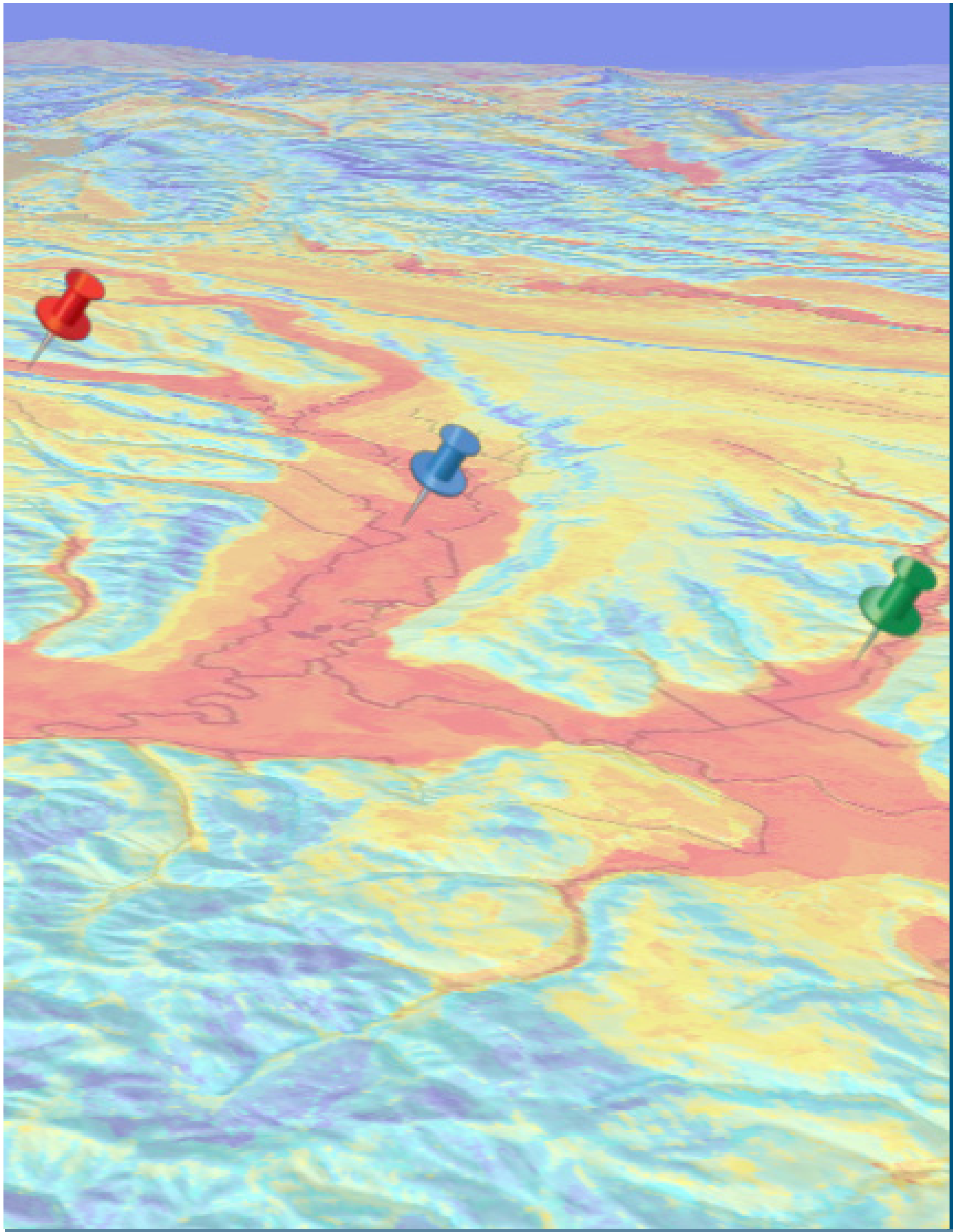

Washington Statewide Archaeology Predictive Model Report

June 30, 2009

GEOENGINEERS

INTRODUCTION

The Department of Archaeology and Historic Preservation (DAHP) identifies and protects archeological resources in Washington State through information and education. Archaeological sites are nonrenewable resources that contribute to our sense of history and place and define our collective shared heritage. In a sense, we are all responsible for protecting these resources, and the challenge for DAHP is to identify, protect and manage these increasingly threatened archeological resources in a cost-effective and useful manner. The goal of this project is to develop a statewide archaeological predictive model that can help DAHP achieve its overall mission to protect archeological resources.

Knowing in advance where archaeological resources might be located will help planners avoid these resources and minimize the regulatory review of construction and development projects. Archaeological predictive models can generally help meet these goals by mapping areas with high, moderate, low or unknown potential for containing archaeological sites based on a series of environmental variables (for example, distance to water, south-facing slopes). This knowledge can then be used to avoid or prepare for appropriate mitigation for appropriate locations when planning construction projects. For example, human remains believed to be those of Native Americans were discovered during a septic tank replacement project on Beckett Point, an 85-acre development located about 10 miles west of Port Townsend, Washington. The purpose of the $2.8-million project was to replace aging septic tanks thought to be polluting Puget Sound. Although an executive order issued in 2005 requires an archaeological survey for state-funded projects, the project permits were filed before that order was issued, and so a survey was not conducted before work began. The unexpected archaeological discovery postponed the project until an archaeological survey and evaluation could be completed at the site. Eventually, this project was allowed to continue, but only after the Public Utility District (PUD) agreed to work with the Jamestown, Port Gamble and Skokomish Tribes and DAHP to ensure that remains or artifacts discovered would be handled properly. The costs of the additional archaeological work totaled more than $30,000, and the additional costs for construction delays are yet to be calculated.

The Graving Dock project in Port Angeles, Washington, provides another example of the usefulness of knowing where archaeological resources might be located. The Graving Dock site was proposed to house an on-shore dry dock facility that was to be used to build anchors and pontoons for the new eastern half of the Hood Canal Floating Bridge. This $17-million project was stopped in August 2003 when construction activities exposed cultural resources at the site. The unexpected archaeological discovery postponed the project until the Lower Elwha Tribe, Federal Highway Administration (FHWA), U.S. Army Corps of Engineers (USACE), Washington State Department of Transportation (WSDOT) and DAHP could negotiate an archaeological treatment agreement for the site. Construction activities were subsequently delayed for an additional four months while archaeologists collected data from the site, and the total additional cost to the project was estimated at $7.9 million ($4.5 million for archaeology and $3.4 million for mitigation). Ultimately, the project was completely halted.

The statewide predictive model developed for DAHP identifies both Beckett Point and Port Angeles Graving Dock as locations with high potential for discovering archaeological sites. Although a predictive model cannot be guaranteed to predict the location of a cultural resource with 100 percent accuracy, it is a valuable tool to help planners and archaeologists augment their experience and knowledge, reduce the possibility of surprises and attempt to avoid costly delays.

For the model to be a useful tool for planning, we developed the model using standardized and repeatable statistical methods, standard software packages and statewide environmental and cultural resource data. In the current project, locations of known archaeological sites are correlated to environmental data to determine the probability that, under a particular set of environmental conditions, another

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location would be expected to contain an archaeological site. In this way, the model uses environmental conditions to leverage what is known about existing archaeological sites and to expand that knowledge to unsurveyed or under-surveyed parts of the state. However, we realize that there are reasons for an archaeological site to exist even at a location that may have little or nothing to do with the environmental conditions that we currently have mapped (for example, scenic views, spiritual or religious factors, solar exposure, Traditional Cultural Properties, etc.). Our existing information regarding archaeological sites shows that not all sites occur at locations with high environmental probability. For this reason, we added a component to the model that incorporates spatial proximity into the predicted values. This is accomplished by evaluating locations within the study area for spatial proximity to archaeological resources and then adjusting the environmental prediction at that location accordingly (see the "Processing Methods" section for more details regarding these methods). Using this method, the model combines the environmental information with the local information developed by field surveys from archaeologists to identify locations across the state with a range of high, moderate, low and unknown probabilities for discovering an archaeological site. The model information will be available via the DAHP web portal (WISAARD) to qualified personnel and agencies for use in project review, planning and protection of these valuable, non-renewable resources.

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PROJECT BACKGROUND

Archaeological predictive modeling for Washington State began as a pilot study completed in 2004 involving a sample area in South-Central Washington, as shown in Figure 1. This pilot study was a very important first step in determining whether a statewide model would be feasible. In many ways, this study helped to lay the foundation upon which the statewide model is now built. Even at the beginning of this first pilot study, our goal was to eventually develop a statewide model. Some of the requirements for the model included the capabilities to: 1) repeat and update the results on a regular basis; 2) expand the model to use other datasets when or if they become available; 3) run the model using standard software packages; and 4) expand the model to a statewide model.

We worked with archaeologists to identify environmental data that would be important in predicting archaeology sites, and then we matched those data elements with the datasets available statewide. It was during this pilot project that we decided on the environmental data that would become the building blocks for the statewide model. These include elevation, slope, distance to fresh water, aspect, soils, geology and landforms. Landforms were the only dataset identified as not being available from another organization, yet vitally important to archaeological predictive modeling. We tested several methods for large-scale landform data development (see the "Data Descriptions" section for details on the methodology we adopted for the statewide model). We also identified the need for cultural information to be gleaned from the Government Land Office (GLO) maps and began the process of georeferencing and digitizing from these maps.

As part of this pilot study, we researched other archaeology models. Specifically, we chose two models for more detailed examination, based on their use of environmental factors combined with statistics and GIS to develop archaeology models for large areas of land: the Minnesota and British Columbia Forest Land Archaeology Models (MnModel and BCModel, respectively). We compared development techniques when possible because statistics, environmental data and GIS were integral to the development of our model (WAModel). The common theme in these predictive methods is the use of environmental data, which can be made available within a GIS database, to identify the most likely locations for new archaeological discoveries. The most objective approach seemed to be logistical regression analysis, but its major shortcoming is that it treats each grid location as being independent of all other grid locations and assumes a linear relationship between a variable and site location. Ideally, spatial dependence and spatial proximity should play a major role in making spatial predictions. We initially tested logistical regression for our pilot study areas; however, the estimation performance of the regression was poor and the models were not statistically significant. We tested and adopted the Bayesian statistical methods as the best way to model archaeological resources in Washington.

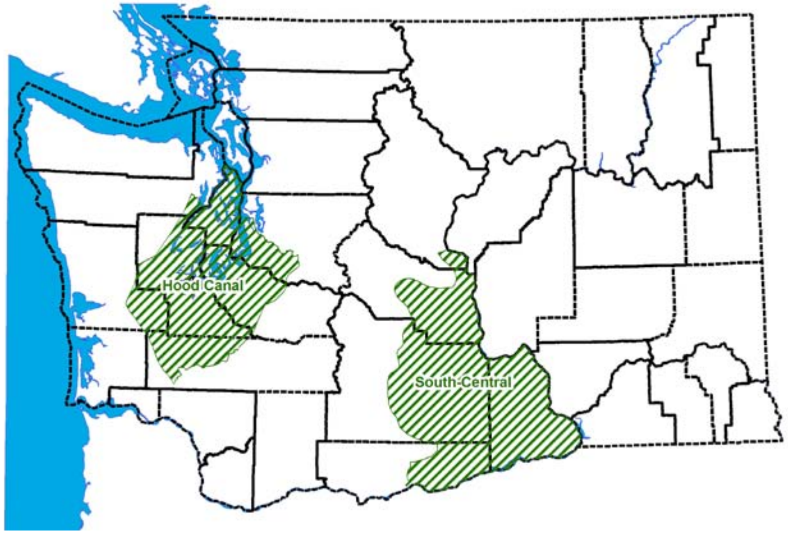

Figure 1. Study Areas for the 2004 (South-Central) and 2006 (Hood Canal) Pilot Studies

The GIS technology and computer processing speeds have changed since this initial model was developed. This pilot study was primarily developed using ESRI's ArcView 3.2 with Microsoft Access databases for some of the processing. The statewide model has been developed using current technology including ArcGIS 9.3, python and model builder scripting, SQL server and .NET programming (see the "Processing Methods" section for additional details).

To complement the first pilot study conducted in Eastern Washington, an area in the Western part of Washington in the vicinity of Hood Canal, as shown in Figure 1, was selected for the second pilot study, which was completed in 2006. This pilot study indicated that the techniques originally developed for Eastern Washington would work in the different environmental conditions of Western Washington. These tests were successful and confirmed that the Bayesian techniques would be appropriate to use on a statewide model. In this second pilot study, we also introduced the concept of integrating spatial proximity with the environmental data into the predictive capabilities of the model. Because of the volume of information being processed, we generalized the spatial proximity calculations to larger areas. Although the end result was not specifically able to be used for management purposes, the testing did confirm that spatial proximity could be integrated into the model. We also developed a preliminary "confidence" layer for the model that could indicate a confidence in the predictions being developed. This was a test case that we have more fully developed for the statewide effort. Full details of these additions are included in the "Processing Methods" section of this discussion. In summary, we have spent several years developing and refining our methods for an archaeological predictive model. Through two separate pilot studies (South Central 2004 and Hood Canal 2006), we have honed our methods for developing environmental data to be used in the WAModel. Additionally, we have tested and compared several methods for statistically estimating the most likely locations for new archaeological discoveries. Our methods were designed to be as automated as possible to allow the model to be updated as new data become available. In developing the WAModel, we used our years of experience and extensive testing to make the model as consistent and accurate as possible at the statewide level.

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STUDY AREAS

In order to develop a statewide model, we needed to divide the state into smaller areas that could be reasonably processed during the modeling efforts. The study area boundaries were generally based on environmental factors including physiographic provinces, ecoregions and hydrographic boundaries. Physiographic provinces are areas of similar terrain that have been shaped by a common geologic history.[1] An ecoregion is an area characterized by a distinct collection of natural communities and species, often heavily influenced by climate. Hydrographic boundaries may include watershed divides or major rivers.

Using these parameters to consider overall environmental factors, the state was divided into specific study areas where pre-contact (that is, prior to any European influence) human land use would likely be consistent. Overall size was also a factor in determining the study area boundaries. Individual study areas were kept within a size range that would be reasonable for computer processing time. Most boundaries were determined in large part by physiographic provinces, with the edges refined by using ecoregions and watershed boundaries. County boundaries were not used to define study areas because administrative boundaries do not accurately portray pre-contact human land use patterns. This approach resulted in dividing the state of Washington into nine study areas, as shown in Figure 1.

The study area boundaries were generally based on physiographic provinces, ecoregions and hydrographic boundaries.

- **Coastal Washington** (6,300 square [sq.] miles). This area includes the Olympic Mountains and the Willapa Hills. The Olympic Mountains form the core of the Olympic Peninsula. The Willapa Hills are defined by the low-lying coastline and major estuaries (Grays Harbor and Willapa Bay).
- **Puget Lowland** (6,200 sq. miles) and **Lower Columbia** (3,600 sq. miles). The Puget Lowland and Lower Columbia have similar characteristics as low-lying areas generally located between Coastal Washington and the Cascade Range. The Puget Lowland area was covered by the continental ice sheet during the Quaternary time period. Glacial erosion and deposition established existing waterways and drainages prevalent in the Puget Lowland. The Lower Columbia study area was delineated using ecoregions and watershed boundaries to create an area of generally consistent fluvial characteristics, with consideration to both geomorphic processes and pre-contact human use.

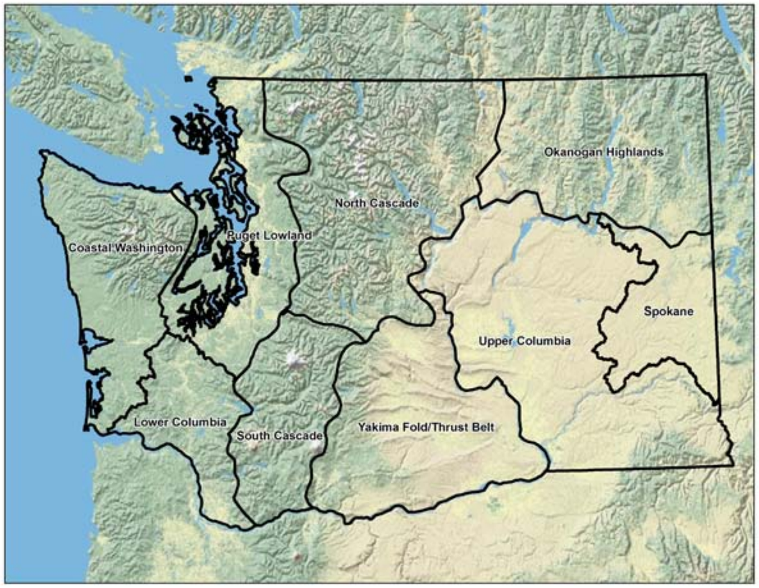

Figure 1. Study Areas for the Washington Archaeological Predictive Model (WAModel)

- **North Cascade** (12,000 sq. miles) and **South Cascade** (4,800 sq. miles). North Cascade and South Cascade have similar characteristics and are defined by high topographic relief. The North Cascade region has the second largest concentration of alpine glaciers in the United States. The South Cascade area is home to three active volcanoes (Mount Rainier, Mount Adams and Mount St. Helens).
- **Upper Columbia** (13,600 sq. miles), **Yakima Fold/Thrust Belt** (8,700 sq. miles) and **Spokane** (3,900 sq. miles). These areas generally constitute the Washington State portion of the Columbia Basin province, which was subdivided along major rivers and ecoregions to maintain a reasonable size range of each study area for practical computer processing time. These areas are defined by loess hills and

rivers overlying basalt. Repeated late-glacial flooding within this area created the Channeled Scablands, which include topographic features such as coulees, buttes, mesas, dry waterfalls, hanging valleys and giant ripples.

- **Okanogan Highlands** (8,600 sq. miles). This area is defined by its rounded mountains and deep, narrow valleys. The Okanogan Highlands area is bisected by the Columbia River. This area was covered by the Okanogan lobe of the Cordilleran ice sheet during the Quaternary time period and formed lakes in the Columbia and Pend Oreille River Valleys.

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Environmental Data - Introduction

This project correlates information about archaeological sites, archaeological surveys and possible site locations with the environmental data to help predict where additional archaeological resources might be found within Washington State. For the purposes of this model, we focused on seven different types of environmental data:

- Elevation
- Slope Percent
- Aspect
- Distance to Water
- Geology
- Soils
- Landforms

The environmental data included in the model were chosen by considering several key criteria—namely, that the data should be: 1) available in GIS format or available for conversion to GIS format; 2) easily obtainable from public sources; 3) available for the entire state; 4) available at a reasonable scale or resolution for the model; and 5) identified by archaeologists as highly influencing the likelihood of the presence of an archaeological site.

The environmental datasets were obtained or derived from the sources (described below) in GIS format. The data were converted to Washington's standard projection (Washington State Plane South North American Datum of 1983 [NAD 83] High Accuracy Reference Network [HARN] feet) and converted to 100-foot grids. The processing methods for the overall model uses interval probabilities to correlate the archaeological data with the environmental data. In order to calculate probabilities across a study area, each dataset needed to be grouped so that the probabilities would be meaningful when processing the model (see "Processing Methods" section for additional details). Datasets were categorized into 8-18 groups each. Archaeologists, geologists and soil scientists, as appropriate, assisted with identifying the groups so that they reflected similarities of the underlying data. For example, geology was grouped based on age of the geological formations as well as geologic types. See below for additional details for each environmental dataset and their specific groupings.

Data Assumptions/Limitations

Archaeological data utilized in developing the Washington State Archaeological Predictive Model is based on simple principles that are relevant to archaeological research. The assumptions and key variables which make up the model are influenced, in part, on research for other large-scale archaeological predictive models, with notable differences. The Washington model is based on a simple premise; prehistoric people in Washington State were hunter/fisher/gatherers who targeted and utilized key resources through time. Although the resource focus and availability sometimes changed, it's possible to focus on a finite set of fundamental variables either required or otherwise sought by prehistoric people.

Archaeological data utilized in developing the Washington State Archaeological Predictive Model is based on simple principles that are relevant to archaeological research.

As with most GIS based geoprocessing models, this model is dependent on the limitations of the input environmental data regarding quality and scale in the original data. Limitations of the original data are applicable to the overall model. Please refer to the original source data for all limitations that may apply.

The following assumptions were made regarding the data used in the model and how they relate to predicting archaeological discoveries.

1. Known archaeological sites represent locations of past human activity.
2. Human and animal behavior is patterned; hence, the locations (archaeological sites) people used in the past should have relationships to specific environmental variables that range from

simple to complex. Proximity to these environmental variables, therefore, is knowable.

3. Archaeological sites are components of broad cultural systems, and their locations are at least in part dependent on the location of other system components, such as water sources, raw material sources and other archaeological sites.
4. Archaeological sites are location-dependent. They exist in planned proximity to activity-specific resources.
5. Travel between archaeological sites may determine site locations; geomorphic features of the landscape play a significant role in land-use preference because mobility to and from necessary resources is a significant factor in the decision making process that leads to their use.
6. Ethnographic and archaeological site data demonstrate that many settlement and activity locations were reoccupied through time.
7. Environmental variables are fluid and change over both short- and long-time frames, fundamentally influencing archaeological site location.

Elevation Data

The clearest intuitive relationship between archaeological sites and relative elevation may occur at the lowest elevations. Gravity ensures that water tends to move downslope. Groundwater recharge occurs at locations where the water base level meets the ground surface, where it is then available for use by humans and animals in a stream, river, lake or wetland. Although relatively few linear relationships exist between elevation and archaeological site locations, archaeological sites may have a relationship to changes in relative elevation. For example, in many environments, land at a relatively higher topographic elevation than the surrounding landscape may promote drainage, may provide a better view of the surroundings, and may also increase defensibility.

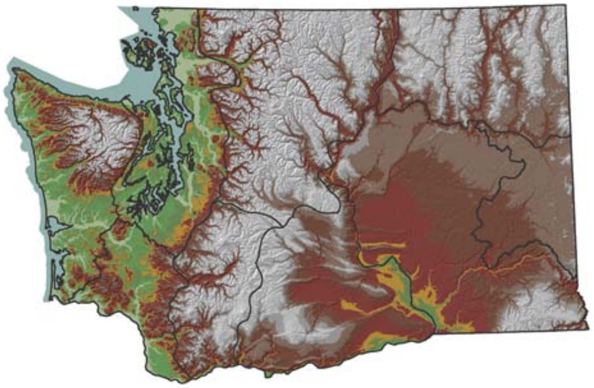


Figure 1: Example of elevation classification

The elevation data we used for the model were obtained from the United States Geological Survey (USGS). The digital elevation data are a product of the USGS's effort to provide 1:24,000-scale Digital Elevation Model (DEM) data for the continental United States. The USGS National Elevation Dataset (NED) is the result of merging the highest resolution elevation data available across the country into a seamless grid of data known as a "raster." The NED has a consistent horizontal and vertical spatial reference (NAD 83 and North American Vertical Datum 1988 [NAVD 88], respectively) and uses a geographic projection with a resolution of one-third arc second (approximately 10 meters) with elevations measured in meters. The NED is a living dataset and is updated by the USGS bimonthly to incorporate the best elevation data available. The DEM for this project was developed from the USGS's NED obtained in June 2007. Once the NED data were downloaded, we generated a resulting DEM for Washington State.

The NED data for Washington State were downloaded from USGS in 250-megabyte increments referred to as "tiles." Once DEM data for the entire state were acquired, the data were mosaicked together to create one seamless dataset. Mosaicking is a process where individual raster files are appended together to create one seamless file. In assembling the Washington State DEM, corrections were made during the mosaic process to minimize errors in the data, to perform edge matching to prevent seams and to fill small areas of missing data. Seams or discontinuities will occur along tile edges because of differences in the quality and accuracy of the input DEM. These seams were corrected to provide useful data for this project. Seams also arise when an offset occurs in the elevation values between two DEMs. An edge-matching operation was used to detect offsets along a seam.

After the elevation data were mosaicked and refined, the units of measure were converted from meters to feet to provide a common unit of measure among all datasets used for this project. Feet were chosen as the unit of choice in order to preserve the higher precision of other datasets already using feet. To make the unit conversion for the elevation data, a projection transformation was required to transform data originally projected in the geographic coordinate system, which uses latitude/longitude as units of measure, to NAD 83 HARN State Plane South (feet), which uses feet. A bilinear interpolation algorithm was used to perform the horizontal projection transformation, and map algebra (the elevation value was multiplied by 3.28) was used in the vertical conversion from meters to feet.

Archaeological sites may have a relationship to changes in relative elevation.

When all the data were transformed into a common unit of measure (feet), the dataset was clipped to the boundary of Washington State. This step removed portions of the DEM that overlapped into Oregon and Idaho. The process of clipping the data to the state boundary performed two functions: (1) reducing the file size, and (2) ensuring that any analysis performed thereafter would focus only on the area within Washington State.

In order to efficiently work with the data, we grouped the elevation values into groups or value ranges. The following table lists the groups for the elevation dataset.

Elevation Group Number	Description	Elevation Range Value From (Feet)	Elevation Range Value To (Feet)
1	<0	0	0
2	>0 and <= 150	0	150
3	>150 and <= 350	150	350
4	>350 and <= 500	350	500
5	>500 and <= 700	500	700
6	>700 and <= 1300	700	1,300
7	>1300 and <= 2000	1,300	2,000
8	>2000 and <= 2700	2,000	2,700
9	>2700 and <= 3300	2,700	3,300
10	>3300	3,300	99,999

DEMs can be used for such purposes as deriving hillshades, generating contours or drainage networks, classifying land cover, geometrically correcting remotely sensed data (orthophoto rectification) or deriving landform characteristics. For this project, the Washington State DEM was also used to derive slope percent, aspect and landforms.

Slope Percent

One way to describe the gradient or steepness of a surface is by calculating slope. Slope is defined as the rate of maximum change in elevation (the rise over the run) from each cell to its neighboring cells. A higher slope value indicates a steeper incline, and a zero slope value indicates flat terrain. Archaeologists use slope as an indicator of the relative likelihood for the presence or absence of archaeological sites. Archaeological researchers assume that a relationship exists between desirable habitation locations and the degree of slope because relatively few activities take place on steep slopes. Notable exceptions include specific resource extraction sites such as lithic raw material quarries. Plant and herb collecting may also take place on steep slopes, and these slopes may be used as transportation routes to connect more desirable locations that are separated by topographic relief. However, utilization of steep slopes in these ways leaves a relatively weak archaeological signature. Even when steep slopes are utilized, they are not conducive to burial and preservation of archaeological materials because material tends to weather downslope.

The output slope value can be calculated in either of two ways: degrees or percent. For this project, slope percent was used. After slope percent was calculated from the DEM, the slope values were reclassified into groups. The following table lists the groups for the slope dataset.

Slope Group Number	Description	Slope Range Value From (Percent)	Slope Range Value To (Percent)
1	<= 8	0	8
2	>8 and <= 20	8	20
3	>20 and <= 40	20	40
4	>40 and <= 60	40	60
5	>60 and <= 80	60	80
6	>80 and <= 100	80	100
7	>100 and <= 128	100	128
8	>128	128	99,999

Archaeologists use slope as an indicator for the likelihood to find archaeological sites.

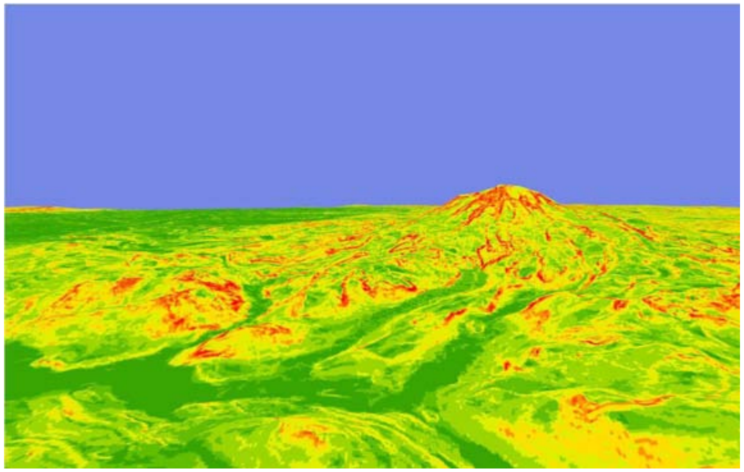
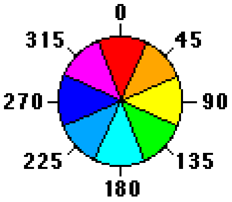


Figure 1: Example of slope classification where green indicates a flat area and red indicates a steep slope.

Aspect

Aspect identifies the steepest downslope direction at a location on a surface, and can be thought of as slope direction or the compass direction a hill faces. Aspect is often considered a critical factor for the likely presence of an archaeological site. For example, south-facing slopes are typically optimal for sun exposure and, therefore, favorable for growing crops.

Aspect is calculated directly within the GIS software program and we used the standard descriptions for determining the angles for north, south, etc. facing slopes. The figure below shows graphically the angles that are grouped for aspect with 0 being north, 90 being east, 180 being south and 270 being west.



Based on aspect angles, the values were also reclassified into nine groups. The following table lists the groups for the aspect dataset.

Aspect Group Number	Aspect Description	Aspect Range Value From (Degrees)	Aspect Range Value To (Degrees)
1	North	0 and 337.5	22.5 and 360
2	Northeast	22.5	67.5
3	East	67.5	112.5
4	Southeast	112.5	157.5
5	South	157.5	202.5
6	Southwest	202.5	247.5
7	West	247.5	292.5
8	Northwest	292.5	337.5
9	Flat	-1	0

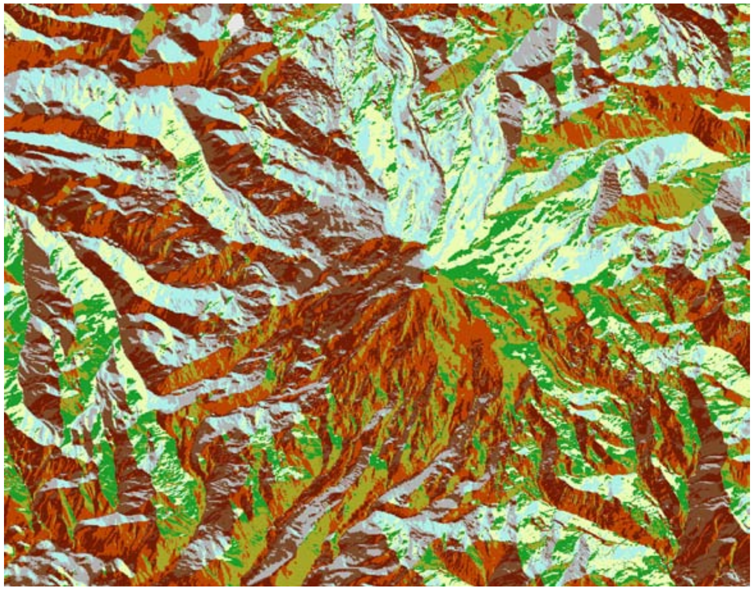


Figure 1: Example of aspect classification (Mt. Rainier, Washington)

Aspect is often considered a critical factor for the likely presence of an archeological site.

Distance to Water

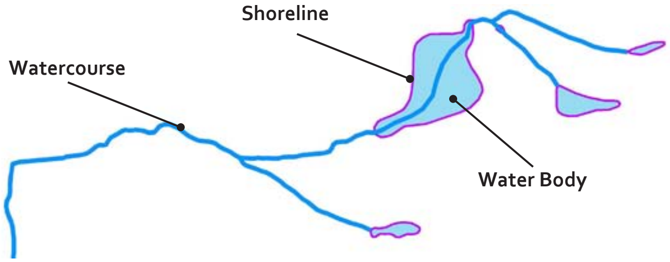
Water, whether an ocean body, lake, stream, river, spring or wetland is a key resource for drinking, cooking, transportation, washing, wildlife, fire protection, and transportation. Therefore, the distance to water was a key consideration for predicting archaeological site locations. Archaeologists generally expect the majority of large archaeological sites and site aggregates to be located in close proximity to shorelines or water sources of some sort. Notable exceptions would include remote resource extraction areas, which although essentially within reasonable range of potable water, may have a relatively weaker frequency of discovery. This may be due to their remote nature and the tendency of archaeological surveys to take place in areas with more intensive land use.

The margins of lakes and wetlands were important for fishing, waterfowl, egg and plant collecting, and as watering places for animals. These areas were often intersected by hunters as the animals traveled to drink. In large portions of eastern Washington, water is a key limiting factor in the location of most archaeological sites. On the west side of the state where water is abundant, the relative importance of distance to water may be slightly less, except with regard to settlement of the coastline where archaeological sites are concentrated, but where aspects of the coastal geomorphology tend to have greater influence on archaeological site location.

Precipitation, a source of fresh water, is subject to climatic regimes, and the GIS data used in this model only reflects modern waterways. Lake levels and stream flow have changed greatly through time as a result of fluctuating climates. Generally, in Western Washington, Upper Pleistocene and Early Holocene streamside environments are located in many places hundreds of feet in elevation and miles from modern waterways. In Eastern Washington, coulees that flowed with sluggish streams at the close of the ice age are now dry, largely ephemeral waterways at best. Generally speaking though, the majority of lakes, rivers, streams and the Washington coastline approached their modern levels by the middle Holocene.

The Washington State hydrography data used for this project was downloaded from the United States Geological Survey (USGS) National Hydrography Dataset (NHD). NHD data comes from various sources throughout the country. The Pacific Northwest Hydrography Framework is a consortium of partners responsible for managing and updating all spatial hydrography and watershed boundary layers within Oregon and Washington. Data for Washington State were initially published in September 2005, and is intended to be used at a 1:24,000 scale. The data were separated by hydrologic unit watersheds. We downloaded the data for this project from each individual watershed. The layers included water bodies, watercourses and associated tables. Once they were all downloaded, we merged the files into a single statewide layer for water bodies, watercourses and associated tables. The statewide layers were re-projected from its native spatial reference of NGS North American 1983 to NAD 1983 HARN State Plane Washington South (feet), the coordinate system specified for this project.

Water is a key consideration for predicting archaeological site locations.



The water body dataset represent features such as sounds, bays, lakes, ponds, wetlands, reservoirs, inundation areas, the double lines portion of streams and other hydrologic features best represented as areas. The watercourse dataset represents features the centerline of streams, canals, flumes and other linear features that are best represented as lines. For this dataset watercourse names were maintained by USGS and kept in a separate table. In order to obtain watercourse names the spatial data were linked to the table containing name information using each feature's unique longitude/latitude identifier number, also known as an LLID. The LLID is a unique 13 character identifier number that is based on the coordinates from the most downstream point or mouth of the watercourse. We selected those watercourses that had names in the associated tables to use for the model.

Once we obtained the statewide data of hydrologic features we used them to calculate a distance to water grid to be used in the model. The distance to water environmental layer was calculated using a straight-line distance algorithm within GIS to hydrologic features identified from the GIS layers (watercourses, water bodies) for the state. The straight-line distance function results in a GIS layer that identifies those areas closest to hydrologic features based on straight-line proximity.

The following is a list of the group names for each of the distance to water ranges.

Distance to Water Group Name	Group Description (feet)
1	>0 and =<500
2	>500 and =<1000
3	>1000 and <= 1500
4	>1500 and <= 2000
5	>2000 and <= 4000
6	>4000 and <= 6000
7	>6000 and <= 8000
8	>8000 and <= 10000
9	>10000 and <= 20000
10	>20000

References

Pacific Northwest Hydrograhy Network (OR/WA Hydrography Framework Partnership) GIS and Metadata. http://hydro.reo.gov/metadata/WaterBodiesOregonWashington.htm

Pacific Northwest Hydrograhy Network (OR/WA Hydrography Framework Partnership) GIS and Metadata. http://hydro.reo.gov/metadata/WatercoursesOregonWashington.htm

Pacific Northwest Hydrograhy Network (OR/WA Hydrography Framework Partnership) GIS and Metadata. http://hydro.reo.gov/metadata/ WaterBodyShorelinesOregonWashington.htm

Geology

Archaeologists use the geologic setting of an area to help reconstruct the age of a cultural resource and gain a better understanding of historical landscapes. For example, rivers forge new pathways, floods deposit material across valley floors, and volcanoes, earthquakes and landslides all change the landscape through deposition, displacement and/or erosion. Therefore, an archaeologist can use the geologic setting surrounding a cultural resource discovery as a factor in determining details about the historical landscape as well as the source of the discovery. For example, the discovery of an arrowhead in the area of a river located between steep riverbanks on a narrow beach would not provide a complete picture until it was placed into a geologic context. The steep slopes make it improbable that Native Americans lived on this beach, but it would be reasonable to conclude that the arrowhead was deposited by the river after erosion and transport. Geology data can also provide insight into the source of the material, or rock type, used to construct tools. By understanding the rock type, it is possible to determine where the material may have come from and, therefore, also to reconstruct potential migration pathways and trade routes.

Geology data can be used to help answer several different archaeological questions. Some examples include:

1. the relationship between the geological setting of a region and settlement location(s);
2. the nature of the site forming processes;
3. the recognition of (geological) activity areas in archaeological sites; and,
4. the role played by geological processes in distorting or preserving the archaeological record.

Geology data used for this project were obtained from the Washington State Department of Natural Resources (DNR) Division of Geology and Earth Resources (DGER). The geology data were originally categorized into 136 unique lithologic types within Washington State. For better use in the model, we categorized the geology data into 18 broader, more general lithologic groups (numbered 0 through 17) containing geologic units with similar properties. We further subdivided geologic groups into Quaternary and older geologic units. Geologic groupings were determined in consultation with geologists and were based primarily on lithology and geologic age. For example, both Grande Ronde basalt flows from the Middle Miocene and Roza Member basalt flows from the Middle Miocene were placed into Geology Group 8, Miocene basalt. The geologic grouping is somewhat subjective and could have been determined in several different ways. The method we used was based on the criteria and level of detail necessary for this model. The following table lists the groups for the geology dataset.

Geology Group Number	Geology Description
0	Water/Ice/Unidentified
1	Alluvium
2	Dune sands
3	Talus deposits
4	Alluvial fan deposits
5	Loess
6	Continental glacial deposits (till, outwash, drift)
7	Alpine glacial deposits
8	Miocene basalt
9	Outburst flood deposits
10	Mass wasting and landslide deposits
11	Peat bog deposits
12	Terrace deposits
13	Beach deposits, Holocene
14	Lacustrine deposits, Holocene
15	Lahars
16	Bedrock, Quaternary
17	Bedrock and deposits, Tertiary and older

Archaeologists use the geologic setting of an area to help reconstruct the age of a cultural resource and gain a better understanding of historical landscapes.

The following sections describe each geologic group in further detail and their relation to archaeological resources.

GROUP 0. WATER/ICE/UNIDENTIFIED

Group 0 was a combination of water, ice and areas where no geology data were present. This map unit includes existing bodies of water such as ponds, lakes, reservoirs, bays, canals, streams, rivers and alpine glaciers that were large enough to be mapped at the scale of the geology data. This unit has tremendous variability in topographic elevation, and covers approximately 1,260 square miles, or less than 2% of the State.

GROUP 1. ALLUVIUM

Alluvium, which is sediment deposited by rivers on their floodplains as flood waters recede, is probably the environmental variable with the single highest correlation to archaeological site prediction. Alluvial environments provide critical resources, transportation and a habitable landscape. Because alluviation is an active process, alluvial environments are particularly conducive to burial and preservation of archaeological sites, often containing nearly complete records of humans in Washington State. Alluvial episodes are easy to define because successive flood events buried former floods, each with a relatively unique sedimentary and pedogenic character. The alluvial record in Washington State is relatively well understood and appears to be tied to climatic change. See Figure 1 for an example of stratified alluvium along the middle Columbia River in Douglas County.

Figure 1. Stratified alluvium along the middle Columbia River, Douglas County

GROUP 2. DUNE SANDS

Dune sands are unique environments for the preservation of specific types of cultural resources. Because unconsolidated dunes are easy to excavate, prehistoric people sometimes used them to inter the dead, particularly during the winter season when excavation into frozen surface soils was difficult. Because dunes can exist in active eolian environments, they are variably conducive to burial and preservation of archaeological materials. During dune aggradation phases, dunes can deeply bury surface archaeological material. If vegetation is able to take hold during periods of stability, then a dune may be preserved indefinitely. Periodically, dunes will be reactivated by disturbance of surface vegetation. It is in this scenario that dune "blowouts" occur, exposing formerly buried archaeological resources.

Dunes form in a variety of environments, but only when sufficient parent material is available. Coastal and riverine beach settings, immediately adjacent and parallel to the source of the sediment, are common dune environments where dunes often form as long, linear geomorphic features. See Figure 2 for an example of coastal dunes.

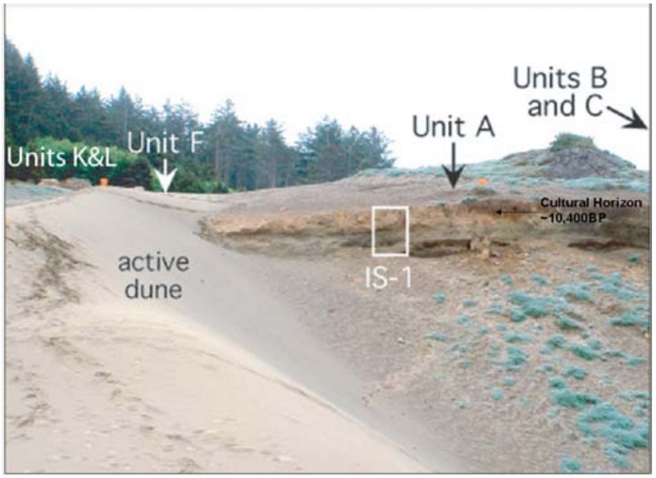


Figure 2. Active (modern) and relict coastal dunes with buried and preserved Paleoindian archaeology (Photo courtesy of Loren Davis, interpretation of cultural horizon by Brett Lenz, based on field report data).

GROUP 3. TALUS DEPOSITS

Talus, which consists of the accumulated deposits of broken rock fragments at the base of cliffs, has a distinct relationship to archaeological deposits. Because of its unconsolidated nature, talus is relatively easy to excavate, even by hand. As a result, prehistoric people on the east side of the Cascade Mountains often buried their dead in talus during seasons when finer-grained sediments were frozen and difficult to excavate. The surface of talus deposits was commonly excavated to form depressions for storage. These depressions, termed "talus pits" by archaeologists, constitute one of the most common archaeological features in Washington State. The locations of talus deposits at the base of cliffs or significant bedrock outcrops occur at important topographic transition zones that would provide strategic vantage points for hunting or defensibility. For these reasons, talus has a clear relationship to the location of archaeological sites. See Figure 3 for an example of a talus slope.

Figure 3. Talus slope in Columbia River basalt formed at base of well-formed columnar section. Talus pits are commonly located near the base of the talus slope.

GROUP 4. ALLUVIAL FAN DEPOSITS

Two types of alluvial fans are grouped together into this category: Arid fans, common on the eastern side of Washington State, and Humid fans, located from the Cascade Mountains to the Washington coast. Arid fans are deposited during relatively extreme precipitation events that can carry relatively large rock clasts. Like streamside alluvium, alluvial fans may either bury archaeological sites that exist on their surface or contain artifacts that have been entrained and re-deposited from their original locations. In prehistoric times, alluvial fans were often burial locations and were also used as travel corridors because they may provide passage through otherwise obstructed landforms or prominent bedrock cliffs. See Figures 4 and 5 for examples of alluvial fan deposits.

Figure 4. Arid Alluvial Fan, Columbia River Gorge

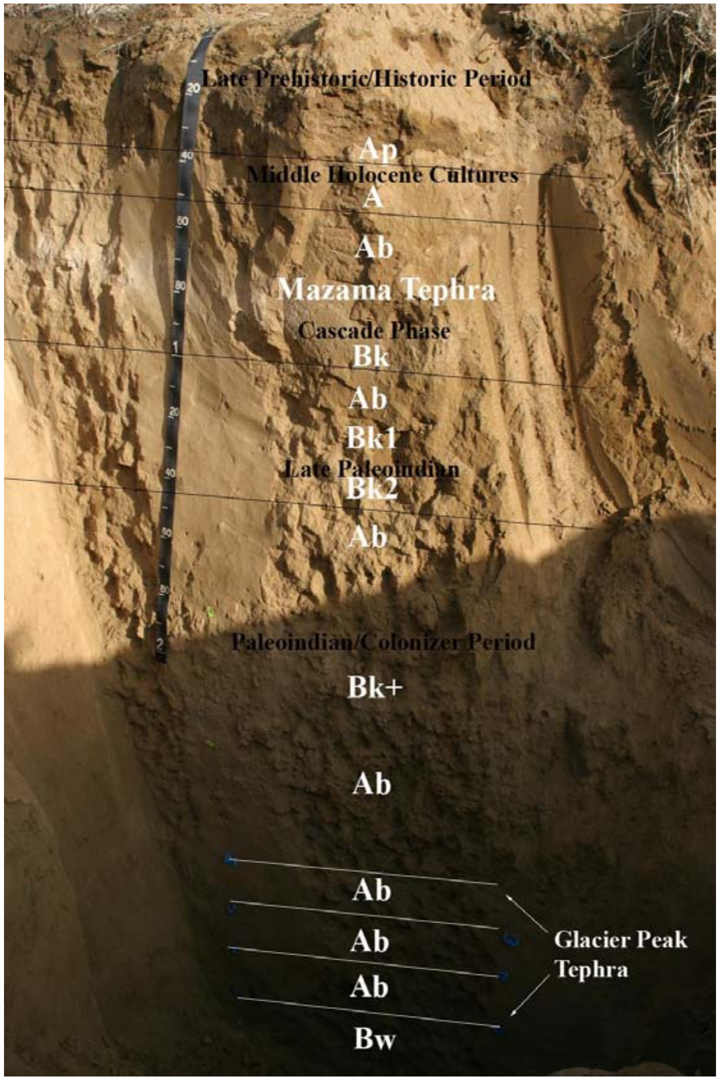


Figure 5. Alluvial fan deposits with pedology and cultural horizons noted. Douglas County, Washington

GROUP 5. LOESS

Loess, which is fine-grained eolian dust, was periodically deposited across the Pacific Northwest, with the heaviest deposition occurring at the close of the Pleistocene period. Silt particles, formed by mechanical weathering of rock material in glaciers, were entrained by the wind as glaciers would ablate. The primary accumulation of loess in Washington State occurred during the Quaternary period and created the Palouse Formation in the southeastern portion of the state. Catastrophic glacial meltwater floods scoured ancient loess accumulations across the Columbia Plateau, depositing the loess in basins at points downstream. These massively redistributed bodies of sediment then formed the parent material for Upper Pleistocene to Holocene loess deposition.

Loess is known to have the potential to deeply bury archaeological deposits. In Washington State, the most significant archaeological site buried by loess is the Richey-Roberts Clovis Cache of East Wenatchee. This site contained a variety of stone and bone artifacts perfectly preserved in the configuration in which they were originally deposited nearly 11,600 years ago. In other parts of the world, loess has buried entire villages, preserving bones, domestic structures and other artifacts, effectively leaving behind a snapshot in time for archaeologists to study. On the west side of Washington State, aerosol loess occurs in much thinner deposits, often capping glacial bodies or weakly disseminated in glaciofluvial alluvium. See Figure 6 for an example of loess deposits.

Figure 6. Charcoal-rich pit feature within loess deposit.

GROUP 6. CONTINENTAL GLACIAL DEPOSITS

The Cordilleran ice sheet created glacial deposits along the northern portion of Washington State as far south as the Puget Lowland in western Washington and south through the Okanogan Valley on the eastern side of the state. The ice sheet entered Washington State at least five times until finally retreating approximately 13,000 years ago, roughly the same time that we see the earliest archaeological sites in the Pacific Northwest.

The relationship between these continental glacial deposits and archaeological sites is poorly understood at this time. Nevertheless, several types of archaeological sites related to glacial deposits should be expected given the recent find of archaeological material at Paisley Caves in Oregon dating back approximately 14,000 years and the known age of the Manis Mastadon site on the Olympic Peninsula at 12,100 years. These may include ice-marginal sites, sites related to ice-marginal lakes, sites along lakes that formed as a result of the glacial melt and sites that are marginal to glaciofluvial alluvium that filled valley floors as glaciers melted. Loading of the Cordilleran ice sheet caused subsidence of the sediment and bedrock underlying the Puget Sound. Isostatic rebound (that is, the post-glacial rise of a land mass that was depressed by the weight of a glacier) has occurred there since the close of the Ice Age, resulting in areas that were formerly next to waterways now located hundreds of feet above and several miles from the modern Puget Sound. . See Figure 7 for an example of glaciofluvial delta deposits and Figure 8 for the location of glacier lakes in King and Snohomish Counties in relation to the Puget Lobe of the continental glacier.

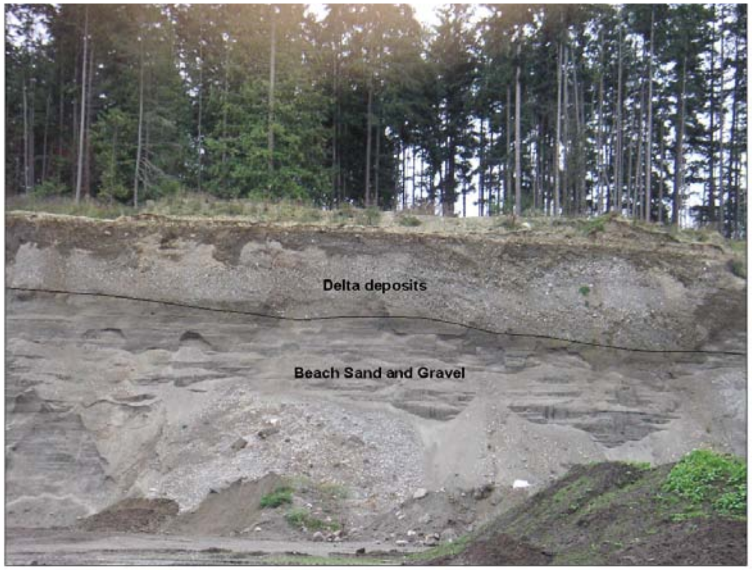


Figure 7. Glaciofluvial delta deposit unconformably overlying beach sands and gravels in upland environment, Camano Island.

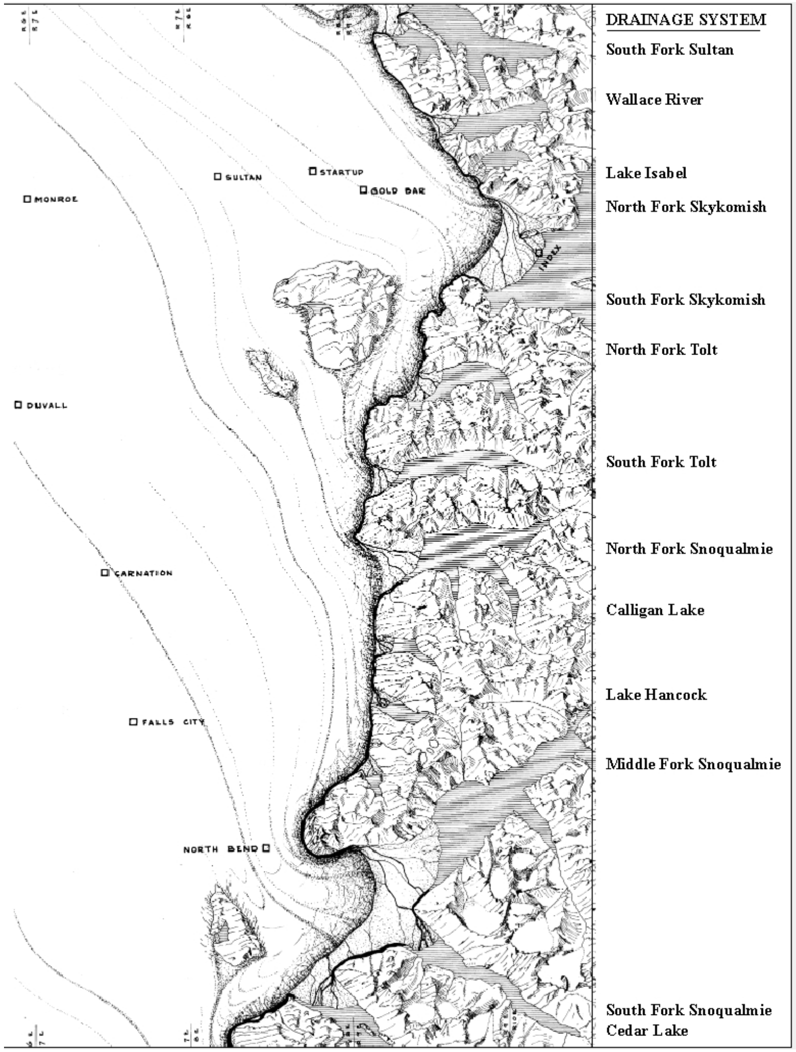


Figure 8. Proximity of glacial lakes to Continental Glacier, King and Snohomish Counties

GROUP 7. ALPINE GLACIAL DEPOSITS

Alpine glacial deposits have waxed and waned since the close of the Pleistocene period. Many relict glacial sediments exist in alpine environments; even in heavily forested cover, their signature on the landscape is clear. One factor that led to prehistoric use of alpine glacial environments is the position of cirque lakes (lakes in bowl-like depressions left by glaciers) at the base of the glacier. Cirque lakes formed at the base of alpine glaciers during ablation, providing a reliable source of water for people who utilized alpine areas of the state for hunting and lithic raw material extraction, among other activities. See Figure 9 for an example of a cirque lake with marginal alpine glacial deposits.

Figure 9. Cirque lake with marginal alpine glacial deposits, North Cascades.

GROUP 8. MIOCENE BASALT

Basalt bedrock data are differentiated from non-basalt based on the abundance of mapped tholeiitic basalt (a specific type of basalt) flows across the Columbia Plateau. In particular, drainages that were carved into basalt through deep loess deposits provided excellent landscape contrast in coulees (see "9. Outburst flood deposits" section, below) that once flowed but that are now dry. The basalt interbeds also contained the highly valued chalcedony and petrified wood deposits which people quarried from interbed deposits between basalt flow units. Unlike the majority of large habitations, lithic quarry and workshop areas are not associated with the major waterways. Well-formed basalt columns were also used through prehistoric times as a palette for rock art. See Figure 10 for an example of prehistoric rock art on face of a basalt column.

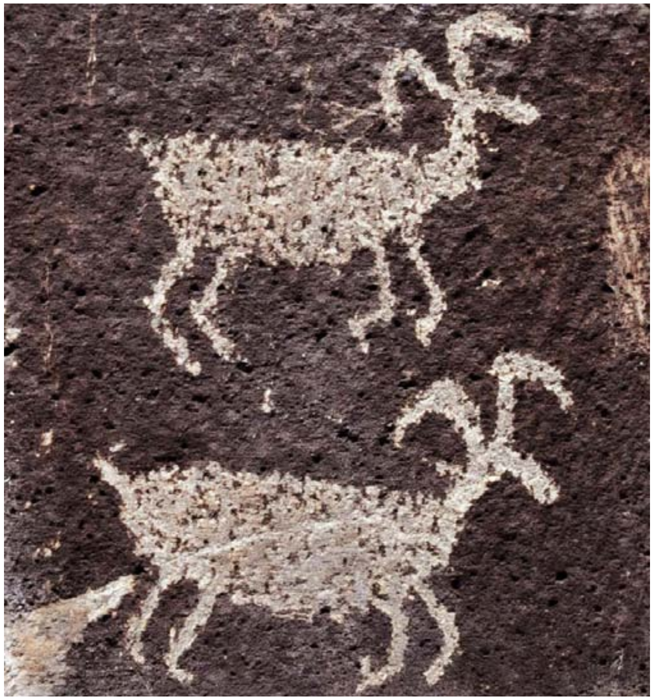


Figure 10. Example of prehistoric rock art on face of basalt column near Vantage.

GROUP 9. OUTBURST FLOOD DEPOSITS

At the close of the Pleistocene period, as the Cordilleran ice sheet receded, a giant lake formed near Missoula, Montana. This lake, together with large subglacial lakes, periodically flooded portions of the Columbia River watershed with the largest floods ever seen on earth. Termed "megafloods," these catastrophic events left behind distinct sediment deposits, including giant flood bars and slackwater lake sediments. Generally, flood bars are rich in cobble and boulder deposits, and back-flood and slackwater deposits include relatively fine-grained sediments.

In parts of the Columbia Plateau, V-shaped canyons and valleys that are dry or those with grossly underfit streams present in their valley floor mark former flow channels of the megafloods, termed "coulees." Coulees are important geologic features because their valley floors contain Upper Pleistocene age sediments, and usually water that flowed for a good portion of the year. Such places are likely spots to find Paleoindian archaeological sites, of which the Lind Coulee site and the Winchester Clovis site are excellent examples. In many cases, the water that is present is from the Columbia River Irrigation Project which recharged former Pleistocene waterways both in coulee and seep areas throughout the Columbia Plateau. See Figure 11 for an example of the location of outburst flood deposits across the Columbia Plateau.

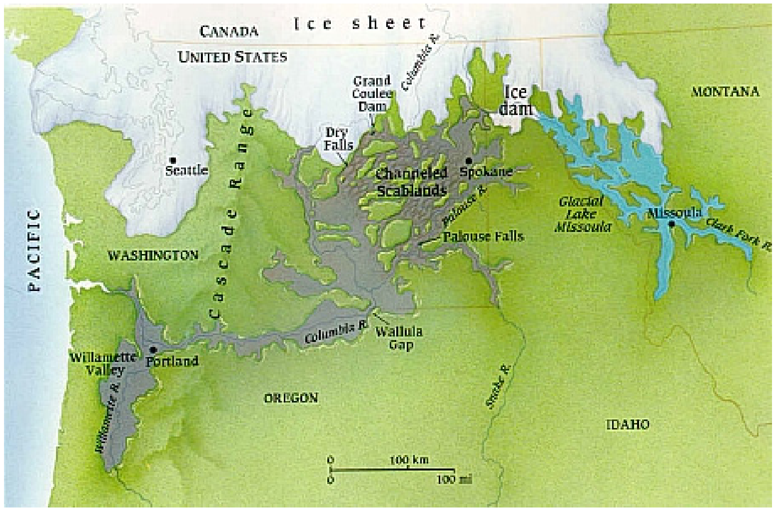


Figure 11. Location of outburst flood deposits across Columbia Plateau. Gray areas represent extent of outburst flood deposits.

GROUP 10. MASS WASTING AND LANDSLIDE DEPOSITS

Mass wasting and landslides occur as gravity causes sediment to move downslope. These processes can take place on timescales of minutes to years; the potential to affect the location or identification of archaeological sites is dependent on a variety of factors. In some places, landslides have potential to expose archaeological sites that are buried in undisturbed deposits that are incorporated into the sediment flow. At the Ozette site on the Olympic peninsula, a large landslide buried a portion of a village, which caused nearly perfect preservation of otherwise perishable artifacts. See Figure 12 for an example of landslide deposits.

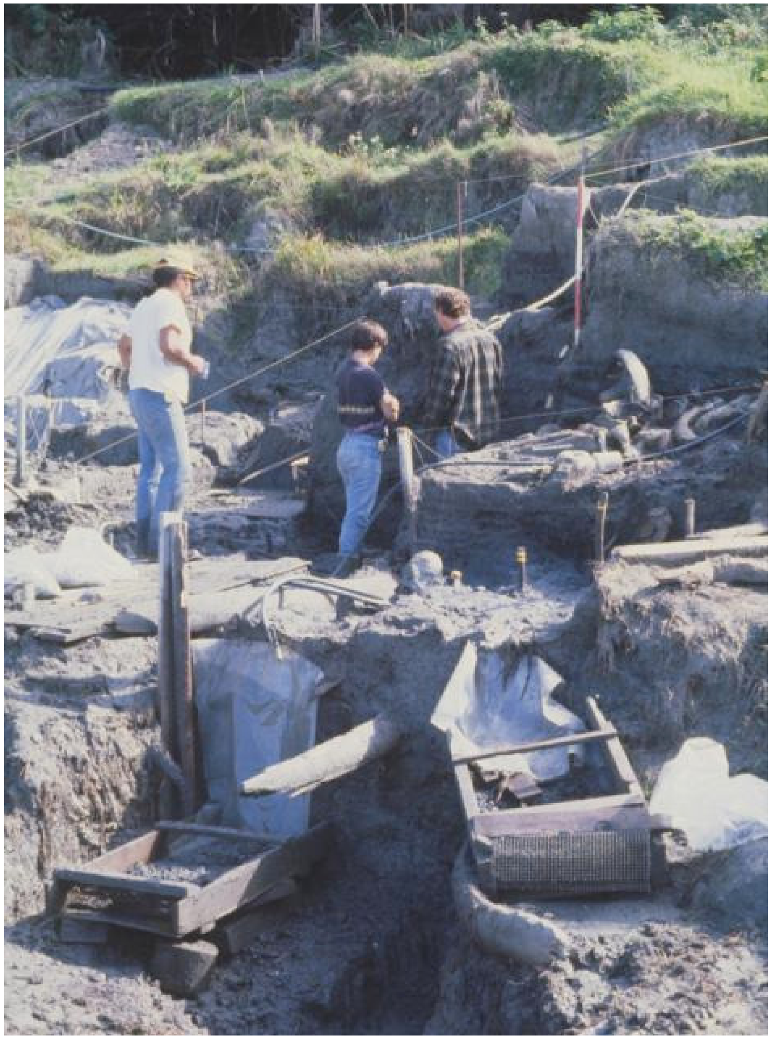


Figure 12. Excavation in landslide deposits at the Ozette site, Olympic peninsula (Photo courtesy of Daniel Leen)

GROUP 11. PEAT BOG DEPOSITS

Peat bogs are unique wetland environments that contain a well-preserved paleoenvironmental record of a given local area. The anaerobic bog environment and presence of tannic acids can lead to near-perfect preservation of archaeological materials. In some places, entire human bodies have been recovered thousands of years after burial.

An example of a peat bog deposit site is the Manis Mastodon site near Sequim, which is at present the oldest archaeological site in Washington State. The remains of a mastodon dating to 12,100 +/- 310 radiocarbon years before present were preserved in a peat bog setting. An antler rib projectile point was preserved, lodged in a rib bone (see Figure 13), suggesting that the animal was hunted by upper Pleistocene humans. See Figure 14 for an example of peat bog deposits.

Figure 13. Rib of Manis Mastodon with embedded antler projectile (Photo courtesy of Mike Waters).

Figure 14. Example of preserved wooden tent stakes in peat bog deposits, Monte Verde Site

GROUP 12. TERRACE DEPOSITS

Alluvial terraces, which are included in the majority of mapped alluvium areas used for the archaeological predictive model, represent former river floodplains that were abandoned as the river base level changed. This base level change forces downcutting of the floodplain, leaving the former floodplain at a higher topographic elevation than the active floodplain.

The timing of aggradation and degredation periods is relatively easy to determine because of the abundance of stratigraphic marker horizons in the alluvium. Archaeological material is buried in the alluvium, leaving behind a rich record of activity. The high-precision dating and the paleoenvironmental record, together with the often unbroken archaeological sequences, result in the largest concentrations of archaeological sites throughout Washington State being on the alluvial terraces.

In the Puget Lowland, isostatic rebound of formerly glaciated terraces has led to the abandonment of terraces at unusually high topographic elevations. Upper Pleistocene Colonizer and early Holocene Olcott sites may be found on these surfaces. Correlative terraces in the interior portion of the state include glacial flood terraces that contain some of the earliest archaeological sites. Later terraces contain pithouse depressions at their surface, capping thousands of years of buried archaeology. See Figure 15 for an example of alluvial terrace sequence in western Washington and Figure 16 for an example of alluvial terrace sequence along the middle Columbia River.

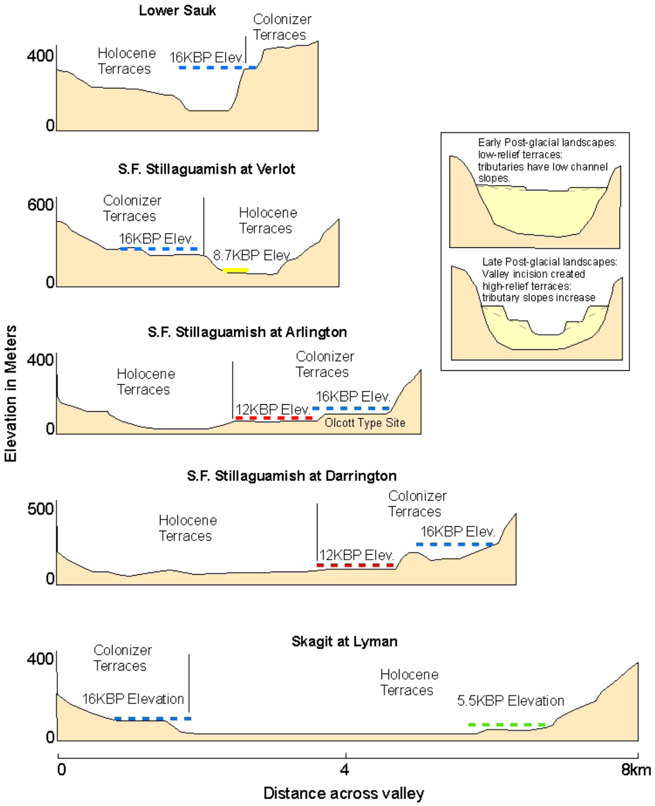


Figure 15. Alluvial terrace sequence in western Washington illustrating topographic relationships based on terrace age

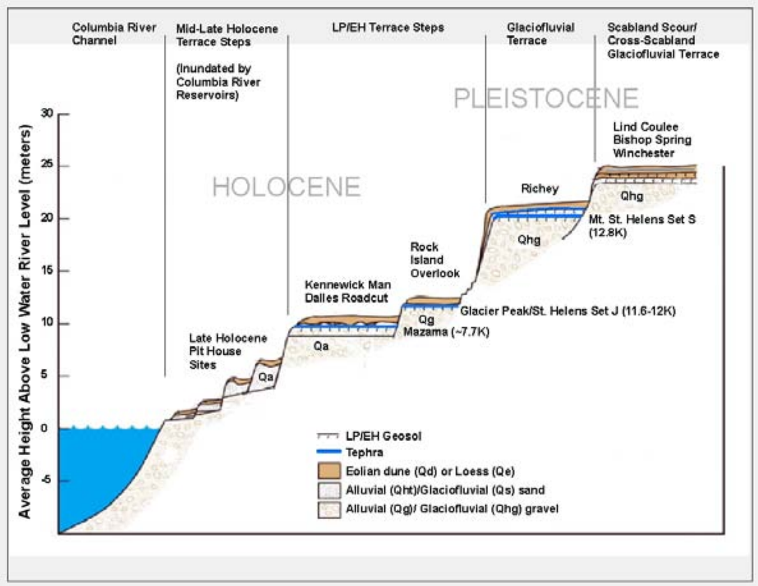


Figure 16. Alluvial terrace sequence along middle Columbia River illustrating terrace relationships to prominent archaeological sites based on terrace age)

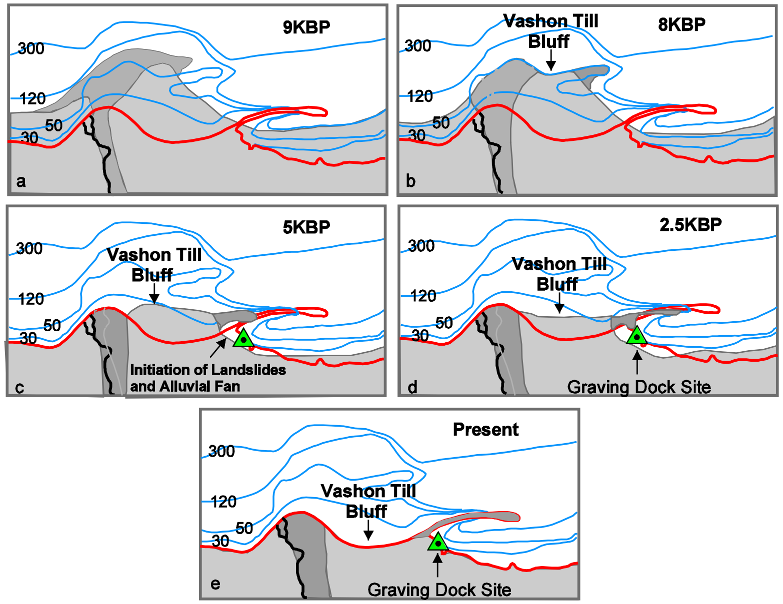


Figure 17. Evolution of beach deposits at Ediz Hook Spit, near Graving Dock site, Port Angeles.

GROUP 13. BEACH DEPOSITS, HOLOCENE

Holocene beach deposits contain the highest density of archaeological sites on coastal Washington. Beach deposits include a variety of coastal landforms that prehistoric people targeted as places to live. Spits and bars can dampen the effects of wave action, providing a living environment that is relatively stable and is also immediately adjacent to marine resources. Deltas and estuaries immediately adjacent to beaches are resource-rich environments utilized by prehistoric people. Shell midden sites, which contain the accumulated remains of harvested shellfish, mammal and fish bones, lithic tools and debitage, are often found in Washington beach environments. See Figure 17 for an example of the evolution of beach deposits at Ediz Hook Spit.

GROUP 14. LACUSTRINE DEPOSITS, HOLOCENE

Because lakes play an important role in providing water, fish and plant resources, lakeshore environments commonly contain archaeological sites. Lake shorelines waxed and waned throughout the Holocene period, and archaeological sites may contain evidence of this fluctuation. Although lakes throughout Washington have deep archaeological records, lakes in eastern Washington are highly correlated with archaeological sites because the availability of fresh water was a key limiting factor in site location. Complementing the archaeological record, lake sediments may contain nearly complete paleoenvironmental records.

GROUP 15. LAHARS

Holocene lahars filled portions of drainages in western Washington. These volcanic mudflows destroyed or deeply buried archaeological sites in their path, essentially erasing our understanding of early prehistoric land use within some watersheds. Large lahar deposits flowing into the Puget Sound area continued through approximately 500 years ago. Although lahar flows have erased our ability to learn about the prehistory of certain portions of western Washington, the eruptions that led to the mudflows also created time-diagnostic marker horizons that help archaeologists interpret the relative age of archaeological sites in the region. See Figure 18 for an example of the Osceola lahar on the White River.

Figure 18. Osceola lahar on the White River

GROUP 16. BEDROCK, QUATERNARY

Quaternary geologic deposits generally include sedimentary basin fills. Also included are far less extensive lava flows. Although this category is relatively non-specific, it was separated from older bedrock deposits because certain geomorphic features within the group are correlated with archaeological site locations (for example, Quaternary alluvium).

GROUP 17. BEDROCK AND DEPOSITS, TERTIARY AND OLDER

These data were lumped together largely because of restrictions in the total number of geologic categories available for the model. In general, bedrock data are valuable where important sources of tool stone such as chert and soapstone were exposed and quarried.

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Figure 1. Soil Survey Coverage

Soils

Soils develop into stable land surfaces across nearly every environment where soil is deposited. Soil development is dependent on a variety of factors, including climate, the effects of organisms (including humans), surface relief, the origin of the parent material and time. Soil distributions are patterned by the systems that lead to their formation and, when they are mapped across the landscape, may provide the basis for landscape-scale models of archaeological potential.

When the rate of soil development is able to keep pace with the rate of deposition at a given location, a soil will remain at the land surface. When the soil development:deposition ratio falls out of balance, soils become buried, forming a buried soil surface called a "paleosol" (see Figure 2). Because these soil layers represent formerly stable land surfaces that, in many cases, were used by humans, paleosols have higher than average potential to contain buried archaeological resources. Evidence of the prior presence of humans is provided by certain characteristics of soils that are affected by humans. Intensive land use by groups of people may lead to compaction of the soil surface, which is manifested by platy soil structure (see Figure 3). Humans also create a large amount of organic waste in the form of refuse, which is recognized in a soil column by significant increases in soil phosphorus.

Organic soils are often representative of lakes or wetlands that have been filled or whose water source is otherwise cut off. These soils form in hydric conditions and may also be accompanied by peat or muck deposits in wetland settings. Generally, these areas are rich in biota and, especially in areas of lower precipitation, may be associated with archaeological sites. Preservation of normally perishable archaeological materials may be particularly good in soils that formed under hydric conditions. The archaeological site at Lake Ozette is an excellent example of a site whose artifacts are preserved in a nearly perfect state after burial and preservation in hydric conditions.

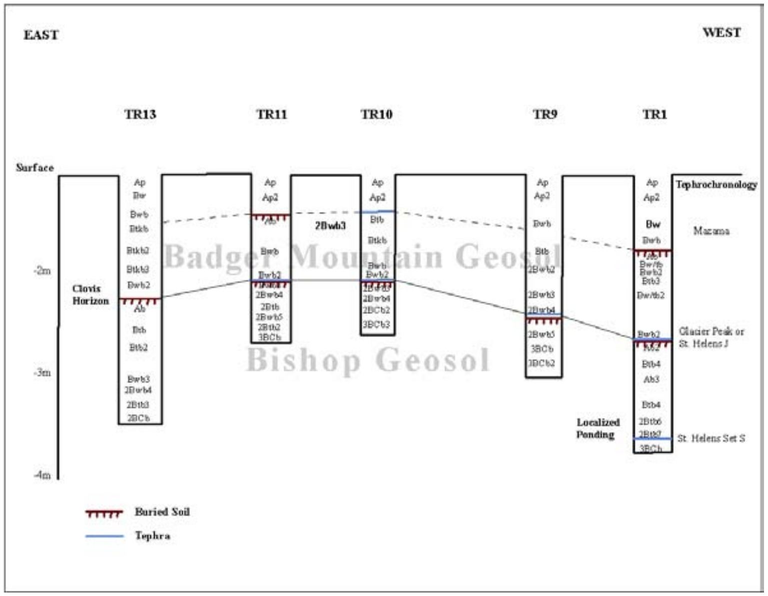

Figure 2. Application of local soils data to high potential archaeological environment, near Richey-Roberts Cache, East Wenatchee.

Soil distributions may provide the basis for landscape-scale models of archaeological potential.

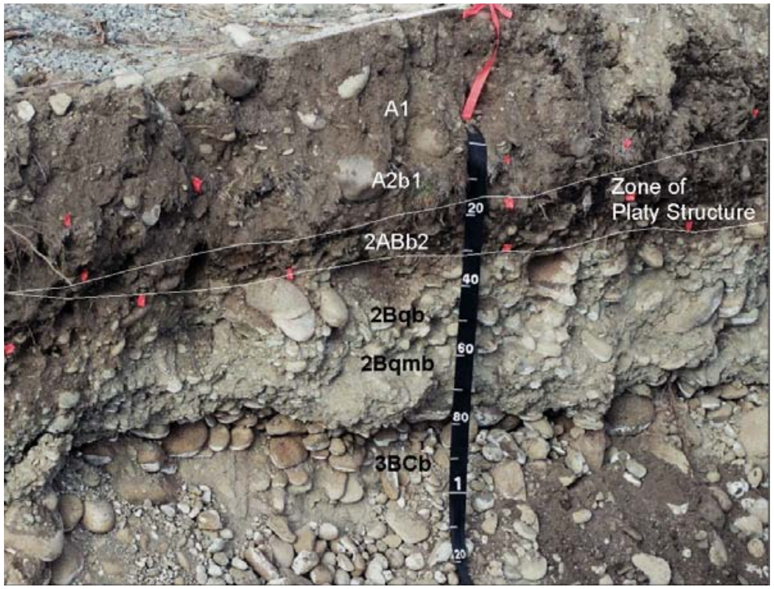

Figure 3. Platy soil structure associated with human use of the landscape, middle Columbia River.

The National Resources Conservation Service (NRCS) leads a partnership of federal, regional, state and local agencies to document soil conditions across the country. GIS soil survey data from NRCS were obtained for all available counties and areas within Washington State.

NRCS created the soils data by digitizing maps and then revising those data using remotely sensed and other information. Although the NRCS generally provides the most detailed level of soils data available for any particular area, the data used for this project are intended to be used at a scale of 1:24,000. Whenever available, certified soil data (SSURGO data) were used for the model; however, for some portions of the study area, only draft data were available, and in other cases no soils data were available. See Figure 1 for soil survey coverage available for Washington State. Draft data are very similar to the SSURGO data but have not been thoroughly reviewed for quality, accuracy or completeness. As the draft data become certified, or new areas completed, those portions of the model should be re-calculated.

Soils data are categorical and were originally classified by NRCS into over 7,600 distinct soil types. We categorized these soil types into 17 groups for modeling purposes, based on similar characteristics and physical properties as determined in consultations with soil scientists. For example, a Logy silt loam and a Lorena silt loam were both classified as silt loam because the primary characteristic of the soil type is silt loam. Soil groupings are somewhat subjective and could have been determined in many different ways. Our methodology was based on the criteria and level of detail necessary for the model. The following table lists the groups for the soils dataset.

Soils Group Number	Soils Group Description
0	Unidentified
1	Silt/Clay Loam
2	Gravelly, cobbly, stony or bouldery loam
3	Sandy Loam
4	Loam
5	Sand
6	Urban Land
7	Water/Dams
8	Complex - Mixed Soils
9	Rocky Complex/Rock Outcroppings
10	Beaches
11	Man-made Land
12	Pits
13	Hydric Soils (Muck, Peat, Tidal Marsh)
14	Torrifluents/River wash
15	Mixed Alluvial Land
16	Rough Mountainous Land

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Landforms

A landform can be described as any of the various natural features that make up the surface character of the earth, such as a discernible part of the landscape that formed as a result of wind, water or geologic process, or a type of large landmass, usually categorized according to differences in relief and steepness. Variation between landforms (valleys, plateaus, cliffs, etc.) can control patterns of land use. Landform data were identified by project archaeologists as an essential part of model development for this project.

Because of the broad definition of landforms, numerous possible landform types exist within the Washington State study area. We collaborated with archaeologists to identify the priority and importance of each landform type. The challenge was not only to represent landforms accurately over a large area but also to categorize the landforms into manageable groups.

For the pilot studies as well as the statewide model, the landform GIS layer was the only environmental dataset that was not readily obtainable from another organization. The fact that archaeologists identified this layer as important for developing the model required us to develop it ourselves. We researched other landform mapping projects, particularly those using GIS, to develop a consistent mapping technique. Most of the reviewed projects covered relatively small areas compared with our study areas or had insufficient detail for our purposes. To create the landform layer for the pilot studies, we used a combination of Spatial Analyst techniques, existing data sources and hand digitizing, all of which needed to be manually verified. This was a labor-intensive process and not well suited to working with large study areas.

We also reviewed the Natural Resource Conservation Service (NRCS) digital soil data as a potential landform layer. The NRCS soil data provided relatively high-resolution (1:24,000) mapping and detailed geomorphic descriptions that could be used to represent landforms. However, the NRCS coverage is not consistent across Washington State, and geomorphic descriptions are not consistent across county boundaries. Furthermore, several counties in Washington do not provide NRCS digital soil data and geomorphic descriptions, resulting in large data gaps. See Figure 1 for a comparison between the NRCS soils geomorphic descriptions and the landform model.

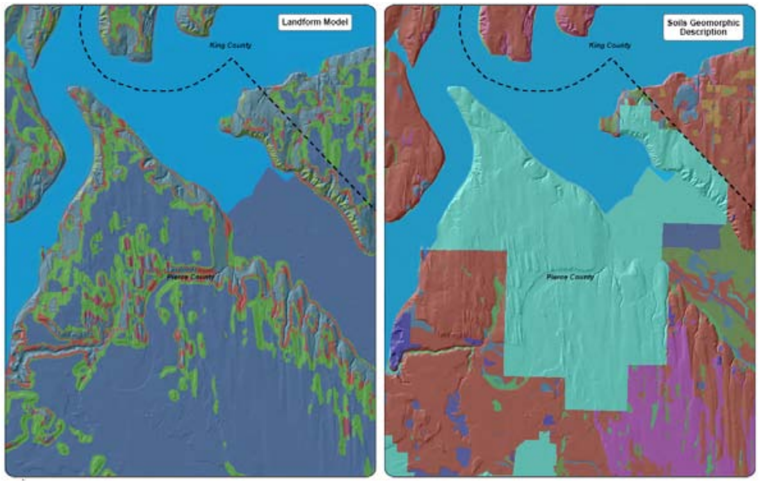

Figure 1. Comparison between the NRCS soils geomorphic descriptions and the landform model

Because of the data gaps with NRCS soil data, we decided to evaluate the feasibility of using a landform model based on elevation data to generate a seamless statewide landform dataset. This method is efficient and can be easily updated as better elevation data become available. We researched several different modeling techniques, ultimately choosing the Morgan Model, which utilizes the 10-meter Digital Elevation Model (DEM) and Hammond's formula to develop a landform classification method. A graphic version of a portion of the Morgan Model is shown in Figure 2

Project archaeologists identified landform data as an essential part for model development.

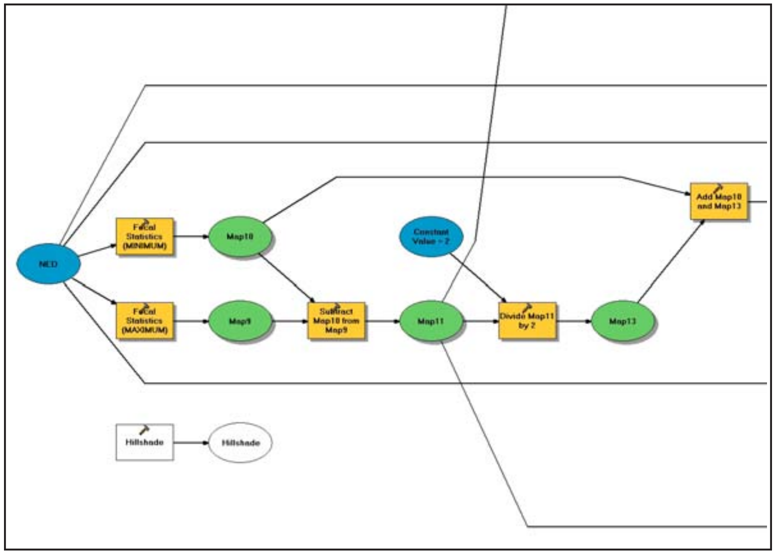

Figure 2. A portion of the Morgan Model

According to Hammond, a geographer and recognized authority specializing in landform mapping, there are three parameters used to calculate landform types:

- Profile: position of a center cell compared to its surrounding cells (higher or lower).
- Relief: elevation range surrounding the center cell.
- Slope: amount of gently sloping area surrounding the center cell.

These parameters are used in the following formula:

Landform Type = Profile + Relief + Slope

The landform dataset created from this model seamlessly covers the state of Washington. Landforms were computed using well respected and widely researched methods described above. Edge effects, which can occur from seams in source data, are not present with this approach because the landform model uses the statewide 10-meter DEM. Additionally, with this model, the landform dataset can be easily updated as higher-resolution elevation data become available.

Once landform types were calculated, a method developed by the Missouri Resource Assessment Partnership (MORAP) was used to classify and visually display the various landform types into more general categories. The MORAP model uses relief and slope to classify landforms. The MORAP model uses a slope parameter defined as the percent of near-level land within a 20-pixel/ cell circular radius. Near-level in this case is defined as less than 8 percent slope.

The landform category descriptions provided by MORAP reflect a typical Midwest origin. However, the landform category descriptions were modified to better represent surface features of the Pacific Northwest. The following table lists the landform categories that were used in the model and additional details about each category.

Landform Group Number	Group Description
1	Valley Floor, Lowlands
2	Smooth Valley Wall
3	Irregular Valley Wall, Gentle Hillslope
4	Valley with Moderate Hillslope
5	Basal to Intermediate Foothills
6	Intermediate Valley
7	Valley Uplands
8	Hillslope Breaks, Bluffs, Cliffs
9	Low-Gradient Foothills
10	Foothills to Intermediate Mountain Slopes
11	Mountain Slopes

GROUP 1: VALLEY FLOOR, LOWLANDS

Lowland valley floors consist of broad straths (wide, flat river valleys) formed by glacial, glaciofluvial or alluvial erosion. These are the environments of large river valleys, but may also include undersized, underfit rivers on valley floors. Lowland valley floors, which contain underfit streams, artificial lakes or reservoirs, are commonly the location of former glacial or post-glacial lakes.

Local topography is influenced by glacial erosion, deposition and alluviation. The physical scale of the valley floors is highly variable, depending on the nature of the local bedrock and internal drainage, varying from 1 to 20 miles wide and up to hundreds of miles long. Riparian zones will support diverse biota, which is much more pronounced in eastern Washington. The alluvial bottoms also provide places for humans and animals to obtain water. Land use patterns may focus on utilization of the active and former floodplains and prairies. Villages and settlements are expected to occur in these areas. (Figure 3).

Physical Parameters of this group include areas located on 0.5 to 1 % near-level land and with relief of 0 to 50 feet.

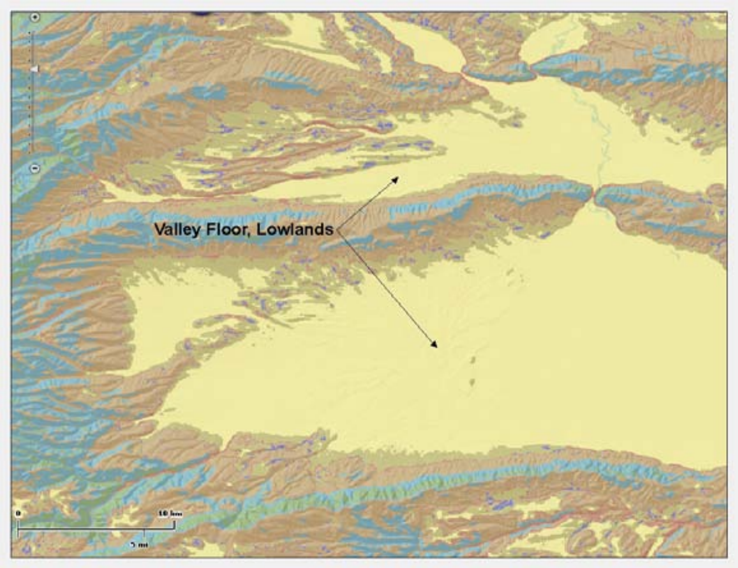

Figure 3. Landform category "Valley Floor," Yakima Fold/Thrust Belt study area

GROUP 2: SMOOTH VALLEY WALL

Smooth valley walls are intermediate landforms located along the margins of the large valley floors. This landform class is often underlain by Quaternary or Upper Tertiary sedimentary deposits. Local topography is influenced by bedrock, by alluvial erosion and, less often, by the cumulative effects of glacial episodes. Valley walls offer vantage points because they are topographically higher than the valley floors. Resource extraction, workshop and processing sites are anticipated to be located on these landforms. Valley walls should contain Upper Pleistocene archaeological sites (Figure 4).

Physical Parameters of this group include areas located on 0.5 to 1 % near-level land with relief of 50 to 100 feet.

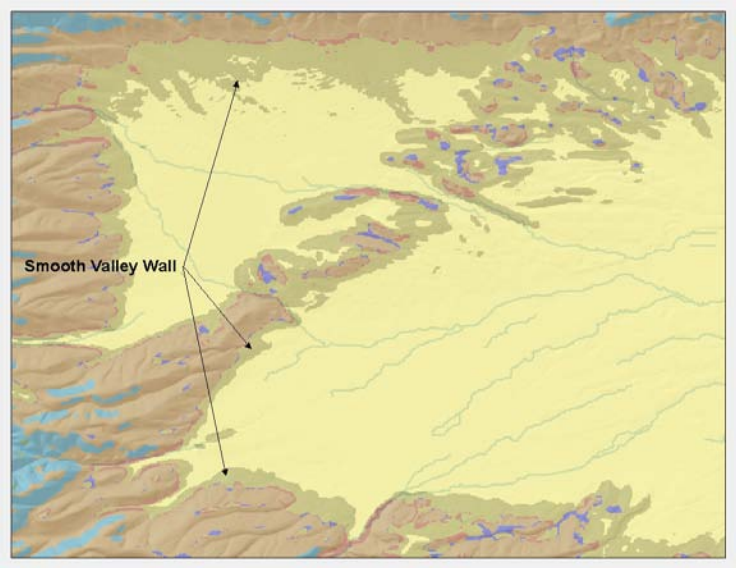

Figure 4. Landform category "Smooth Valley Wall," Yakima Fold/Thrust Belt study area

GROUP 3: IRREGULAR VALLEY WALL, GENTLE HILLSLOPE

Irregular valley walls on gentle hillslopes are transitional landforms located along the margins of valley floors. In many places, these landforms are bounded by smooth valley walls towards the basin, and by breaks, bluffs and cliffs in the upslope direction. This landform class may contain local bedrock outcrops. Local topography is influenced by bedrock, by alluvial erosion and, less often, by the cumulative effects of glacial episodes. Valley walls offer vantage points because they are topographically higher than the valley floors. Valley walls are often coincident with ecotones (that is, overlapping transition areas between two plant communities, with mixed vegetation). Lithic procurement and workshop sites, tool rejuvenation locales and hunting and butchering sites are anticipated to be found in these areas (Figure 5).

Physical Parameters of this group include areas located on 0.5 to 1 % near-level land with relief of 100 to 300 feet.

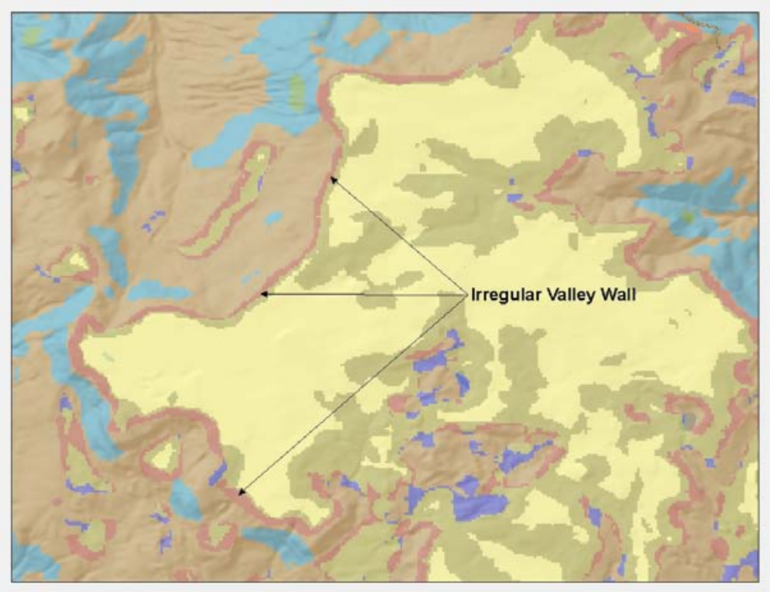

Figure 5. Landform category "Irregular Valley Wall," Upper Columbia study area

GROUP 4: VALLEY WITH MODERATE HILLSLOPE

Valleys with moderate hillslopes are transitional landforms located along the margins of large valley floors (Figure 6). They are similar to irregular valley walls (Group 13) in most respects, but with greater relief. In many places, these landforms are bounded by smooth and irregular valley walls towards the basin, and by breaks, bluffs and cliffs in the upslope direction. This landform class may contain local bedrock outcrops. Local topography is influenced by bedrock, by alluvial erosion and, less often, by the cumulative effects of glacial episodes. Valley walls offer vantage points because they are topographically higher than the valley floors, and they are often coincident with ecotones. Lithic procurement and workshop sites, tool rejuvenation locales and hunting and butchering sites are expected to be found in these areas.

Physical Parameters of this group include areas located on 0.5 to 1 % near-level land with relief of 300 to 500 feet.

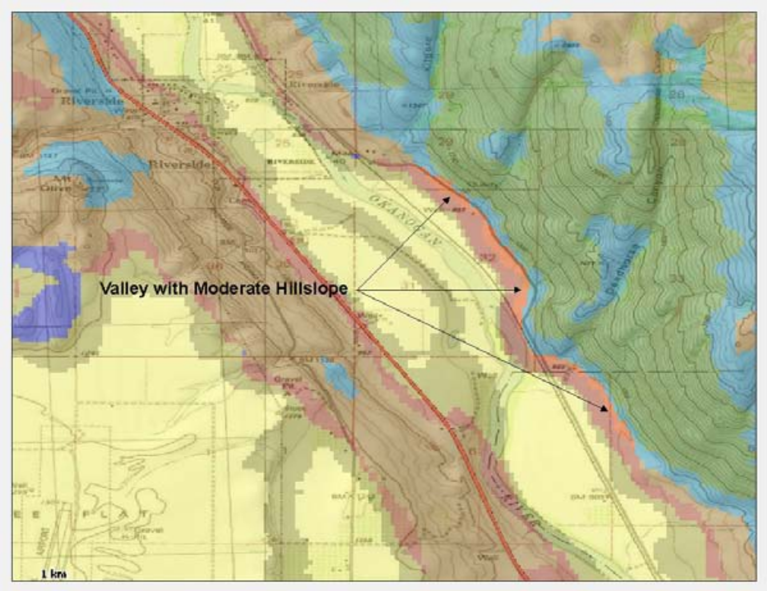

Figure 6. Landform category "Valley With Moderate Hillslope," located at the margin of the North Cascade study area with the Okanogan Highlands study area

GROUP 5. BASAL TO INTERMEDIATE FOOTHILLS

This landform category is composed of low ridges and hills separating a lowland valley from the nearby uplands (Figure 7). Basal to intermediate hills have a transitional character that may include prairies on the lower slopes, giving way to undulating, locally steep terrain, although only for short distances. The ridges are subdued and rounded hills, in most cases rising no more than several hundred feet in relief. Low ridges provide good visibility onto the lowland landscape. The transitional nature of this broad landform type is reflected in land cover and vegetation, which may range from sparse forest stands to sage-steppe. Given the relative proximity to the lowlands, archaeological sites related to resource extraction and processing and hunting are anticipated to be found in these areas.

Physical Parameters of this group include areas located on 0.5 to 1 % near-level land with relief of 500 to 1000 feet.

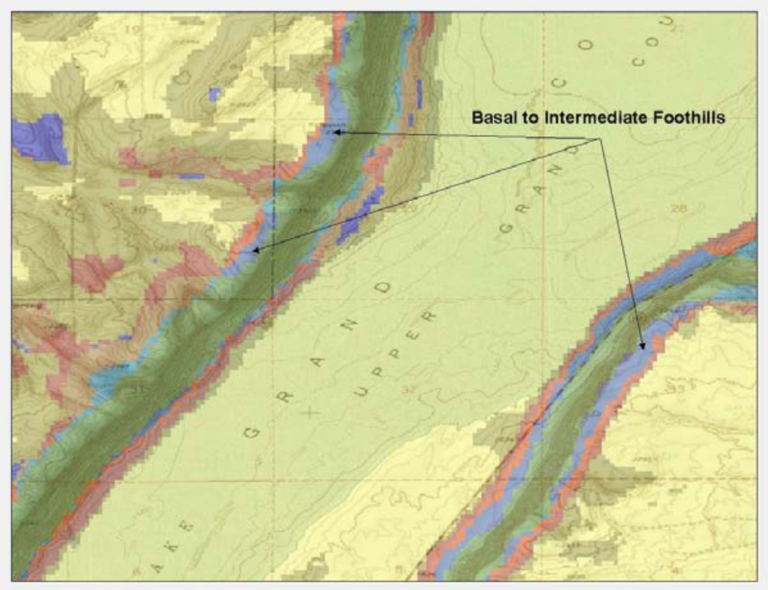

Figure 7. Landform category "Basal to Intermediate Foothills," located in the Okanogan Highlands study area

GROUP 6: INTERMEDIATE VALLEY

Intermediate valleys are transitional landforms located along the margins of large valley floors (Figure 8). They are similar to valley uplands (Group 22) in most respects, but with less relief. In many places, these landforms are bounded by smooth and irregular valley walls towards the basin, and by breaks, bluffs and cliffs in the upslope direction. This landform class may contain local bedrock outcrops. Local topography is influenced by bedrock, by alluvial erosion and, less often, by the cumulative effects of glacial episodes. Intermediate valley walls offer vantage points because they are topographically higher than the valley.

Physical Parameters of this group include areas located on 0 to 0.5 % near-level land with relief of 0 to 50 feet.

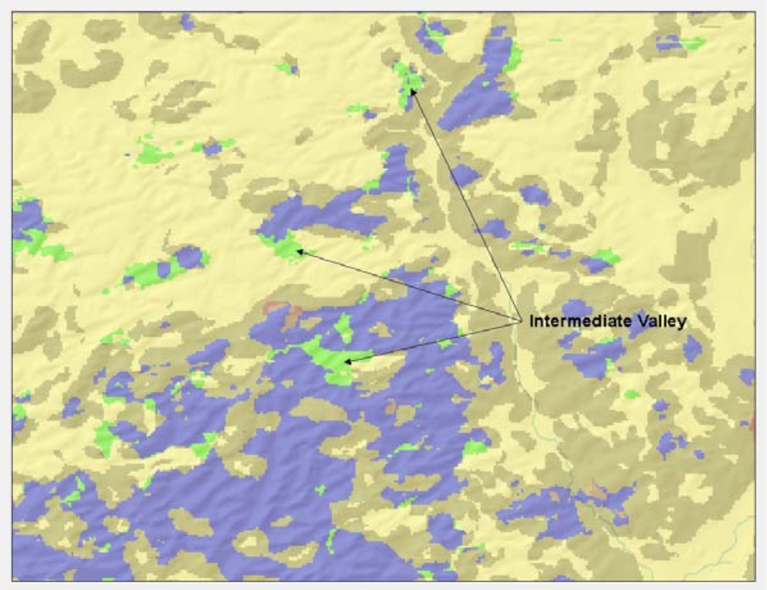

Figure 8. Landform category "Intermediate Valley," located in the Upper Columbia study area

GROUP 7: VALLEY UPLANDS

Valley uplands are transitional landforms located along the margins of large valley floors (Figure 9). They are similar to intermediate valleys (Group 21) in most respects, but with greater relief. In many places, these landforms are bounded by smooth and irregular valley walls towards the basin, and by valley uplands and breaks, bluffs and cliffs in the upslope direction. Local topography is influenced by bedrock, by alluvial erosion and, less often, by the cumulative effects of glacial episodes. Valley uplands offer vantage points because they are topographically higher than the valley.

Physical Parameters of this group include areas located on 0 to 0.5 % near-level land with relief of 50 to 100 feet.

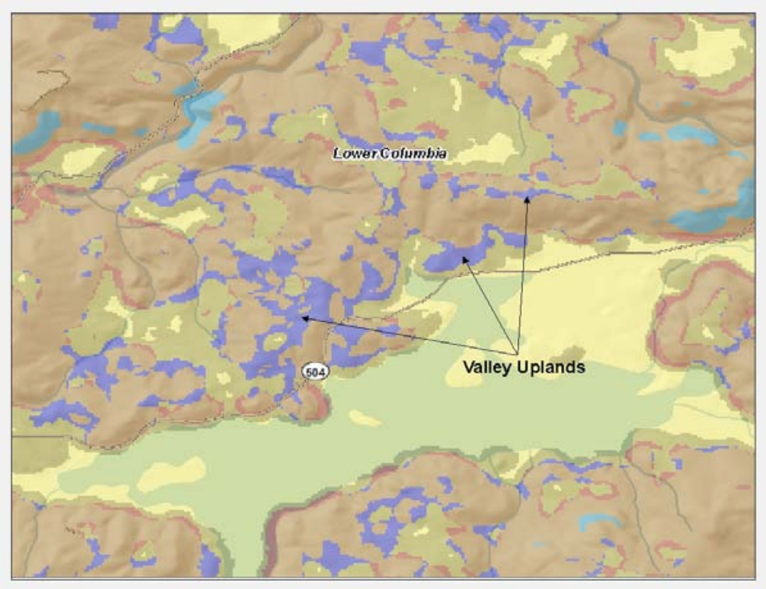

Figure 9. Landform category "Valley Uplands," located in the Lower Columbia study area

GROUP 8: HILLSLOPE BREAKS, BLUFFS, CLIFFS

Hillslope breaks, bluffs and cliffs consist of large tracts of land with convex or concave slope segments adjacent to valleys (Figure 10). These are landforms that serve as vantage points. These areas hold rock shelters and caves that transition into upland areas of higher relief. Prehistoric use of this landform included hunting and plant gathering, resource extraction sites, cave and rock shelter use and small site aggregates near stream confluences.

Physical Parameters of this group include areas located on 0 to 0.5 % near-level land with relief of 100 to 300 feet.

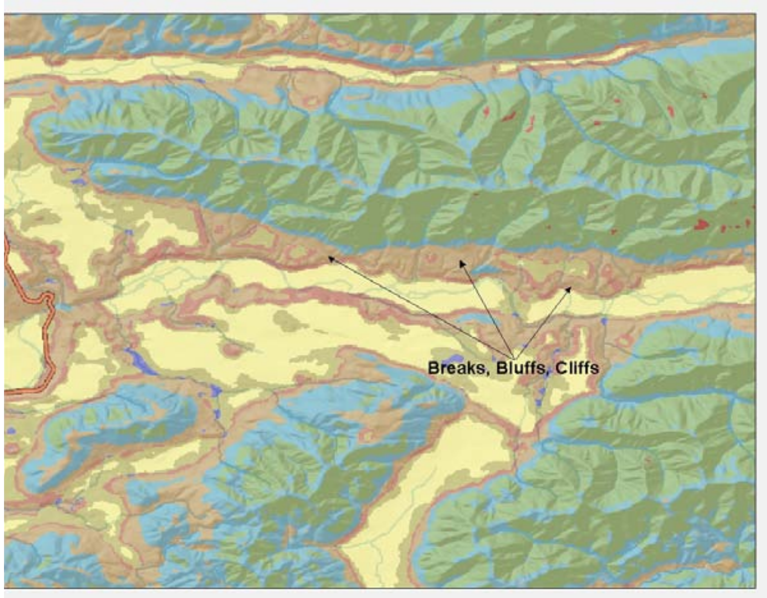

Figure 10. Landform category "Hillslope Breaks, Bluffs, Cliffs," located in the Coastal Washington study area.

GROUP 9: LOW-GRADIENT FOOTHILLS

The Low-Gradient Foothills landform category represents a transitional zone between the mountain slopes of the Cascade and Blue Mountains, the Okanogan Highlands and the lower elevation valleys. Topography is characterized by moderately sloping mountains with medium gradient streams (Figure 11). Much of the topography in the foothill zone is lightly to moderately forested, or transitional into high mountain forests. Prehistoric land use in this zone is likely related to hunting and plant gathering forays from site clusters or small villages situated at stream confluences.

Physical Parameters of this group include areas located on 0 to 0.5 % near-level land with relief of 300 to 500 feet.

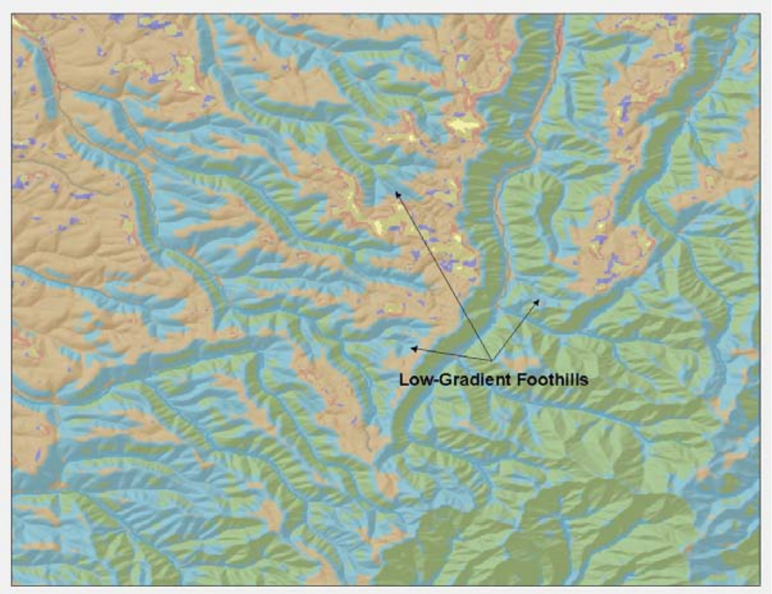

Figure 11. Landform category "Low-Gradient Foothills," located in the Upper Columbia study area.

GROUP 10: FOOTHILLS TO INTERMEDIATE MOUNTAIN SLOPES

The Foothills to Intermediate Mountain Slopes landform category represents land in the North and South Cascades, the Blue and Olympic Mountains as well as the Okanogan Highlands (Figure 12). These landscapes are rugged. The valleys are quite low relative to peaks and ridges, resulting in great relief. Mountain slopes support rich flora and fauna, with the land cover tending to be dominated by forests. This seemingly remote landscape formed an important part of prehistoric ways of life in Washington State. Human activity was specialized in the mountainous uplands because of the variety of large mammals and relatively low-elevation mountain passes present in these areas. Prehistoric land use included summer and fall hunting grounds and the seasonal use of transportation routes across the Cascades, connecting the interior and coast whenever these routes were passable. Archaeological site types represented in this landscape classification range from resource extraction locales to hunting sites to caves and rock shelters.

Physical Parameters of this group include areas located on 0 to 0.5 % near-level land with relief of 500 to 1000 feet.

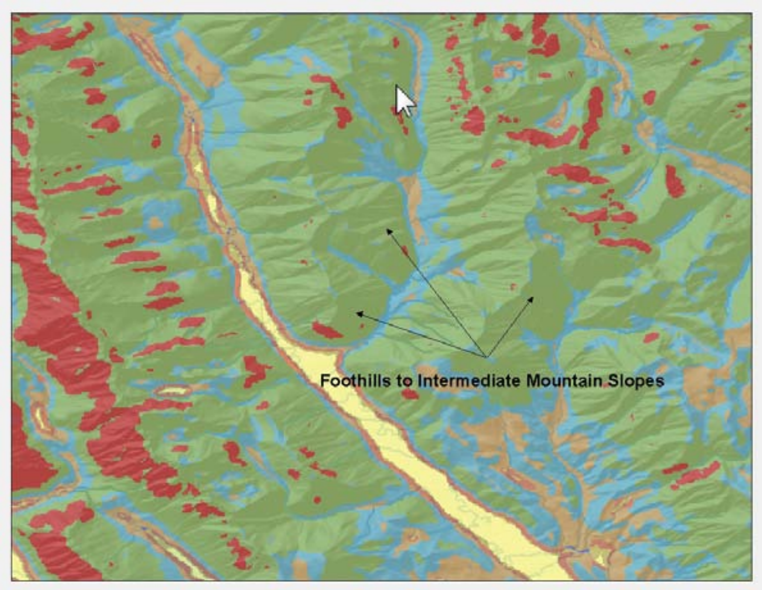

Figure 12. Landform category "Foothills to Intermediate Mountain Slopes," located in the North Cascades study area.

GROUP 11: MOUNTAIN SLOPES

The Mountain Slopes landform category represents land in the North and South Cascades, the Blue and Olympic Mountains as well as the Okanogan Highlands (Figure 13). These landscapes are extremely rugged; many of the peaks are steep, and alpine glaciers are present in places adjacent to high tundra. The valleys are quite low relative to peaks and ridges, resulting in great relief. Mountain slopes support a rich alpine flora and fauna with the land cover tending to be dominated by forests giving way to clumped tree groups scattered among meadow communities in subalpine zones. Landscape features include bare rock outcrops, glacial features, active glaciers and expansive views. This seemingly remote landscape formed an important part of prehistoric ways of life in Washington State. Human activity was specialized in the mountainous uplands because of the variety of large mammals and relatively low-elevation mountain passes present in these areas. Prehistoric land use included summer and fall hunting grounds and the seasonal use of transportation routes across the Cascades, connecting the interior and coast whenever these routes were passable.

Physical Parameters of this group include areas located on 0 to 0.5 % near-level land and has a relief of 1000 to 3000 feet.

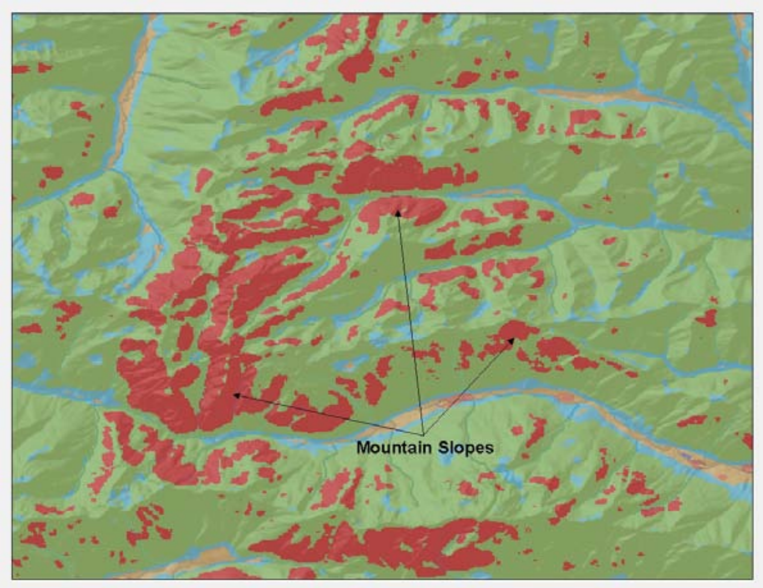

Figure 13. Landform category "Mountain Slopes," located in the Olympic Mountains of the Coastal Washington study area.

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Cultural Resources - Introduction

This project correlates information about archaeological sites, surveys and possible site locations with the environmental data to help predict where additional archaeological resources might be found within Washington State. For the purposes of this model, we focused on three different sources and types of archaeological data:

1. Archaeological sites recorded with DAHP;
2. Archaeological Surveys; and
3. Possible archaeological sites digitized from GLO maps (GLO sites).

Archaeological sites and surveys are recorded at the DAHP office in Olympia. DAHP staff digitized the locations based on submitted reports and archaeological site forms. We obtained these GIS layers from DAHP in July of 2008 for use within the model (see "Archaeological Sites" and "Archaeological Survey" sections below for more specific discussions of the data used in the model). The GLO sites used in the model were not available from DAHP and were processed and digitized into GIS as part of this project (see the "GLO Sites" section below).

All of the archaeological sites, surveys and GLO sites used in the model were generalized to 100 ft by 100ft cells within GIS. These data were combined into a single GIS layer. Where these three datasets overlapped spatially, they were processed in the following order: archaeological sites, GLO sites and archaeological surveys. Each type of information derived from these datasets was assigned weights to be used in the model calculations. These weights were based on conversations with DAHP personnel, other archaeologists and our statistician. Generally, the higher the weighted values, the more influence the feature would have in the model calculations (see the "Processing Method" section for additional information). The weights are summarized below:

- Archaeological sites: 1
- Indian Sites: 0.5
- Trails intersecting streams: 0.3
- Trails intersecting Trails: 0.2
- Trails: 0.1
- Archaeological surveys ("negative sites"): 0

We refer to these data with these weights assigned to them collectively as "control points" during model processing. See the "Processing Method" section for additional information on how this information was integrated into the model.

This project extends protection to non-surveyed locations by correlating cultural resource and environmental data.

Archaeological Sites Recorded with DAHP

Archaeology is the study of historical artifacts, features and sites to better understand human history. When an archaeological resource is discovered in Washington, by law it must be reported to the Washington Department of Archaeology and Historic Preservation (DAHP) who is responsible for managing an inventory of these archaeological sites. The location of each site is field verified and reported to DAHP in the form of a base map which is then digitized into GIS data. The size and complexity of each archaeological site can range from large permanent villages to the discovery of a few artifacts. Regardless of the size, archaeological resources have been documented in every county in the state and in a multitude of natural environments. For the purposes of this model, only sites identified in the GIS layers and databases as having pre-contact components were used to construct the model.

The archaeology data used for this project consisted of point, line and polygon data representing confirmed archaeological site locations. For use in the model the point, line and polygon archaeology data were converted into a grid (see graphic below) using 100-foot cells where a value of 1.0 was used to represent a confirmed archaeological site. These archaeological sites data were used directly in the probability calculations for the model. See the "Processing Method" section for additional information on how this data were integrated into the model.

Polygon Data vs. Grid Data

Shell Midden site

Stone artifact

When an archaeological resource is discovered in Washington, by law it must be reported to the Washington Department of Archaeology and Historic Preservation (DAHP)

Archaeological Surveys

DAHP manages and maintains an inventory of locations within Washington that have been surveyed for cultural resources. Only surveys that have been reported to DAHP from 1995 to present and can be reasonably mapped are included in this inventory. The location of each survey is field verified and reported to DAHP in the form of a base map. DAHP staff then digitized the information into point, line and polygon GIS layers. For the purposes of this model, we defined archaeological survey data as being those where no archaeological sites were discovered ("negative sites"). Whether or not an archaeological site is discovered is sometimes unclear in the associated databases. Because of this, we removed any archaeological survey locations that were within 300 feet of an archaeological site. For use in the model, the point, line and polygon survey data were converted into a grid (see graphic above) using 100-foot cells where a value of 0 was used to represent a "negative site". The survey data were used to influence the model after initial correlations with the environmental data. See the "Processing Method" section for additional information on how this data were integrated into the model.

Only surveys that have been reported to DAHP from 1995 to present and can be reasonably mapped are included in this inventory.

GLO Sites

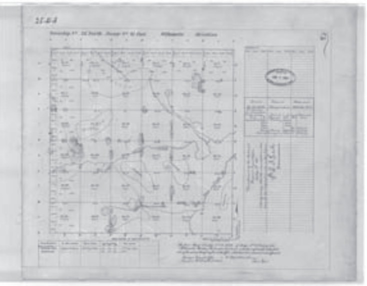


Figure 1. Example of GLO map

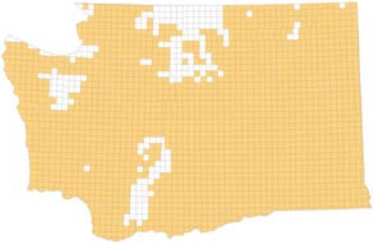


Figure 2. Available GLO coverage

In order to enhance the archaeological data used in the model, historical features were recorded from Government Land Office (GLO) maps obtained from the Bureau of Land Management. These maps date back to the 1880s and contain a broad variety of records for both Native American and European cultural and natural features. GLO maps typically include the locations of historical roads, trails, cabins, logging camps, Native American (Indian) villages, dunes, springs and early homesteads and settlements. In some cases, they may indicate historical period Native American encampments that were used since the prehistoric period. A limiting factor when using GLO maps is the practice of the surveyors to record only cultural and natural features that were visible from section lines. Historical transportation routes, whether Indian trails or stagecoach lines, tended to follow least-cost path or trail systems across the state, which supported trade and exchange of resources from the coast to the interior. Once these routes were established, many of them were perpetuated. During the historical period, Euro-American roads were sometimes placed in or along the path of Indian trails that would lead to important resources, settlements or larger transportation routes such as the river systems. These features are not considered known archaeological sites since they have not been field verified since the 1880s; however, they were used to identify areas that would have a strong possibility of finding an archaeological site.

Based upon conversations with archaeologists at DAHP, we decided to record the following features from the GLO maps:

- **Indian Sites (Native American settlements or graves):** These features are indicators of historical occupations and, therefore, potential archaeological resources.
- **Trails:** These features are indicators of potential trade routes and potential migration and settlement pathways.
- **Springs:** These features are indicators of historical water sources and may point to historical settlement locations. These features were recorded but were not used in the archaeological feature calculations.

We also recorded locations where a trail intersected another trail and locations where a trail intersected a river or stream. These features may also be indicators of potential trade routes and migration and settlement pathways.

Figure 3. Example of GLO map with digitized features

GLO maps are a result of the effort to survey all United States public lands before settlement. Starting in 1812, land was divided into square 6-mile blocks called townships, then subdivided into sections and ranges. See Figure 1 for an example of a GLO map. Each subdivided area was surveyed and given its own GLO map. During this process, surveyors were required to indicate cultural resources such as roads and Indian trails, and standardized symbols were used to represent geographic features. These GLO maps are now maintained by the Bureau of Land Management (BLM) as part of the official Land Status and Cadastral Survey records. Over time, as land was divided into parcels of individual ownership, additional cadastral survey maps were created. For this reason, there are often multiple GLO maps or "cadastral survey maps" for one township/range, generally numbered

GLO maps date back to the 1880s and contain a broad variety of records for both Native American and European cultural and natural features. These maps typically include the locations of historical roads, trails, cabins, logging camps, Native American (Indian) villages, dunes, springs and early homesteads and settlements.

1 through 4. Because this project is focused on archeology-related resources, we concentrated our efforts on the more historical GLO maps, which were usually listed as image number 1 or 2 for that specific township/range in the BLM Cadastral Survey records. In some areas, no GLO maps were available for review. Such areas included National Forest Lands, National Parks, Indian Reservations and remote wilderness areas. See Figure 2 for statewide GLO coverage.

In order to obtain spatial data from the GLO maps, we needed to assign a coordinate system to each map, a process called "georeferencing." Each GLO map was georeferenced within NAD 83 HARN Washington State Plane South (feet), the coordinate system specified for the final GLO dataset (see the "Data Descriptions" section). During the georeferencing process, we used a minimum of four control points, with the corners of the corresponding township/range used when possible. Township and section data used for georeferencing were obtained from the Department of Natural Resources. These data were designed to comply with the National Map Accuracy Standard for 1:24,000 scale mapping, under which 90 percent of all GIS positions will be accurate within 40 feet. In cases where township/range corners were not available, coastline features or distinct land formations were used as control points.

Total error is calculated by taking the root mean square (RMS) sum of the error values from each control point during the georeferencing process. This RMS value describes how consistent the transformation is between control points, and the value can be used to judge overall accuracy. A lower RMS value equates to less overall error. We attempted to achieve RMS values between 50 and 150 during georeferencing. Overall, the average RMS value was 67.2 with a median value of 58.5 for all the GLO maps georeferenced in Washington. A type of georeferencing known as "rectifying" was used to ensure that spatial reference information was permanently saved as part of each GLO image file.

Once GLO maps had been georeferenced, the maps were reviewed for the presence of features to be digitized. Digitizing is the process of converting features on a paper map to digital format, which could be used for modeling purposes. For this project, features of interest included historical Indian sites such as settlements or graves and other relevant features such as trails or springs. Once identified, these features were digitized at a scale no larger than 1:24,000 to ensure a reasonable level of accuracy. See Figure 3 for an example of a GLO map with digitized features. Trails digitized from the GLOs were then intersected with streams and intersected with other trails to indicate other areas within the state that may have slightly increased probabilities for discovering archaeological sites. With the assistance of archaeologists, DAHP staff and our statistician, these data were assigned values 0.1, 0.2, 0.3 and 0.5 (as indicated in the section above) and used for the probability calculations of the model. See the Processing Methods section for more details of how this information was incorporated into the model.

After georeferencing and digitizing were complete, every GLO map went through an internal quality control process. Each GLO image file was individually opened and viewed within its newly assigned spatial extent to ensure its correct placement and georeferencing quality. In some cases, the georeferencing process was repeated to improve accuracy. A visual check of digitized features within each GLO map was also conducted at a scale no larger than 1:60,000 to ensure accuracy and thoroughness.

The GLO maps were clipped to the extent of the township they represent, which removed the surrounding "collar" containing notes and referencing information. All GLO maps used for this project were provided in a statewide seamless layer.

Processing Methods — Introduction

Predictive models, developed through experience, intuition or statistical analysis, are nothing new to the world of archaeology. Landscape archaeologists generally agree that spatial distribution of archaeological sites is dependent on a variety of environmental factors (such as landforms, soil type, proximity to water, slope, etc.) that characterize the environmental context where the sites are located. Therefore, predictive models based on these environmental factors associated with known archaeological sites can be used to predict where new discoveries are most likely to occur. With this information, planners and archaeologists can evaluate the potential for archaeology resources early in construction projects and can plan appropriate avoidance or mitigation measures.

In addition to using environmental factors and known archaeological sites, spatial dependence and spatial proximity should play a major role in making predictions. For this study, we have developed a GIS archaeological predictive model using Bayesian statistical analysis (focused on environmental factors) combined with geostatistical spatial estimation (a method known as "point kriging"). Point kriging relies heavily on proximity to locations with archaeological information to predict the potential for archaeological sites at unsampled locations in the general vicinity. This proximity measure includes the influence of both distance and direction.

Initially, we developed a simple Bayesian analysis using only known archaeological site locations and their environmental characteristics to calculate the probability that an archaeological site would be found at any specified location, given a particular set of environmental conditions at that location. Such locations in the GIS model are contiguous square cells that measure 100 feet by 100 feet, and the Bayesian results can be displayed as a simple GIS archaeological prediction map based solely on environmental factors. This map does not include the influence of negative archaeological ground surveys, the potential influence of historical settlements and trails, or the influence of spatial proximity to locations with recorded archaeological information.

We added more complexity to the Bayesian model in order to include "soft" archaeological site information, such as historical trails and Native American (Indian) sites identified on Government Land Office (GLO) maps (see the "Data Descriptions" section). Environmental influences now could be based on these soft sites, as well as on the known archaeological sites. The Bayesian calculations include a conditional weighting scheme so that cells with known archaeological sites receive the maximum weight of 1.0, and cells that contain soft data receive lesser weight (for example, 0.50 for an Indian site, and 0.10 for a trail).

Using the predictive model, planners and archaeologists can evaluate the potential for archaeology resources early in construction projects and can plan appropriate avoidance or mitigation measures.

The kriging component of the predictive model incorporates the influence of negative ground surveys and also strongly considers the spatial proximity to locations with archaeological information (including the known sites and the GLO soft data). Essentially, kriging provides estimates at unsampled locations using spatial dependence (covariance) and a weighted, linear combination of known neighborhood data, such that the estimates are unbiased and have low estimation variance. Kriging also provides a measure of "confidence" in each estimate because the computed kriging standard deviation, which always is less than the original sample standard deviation, will equal exactly zero when a location with a known data value is kriged. Thus, after kriging the archaeological data, each cell in the GIS database has an assigned kriged estimate for the archaeological value and a computed standard deviation (measure of estimation error), both of which can be displayed as GIS maps. A low standard deviation (error) value implies greater confidence in the kriged estimate at any given cell.

GeoEngineers designed and built a number of ArcGIS Geoprocessing Models to handle the various GIS analysis and data processing steps required to generate Bayesian values and prepare the datasets for kriging. All of the GIS processing steps were completed using ESRI's ArcGIS 9.3 platform. Furthermore, we decided to automate as many of the tasks as possible to reduce processing errors and expedite the process using ESRI's Model Builder, which is an application wherein GIS models are created, edited and managed. All processing steps were developed into ArcGIS Geoprocessing Models that can be called individually or through the master model. GeoEngineers will deliver GeoProcessing tools after the next update of the statewide model (WAModel), scheduled in 2010. See Appendix for list of software used in model development.

Environmental Influence Calculations Using Bayesian Analysis

Bayesian statistical analysis relies on information about past prior events to predict future events. Therefore, using known archaeological site locations, this method can help identify where new archaeological sites likely would be located, based on how closely the specific environmental conditions resemble those common to known archaeological sites. The final output, cell by cell, is a Bayesian "score" than can range in value from 0 to 1, and it depends solely on the environmental factors at each cell. Thus, there always will be some areas on the final GIS map of Bayesian scores where a high Bayesian value coincides with a negative archaeological survey site, and where a low Bayesian value coincides with a known archaeological site. However, these anomalies should be relatively few if the model is based on a reasonable amount of known archaeological information scattered across varying environmental terrains.

Value and categorical data from the seven environmental characteristics (see "Data Descriptions" section) were converted to ESRI grids with 100-foot by 100-foot cell size. All environmental factors (characteristics) were assigned to groups or categories; the number of such groups ranged from 8 to 18 for each of the seven environmental factors: elevation, slope percent, aspect, distance to water (DTW), soil, geology and landform. For example, a given cell may have been assigned elevation group 2, slope percent group 3, aspect group 7, DTW group 1, soil group 10, geology group 6 and landform group 12. This collection of environmental information at a GIS grid cell can be considered an environmental vector at that cell (see Figure 1).

For the simple Bayesian method, two probability values were calculated for each environmental group using frequency of occurrence. One probability, called "total area probability," was calculated based on the known frequency of that environmental group occurring across the entire study area. The second probability, called "archaeology probability," was based on the known frequency of that environmental group occurring at known archaeological sites in the study area; archaeology probability is a conditional probability, because it is a frequency of occurrence given the particular location (cell) that contains an archaeological site. Examples of these two probabilities are illustrated in Figure 2. Every cell had these two probability values calculated for each of the seven environmental factors.

For each cell, a Bayesian probability was calculated using the probabilities assigned for the environmental data identified for each cell (see equation below). Strictly speaking, the calculated result cannot be considered an exact probability value, because the total probability terms in the denominator may not always be statistically independent (which is a required condition for the Bayesian probability approach). Thus, we refer to these results as Bayesian "scores." After summarizing the information into cells, GIS tools were used to calculate a Bayesian score for each cell within the study area. For mapping displays, these scores can be grouped into categories indicating Very High, High, Moderate, Low and Very Low archaeological potential and subsequently modified for management techniques (see the "Implementation" section for additional details).

Bayesian statistical analysis relies on information about past events to predict future events.

Bayesian Probability Equation:

$$P(A|Ev) = \frac{(AP_1)(AP_2)(AP_3)(AP_4)(AP_5)(AP_6)(AP_7)(RAP)}{(TP_1)(TP_2)(TP_3)(TP_4)(TP_5)(TP_6)(TP_7)}$$

where:

$P(A\|Ev)$ =	Probability of an archaeological discovery, given the environmental vector at the cell;
AP =	Archaeology Probability for each environmental group at the cell;
RAP =	Reference Archaeology Probability (number of archaeological-site cells divided by the total number of cells in the study area);
TP =	Total Area Probability for each environmental group at the cell;
1-7 =	Environmental factors/characteristics at the cell.

An example calculation is given below for a single grid cell with a five-element environmental vector (Geology 6, Slope 2, Elevation 4, Aspect 5, DTW 1):

$$\text{Bscore} = \frac{(0.775000)(0.360714)(0.330935)(0.248200)(0.453571)(0.000445)}{(0.806382)(0.249387)(0.423274)(0.263093)(0.091690)} = 0.00225$$

Geology Group 6 Slope Group 2 Elevation Group 4 Aspect Group 5 DTW Group 1 Soils Group 10 Landform Group 11	Geology Group 2 Slope Group 4 Elevation Group 3 Aspect Group 3 DTW Group 4 Soils Group 8 Landform Group 5

Figure 1. Examples of Environmental Data Assigned to Groups at Individual Cells (each shaded block represents a summary of environmental data at a grid cell)

Geology Group 6
Total Area Probability (0.775000)
Archaeology Probability (0.806382
Slope Group 2
Total Area Probability (0.360714)
Archaeology Probability (0.249387)
Elevation Group 4
Total Area Probability (0.330935)
Archaeology Probability (0.423274)
Etc.

Figure 2. Example Probabilities for a Single Grid Cell

These Bayesian scores for predicting new archaeological sites are based entirely on the hard data of known ground surveys that resulted in archaeological discoveries, considering that the available survey information can be sorted into two categories: "1" for a cell containing a known archaeological site and "0" for a cell where a ground survey resulted in negative results (that is, where no archaeological site was found). In order to enhance this background archaeological information used in the predictive model, pertinent historical features were identified and recorded from GLO maps (see the "Data Descriptions" section). This historical information serves as "soft" archaeological information that adds useful supplementary data to the Bayesian model using pseudo-probability values that we assigned to the mapped features:

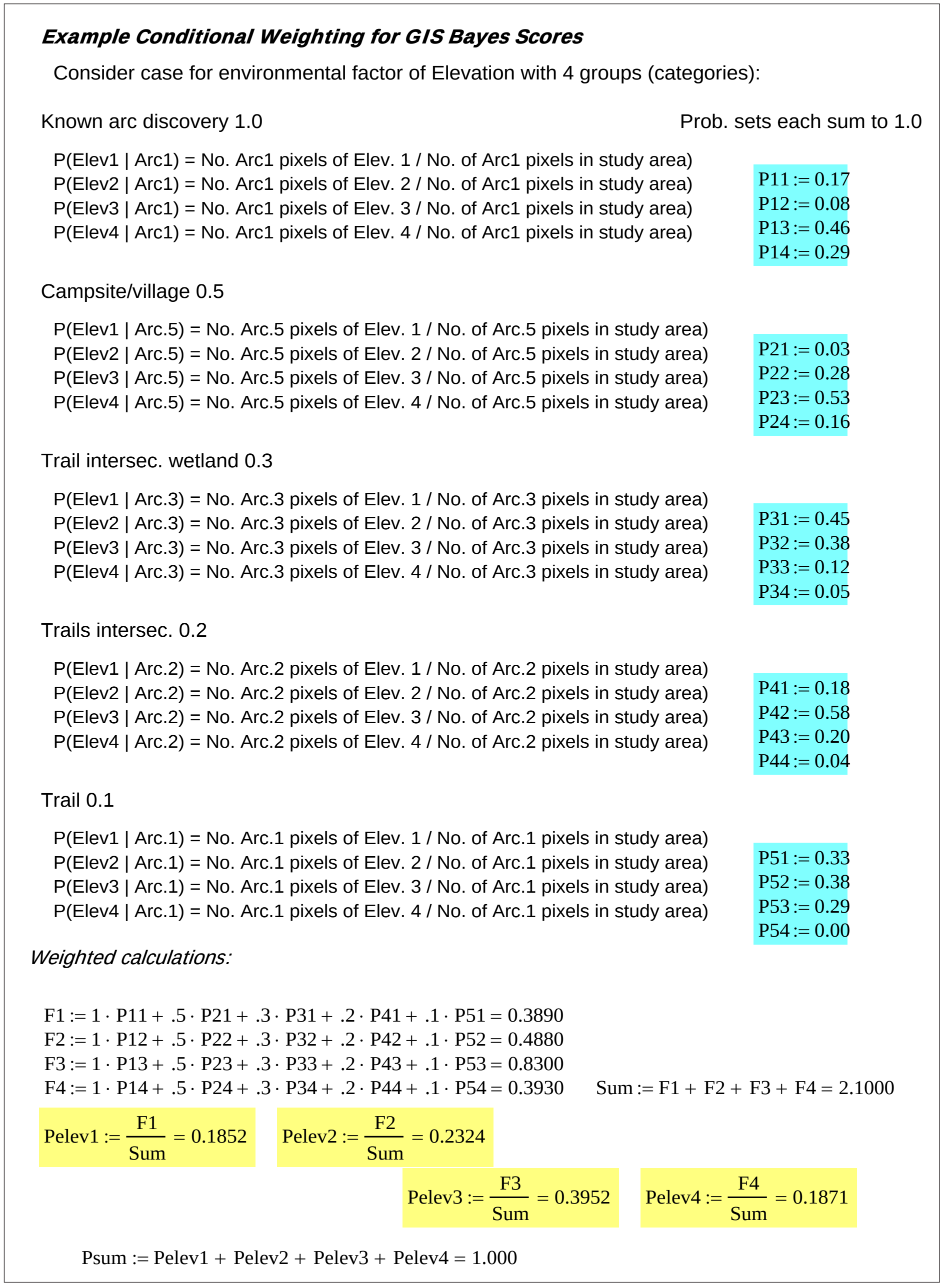
Known archaeological sites (hard data at known sites)	1.0
Mapped Indian sites	0.5
Mapped trails	0.1
Mapped intersections of trails	0.2
Mapped intersections of trails with streams	0.3

The key assumption used in this more complex Bayesian scheme is that the soft data provide somewhat reliable indicators of cells more likely to contain archaeological sites than any random cell across the study area (also referred to statistically as "high-value targets").

Environmental conditions that occur at these soft-data cells can be incorporated into the Bayesian calculations using a conditional weighting method, which we applied to the enhanced archaeological database. Repeated data-frequency calculations must be completed for each category for each environmental factor at each of the known-site cells (hard data of 1.0), and at each of the soft-data cells (soft data of 0.5, 0.3, 0.2 or 0.1). That is, archaeology probabilities and total area probabilities must be computed for each of the new soft data types in a manner similar to that used previously for the hard data type (the known archaeological sites). Then, a weighting method must be used to combine all these individual probabilities into representative values for the Bayesian probability equation.

Figure 3 shows an abbreviated example (using only four elevation groups) of this conditional weighting for computing the revised total area probability values for elevation groups. In essence, this weighting method adjusts the original total area probability values for the known archaeological sites using frequency data from the soft data. The adjustments for this example may go up or down, depending on the characteristics of the soft data, as shown by the summary below:

Original total area probability for known archaeological sites	Revised total area probability including the soft data
P(Elev1) = 0.17	0.185
P(Elev2) = 0.08	0.233
P(Elev3) = 0.46	0.395
P(Elev4) = 0.29	0.187



Example Conditional Weighting for GIS Bayes Scores

Consider case for environmental factor of Elevation with 4 groups (categories):

Known arc discovery 1.0 — Prob. sets each sum to 1.0

P(Elev1 | Arc1) = No. Arc1 pixels of Elev. 1 / No. of Arc1 pixels in study area)
P(Elev2 | Arc1) = No. Arc1 pixels of Elev. 2 / No. of Arc1 pixels in study area)
P(Elev3 | Arc1) = No. Arc1 pixels of Elev. 3 / No. of Arc1 pixels in study area)
P(Elev4 | Arc1) = No. Arc1 pixels of Elev. 4 / No. of Arc1 pixels in study area)

P11 := 0.17
P12 := 0.08
P13 := 0.46
P14 := 0.29

Campsite/village 0.5

P(Elev1 | Arc.5) = No. Arc.5 pixels of Elev. 1 / No. of Arc.5 pixels in study area)
P(Elev2 | Arc.5) = No. Arc.5 pixels of Elev. 2 / No. of Arc.5 pixels in study area)
P(Elev3 | Arc.5) = No. Arc.5 pixels of Elev. 3 / No. of Arc.5 pixels in study area)
P(Elev4 | Arc.5) = No. Arc.5 pixels of Elev. 4 / No. of Arc.5 pixels in study area)

P21 := 0.03
P22 := 0.28
P23 := 0.53
P24 := 0.16

Trail intersec. wetland 0.3

P(Elev1 | Arc.3) = No. Arc.3 pixels of Elev. 1 / No. of Arc.3 pixels in study area)
P(Elev2 | Arc.3) = No. Arc.3 pixels of Elev. 2 / No. of Arc.3 pixels in study area)
P(Elev3 | Arc.3) = No. Arc.3 pixels of Elev. 3 / No. of Arc.3 pixels in study area)
P(Elev4 | Arc.3) = No. Arc.3 pixels of Elev. 4 / No. of Arc.3 pixels in study area)

P31 := 0.45
P32 := 0.38
P33 := 0.12
P34 := 0.05

Trails intersec. 0.2

P(Elev1 | Arc.2) = No. Arc.2 pixels of Elev. 1 / No. of Arc.2 pixels in study area)
P(Elev2 | Arc.2) = No. Arc.2 pixels of Elev. 2 / No. of Arc.2 pixels in study area)
P(Elev3 | Arc.2) = No. Arc.2 pixels of Elev. 3 / No. of Arc.2 pixels in study area)
P(Elev4 | Arc.2) = No. Arc.2 pixels of Elev. 4 / No. of Arc.2 pixels in study area)

P41 := 0.18
P42 := 0.58
P43 := 0.20
P44 := 0.04

Trail 0.1

P(Elev1 | Arc.1) = No. Arc.1 pixels of Elev. 1 / No. of Arc.1 pixels in study area)
P(Elev2 | Arc.1) = No. Arc.1 pixels of Elev. 2 / No. of Arc.1 pixels in study area)
P(Elev3 | Arc.1) = No. Arc.1 pixels of Elev. 3 / No. of Arc.1 pixels in study area)
P(Elev4 | Arc.1) = No. Arc.1 pixels of Elev. 4 / No. of Arc.1 pixels in study area)

P51 := 0.33
P52 := 0.38
P53 := 0.29
P54 := 0.00

Weighted calculations:

$F1 := 1 \cdot P11 + .5 \cdot P21 + .3 \cdot P31 + .2 \cdot P41 + .1 \cdot P51 = 0.3890$
$F2 := 1 \cdot P12 + .5 \cdot P22 + .3 \cdot P32 + .2 \cdot P42 + .1 \cdot P52 = 0.4880$
$F3 := 1 \cdot P13 + .5 \cdot P23 + .3 \cdot P33 + .2 \cdot P43 + .1 \cdot P53 = 0.8300$
$F4 := 1 \cdot P14 + .5 \cdot P24 + .3 \cdot P34 + .2 \cdot P44 + .1 \cdot P54 = 0.3930$ $Sum := F1 + F2 + F3 + F4 = 2.1000$

$Pelev1 := \frac{F1}{Sum} = 0.1852$ $Pelev2 := \frac{F2}{Sum} = 0.2324$

$Pelev3 := \frac{F3}{Sum} = 0.3952$ $Pelev4 := \frac{F4}{Sum} = 0.1871$

$Psum := Pelev1 + Pelev2 + Pelev3 + Pelev4 = 1.000$

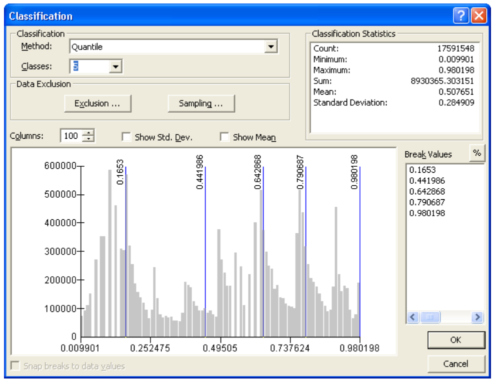
Figure 3. Example of Conditional Weighting for Bayesian Scores

We used this revised Bayesian conditional weighting method to calculate Bayesian scores across each of the study areas and then merged the results into a final statewide grid. These steps not only were necessary to maintain regional differences among the study areas but also allowed faster computer processing times. Because each study area was processed individually, the calculated Bayesian scores produced a slightly different range of scores within each study area. Even after the ranges were grouped, the differences were apparent along the boundaries of the study areas, causing edge effects. In order to reduce the edge effects and to “standardize” the scores across the state, we transformed the Bayesian scores in each study area using a uniform-rank transform. These new Bayesian rank scores provided a final statewide GIS map displayed with five resulting management groups or “map classes” that indicate Very High (5), High (4), Moderate (3), Low (2) and Very Low (1) archaeological potential. These groups were subsequently refined for management purposes (see the “Implementation” section for additional details).

These five map groups also can be defined for field application purposes using the following three categories:

- Archaeological Survey Contingent upon Project Parameters (Groups 1 and 2)
- Archaeological Survey Recommended (Group 3)
- Archaeological Survey Required (Groups 4 and 5)

These groups were established by examining histograms, such as the example in Figure 4. We completed many tests to determine the best categories for the scores. We used the quantile classification and the computer defaults to assign the category break values in each study area.



Method: Quantile

Classes: 5

Columns: 100

Count: 17591548
Minimum: 0.009901
Maximum: 0.980198
Sum: 8930365.303151
Mean: 0.507651
Standard Deviation: 0.284909

Break Values
0.1653
0.441986
0.642868
0.790687
0.980198

Figure 4. Example Histogram for Bayesian Calculations, Study Area 1

Spatial Proximity Calculations Using Kriging

Kriging is a geostatistical estimation tool that uses available spatial information (control points) to make estimates at unsampled locations. The estimates are based on the spatial dependence patterns of the control points (in other words, their similarity based on proximity using distance and direction) across the study area. For this GIS archaeological predictive model, the control points consist of the known archaeological sites, the negative survey sites and the features obtained from the GLO maps (Indian sites, trails, trail intersections, and trails intersecting streams). A major advantage of kriging is that it provides not only a map of estimates, but also a map of kriging standard deviations (errors), which describe the uncertainty in the spatial estimates. Furthermore, kriging is an exact interpolator, so that when a kriged location coincides with a known control point, the kriged estimate equals the known value and the kriging standard deviation is zero (that is, there is no uncertainty about that estimate). See the “Appendix – Mathematical Description of Kriging” for additional details.

A major advantage of kriging is that it provides not only a map of estimates, but also a map of kriging standard deviations (errors), which describe the uncertainty in the spatial estimates.

A clearly defined spatial dependence model of the control points is required input for kriging. In our case, these data include the following: known archaeological sites (1), negative survey sites (0), and the soft data from the GLO maps, including Indian sites (0.5), trail intersecting a stream (0.3), trail intersecting trail (0.2), and trails (0.1). One common way to describe the spatial dependence in a data set is to compute the sample **semivariogram**, or **variogram**, which can be defined as:

$$\gamma(h) = \frac{1}{2n_h}\sum_{i=1}^{n_h}\left(x_i - x_{i+h}\right)^2$$

where: x_i and x_{i+h} = pairs of data values separated by lag *h*, and n_h = number of data pairs separated by lag *h*, or by a set of lags defined over a constrained interval. The lag *h* is a separation distance between any two locations of a pair of data (control points).

For any given lag interval, the representative *h* is the computed mean of all lags in the specified interval. Typically, from 6 to 20 intervals are specified, and a plot is generated of discrete points showing the variogram vs. lag *h*. A smooth variogram model (function) then is fitted to these points to mathematically describe the estimated spatial dependence in the study area (as shown in Figure 5). If the graph does not pass through the origin, but instead has a *y*-intercept, then that intercept value is known as the "nugget."

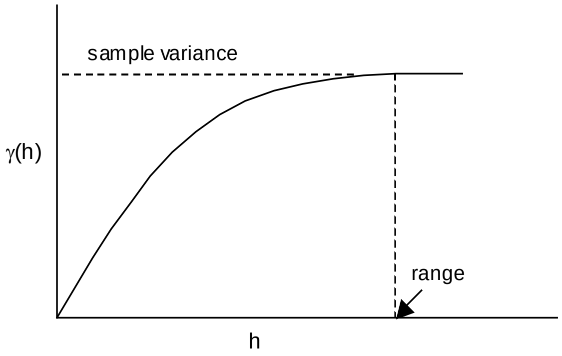


Figure 5. A typical variogram plot (model) depicting spatial dependence

A very common variogram model appropriate for many natural spatial data sets is the spherical model, given by (note: h_r = range of influence, γ_o = nugget value, and σ^2 = the population variance, which is estimated by the sample variance, or sill value):

For nugget = 0:

$$\gamma(h) = \sigma^2\left[\frac{3}{2}\left(\frac{h}{h_r}\right) - \frac{1}{2}\left(\frac{h}{h_r}\right)^3\right] \quad \text{for } 0 \le h \le h_r$$

$$\sigma^2 \quad \text{for } h > h_r$$

For nugget > 0:

$$\gamma(h) = \gamma_o + (\sigma^2 - \gamma_o)\left[\frac{3}{2}\left(\frac{h}{h_r}\right) - \frac{1}{2}\left(\frac{h}{h_r}\right)^3\right] \quad \text{for } 0 \le h \le h_r$$

$$\sigma^2 \quad \text{for } h > h_r$$

When a statistical condition known as "local covariance stationarity" is deemed appropriate for the study area, then the spatial covariance can be related directly to the variogram by the following expression:

$$C(h) = \sigma^2 - \gamma(h)$$

The plot of this spatial covariance is the complement of the variogram plot, as shown in Figure 6.

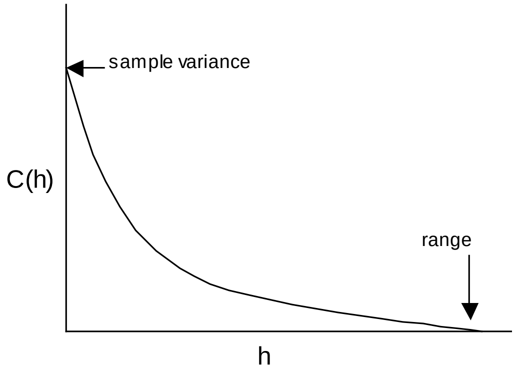


Figure 6. A typical spatial covariance plot depicting spatial dependence

Directional variogram computations are useful to help identify anisotropy in spatial dependence. For example, there may be a longer range of influence in one direction resulting from environmental influences oriented in that particular direction. Variogram directions most often are referenced to East as 0°, North as 90°, and with directional bins (windows) that often span 10 to 45 degrees. For this study of archaeological data, our directional variogram calculations were centered at 0, 15, 30, 45, 90, 105, 120, 135, 150 and 165 degrees with a bin span of +/- 7.5 degrees. A "rough" range ellipse was constructed to help discern the directions of the longest and shortest spatial-dependence ranges (see example in Figure 7). In a general sense, the range ellipse can be rotated and fine-tuned to provide a geometric model of anisotropy for the spatial attribute (archaeological value). The magnitude of the major and minor axes (two ranges) of the final ellipse and the direction of the major axis were identified for subsequent use in kriging.

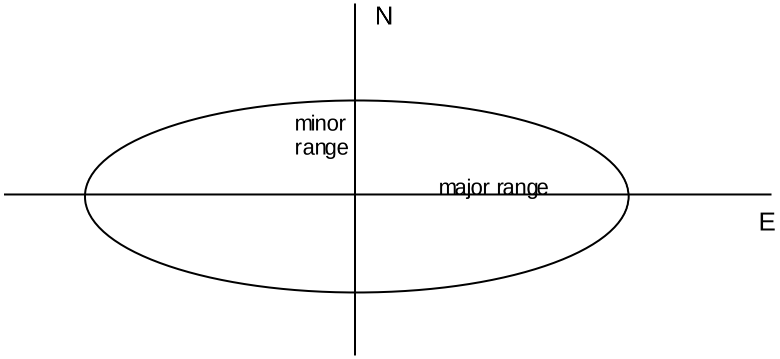


Figure 7. Spatial-dependence range ellipse with major range at 0° (E-W)

We used the GIS database of archaeological data (control points) in each study area to compute directional variograms. We then fit the raw variograms with spherical variogram models (as illustrated in Figure 8) and defined the range ellipse for each study area.

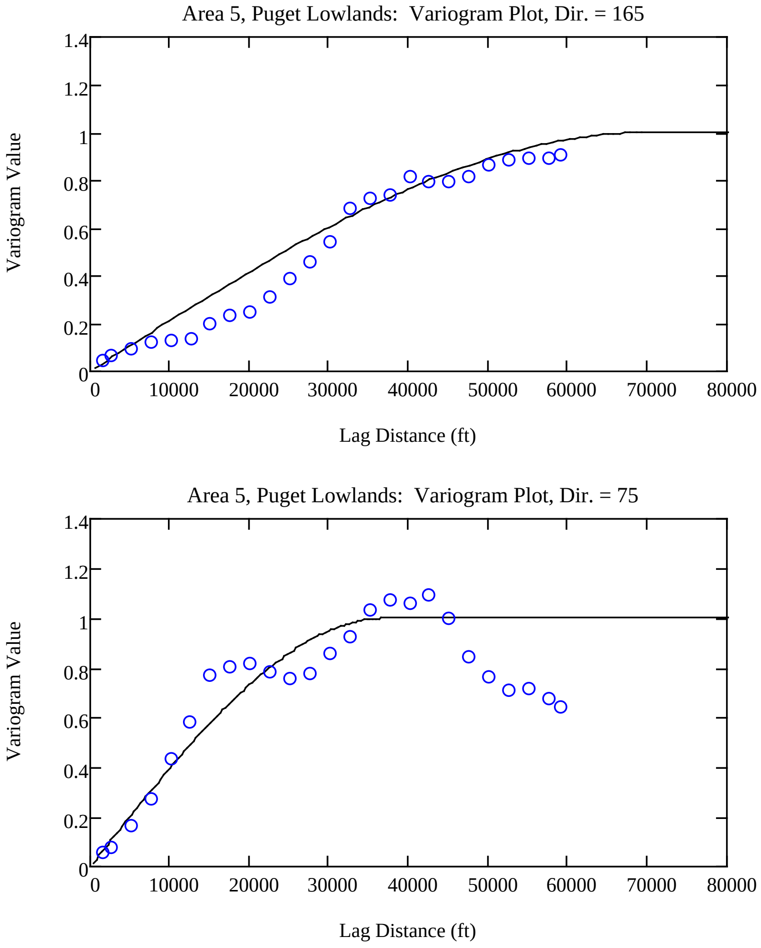


Figure 8. Examples of directional variograms for archaeological control points.

We used Surfer® software to compute the kriging estimation and standard deviation grids. We would expect all the archaeological kriged estimates to be between 0 and 1, because our input data consisted of the archaeological control points, which ranged from 0 to 1. However, because of computational round-off errors, some of the kriged cells fell slightly outside this range. Therefore, the kriging grids were corrected to make sure that all kriged estimates slightly larger than 1.0 were assigned values of 1.0, and all estimates slightly less than 0.0 were assigned values of 0.0.

The kriged maps take into account the negative survey data and the spatial proximity of available archaeological information. Kriged estimates also honor the available information. Thus, the kriged maps often do not look like the Bayesian score maps as shown by visual comparisons of Figures 9 and 10. The final archaeological prediction maps should include both types of estimations to provide a comprehensive picture of archaeological potential across the state.

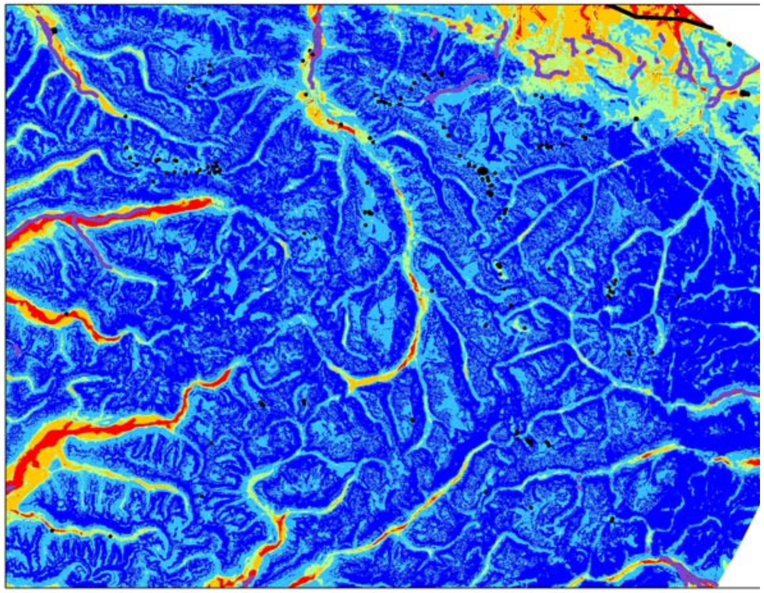


Figure 9. Example with Archaeological Sites (black dots) overlain on Bayesian grid (map)

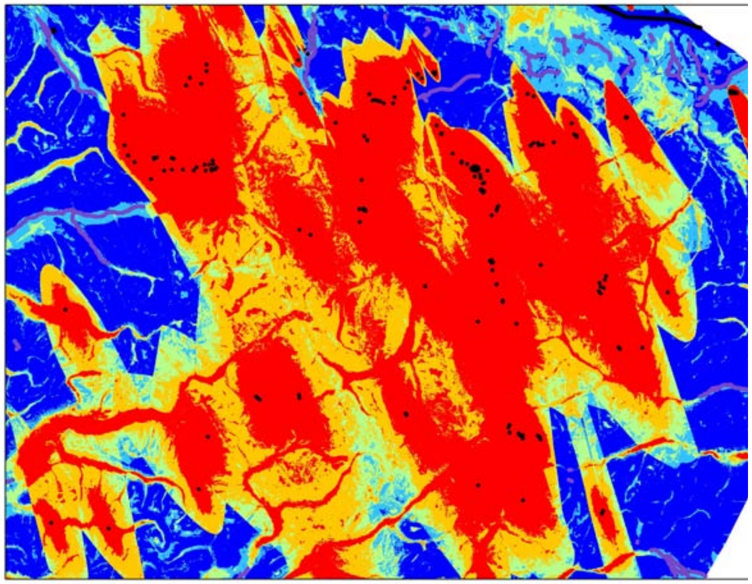


Figure 10. Example with Archaeological Sites (black dots) overlain on the kriged grid (map)

Merging the Bayesian and Kriging Results

Reviewing statewide results from both GIS models (Bayesian scores and kriging estimates) made it clear that each model contained important information that should be merged in the final archaeological prediction model. Bayesian scores tend to generally indicate the most likely terrain for finding archaeological sites, but known archaeological sites can occur in local areas predicted to have low environmental indicators (low Bayesian scores). Conversely, the kriging estimates honor the known data, but the resulting maps tend to over-generalize, perhaps place too much emphasis on the known data, and can be spatially "noisy" as a result of the occasional close proximity of known sites to negative survey sites.

We developed a weighting system to merge the two types of results, initially based on the kriging error (standard deviation) at any given cell. The rationale behind the weighting was that the higher the kriging error, the greater the influence that should be placed on the Bayesian score (and less on the kriged estimate). Furthermore, because of the heavy emphasis placed on archaeologically preferred environments in deriving the Bayesian scores, in most cases such scores probably should outweigh the kriging estimates to appeal to the professional expertise of practicing archaeologists. After reviewing several different weighting systems, we selected a simple procedure that results in a preference for the Bayesian scores (0.25 assigned to kriged values and 0.75 assigned to the Bayesian scores), after first applying the kriging error adjustment.

This merging procedure as applied cell-by-cell is summarized below, using the following defined terms:

Ewt = initial error weight at the cell;
SDk = kriging standard deviation at the cell;
SDkmax = the maximum kriging standard deviation in the entire study area;
Awt = weight assigned to kriged estimate at the cell;
Bwt = weight assigned to Bayesian score at the cell;
Afinal = final archaeological value for the GIS prediction map;
Bval = Bayesian score at the cell;
Kval = kriging estimate at the cell.

Steps completed for each cell:

1. Ewt = SDk/SDkmax
2. Awt = (1 – Ewt) * 0.25
3. Bwt = 1 – Awt
4. Afinal = Kval*Awt + Bval*Bwt

These merging calculations were efficiently conducted within the GIS system for each study area. Clearly, in those areas with large kriging errors, the emphasis on the final predictions is more heavily weighted to-

Merging the Bayesian and kriging results, the model combines environmental information with local information developed by field surveys from archaeologists to identify locations across the state with a range of high, moderate, low and unknown probabilities for discovering an archaeological site.

ward the Bayesian scores. Conversely, in areas with known archaeological information and small kriging errors, the final predictions are more weighted toward the kriged estimates. Figure 11 shows an example of a final predictive map based on GIS merging of Figures 9 and 10.

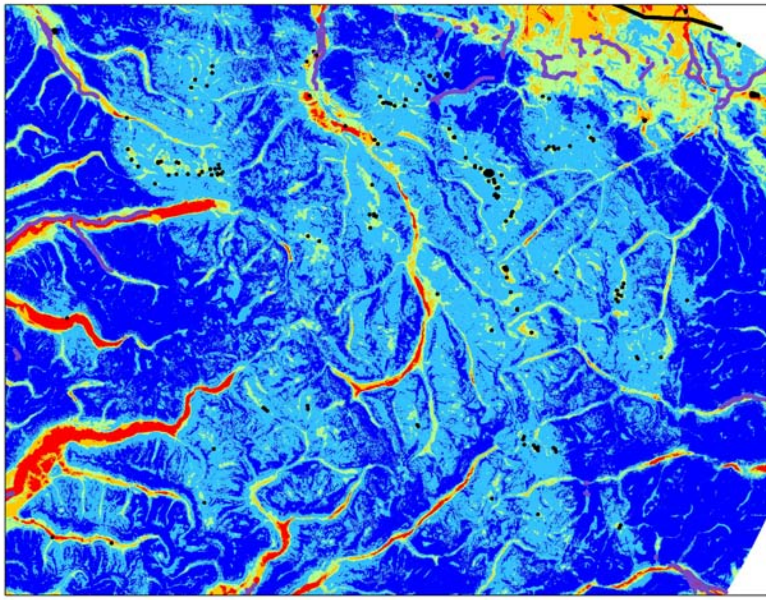


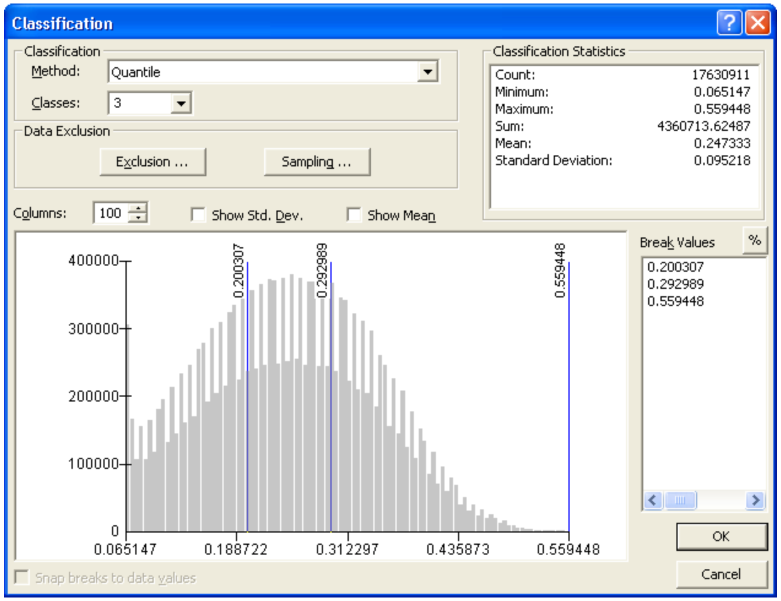
Figure 11. Example with Archaeological Sites (black dots) overlain on a merged grid (map)

Uncertainty in Model Predictions

Having a measure of uncertainty in model predictions is an important aspect of prudent implementation of a predictive model. In the case of this particular archaeological predictive model, the uncertainty (also referred to as lack of confidence) is provided directly by the kriging standard deviation values computed at each cell in the kriging model. The higher the standard deviation, the greater the uncertainty.

The basic premise here is that in areas where we have archaeological survey information, we have greater confidence that those data will inform future field studies in those areas. However, in areas lacking any archaeological information, we have much less confidence in the model predictions and must rely more heavily on environmental indicators. As new field surveys are conducted and new data are obtained, both the Bayesian model and the kriging model can be updated, and confidence levels will increase in those sampled areas.

The kriging standard deviations were classed into three categories (low, moderate and high confidence) using the quantile classification and the computer defaults to assign the category break values in each study area. These groups were established by examining histograms (Figure 12). The classes then were displayed as a GIS map layer that can be imposed over the predictive map layer to provide users with a measure of uncertainty in the model predictions. These uncertainties are not directly included in the results provided to a broader audience, but are expected to be used by DAHP staff during consultations.



Classification

Classification
Method: Quantile
Classes: 3

Classification Statistics
Count: 17630911
Minimum: 0.065147
Maximum: 0.559448
Sum: 4360713.62487
Mean: 0.247333
Standard Deviation: 0.095218

Columns: 100
☐ Show Std. Dev.
☐ Show Mean

Break Values
0.200307
0.292989
0.559448

☐ Snap breaks to data values

Figure 12. Example Histogram for Confidence Calculations, Study Area 1

In the case of this particular archaeological predictive model, the uncertainty (also referred to as lack of confidence) is provided directly by the kriging standard deviation values computed at each cell in the kriging model. The higher the standard deviation, the greater the uncertainty.

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RESULTS

A common question at the conclusion of any modeling effort is: "How well do the results accurately describe what is 'on the ground'?" Part of the challenge of reviewing the results is that archaeological resources are typically hidden below the surface to unknown extents. Even the most robust sampling strategies during surveys could still potentially miss some sites (possibly buried below sampling depths). In addition, the overall size of a model can make the review of the results challenging. The statewide scale of this model covers a very large land area, resulting in the modeling effort being an enormous task. Only two other states, Minnesota and North Carolina, have attempted such large-scale modeling efforts for archaeological resources, so there is limited precedence on which to rely. For review of our results, we used four different techniques: 1) soliciting review by archaeologists to make sure that the results reflect current archaeological opinions about the landscape and environment; 2) evaluating the limitations of the input data; 3) analyzing the results relative to known archaeological sites; and 4) performing a more detailed review of the results relative to specific landform types, soil types and geologic history.

Archaeologists from the Washington Department of Archaeology and Historic Preservation (DAHP), Washington State Department of Natural Resources (DNR), Washington State Department of Transportation (WSDOT), Suquamish Tribe, Yakama Nation, Fort Lewis, Minnesota Department of Transportation and Columbia GeoTechnical, as well as other archaeologists, provided reviews of the predictive modeling results. In all cases, the professional reviews indicated that the results reflected current archaeological opinions about the landscape and environments in Washington State. Once the results are used consistently to review projects (a process that is expected to occur between July 1 and December 31, 2009), then additional results and opinions will be obtained regarding the overall effectiveness and performance of the model. There is a scheduled update for the model in January 2010. To the extent possible, feedback is expected to be incorporated into the update. See the "Future Considerations" section for additional details.

A general overview of the model suggests that many locations where development is concentrated—the highly populated areas—are also some of the most archaeologically sensitive areas of the state, and this is no coincidence. Components of the landscape such as available food and economic resources, geographic landmarks, overland transportation routes and even certain aesthetic considerations may serve universal human needs and interests from prehistoric times through the present day.

We know that the connection between archaeological sites and environmental variables is important and that our model can reasonably use only a handful of these datasets. As more information becomes available, the methodology allows for these data to be included at a future date, but for now, the information is not exhaustive when considering the complex components of prehistoric land use. The data used for the model are considered the best source for a particular type of information (for example, soils from Natural Resources Conservation Service [NRCS]), yet they were not specifically collected in a manner to predict archaeological sites. The model and results are based primarily on the relationship between archaeological sites and a limited number of environmental variables. We add complexity to the model by taking into account the locations of known recorded sites, Government Land Office (GLO) sites and "negative sites" and adjusting the model results. See the "Processing Methods" section for additional details.

As a further review of the results, we compared the locations of known recorded archaeological sites with the five resulting management groups that indicate Very High, High, Moderate, Low and Very Low archaeological potential and were refined for management purposes into the following three categories: (1) and (2) Archaeological Survey Contingent upon Project Parameters, (3) Archaeological Survey Recommended and (4) and (5) Archaeological Survey Required.

We expect that the known sites should generally occur on locations where future surveys will be required. We analyzed the results relative to the known archaeological sites. We used GIS processing to de-

Part of the challenge of reviewing the results is that archaeological resources are typically hidden below the surface to unknown extents.

termine these results and have summarized them in the tables below. Table 1 shows how the known archaeological sites are distributed in the management groups based strictly on the environmental factors (Bayesian). While the model performed well, Table 2 shows that the Bayesian values adjusted with the kriged information increased the percentage of known sites that are within groups 4 and 5 (see the "Processing Methods" section for additional details). Table 2 reflects the model results that will be used during implementation.

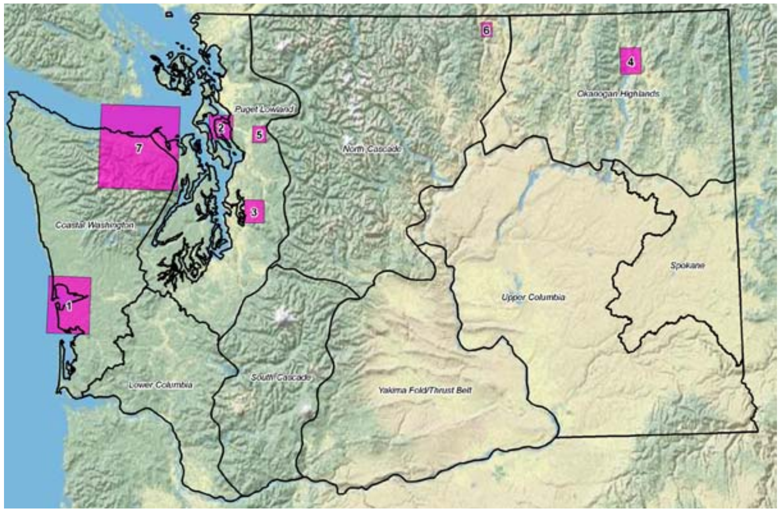
Management Group	Percent of Known Archaeological Sites Occurrence by Management Group
1 and 2 - Survey contingent upon project parameters	5.5
3 - Survey recommended	6.9
4 and 5 - Survey Required	87.6

Table 1. Model Results (Bayesian) compared to the Known Archaeological Sites

Management Group	Percent of Known Archaeological Sites Occurrence by Management Group
1 and 2 - Survey contingent upon project parameters	2.5
3 - Survey recommended	2.5
4 and 5 - Survey Required	95

Table 2. Model Results (Bayesian and Kriging Merged) compared to the Known Archaeological Sites

Our fourth and most comprehensive review of the results included comparisons to specific landform types, soil types and geologic history. Professional archaeological knowledge of the landforms, soil and geology was used to extrapolate where sites would be expected to occur, and then we compared these expectations to the modeling results. We specifically looked at seven locations around the state and in several different study areas to make these comparisons. These included:



1. Vicinity of Grays Harbor
2. Vicinity of Camano Island
3. Vicinity of Lake Sammamish
4. Vicinity of Lake Roosevelt
5. Vicinity of Arlington
6. Vicinity of Palmer Lake
7. Vicinity of Port Angeles

These locations were chosen because of the landforms within the landscapes, professional knowledge of the local geology and environmental factors in these areas, and representation of archaeological sites not currently well documented within the databases used to develop the model in the first place. These sites are typically found on the upper Pleistocene to early Holocene landforms in the landscape. We would consider the model effective if it includes at least some of these areas within the modeling groups that require surveys. The following examples and descriptions demonstrate the effectiveness of the model as well as some limitations.

Results were grouped into three management categories: (1) and (2) Archaeological Survey Contingent upon Project Parameters, (3) Archaeological Survey Recommended and (4) and (5) Archaeological Survey Required.

Vicinity of Grays Harbor

This vicinity was chosen for comparison with the results because of the expectation to find archaeological sites in the upper Pleistocene landforms occurring along the immediate coastline as well as upland landforms in the area (Figure 2). The Chehalis River flows into Grays Harbor and is the first river south of the continental ice sheets that would have provided an inland travel corridor at the close of the Pleistocene period (although the Cowlitz River is also a reasonable candidate for a travel corridor). The Chehalis River has recent sediments and landforms that may contain buried archaeology from the Colonizer Period (dating to about 14,000 years ago). Sites from the Colonizer Period are not common within the archaeological databases used to calibrate the model, yet are very likely to be in this location because of the age of the Pleistocene landforms in the area. The model in this location confirms this expectation of archaeological sites.

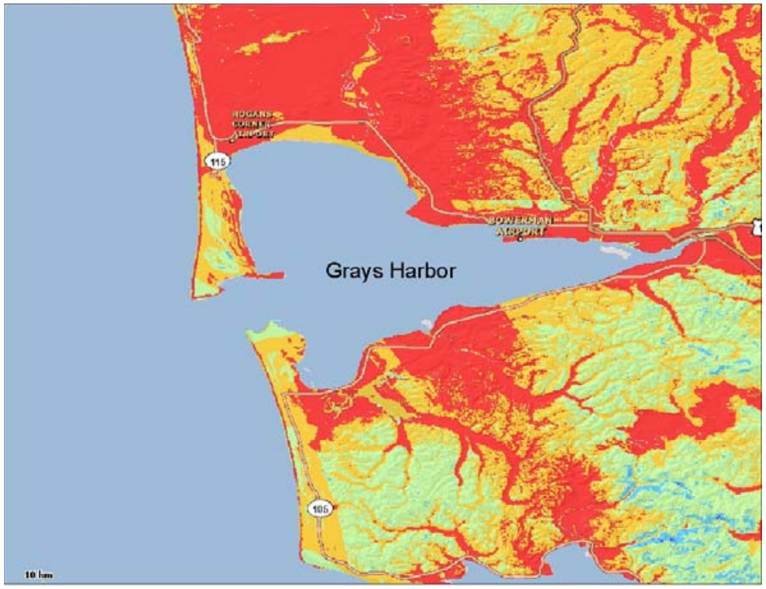


Figure 2. Model Coverage in the Vicinity of Grays Harbor

Vicinity of Camano Island

The Camano Island vicinity provides an interesting test of the effectiveness of the archaeological model. This area has numerous paleoshorelines dating from the upper Pleistocene (also known as beach strandlines and high beaches), which would have been a feature on the landscape 11,000 to 12,000 years ago. We digitized these beach strandlines from Light Detection and Ranging (LiDAR) imaging and compared them to the results of the model (Figure 3). These beach strandlines act as a topographic boundary in the landscape. Surface landscape elements that lie at a lower topographic elevation than the strand lines are younger in age. Those landscape elements that are located at higher relative topographic elevations than the strandlines have the potential to include upper Pleistocene archaeological sites. In comparison with the model, the paleoshorelines, as indicated by the strandlines, are captured within the highest probability areas indicated in Figure 3.

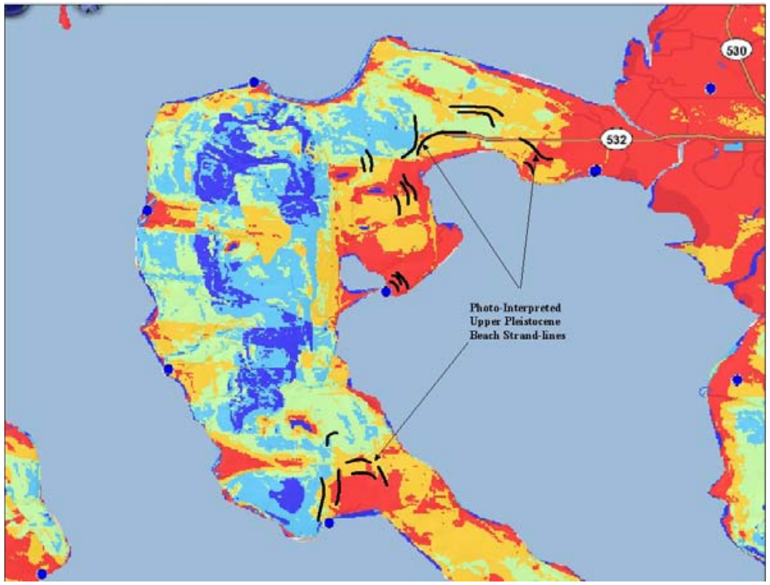


Figure 3. Model Coverage in the Vicinity of Camano Island

Vicinity of Lake Sammamish

The Lake Sammamish area provides another example of the model confirming the high probability of archaeological sites along paleo-shorelines. Archaeological sites would be expected in this location because it contained a glacial lake that existed during the Colonizer Period (though significantly larger than present-day shorelines indicate, as illustrated in Figure 4). Pleistocene landforms in the uplands surrounding the paleolake would also be areas where we would expect Colonizer Period sites. In these locations, the model does not perform quite as well. These areas are indicated in the model as low potential for discovering archaeological sites (and therefore surveys are required only when certain project parameters exist), despite landform and geologic contexts to the contrary. We expect that more rigorous surveying methods, which include a subsurface component, will document these areas as containing archaeological sites in the future and that these types of locations will be better integrated as the model is updated. Similar results where archaeological sites are occurring on areas of low potential within the model also reinforce the need to use other tools and information when determining whether or not surveys should be performed. See the "Implementation" and "Future Considerations" sections for additional details.

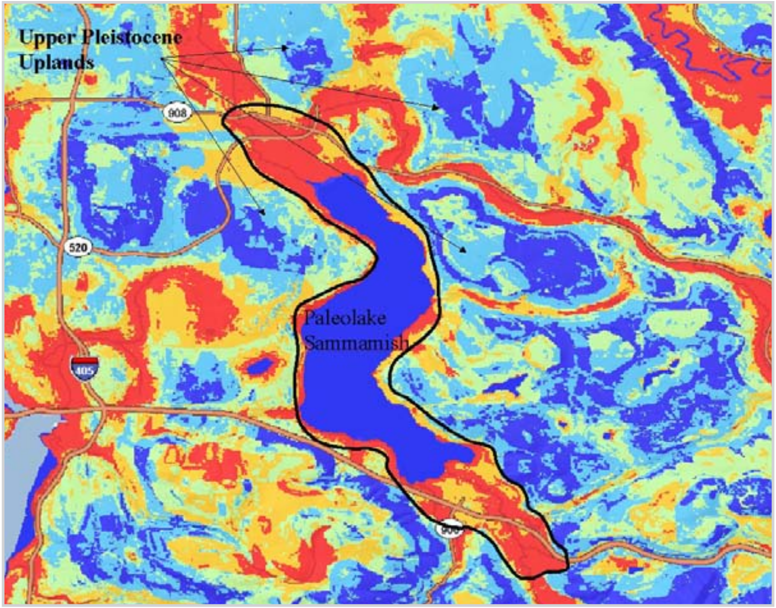


Figure 4. Model Coverage in the Vicinity of Lake Sammamish

Vicinity of Lake Roosevelt

This vicinity location is also characterized in the landscape by upper Pleistocene terraces adjacent to the river valleys as well as alluvial landforms at the bottom of the lake and surrounding rivers. The model indicates that the alluvial areas and the adjacent landforms are within the management groups that would trigger a survey (Figure 5). In this case, the model reflects the professional knowledge of these locations and confirms the benefits of using the model.

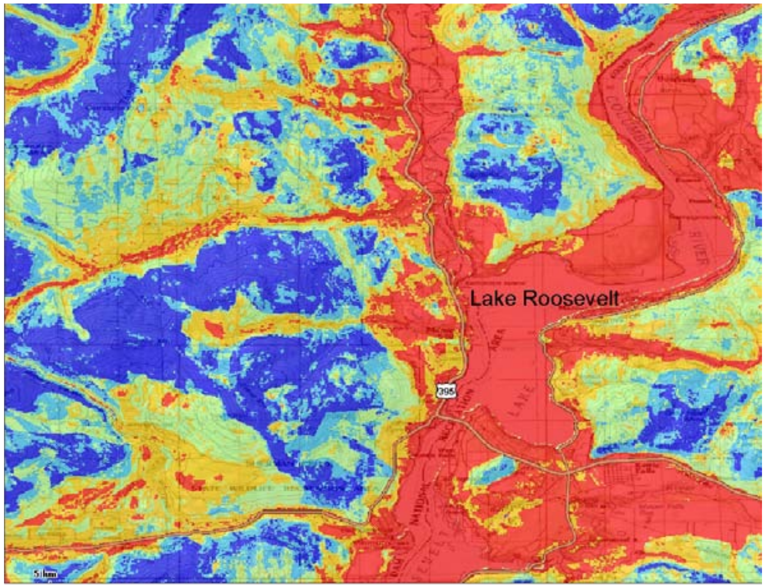


Figure 5. Model Coverage in the Vicinity of Lake Roosevelt

Vicinity of Arlington

The Arlington vicinity contains several different landforms dating from early Holocene to upper Pleistocene. Middle to late Holocene landforms are located on the valley bottoms within this watershed and have related archaeological sites. These sites are well represented within the databases used to calibrate the model. High valley terrace landform types located within this general area date from the upper Pleistocene to early Holocene periods. Theses landforms occurred during the iostatic rebound of the underlying glacial sediments and are located hundreds of feet above the valley floor. The model results indicate that relevant geomorphic surfaces from upper Pleistocene through late Holocene in age are included within the group where surveys will be required (Figure 6).

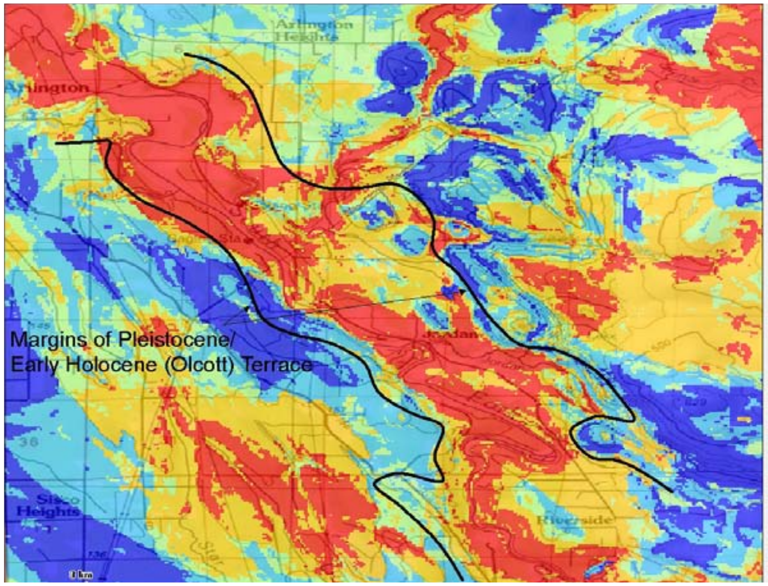


Figure 6. Model Coverage in the Vicinity of Arlington

Vicinity of Palmer Lake

The Palmer Lake area in the North Cascades is characterized by a glacial paleolake. The landscape contains numerous middle to late Holocene sites along the valley bottom. The model appears to do a good job capturing the entire range of time represented since the end of the Pleistocene period (Figure 7).

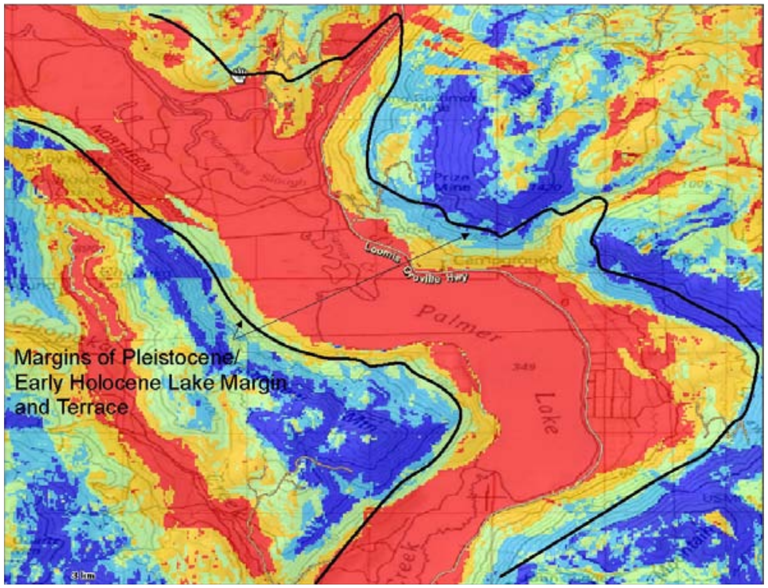


Figure 7. Model Coverage in the Vicinity of Palmer Lake

Vicinity of Port Angeles

The area around Port Angeles is an interesting example where the archaeological sites along the alluvial drainages are shown as high potential areas that meet the management requirement for surveys, yet others in a similar landform and geologic context are in lower potential areas where surveys may or may not be required (Figure 8). These results indicate that although the model is a good planning tool and is able to prioritize the landscape for surveying, it is not a replacement for archaeological consultations. These results may also indicate that the survey methods did not include sufficient subsurface methods and that other sites exist in buried contexts, but are not recorded in the databases and therefore not used to calibrate the model. Future work on the model and within these areas should help to improve the model performance.

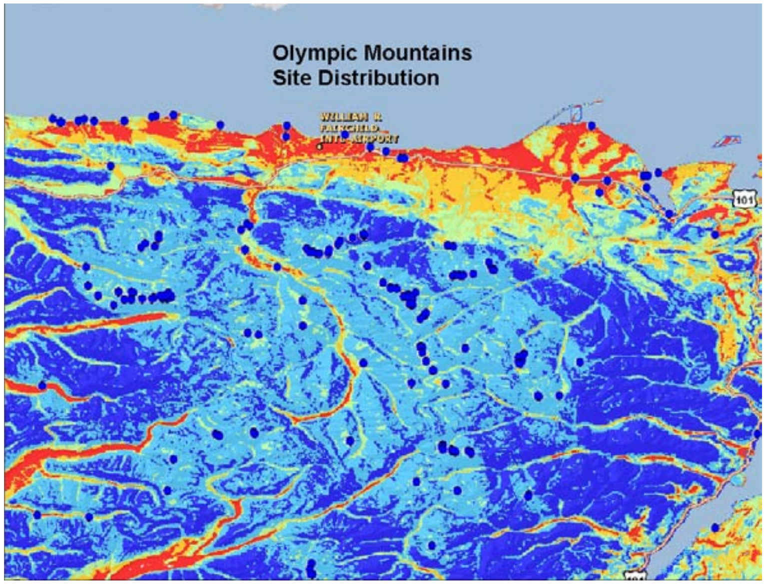


Figure 8. Model Coverage in the Vicinity of Port Angeles

SUMMARY

The Washington State archaeological predictive model was created to accurately predict areas with a relatively high potential to contain archaeological sites. Although the model is particularly well suited for identifying archaeological site locations that span the past several thousand years, in most cases its effectiveness extends throughout the known occupation of Washington State, approximately the past 14,000 years.

There is still more to learn about applying the model across the state, and it may take some time in applying the methods to realistically understand the results and how well they reflect on-the-ground information (see the "Implementation" section for additional details and discussions). The challenge in verifying this model includes the sheer size of the land area being modeled and the difficulty in predicting any resources that are below the surface and of unknown extent. We have taken reasonable steps to obtain professional archaeological reviews of the results, discussed limitations of the data, compared results to what is currently recorded about archaeological sites and performed a detailed review of the results relative to specific landform types expected to contain archaeological resources. We expect improvements to occur in the model over time and that the model can be used as an effective planning tool.

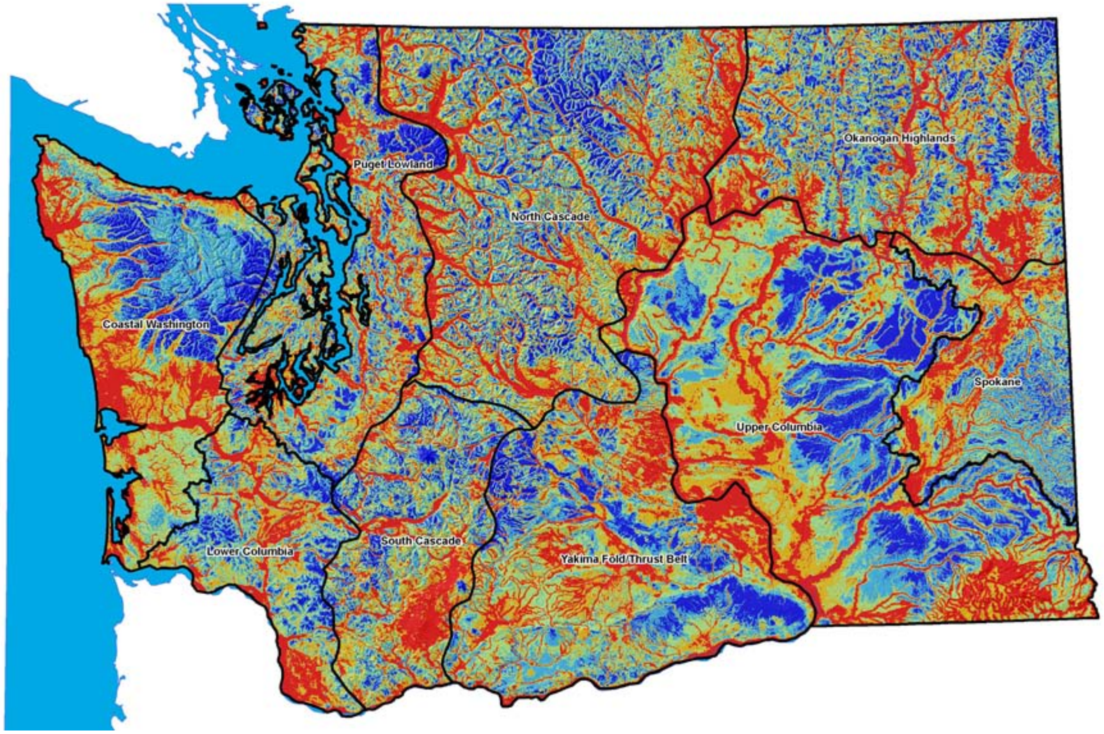


Figure 9. Statewide results

Implementation of the Model

The Washington State archaeological predictive model was created to accurately predict areas with a relatively high potential to contain archaeological sites. Although the model is particularly well suited for identifying archaeological site locations that span the past several thousand years, in most cases its effectiveness extends throughout the known occupation of Washington State, approximately the past 14,000 years. Because of the initial performance of the model, we believe that implementation of the model will be very useful in protecting archaeological resources within the state.

The model categorizes the results into five management groups that indicate Very High (5), High (4), Moderate (3), Low (2) and Very Low (1) archaeological potential and were refined for management purposes into the following three categories:

- Groups 1 and 2: Archaeological Survey Contingent upon Project Parameters (represented by dark blue and light blue in the graphics below),
- Group 3: Archaeological Survey Recommended (represented by light green in the graphics below), and
- Groups 4 and 5: Archaeological Survey Required (represented by orange and red in the graphics below).

These groups form the basis for implementation of the model.

The model is intended to be used as a planning tool and not a replacement for professional archaeological opinions. Not all scenarios will be fully covered by the model, and there are always exceptions to any rule. We anticipate the model being used by project managers, planners and reviewers to determine which development projects are located within groups 3, 4 and 5 and require surveys prior to development. Professional archaeologists and cultural resources contractors may use the model to augment their intuitive understanding of archaeological site locations. In order for the model to be effective for planning purposes, it is important for users to apply the model during the earliest phases of planning and design. The model should be used as part of the environmental, critical area, cultural resource and other pre-project review processes. In all cases, the model will provide an objective means of analyzing land surface area within Washington State and the potential for a given location to contain either surficial or buried archaeological resources.

One important caveat regarding the reliability of the model to address the breadth of cultural resource issues is related to Traditional Cultural Properties (TCPs), a specific type of cultural resource that differs from archaeological sites. Although some archaeological sites are TCPs, not all TCPs are archaeological in nature. Many important places exist on the landscape with little to no tangible evidence of their cultural importance (for example, vision quest locations or places that are associated with creation mythologies). Stories about these important places have been passed down through generations of Native American people, and in many cases these stories are the only source of this information. Although the archaeological model will provide a clear understanding of the potential location of archaeological sites, land and project managers, consultants and local and county planners should make every effort to ensure that adequate consultation with Native American people and local communities takes place before a project is permitted or otherwise moves forward.

To ensure that the effects of our on-going development needs do not inadvertently affect cultural resources across Washington State, the following guidelines are presented for interpreting and applying the archaeological predictive model.

Groups 4 and 5 – Archaeological Survey Required

Groups 4 (orange) and 5 (red) indicate that the potential for encountering archaeological sites within the footprint of the proposed action is high to very high (Figure 1). An archaeological survey is required by the Department of Archaeology and Historic Preservation (DAHP) prior to permitting or moving forward with a proposed action. The archaeological survey is required to conform to Washington State Standards for Cultural Resource Survey Reporting, published at: http://www.dahp.wa.gov/pages/Documents/documents/ExternalFINAL_000.pdf

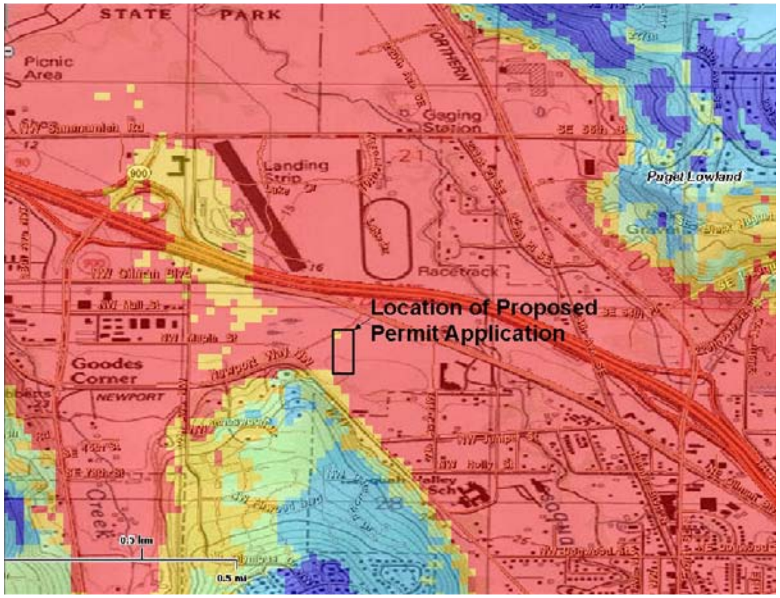


Figure 1. Example of a project located within groups 4 and 5 – Archaeological Survey Required. Proposed project area is outlined in black and falls in the red and small portion of the orange area. This project requires an archaeological survey.

Projects falling within areas of the landscape that are colored red (Group 5) or orange (Group 4) should be considered the most archaeologically sensitive portions of the landscape. These are areas with a high potential for identifying archaeological sites during the course of development, based on the proximity of known archaeological resources and environmental variables with known correlation to archaeological sites. Many recorded archaeological sites exist in the red and orange zones, and the likelihood for affecting one or more recorded cultural resources is very high. Within this zone, planners, developers and project managers need to carefully consider the nature, scope and scale of each project to assess the potential effect on archaeological resources. Every project within this zone has the potential to impact these sites and any sites that may lie buried, undiscovered.

Group 3 – Archaeological Survey recommended

Group 3 (light green) indicates that the potential for encountering archaeological sites within the project footprint is moderate (Figure 2). An archaeological survey is recommended prior to permitting or moving forward with a proposed action.

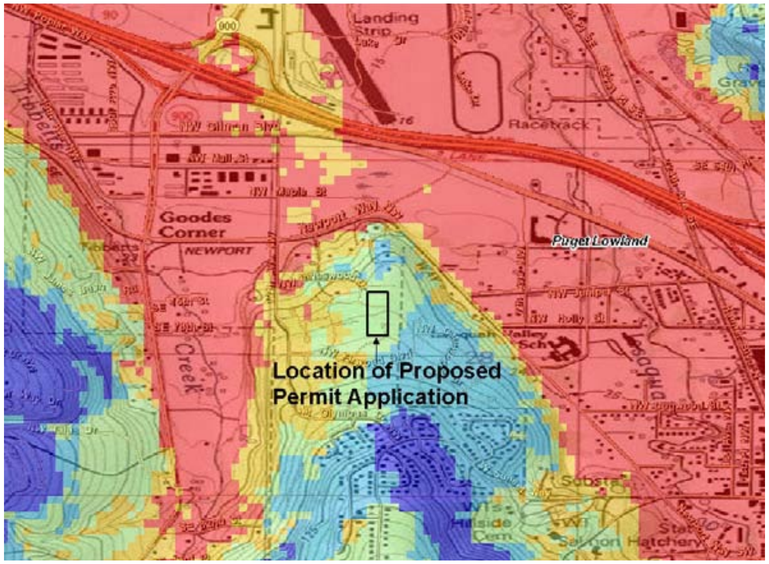


Figure 2. Example of a project located within group 3 – Archaeological Survey Recommended. The proposed project area is outlined in black and falls within the light green area. An archaeological survey is recommended for this project.

Groups 1 and 2 – Archaeological Survey Contingent upon Project Parameters

Groups 1 and 2 (light blue and dark blue) indicate that an archaeological survey should be considered based upon project design parameters (Figure 3). In general, if the proposed action has the potential to disturb more than 10,000 square feet or has a significant ground disturbing or subsurface component, an archaeological survey is recommended.

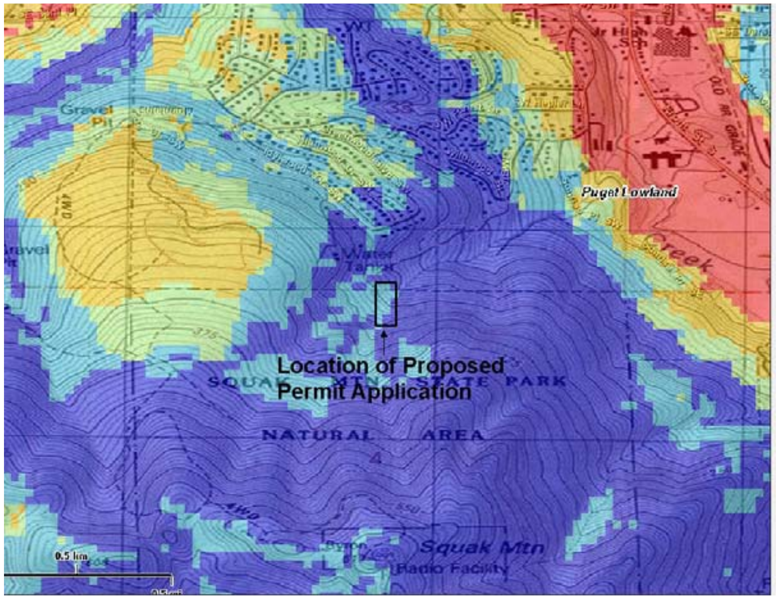


Figure 3. Example of a project located within groups 1 and 2 – Archaeological Survey Contingent upon Project Parameters. The proposed project area is outlined in black and falls within the light blue and dark blue areas. Depending on the project parameters, an archaeological survey may or may not be required or recommended.

Multiple Groups

In areas where a development proposal or project falls within more than one of the above categories, the survey requirement will generally be governed by the highest category (Figure 4). The footprint and overall project parameters will play an important role in determining whether or not a survey is required or recommended. In these cases, when the survey requirements are not as clear, we recommend that the project proponent or permitting agency discuss the project with DAHP to determine the most appropriate action at the project location. It may be possible to survey portions of the project location at an increased level in the red areas and less in the blue areas, though some level of survey should be expected across the site. For planning purposes, the area should defer to the most protective management group and possibly refined as the project moves forward.

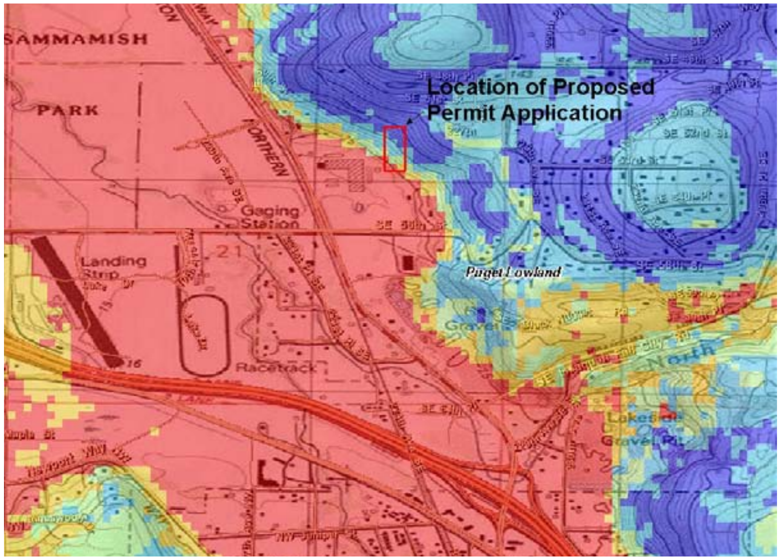


Figure 4. Example of a "mixed-zone" project located within several groups. The proposed project area is outlined in black and falls within the red, orange, light green, light blue and dark blue areas. For planning purposes, a survey will be required. Depending on the project parameters, survey methods or density may be different across the site. Consult DAHP when the predominant management groups are unclear.

Future Considerations

We took great care in developing this model so that it can provide a meaningful tool for planners and archaeologists, is repeatable for future use and can be improved over time. This model should be considered dynamic, with improvements integrated during updates as budget and time allow. We have organized the future considerations into three categories: updates to the model, survey quality and statistical enhancements.

Updates to the Model

- Update to the model on a regular basis – This predictive model should be considered dynamic and should be updated when data updates are made available. We recommend that an update be completed approximately every two years. A time frame of two years should be frequent enough to keep the model fresh and also allow enough new cultural resource data to be collected to make an update worthwhile.
- As updated datasets (such as soils) are available, we recommend including these data in model updates. In addition, as new datasets that are considered important from an archaeological discovery standpoint (such as vegetation cover) become available statewide, we may want to incorporate the data into the model updates.

Survey Quality

- Improvements to the databases – The "negative site" information (that is, sites that were surveyed but no archeological resources discovered) is critical to the development of the model. Currently, all negative site information is considered the same in the model. In the future, distinguishing those surveys with a subsurface component from those without would be useful for calibrating the model. Hence, we recommend incorporating a field in the cultural resources survey reports database to capture information on survey methods, particularly those with a subsurface component. This information could eventually be used to improve that portion of the model in future updates.
- Review field methodologies – DAHP has implemented exceedingly high data reporting standards and does an excellent job of monitoring the work products of professional archaeologists to ensure conformance to the standards. Surveys form the backbone of the model, whether by identifying additional cultural resources or by identifying areas without resources. Because this information is so important, DAHP may want to consider an effort to standardize field methodologies or have recommendations for surveying. This improvement will have tremendous bearing on the effectiveness of the model into the future.
- Subsurface sampling – Related to the notion of reviewing field methodologies, subsurface sampling during surveys is an important component to accurately determine whether an area contains an archaeological site. Educational materials related to geosols, paleosols and stratigraphic units would aid in the identification and interpretation of buried archaeological deposits. Subsurface sampling is a potentially under-utilized archaeological tool, and improvements in data collection and identification would eventually lead to better protection of subsurface resources in the model. See "Appendix – Subsurface Sampling" for additional discussion on this topic.

This model should be considered dynamic.

Statistical Enhancements

This archaeological predictive model was developed using statistical methods to merge Bayesian statistics and kriging estimation. During the course of this project, we tried several different options for merging the data and chose the method to merge the Bayesian and kriging results that reflected archaeologists' view of the landscape, based on what we know today. Future statistical enhancements to the model could incorporate one of the following methods to continue to improve the results.

- Indicator kriging – This method would require the computation and modeling of several variograms (one for each category, such as known archaeological sites and features derived from Government Land Office [GLO] maps like Indian sites, trails and trail intersections), including one for the Bayesian rank scores, then multiple kriging operations to predict the archaeological probability at each cell. A possible simplification of this type of kriging would be to focus on just co-kriging the Bayesian scores together with the known archaeological site information in one co-kriging calculation. Implementation of this method will require advances in GIS computational processing speed and hardware processing speeds in order to be practical.
- Kriging with exhaustive secondary information – This method of kriging incorporates the known archaeological information and the Bayesian scores in a single kriging calculation. Its capability to "internally merge" the Bayesian and kriging results would be potentially useful for the model results. We reviewed this option during this project, but implementation of this method will require advances in GIS computational processing speed and hardware processing speeds in order to be practical.
- Enhanced Bayesian model – Forgo the kriging process altogether and instead incorporate the proximity concept into the Bayesian environmental model. Using this method, the "distance to a known archaeological site" and the "distance to a mapped Indian site" would become two new environmental factors in the Bayesian computations. If this new Bayesian model shows promise, then we could also look at including the trail and trail intersection information. The fundamental Bayesian formula remains the same, so this key portion of the predictive model continues to serve as a consistent engine to process the new input information.

Appendix

Click on the title to go directly to each section

Deliverables

Mathematical Description of Kriging

Subsurface Sampling

Software Compatibility

FAQs

Presentation Schedule

Deliverables

The following was provided to the Department of Archaeology and Historic Preservation on an external hard drive in support of the Washington Archaeology Statewide Predictive Model:

- **Elevation** - ESRI Grid and Metadata
- **Slope Percent** - ESRI Grid and Metadata
- **Aspect** - ESRI Grid and Metadata
- **Distance to Water** - ESRI Grid and Metadata
- **Geology** - ESRI Grid and Metadata
- **Soils** – ESRI Grid and Metadata
- **Landforms** - ESRI Grid and Metadata
- **Government Land Office Maps (GLOs)** –
  - Digitized Features (Indian sites, trails, springs),
  - Original Georeferenced Images (non-seamless) and Metadata and
  - Seamless Georeferenced Images and Metadata
- **Model Results Layer** - ESRI Grid and Metadata
- **Confidence Results Layer** - ESRI Grid and Metadata
- **PDF** - Washington Archaeology Statewide Predictive Model Report

Mathematical Description of Kriging

The kriging system of equations to be solved in order to find the kriging weights (based on *n* neighbors) is given by:

$$\sum_{j=1}^{n} a_j C_j + \lambda = C_{0i} \quad \text{for i = 1, 2, ... n}$$

$$\sum_{j=1}^{n} a_j = 1$$

where: C_{ij} = covariance between neighborhood points;

C_{oi} = covariance between the estimation point and the neighborhood points;

a_j = weight assigned to the j-th neighborhood point (all weights sum to 1.0);

λ = Lagrange term needed to invoke the condition that weights sum to 1.0.

In matrix notation, this kriging system of equations is expressed as:

$$\begin{bmatrix} C_{11} & C_{12} & \cdots & C_{1n} & 1 \\ C_{21} & C_{22} & \cdots & C_{2n} & 1 \\ \vdots & \vdots & \ddots & \vdots & 1 \\ C_{n1} & C_{n2} & \cdots & C_{nn} & 1 \\ 1 & 1 & 1 & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \\ \lambda \end{bmatrix} = \begin{bmatrix} C_{01} \\ C_{02} \\ \vdots \\ C_{0n} \\ 1 \end{bmatrix}$$

$$\mathbf{CA} = \mathbf{C_{0i}}$$

We solve for the weights by using a matrix inverse: $\mathbf{A} = \mathbf{C}^{-1}\mathbf{C_{oi}}$

Kriging also provides an estimate of the "prediction error" (or estimation error) through the term known as the "estimation variance". The prediction error also is known as the "kriging variance", which is given by:

$$\sigma_K^2 = s^2 - \sum_{i}^{n} \hat{a}_i C_{0i} - \hat{\lambda}$$

where: s^2 = sample variance of the data set.

The kriging standard deviation (s.d.), which often is useful for map displays, is equal to the square root of the kriging variance, or

$\sigma_K = \sqrt{\sigma_K^2}$. This kriging s.d. will have the same measurement units as the data.

Finally, the estimated value at the kriging point is obtained by calculating the weighted average of the n data in the neighborhood:

$$\hat{V}_e = \sum_{i=1}^{n} \hat{a}_i x(u_i)$$

For our case, this kriged estimate will be a predicted value of archaeology score, which ranges from 0 (no archaeology discovery) to 1 (confirmed archaeology discovery). Thus, scattered values of archaeology values can be used to "fill in the grid" and provide estimates at a fine grid across the study area.

The kriging weights are based on spatial dependence patterns in the study area, including: 1) the spatial covariance between the estimation location and each of the nearby data; and 2) the spatial covariance between pairs of the nearby data (this allows us to deal with data redundancy; i.e., more than one data value in close proximity within the neighborhood).

A map of kriged estimates can be produced, as well as a map of the kriging s.d. values, which provide a measure of uncertainty in regards to the estimation map. High kriging s.d. values can result from one or both of the following conditions, which add to our uncertainty in the kriged estimates:

1. Lack of known data located near the estimation point (kriging point);
2. Adequate data near the estimation point, but that data is very irregular (in our case, this means that the local archaeology data is a mix of closely spaced 0's and 1's).

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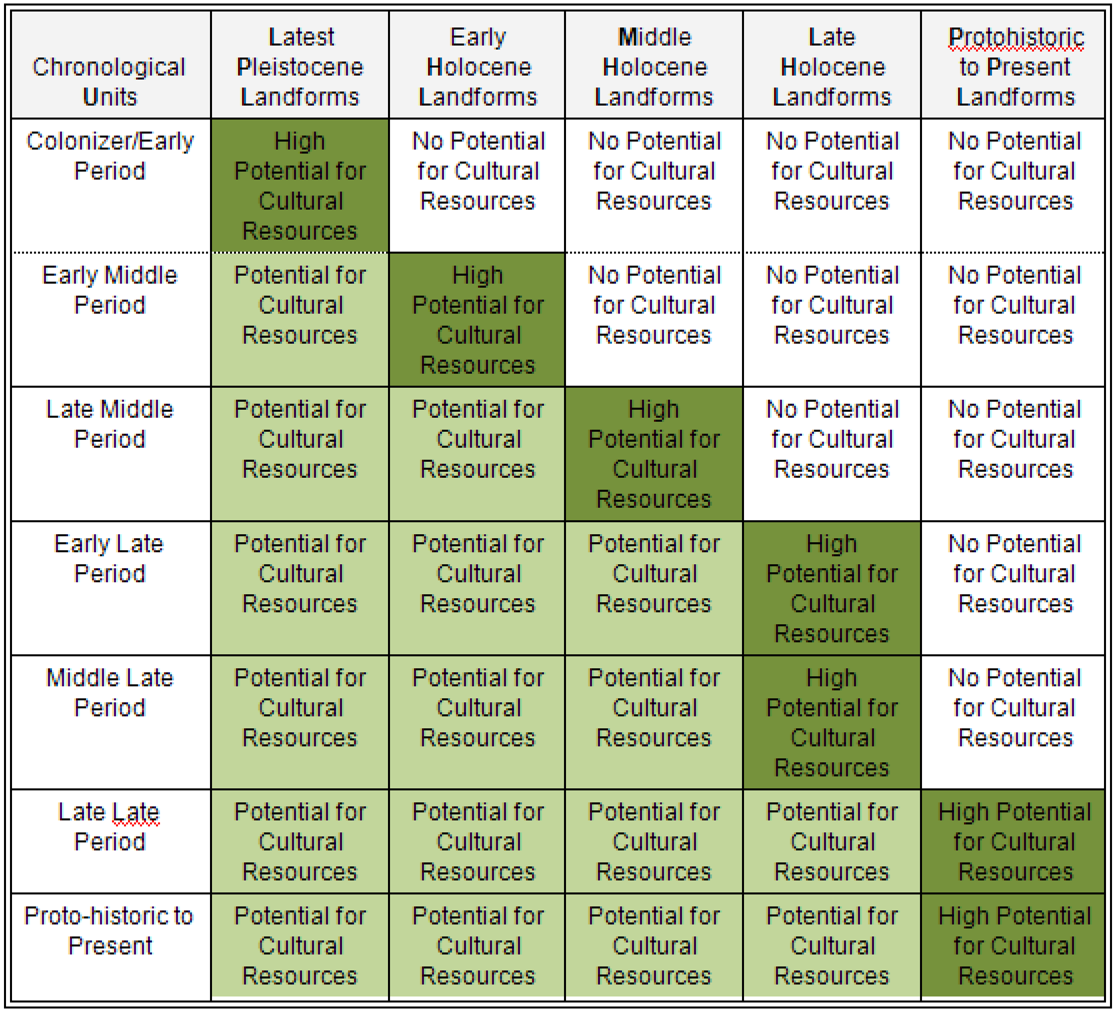
Subsurface Sampling

Relationship of Landform and Geologic Context to Archaeological Site Potential

Subsurface sampling during archaeological surveys is an important component for accurately determining whether the area contains an archaeological site. Landforms and geologic context provide information that can be helpful in identifying sites. This appendix provides information on understanding these contexts and the importance of using the subsurface clues to discover archaeological sites, particularly those from the Colonizer period. The following table summarizes the relationships among significant periods of time for human land use in Washington and the landform ages that these archaeological sites are likely to be discovered on.



Chronological Units	Latest Pleistocene Landforms	Early Holocene Landforms	Middle Holocene Landforms	Late Holocene Landforms	Protohistoric to Present Landforms
Colonizer/Early Period	High Potential for Cultural Resources	No Potential for Cultural Resources	No Potential for Cultural Resources	No Potential for Cultural Resources	No Potential for Cultural Resources
Early Middle Period	Potential for Cultural Resources	High Potential for Cultural Resources	No Potential for Cultural Resources	No Potential for Cultural Resources	No Potential for Cultural Resources
Late Middle Period	Potential for Cultural Resources	Potential for Cultural Resources	High Potential for Cultural Resources	No Potential for Cultural Resources	No Potential for Cultural Resources
Early Late Period	Potential for Cultural Resources	Potential for Cultural Resources	Potential for Cultural Resources	High Potential for Cultural Resources	No Potential for Cultural Resources
Middle Late Period	Potential for Cultural Resources	Potential for Cultural Resources	Potential for Cultural Resources	High Potential for Cultural Resources	No Potential for Cultural Resources
Late Late Period	Potential for Cultural Resources	Potential for Cultural Resources	Potential for Cultural Resources	Potential for Cultural Resources	High Potential for Cultural Resources
Proto-historic to Present	Potential for Cultural Resources	Potential for Cultural Resources	Potential for Cultural Resources	Potential for Cultural Resources	High Potential for Cultural Resources

Table 1. Relationship of Recognized Cultural Chronological Units to Cultural Resource Probability Based on Landform Age

As you can see from the table, the potential for discovering cultural resources has a relationship to landforms and their relative ages. For this reason, simple geologic principles help archaeologists understand the differences in these areas to find archaeological sites. It is for this reason that a subsurface component to archaeological surveys is important to fully identify cultural resources. The trick is to be able to recognize buried landforms during subsurface surveys. For full discussions of these principles, please refer to the references included at the end of this section. One of the most important features (namely, Geosols) to understand and recognize during subsurface sampling in Washington is summarized below.

GEOSOLS: THE COMMON DENOMINATOR OF ALL LANDSCAPES

Soils formed across Washington State during the course of three relatively broad periods of deposition and were primarily due to climatic change since the close of the Pleistocene period. The climatic change has resulted in episodic depositional events followed by relatively long periods of landform stability. Soils formed this way are now buried, and archaeological material is commonly found in association with these locations. The discovery of buried archaeological sites is made possible, in part, by our ability to identify these buried soil surfaces, which are present in all depositional environments across Washington State. The National Resources Conservation Service Soil database (SSURGO) is an easily obtainable source of information regarding soil associations in Washington. We used this data in development of the Washington Archaeological Predictive Model. It can also be used to help identify these buried archaeological resources.

Within the landforms and soil associations are often buried time-stratigraphic markers such as volcanic ash or clean, mineral sands. These materials can be used to help determine the relative age of archaeological deposits across Washington State. Stratigraphic markers essentially bookmark buried soils that represent former ground surfaces stable enough for a significant duration and developed recognizable soil properties. The buried soils or geosols were exposed for a relatively long period of time as surficial materials. Because of this, they have the highest probability for containing buried and preserved archaeological sites.

Three significant regional buried geosols have recently been defined and are significant to subsurface surveying in that they exist in nearly every depositional environment across Washington. They are time- and rock- based stratigraphic units which also makes them identifiable during subsurface exploration. Two of these soils, the Bishop and Badger Mountain Geosols, date to the Colonizer period—generally, the upper Pleistocene to the earliest Holocene, when the initial colonizers of the Pacific Northwest landscape arrived here. These Geosols have the highest probability for containing Colonizer period archaeological sites. The third Geosol, the Willow Lake Geosol, is a middle to late Holocene soil. These stratigraphic units, are significant to the identification and interpretation of buried archaeological deposits. Summaries of the Geosols are presented below.

Bishop Geosol

The Bishop Geosol is a latest Pleistocene age soil (See Table 1 above) that is present from western Idaho to the Washington coast. The Bishop Geosol is often characterized by well-developed soil horizons referred to as the A horizon and relatively thin Cambic (Bw) or Argillic (Bt) horizons (Figure 1 and 2). The age of this soil can be determined because it is constrained by its relative position between two tephras (that is the air borne material from volcanic explosions) in the soil profile. In this case, between the Mt. St. Helens tephra and the Glacier Peak tephra.

The Bishop Geosol was first recognized at the David Bishop Ranch, on the Babcock Bench in Grant County. The Bishop Ranch lies on a structural bedrock bench capped by Pleistocene landforms. In weathered conditions of the soil profile, these can be difficult to identify, but fresh cuts in the soil profile can help identify the subtle changes that occurred. The relative stratigraphic position of the Bishop Geosol helps in understanding the age of the geosol/paleosol and thus the potential for archaeological sites to be discovered.

Badger Mountain Geosol

The age of the Badger Mountain Geosol can be estimated based on the stratigraphic markers of tephra and direct radiocarbon dates on charcoal. The Bishop and Badger Mountain Geosols are often associated together, but separated by stratigraphic markers of wind deposited glacier material. These deposits generally correspond with the Younger Dryas cooling episode which marked the end of the last major climate reorganization during the deglaciation period of Washington.

The Badger Mountain Geosol has the stratigraphic markers of the Glacier Peak tephra (important in the Bishop Geosol identification) and the Mazama tephra (the volcano whose caldera now holds Crater Lake in Oregon). It is characterized by multiple, stacked, buried soil horizons. In arid portions of Washington (for example the Yakima Thrust/Fold Study Area), the Badger Mountain Geosol includes prominent stratigraphic markers and characteristics that allow for identification. In every instance where Mazama tephra is present, the Badger Mountain paleosol immediately underlies the tephra. The Badger Mountain Geosol is therefore important for discovering buried archaeological sites during subsurface surveying.

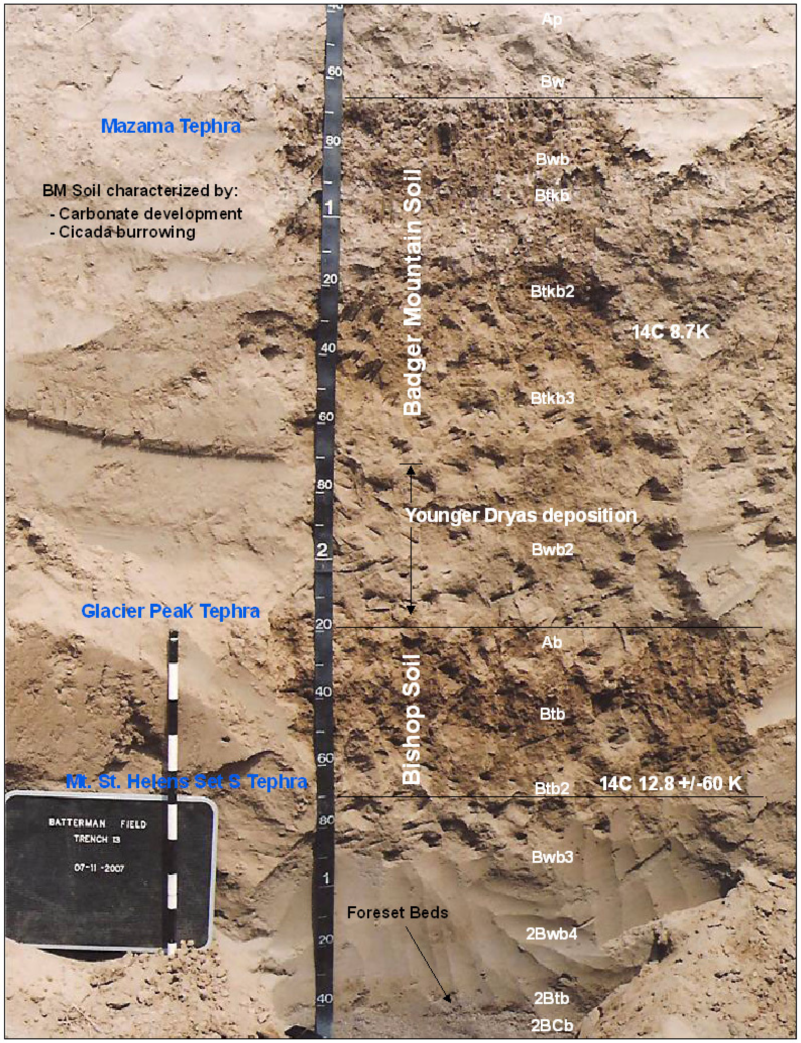


Figure 1. Typical exposure of Bishop and Badger Mountain Geosols, Upper Columbia Study Area

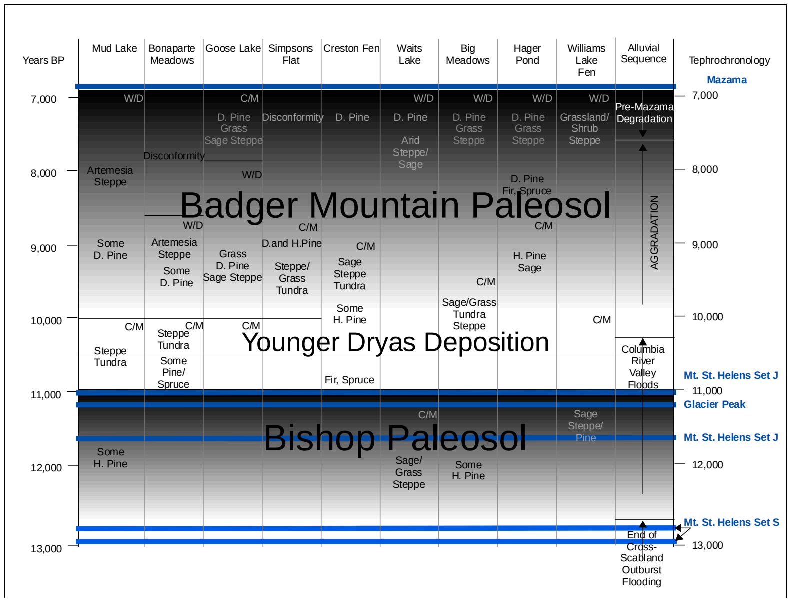


Figure 2. Stratigraphic and Paleoecologic Correlation Chart Displaying the Relationship Between Palynologic Reconstruction, Outburst Flood and Alluvial Chronologies, Tephrochronology and Pedology of the Yakima Fold and Thrust Belt, Upper Columbia, Okanogan Highlands, Spokane and Northern Cascades subregions.

Willow Lake Geosol

Stratigraphically, the Willow Lake Geosol can be identified because it overlays the Mazama tephra. There is a gradual decrease in tephra closer to the surface. This Geosol is important in the identification of subsurface archaeological sites, however, it can be quite complex. A full description of identification can be found in the references below.

These Geosols provide critical context to aid in the identification and interpretation of archaeological sites across Washington State. Recognition of the soils is a critical part of the identification process and only possible during subsurface surveys. Subsurface sampling protocols should adopt and expand the methods to include this stratigraphic scheme so that deep archaeological horizons are not overlooked during the cultural resource inventory process.

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Lenz, Brett R., 2009, Archaeological Geology of the Initial Colonization of the Pacific Northwest Region, USA.: Unpublished Doctoral Dissertation, Department of Archaeology and Ancient History, University of Leicester, UK.

Software Compatibility

The following lists the software used in Washington Archaeology Statewide Predictive Model generation:

- ArcGIS Desktop 9.3
- ArcGIS Spatial Analyst
- ArcSDE 9.3
- ESRI Model Builder
- SQL Server 2008 SP1
- Windows 2008 Server
- Microsoft Visual Studio .NET 2005
- Microsoft SQL Server 2008
- Python 2.5
- Surfer 8

Frequently Asked Questions

What are Cultural Resources?

The term "cultural resources" covers a variety of things. It includes both tangible resources—those items and features of the landscape that are recognizable by most people—and less tangible resources including Indian Traditional Cultural Properties and Sacred Sites. Tangible cultural resources that are familiar to most people are archaeological sites—places where people lived at some point in the past where they left behind some physical evidence of their stay (artifacts). Archaeologists use artifacts to explain how people used a location, the duration it was used and how the site fits into the context of other known resources. Archaeologists divide archaeological sites into two broad types based on time: prehistoric archaeological sites (>12,000-500 years old), which are sites that date to the period prior to the arrival of Europeans in North America, and historic archaeological sites (500 to 50 years old).

Prehistoric artifacts include pieces of stone or bone that are shaped into tools, or that are the byproduct of butchering, consumption and toolmaking; in very rare instances, prehistoric artifacts may also include wood, basketry and other perishable materials that have survived in a protected environment such as a cave or rockshelter. Within Washington State, we have evidence of some of the oldest habitation and use areas in North and South America, spanning at least the past 12,000 years or more. Specific sites in Wenatchee, Lind, Sequim and Kennewick are internationally significant and have recently been the focus of scientific and popular media from National Geographic Magazine to the Discovery Channel.

Historic archaeological sites include artifacts that are relatively easy for most people to identify. Historic artifacts are often rusty, decayed or broken, and may include a range or items from horseshoes to combs to broken, colored bottle glass, which is often one of the first signs of historic use of a land parcel. Unlike the majority of prehistoric archaeological sites, historic sites often have aboveground structures such as homes and barns, historic buildings, or semi-subterranean features such as root cellars.

What are TCPs and Indian Sacred Sites?

Traditional Cultural Properties (TCPs) and Indian Sacred Sites may include aspects of the landscape that are used by Native American (Indian) people today or that were used at some time in the past, but that may not necessarily have a tangible, highly visible presence that is recognizable to non-Indian people or to people who are unfamiliar with Indian culture. Archaeologists and Cultural Resources specialists who lead and administer the cultural resource survey process rely on Indian people and, in some instances, ethnographic literature to identify such places.

What is an Archaeological Survey?

An archaeological survey is the first step in determining whether the location of a proposed development project contains any potentially significant cultural resources. Specific tasks of the survey include background research (outlined below) and field investigations. When accomplished according to the Washington State Standards for Cultural Resource Reporting, an archaeological survey produces a final report that identifies prehistoric and historic archaeological sites, historic standing structures and traditional Indian places within a project area. Most importantly, the report addresses the potential of the project to impact the resources and provides recommendations to keep the project moving forward on schedule with the least impact to the cultural resource site—preferably, by avoidance of the resource.

What is the Purpose of an Archaeological Survey?

The purpose of an archaeological survey is to determine whether cultural resources are present on a property. If cultural resources are discovered to be present, the survey will also serve to identify and protect them from development impacts.

What Does Background Research for an Archaeological Survey Entail?

Background research is a critical part of the archaeological survey process because it helps determine the level of effort required during subsequent stages of the survey.

Background research includes, for example:

- Review of state archaeological site files to determine what archaeological sites exist within the footprint of the project as well as in the general vicinity of the project area;
- Resource-specific background research (histories, pre-histories, archaeological reports, soil surveys, environmental reports, land ownership records, etc.);
- Personal interviews with people who may have knowledge the history of land use and what may or may not have been found within the project area (Indian people, landowners, local historians, amateur archaeologists, etc.).

What Does an Archaeological Survey Field Investigation Entail?

When a proposed project area has a high probability of containing cultural resources, archaeological surveys are required. Various methods are used to accomplish these investigations; together, they constitute an archaeological field survey. Survey methods may include:

- Systematic Surface Survey. During a systematic surface survey, archaeologists identify, map and record details about archaeological sites and artifacts within the limits of the project area. This process defines the Area of Potential Effect (APE), discussed below.
- Subsurface Probing. This method involves manual excavation of small test holes at fixed intervals not to exceed 20 meters (60 feet). These probes can be either round or square, can be excavated by hand or mechanical auger and should measure at least 30 centimeters (12 inches) in diameter. The soil from these holes is screened through a maximum of 1/4-inch mesh to standardize the recovery of a full range of artifacts. In some instances, such as along particularly deep depositional environments, backhoe trenching or other machine-assisted methods may be necessary to identify deeply buried archaeological sites and to understand the context of potential resources.
- Laboratory Processing. Archaeologists must clean, stabilize and inventory cultural material removed from the field. An artifact catalog notes the location of each piece (for example, subsurface probe number or surface collection location), the depth at which it was found and a description of the object, as well as other pertinent information. This catalog applies terms that are commonly used by other archaeologists and that are current with the state-of-the-art. All collections, including artifacts, field records and photographs, are generally considered the property of the landowner.
- Reporting. At the conclusion of the project investigations, the consultant will produce a written report that conforms to the Washington State Standards for Cultural Resource Reporting. The report contains a summary of what (if anything) was found and also includes recommendations about the next step in the process. This summary report is reviewed by the Washington State Department of Archaeology and Historic Preservation (DAHP) and outside agencies, and their decision determines whether the project moves forward according to the report recommendations or if further work at the location is needed.

How Does Paying for an Archaeological Survey Benefit Me or My Project?

Under Washington State law, it is illegal to knowingly disturb an archaeological site. The DAHP also provides development guidelines that help ensure that archaeological resources are considered within the scope of development. In order to avoid impacts to archaeological sites, it is necessary to implement a proactive approach to identify potential effects before starting work on the development project. This is in the best interest of the landowner/manager as well as the project development or construction teams. When development projects inadvertently uncover buried archaeological resources, Washington State law requires the work to be halted so that damage to the resource is minimized, and DAHP and other affected parties determine an appropriate course of action. Work stoppage is costly and causes inevitable delays to the overall project. Depending on the outcome of the site assessment, it may be necessary to fundamentally alter or even abandon the project under certain circumstances.

What Happens if Archaeological Sites or Artifacts are Found on a Property as a Result of an Archaeological Survey?

If archaeological sites or artifacts are identified during an archaeological survey, the survey report will also identify recommendations that DAHP will consider. DAHP will review the survey report to make sure that it meets technical and regulatory standards. DAHP will then outline necessary steps that are required prior to implementation of the project.

What is Archaeological Monitoring and How Does it Differ From an Archaeological Survey?

Archaeological monitoring refers to the process of field review during the implementation and development phase of a project. Under some circumstances, it may not be feasible or practical to conduct an archaeological survey prior to initiation of activity. If archaeological potential is generally high, but potential resources may be buried very deeply, monitoring may be an appropriate course of action. The primary difference between survey and monitoring relates to the resource discovery process. During an archaeological survey, the primary goal is to identify all cultural resources that have potential to be affected by a proposed project, and to mitigate the effects by design, avoidance or some other measure. Monitoring, on the other hand, has a goal of identifying resources as they are encountered during the implementation phase of a project, and, as a result, some level of damage to the resource may be assumed as part of the identification process. Once a resource is identified during monitoring, work stops around the location and does not resume until DAHP makes a determination of how to treat the identified resource.

What is an APE?

An Area of Potential Effect (APE) is a geographic area that contains the entire land surface area that has potential to be impacted by the proposed project. An APE includes staging and laydown areas, parking lots and paved or graveled access routes.

How Long Does it Take to Review an Archaeological Survey Report?

DAHP is the key player in the cultural resources survey report review process. Once a report is submitted to DAHP, you can expect to wait up to 30 days for a decision. The amount of time depends on the complexity of the project and whether more information is needed. DAHP may consult with local Tribes and applicable state and federal agencies during this time, and may solicit their comments on the project and report findings. If DAHP agrees with the report findings and receives no comments to the contrary, then the department issues a statement of concurrence and the project moves forward according to the recommendations (or some modified version) of the consulting archaeologist.

What Happens if an Archaeological Site is Identified as a Result of an Archaeological Survey?

If an archaeological site is identified during an archaeological survey, several steps are initiated to determine whether or not the site is "significant," generally meaning that it is associated with an important person or persons, or otherwise has potential to contribute to scientific knowledge of the area and therefore warrants further consideration. Details of the site attributes are recorded on a standardized Washington State Archaeological Site form, and the site is recorded with DAHP. DAHP then provides a standardized number for the site. If the site is significant, then the consulting archaeologist will work with DAHP to determine an approach that will protect the site. Standard mitigation options include redesign of the project to avoid the site completely (termed avoidance), formal excavation of the site if avoidance is not possible (termed data recovery) and, in some circumstances, abandonment of the project.

How Can I Obtain the Washington State Archaeological Predictive Model?

Contact DAHP. A data sharing agreement may be required.

Presentation Schedule

The following information details the presentations and papers related to the DAHP predictive modeling project.

Papers / Articles:

- Brett R. Lenz, Joanne Markert, Allyson Brooks, Elson T. Barnett, Tonya Kauhi. "The application of region-scale pedologic and geologic data to archaeological predictive modeling: an example from Washington State, Pacific Northwest, USA." Presented at Geoarchaeology 2009, Sheffield, England. April 15, 2009
- Rob Whitlam. "Using GIS to Ensure Effective Communication and Protection: Protecting Archaeological Resources During an Oil Spill in Washington State." ESRI ArcNews Online Article. Spring 2006.

Presentations:

- Joanne Markert. "Stop Work! Archaeology Site Found! – tools for managing this risk," 2009 American Public Works Association Spring Conference, Tacoma, WA. April 8, 2009.
- Joanne Markert and Tonya Kauhi, "Protecting the Past Using Tools of the Future: Archaeology Predictive Modeling", Mountain Home Air Force Base, April 2009.
- Joanne Markert. "Washington Statewide Predictive Model," Joint DAHP and Oregon SHPO meeting, November 2008.
- Joanne Markert and Allyson Brooks. "Protecting the Past Using Tools of the Future: Archaeology Predictive Modeling," 2008 American Planning Association Washington Regional Conference, Spokane, WA. October 2008.
- Joanne Markert. "Protecting Our Past Using Tools of the Future: Archaeology and GIS Modeling," 2007 GeoSpatial Conference, Portland, OR. April 2007.
- Rob Whitlam and Joanne Markert. "Cultural Resource Contacts GIS Layers." 2006 Coast Guard Regional Response Team / Northwest Area Committee Public Session Meeting, Everett, WA. February 2, 2006.
- Joanne Markert and Erin Wilkowski. (Protecting Our Past Using Tools of the Future). 2006 Washington GIS Conference, Washington Chapter of the Urban and Regional Information Systems Association, Tacoma, WA. May 2006
- Joanne Markert. "Protecting the Past Using Tools of the Future: Washington Archaeology Predictive Model for South-Central Washington," Society for American Archaeology Conference, 2005.
- Stanly Miller, Joanne Markert, Tonya Kauhi and Allyson Brooks. "An Archaeology Predictive Model Based on Conditional Probability and Geostatistics", 4th Annual Hawaii International Conference on Statistics, Mathematics, and Related Fields, Honolulu, HI. January 10, 2005.
- Joanne Markert. "Applying GIS to Archaeological Information Management," 2002 Northwest ESRI User Group Conference. September 2002.

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REPORT LIMITATIONS AND GUIDELINES FOR USE

This appendix provides information to help you manage your risks with respect to the use of this report.

Data Management Services are Performed for Specific Purposes, Persons and Projects

This report has been prepared for use by the Washington Department of Archaeology & Historic Preservation (DAHP). This report is not intended for use by others, and the information contained herein is not applicable to other areas.

GeoEngineers structures our services to meet the specific needs of our clients. No one except DAHP should rely on this data management report without first conferring with GeoEngineers. This report should not be applied for any purpose or project except the one originally contemplated.

Reliance Conditions for Third Parties

If parties other than DAHP intend to place legal reliance on the product of our services, we require that those parties indicate in writing their acknowledgement that the scope of services provided, and the general conditions under which the services were rendered including the limitation of professional liability, are understood and accepted by them. This is to provide our firm with reasonable protection against open-ended liability claims by third parties with whom there would otherwise be no contractual limits to their actions.

Data and Technology can Change

This report is based on conditions that existed at the time the study was performed. The findings and conclusions of this report may be affected by the passage of time including new data collection techniques, improved levels of quality, and greater availability of detailed information. Information technology is always changing, particularly in the realm of hardware, network systems, the Internet and security management. Always contact GeoEngineers before applying this report to determine if it is still applicable.

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Notes

[1]. Developed based on material provided by ASFE, Professional Firms Practicing in the Geosciences; www.asfe.org.

Statewide Archaeological
Predictive Model
File No. 15265-002-01

June 30, 2009

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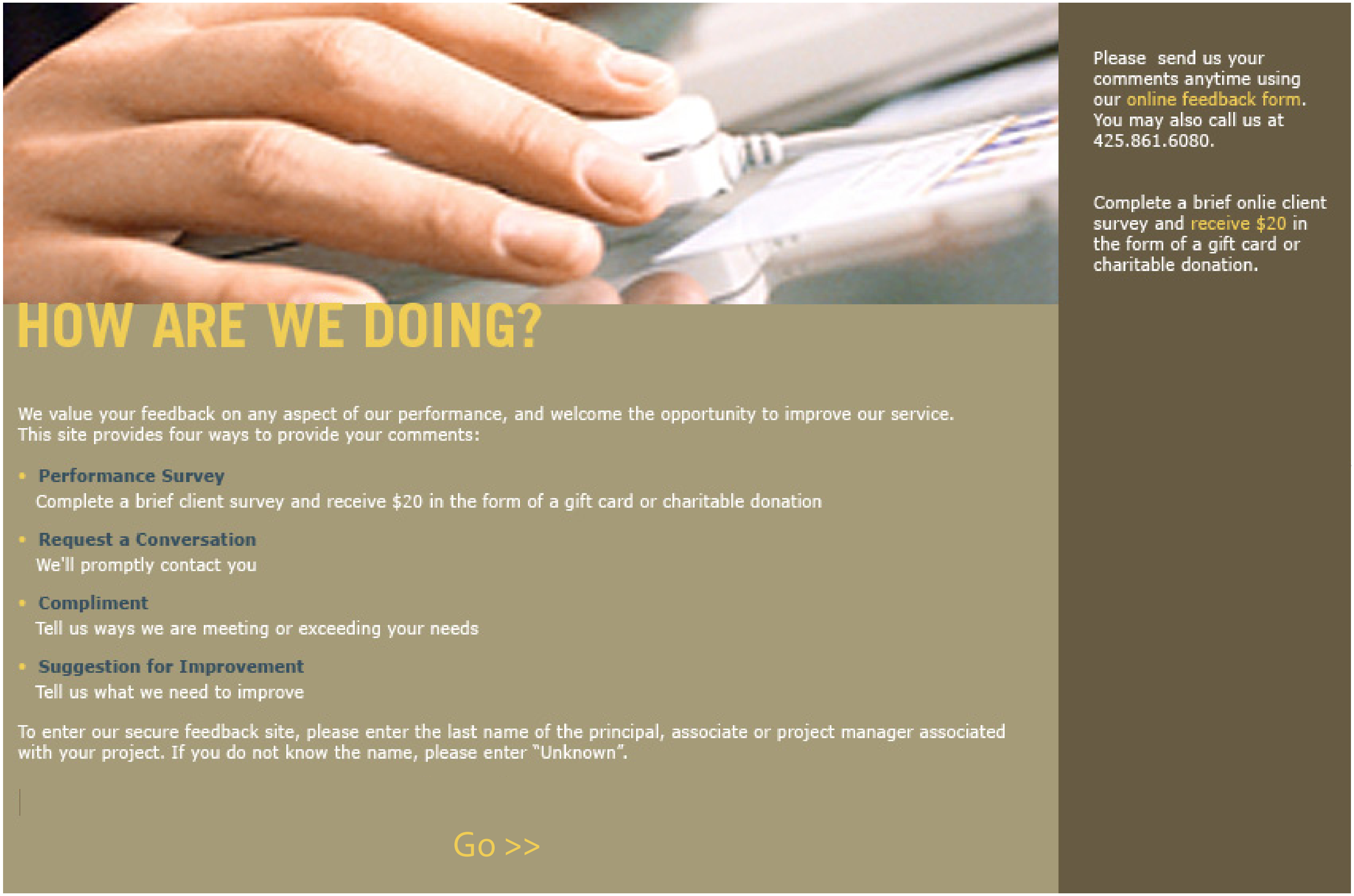
Within the limitations of scope, schedule and budget, our services have been executed in accordance with our contract and generally accepted practices in the field of GIS services in this area at the time this report was prepared. No warranty or other conditions, express or implied, should be understood.



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