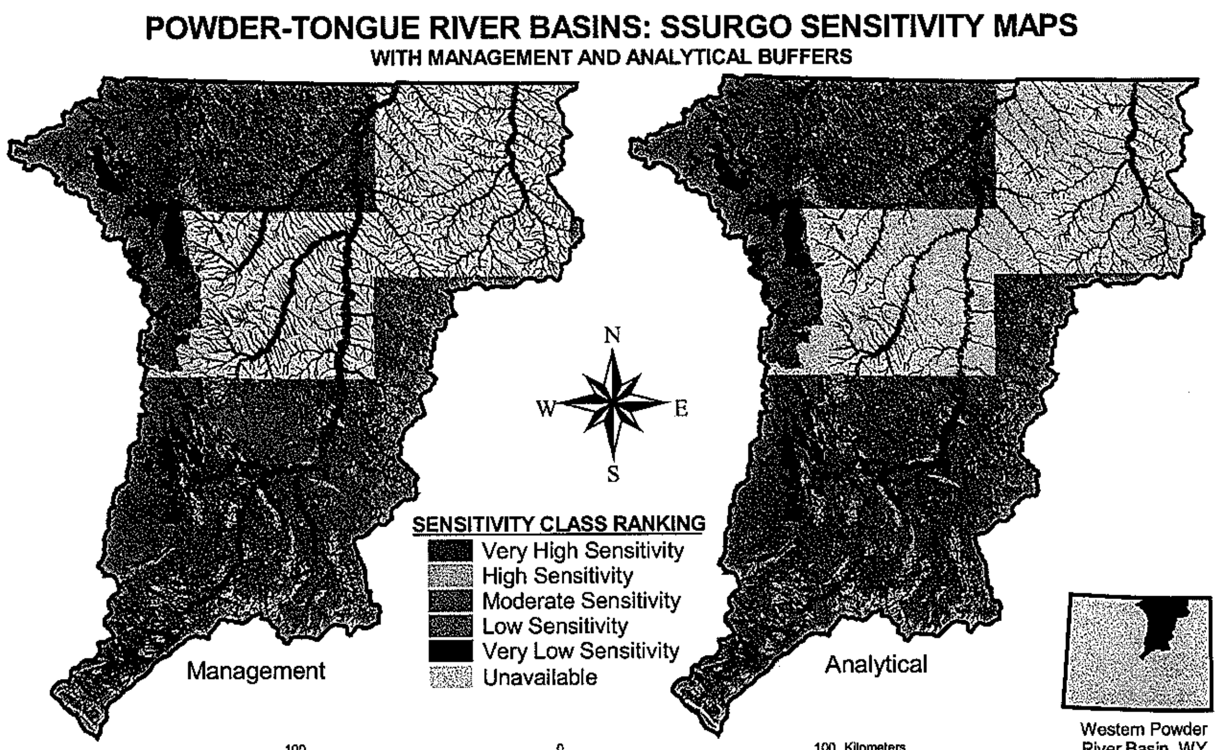


**Figure 14. Sensitivity map based on SSURGO (1:24,000 base soil mapping) and stream buffers**

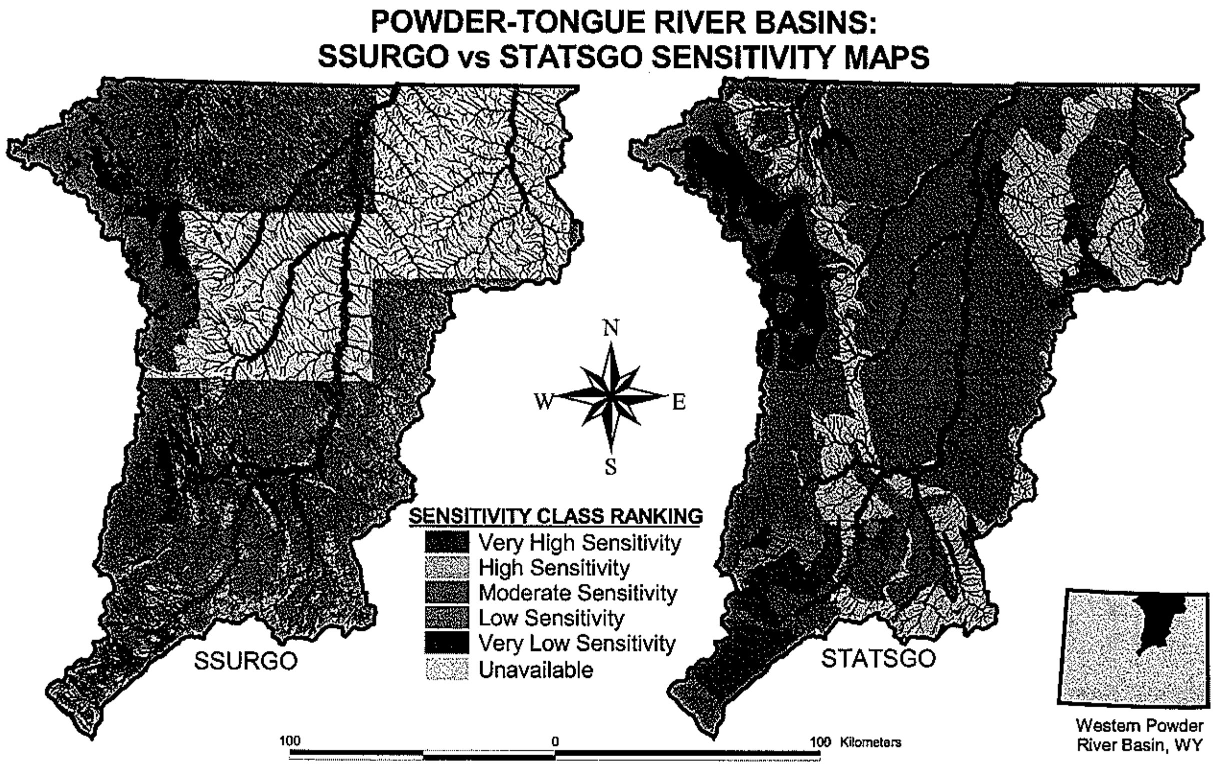


**Figure 15. Side-by-side comparison of SSURGO and STATSGO (1:24,000 and 1:250,000 base) sensitivity maps**

Ultimately, this information should be supplemented by training in its use. As well, the proper application of this information will require targeted field visits by agency and project archaeologists. A Protocol Handbook (Appendix A) facilitates use of the sensitivity map in the field, and provides a quick reference to its recommended use.

## SPATIAL ASSOCIATION OF SENSITIVITY ZONES OF KNOWN SUBSURFACE SITES AND RECOVERED RADIOCARBON DATES

Data from the Wyoming SHPO Cultural Records Office are used to evaluate the fit between archaeological data and the sensitivity model. Area and percent of study area within the sensitivity zones for each model (SSURGO [24k base]) analytical, SSURGO management, STATSGO [250k base] analytical, and STATSGO management) are presented in Tables 4 and 5 and Figures 16 and 17. Moderate sensitivity composes the highest proportion of the study area in all four models although less so in the SSURGO models. Additionally, the SSURGO analytical model exhibits the most even aerial distribution of very high and high, combined compared to low and very low, combined. Note that components within rockshelter sites are omitted from the analysis presented below. Because of their small aerial extent, the sensitivity model makes no attempt to model the location of rockshelters, despite the fact that these geomorphic features are important archaeological archives. In fact, rockshelters are often located on areas otherwise exhibiting low or very low burial sensitivity due the fact that they occur in steep, rocky locations.

Table 3. Summary characteristics for sensitivity classes

| Sensitivity Ranking | Landforms | Soil Parent Material | Engulfing/ Overlying Soil Age | Depth to Bedrock (60 " ax) | Minimum Slope | Average Slope | % Clasts ≥3 " | % Clasts ≥2mm |
|---|---|---|---|---|---|---|---|---|
| **Very High** | Low-Gradient Stream Valleys<br>Floodplains, Terraces, Sand Dunes | Alluvium<br>Eolian | — | — | — | — | — | — |
| **High** | Moderate-Gradient Stream Valleys<br>Alluvial Fans | Alluvium<br>Eolian<br>Slope Wash | Holocene Age Soils | 60-40" | 0-10% | n/a | 0-2.9% | 0-14% |
| **Moderate** | All Moderate areas fail to completely meet the criteria for other sensitivity classes. They may meet one or many criteria, but not all. This category can't really be given value ranges that would produce the selected areas within ArcView. | | | | | | | |
| **Low** | Non-Soil-Bearing Landforms (Badlands, Cirques, Bedrock, etc.)<br>Steep-Gradient Stream Valleys<br>Uplands, Interfluves | Colluvium<br>Residuum<br>Channel | Questionable Holocene Age Soils | 25.1-35" | n/a | 15-19.9% | 3-6.9% | 30-39.9% |
| **Very Low** | Non-Soil-Bearing Landforms<br>Very Steep-Gradient Stream Valleys<br>Uplands Interfluves | Colluvium<br>Residuum<br>Channel | Very Unlikely Holocene Age Soils | 0-25" | n/a | 20-100% | 7-100% | 40-100% |

**Table 4. Area by sensitivity class for each model**

| | STUDY AREA (ha) | | | | |
|---|---|---|---|---|---|
| MODEL | Very High | High | Moderate | Low | Very Low |
| SSURGO A | 413358 | 185780 | 1036473 | 66218 | 320363 |
| SSURGO M | 746570 | 153686 | 895480 | 62139 | 279676 |
| STATSGO A | 519127 | 516868 | 1501808 | 58645 | 241361 |
| STATSGO M | 837562 | 430224 | 1301170 | 50481 | 218415 |

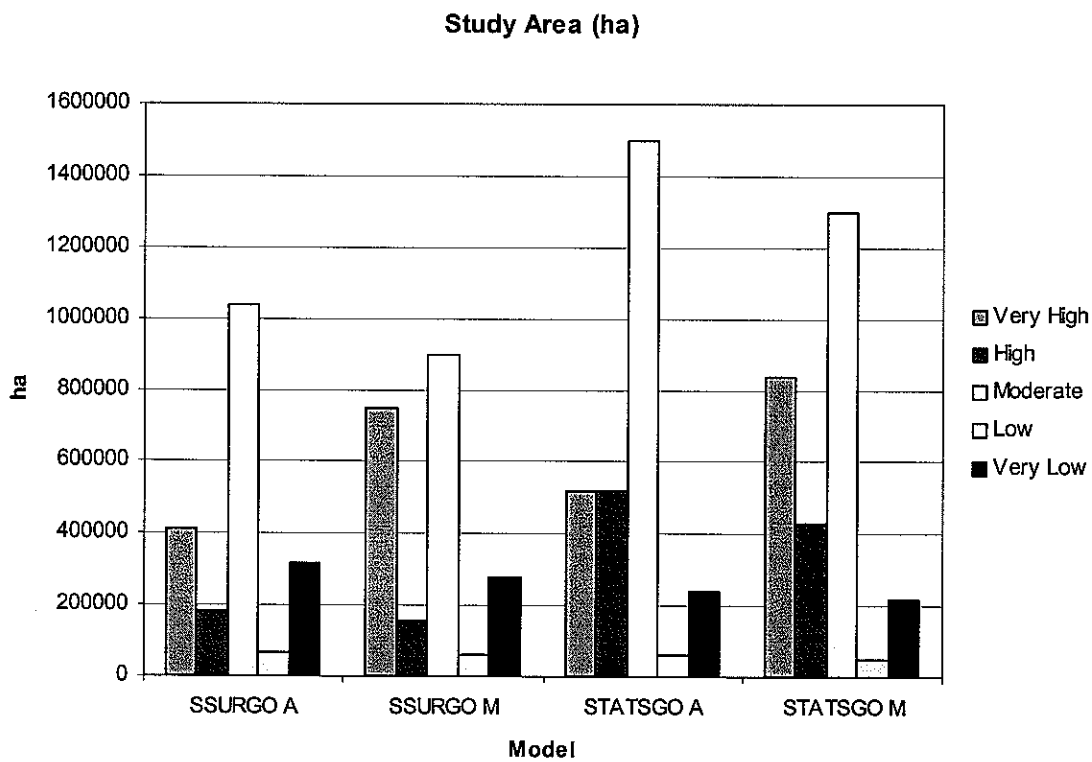


**Figure 16. Area by sensitivity class for each model**

**Table 5. Percent sensitivity class for each model**

| | PERCENT OF STUDY AREA | | | | |
|---|---|---|---|---|---|
| MODEL | Very High | High | Moderate | Low | Very Low |
| SSURGO A | 20.44 | 9.19 | 51.25 | 3.27 | 15.84 |
| SSURGO M | 34.93 | 7.19 | 41.89 | 2.91 | 13.08 |
| STATSGO A | 18.29 | 18.21 | 52.92 | 2.07 | 8.51 |
| STATSGO M | 29.51 | 15.16 | 45.85 | 1.78 | 7.70 |

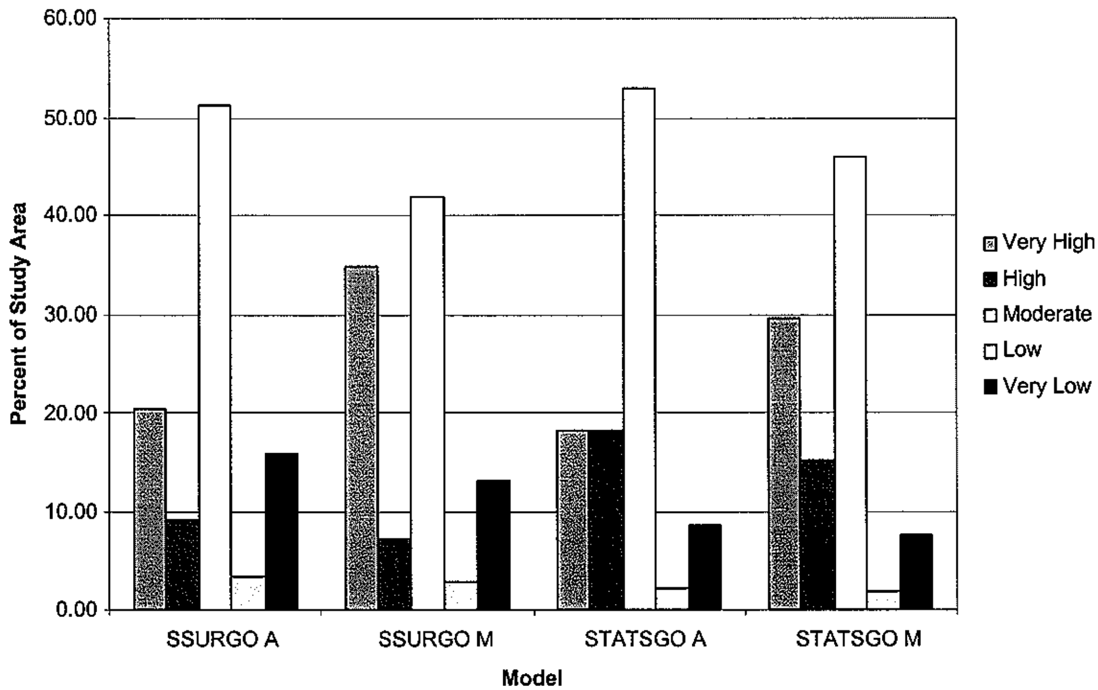


**Figure 17. Percent sensitivity class for each model**

Inventory coverage (Table 6, Figure 18) is important to help evaluate the evenness of archaeological investigation among the different sensitivity zones. When evaluated on a percentage basis (Table 7, Figure 19) there is a relatively equitable distribution of inventory among all sensitivity zones. It can be seen that the very high sensitivity class has had the most inventoried acreage at 12 percent, with all other classes falling around or below 11 percent inventoried. The very low sensitivity classes within SSURGO Analytical and SSURGO Management models have had the least amount of previous inventory. The highest concentration of previous inventory has occurred in Campbell and northern Converse Counties. Areas within the Tongue and Powder river basins have just begun to see more Class III inventory due to the increase in coal bed natural gas development. However, a very consistent percentage of the very high, high, moderate and low are represented within the study area. Site occurrence within the sensitivity zones indicates that more sites occur within the very high and moderate zones (Table 8, Figure 20). The frequent occurrence of sites in the very high sensitivity zones is probably a result of an association of sites near drainages.

**Table 6. Inventoried area of sensitivity classes for each model**

| | Inventoried Study Area | | | | |
|---|---|---|---|---|---|
| MODEL | Very High | High | Moderate | Low | Very Low |
| SSURGO A | 41116 | 16738 | 93940 | 6865 | 14448 |
| SSURGO M | 71959 | 14001 | 80931 | 6464 | 12148 |
| STATSGO A | 62334 | 54554 | 127366 | 5780 | 21213 |
| STATSGO M | 91061 | 45819 | 110206 | 5211 | 18951 |

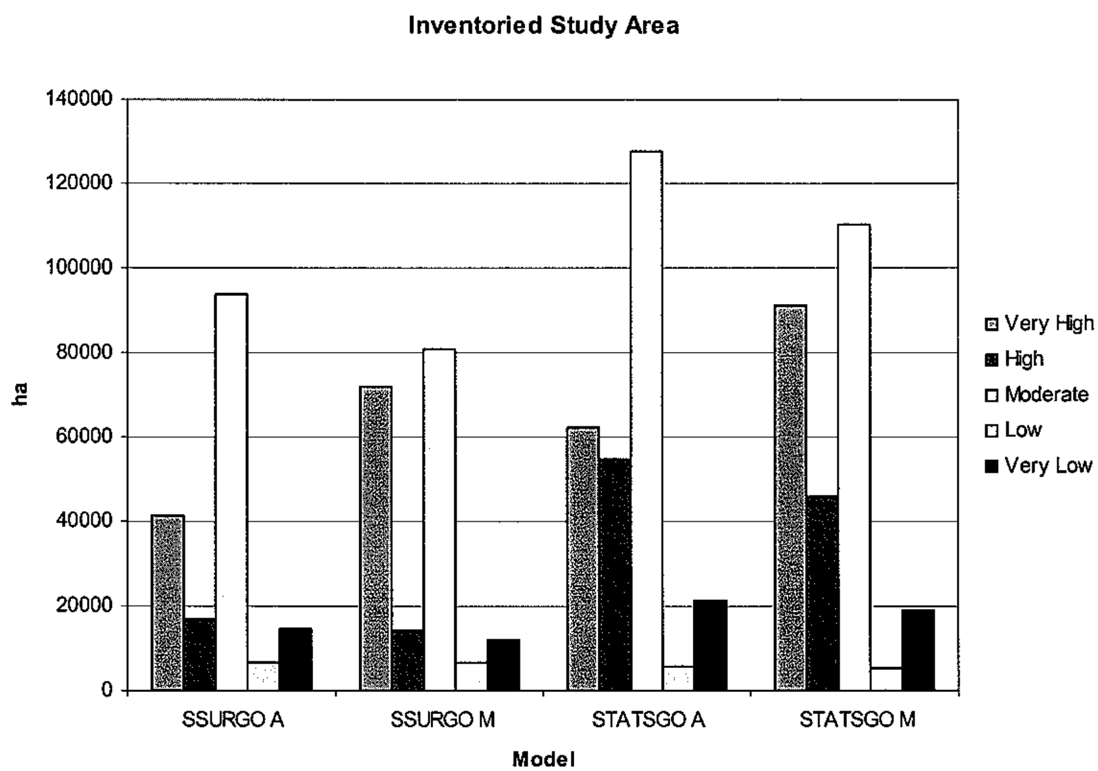


**Figure 18. Inventoried area of sensitivity classes for each model**

Buried components (Tables 9-10, Figures 21-22) are evaluated to see if their distribution parallels the sensitivity classes. One consideration in evaluating any association of buried cultural materials with the sensitivity model is defining a subsurface component. Artifacts found at depths of less than 20 cm below surface are easily bioturbated downward to this depth from an occupation on the existing soil surface (Albanese 1981). One of the problems in compiling this data on subsurface components is variation among investigators (crew chiefs) regarding their individual concept of subsurface and stratigraphic context.

**Table 7. Percent inventoried area of sensitivity classes**

| | Percent of Category Inventoried | | | | |
|---|---|---|---|---|---|
| MODEL | Very High | High | Moderate | Low | Very Low |
| SSURGO A | 9.95 | 9.01 | 9.06 | 10.37 | 4.51 |
| SSURGO M | 9.64 | 9.11 | 9.04 | 10.40 | 4.34 |
| STATSGO A | 12.01 | 10.55 | 8.48 | 9.86 | 8.79 |
| STATSGO M | 10.87 | 10.65 | 8.47 | 10.32 | 8.68 |

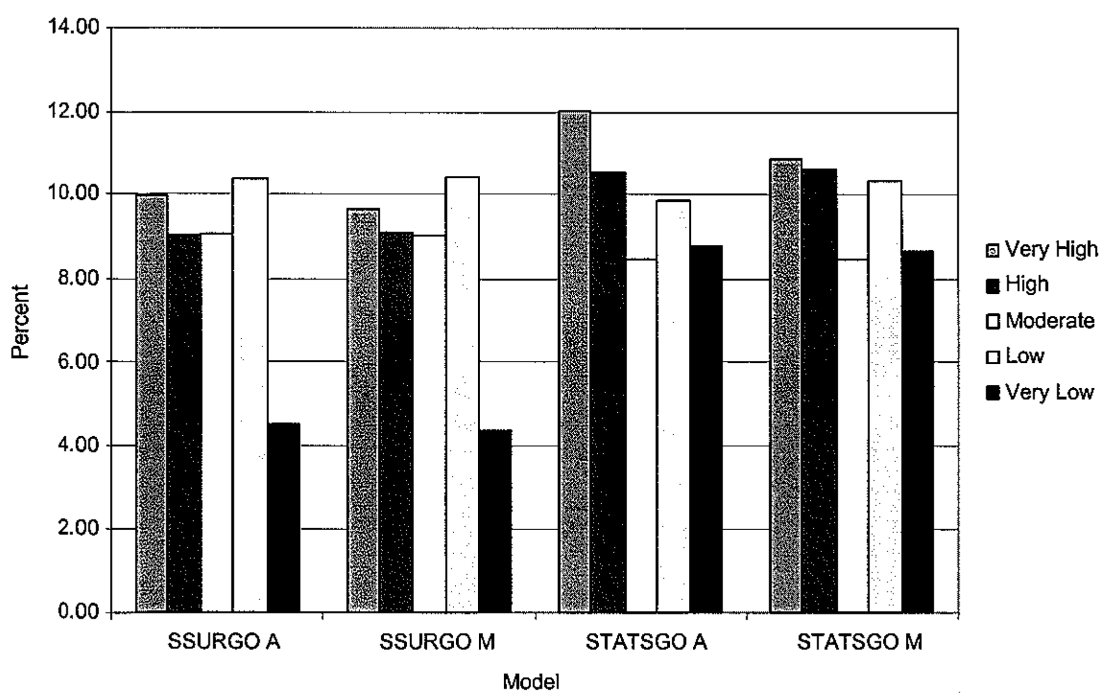


**Figure 19. Percent inventoried area of sensitivity classes for each model**

Subsurface, as used in the site form, refers to any buried materials. This includes artifacts in the 1-20 cm layers that in many settings result from a combination of bioturbation, trampling, freeze-thaw cycling, or churning. However, the near-surface mixed materials should NOT be considered in good stratigraphic context. Stratigraphic context, as used in the site form, means the presence of one or more distinct depositional episodes (excluding the surface context).

**Table 8. Number of sites by sensitivity class for each model**

| | Number of Sites Per Category | | | | |
|---|---|---|---|---|---|
| MODEL | Very High | High | Moderate | Low | Very Low |
| SSURGO A | 552 | 134 | 811 | 34 | 184 |
| SSURGO M | 921 | 98 | 649 | 29 | 137 |
| STATSGO A | 731 | 453 | 853 | 60 | 162 |
| STATSGO M | 1071 | 337 | 671 | 47 | 133 |

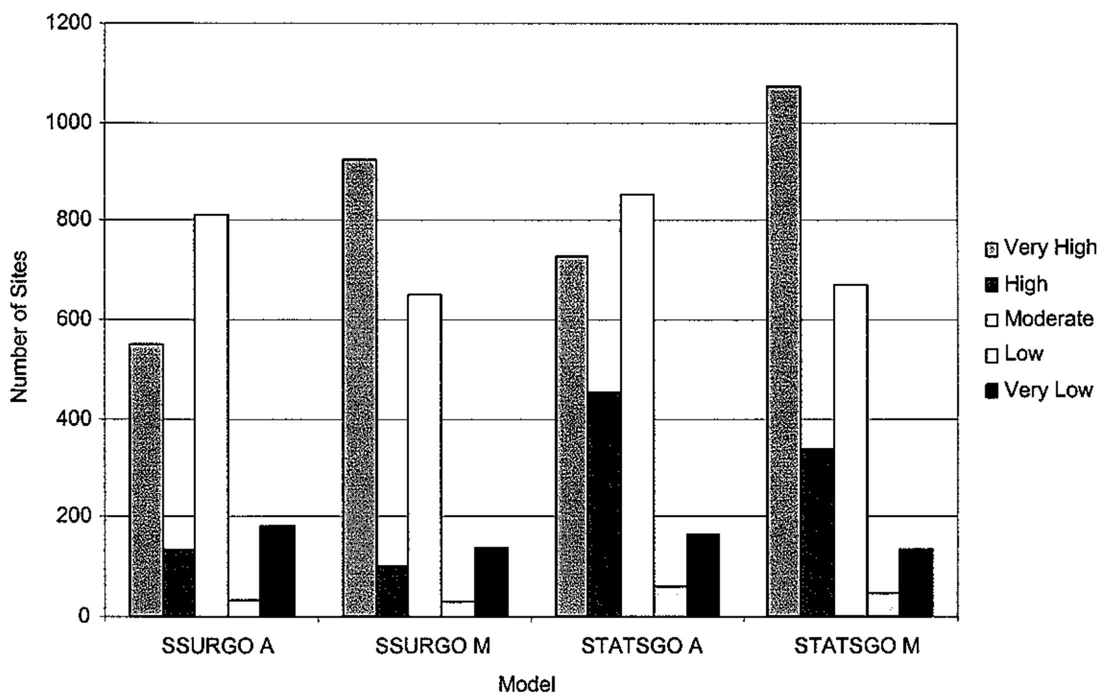


**Figure 20. Number of sites by sensitivity class for each model**

This can be demonstrated by geological stratigraphy, by buried soil horizon associations, or by artifact frequency peaks. Nearly all surface sites, however, contain at least a few artifacts in the near surface deposits. For the purposes of the DOE PUMP III encoding presented here, a site is described as having a potential for subsurface components only when cultural remains are found below a depth of 20 cm or more or when a subsurface component with good stratigraphic context is demonstrated to exist in the upper 20 cm of deposition.

**Table 9. Number of sites with reported buried components by sensitivity class for each model**

| | Number of Sites with Buried Components | | | | |
|---|---|---|---|---|---|
| MODEL | Very High | High | Moderate | Low | Very Low |
| SSURGO A | 132 | 19 | 65 | 5 | 16 |
| SSURGO M | 175 | 14 | 49 | 5 | 9 |
| STATSGO A | 132 | 19 | 65 | 5 | 16 |
| STATSGO M | 185 | 40 | 64 | 2 | 8 |

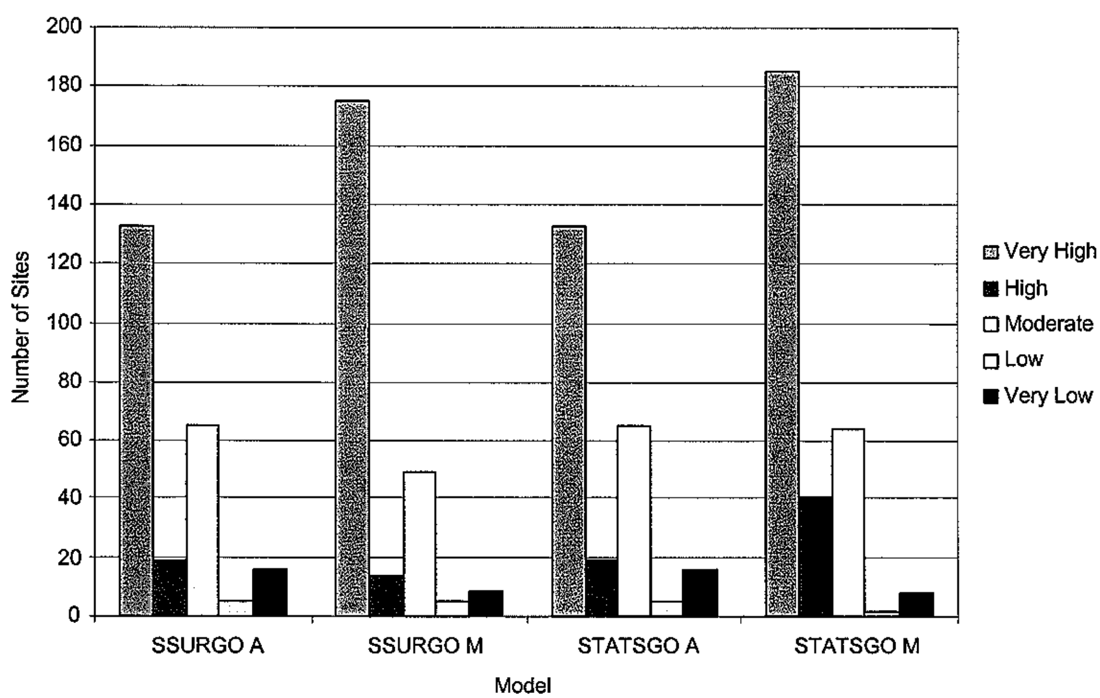

**Figure 21. Number of sites with reported buried components by sensitivity class for each model**

There is a very high correlation with reported sites having buried components within the very high sensitivity class across all four models. The high number of buried sites which fall into the very high sensitivity classes is a strong indication that the model adequately predicts the potential

**Table 10. Percent of sites with reported buried components by sensitivity class for each model**

| MODEL | Very High | High | Moderate | Low | Very Low |
|---|---|---|---|---|---|
| SSURGO A | 23.91 | 14.18 | 8.01 | 14.71 | 8.70 |
| SSURGO M | 19.00 | 14.29 | 7.55 | 17.24 | 6.57 |
| STATSGO A | 18.06 | 4.19 | 7.62 | 8.33 | 9.88 |
| STATSGO M | 17.27 | 11.87 | 9.54 | 4.26 | 6.02 |

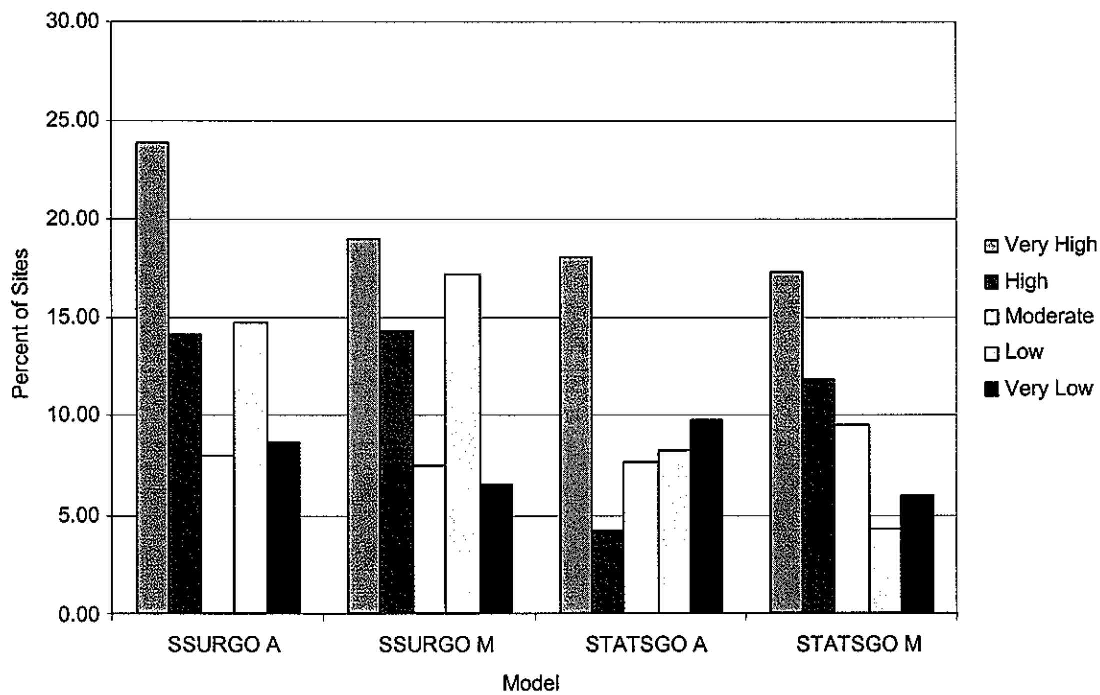


**Figure 22. Percent of sites with reported buried components by sensitivity class for each model**

of buried resources within the very high sensitivity class. The high sensitivity class does not seem to represent the reported sites as well as the very high sensitivity class. Additional fieldwork would be helpful to determine if sites are properly reported and evaluated. Surface components are also analyzed (Table 11; Figure 23. In general the analysis indicates sites that contain only surface components are more likely to occur in the lower sensitivity classes.

**Table 11. Percent of sites with surface components only**

| MODEL | Very High | High | Moderate | Low | Very Low |
|---|---|---|---|---|---|
| SSURGO A | 76.09 | 85.82 | 91.99 | 85.29 | 91.30 |
| SSURGO M | 81.00 | 85.71 | 92.45 | 82.76 | 93.43 |
| STATSGO A | 81.94 | 95.81 | 92.38 | 91.67 | 90.12 |
| STATSGO M | 82.73 | 88.13 | 90.46 | 95.74 | 93.98 |

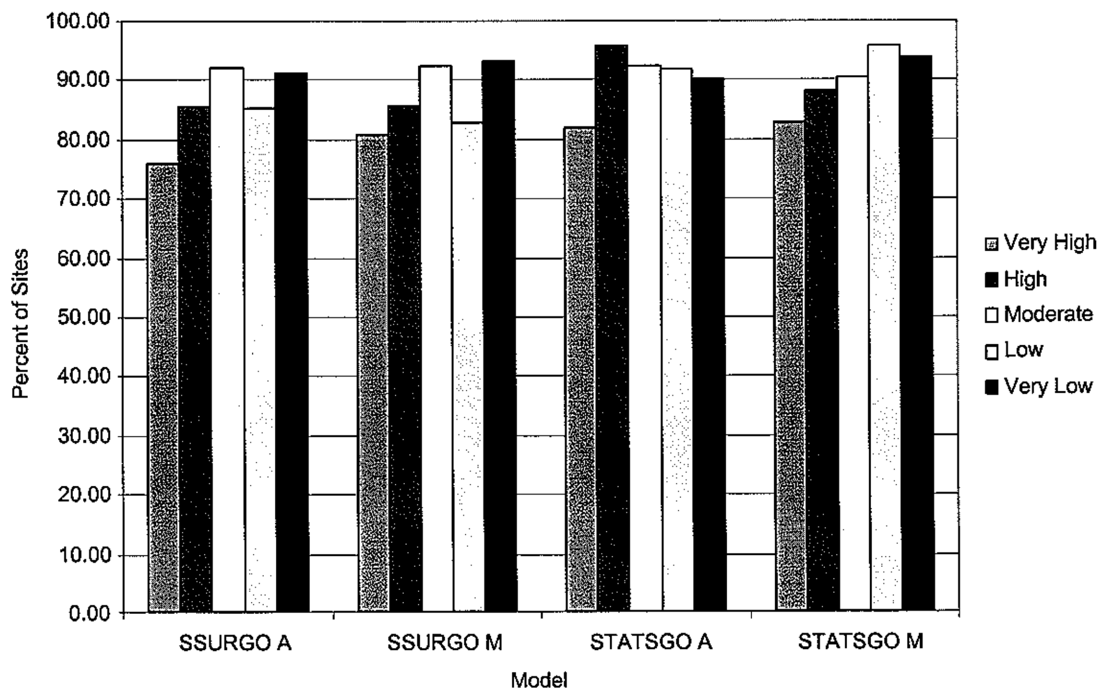


**Figure 23. Percent of sites with surface components only**

Sites that have produced radiocarbon dates (Tables 12-13; Figures 24-25) are a suitable measure to use in the evaluation of the sensitivity model. Because of their substantial cost, radiocarbon dates are derived from either relatively intact hearth features, or organic remains within known or suspected intact archaeological components, both the types of remains we assume to be important data categories for buried components. Sites in the Powder River Basin have a greater sod cover than sites in more arid and more deflated portions of Wyoming so most of the radiocarbon dates are expected to be from components that are subsurface. There is a high correlation of number of sites producing radiocarbon dates with the very high sensitivity classes. The majority of radiocarbon dates, approximately 75 percent, collected within the study area fall within the very high sensitivity class. It is interesting to note there are no sites producing radiocarbon dates within the low sensitivity classes. Table 14 is a summary of the site data.

**Table 12. Number of sites with radiocarbon dates by sensitivity class for each model**

| | Number of Sites with Radiocarbon Dates | | | | |
|---|---|---|---|---|---|
| MODEL | Very High | High | Moderate | Low | Very Low |
| SSURGO A | 50 | 7 | 11 | 0 | 3 |
| SSURGO M | 63 | 5 | 7 | 0 | 2 |
| STATSGO A | 50 | 7 | 11 | 0 | 3 |
| STATSGO M | 67 | 3 | 10 | 0 | 0 |

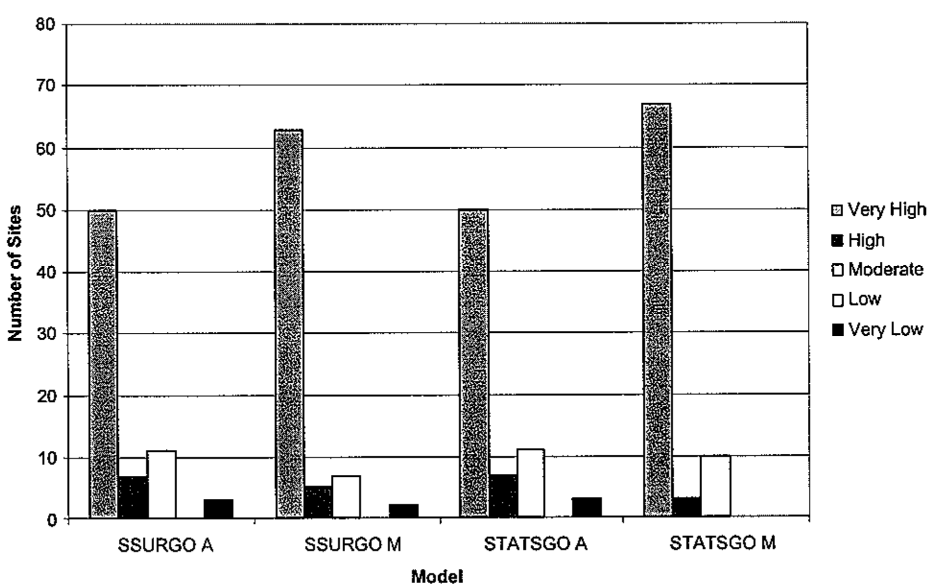


**Figure 24. Number of sites with radiocarbon dates by sensitivity class for each model**

**Table 13. Percent of sites with radiocarbon dates by sensitivity class for each model**

| MODEL | Very High | High | Moderate | Low | Very Low |
|---|---|---|---|---|---|
| SSURGO A | 9.06 | 5.22 | 1.36 | 0.00 | 1.63 |
| SSURGO M | 6.84 | 5.10 | 1.08 | 0.00 | 1.46 |
| STATSGO A | 6.84 | 1.55 | 1.29 | 0.00 | 1.85 |
| STATSGO M | 6.26 | 0.89 | 1.49 | 0.00 | 0.00 |

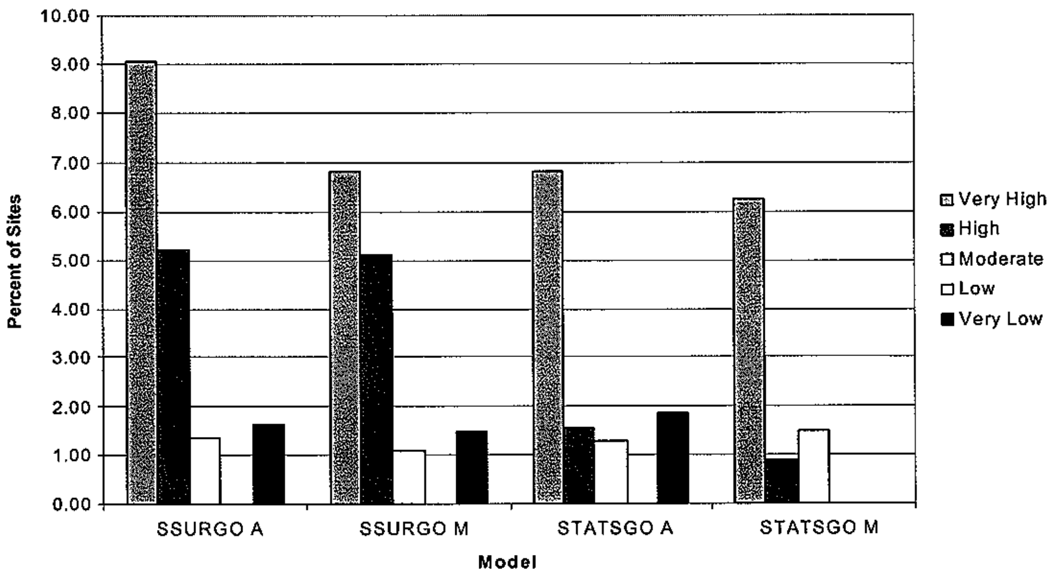


**Figure 25. Percent of sites with radiocarbon dates by sensitivity class for each model**

**Table 14. Summary table of study area archaeological characteristics by sensitivity class for each model**

| Category | Area (ha) | Percent Study Area | Area Inventoried (ha) | Percent of Category Inventoried | Number of sites per Category | Number of sites with buried component | Percent Sites With Buried Component | Percent Of Sites With Surface Component Only | Number of Sites with Radiocarbon Dates | Percent Of Sites Producing Radiocarbon Date (excluding rockshelters) | Number of Buried Sites with Shovel Tests and Formal Excavations | Percent of Buried Sites with Shovel Tests and Formal Excavations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SSURGO A** | | | | | | | | | | | | |
| Very High | 413358 | 20.44 | 41116 | 9.95 | 552 | 132 | 23.91 | 76.09 | 50 | 9.06 | 10 | 7.58 |
| High | 185780 | 9.19 | 16738 | 9.01 | 134 | 19 | 14.18 | 85.82 | 7 | 5.22 | 2 | 10.53 |
| Moderate | 1036473 | 51.25 | 93940 | 9.06 | 811 | 65 | 8.01 | 91.99 | 11 | 1.36 | 5 | 7.69 |
| Low | 66218 | 3.27 | 6865 | 10.37 | 34 | 5 | 14.71 | 85.29 | 0 | 0 | 0 | 0 |
| Very Low | 320363 | 15.84 | 14448 | 4.51 | 184 | 16 | 8.7 | 91.3 | 3 | 1.63 | 1 | 6.25 |
| Total | 2022192 | | | | | 237 | | | | | 18 | 7.59 |
| **SSURGO M** | | | | | | | | | | | | |
| Very High | 746570 | 34.93 | 71959 | 9.64 | 921 | 175 | 19 | 81 | 63 | 6.84 | 13 | 7.43 |
| High | 153686 | 7.19 | 14001 | 9.11 | 98 | 14 | 14.29 | 85.71 | 5 | 5.1 | 1 | 7.14 |
| Moderate | 895480 | 41.89 | 80931 | 9.04 | 649 | 49 | 7.55 | 92.45 | 7 | 1.08 | 5 | 10.2 |
| Low | 62139 | 2.91 | 6464 | 10.4 | 29 | 5 | 17.24 | 82.76 | 0 | 0 | 0 | 0 |
| Very Low | 279676 | 13.08 | 12148 | 4.34 | 137 | 9 | 6.57 | 93.43 | 2 | 1.46 | 0 | 0 |
| Total | 2137551 | | | | | 252 | | | | | 19 | 7.54 |
| **STATSGO A** | | | | | | | | | | | | |
| Very High | 519127 | 18.29 | 62334 | 12.01 | 731 | 132 | 18.06 | 81.94 | 50 | 6.84 | 10 | 7.58 |
| High | 516868 | 18.21 | 54554 | 10.55 | 453 | 19 | 4.19 | 95.81 | 7 | 1.55 | 2 | 10.53 |
| Moderate | 1501808 | 52.92 | 127366 | 8.48 | 853 | 65 | 7.62 | 92.38 | 11 | 1.29 | 5 | 7.69 |
| Low | 58645 | 2.07 | 5780 | 9.86 | 60 | 5 | 8.33 | 91.67 | 0 | 0 | 0 | 0 |
| Very Low | 241361 | 8.51 | 21213 | 8.79 | 162 | 16 | 9.88 | 90.12 | 3 | 1.85 | 1 | 6.25 |
| Total | 2837809 | | | | | 237 | | | | | 18 | 7.59 |

| Category | Area (ha) | Percent Study Area | Area Inventoried (ha) | Percent of Category Inventoried | Number of sites per Category | Number of sites with buried component | Percent Sites With Buried Component | Percent Of Sites With Surface Component Only | Number of Sites with Radiocarbon Dates | Percent Of Sites Producing Radiocarbon Date (excluding rockshelters) | Number of Buried Sites with Shovel Tests and Formal Excavations | Percent of Buried Sites with Shovel Tests and Formal Excavations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STATSGO M** | | | | | | | | | | | | |
| Very High | 837562 | 29.51 | 91061 | 10.87 | 1071 | 185 | 17.27 | 82.73 | 67 | 6.26 | 19 | 10.27 |
| High | 430224 | 15.16 | 45819 | 10.65 | 337 | 40 | 11.87 | 88.13 | 3 | 0.89 | 5 | 12.5 |
| Moderate | 1301170 | 45.85 | 110206 | 8.47 | 671 | 64 | 9.54 | 90.46 | 10 | 1.49 | 4 | 6.25 |
| Low | 50481 | 1.78 | 5211 | 10.32 | 47 | 2 | 4.26 | 95.74 | 0 | 0 | 1 | 50 |
| Very Low | 218415 | 7.7 | 18951 | 8.68 | 133 | 8 | 6.02 | 93.98 | 0 | 0 | 1 | 12.5 |
| Total | 2837852 | | | | | 299 | | | | | 30 | 10.03 |

## Very High Sensitivity Zone

Locations predicted to have very high archaeological landscape sensitivity (Figure 15) are situated, either within fine-textured alluvial fill located in low gradient, basin valleys, or in eolian deposits. Earth-disturbing construction activities within this zone should only occur under the most controlled circumstances. Intensive archaeological inventory, subsurface prospecting of non-site areas, and complete construction monitoring are recommended to prevent inadvertent destruction of significant archaeological resources within this zone. Experience within other areas in Wyoming suggests that it is reasonable to postpone data recovery efforts at some site types until after archaeological open-trench inspections are completed. The reason for this is that often-times highly significant buried components are found during open trench inspection whereas, these components are difficult to locate using traditional site prospecting and testing methods. To facilitate data recovery at discoveries made during open trench inspection, it is generally desirable to have administrative and budgetary contingencies built into the permit process.

## High Sensitivity Zone

Some locations, not necessarily situated along major drainages in the project area, are mapped as having high archaeological landscape sensitivity. These areas are derived from NRCS map units and have low slope, exhibiting thick accumulations of surficial sediment, lacking evidence of old surface soils, and containing little large and small gravel. At the SSURGO scale (Figure 15), high sensitivity zones occur in fine-textured alluvial, eolian, alluvial fan, and slope wash depositional environments. The high sensitivity zone is predicted to contain buried cultural occupation zones that exhibit similar site preservation as those in the very high sensitivity zone. Management implications and suggested recommendations are identical for high and very high sensitivity zones. As with the very high sensitivity zone, earth disturbing construction activities within the high sensitivity zone should only occur under controlled circumstances. Intensive archaeological inventory, prospecting, and construction monitoring, including 100 percent inspection of construction trenches, will be necessary to totally prevent the inadvertent destruction of significant archaeological resources.

## Moderate Sensitivity Zone

Some areas within the project area failed to meet the distinctive criteria that characterized the very high, high, low, and very low sensitivity classes. These areas are classified as moderate sensitivity (Figure 15). At the SSURGO scale, the moderate class encompasses low and very low areas delineated by STATSGO, especially in the basin area. While sizeable tracts of the moderate zone have a low risk, other, smaller areas (especially at the STATSGO scale) might be more sensitive. As the NRCS makes SSURGO data available for the remaining portions of the project area, it will be desirable and possible to reclassify additional areas of low and very low concern within basin areas. Until that time, professional archaeologists working in STATSGO areas mapped as a moderate zone will need carefully assess slope, depth to bedrock, percent sediment less than 7.62 cm (3 in), and percent sediment less than 2 mm (0.08 in) to distinguish areas of higher sensitivity from those of lower sensitivity within the basin. Project-specific, geoarchaeological evaluations can help identify which portions of the moderate zone are more or less sensitive. In addition to normal Section 106 process inventory and evaluation, this zone would benefit from construction monitoring of known archaeological resources and monitoring of construction trenches. The moderate sensitivity zone has the potential to contain some deep deposits.

## Low Sensitivity Zone

Areas predicted to have low archaeological landscape sensitivity include NRCS map units that exhibit characteristics such as a thin mantle of sediment, steep slope, and coarse-grained texture. As well, this zone is mostly mantled by questionable Holocene-age surface soils (i.e., Argiaquolls, Argiborolls, Argiustolls, Calciargids, Calciborolls, Calciorthids, Cryoboralfs, Eutroboralfs, Gypsiorthids, and Haplustalfs). Although small areas of probable Holocene-age soils are included, the surface soil age of the bulk of the included map units suggests that the sediments in and under the soils are too old to contain intact archaeological material. Thus, the potential for preserving occupation integrity, perishables, and stratigraphic separation of occupations in this zone is lower in comparison to the higher-ranked (very high, high, moderate) sensitivity zones. In addition to normal Section 106 process inventory and evaluation, construction monitoring would be necessary on a case-by-case basis, as identified by agency or project archaeologists.

### Very Low Sensitivity Zone

Areas at the lowest extreme of the sensitivity scale are characterized as the very low sensitivity zone. Some areas within the project area contain a combination of attributes that render them unlikely to contain intact, well-preserved, and stratigraphically separable occupation zones. This prediction is based on one or more of the following attributes, which correspond to the NRCS map units they occupy: (1) a large amount of non-soil land is present (e.g., badlands, gravel pits, rock outcrops, etc.); (2) surface soil type is thought to be too old to engulf any intact and buried cultural material; (3) depth to bedrock is very shallow; (4) slopes are steep; and/or (5) gravel comprises a relatively large proportion of the soil component. Generally speaking, much of this zone is situated on steep slopes in mountainous areas. As with the low sensitivity zone, small inclusions of other soils occur within the boundaries of the very low sensitivity zone, and thus some of these areas could potentially contain intact, well-preserved, and stratigraphically separable occupation zones. However, if smaller potential sensitive inclusions are not identified in the field by agency or project archaeologists, construction monitoring and other post-inventory discovery techniques can be omitted without overt risk to sensitive cultural resources.

## MAINTAINING THE MODEL

When implemented, the model will need to be subjected to ongoing maintenance to fulfill its adaptive management goal. This will include monitoring, periodic reevaluation, and adjustment. Monitoring should include the specific tracking of CRM management and field archaeological actions taken in which the model was used. This should especially include tracking any construction monitoring such as open trench inspections. A logical way to do this is to periodically retest the model against the growing WYCRO database.

### Adjust Process

In addition to validation of the burial model in open trenches, the SSURGO model is hampered by the absence of NRCS mapping at the 24k scale for parts of the project area. This restricts the usefulness of the modeling. The STATSGO model contains few very low and low sensitivity zones within the basin area, although these classes are mapped in the mountains. Areas within the basin for which SSURGO scale data are available do have areas mapped as low and very low. With more complete coverage, additional areas of low and very low sensitivity within the basins could be delineated with the result that the moderate class could be reduced in size. This would allow better planning and help reduce conflicts between management goals of site preservation and resource development. In order to maximize the usefulness of the model at the 24k scale, it is desirable to add coverage to the model at 2-year intervals as 24k NRCS data becomes available.

## CONCLUSION

Geoarchaeological modeling of the Powder River and Tongue River hydrological basins is undertaken in this report. Modeling is based on sediment age and depositional energy regime. This project was conducted for Gnomon, Inc., under a PUMP III Cooperative Agreement Program from the Department of Energy (DOE). The purpose of the project is to build a spatial model allowing prediction of geological settings conducive to the preservation of significant, buried, prehistoric archaeological sites. Modeling utilizes information taken from literature review, fieldwork, and geological and soils mapping.

The project area includes the western Powder River Basin as well as the eastern Bighorn Mountains. Intrusive igneous rocks and tilted sedimentary beds predominate in the mountains and gently dipping rocks are most common in the basin. In the mountains, glacial, colluvial, and residual surficial materials are most common with lesser amounts of alluvium. Larger areas of surficial fluvial deposits are present in the basin accompanied by residual and eolian materials. The climate of the area is strongly influenced by elevation. Mountains experience colder temperatures, more precipitation, and a shorter growing season than the basin. Entisols, Alfisols, Mollisols, and Inceptisols are the most common soils in the mountains. Entisols and Mollisols also occur in the basins where they are accompanied by Aridisols. Mountain vegetation communities includes, in descending elevation, alpine meadow/tundra, spruce-fir forest, and Ponderosa pine-Douglas fir forest. Grassland dominates the foothills and the basin and areas of sagebrush steppe also occur.

We assume that important buried prehistoric cultural resources are usually, and perhaps always, found in geological strata less than 14,000 years old. Archaeological materials buried within moderate to low energy depositional environments can be buried deeply enough to have escaped the effects of disturbance processes and maintained integrity. Sites with high stratigraphic integrity are important but difficult to manage and expensive to treat under Section 106 of the NHPA.

NRCS inventories generate two data sets for these variables, one at a scale of 1:24,000 (24k) and another at a scale of 1:250,000 (250k). We manipulated these data sets separately. The analysis utilizes geological and soil characteristics such as sediment type, geomorphic setting, sediment texture, slope, and soil type as variables. A range of values occurs for each of the variables. Each variable is classified to approximate its appropriate contribution to a particular sensitivity class. The classified data becomes part of a geographic information system that uses NRCS soil map units and stream valley boundaries to plot the occurrence of the classified variables. The plotted classified variables are then combined by sensitivity class. This results in a map which represents the potential of the landscape to contain sediment of the appropriate age, and depositional regime to contain relatively intact buried cultural material. Individual maps were generated at the 24k and 250k scales.

Caution is warranted as the sensitivity model only predicts where site preservation conditions might be favorable, and not locations that may have been attractive to human activity. As well, utilization of the 250k scale data can only provide a general view of landscape sensitivity. Where available, use of the 24k data is recommended, and then only down to the limits of this scale. Enlarging the 24k data by optical or digital means will not yield more accurate locational information regarding the boundaries of the sensitivity zones. As a final caution, sensitivity maps are designed to be used as part of a process that includes field visits by competent field archaeologists. Professional geoarchaeological field assistance should be sought when the map predictions do not seem to reflect the landscape observed in the field.

WYCRO site records are used to evaluate the model. Data on the locations of buried components and sites that have produced radiocarbon dates tend to support the validity of the model.

Locations with very high archaeological landscape sensitivity are situated primarily along the floodplains and low terraces of low gradient, basin alluvial valleys with lesser areas of eolian sand. Earth-disturbing construction activities within this zone should only occur under the most controlled circumstances, including a pre-construction archaeological inventory, and monitoring of construction activity, or at a minimum post-disturbance (pre-refill or pre-regrade) inspection.

High sensitivity zones occur on low slopes, exhibit thick accumulations of surficial sediment, lack evidence for mature soils, and contain little large and small gravel. Monitoring of construction activity or at a minimum post-disturbance (pre-refill or pre-regrade) inspection should be considered in these areas.

The moderate sensitivity zone consists of areas that did not fall into the very high, high, low, and very low zones. As such, they either have a "moderate" or an "unpredicted" sensitivity. Some areas of sensitive sediments will be situated within areas mapped as moderate. STATSGO lumps small areas of higher and lower sensitivity in with the moderate class, especially within the basin portion of the project area. In areas where SSURGO mapping is lacking, common sense use of the sensitivity outline by professional archaeologists can help discriminate areas of higher sensitivity from areas of lower sensitivity. On-site, geoarchaeological evaluations might help discriminate these areas from larger portions of the moderate zone that might be less sensitive. Post-disturbance (pre-refill or pre-regrade) inspection should be considered in all moderate areas.

Areas predicted to have low archaeological landscape sensitivity include areas with a thin mantle of sediment, steep slope, and coarse-grained texture. As well, this zone is mostly mantled by surface soils that are of questionable Holocene-age. The potential for preserving occupation integrity, perishables, and stratigraphic separation of occupations in this zone is lower in comparison to the moderate sensitivity zone. Agency and consulting archaeologists should make an effort to identify smaller areas of higher sensitivity within this zone. The protocol handbook presented in Appendix A is designed to assist in identifying these areas.

Areas at the lowest extreme of the sensitivity scale are within the very low sensitivity zone. Included are large areas of non-soil land such as badlands, gravel pits, rock outcrops, etc.; areas containing soil types thought to be too old to engulf any intact and buried cultural material; depth to bedrock is very shallow; slopes are very steep; and/or gravel comprises the largest proportion of the soil component. Generally speaking, much of this zone is situated on steep slopes in mountainous areas. As with the other zones, inclusions of other soils occur within the boundaries of the very low sensitivity zone, and thus some of these areas could potentially contain smaller areas of higher sensitivity. As with the low zone, agency and project archaeologists should attempt to identify these areas. Only at these specially identified areas are open trench inspection and other monitoring recommended.

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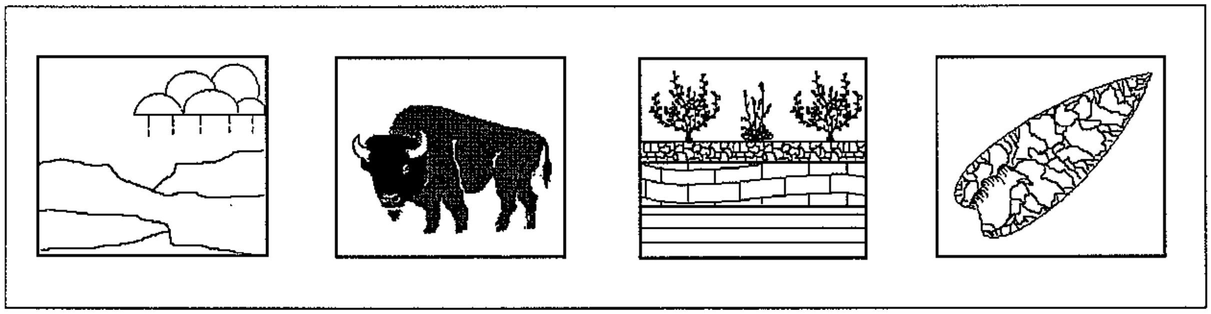

Adaptive Management and Planning Models for Cultural Resources in Oil and Gas Fields

# APPENDIX A:

# PROTOCOL HANDBOOK AND GUIDE TO AN ARCHAEOLOGICAL BURIAL MODEL: POWDER RIVER AND TONGUE RIVER HYDROLOGICAL BASINS, WYOMING

by

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## ABSTRACT

This document is a protocol handbook and guide for users of *Archaeological Burial Model: Powder River And Tongue River Hydrological Basins, Wyoming* (Eckerle et al. this volume). Four categories of users are envisioned for this model: (1) land managing agencies; (2) industry segments needing development permits on public land; (3) cultural resource management (CRM) consultants; and (4) field archaeologists. The model uses geomorphic and soils data in a geographic information system (GIS) to assess the sensitivity of specific localities within the study area in order to facilitate effective implementation of Section 106 compliance and the effective management of archaeological sites. Buried prehistoric sites often have great potential for listing on the National Register of Historic Places (NRHP) and are often considered (in the sense of management and development) to be at risk in Section 106 compliance. Importantly, buried sites consume a disproportionate amount of effort, time, and cost to manage under the Section 106 Process. In the following manual, we outline the logic and principles behind the model and suggest how different users might implement the model outcomes given individual, project-specific needs.

## INTRODUCTION

A model having the ability to predict the location of sediments of a suitable age and likely depositional type to bury and preserve archaeological sites can help to effectively manage archaeological resources. Such a model has value both to cultural resource management and proponents of oil and gas development on public land. Geographic Information System (GIS) tools facilitate the model. Since the archaeological record is a landscape-scale phenomenon, any practical predictive model must be designed at a concordant analytical level and GIS is an effective tool to build, visualize, and analyze the model. The archaeological record contains a geological component: the human behaviors involved in its formation, as well as the geological processes involved in its subsequent preservation, which are inherently linked with their environmental context. Thus, an appropriate model of potential locations where archaeological sites might be buried has its foundations in geological (i.e., geomorphic and soils) data.

This project is designed for specific use in the hydrological Powder and Tongue River basins, northeastern Wyoming, and area sometimes referred to as the western Powder River Basin (WPRB). Much of the archaeology identified and evaluated in this area during cultural resource investigations is prehistoric in nature. National Register of Historic Places (NRHP) significance for prehistoric sites often falls under Criterion D, "...that have yielded, or may be likely to yield, information important in prehistory or history" (36 CFR 60.4). Many sites that exhibit significance under Criterion D owe their value to the fact that they became buried and thus preserved in a secure stratigraphic context that maintains behavioral integrity and preserves perishable remains. While such sites are essential to advancing our understanding of ancient lifeways, land developers and agency managers consider such sites as risks because they are difficult to manage, costly to mitigate, and may add months to completion of the Section 106 process. Thus a model predicting the sensitivity (or risk, in other terms) of specific localities within a proposed project area to contain significant, buried archaeological sites is an effective tool for use by developers, agencies, CRM consultants, and field archaeologists alike in the planning and implementation stages of their projects.

## BUILDING A RISK-SENSITIVITY MODEL FOR THE WESTERN POWDER RIVER BASIN

Several types of geoarchaeological models are possible. The first type uses earth science data to predict which portions of the landscape contain deposits of the right age and appropriate depositional type to bury and preserve archaeological materials (Eckerle et al. 1999; 2000). Another type of model employs biological survey date to predict the intensity of human land use on the landscape (Raven and Elston 1989; Zeanah 1996). Still another type of landscape modeling uses biological survey information in conjunction with climatic modeling to predict changes in human use of the landscape over time (Eckerle et al. 2003; Eckerle and Taddie 2002). Finally, several types of modeling can be combined (Drews et al. 2004; Eckerle et al. 2000). The modeling used in this report uses earth science data and is designed to predict appropriate geological settings that might contain buried and intact sites. This type of modeling is particularly applicable to the management of cultural resources in that the intensity of landscape use is generally of less interest than the potential to destroy a widely recognized category of important sites.

The risk-sensitivity model developed for the study area is based on the assumption that the most important, buried, prehistoric archaeological sites are found in geological deposits less than 14,000 years old. Archaeological deposits that accumulated within moderate-to-low-energy depositional environments are likely buried deeply enough to have escaped the effects of long-term surface and near-surface disturbance processes, maintaining stratigraphic and behavioral integrity. The model divides the landscape into archaeological site burial sensitivity categories ranked in a continuum from very high, high, moderate, low, to very low sensitivity (Table A-1). Sensitivity categories reflect the potential of a landscape to contain buried and relatively intact occupation strata, which exhibit both contextual and associational integrity. Sensitivity categories also predict the preservation potential of sites to yield perishable archaeological residues (primarily bone and charcoal).

## The Project Study area

The study area (Figure A-1) is both a hydrologic and structural basin. In hydrologic terms, it is part of the greater Yellowstone River Basin (Zelt et al. 1999). Major streams draining the area include the Powder and Tongue Rivers. Numerous tributaries add to the network of drainages in the study area. Structurally, the Powder River Basin formed during the Laramide Orogeny (ca. 60 million years ago) as a function of the downward displacement of rock layers associated with upthrusting of the nearby Bighorn Mountains, Black Hills, Casper Arch, and Miles City Arch. Thick Tertiary-age basin-fill rocks are targets of economic development but play a lesser role in the human prehistory of the region. In general, the study area has a cold, continental climate with January and July extremes and relatively low average annual precipitation (approximately 35 cm [14 in] in the basin but increasing with elevation in the nearby mountain ranges). The area has a long and significant human history spanning the last 11,000 years (Frison 1991). Into Historic times the Powder River country was important to Indian peoples, remaining unceded Indian Territory well into the 1870s and the source of much conflict between indigenous populations and colonizing Americans.

Stream systems were an important resource to both prehistoric and historic populations. While the recycling of alluvium over time can have a cumulative, detrimental effect on valley bottom sites (Albanese 1978), flood plain alluvium and adjacent low-angle toe slopes can bury and preserve sites. Thus, valley bottoms continue to be important today, particularly within the context of managing archaeological resources but are areas where traditional archaeological surface survey may fail to make necessary discoveries. Because they have substantial potential to contain significant, buried archaeological deposits, all valley bottoms are considered to have very high sensitivity within the guidelines of this project.

**Table A-1. Summary Characteristics for Sensitivity Classes**

| Sensitivity Ranking | Landforms | Soil Parent Material | Engulfing/ Overlying Soil Age | Depth to Bedrock (60" max) | Minimum Slope | Average Slope | % Clasts ≥3" | % Clasts ≥2mm |
|---|---|---|---|---|---|---|---|---|
| **Very High** | Low-Gradient Stream Valleys<br>Floodplains, Terraces, Sand Dunes | Alluvium<br>Eolian | — | — | — | — | — | — |
| **High** | Moderate-Gradient Stream Valleys<br>Alluvial Fans | Alluvium<br>Eolian<br>Slope Wash | Holocene Age Soils | 60-40" | 0-10% | n/a | 0-2.9% | 0-14% |
| **Moderate** | All Moderate areas fail to completely meet the criteria for other sensitivity classes. They may meet one or many criteria, but not all. This category can't really be given value ranges that would produce the selected areas within ArcView. | | | | | | | |
| **Low** | Non-Soil-Bearing Landforms (Badlands, Cirques, Bedrock, etc.)<br>Steep-Gradient Stream Valleys<br>Uplands, Interfluves | Colluvium<br>Residuum<br>Channel | Questionable Holocene Age Soils | 25.1-35" | n/a | 15-19.9% | 3-6.9% | 30-39.9% |
| **Very Low** | Non-Soil-Bearing Landforms<br>Very Steep-Gradient Stream Valleys<br>Uplands Interfluves | Colluvium<br>Residuum<br>Channel | Very Unlikely Holocene Age Soils | 0-25" | n/a | 20-100% | 7-100% | 40-100% |

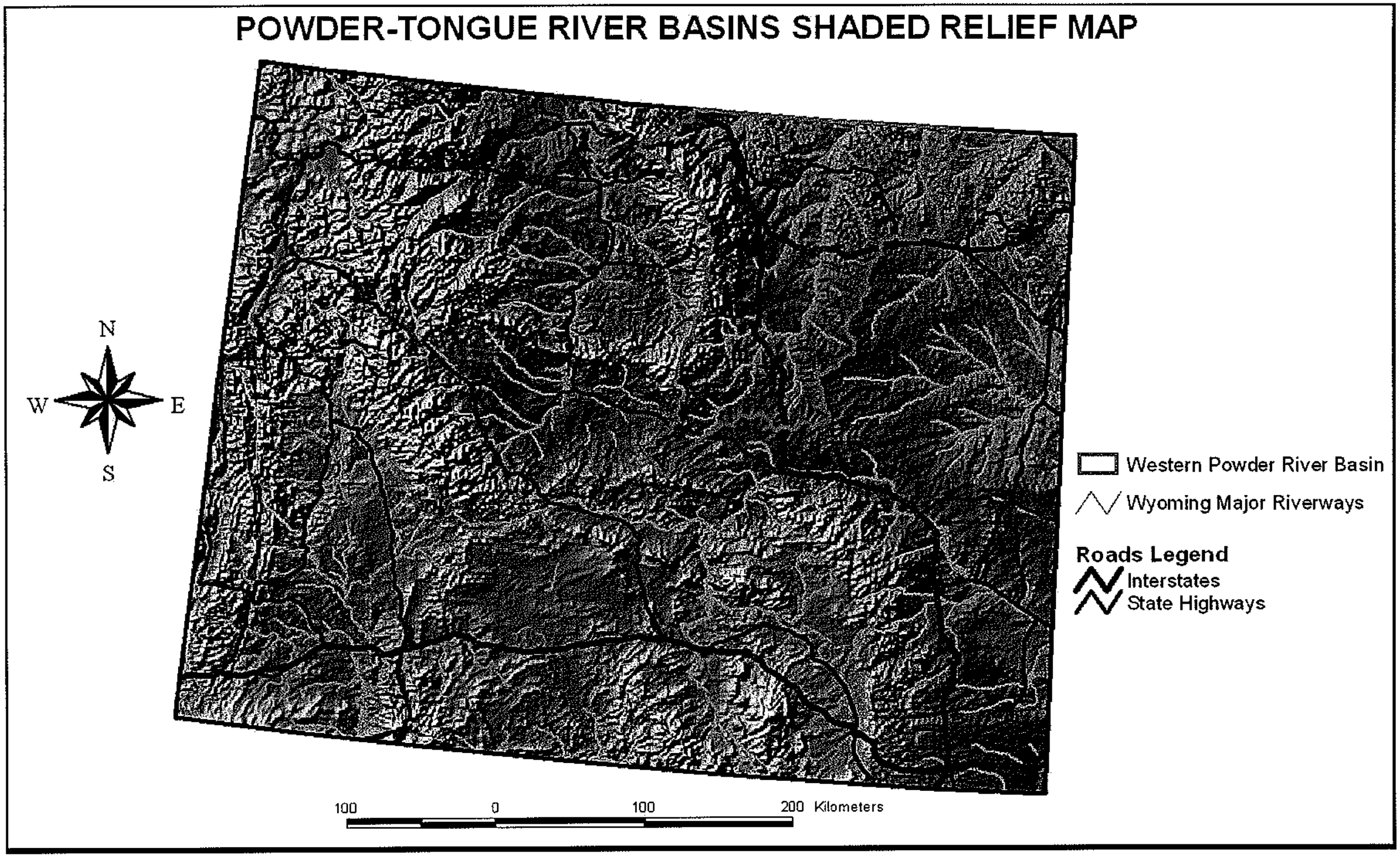


**Figure A-1. Map of the project area illustrating its location in the Powder-Tongue River Basins, northeastern Wyoming**

The risk-sensitivity model is based on geomorphic and geoarchaeological investigations (Albanese 1990; Leopold and Miller 1954) that have investigated the historical development of the Powder River landscape, particularly in relation to river and tributary valleys. These studies are summarized below followed by the logic incorporated in the model design to create buffers around streams as very high sensitivity areas within the risk-sensitivity model.

**The Model Data**

Geological landform and soils data are used in a GIS to create multiple, overlaying map images that illustrate burial sensitivity categories for specific localities within the study area. Digital data used in the GIS are available in multiple forms: geological data are from the *Wyoming Surficial Geology Map* (Case et al. 1998); soils data are available at the state level from the Natural Resource Conservation Service (NRCS) *State Soil Geographic (STATSGO; 1:250,000)* database (Soil Conservation Service 1994); soils data are also available at the county level from the USDA NRCS *Soil Survey Geographic (SSURGO; 1:24,000)* database. Model outputs are available at a 1:250,000 and a 1:24,000 scale where available. NRCS map data also provide information important for understanding the potential age of specific land surfaces and the depth to which archaeology-bearing deposits may be found. These data have significant implications within a risk-sensitivity model, and subsequent sections discuss the logic in using soils data. Finally, this manual concludes with a discussion of how the model output specific to the study area can be applied within a variety of decision-making arenas.

***The Powder River Basin Alluvial Sequence.*** Leopold and Miller (1954) recognized strong patterning in the geomorphic relationships of Late Quaternary (Late Pleistocene and Holocene) river valleys in the Powder River Basin (Figure A-2). They defined three inner-valley terraces (from lowest to highest): 1) Lightning (1.2-2.1 m [4-7 ft]), 2) Moorcroft (2.4-3.7 m [8-12 ft]), and 3) Kaycee (6-15.2 m [20-50 ft]). Leopold and Miller also proposed that a predictable set of sediments, designated as geologic formations, underlies these terraces. Deposits associated with the youngest Lightning terrace (the Lightning Formation) are composed of fine-textured overbank alluvium. The Kaycee Formation is composed of mixed slope wash and alluvium underlying the Moorcroft terrace and also forming the uppermost bed of the Kaycee terrace. The Ucross Formation, a recent (post-Wisconsin) pebbly gravel, underlies the Kaycee formation within the Kaycee terrace. Finally, the Arvada Formation, the oldest Late Quaternary deposit, is weathered, cobbly gravel containing extinct late Pleistocene fauna. Arvada sediments fill deeply cut channels on the valley floors and overly a bedrock strath under the Kaycee terrace.

Leopold and Miller's (1954) model guided several decades of subsequent work by fluvial geomorphologists; however, their proposed chronology and the climatic processes they invoked to explain the depositional and erosional cycles oversimplified an otherwise complex geological environment. Albanese (1990) demonstrated that terraces are not always underlain by sediments of the age Leopold and Miller proposed, local depositional/erosional processes produced unique terrace sequences, and the number of terraces may vary according to stream order. Regardless, Leopold and Miller's alluvial model applies to the risk-sensitivity model in two ways: 1) a textural difference exists between potential archaeological bearing deposits (latest Pleistocene and Holocene) and older, Glacial/Post Glacial (18,000-12,000 B.P.) deposits; and 2) non-gravelly, post-12,000 B.P. valley fill, which was deposited in moderate depositional regimes, is present in most valleys. Thus, at a minimum, most river valleys in the project area should have very high or high risk-sensitivity in the GIS model.

***Site Formation and Post-Depositional Processes.*** An important aspect of archaeological research, and criterion determining NRHP significance, deals with the degree of preservation, or integrity, that individual sites possess. In an ideal situation archaeological sites are preserved in a 'Pompeii-like' setting, representing a snapshot of time frozen for eternity. Such situations are rare and instead, archaeologists have become intimately familiar with many factors that alter archaeological deposits. These are referred to generally as site formation or post-depositional processes (Schiffer 1987; Wood and Johnson 1978). Among these factors are trampling by both humans and animals; dispersal due to wind, water, or gravity; frost-heaving; rodent and insect burrowing; and plant growth (including tree throw)

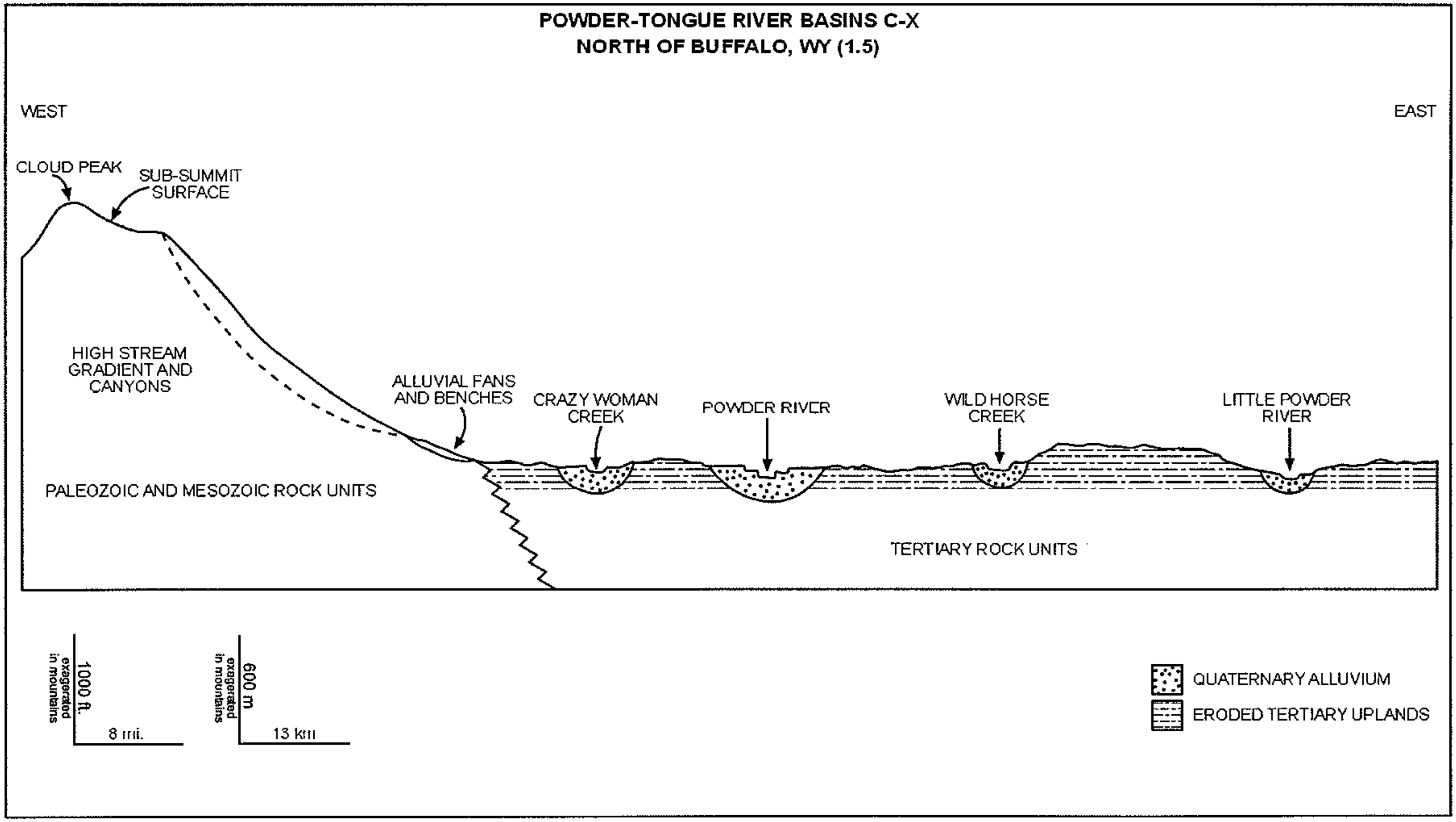


**Figure A-2. Schematic cross section of the study area illustrating topography, surface geology, and soil relationships**

resulting from soil formation. Alluvial settings are ideal for archaeological preservation because the rates of sediment deposition are often rapid enough to preserve sites without the impact of significant post-depositional processes. Sites exposed for millennia on bedrock surfaces or those with shallow soils likely have relatively poor preservation.

***Factors Affecting Site Discovery in Plan View Versus Profile.*** The archaeological record, as a landscape phenomenon, has both horizontal and vertical components. Human occupation leaves artifacts and features in horizontal distributions across the landscape. With time, these artifacts become buried adding a vertical component to the archaeological record. Archaeological survey is designed to discover horizontal distributions; thus, buried sites often remain undiscovered until earth-moving activities occur during development. Alluvial settings are ideal for the formation and preservation of vertical deposits; but, as Albanese (1978) noted, few sites in the PRB have been discovered in such contexts. He accounted for this by the fact that streams destroy many sites over time. Conversely, site discovery is difficult in alluvial settings compared with their upland counterparts. It is simply less likely to locate eroded cultural material at the base of a cutbank than on flat or rolling landscapes. Erosion in non-alluvial settings leaves artifacts behind as a horizontal lag deposit, whereas artifacts that erode out of arroyo walls are flushed downstream during subsequent flood events, thus, failing to accumulate to any significant surface density below the cutbank. A site exposed in cross-section rather than plan view logically makes fewer artifacts visible for discovery, further reducing the probability that buried sites will be discovered during survey.

***Creating a Stream Buffer.*** Alluvial settings have the potential to preserve significant, intact, archaeological deposits that may escape discovery during traditional archaeological survey. Within the risk-sensitivity model for the study area all alluvial settings (i.e., valley bottoms) in basin and montane settings are ranked as 'very high' sensitivity. These valley bottoms are defined using the stream course and then the valley-sensitivity-zone is defined by using the buffering capability of the GIS. Stream buffers are accomplished in two stages: 1) delineation of valley bottoms, and 2) exclusion of steep areas within valley bottoms. Widths for stream buffers are constructed using both a vertical and horizontal component. The Leopold and

Miller alluvial model provides the basis for the vertical component, calculated in the model as elevation above stream shoreline, and is determined by the maximum upper elevation at which fine-textured alluvium is found, or where toeslope that merges with the highest fine textured terrace thins laterally onto the backslope. An increase in the estimated elevation provides for a margin of error in these approximations; however, the maximum elevations were field checked as part of the project. The horizontal component was constructed with 1:24,000 scale maps by fixing a horizontal line, perpendicular to the trend of the valley, from sample locations where contour intervals crossed streams to the estimated elevation above shoreline. This method provided a sample of half-valley widths, which were calculated for different stream orders. The half-valley-width calculations often overlap with local topography that may include steep valley walls or bedrock slopes that should not be included into the 'very high' sensitivity category. Areas possessing slopes greater than 10 percent were removed from the very high sensitivity class.

A slightly different technique was uses for montane settings of the study area (i.e., the crest and eastern slope of the Bighorn Mountains). There, stream buffers were calculated in four categories according to stream gradient: very low gradient (<2.5 percent), low gradient (2.5-5 percent), moderate gradient (5-10 percent), and high gradient (10-100 percent). As in the basin configuration, elevation above shoreline was calculated for a sample of streams producing an average half-valley width approximation to calculate stream buffers.

***Soil Map Units.*** Time, temperature, topography, parent material, and biota all interact to form soils. Time is, perhaps, the key and soil taxonomy can be thought of in those terms as well. Soil taxonomy is less than user friendly, but a few key concepts can ease the pain of the uninitiated. This study is concerned with soils that formed primarily during the Holocene, which fall mostly within the orders of Entisols, Aridisols, and Mollisols. Consider these as recent or young soils, desert soils, and grassland soils respectively. One might encounter bewildering names at the family or great group level such as Fluvent, Calciorthid, or Haploboroll. Know that the first syllable of the order name typically forms the final syllable of the family or great group name. Other syllables denote temperature and/or moisture regimes or other criteria that give a soil its distinct characteristics. For this model, soil taxonomy was used to estimate the age of the underlying deposits using the following: 1) Entisols (Orthents and Fluvents) <1,000 B.P.; Camborthids (weak Aridisols) 1,000-10,000 B.P.; Argids and Calciorthids (clay-rich and $CaCO_3$ indurated Aridisols) 10,000-100,000 B.P.; and Paleargids and Paleorthids (ancient Aridisols) >100,000 B.P.

Soil studies provide a robust data set crucial to the risk-sensitivity model. Key variables encoded as part of soil surveys include landform type, parent material or deposit type, depth to bedrock, percent slope, percent gravel, and percent cobbles. As already noted, most alluvial landforms (valley bottoms, floodplains, and terraces) are prime settings for archaeological preservation. Alluvial fans, footslopes, and dunes also have excellent preservation potential. Deposit types are closely related to landforms and include alluvium, low angle alluvial fans and colluvial slopes, and eolian dunes or sandsheet deposits. These are typically deep deposits with high burial potential. Shallow deposit types with little or no preservation potential include residuum, regolith, channel gravels, or talus. The remaining variables all relate to the energy of the sedimentary depositional environment. Areas with steep slopes are subject to high-energy movements (typically a function of gravity or mass wasting) with poor burial or preservation potential. Relative percentages of gravel (clasts 2 mm) are a proxy of either energy regime or proximity of bedrock—high gravel percentages equate to high-energy alluvial settings or shallow depth to bedrock. Relative percentages of cobbles (>55 mm) provide similar information.

## SUMMARY

The risk-sensitivity model uses a variety of data sources that are manipulated to create layers in a GIS. The foundation is a historical model based on the fluvial geomorphology of the study area. Fine-grained alluvium deposited in low-energy environments has significant potential to preserve buried archaeological sites; hence, all valley bottoms are given a very high sensitivity classification and buffered through a set protocol. Soils data, available at two spatial scales, provide a suite of information that aids in projecting the model predictions to non-alluvial environments. Variables fundamental to soil classification are relevant to archaeological site burial and preservation. In the GIS, these data are output at the two spatial scales to provide set criteria for specified sensitivity areas, which ultimately act as a land development and management tool. Model output and management recommendations are discussed below.

**The Model Output**

The two sensitivity maps (SSURGO [1:24,000], Figure A-3 and STATSGO [1:250,000], Figure A-4) illustrate the distribution of sensitivity zones within the study area study area.

County-level soils data were not available for the entire study area making SSURGO projections impossible across the entire study area; thus, the STATSGO data supplement missing SSURGO data. Both models use the same criterion to define the sensitivity-area categories (Table A-1). When planning or implementing projects, we caution model users to remember that the sensitivity model only predicts where site preservation conditions might be favorable, and not locations that may have been attractive to human activity.

All trunk and tributary stream valley bottoms in the study area except for those with very high gradients are given a very high sensitivity classification. Very high sensitivity areas also include areas with extensive eolian sand deposits located in the southwestern PRB (near Powder River, Wyoming and Hell's Half Acre).

High sensitivity zones are sometimes proximal to fluvial and eolian depositional environments. These areas meet stringent criteria which indicate a setting conducive to the burial and preservation of cultural remains. These criteria include sediment accumulation depth (depth to bedrock), depositional energy regime (minimum slope, bedload transport energy [e.g., percent of 3 in clasts and percent of clasts greater than 2 mm]), and sediment age using likely Holocene-age surface soils as a proxy. Post-glacial age, fine textured alluvial fans fall within this category. Remnant and dissected fluvial terraces like those to the west of Kaycee are high sensitivity areas.

Some areas within the study area are similar in many respects to the very high and high sensitivity zones, except for the fact that they contain smaller areas of probable Holocene-age deposits and soils within larger areas where deposits and soils are only of questionable Holocene age. It is possible that Early Archaic and Paleoindian age occupations might be buried in or under these surface soils, however dating of the soil taxon under local soil formation conditions would be necessary to demonstrate this potential. Given that smaller areas of younger soils are present, the moderate sensitivity zone still presents a management concern for the protection of archaeological resources. Professional on-site, project-specific geoarchaeological evaluations might help identify the smaller and more sensitive portions of this zone.

Low sensitivity areas are characterized by landscapes having thin sediment/soil mantle or high energy (violent) depositional regimes. In addition to the model maps, consulting surface geology maps will help users recognize these types of sediments and soils in the field. In some basin areas upland, interfluvial landforms are characterized by surface or near-surface bedrock. All areas where clinker and/or residuum occur near the surface are classified as low sensitivity. In the Bighorn Mountain uplands, low sensitivity areas are landforms with exposed bedrock, glaciated bedrock, grus (decomposed granite bedrock), or landslide deposits. Generally, low sensitivity areas have a thin sediment mantle, steep slope, and coarse-grained texture. Most surface soils are of questionable Holocene-age, although small areas of probable Holocene-age soils are included. The potential for preserving occupation integrity, perishable materials, and stratigraphic separation of occupations is lower in comparison to the moderate sensitivity zone. Like the low sensitivity category, the key defining variable of this category is sediment/soil depth; very low sensitivity areas also have a similar distribution in the study area and are often adjacent to low sensitivity zones. Areas that contain a combination of attributes rendering them unlikely to contain intact, well-preserved, and stratigraphically separable occupations include a soil type thought to be too old to hold buried cultural material, very shallow depth to bedrock, steep slopes, and/or gravel comprising a relatively large proportion of the soil component. Generally speaking, much of this zone is situated on upland, interfluvial landforms in the basin interior and steep slopes in montane areas.

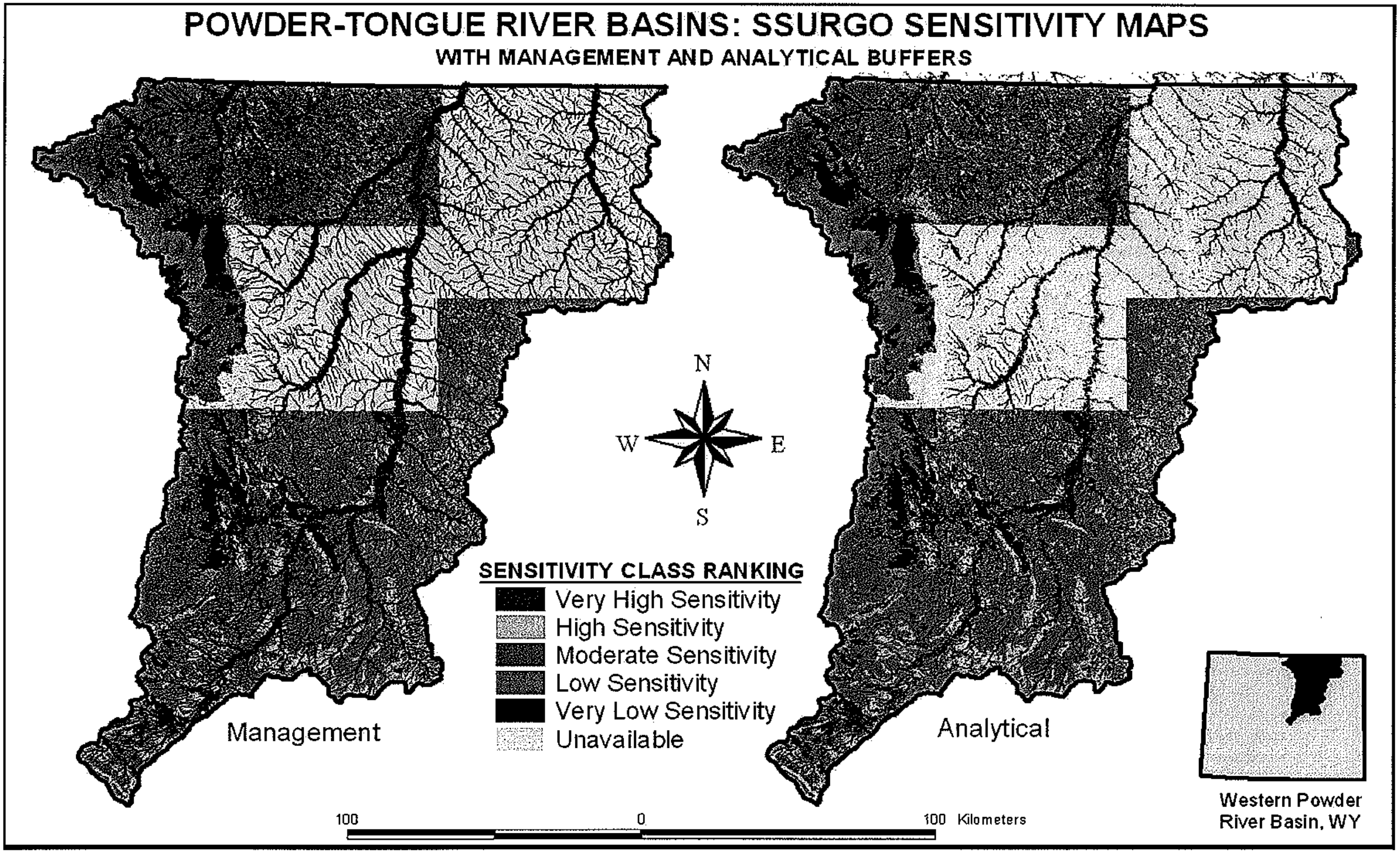


**Figure A-3. Sensitivity map based on SSURGO (1:24,000 base soil mapping) and stream buffers**

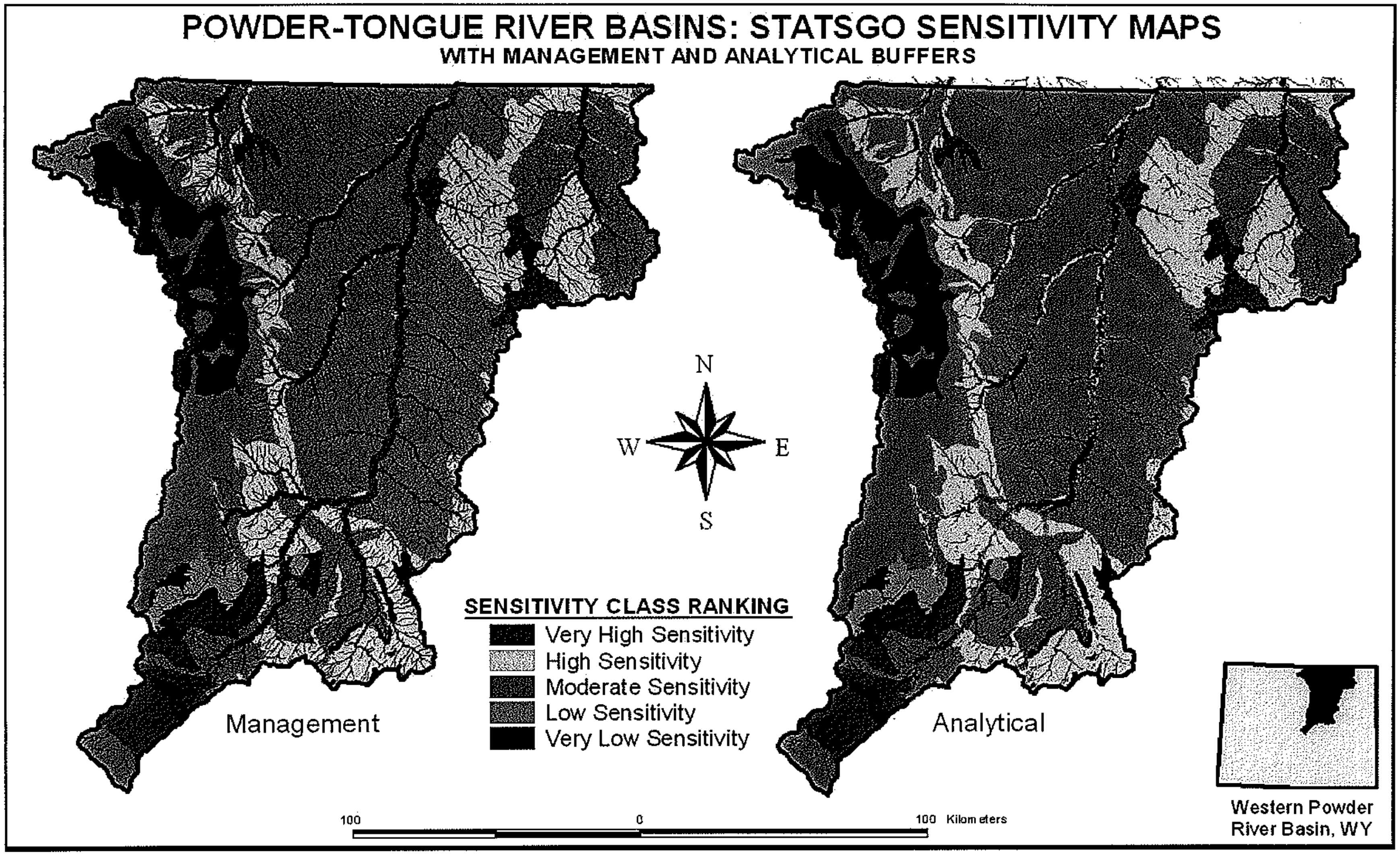


**Figure A-4. Sensitivity map based on STATSGO (1:250,000 base soil mapping) and stream buffers**

## SITE DATA FROM THE WYOMING SHPO CULTURAL RECORDS OFFICE

Site data from the Wyoming State Historic Preservation Office, Cultural Records Office are used to evaluate the model. This process is more fully described in Eckerle et al. (this volume). The frequency of sites that contain buried components generally corresponds to sensitivity zones, with the higher sensitivity zones containing more buried components (Figure A-5.). Sites that have produced radiocarbon dates are another measure of the presence of relatively intact cultural material. The distribution of sites with radiocarbon dates also corresponds to the sensitivity zones (Figure A-6.). High and very high zones contain the majority of the radiocarbon dated sites.

### Applying the Risk-Sensitivity Model

Ultimately, we have envisioned the model data serving as the basis for guiding individual, project-specific management decisions. Given this, the models need to be used at an appropriate scale. All stream buffers are based on 1:100,000 hydrography. An attempt has been made to make the stream buffers useful at a scale of 1:24,000 but no warranty is made. The STATSGO data should be used at a scale no larger than 1:250,000. From a project standpoint, the models are most useful for predicting risk in planned fields, as opposed to individual well pads. We anticipate that the models will be very useful for assessing the risks of pipeline construction and believe that the model output can be useful for predicting where open trench inspection is warranted. Adequate open trench inspection will require a project-specific plan and perhaps a pre-plan reconnaissance by a geoarchaeologist.

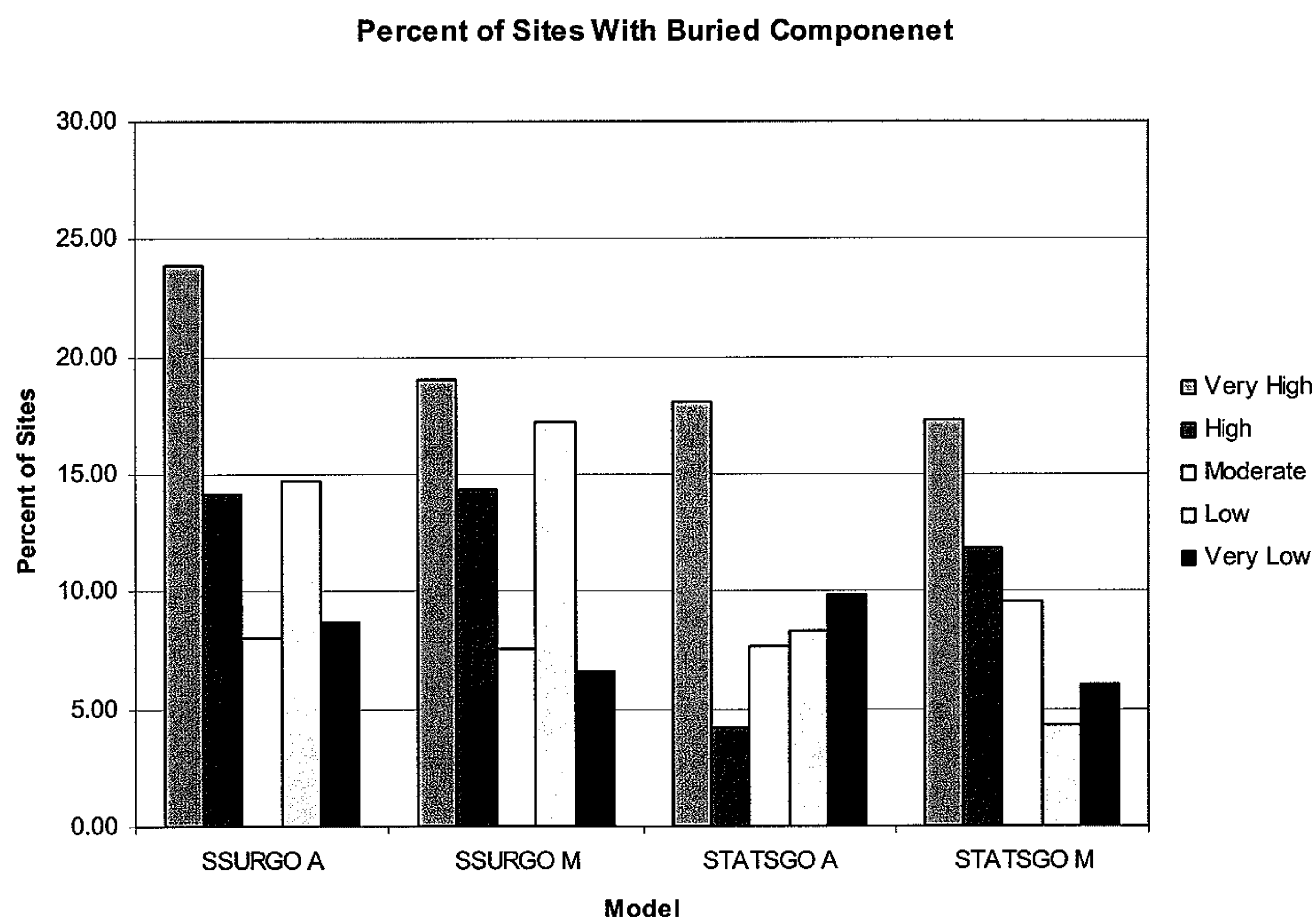


**Figure A-5. Percent of sites with reported buried components by sensitivity class for each model**

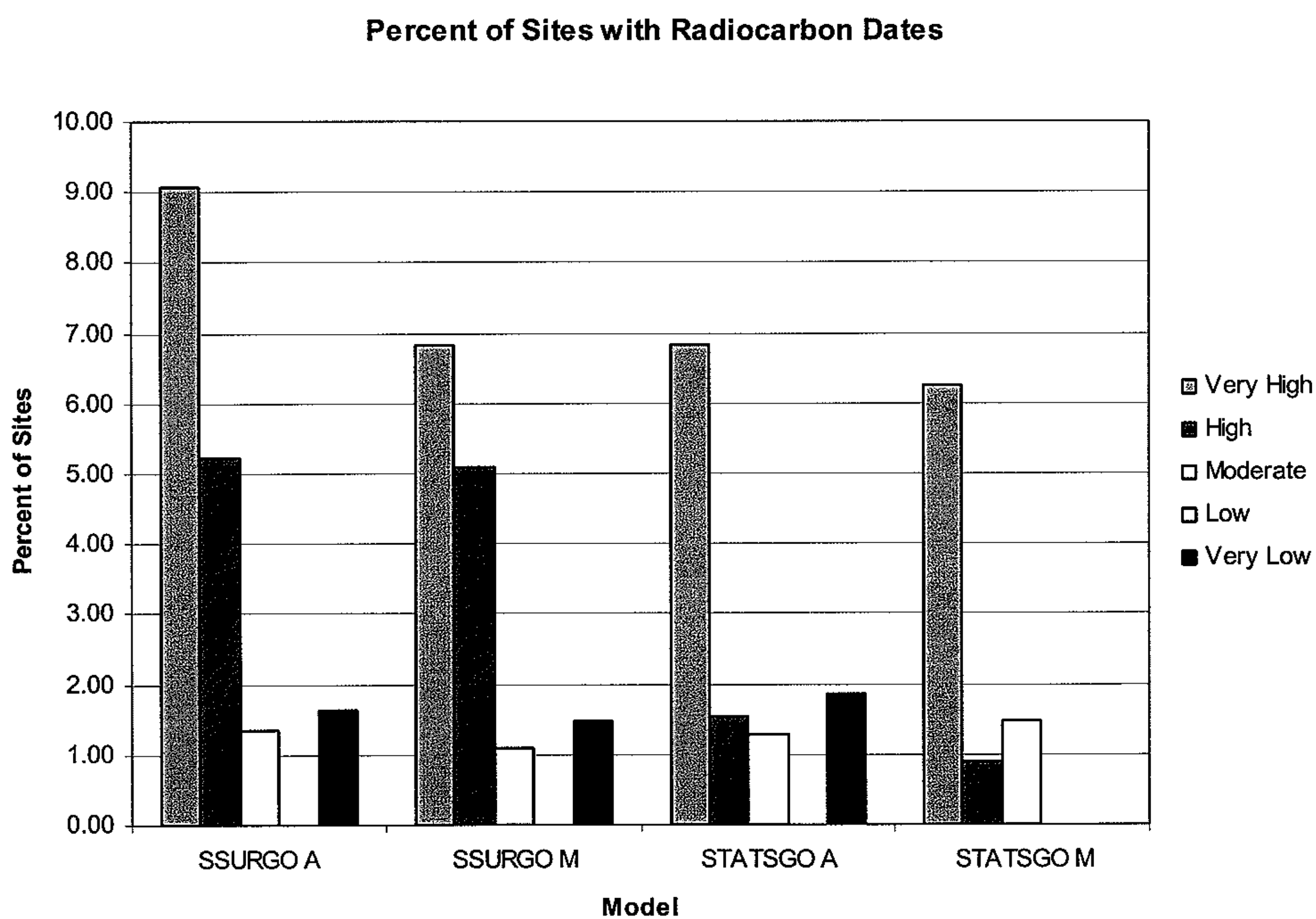


**Figure A-6. Percent of sites with radiocarbon dates by sensitivity class for each model**

Within this limitation and context, land managers can use this information to anticipate areas of archaeological concern. Meanwhile, developers can use it to project the costs of development in targeted and alternative areas to anticipate compliance with Section 106. We offer the following suggestions for applying the models to the planning and implementation stages of projects.

***Very High Sensitivity Zone.*** All model users should recognize that virtually any low to moderate gradient alluvial valley in the study area is a very high sensitivity area. Intensive archaeological inventory, subsurface testing (hand, mechanical, geophysical), and complete construction monitoring would be necessary to limit the inadvertent destruction of significant archaeological resources. Construction activities within this zone should only occur under the most controlled circumstances. Developers and consultants should plan on having archaeologists monitor all earth-moving activities. Open trench inspection of all pipeline construction is recommended.

***High Sensitivity Zone.*** As with the very high sensitivity zone earth-disturbing construction activities within the high sensitivity zone should occur only under the most controlled circumstances. Intensive archaeological inventory, prospecting, and complete construction monitoring would be necessary to totally prevent the inadvertent destruction of significant archaeological resources. As with the very high sensitivity zone open trench inspections of any pipeline construction are highly recommended.

***Moderate Sensitivity Zone.*** Some areas within the project area failed to meet the distinctive criteria that characterized the very high, high, low, and very low sensitivity classes. It seems fair to characterize the sensitivity of such areas as moderate. At the SSURGO scale, the moderate class encompasses low and very low areas delineated by STATSGO, especially in the basin area. While sizeable tracts of the moderate zone have a low risk other, smaller areas (especially at the STATSGO scale) might be more sensitive. As the NRCS makes SSURGO data available for the remaining portions of the project area, it will be possible to delineate areas of low and very low concern from the basin areas. Until that time, professional archaeologists working in STATSGO areas mapped as moderate zone will need to estimate slope, depth to bedrock, percent sediment >3 in, and percent sediment > 2mm to distinguish areas of higher sensitivity from those of lower sensitivity within the basin. Project-specific, geoarchaeological evaluations can help identify which portions of the moderate zone are more or less sensitive. In addition to normal Section 106 process inventory and evaluation, this zone would require construction monitoring of known archaeological resources and monitoring of construction trenches.

***Low Sensitivity Zone.*** Preservation of significant buried archaeological deposits is minimal within the low sensitivity zone. This is because the deposits are generally thin and the sediments may be too old to contain cultural remains within this zone. Within this zone, construction monitoring should be planned on a case-by-case basis following archaeological inventory and evaluation. Field archaeologists evaluating archaeological sites for NRHP significance should consider subsurface testing to a maximum depth of 90 cm or as depth to bedrock necessitates on a case-by-case basis. Although occasional buried site components might be found in this zone, open trench inspections might be dispensed with, except in areas where the low sensitivity is intimately intermixed with mapped areas of very high or high sensitivity at the 1:24,000 scale.

***Very Low Sensitivity Zone.*** Like low sensitivity zones, here little potential exists for the presence of intact, buried archaeological deposits. Development activities following inventory and evaluation procedures need to be considered on a case-by-case basis as determined by field archaeologists. Field archaeologists should consider subsurface testing to a maximum depth of 65 cm or as depth to bedrock necessitates on a case-by-case basis. Younger Holocene-age soils could occur within the boundaries of the very low sensitivity zone. Thus sites with well-preserved, stratigraphically distinct occupations may be present. However, if potential archaeologically sensitive inclusions are not identified during inventory and evaluation, construction monitoring and other post-inventory discovery techniques can be minimized or dispensed with without overt risk to sensitive cultural resources. Like the low sensitivity zone, open trench inspections could be dispensed. The exceptions are areas where the low sensitivity is intimately intermixed with mapped areas of very high or high sensitivity at the 1:24,000 scale.

**Summary and Conclusions**

The study area is the scene of extensive oil and gas development on federal lands that must be considered within NEPA and NHPA guidelines prior to development. Consultation under

Section 106 of the NHPA can become a lengthy process due to unexpected discovery and mitigation of significant archaeological resources. The sensitivity model uses geomorphic, geologic, and soils data to categorically identify the risk of encountering buried archaeological sites. Very high sensitivity zones in the study area occur in all stream valleys and sand dune areas. Here, geologic processes contribute to site formation in a manner conducive to behavioral and spatial integrity, two factors essential to determinations of archaeological significance. Developers, managers, consultants, and field archaeologists should assume encounters with buried archaeological sites as rule rather than exception. High sensitivity categories are sometimes adjacent to very high zones, and, warrant the same concern as the very high sensitivity category. Model users should consider a similar approach in utilizing these areas as they would very high sensitivity zones. Moderate sensitivity areas are the most common category and cover the largest array of depositional settings and landforms. They also require the broadest management strategy. Conservative model users should prepare for extensive archaeological consultation in alluvial or near alluvial settings where probability of burial is high. Geoarchaeological fieldwork and mapping will be beneficial in identifying areas of higher potential within the moderate sensitivity zone and may allow strategies to shift to a less-conservative approach as conditions warrant. Low and very low categories occur where bedrock occurs at or near the surface, defined in model terms as a depth to bedrock of less than 90 cm (35 in). Low and very low sensitivity areas occur in the study area as upland, interfluvial landforms and in montane areas where bedrock or glaciated bedrock outcrops. Although the likelihood of significant, buried archaeological sites to occur in these areas is small, model users should be prepared for occasional significant discoveries to occur.

In conclusion, we would like to clarify that predictive models, such as the one presented here, can only serve as the basis for informed decision making. It should in no way replace the common-sense, on-the-ground, archaeological fieldwork. Yet, we know the importance of knowing what to look for and where to look goes without saying, regardless of which end of the project you are on. We see the archaeological record as both a geologic and cultural phenomenon. Thus it is a valid and useful model for predicting where sites possessing archaeological significance (or risk, if that is your perspective) are located. These are predicated by geological data. But one should be wary of model "theism," as the physicist Niels Bohr implored, for models are only analogs for the way the world operates, at best. We should be prepared to use models only when they work within given circumstances. Use other models when circumstances changes, and abandon all models if and when the time comes to adopt a new one. As such, the site burial model will function best within an adaptive management paradigm. To facilitate this, the model needs to be expanded and reevaluated at periodic intervals. Users of this model should seek some way of funding and implementing reevaluation of the model at appropriate intervals. Since archaeology is a cumulative discipline, building on the knowledge base of previous work, applications of this model and new data generated from its application will only result in refining it for future use.

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# APPENDIX B

## ESTIMATED HEIGHTS OF THE HIGHEST FINE TEXTURED TERRACE ALONG STUDY AREA STREAMS

Field reconnaissance was conducted as part of this project. Fieldwork consisted of a vehicular reconnaissance focused on observing valley fill. It was possible to observe the highest, fine-textured Holocene alluvial fill (Hfh) at almost all observation points. A general decrease in the height of the highest Holocene fills from high stream order and low gradient classes to low stream order and high gradient classes were observed. Height of the highest Holocene alluvial fill was visually estimated at each stop. The resulting estimations are presented in Table 1. These heights are classified into three classes: (a) $\leq$ 5 m, (2) >5 to $\leq$8 m, and (3)>8 to $\leq$20 m. The classified observations are plotted in Figure B-1 that illustrates stream order and gradient class. As can be seen, the relationship between stream order and terrace height is strong, although not invariant. The highest Holocene terrace fills are generally located along stream orders 4-6, moderately high fills generally on stream orders 2-3, and the lowest fills on the lowest stream orders. These observations were used to help refine terrace heights presented in the regional literature and used to help guide the estimation of the highest Holocene valley fill for the stream buffering in this report.

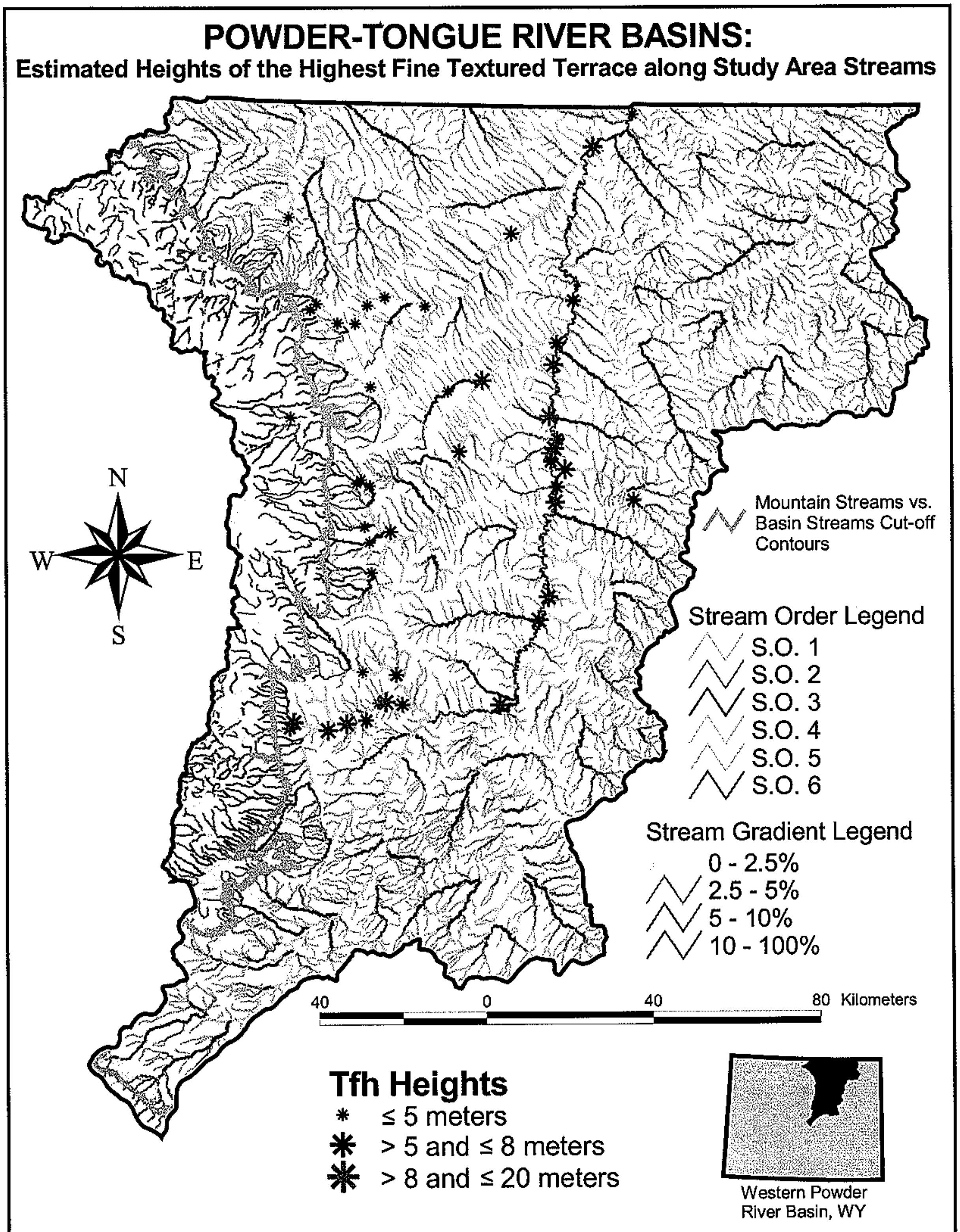
POWDER-TONGUE RIVER BASINS:
Estimated Heights of the Highest Fine Textured Terrace along Study Area Streams
N
W
E
S
Mountain Streams vs. Basin Streams Cut-off Contours
Stream Order Legend
S.O. 1
S.O. 2
S.O. 3
S.O. 4
S.O. 5
S.O. 6
Stream Gradient Legend
0 - 2.5%
2.5 - 5%
5 - 10%
10 - 100%
40
0
40
80 Kilometers
Tfh Heights
≤ 5 meters
> 5 and ≤ 8 meters
> 8 and ≤ 20 meters
Western Powder River Basin, WY

**Figure B-1**