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Paleoindian Predictive Model for Yellowstone National Park

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PALEOINDIAN PREDICTIVE MODEL FOR YELLOWSTONE NATIONAL PARK

By

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PALEOINDIAN PREDICTIVE MODEL FOR YELLOWSTONE NATIONAL PARK

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Abstract

The Greater Yellowstone Region was a destination for nomadic hunter-gatherers for at least 12,000 years. Archaeological sites representing the whole spectrum of time, cultures, and activities, have been found throughout the region. Within Yellowstone National Park a number of Paleoindian projectile points and other related cultural materials have been recorded, however, only a handful of buried Paleoindian sites have been identified and excavated. Considering the nature of the archaeological record in the area, some interesting questions surface about the value of the information recorded on the Paleoindian sites. In terms of Yellowstone National Park (YNP) Paleoindian archaeology, is it possible to use the existing Paleoindian sites to make inferences about the landscape choices of Paleoindian cultures? Can the relationship between the location of known Paleoindian sites and the environment be modeled using quantitative methods? If so, is it possible to use the information about land use patterns derived from a known set of sites to find additional, currently unknown, Paleoindian sites? This paper attempts to answer those questions through the development of an archaeological predictive model, focused on Paleoindian sites, for Yellowstone National Park. Utilizing Geographic Information Systems (GIS) and statistical software, a probability model has been created that relates the existence or nonexistence of Paleoindian cultural materials with sixteen selected environmental features. The model output classifies areas within YNP through a set of environmental characteristics favorable for finding Paleoindian cultural material.

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Chapter 1

Introduction

Established in 1872, Yellowstone National Park was the United States first National Park and has since become the destination of millions of visitors every year. Prior to this designation, the Greater Yellowstone Region was a destination for nomadic hunter-gatherers for at least 12,000 years (Macdonald 2012b). Yellowstone National Park (YNP) is located in the Intermountain region and borders the Northwestern High Plains (see Figures 1, 2, 3). Archaeological sites representing the whole spectrum of time, cultures, and activities, have been found throughout the region (Frison 1991). Within Yellowstone National Park a number of Paleoindian projectile points and other related cultural materials have been recorded. However, only a handful of buried Paleoindian sites have been identified and excavated. This thesis describes an archaeological predictive model developed for Paleoindian site locations in Yellowstone National Park.

Considering the nature of the archaeological record in the area, some interesting questions surface about the value of the information recorded on the Paleoindian sites. In terms of Yellowstone National Park Paleoindian archaeology, is it possible to use the existing Paleoindian sites to make inferences about the landscape choices of Paleoindian cultures? Can the relationship between the location of known Paleoindian sites and the environment be modeled using quantitative methods? If so, is it possible to use the information about land use patterns derived from a known set of sites to find additional, currently unknown, Paleoindian sites?

This paper attempts to answer those questions through the development of an archaeological predictive model, focused on Paleoindian sites, for Yellowstone National

Park. Utilizing Geographic Information Systems (GIS) and statistical software, a probability model has been created that relates the existence or nonexistence of Paleoindian cultural materials with sixteen selected environmental features. The model output classifies areas within YNP through a set of environmental characteristics favorable for finding Paleoindian cultural material. A ‘probability surface’ was generated in which each of the 88,901,690 cells, representing land parcels (10m x 10m), within YNP was assigned a probability score for containing Paleoindian cultural material. Individual probability scores were calculated from the unique environmental characteristics at each land parcel.

A large number of the artifacts used to develop this model were identified during pedestrian survey’s and test excavations were conducted by the 2009-2013 University of Montana’s MYAP (Montana Yellowstone Archaeological Project), led by Professor Douglas Macdonald (Douglas H. MacDonald and Hale 2011; MacDonald and Hale 2013; MacDonald and Livers 2010). The MYAP investigations identified a large proportion of the Paleoindian artifacts around the shores of Yellowstone Lake and provided the inspiration for this study. Specific inspiration arose from the similarities observed in the field at many of the Paleoindian artifact locations.

The fundamental components of an archaeological predictive model will be discussed in chapter two, including a brief discussion of the history, theoretical foundations and critiques of APMs. As well as a description of the logistic regression processes utilized for the development of the model. A concise background of the previous archaeological research in the Park will be addressed in chapter three. Along with a more in-depth discussion of the Paleoindian record in Yellowstone, along with descriptions of the lithic sources available to and utilized by Paleoindians.

Chapter four and five describe the methods used to construct the variable layers and site sample data needed to develop the predictive model. This includes the creation of a site database, conversion of file types, extraction of raster values, and the implementation into statistical analyses program. The last two chapters consist of the assessment of the model and the discussion of the results. The model developed for this study appears to be successful, however, the assessment of the model would benefit from a larger testing Paleoindian site sample. Regardless, visual analyses and the limited assessment of the model both are performing very well and will be discussed in detail in the later chapters.

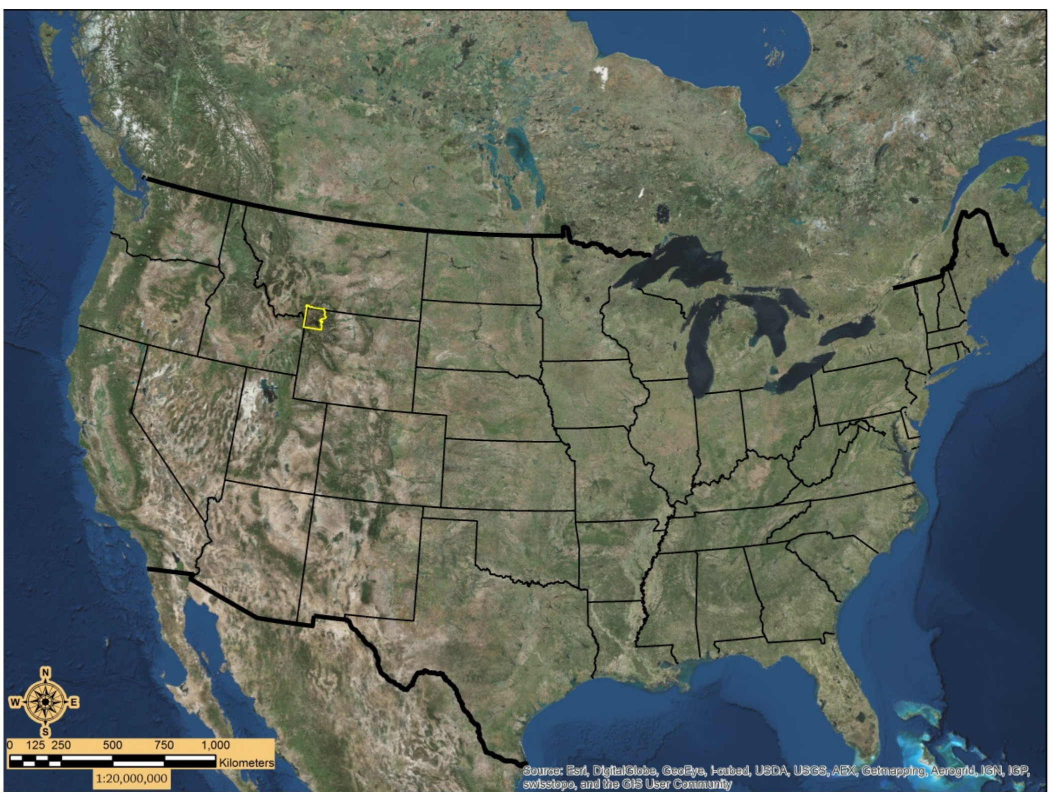

Figure 1. Location of Yellowstone National Park in relation to Continental U.S. shown in yellow

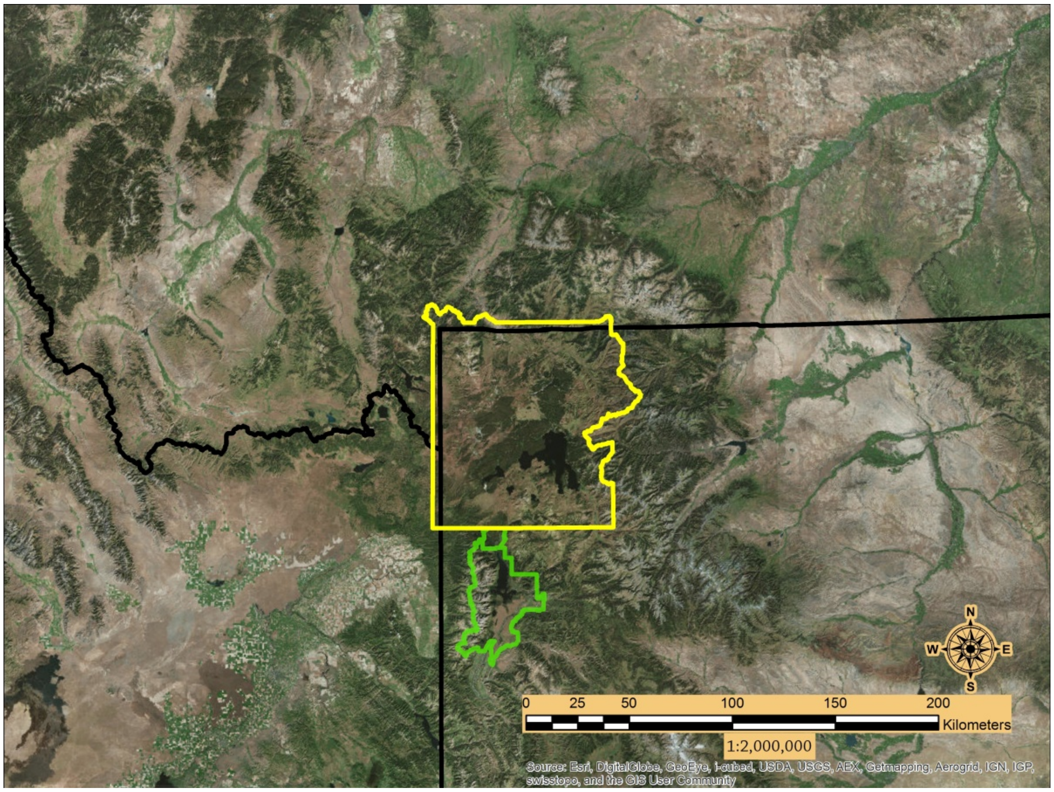

Figure 2. Location of Yellowstone National Park shown in yellow with state borders shown as black lines and Grand Teton National Park shown with green line

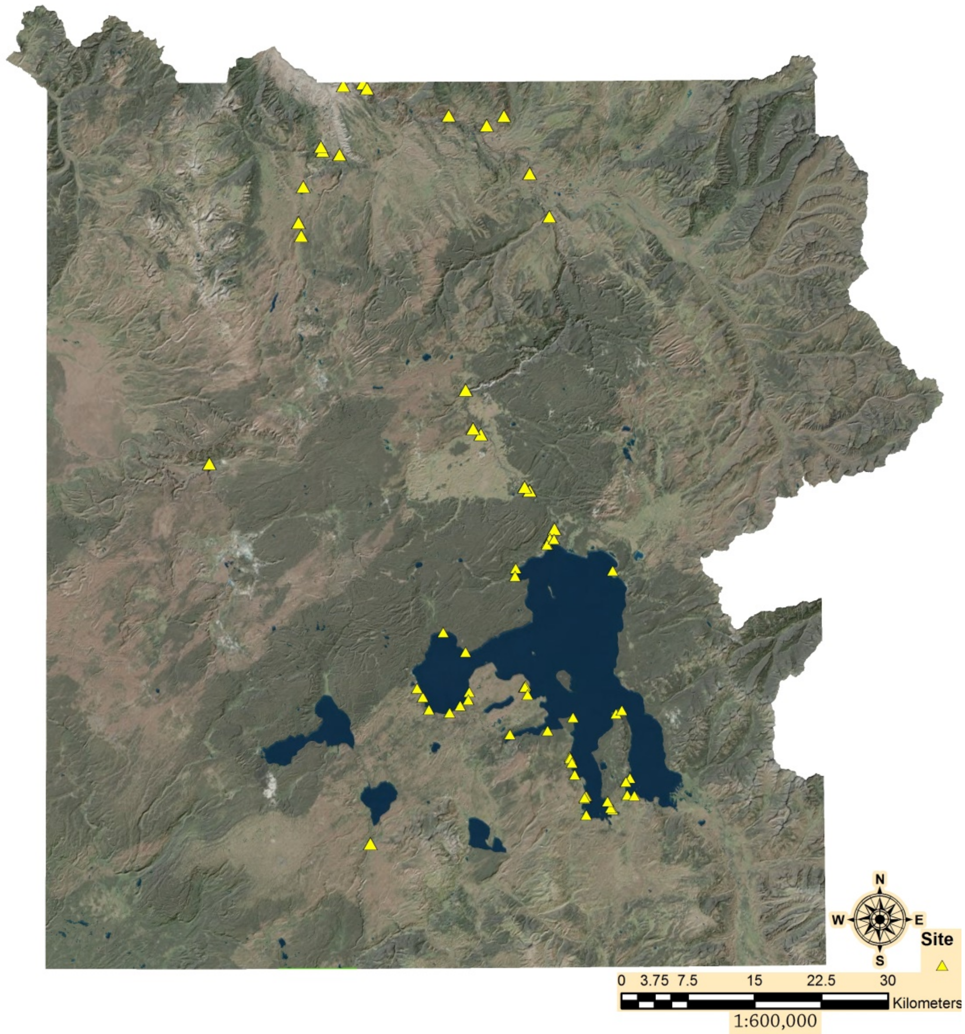

Figure 3. Displays the locations of all Paleoindian sites used in development of the predictive model. Not all Paleoindian sites are shown

Chapter 2

Archaeological Predictive Modeling Review

This section provides an overview of the theoretical background and range of applications of archaeological predictive modeling. An archaeological predictive model (APM) can be generally defined as a tool that indicates the likelihood of cultural material being present at a location (Warren and Asch 2000). APMs attempt to quantify the spatial pattern identified in a sample of archaeological site locations with respect to a set of non-archaeological input variables and project the theorized pattern to a larger area (Kvamme 1992).

Interestingly, archaeological predictive models (APMs) were first employed, not in cultural resource management frameworks (e.g. Jochim 1976; Pilgrim 1987) or as a means to save research money, but only as a way to investigate prehistoric land usage, through the use of assessing the statistical correlations between sites and ecological variables (Whitley 2000:11). An APM is most commonly used as a tool to indicate the probability of cultural materials being present at a given location (Warren and Asch 2000). A predictive model is essentially an "assignment procedure" that accurately designates an archaeological result at a specified location with a higher probability than could be attributed to random chance alone (Kvamme 1990a:261). This is done by attempting to identify and quantify spatial patterns inherent to a sample of known archaeological site and site absent locations in conjunction with often non-archaeological input variables and project the identified pattern onto a larger area (Kvamme 1992).

Archaeological predictive modeling's theoretical basis counts on a lack of randomness in human settlement behaviors, and that the distribution of resources within a given locale greatly influenced the decisions humans made; particularly in regards to settlement locations (Campbell 2006). In hunter-gatherer archaeology, this is reinforced by the observed spatial patterns of archaeological materials found throughout an area and the apparent relationships between the distribution of specific environmental resources and activity locations related to the search for and utilization of resources (Campbell 2006). Inherently, predictive models assume the environmental factors that influenced settlement decisions are accurately represented in modern maps of environmental resources (Warren and Asch 2000); thus modern maps can be utilized to provide information regarding the distribution of activity locations (Campbell 2006).

An APM develops a set of criteria that is used to classify each individual cell, pixel or land parcel into an archaeological event class most often based on non-archaeological data (i.e. environmental variables). "Predictive models take the conclusions of settlement analyses and turn them around to develop a probabilistic generalization of where sites are likely to occur in a given unsurveyed area" (Whitley 2000:11). Archaeological predictive models typically use measurements from pertinent environmental variables to determine the likelihood that a site occurs at a specific location.

There are two types of predictive modeling: inductive modeling and deductive modeling. Inductive models tend to look for quantifiable relationships between known site data and environmental datasets like landforms, soil type, distance to water, relief, and slope, typically through the use of statistical techniques such as, logistic regression (e.g. Warren 1990; Wheatley and Gillings 2002). Inductive models derive rules from observations using various factors, mostly environmental in prehistoric hunter-gatherer research.

Deductive models derive rules from expert knowledge or knowledge-based theory deductive approaches do not rely on correlations with known archaeological site data. Preferring instead to use deductive reasoning and using archaeological site data for testing purposes (Verhagen and Whitley 2012) only after their statistical analysis (e.g. Van Leusen, et al. 2009; Verhagen 2006), or GIS procedure (e.g. Dalla Bona 1994) has been conducted (Cable and Standley 2012). Deductive models are often referred to as "intuitive" of "expert judgment" models due to the fact that they tend to rely on their knowledge of a region to develop a model based on a set of characteristics believe to influence settlement location preferences (Cable and Standley 2012).

According to Cable and Standley (2012:13) "Both approaches are driven by 'ecological determinism' (see Gaffney and Leusen 1995)…, a reliance on available environmental data sets to define the archaeological model, without regard to causality, agency or cognitive behavior (see Gaffney and Leusen 1995)". Environmental variables, either current or reconstructed, are the principal base for most predictive models. Although most predictive models are multilinear, this prevalence is seen as a form of ecological determinism (Whitley 2000). Both methodologies are capable of providing an effective predictive model, however, both are used to produce regional scale models that attempt to predict prehistoric site locations. The focus of this study is on inductive modeling methods

Predictive modeling literature generally point to the 1970s and 1980s as the time that contemporary styles of archaeological predictive modeling were developing. By the mid-1980s inductive modeling techniques were well established (Carr 1985; Judge and Sebastian 1988; Kohler and Parker 1986). Ultimately the combination of CRM projects and settlement pattern studies produced what is known as “predictive models” (Judge and Sebastian 1988; Kohler and Parker 1986). In the United States the National Historic Preservation Act of 1966 required the management and protection of cultural resources on federal lands, this combined with other administration requirements for large federal land management agencies provided a motivating factor for the implementation of these types of models. Fortunately, in the early 1980s, the availability of technologically advanced computer systems and Geographic Information Systems (GIS) software provided the resources to develop complex computerized archaeological predictive models (Berry, et al. 1983; Carr 1985; Chandler and Nickens 1983; Sally Thompson Greiser 1985; Kvamme 1983). Inductive predictive models were originally developed on paper maps; coded, plotted, and organized by hand. Computerization of these processes had been done, but the limited computational capabilities of early computers and extraction of map data had substantially reduced the effort required to produce an archaeological predictive model. However, it was still tedious work to produce an accurate and limited scale APM (Kvamme 1990b; Pilgrim 1987).

GIS and digital spatial provided the first adequate digital instrument able to construct and develop larger and more detailed inductive predictive models (Judge and Sebastian 1988; Kohler and Parker 1986; Kvamme 1988, 1989; Kvamme and Kohler 1988). By the late 1980s GIS software and computer computational power was capable of providing thousands of consistent measurements of environmental or other spatial characteristics in seconds across entire regions (Kvamme 1989). “Indeed, it is only through a GIS that real access to our diverse regional data sets will be possible and that certain regional analysis, simulation, and modeling strategies can be implemented" (Kvamme 1989:144).

Predictive models in the academic sense sometimes attempt to establish determinants that influenced the settlement behavior of prehistoric people. Attempts are made to incorporate the human component within location modeling, acknowledging the role of subjective judgment. Incorporating these may make models more cognitive, but it also introduces a nearly unmanageable level of complexity (Veljanovski and Stancic 2006).

Fundamental Components of Predictive Models

Three fundamental components of an APM are recognized: the unit of analysis as a land parcel, the development of an assignment procedure, and the application of the assignment procedure to each land parcel.

Unit of Investigation

The unit of investigation, generally the archaeological site, is the fundamental component of any archaeological predictive model. In archaeological studies this unit is typically the archaeological site, but in archaeological predictive modeling, this unit is the individual land parcel (Kvamme and Kohler 1988). GIS is well suited to divide the landscape into a series of contiguous land parcels, as a single land parcel forms the standard raster grid cell. The assignment procedure of the APM is then applied to each grid cell that represents a land parcel.

The unit of investigation involves consideration of the modeling goals and the available geographical data. The most common modeling goal is to predictive previously unknown site locations. Considerations of scale in regards to the available environmental datasets are important due to the fact that spatial datasets are collected with a specific margin of error and consequently have limits to the positional accuracy of the data. Use of a land parcel size that is at a finer resolution than the mapping scale of the geographic data risks the introduction of error or false precision into the model. The last several years have seen the average land parcel size for environmental datasets is $30m^2$, however, there are currently available elevation datasets for most of the United States that have a land parcel or raster cell size of $10m^2$.

Archaeological Event Classes

The final output result of an archaeological predictive model is an assignment of each land parcel to an archaeological event class. Each land parcel must be classified into only one of the event classes and all parcels or cells must be classified (Macdonald 2012a).

The following section will describe the potential event classes used in this APM using notation from Kvamme (1992). For each land parcel used to construct the model, two possible archaeological events that represent the true condition of the land parcel are possible:

S = {site present}

or

S' = {site absent}

Output of the model is the assignment of every land parcel into one of the two potential archaeological event classes:

M = {model predicts site present}

or

M' = {model predicts site absent}

The comparison of these two sets of event classes is crucial for interpreting model results. Any single land parcel can be classified according to its condition in reality (S or S') and by its condition predicted by the model (M or M'). Comparing the relative values of S, S', M, and M' provides a quantitative method for evaluating model performance. This notation is used throughout this report.

The site present class (S) is meant to represent all the different functional classes of Paleoindian open-air activities or what (MacDonald and Hale 2011) refers to as an *activity space.* Recognizing that different functional classes could occupy different kinds of contexts within the activity space, this notion is useful in the present model because the overall goal is to create a map of where the locations of any Paleoindian open-air activity may be present in Yellowstone National Park. The reason for specifying open-air sites is that at the current time we lack the ability to model rock shelter and rock art locations accurately enough Kvamme (1992). It should also be mentioned that no evidence of Paleoindian occupations have been discovered in a rockshelter setting within YNP.

Assessment

To determine the accuracy of the model the GIS toolkit is utilized, both through visual evaluation of the model and analytical evaluation. For visual evaluation, every land parcel is mapped as a continuous probability surface in GIS, allowing the researcher to visually analyze and interpret the spatial pattern of the model results. This visual analysis of the probability surface is not quantitative, but provides a valuable tool to gain insights into the spatial implications of the model. To quantitatively evaluate the model, predicted probabilities are exported for each land parcel to a statistics program in which the actual assessment and graphic productions are executed.

Critiques

Discussed in the following are the two primary critiques of archaeological predictive modeling 1) the lack of reliability of currently available spatial datasets as representations of the past environmental conditions, and 2) they are primarily environmentally deterministic.

Opponents of the inductive modeling method argue that models constructed an environmentally deterministic framework do not sufficiently explain the nature of the archaeological distributions being modeled (Ebert 2000). This determinism is due to the fact that "In most regional analyses, environmental data generally are easier to obtain than prehistoric socio-cultural information" (Kvamme 1992:22).

Environmental information, however, can be easily obtained at site locations in the field or from GIS. A common debate is over the degree to which present environment represents the prehistoric environment However, Kvamme (1992) states that, "…this issue may be a moot point in view of the pattern recognition and classification methodology employed for modeling." (Kvamme 1992:22-23). In other words, if the sites and these modern variables result in a model that predicts archaeological remains more accurately than random chance then the model is still effective. However, if variables that make sense archaeologically are used it is easier to understand and explain settlement behavior patterns and those variables are more likely to reveal strong patterns in regard to site samples and in turn provide more significant modeling outcome (Kvamme 1992).

As with most things it has been criticized a great deal in terms of methodology and theory. Post-processualists have voiced concern that it may remove the human aspect, i.e. agency, and that it therefore produces inaccurate or bias analyses of geographically significant areas.

Postprocessualism's lack of concern with contextual meaning, has implied that processual explanations focus more on the questions of generalities, and only those which are assessed through causal-functional type analyses, such as social-ecological connections (Hodder 1987). A lack of contextual understanding would therefore seem to argue against the full explanation of the target behavior, rather only expounding on those parts of the process, which are common to all cultures(Whitley 2000). Some postprocessualists feel that through interpretative explanation of cultural constructs in a historical context it becomes possible to apply "meaning" to archaeology, or at least to better reconstruct the inherent meaning in the archaeological record (Hodder 1991).

Although spatial technologies have been widely accepted and utilized in archaeological research, debates over processual and post-processual theoretical approaches are still present. Although there are still critics and admittedly problems with these spatial technologies that will be discussed later, these remain critical tools for archaeologists who hope to achieve a more complete understanding of the peoples they are studying. This is especially true for hunter-gatherer archaeology and Paleoindian research in particular, which often have relatively limited data sets, from which only a certain amount of information can be inferred.

Settlement pattern studies and human ecology were not characteristically the method of investigation followed by postprocessualists, but traces of these appear in some postprocessual writings (e.g. Duke and Wilson 1995; Hodder 1990; Wilson 1995; Zubrow 1994). Typically postprocessual approaches to settlement strategies are more theoretical since they involve interpretations of symbolic structures and are often limited to ethnographically known cultures. However, postprocessualists make a valid point, that in our own current complex human societies we recognize that our own motivations are not limited by conscious ecological or economic concerns. These are concepts that are not typically addressed by the ecological functionalist models (Whitley 2000).

Wheatley (2000:123) makes an interesting point regarding the debate over GIS and it's role in archaeological theory, that is, "...it is not theories about spatial technologies per se which are needed, but theories about the spatial organization of culture without which such technologies would be of limited benefit." This is as mentioned above, is due to the fact that the design of these applications fit more efficiently and easily with archaeologists who adhere to a more processual based research framework. Furthermore, the data that are typically compiled and analyzed from hunter-gatherer and other prehistoric archaeological sites fit into these applications framework with ease and produce results that directly answer the questions that were posed. Contrasting some postprocessual questions that may require inferences from the results that processualist's would not feel comfortable with making. As a processual approach is based on attempting to keep inferences based on empirical data and results, post-processualists feel more comfortable making inferences that can't be necessarily be empirically proven.

Logistic Regression

The most widely used method for constructing quantitative archaeological predictive models is a logistic regression technique, whether binary or multivariate. Binary logistic regression is used when the observed outcome is limited to only two values, in this case coded 0 and 1, representing the site absent {S'} and site present {S} event classes respectively. The output of the binary logistic regression represents in this case the probability of a site occurring Pr(M) or probability of a site not occurring Pr(M'). Since the output of the logistic model is a probability it must be constrained between 0 and 1. The ordinary output value of the equation (Z) must be converted to a probability value restricted between 0 and 1 (Davis 1993). The standard linear regression equation is generally described as:

$$\mathbf{Z=B_0+B_1X_1+B_2X_2+\ldots+B_PX_p}$$

"where, Z is the predicted output of the regression equation (dependent variable), B_0 is a constant term, B_P is a coefficient and X_p is an independent variable for every variable in the equation" (Campbell 2006:29). The following equation needs to be implemented to convert the probability of an event occurring:

$$\mathbf{Pr(M) = 1/(1+}e^{-Z}\mathbf{)}$$

Where e is the natural log and ($-Z$) is the ordinary regression output multiplied by -1 (Campbell 2006). The probability of an event not occurring is written as:

$$\mathbf{Pr(M') = 1 - Pr(M)}$$

Logistic regression is often utilized due to its robustness in regard to the data normality and equality of variance assumptions required of related techniques and its ability to handle nominal, ordinal, interval, or ratio level data (Kvamme 1990a; Warren and Asch 2000). Kenneth Kvamme's (1992) method of model development and assessment is used for the model constructed in this thesis. This method was chosen over more basic binary classification and more elaborate multilinear regression models for its relative simplicity and robustness. Also it has been shown to be effective in large area, regional predictive models previously, with an increasing number the size of the Yellowstone National Park model presented here (Campbell 2006; Kvamme 1992).

Chapter 3

Study Area

Background and Study Area

Yellowstone National Park is larger than Rhode Island and Delaware combined and home to the largest high-altitude lake on the continent. Nearly three million tourists a year visit the Park and this rate increases continually. Yellowstone is located in the Intermountain region and at the edge of the Northern High Plains; most of the Park is situated in Wyoming with small portions in Montana and Idaho (NPS 2011).

Yellowstone is home to a number of large lakes, such as Yellowstone, Lewis, Shoshone, and Heart Lakes that are all located in the southern half of the Park (Shortt 1999). The major rivers that either originate in the park or flow through it include the Yellowstone, Madison, Firehole, Gibbons, Gardiner, Gallatin, Lamer, Bechler, Lewis, and Snake Rivers that are located throughout the Park, but concentrated in the northern, western, and southern portions of the park. Generally speaking the eastern and northern portions of the park consist of more rugged mountains giving way to more open valleys and plateaus in the central, western, and southern areas.

The Park has a number of plateau areas including: the Buffalo and Blacktail Plateaus in the northern portion. The Solfatara, Central, and Mirror Plateaus are located in the central portion and the Madison and Pitchstone Plateaus are located in the western and southwestern portions respectively. Finally the Two Ocean Plateau is located just south of Yellowstone Lake in the south-central and southeastern area of the park.

Conifer forests are the most prominent vegetation, with Lodgepole Pine comprises 80% of the total forested areas. Other common flora include; various Firs, Whitebark Pine, Quaking Aspen, Willows, a variety of sage, and grasses (Whitlock 1993). The area is home to a number of large animal species, most notably, bison, elk, bighorn sheep, and deer.

In general, the park area is at the edge of the lower flatlands of Idaho to the southwest, with the foothills, small mountain ranges, and wide valleys to the west, and the more rugged mountain ranges to the north, east, and south. To the east of the park the mountains give way to the open Northern High Plains region near Cody, Wyoming.

Indigenous lifeways on the High Plains and Intermountain region consisted almost exclusively of nomadic hunter-gatherer adaptive strategies for the majority of human occupation, about 11,000 radiocarbon years BP (Frison 1990, 1991, 2007). Much remains unknown regarding the Paleoindian period of the High Plains and Intermountain region, recent research has substantiated that these cultures employed highly adaptable hunting and foraging strategies utilizing a vast array of available resources. The predominant characterization of these cultures was that of primarily big game hunters, however, the compiled evidence has begun to show a diverse and adaptive subsistence strategies (Hill 2007; Johnson, et al. 2004; Knell 2007; Knell and Hill 2012; Vivian 2005).

Examples of Paleoindian sites in the region that are located outside the Park's boundary are described briefly in the following. The Clovis age (10,680RCYBP), Anzick site (24PA506) is located approximately 110 km north of Yellowstone National Park (YNP) (MacDonald and Hale 2011). The Horner site (48PA29), is a stratified kill site (mean age of 9899± 79 RCYBP) situated on the western edge of the Big Horn Basin and is the type site of the Late Paleoindian Cody Cultural Complex, positioned approximately 80 km east of YNP, near Cody, Wyoming (Cannon, et al. 2010; Frison 1987). Located approximately 100 km to the northwest of the park, the Barton Gulch site (24MA171), a Late Paleoindian (9,800yrs BP) stratified campsite is located near the Ruby Reservoir, Montana (Davis 1993). These are merely a small sample of the Paleoindian sites that have been recorded in the areas outside YNP.

Archaeology in Yellowstone

A formal interest in the prehistoric occupations of Yellowstone National Park dates 1887 when Supt. P.W. Norris, the U.S. Geological and the Bureau of American Ethnology collected hundreds of Native American artifacts from the park and sent them to the Museum of Natural History, Smithsonian institution where they have remained (Hale and Livers 2013). Hale and Livers (2013) note that a number of these artifacts appear to be related to Paleoindian cultures dating to around 10,000 years before present through the Late Prehistoric cultures 1,000 years before present (Sanders 2013). The first "systematic" archaeological survey of Yellowstone National Park was conducted over a two-month period in 1958, led by Dr. Carling Malouf, head of the Montana State University (now the University of Montana) Anthropology Department. This survey generally focused on drainages along the Yellowstone River, the Madison River, the Gallatin River, and Yellowstone Lake. The co-director of the Yellowstone Survey, Dee C. Taylor, continued the survey in 1959; locating 195 sites within the park, 78 of which Replolge had mapped previously (Hale and Livers 2013).

Smaller scale archaeological projects continued through the 1970s, 1980s and into the 1990's; these were generally undertaken in response to construction projects within the park. In the late 1990's relatively larger scale archaeological projects were becoming more prevalent; these were focused primarily along highways and major rivers. From 2004 to 2005 Lifeways of Canada was responsible for surveying the lakeshores around the entire south half of Yellowstone Lake.

With only 4% of the park inventoried for archaeological resources, that is approximately 140 of the 8,972km^2, of which The University of Montana's and Yellowstone National Park (YNP) Montana Yellowstone Archaeological Project (MYAP) have been surveyed approximately 4,000 acres in the past 4 years (Hale and Livers 2013:3). It has taken over 40 years to account for this 4% of archaeological coverage of Yellowstone, due in most part to the limited amount of funding for archaeological work. This provides another motivation for identifying environmental and ecological variables that relate to site selection for prehistoric populations in Yellowstone.

This study will contribute to these advancements by focusing on the environmental and ecological variables responsible for the spatial patterns of Paleoindian (11,500-8,000 years BP) artifacts in Yellowstone National Park. An increasing number of Paleoindian artifacts have been identified in Yellowstone since the 1950s, particularly due to the large scale surface surveys conducted generally in the North, Central, and Lake areas of the park. Finding a pattern or patterns poses a fascinating challenge for geospatial analysis. Given that an overwhelming majority of the Paleoindian artifacts are recovered from the surface and are therefore utilized in archaeological research on a limited basis. GIS provides a useful platform from which to analyze this growing dataset and most importantly gain insight into Paleoindian people's use of the park and the

Central Rocky Mountain or Intermountain Region. There is a need for more in depth and detailed information on the settlement and migration patterns in the Yellowstone region during the Paleoindian period (Sanders 2013). The lithic raw materials near and within Yellowstone coupled with its general geographic location and physiology leading one to infer that the area should have a high potential for Paleoindian occupations.

There have been limited excavations of Paleoindian sites within Yellowstone, the most expansive appear to be: Malin Creek site on the Yellowstone River near Gardiner (Vivian, et al. 2008), Fishing Bridge site on the North Shore of Yellowstone Lake (Reeve 1989), and the Osprey Beach site on the West Thumb of Yellowstone Lake (Johnson, et al. 2004). These are widely distributed throughout the Park and shed only limited light on the prehistory of the area. Nearly all of the Paleoindian sites have resulted from surface surveys. At sites where Paleoindian artifacts were recovered from the surface and were also test excavated few have resulted in the recovery of any subsurface diagnostic artifacts.

Paleoindians in Yellowstone

The predominant characterization of these cultures was that of primarily big game hunters, however, the compiled evidence has begun to show diverse and adaptive subsistence strategies (Hill 2007; Johnson, et al. 2004; Knell 2007; Knell and Hill 2012; MacDonald, et al. 2012; Vivian 2005). It is widely accepted that Paleoindians were organized into small, highly mobile bands that left evidence of short-term habitations. A wealth of knowledge exists about the current and historic environmental conditions of YNP, but specific details of the postglacial environment are not as well understood due mainly to the lack of organic materials surviving from that time (Frison, et al. 1996). Dynamic environmental and ecological change at the end of the Pleistocene likely resulted in habitat variation which caused significant changes in how early people used the high altitude areas of the Northwestern Plains, with some strategies never to be used again (Hofman and Graham 1998).

Clovis

The earliest known occupation in the Yellowstone region is the Clovis culture, radiocarbon dated from 11,500 to 10,900 years ago. The Clovis cultural complex is generally comprised of projectile points that are long, finely crafted lanceolates with retouched edges and a flat, or slightly concave or convex proximal end that is sometimes rounded. Fluting at the proximal ends is another characteristic of the Clovis Complex projectile points. Percussion flaking initiated at one margin and terminating at the opposite margin is characteristic of Clovis and can be seen in both their biface performs as well as their projectile points.

Few Clovis points have been recovered within the park boundaries. The first Clovis point recovered was from the construction of the Gardiner Post Office (Janetski 2002). Approximately 120 km north of North Entrance to YNP, the Anzick Clovis cache and burial yielded a wealth of data regarding Clovis burial and cache behavior in the northern Plains (Lahren and Bonnichsen 1974). During the 2007 University of Montana survey north of Gardiner, a red porcellanite Clovis point was recovered at site 24YE355 (MacDonald, et al. 2010). Finally, during the 2013 University of Montana investigations at the southern shore of Yellowstone Lake, an obsidian Clovis-like point portion (lower half) was recovered at site 48YE1578 and was geochemically similar to the Teton Pass obsidian source near Jackson Hole, Wyoming (see figure 5).

Goshen and Folsom

As with Clovis, the Folsom complex, radiocarbon dated from 10,800 to 10,300 years before present, is characterized by a subsistence pattern oriented toward bison hunting (Hill 2007; MacDonald 1999). A majority of Folsom sites with faunal remains yield bison, yet, excavations conducted at the Indian Creek (Davis and Greiser 1992) and MacHaffie (Davis 1997) sites in Montana, northwest of YNP, point toward a broad subsistence base for Folsom peoples in the Rocky Mountain foothills, confirming recent research by (Hill 2007). Associated with the Folsom complex are the technologically similar but unfluted Goshen, Midland, and Plainview points (Maas, et al. 2011).

While Goshen may represent a completely separate cultural group from Folsom, the few excavated Goshen sites do not allow for a full understanding of their cultural association to Folsom (Frison, et al. 1996). Technologically, Plainview and Midland points are inseparable from Goshen as well, with all being technologically and chronologically similar to Folsom (Frison, et al. 1996; Hofman and Graham 1998). Most Folsom sites contain both fluted and unfluted varieties of Folsom points, further confusing the Plainview/Midland/Goshen typology.

Evidence of Folsom, Goshen, Midland, and Plainview technology is rare in YNP. An obsidian Folsom point found in the Bridger-Teton forest south of Yellowstone was sourced to Obsidian-Cliff, indicating that Folsom individuals evidently entered the park to collect stone (Cannon and Hughes 1997). An unfluted Folsom or Plainview point, geochemically similar to stone from Obsidian Cliff, was recovered during archaeological excavation on the shores of Yellowstone Lake (Maas, et al. 2011). The Folsom component of the Indian Creek Site also yielded obsidian sourced to Obsidian Cliff in YNP (Davis and Greiser 1992).

Lifeways of Canada survey recovered two Goshen points from the surface at site 48YE736 on the shores of Yellowstone Lake. The materials used for these points included petrified wood and quartzite (Vivian 2005). The University of Montana survey of the Lewis River found an obsidian Goshen point at site 48YE2221, shown in figure 6 below, which was geochemically similar to the Teton Pass source near Jackson Hole, Wyoming.

Agate Basin

Agate Basin cultural complex occupations have been radiocarbon dated to 10,500 to around 10,000 years before present at the Brewster and Agate Basin sites in Wyoming and the Frazier site in Colorado. Agate Basin projectile points are long, narrow, and finely crafted straight-based lanceolates projectile points with thick lenticular cross sections (Frison 1991; Frison and Stanford 1982; McLeod and Melton 1986).

During 1958-1959 archaeological investigation in YNP, two Agate Basin points were identified in collections at Mammoth Hot Springs Museum (Taylor, et al. 1964). One of these was collected from Alum Creek, a tributary of the Yellowstone River, while the other was collected in the Fishing Bridge area at the outlet of Yellowstone Lake. Two more Agate Basin-like points were recovered via pedestrian inventory from the

Yellowstone Lake shore sites at Fishing Bridge and Pumice Point 48YE301 (Taylor, et al. 1964).

Cascade

Cascade points found in the Eastern Yellowstone Plateau, have morphological similarities to Agate Basin points, but generally are attributed to cultures inhabiting the Columbia Plateau and northern Great Basin to the west (Maas, et al. 2011; McLeod and Melton 1986; Roll and Hackenberger 1998). Reeve (1989) notes that a chert Cascade point and an obsidian Hell Gap point were recovered near Grebe Lake, but no coordinates were recorded on the artifact bags.

Hell Gap

The 1958-1959 survey of YNP recovered four Hell Gap points from the surface; three sites along the shores of Yellowstone Lake and one on the banks of the Yellowstone River near Cascade Creek. Records of two additional Hell Gap points that were previously collected and curated in the Mammoth Museum indicate one point was found at the mouth of Bridge Creek on the Yellowstone Lake (Taylor, et al. 1964). Again, there have been no excavations conducted to investigate the nature of any of the Hell Gap points.

Other Hell Gap points have been recovered at sites 48YE319, 48YE397, 48YE410, 48YE366, 48YE456, and 05YPB43. Meyer (2004) notes an obsidian Hell Gap point being recovered near the Grand Canyon of the Yellowstone River at site 48YE456. Hell Gap points recovered at site 48YE319 was made of chalcedony, the points from

48YE397 and 05YPB43 were made of basalt, and the Hell Gap points recovered at sites 48YE410 and 48YE366 were made of obsidian.

Generally included in with Agate Basin points in the Plano Complex of unfluted Paleoindian lanceolates, Hell Gap points are characterized by a distinct shoulder and a broad point that tapers to a straight base. The base, which can sometimes be slightly concave, has medial flaking patterns that result in a lenticular cross section (Hofman and Graham 1998). It is thought that Hell Gap complex is a direct descendant of the Agate Basin (Frison 1991) .

Windust

Windust reflects the Western Stemmed Point Tradition of which Haskett is a member, and similarities exist with Agate Basin, Hell Gap, and Cody/Alberta Cody Complexes. Reeves (2006) indicates that indented base projectile points with stems, attributed to the Windust Complex within the Columbia Plateau and Great Basin to the west, have been identified within Yellowstone National Park. Taylor, et al. (1964) recovered one of these points from site 48YE303 along the Yellowstone River. In 2001, a stemmed point of this tradition was also recovered (Meyer 2004) at site 48YE1025 along Hellroaring Creek near its confluence with the Yellowstone River.

Two obsidian points of this tradition were located at site 48YE1592 and were geochemically similar to the Obsidian Cliff and Teton Pass sources. Reeves (2006) notes three possible stemmed points or portions of points, of this tradition being recovered 1) an obsidian point recovered at site 48YE598, 2) a chert point from site 48YE387, and 3) a point of silicified sediment at site 48YE554. Further evidence of this tradition is seen at site 48YE307 near Indian Creek.

Haskett

Two Haskett points were excavated at the Malin Fishing Hole site (24YE353) one of which was made from Obsidian Cliff obsidian (Vivian, et al. 2008). The University of Montana (MYAP) 2011 survey around Yellowstone Lake recovered another Haskett point at site 48YE1601, which was also from Obsidian Cliff obsidian. Another Haskett point was recovered around Yellowstone Lake at site 48YE395 (Cannon 1992).

Lovell Constricted

A jasper Lovell Constricted point was collected at site 48YE408 near Osprey Beach and another quartzite point of the same tradition was collected at site 48YE701 (Cannon, et al. 1996).

Lusk

A quartzite Lusk point was excavated at the Malin Creek site (24YE353) (Vivian, et al. 2008). A chalcedony point was collected during a surface survey of the Yellowstone Lake shoreline (Vivian, et al. 2007). An obsidian Lusk point was recovered at site by the 2004 Lifeways of Canada surface survey at site 48YE1666 (Vivian, et al. 2007). Another probable Lusk point was collected from site 48YE149. Shortt and Davis (1998) discovered a Lusk point at site 24YE9.

Cody Complex

Scottsbluff

Scottsbluff points have triangular or parallel side blades with small shoulder and broad stems nearly the width of the blades. The cross section is generally oval in shape, while the stems are usually ground. Variations of the Scottsbluff have wider triangular blades, are thin and lenticular in cross sections, and have more clearly defined shoulders. Eden points are similar to the typical Scottsbluff, but are narrower in relation to their length. The shouldering for the stems is more subtle and sometimes not noticeable.

Reeve (1989) reports that the Fishing Bridge site (48YE1) a fossil-wood Scottsbluff point was collected. Reeves (2006) reports three possible Scottsbluff points being found during a surface survey in the northern portion of the Park: 1) a chert point of this tradition was collected at site 48YE626, 2) at site 24YE26, and 3) an obsidian point produced from obsidian cliff obsidian was collected from site 24YE139.

More evidence of the Scottsbluff tradition have been discovered at sites: 24YE353 (chalcedony), 24YE2, 48YE448 (chert), 24YE329 (orthoquartzite), 98YP205 (Madison chert), and multiple points at Osprey Beach 48YE409/410 (one of Park Point obsidian).

Eden

Most Eden points are collaterally flaked and have well defined median ridges and diamond cross section. Some cases of transverse parallel and median ridges are known, but these are considered rare variations of the Eden typology.

Truesdale (2000) reports finding a chert point thought to be an Eden point at site 48YE365 along the Madison River in western Yellowstone. At Osprey Beach (48YE409/410) multiple Eden points were recovered through excavation and from the surface, with one being obsidian that is geochemically similar to the Bear Gulch source (Johnson, et al.).

Cody Knife

Cody knives consist of two main parts, a stem and a blade. While the stem, which is very similar to a Scottsbluff or Eden projectile point stem is very difficult to distinguish, the blade is distinctive. The blade, which usually has an angle of less than 45 degrees, usually has a small shouldering or notching where the stem edge and blade meet which sometimes forms a small spur. The blade is usually transversely flaked.

Johnson, et al. (2004) remarks that the Osprey Beach Subphase component of the Cody Complex, is well represented in Yellowstone National Park, especially at Yellowstone Lake. The first substantive information about Paleoindian use of Yellowstone comes from Cody Complex excavations located along the shores of Yellowstone Lake. Prior to subsurface investigations, the 1958-1959 inventories recovered a Cody knife from the south shore of the West Thumb of Yellowstone Lake.

Excavations conducted in 1989 at the Fishing Bridge peninsula (Reeve 1989) recovered a Cody Complex lanceolate (Scottsbluff) projectile point.

In 1992, the Midwest Archaeological Center (MWAC) of the National Park service conducted surface collections and subsurface testing of the Fishing Bridge area in anticipation of road construction. Three Cody Complex tools were recovered, including a Cody knife and portions of two stemmed projectile points. A Cody knife (or fragments of a Cody Knife) was found at 48YE979 along the Yellowstone River by Reeves in 1999 (Reeves 2006).

In 1996, Shortt and Davis (1998) recovered a Scottsbluff point from 24YE26, located about 700 meters west of Cottonwood Creek on the north bank of the Yellowstone River. Sanders (2000) Class III inventory of the Canyon-Lake road in 1999 recovered a gold chert Scottsbluff point from the surface.

The 2000 Wichita State University surface reconnaissance of the beach of the south shore of the West Thumb of Yellowstone Lake produced Cody knives and diagnostic portions of Eden and Scottsbluff projectile points. Multiple tool types were discovered such as shaft abraders, perforators, a hide abrader, core, biface knives, gravers, hammer stone and choppers were identified (Shortt 2002). These tools were associated with nearby charcoal dated to 9,360 years before present. Subsequent excavations by Johnson, et al. (2004) provide an outstanding window into the Late Paleoindian Cody Complex period at Yellowstone Lake.

Reeves (2006) notes that the West Thumb Subphase, which he describes as obliquely flaked lanceolates and stemmed points, were discovered by surface finds and test excavation in Yellowstone (Reeves 2006) as well as from the Malin Creek Site

(24YE353). During the inventory of sites 24YE139, 48YE712, and 48YE979, Reeves (2006) notes that the lanceolate point tips recovered maybe related to the West Thumb Subphase or the earlier Osprey Beach Subphase. Other portions of or complete Cody knives have been identified at around Yellowstone Lake (see Figure 4) at sites: 48YE1324 (one obsidian, one unknown), 48YE1553 (Obsidian Cliff obsidian), 48YE411, 48YE417, 48YE448, 48YE1558 (chert), 48YE1660 (chalcedony), 48YE1664 (orthoquartzite), 48YE469 (chert), 48YE984 (chert), 48YE1022 (chert), 48YE231 (Obsidian Cliff obsidian), 48YE1535 (Obsidian Cliff obsidian), 48YE1331, 48YE623 (obsidian), 48YE1333 (dacite), 48YE1331 (chalcedony), 48YE1699 (chalcedony), 48YE1709 (chert), 48YE1703 (four obsidian), 48YE1576 (two obsidian, one chert), 48YE1588 (obsidian).

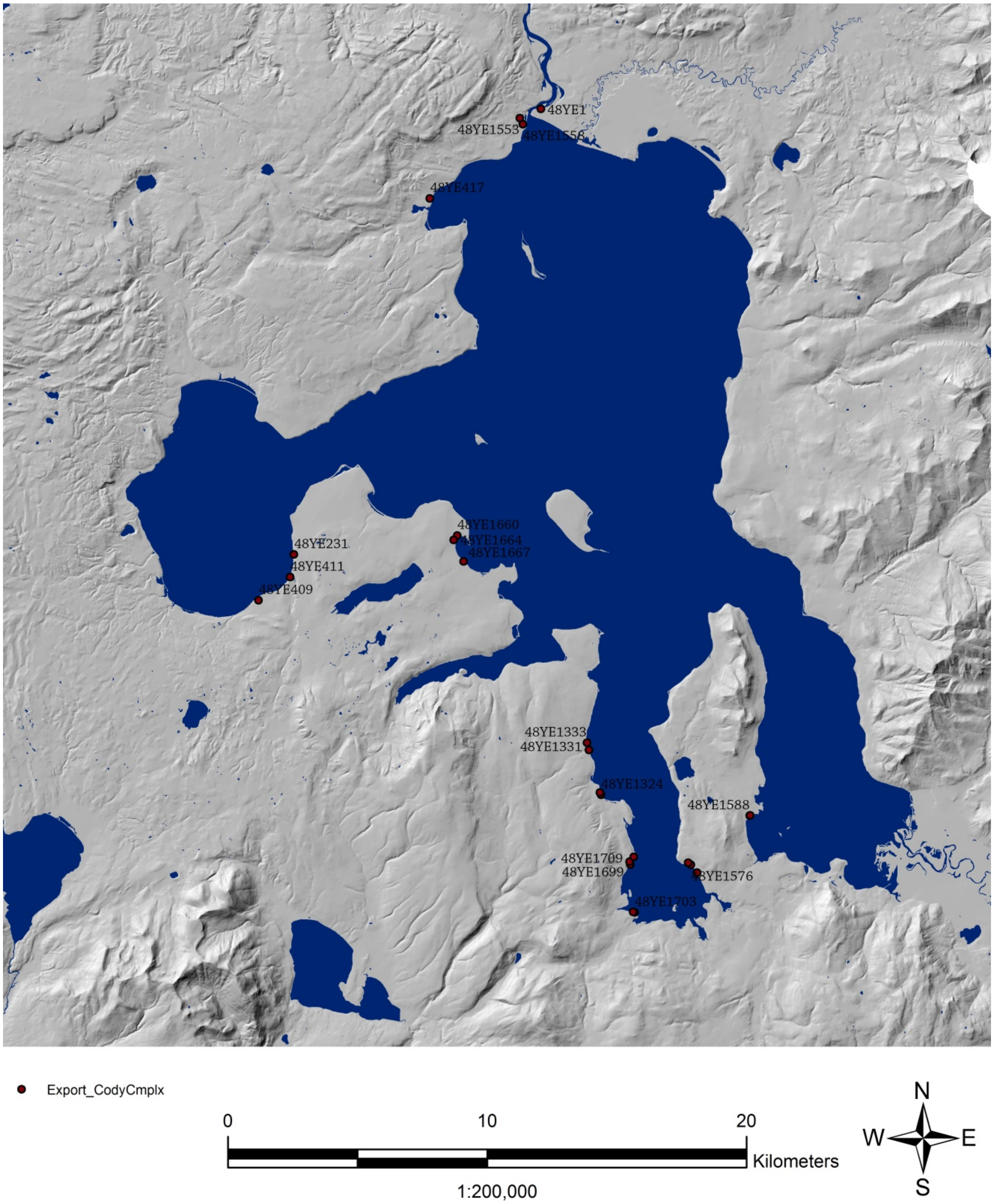

Figure 4. Displays all sites with Cody Complex materials around Yellowstone Lake.

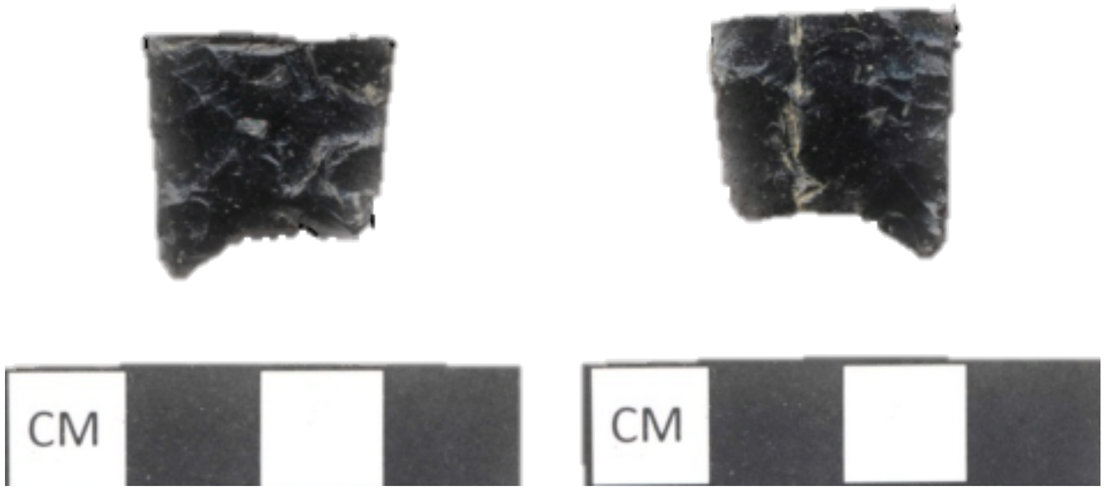

Figure 5. Portion of obsidian, Clovis-like or Goshen point portion from Yellowstone Lake at site 48YE1578; sourced to Teton Pass obsidian source near Jackson Hole, Wyoming.

Figure 6. Shows the obsidian Goshen projectile point discovered by UM along the Lewis River at site 48YE2221.

Lithic Sources

The types of tool stone locally available in Yellowstone include chert, chalcedony, petrified wood, quartzite, sandstone, dacite, and obsidian (Douglas H. MacDonald and Hale 2011; MacDonald and Hale 2013). Hunter-gatherer decision-making regarding lithic raw material procurement strategies is often dependent on many variables, such as human and geological factors (Andrefsky 1994; Elston 1992). Looking at the differential use of raw materials at archaeological sites provides a vast amount of information regarding the lithic technological organization of these peoples (Nelson 1991). When examining the relationship of archaeological sites and raw material procurement locations, it is of extreme importance to be able to match chipped stone artifacts to their initial procurement location. This illuminates a vast amount of information in regard to hunter-gatherer land use and mobility patterns.

A variety of lithic varieties are available throughout much of the Yellowstone National Park and the surrounding region. "These include coarse-grained Precambrian quartzite (usually clear, white or off-white) fine Tensleep quartzite, fine-grained chert, chalcedony, and jasper (gray to black, variable, and yellow to red respectively), volcanic glass, and steatite" (Whitley 2000:112).

Chert nodules of both solid colors and banded varieties occur mostly in the northern sections of YNP, particularly in the Blacktail Deer and Buffalo Plateaus, as well as the Black Canyon of the Yellowstone (Whitley 2000). The Crescent Hill site (48YE729) in the Northern portion of the Park is a prime example of the utilization of chert in the region(Adams 2011; Adams and MacDonald 2015).

Quartz and quartzite stone tools and debitage are commonly found at archaeological sites in the region. Small amounts of quartzite or cherts are possible throughout the park, however, due to the three periods of glaciation when they may have been transported and deposited in glacial moraines and as isolates. However, sedimentary outcrops do occur in areas that were not covered by later volcanic activity (Whitley 2000:113).

Obsidian is arguably the most utilized toolstone material in Yellowstone National Park. A variety of obsidian sources are located in and around Yellowstone due to volcanic nature of the area. The largest and most famous source of obsidian in the region is Obsidian Cliff; which has been extensively used and sought after by prehistoric populations (Davis, et al. 1995; Park 2010; Sanders 2013). Obsidian Cliff is a dense, fairly concentrated source of high-quality homogeneous obsidian that encompasses an area of approximately 3,580 acres. There are a number of other sources of naturally occurring obsidian throughout the region, however, those sources usually occur in relatively smaller amounts and in varying degrees of quality.

The Park Point or Lava Creek source(s) found in the general vicinity of Yellowstone Lake, as well as, a red variant that was recently discovered along the Snake River, during the University of Montana's 2014 Snake and Lewis River Headwaters Archaeological Project inside the YNP southern boundary. Teton Pass sources are located further to the south near Jackson, Wyoming. To the west, the Cougar Creek source is located inside YNP near the West Entrance, north of the Madison River drainage. Further to the west, approximately 65 km outside of YNP, in the Centennial Mountains on Idaho and Montana border is the Bear Gulch obsidian source; which is one of the major obsidian sources for Paleoindian artifacts found in YNP (Cannon and Hughes 1997; Hughes and Cannon 1997; Park 2010). Another lithic raw material source used by Paleoindian cultures in YNP is the Cashman dacite quarry source, located approximately 90 km northwest of the Park. A number of dacite artifacts found within YNP have been sourced to the Cashman Quarry near Ennis, Montana northwest of the Park in the Madison valley (MacDonald 2012).

This shows that the Greater Yellowstone Region had a great deal of resources that could be and were utilized by Paleoindian peoples for at least 11,000 years. The modern ability to combine the recent increase in our knowledge of the environmental and archaeological resources of the region with advancements in GIS database management and research capabilities can aid in focusing our efforts to expand on the mere four percent of YNP that has been inventoried thus far.

Chapter 4

The Yellowstone Paleoindian Model

Methods and Model Development

Data Collection

Exhaustive research was conducted to acquire and create digital resources that could be used in a GIS analysis of environmental variables influencing Paleoindian site location in Yellowstone National Park. The initial database was collected from the NRCS USDA data gateway from August 2013 to February 2014. The 1/3 arc-second Digital Elevation Models (DEMs) were mosaiced together following standard procedure and projected to Universal Transverse Mercator (UTM) North American Datum (NAD) 1983 zone 12N providing an accurate and continuous coverage of digital elevation data from which all elevation derived GIS analyses commenced.

Paleoindian Site Database

Paleoindian site data for Yellowstone National Park was acquired through intensive research of previous archaeological reports largely in paper form. Professor Douglas MacDonald, of the University Montana, provided a number of research reports and unpublished raw site data. Another integral source of Paleoindian site data was the Wyoming Cultural Resource Online (WYCRO) digital database. The WYCRO database provided a good deal of information, in regard to site location coordinates, through digitized site forms, reports, and digitized site locations.

Microsoft Excel was used to compile the site information and coordinates for use later spatial statistical analyses and for ease of modification. Information incorporated into the database included: site numbers, Universal Transverse Mercator (UTMs) coordinates, artifact type, cultural type, lithic material (when available) and raw material source (when available). The site database was imported into ArcMap 10.1 in a vector point shapefile format. North American Datum 1983 UTM Zone 12N (referred to as NAD83 for the remainder of the paper) was chosen as the projected coordinate system, as a majority of the site coordinates and shapefiles were already in NAD83. A sample of site absent locations were created using the *create random points* tool in ArcMap 10.1.

For each of the sample databases, a site score field was created, with the site present database being composed of a score of 1 and a 0 for the site absent database. This was done in preparation for the binary logistic regression procedure that was used to create the model. The point vector format for the both sample data files was then buffered to 10 meters, using *buffer* tool in ESRI's geoprocessing toolbox creating polygon features around each individual point for each site present or site absent files. Sites that had been excavated or had multiple points were made into larger polygons to encompass the respective area. Once the buffer operation was completed these files were converted to raster shapefiles using the *convert features to raster* tool with a cell size of $10m^2$.

Data were extracted from each of the environmental data raster files by using the *Sample* tool in the *Spatial Analyst* toolbox, in the *Extraction* toolset. This was done for the site present and site absent shapefiles. All of the sought after variables were extracted to the shapefiles *Site* or *NoSite*. Once that was complete, each shapefile's attribute table was opened to ensure a proper extraction of the variables had occurred and then the table was exported by right clicking on the desired shapefile in the *Table of Contents* window, scrolling down to *Data* and selecting to *Export Data* and exporting to a *txt*. file format to for later use in *Microsoft Excel* for editing.

Shapefiles and Environmental Variables

A variety of primary and derived shapefiles were necessary to accomplish the creation of this APM. The processes used to create each variable will be discussed below. The exact methods followed for applying these variables to the analysis is discussed in the following section. To provide a consistent raster size, all raster and vector files were clipped to the YNP boundary layer; this enabled the creation of GRID integer raster layers for each environmental variable.

The output attribute table provided cell counts for each class; this was exported from ArcMap to a .txt file and imported into *Microsoft Excel* for statistical analysis. Class values were extracted by site using the *extract values to point* tool in the spatial analyst toolbox. The desired raster's value is added to the representative site, in the site attribute table, these were also extracted in .txt file format and imported into *Excel*. These final two steps were conducted for each dataset, yielding a total of 14 variable raster files.

Datasets

Elevation

Elevation plays an important role in a variety of environmental characteristics. For this study, fifteen U.S. Geological Service (USGS) National Elevation Datasets (NED) 1/3 arc-second Digital Elevation Models (DEMs) downloaded, mosaiced into one projected DEM for the Greater Yellowstone Region (see Figure 7). As mention above

UTM NAD 83 zone 12N was chosen as the projected coordinate system. The 1/3 arc-second DEM has an accuracy of approximately 10m, thus each cell of the raster measures $10m^2$ and is the standard raster grid cell size for the model. The raw elevation values were utilized, but given the vastness of the study area the utility of these values may vary. Elevation values from the DEM were used to calculate a number of derivatives, which produced individual slope (Figure 8), and relief raster's (hillshade was derived for visualization) utilizing the standard routine within ESRI's Spatial Analyst extension for ArcGIS 10.1. Each of these variables has been shown to have an impact on prehistoric settlement patterns, as such, they are appropriate variable choices for inclusion in the models (Butzer 1982; Campbell 2006; Sally T. Greiser 1985; Jochim 1976; Kvamme 1989, 1992, 2006; Peterson 2008; Pilgrim 1987).

The multiple relief measures were produced using Focal (neighborhood) functions and completed using the Raster Calculator with Spatial Analyst. Relief was calculated by determining the range of elevation values (range = maximum – minimum value) within a given neighborhood. Although relief has been shown to play a role in site selection (Kvamme 1979, 1992), the extent of the relief to calculate was unknown, therefore four relief measures were calculated with radii of 150m, 300m, 600m, and 1000m respectively (Figures 9, 10, 11, and 12).

Hydrology

Another dominant environmental factor in hunter-gatherer settlement studies is water (Butzer 1982; Duncan and Beckman 2000; Sally T. Greiser 1985; Jochim 1976; Kohler and Parker 1986; Kvamme 1979, 1992; Lock and Stancic 1995; Maschner and Stein 1995; Peterson 2008; Verhagen 2007). All hydrological data (i.e. Rivers/streams, Lakes, etc.) used in the model came from or derived from a National Hydrography Dataset (NHD) generated and distributed by the NRCS/USDA through the National Geospatial Management Center. Yellowstone Park has eight prominent river valleys (Yellowstone, Gardiner, Lamar, Madison, Gibbon, Firehole, Lewis, Bechler, and Snake) along with many smaller streams, all of which were downloaded in a single vector polyline shapefile, labeled *NHD flowline*. The original dataset was separated into two new datasets, perennial and intermittent streams, and accomplished through the *select by attributes* tool from the shapefiles attribute table and using a *query* to select for the appropriate 'FCODE' classes. Subsequently the selected data was extracted, creating individual shapefiles for rivers, perennial, and intermittent streams.

Distances from: rivers (Figure 13), perennial streams (Figure. 14) and distances from intermittent streams (Figure 15), were calculated in a separate raster file. Distance from the confluences with rivers (Figure 16) was also calculated. All of these 'distance from' measures were on a meter scale with the 1/3 arc-second DEM as a raster surface using the *distance from* tool in ESRI's predictive analysis toolbox.

Confluences of waterways, from my experience, tend to have higher densities of archaeological sites. To create a confluence variable layer, it was decided to create a variable to represent the confluences of streams with the major rivers listed above. This was accomplished by buffering each of the three-*flowline* shapefiles, then using the ESRI geoprocessing *intersect* tool to create two shapefiles that represent the confluences of rivers and streams (Figure14), as well as, lakes, rivers, and streams (Figure 17).

Also a *distance from springs* layer (Figure18) was derived from the *NHD waterbody* polygon shapefile following the same procedures mentioned above. This was utilized in an attempt to determine if there was any spatial patterning in relation to water resources away from the primary sources listed above. As with the swamp and marsh theme mentioned below it was hypothesized that springs would have been an attractor for animals and possibly for certain plants as well.

Vegetation or Land Cover

Three shapefiles were derived from the National Land Cover Dataset (NLCD) polygon shapefile. The three derived themes were: Forests, Shrubs and Herbaceous, and Swamps and Marshes. Then, in an attempt to represent a forest to grassland ecotone, the distance from the polygon edge was calculated using ESRI's *predictive analyst* toolkit. The output from this tool is a raster and in this case a 10m output raster cell size was selected. This was done for both, the forest and the shrub/herbaceous polygons layers, which are shown in Figures19 and 20 respectively.

It was thought that by using the swamps and marshes it may be possible to model areas where possible hunting areas may have been, as well as, possibly representing prehistoric water resources. Thus a distance from layer was calculated for the swamp and marsh layer as shown in Figure 21.

Landforms

The process of creating the landform layers used in the model follow the same techniques used in the vegetation section above. Three landform *distance from* layers were derived: 1) a glaciated rolling uplands layer (Figure 22), 2) a glaciofluvial terraces and plains layer (Figure 23), and 3) an alluvial landform layer (Figure 24). Distance from was used instead of the representative values previously assigned to each landform class, as there were problems implementing these categorical variables into the logistic regression modeling process in the statistical program SPSS (Statistical Package for the Social Sciences). These specific landforms were chosen after visually inspecting the site locations in relation to the landforms and the overall distribution of the landforms throughout YNP.

Data Extraction and Model Construction

Upon completion of constructing the GIS database, environmental data for site and non-site locations were extracted and exported to SPSS (Statistical Package for Social Scientists) software for analysis. Data were extracted for each of the independent variables each of the site and non-site cells using the *sample* tool in ESRIs spatial analyst toolbox. The output of the *sample* tool is a tab-delimited text file that was imported into SPSS and compiled into a single dataset. For each land parcel or cell, the archaeological condition and associated values from the environmental variables are written out to an individual row; therefore 11,700 site present and 14,585 site absent rows of data were extracted. Once compiled in SPSS, the data were ready for statistical analysis.

In order to determine if the proposed environmental variables should be included in the model, univariate statistical comparisons (Mann-Whitney U and Komolgorov-Smirnoff) were used to establish if the dependent variable, the two archaeological event classes (site or non-site) had significant differences between them for each continuous independent variable. Of all of the variables were found to be significantly different at $\propto$=0.005. Significant differences for all the independent variables signify that each of the environmental variables is suitable for inclusion in the model, necessary for the general validity of the model.

In terms of statistical analysis, the specific method chosen for model construction was a backward, step-wise binary logistic regression. In this mode of logistic regression, all independent variables are initially used in the equation and the power of the model is calculated; next, each independent variable is iteratively removed and the power is recalculated. If the change in model power is significant, the variable with the least explanatory power is removed from the set of independent variables and the process of power calculation and variable removal is repeated (Campbell 2006). Processing continues until the removal of a variable does not significantly change the power of the model. Once completed, the remaining variables all have significant explanatory power (Clark and Hosking 1986).

The specific model was run in a backward step-wise method, which resulted in the *distance from springs* and the *distance from alluvial landforms* layers being excluded. The backward stepwise model was a logical approach because all the environmental data layers are used initially as explanatory variables. From an archaeological perspective, it is reasonable to assume that site selection was based on a simultaneous evaluation of multiple environmental criteria; this is best represented statistically in the backward stepwise method (Campbell 2006). Additional discussion of the internal statistical metrics is not required for two reasons. Specific details of the regression model construction are included in Appendix A in the form of SPSS output tables.

Model Output

The regression equation within SPSS is mathematically written as follows:

Z = 2.48446 + (Relief1000 * 0.00265) + (Relief600 * - 0.00919) + (Relief300 * - 0.01674) + (Relief150 * - 0.03408) + (Slope * 0.10620) + (SwampMarsh * 0.00023) + (Dist. to Inter. * 0.00073) + (StrmRvrConf. * - 0.00003) + (LkConf. * - 0.00090) + (Perr. Strms * - 0.00035) + (ShrubHerb * - 0.00130) + (Forest * - 0.00225) + (TerracePlains * - 0.00051) + (RollUplands * - 0.00018)

"Positive coefficients indicate that high values of the corresponding variables are related to the site-present class while negative coefficients link low values of a variable with that class" (Kvamme 1992:29). Therefore, moderate values of relief (1000), slope, distance to swamps or marshes, and distance to intermittent streams tend to be more associated with Paleoindian site locations.

The relationship between Paleoindian sites and moderate values of slope was surprising initially, however, realizing that a majority of the Paleoindian artifacts I have discovered and seen discovered are typically very near eroding terraces or embankments; which the GIS cannot discern without more accurate elevation datasets. Therefore it is more likely that these terrace edges, combined with the other variables are more likely to yield Paleoindian artifacts than pure chance alone. The model also shows that Paleoindian sites are more closely associated with lower values in the variables: relief 600m, 300m, and 150m, as well as, stream and river confluences, confluences with lakes, streams and rivers, distance to perennial streams, distance from glaciofluvial terraces and plains, glaciated rolling uplands. These all seem relatively obvious, but if one was to look at the landscape of all of Yellowstone National Park, it is clear that areas with these types values coincide only over a fraction of the Park. Not surprisingly the lower the values in distance to shrub and herbaceous vegetation, and distance to forests were more associated with Paleoindian sites. The use of these variables in a distance from manner was an attempt to represent the ecotone between grassland and forest and appears to have succeeded. Although as mentioned in chapter 4 this could possibly be refined further by also doing an internal distance from the edge of the polygons, therefore providing multiple measures of Paleoindian sites distance from grassland and forest boundaries.

The results show generally what was already assumed about Paleoindian site locations in YNP, but the ability to visually display these areas that meet the selected environmental criteria is valuable, particularly to resource managers and researchers in planning future projects.

The following equation was used to convert the output of the regression into a probability score:

$$\mathbf{Prob(S) = 1/(1+EXP(-Z))}$$

"This equation represents the best quantitative description between the occurrence of archaeological sites and the environment developed for the study area" (Campbell 2006:62). Utilizing the Raster Calculator tool within the Spatial Analyst toolbox these two equations were input with their corresponding layers into GIS. Once calculated, the regression equation is applied to every $10m^2$ land parcel in the study area. The GIS calculates the output of the regression equation for every land parcel or raster cell in the study area, which in this case is 88,901,690 land parcels. The output for every cell is a numerical value, constrained between 0 and 1, which describes the potential of that raster cell or land parcel to contain archaeological material. A location with a score near 0 indicates a set of environmental characteristics more similar to the characteristics of the site absent class, while a score near 1 represents a location with characteristics similar to those in the site-present class.

The resulting output is a decision or probability surface of continuous data values containing the probability score of each land parcel in the study area. The final model overview image can be seen in Figure 25.

The visual analysis of the spatial patterns generated by mapping the output equation reveals some interesting landscape patterns. From a macro perspective, the first obvious observations are of the high probability values along the major hydrological drainages, around the major lakes, and interestingly on the edge of steeper slopes where the topography bends. Low values are observed in the more mountainous, thickly forested slopes, and where there are fewer concentrations of streams. When zoomed in to a scale of 24,000 or larger, such as the examples shown in figures 26 and 27, the unique computation of each land parcel becomes apparent.

Two sites that weren't entered into the developmental process due to a lack of coordinates did have associated descriptions that generally explain their location. When these areas are viewed with the probability surface one site near Grebe Lake appears to be quite accurate as seen in Figure 28. However, other site shown in Figure 29 near Fawn Pass does not match up quite as well although there are areas near to the estimated location that may be the actual location. It should be noted that the site description of the Fawn Pass find was substantially less detailed than the description of the surface finds (Hell Gap and Cascade point) near Grebe Lake.

Chapter 5

Model Testing

Base-Rate Probabilities

In order to conduct most quantitative model assessments a base-rate probability must be computed. A total of 64 Paleoindian sites or isolated finds, as mentioned above, were used to develop this model. The sites occupy a total of 11,700 10m x 10m raster cells or land parcels, out of the 88,901,690 total units in the entire YNP study area. The base rate or a priori probability of site-present (S) event class was calculated as:

$$Pr(S) = 11,700/ 88,901,690 = 0.0001316$$

And the site-absent class (S') as:

$$Pr(S') = 88,889,990 / 88,901,690 = 0.99987$$

The event classes are mutually exclusive and represent all possible outcomes, i.e., $Pr(S) + Pr(S') = 1$. The base-rate probabilities provide "pure-chance" probabilities for each archaeological event class. With the establishment of the a priori probabilities for the two event classes there is a standard by which to evaluate the predictive model. Kvamme (1992:28) states that in order to be considered effective a model must predict the occurrence of an event with a probability greater than the events base-rate chance of occurrence. The mathematical representation of this statement is written as such:

$$Pr(S|M) > Pr(S)$$

Where $Pr(S|M)$ is the probability of a site given that the model specifies a site. The calculated value of $Pr(S)$ is artificially lower than reality due to how rare known

Paleoindian sites are in a majority of Yellowstone. Calculation of Pr(S|M) was designed to be conservative due to the inclusion of all known site-present parcels in calculation of the base-rate probability, Pr(S). The base-rate probability was computed using only the training sample, this is not optimal; it's due to the limited Paleoindian sites recorded and the need for sites to use in the 'training' of the model. Optimally, there would be a number of sites withheld from the developmental stages of the model and used only to assess the models accuracy and performance. This is mentioned here, due to the fact that the base-rate probability would be greater for the Pr(S) class and would have increased the model's statistical predictive power over random chance.

Using the methodology and nomenclature, the results of the model can be summarized as follows:

$$Pr(S) = 0.000132$$

$$Pr(S') = 0.9999986$$

Model Assessment

Model accuracy is assessed using the methods described in (Kvamme 1992). Methods and logic for the accuracy assessment are reported below. The optimal modeling goal is to maximize the percentage of correctly classified site present (S) in a minimum of land area (M). The techniques for calibrating the model for this goal are a critical component of model assessment.

The predictive model's accuracy is measured in terms of its ability to properly classify both known site locations and known non-sites. Accuracy includes both the percentage of correctly classified site, as well as the percentage of correctly classified non-sites. The percentage of correct sites represents the percentage of sites (S) that are correctly classified within the site-present class of the model (M), whereas the percentage of correctly classified non-sites (S') represents the percentage of the site-absent class of the model (M'). These two measures can be described as 100Pr(M|S) and 100Pr(S'|M'). Additional assessment measures include the probability of a site occurring when the model predicts a site, Pr(S|M)m and the probability of a site occurring when the model does not predict a site, Pr(S|M') (Kvamme 1988, 1992).

Output of the model classifies the landscape into two event classes (M and M'), yet the output of the regression is a probability score ranging from 0-1. A 'cut-point' in the range of probabilities must be established. For example, the standard cut-point is 0.5, meaning that any land parcel or cell value with a probability score of 0.5 or less would be assigned to the site-absent (M') class and any score with a score higher than 0.5 would be included in the site-present (M) class. Mathematically, this relationship is described as:

$$M=L\geq 0.5$$

And

$$M' = L\leq 0.5$$

Where L is the decision or cut-point at which the range of values is divided. Although 0.5 is the standard cut-point, the value can be shifted higher or lower based on modeling needs. For instance, if the cut-point was 0.4, the percentage of archaeological locations correctly identified would increase, but an associated decrease would occur in the percentage of non-site locations correctly identified. This is due to more land area or cells in GIS being included in the site-present class (M) as the cut-point is lowered. Theoretically, if the cut-point was extremely low, for instance 0, then the model would accurately predict 100% of the archaeological sites and 0% of the site-absent (M') classes. Therefore, consideration of the cut-point is critical in the development of an effective model.

The method for determining an accurate cut-point for this predictive model was guided by Kvamme (1992), who indicates that a predictive model should correctly identify at least 85% of the site-present sample. Optimally, the cut-point represents the point at which the model correctly predicts the greatest percentage of the site present (S) and site absent (S') classes simultaneously (Warren and Asch 2000). Campbell (2006) and Kvamme (1992) use the graphical intersection of the (S) and (S') classes to establish their cut-point, each adjusting their cut-point to varying degrees decreasing their cut-point to improve the percentage of the correctly classified site present (S) class. The graphical intersection of the two classes in this study displays an optimal cut-point between 0.5 and 0.6. Only after viewing the graphical intersection of the two classes and visualizing the possible changes in GIS was the standard cut-point of 0.5 was deemed to be adequate and therefore used in this model.

A cut-point of 0.5 will accurately predict 88.6 percent of known sites and 89.1 percent of non-sites while only predicting 11 percent of the land area as the site likely (M) region. The probability of a site occurring in the area predicted as site-present is calculated as:

$$\Pr(S|M) = \frac{\Pr(S|M)\ \Pr(S)}{\Pr(M|S)\ \Pr(S) + \Pr(M|S')\ \Pr(S')}$$

The probability of a site occurring in the area predicted as site-absent is calculated as:

$$\Pr(S|M) = \frac{\Pr(S|M)\,\Pr(S)}{\Pr(M'|S)\,\Pr(S) + \Pr(M'|S')\,\Pr(S')}$$

Comparison of the predicted sites-present probability and the base-rate site-present probability indicates that Pr(S|M) is greater than Pr(S) (0.00105>0.000132), therefore the model is outperforming random chance alone.

Possible Test of Data

During the 2014 University of Montana survey two previously unknown Paleoindian artifacts were recorded at sites near Yellowstone Lake and one along the Snake River. With the data from these new sites it is possible to provide an assessment of the model without relying solely on the training data used to develop the model. The processing and data extraction for the new site data follows the methods described above for the training data. The two new sites occupied 36 cells (10m x 10m) or land parcels. The model, at a 0.5 cut point, correctly classified 34 of the 36 cells and correctly classified 5,510 of the 6248 randomly generated10m x 10m sample cells for the site absent class.

The testing results indicate that, 94.4 percent of the site present cells and 88.2 percent of the site absent cells were correctly classified at a 0.5 cut point. With only 11 percent of the total land area being classified as (M) or site likely area. This indicates that the model is classifying very well.

The comparison of the predicted site-present probability and base-rate site present probability reveals that Pr(S|M) is greater than Pr(S) (0.00106>0.00013), therefore the model is performing better than random chance. However, it is likely that there is a sampling bias that correlates with the recorded Paleoindian sites. Regardless the model is appears to be meeting and surpassing all the modeling goals mentioned above. Further results indicate that the probability of finding Paleoindian cultural materials in the area predicted as site present is Pr(S|M)/Pr(S)= 0.00106/0.000132=7.992 times more likely than pure chance, which is a very significant improvement. Also, the probability of there being a site located in the area predicted as site absent is roughly 125 times less than the probability of a site in the area predicted to have a site. About 0.00084 percent of the locations in M' will contain a site.

Training Data table:

at 0.5 Cut Point				Pr(S|M)	
Pr(S')	0.9999986			0.001071806	If Model predicts a site the probability of S presence
Pr(M|S')	0.109				
Pr(M'|S)	0.124			8.119739626	Times more likely than pure chance
Pr(M'|S')	0.891			11	% of Model
Pr(S)	0.000132			Pr(S|M')	
Pr(M|S)	0.886			0.0000184	probability of paleo site in M' region
	(M) Site Present L≥	(M') Site Absent ≤	N		
(S) Site Present	10370 (88.6%)	1330 (12.4%)	11700		
(S') Site Absent	1596 (10.9%)	12989 (89.1%)	14585	89	% of Model

Table 1: Shows values calculated for and used in assessment of the training data.

Testing Data Table:

at 0.5 Cut Point	a priori Baseline			Pr(S|M)	
Pr(S')	0.9999986			0.001054888	If Model predicts a site the probability of (S) presence
Pr(M|S')	0.118				
Pr(M'|S)	0.056			7.991572088	Times more likely than pure chance
Pr(M'|S')	0.882			11	% of Model
Pr(S)	0.000132			Pr(S|M')	
Pr(M|S)	0.944			0.00000838	probability of paleo site in M' region
	(M) Site Present L≥	(M') Site Absent ≤	N		
(S) Site Present	34 (94.4%)	2 (5.6%)	36		
(S') Site Absent	738 (11.8%)	5510 (88.2%)	6248	89	% of Model

Table 2: Shows values calculated for and used in assessment of testing sites.

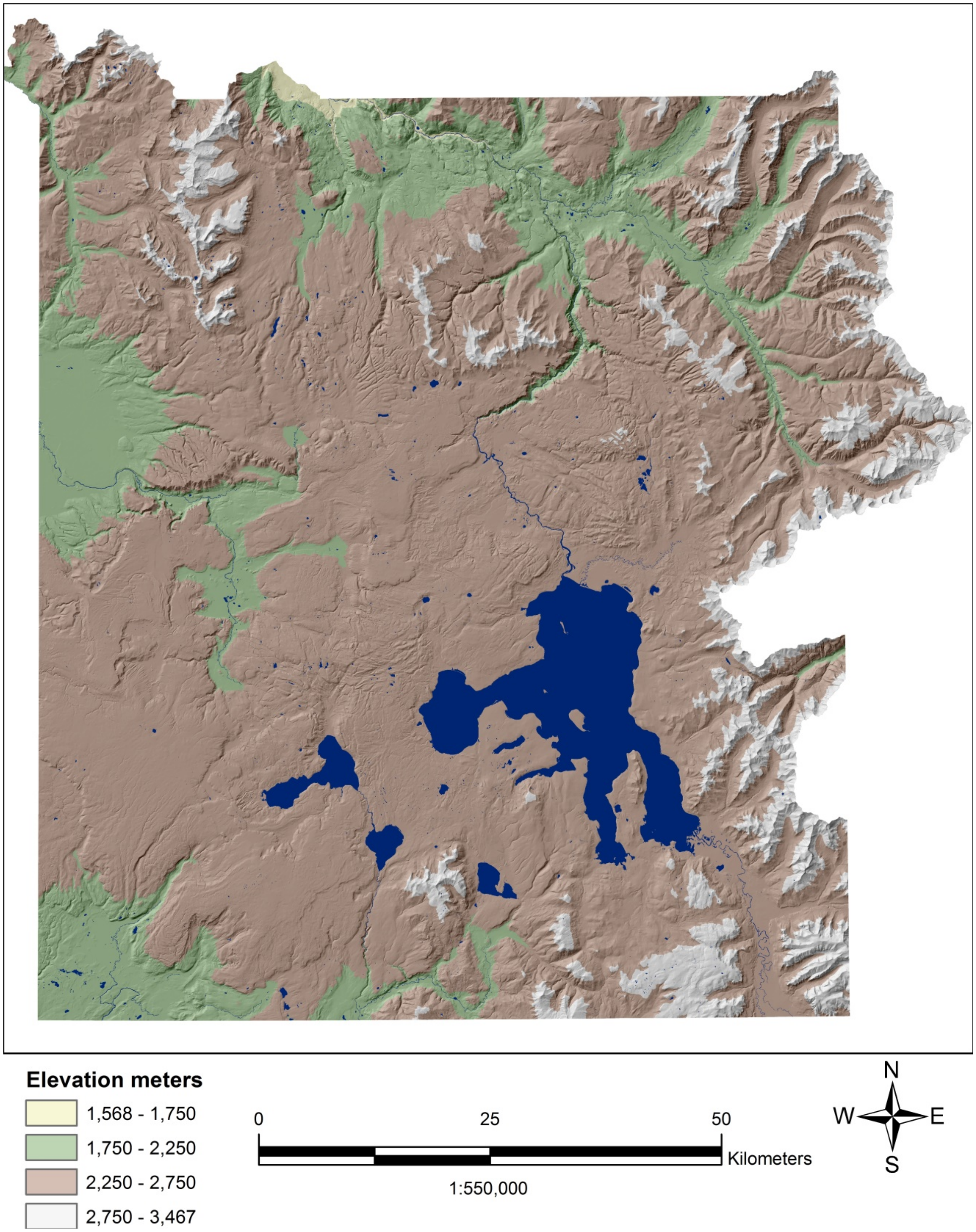

Figure 7. Displays the DEM over a Hillshade (that was derived from the DEM shown) with elevation breaks in meters

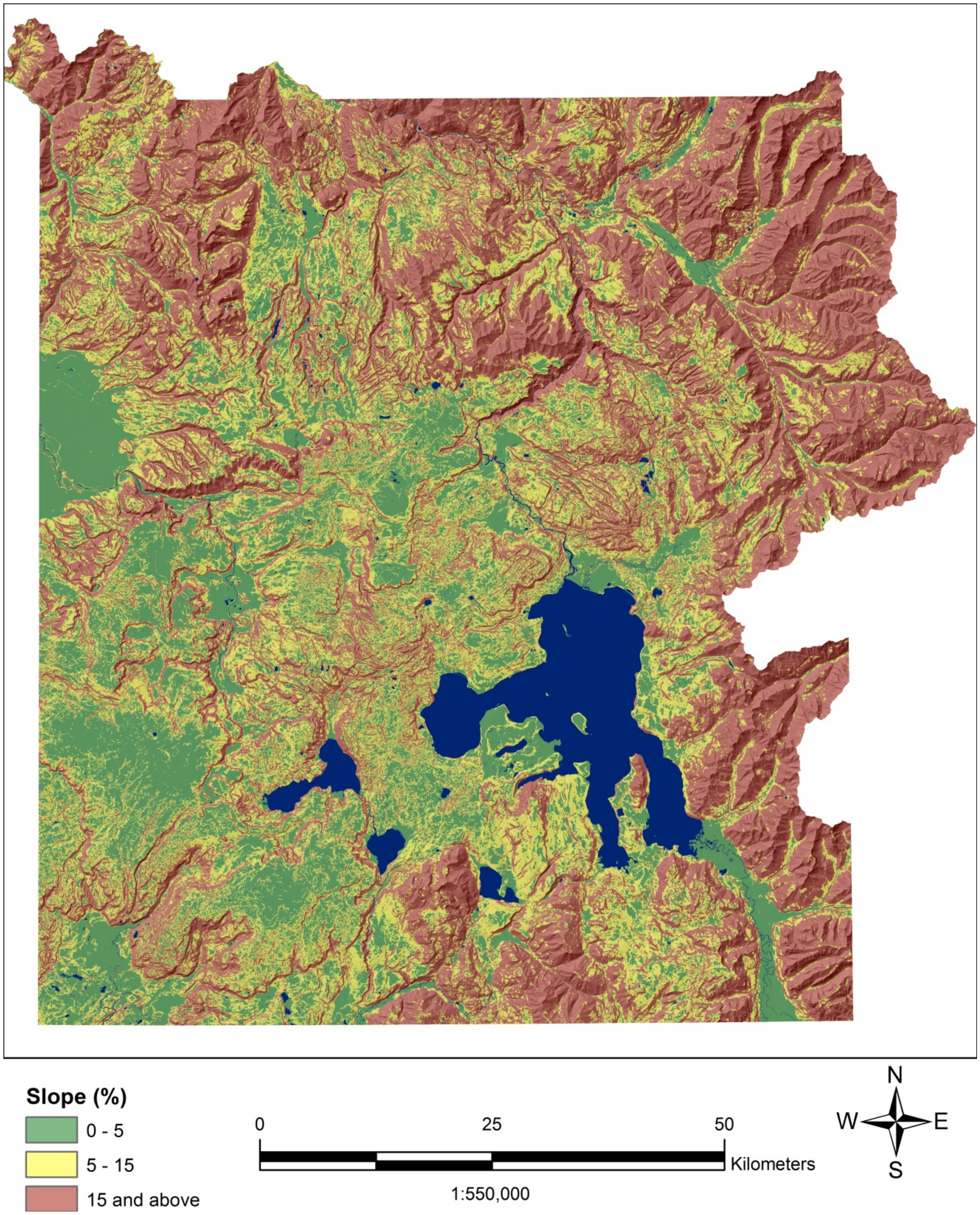

Figure 8. Displays the derived slope (in percent rise) layer with three classes; 0-5%, 5-15%, and 15% and above.

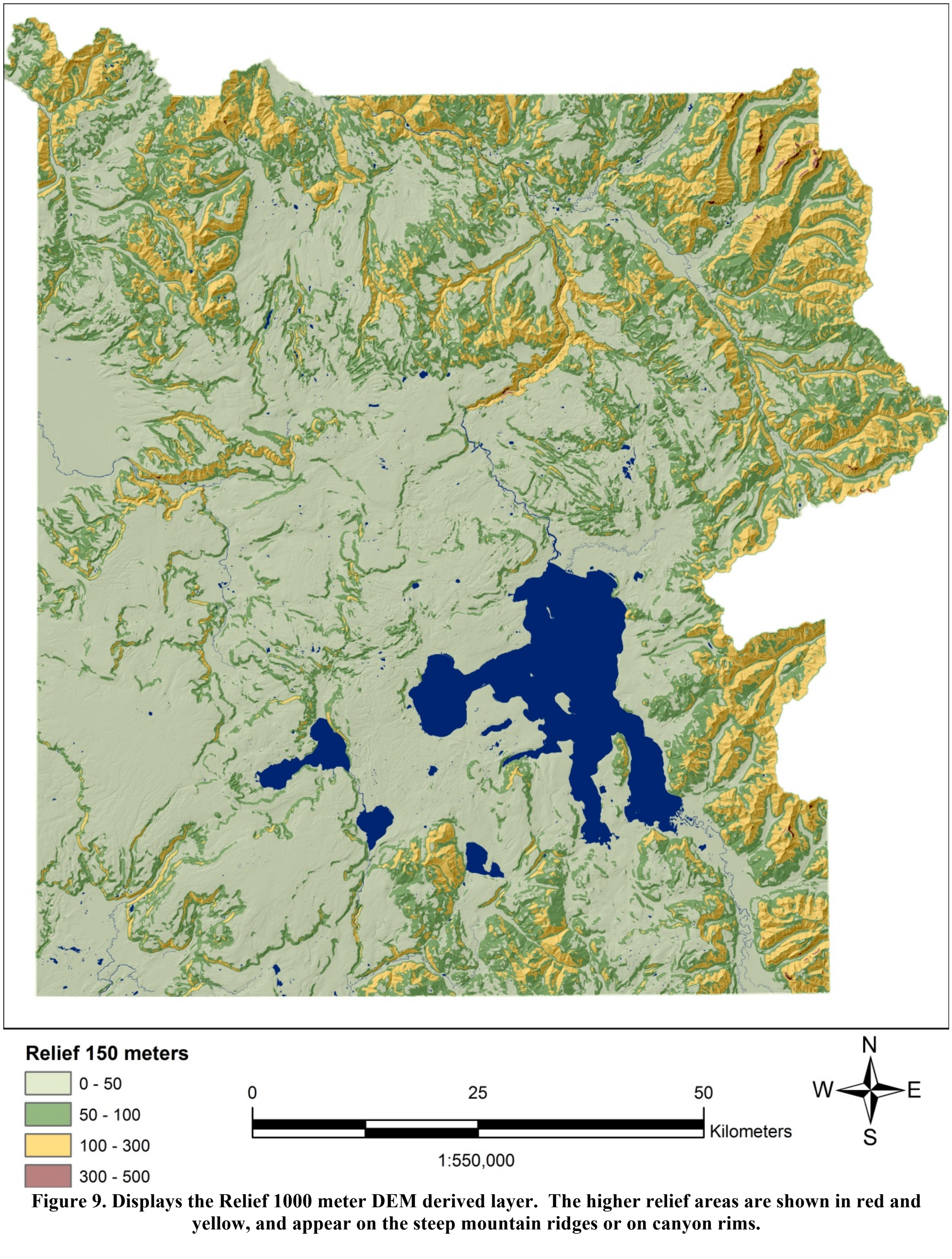

Figure 9. Displays the Relief 1000 meter DEM derived layer. The higher relief areas are shown in red and yellow, and appear on the steep mountain ridges or on canyon rims.

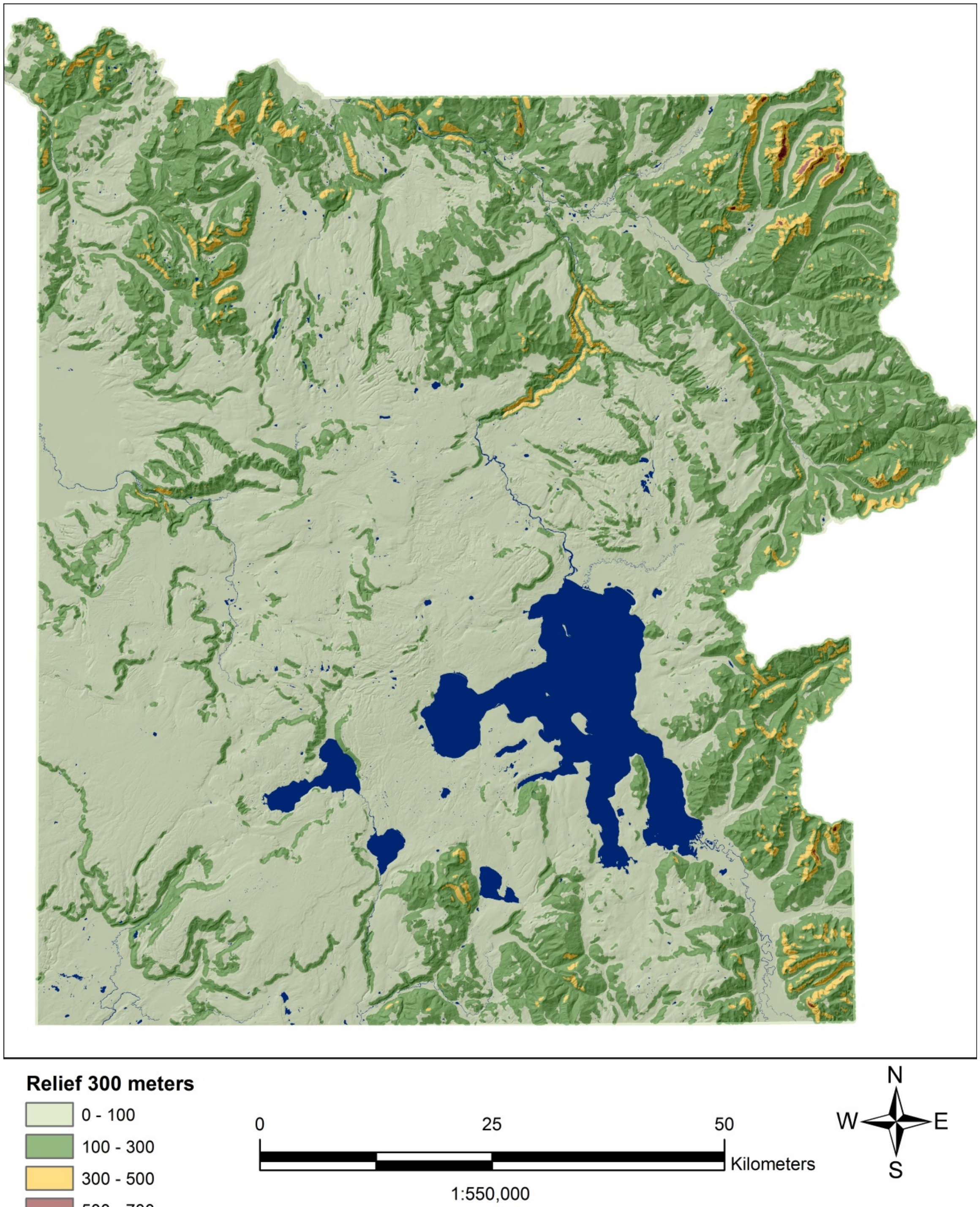

Figure 10. Displays the Relief 300 meter DEM derived layer. The higher relief areas are shown in red and yellow, and appear on the steep mountain ridges or canyon rims.

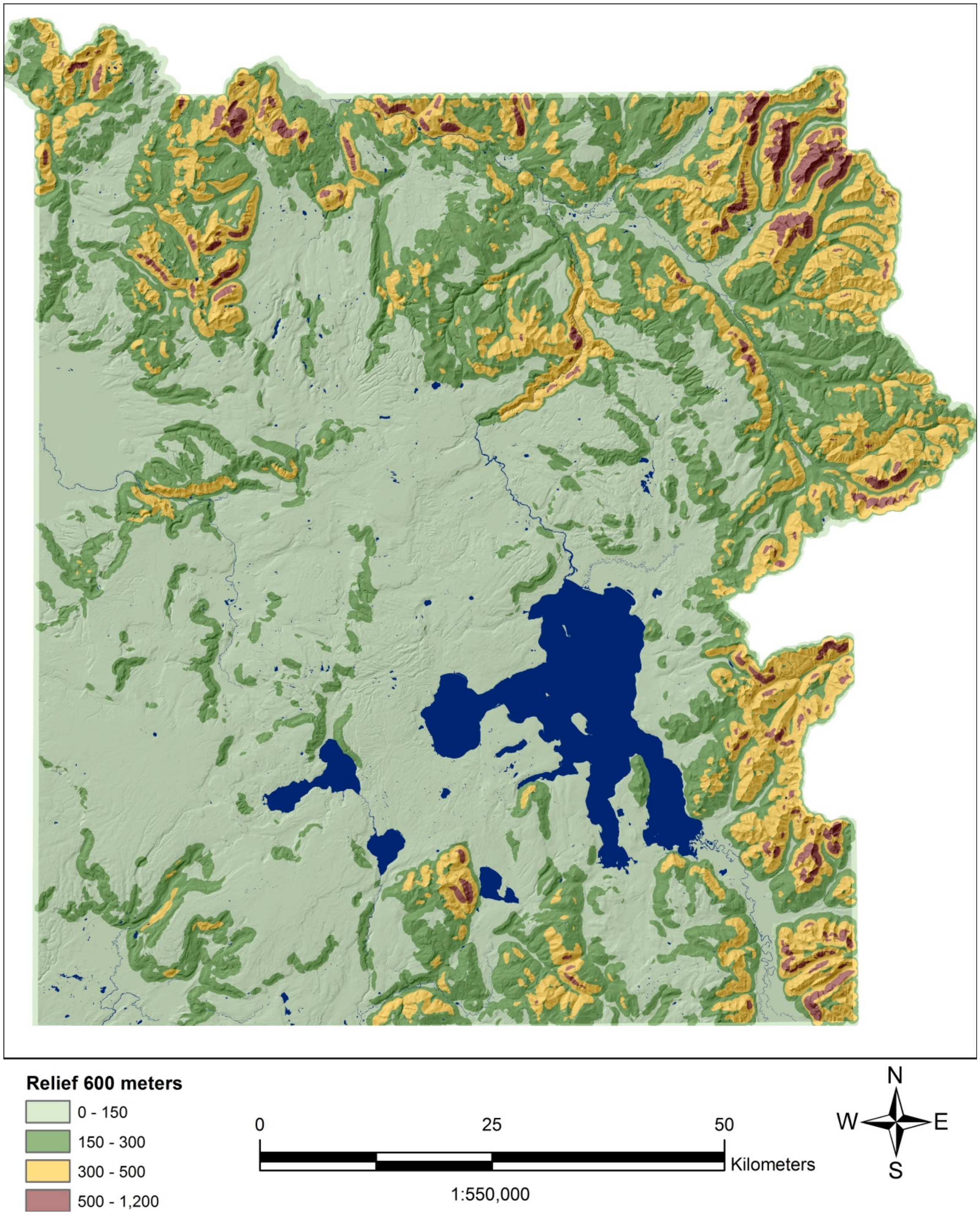

Figure 11. Displays the Relief 600 meter DEM derived layer. The high relief areas are visible in red on the steep mountain ridges.

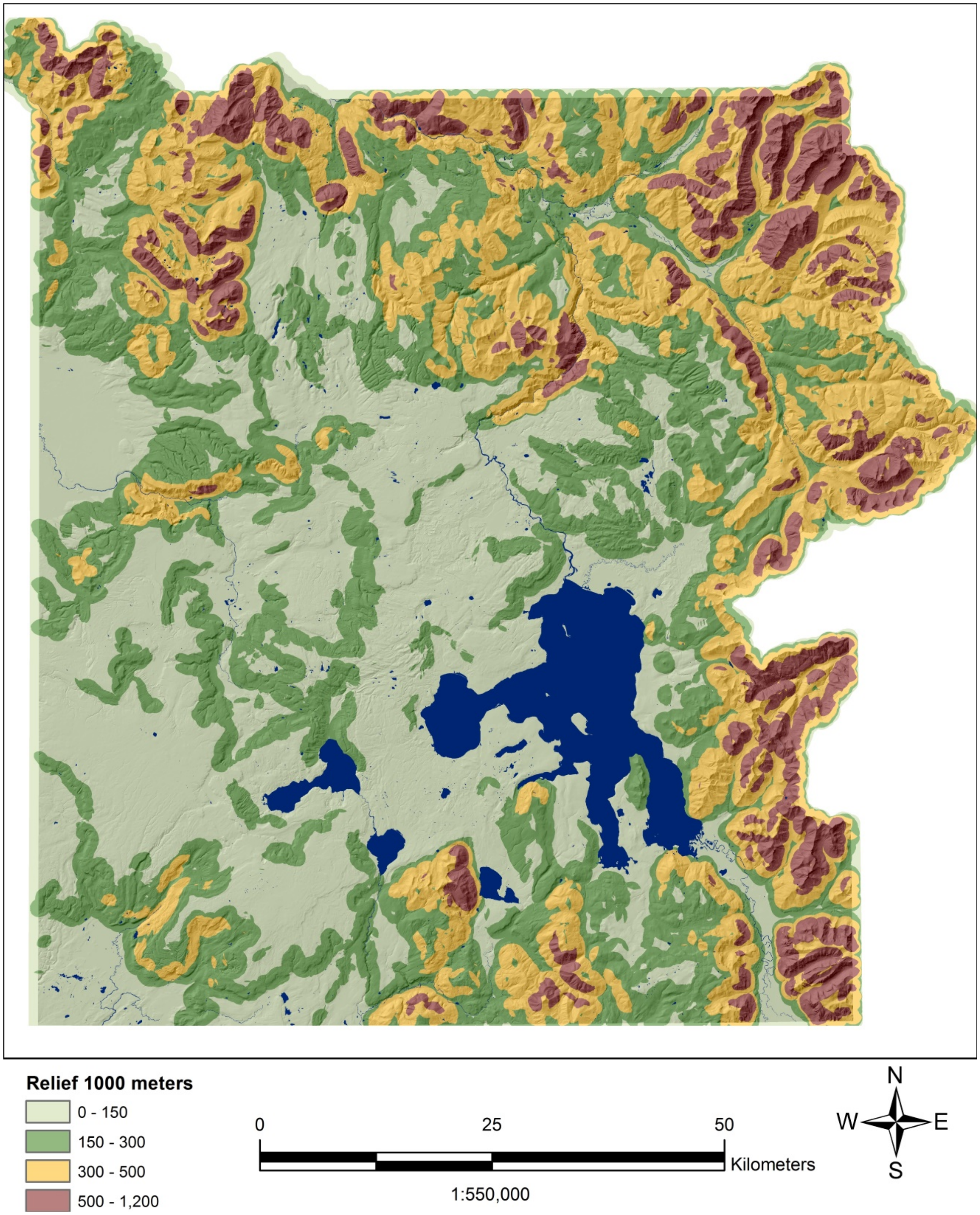

Figure 12. Displays the Relief 1000 meter DEM derived layer. The high relief areas are obvious on the steep mountain ridges.

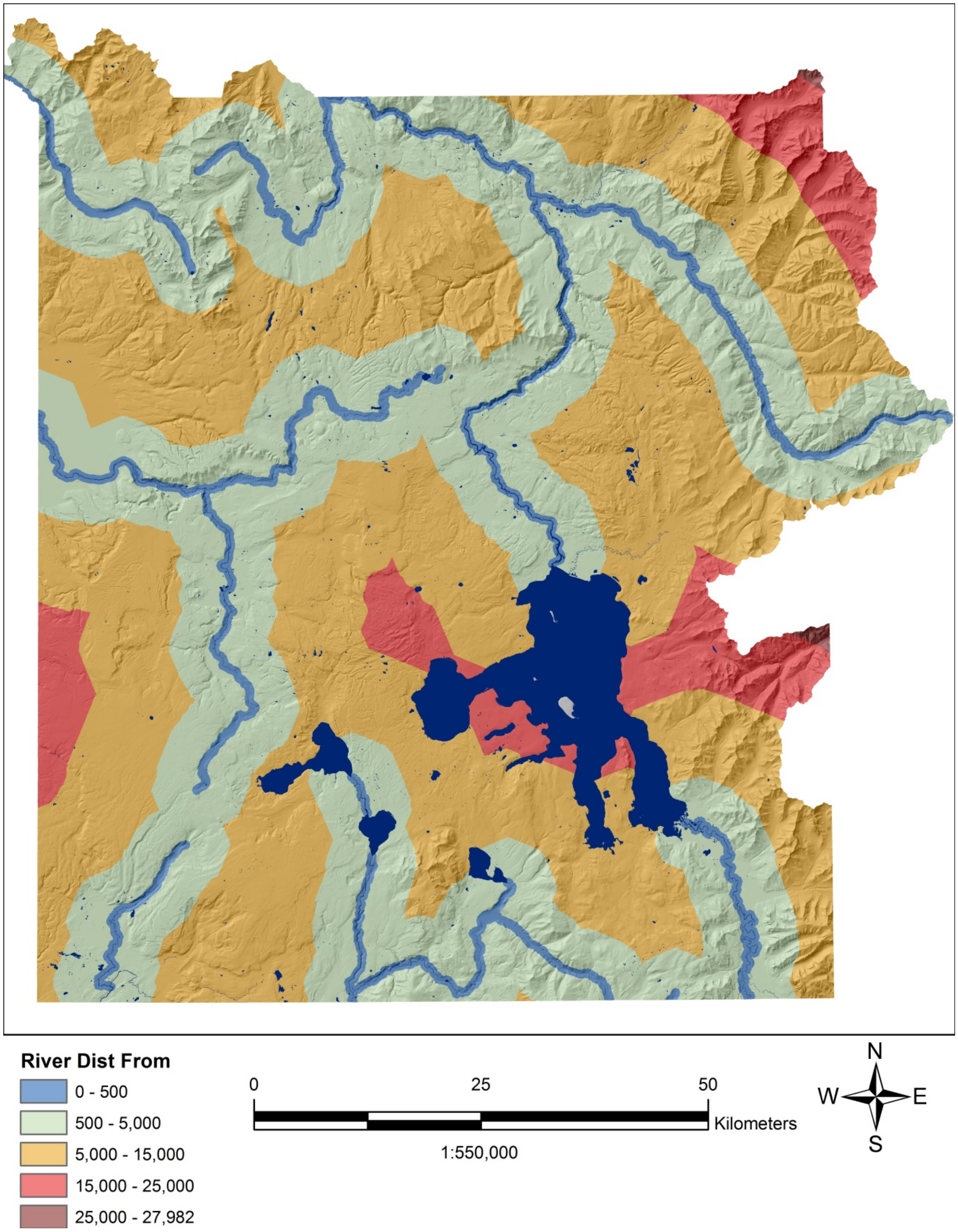

Figure 13. Displays the 'distance from rivers' layer derived from the NHD flowline dataset and calculated with ESRI's predictive analysis toolkit.

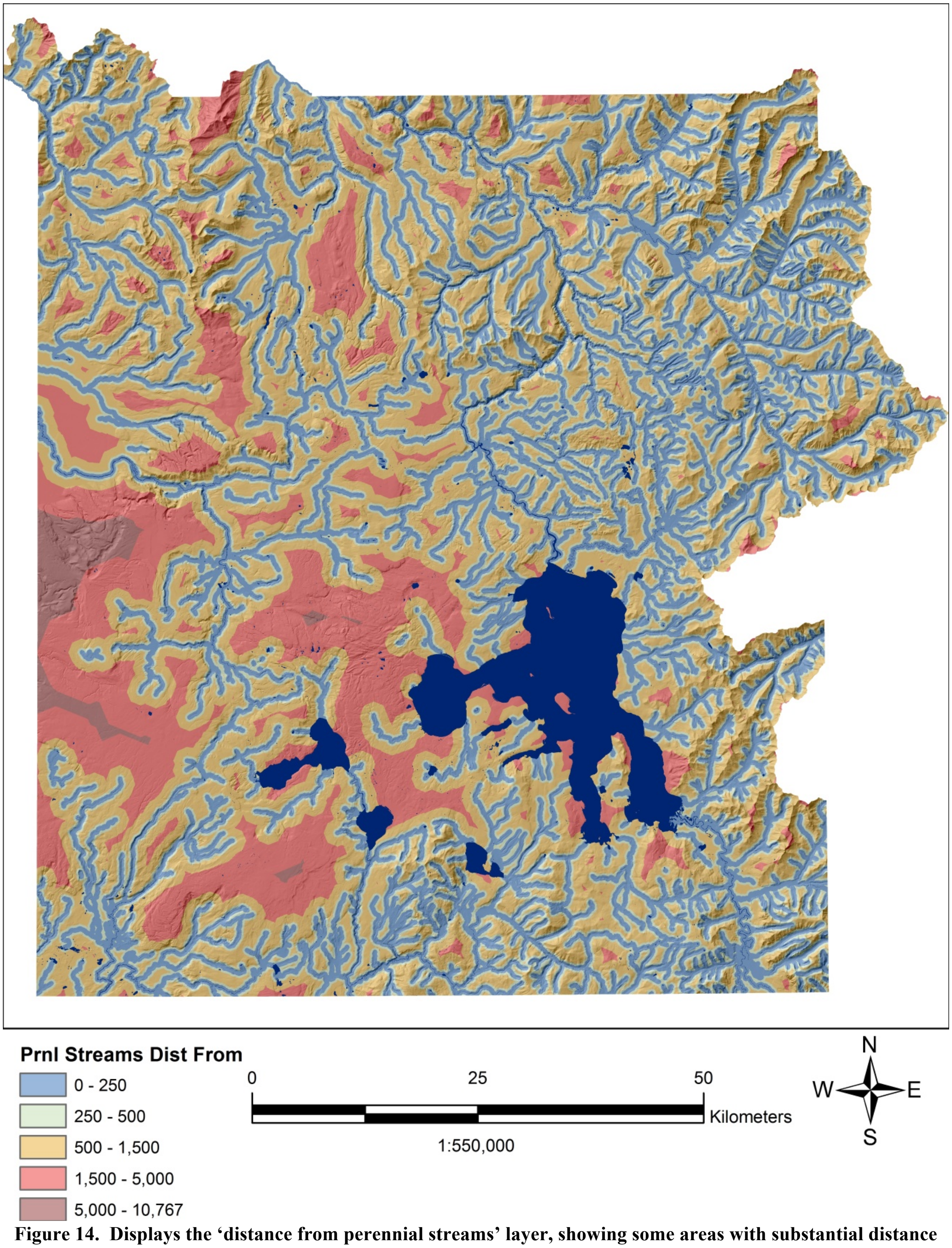

Figure 14. Displays the 'distance from perennial streams' layer, showing some areas with substantial distance from permanent streams.

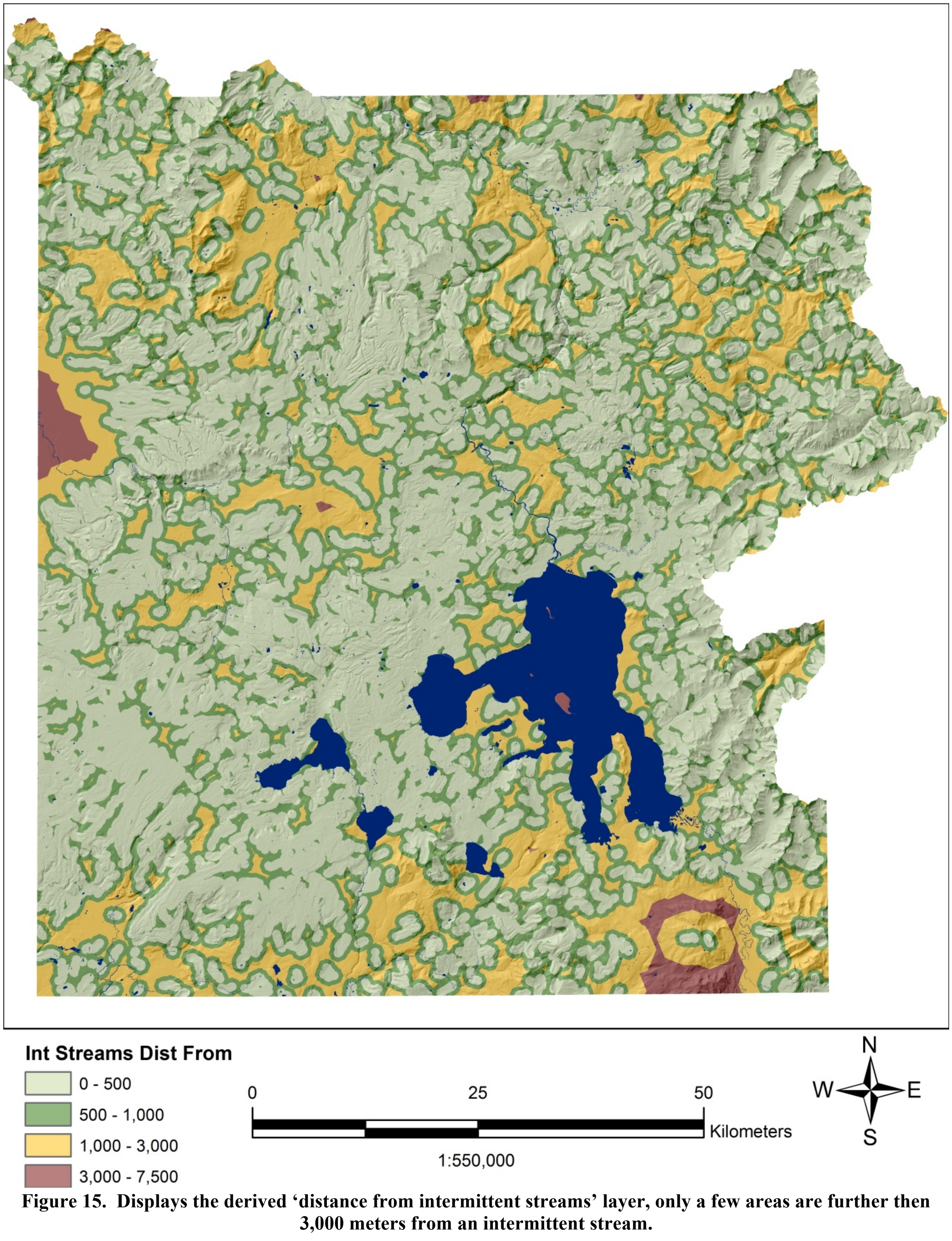

Figure 15. Displays the derived 'distance from intermittent streams' layer, only a few areas are further then 3,000 meters from an intermittent stream.

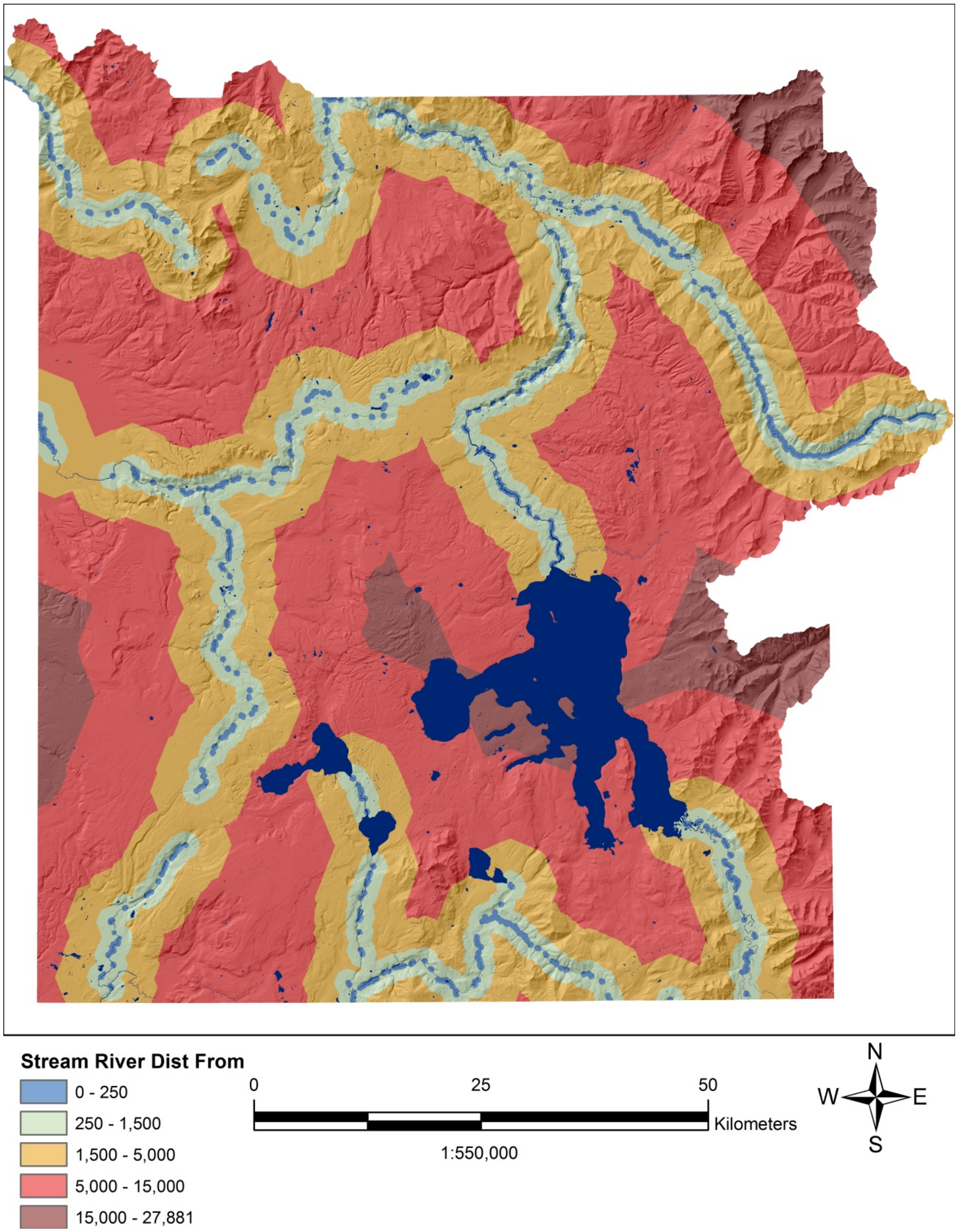

Figure 16. Displays the 'distance from streams and river confluences' layer, distances are represented in meters

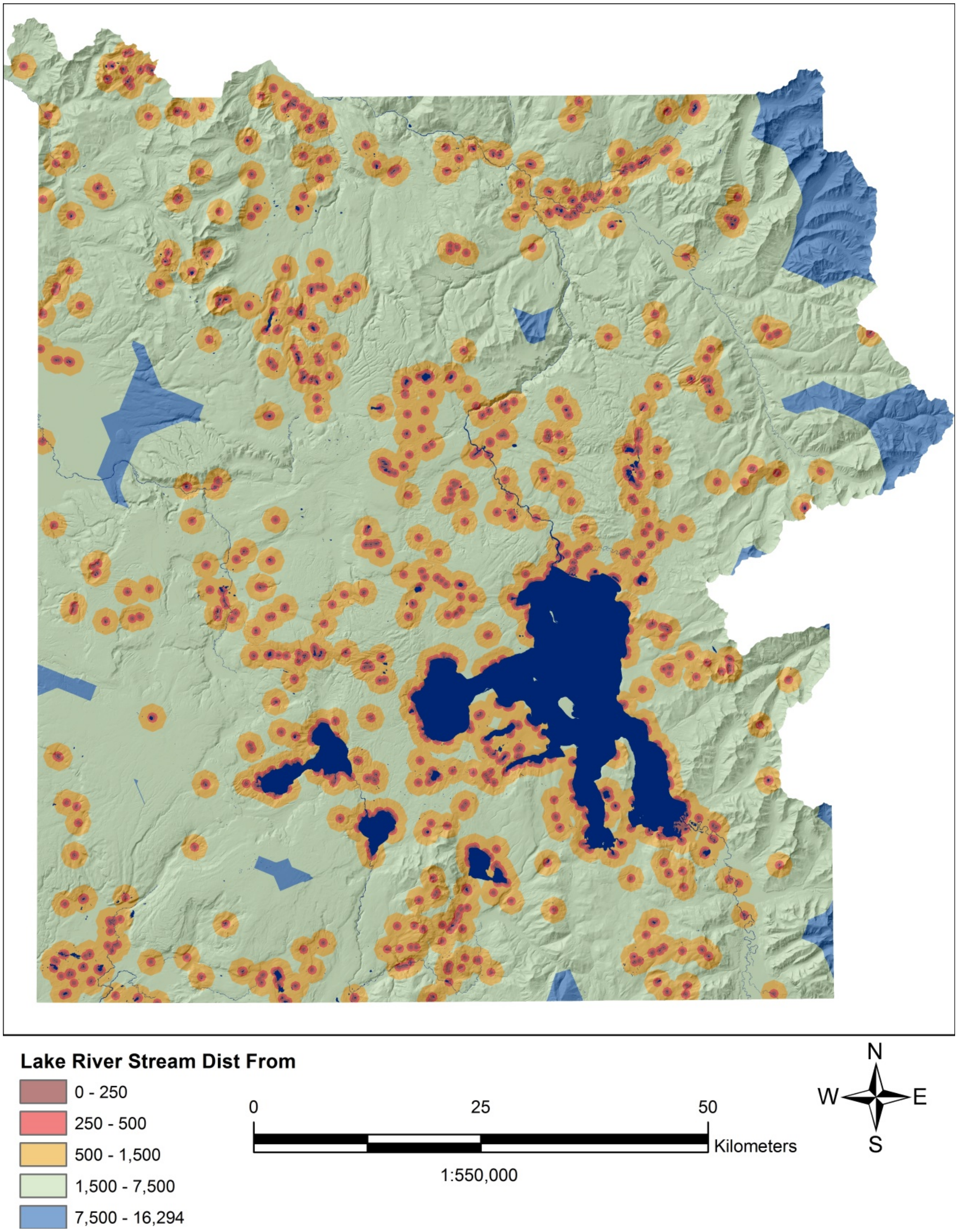

Figure 17. Displays the 'distance from inlets and outlets of streams and rivers at lakes, measured in meters

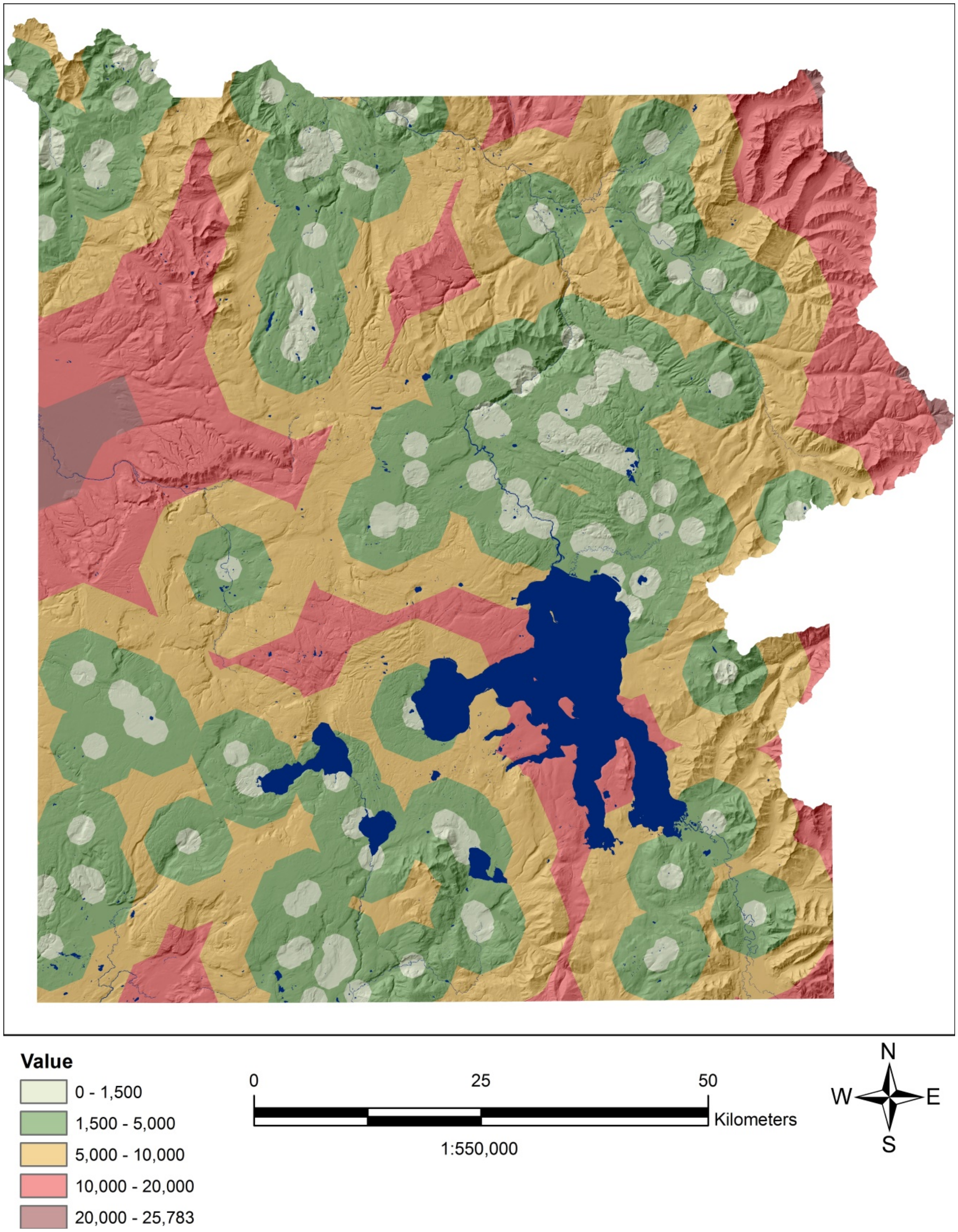

Figure 18. Displays the 'distance from springs' layer measured in meters, concentrations of known springs are very pronounced.

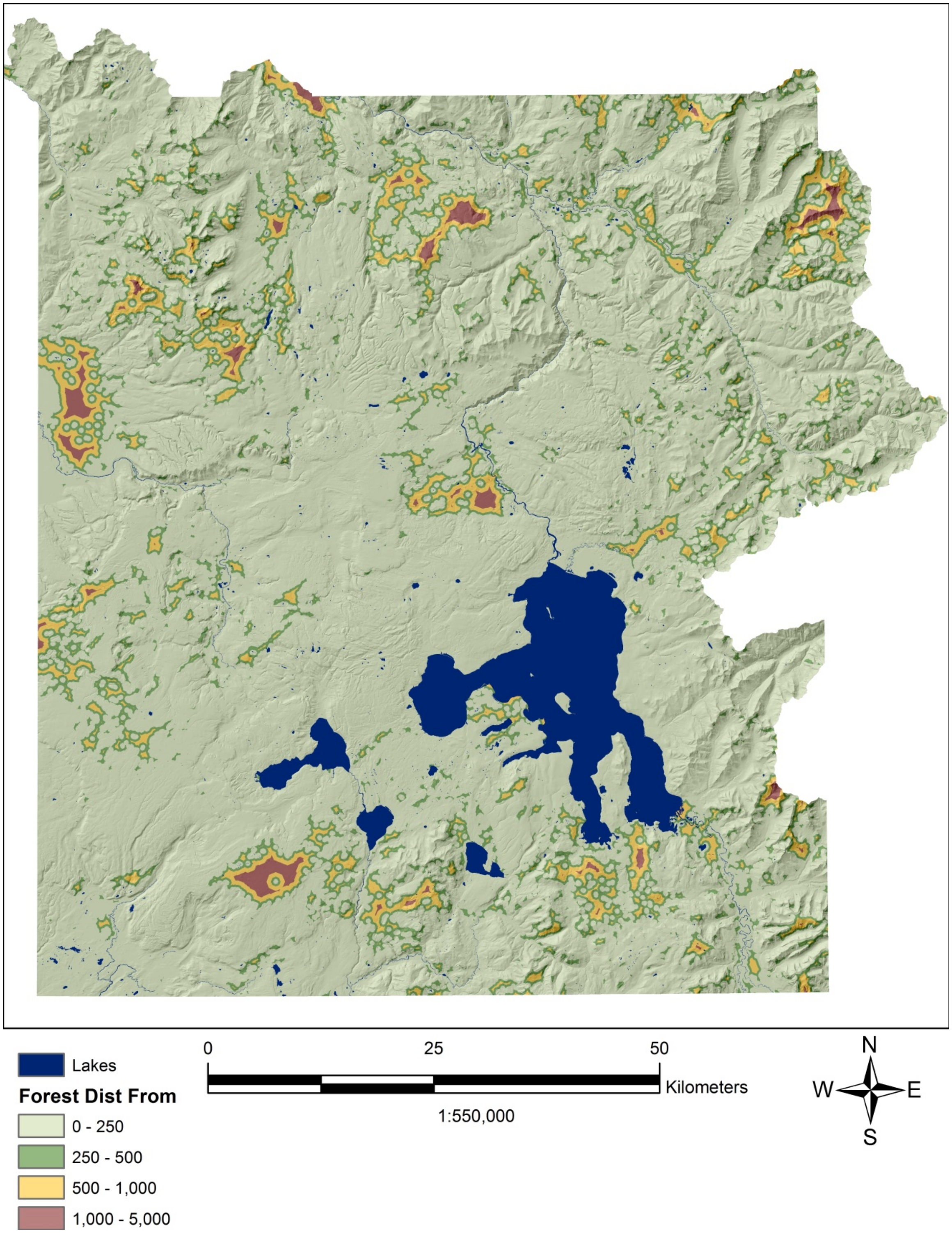

Figure 19. Displays the 'distance from forests' layer that was derived from the NLCD dataset and calculated distance is in meters using ESRI's predictive analysis toolkit. It's easy to see how much of the landscape is forested in YNP.

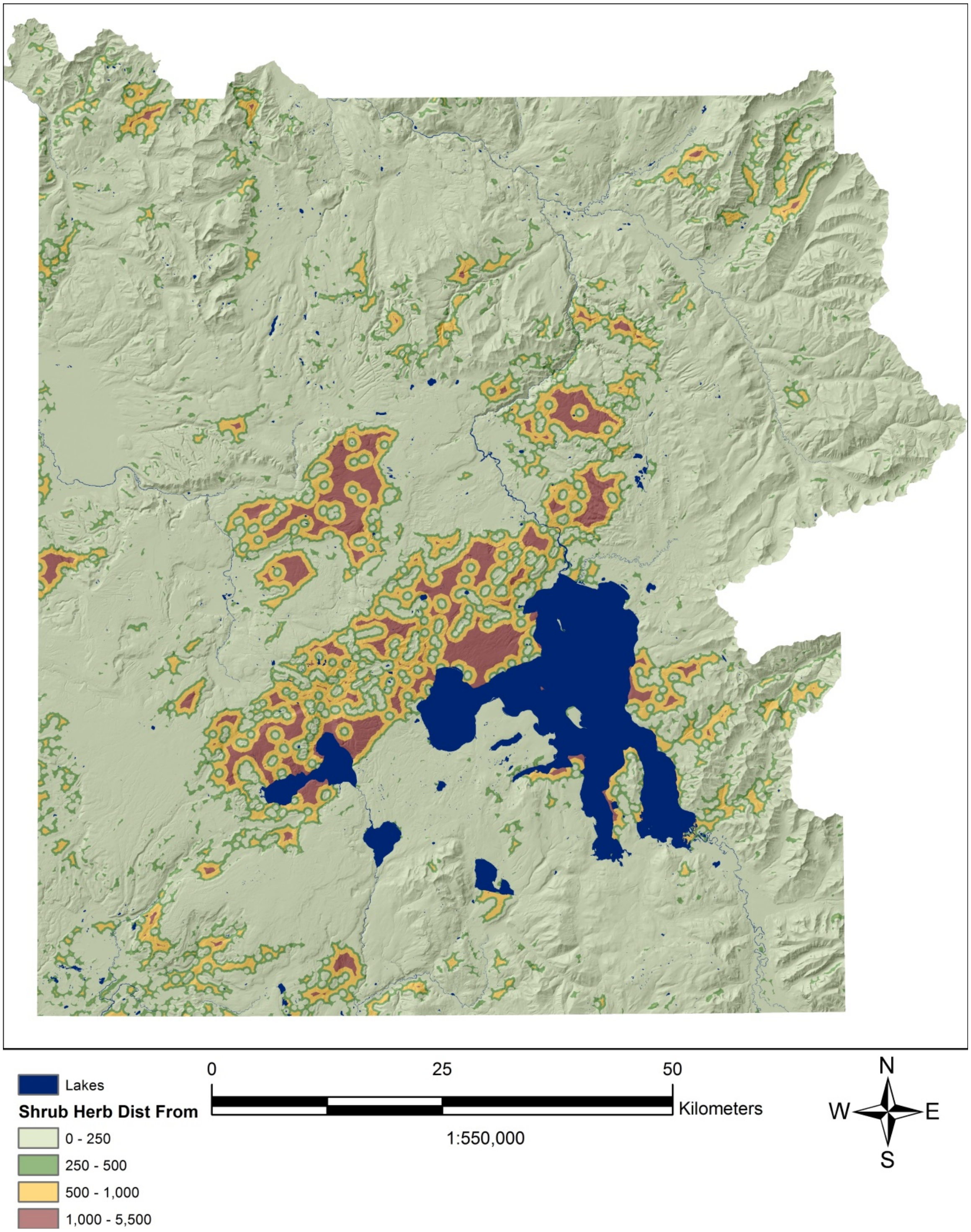

Figure 20. Displays the 'distance from shrub and herbaceous' layer derived from the NLCD dataset and calculated in meters using ESRI's predictive analysis toolkit.

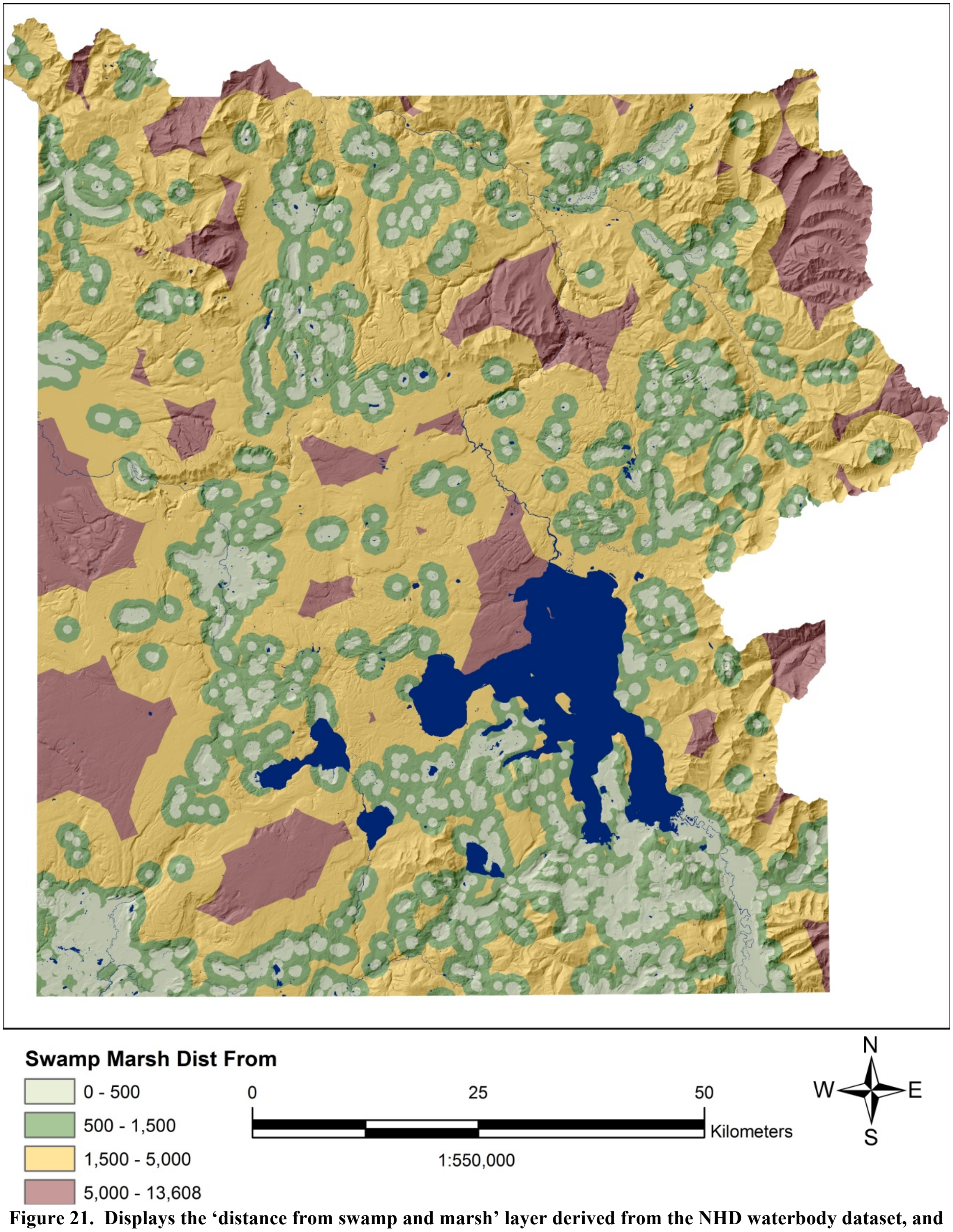

Figure 21. Displays the 'distance from swamp and marsh' layer derived from the NHD waterbody dataset, and calculated in meters using ESRI's predictive analysis toolkit

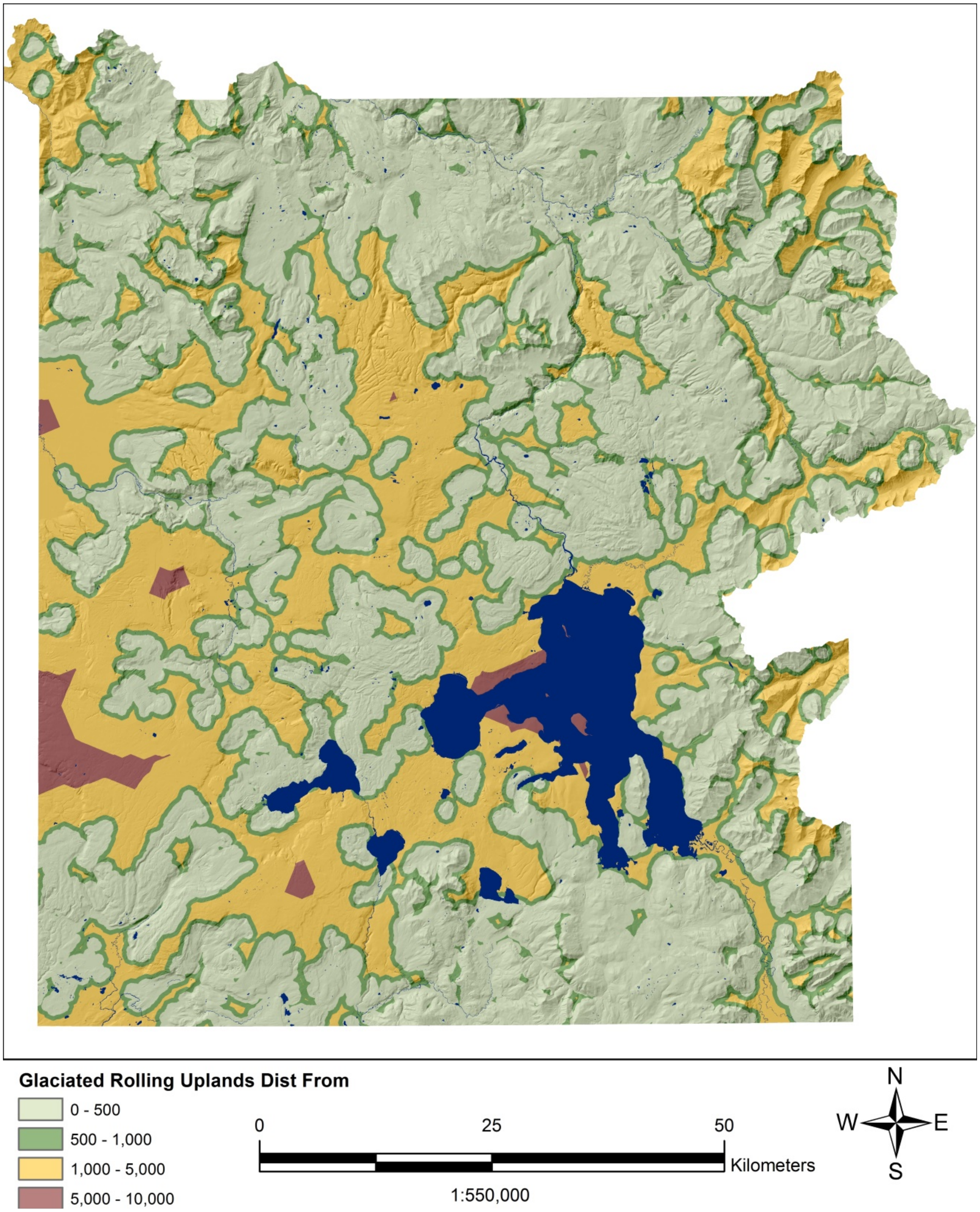

Figure 22. Displays the 'distance from Glaciated rolling upland landforms' layer derived from the ___ dataset and calculated in meters using ESRI's predictive analysis toolkit.

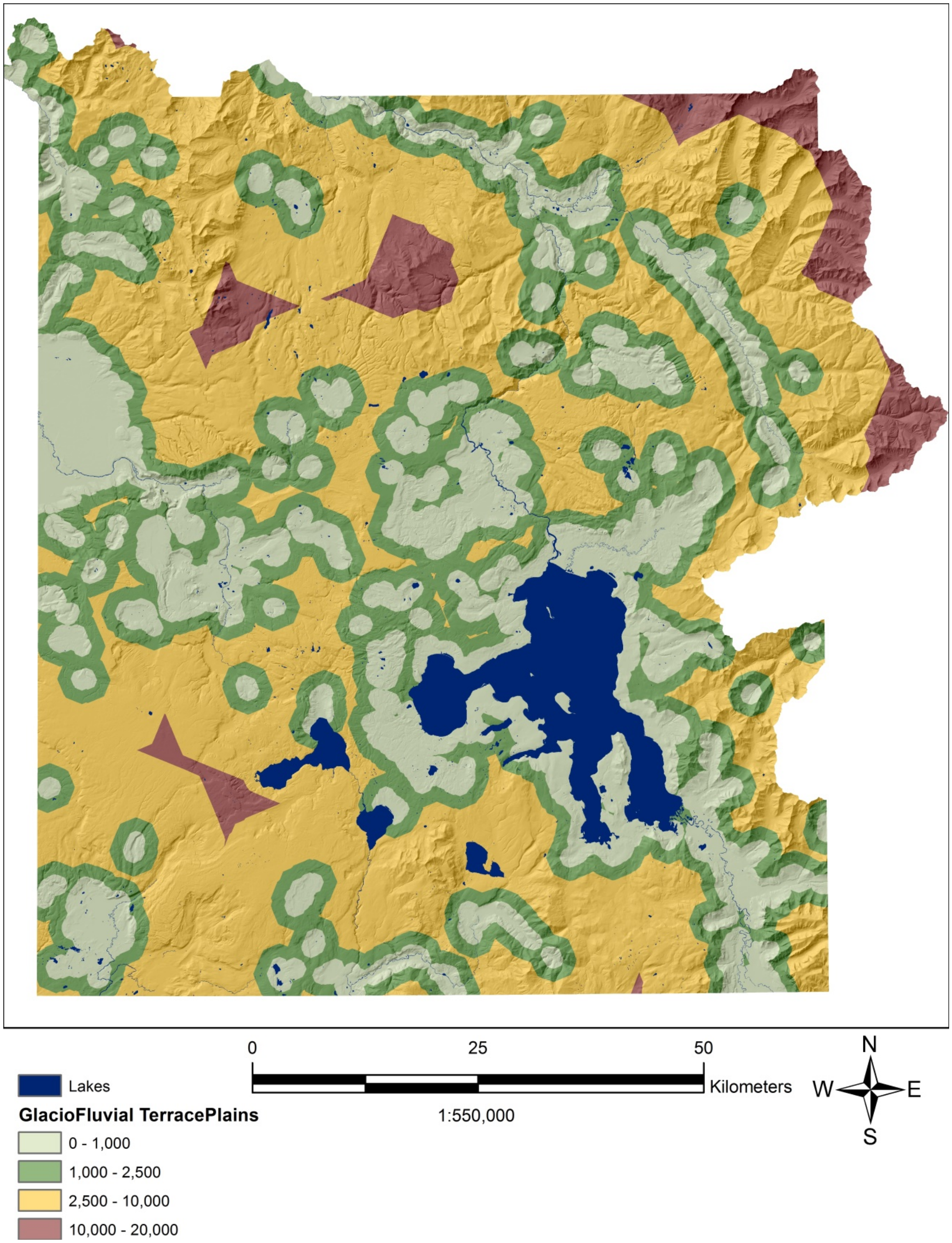

Figure 23. Displays the 'distance from glaciofluvial terraces and plains' layer derived from the ___ dataset and calculated in meters using ESRI's predictive analysis toolkit.

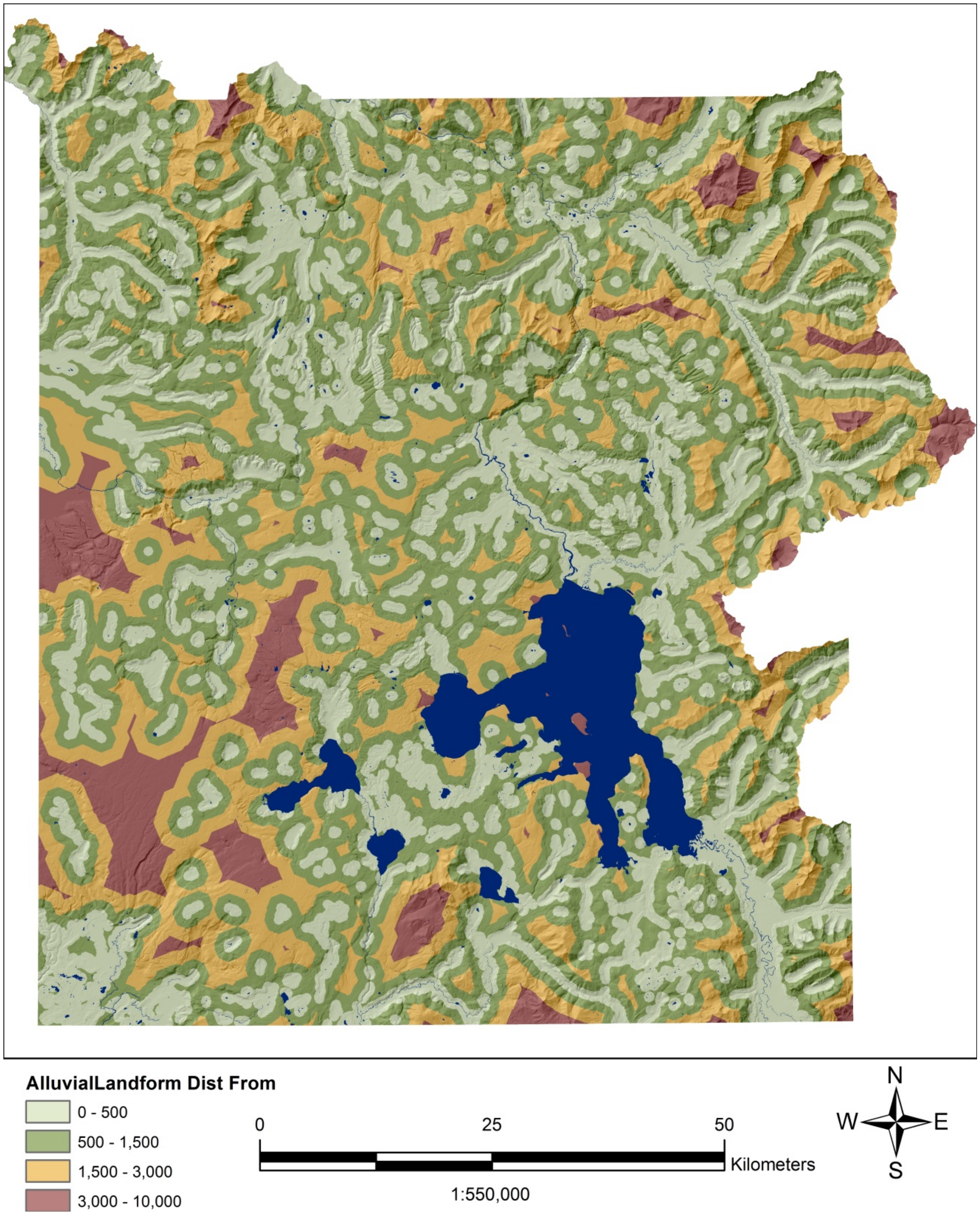

Figure 24. Displays the 'distance from alluvial landforms' layer that was removed at step two of the logistic regression

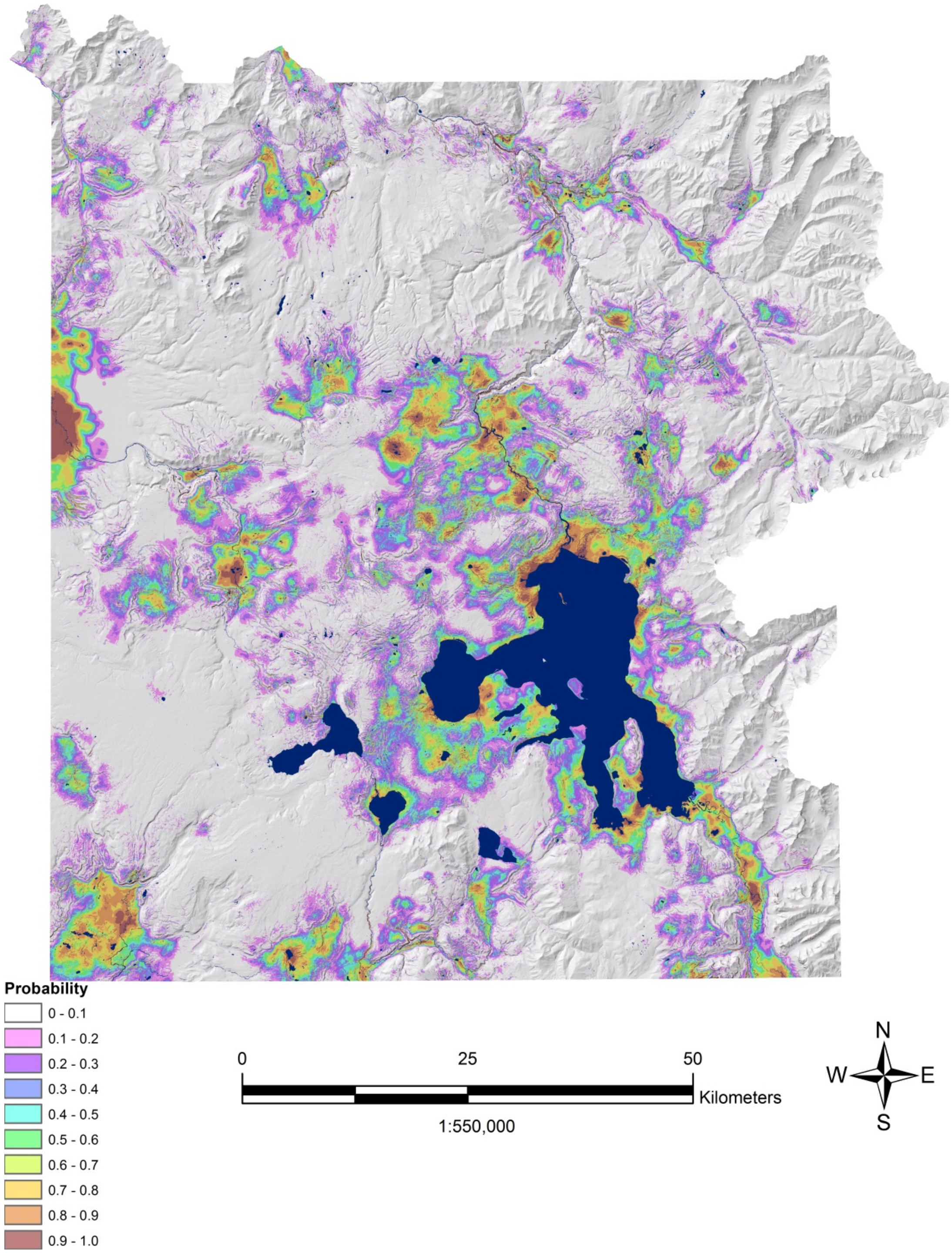

Figure 25. Displays the final model overview of the probability surface. Notice the high probability areas in red, orange, yellow, and green. Note how much of the landscape is also classified extremely low (site absent).

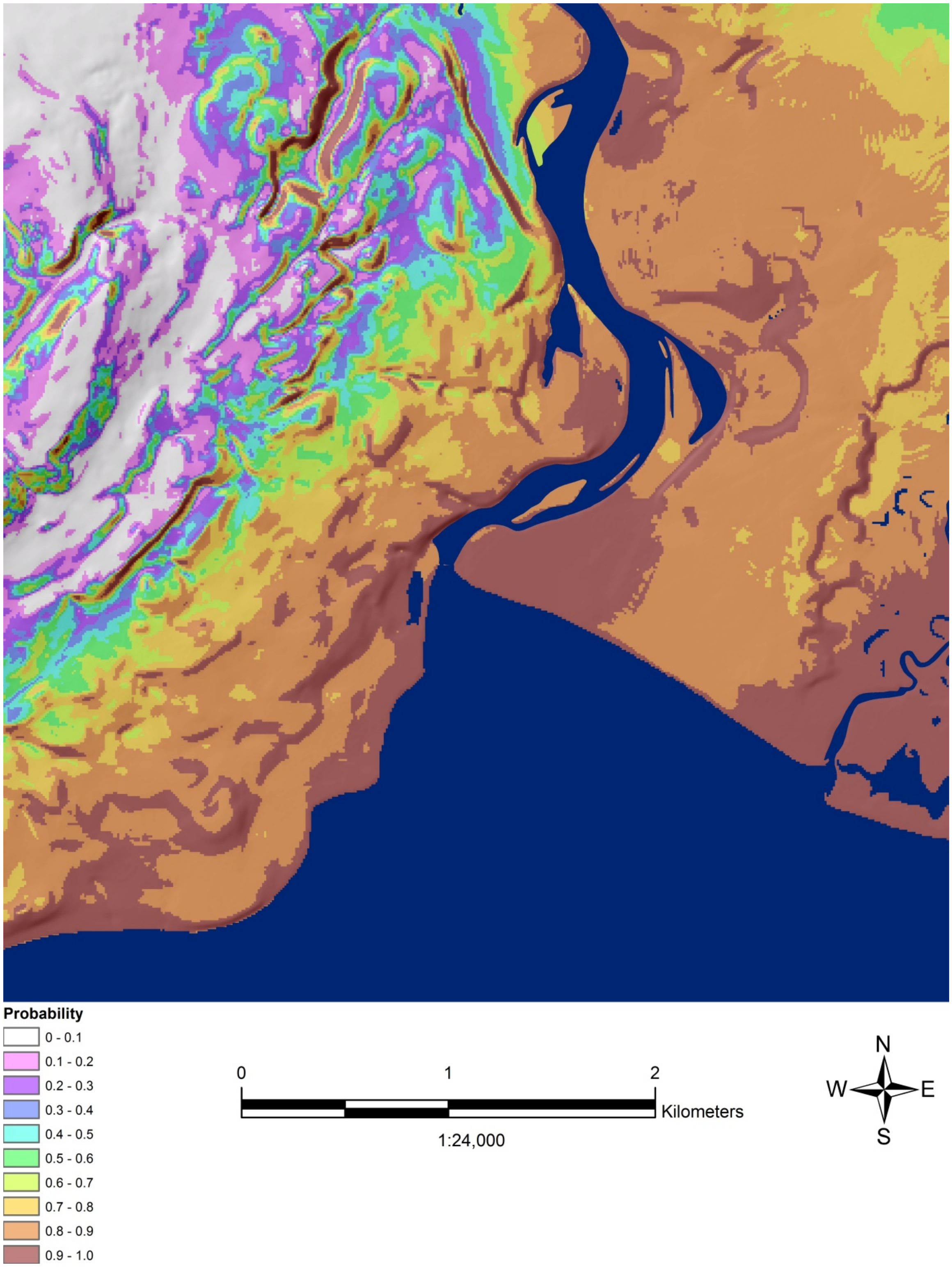

Figure 26. Displays the final probability surface for the Fishing Bridge area at 1:24,000 scale. The flats and terraces, particularly the terrace edges have high probability scores, due to the fact most Paleoindian artifacts are found due to eroding banks and terraces.

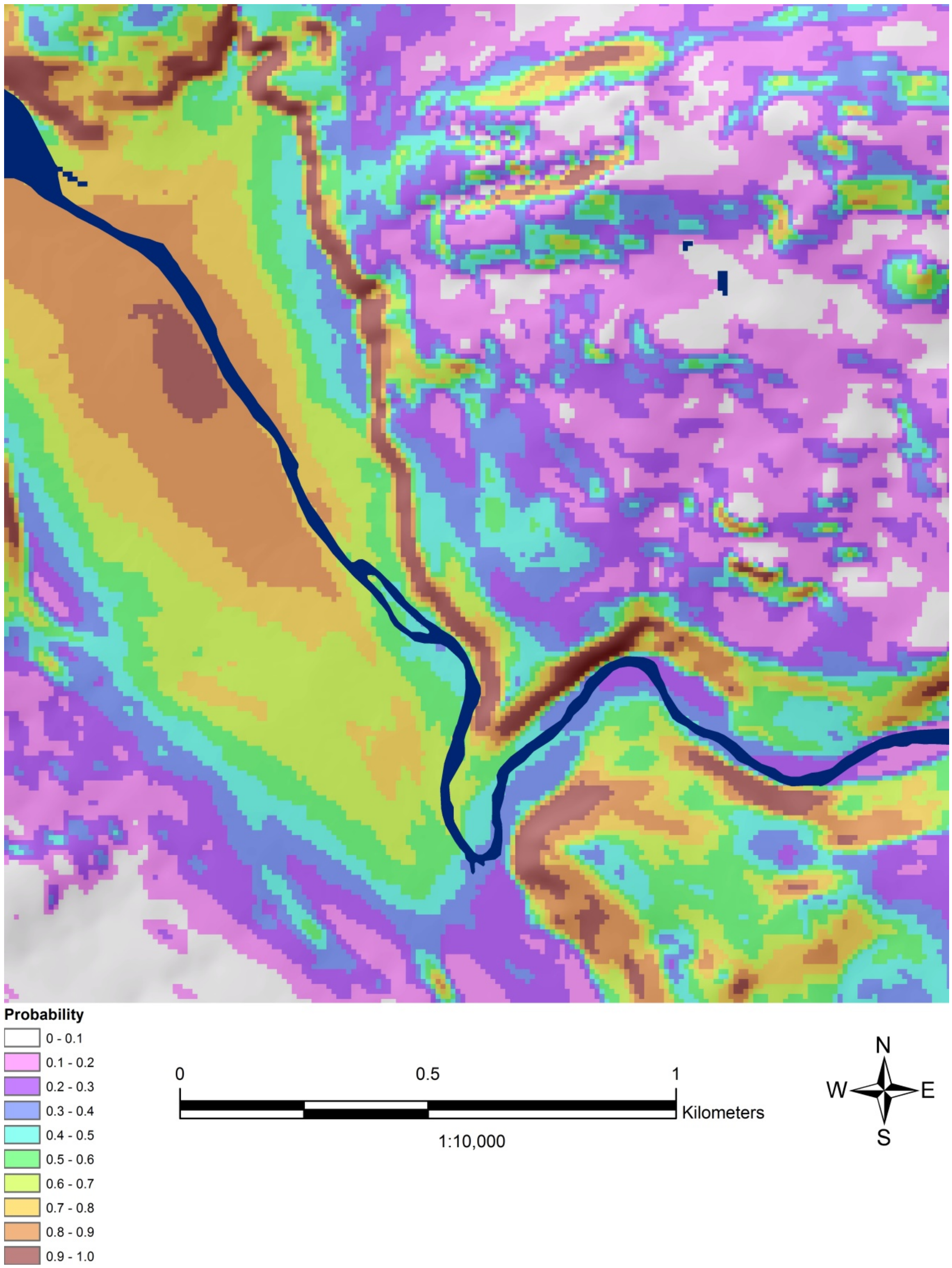

Figure 27. Displays the area along the Snake River at a 1:10,000 scale, at which each pixel probability is depicted more clearly. The terrace edges still score high probabilities.

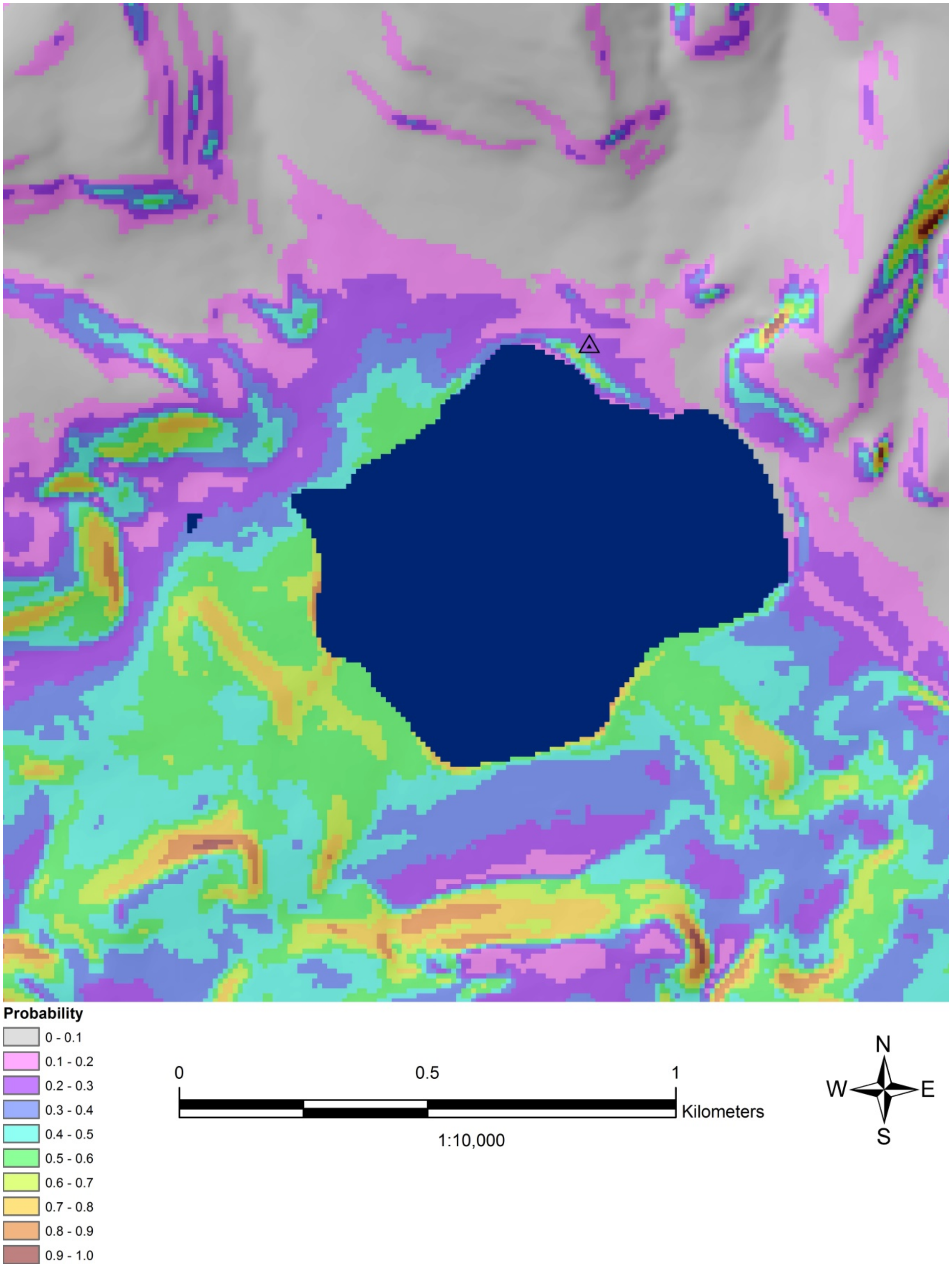

Figure 28. Displays the estimated location of two Paleoindian artifacts found and shows the probability surface. The estimated location seems to lie in low probability, but the rest of the lake appears to have high probability scores all around it.

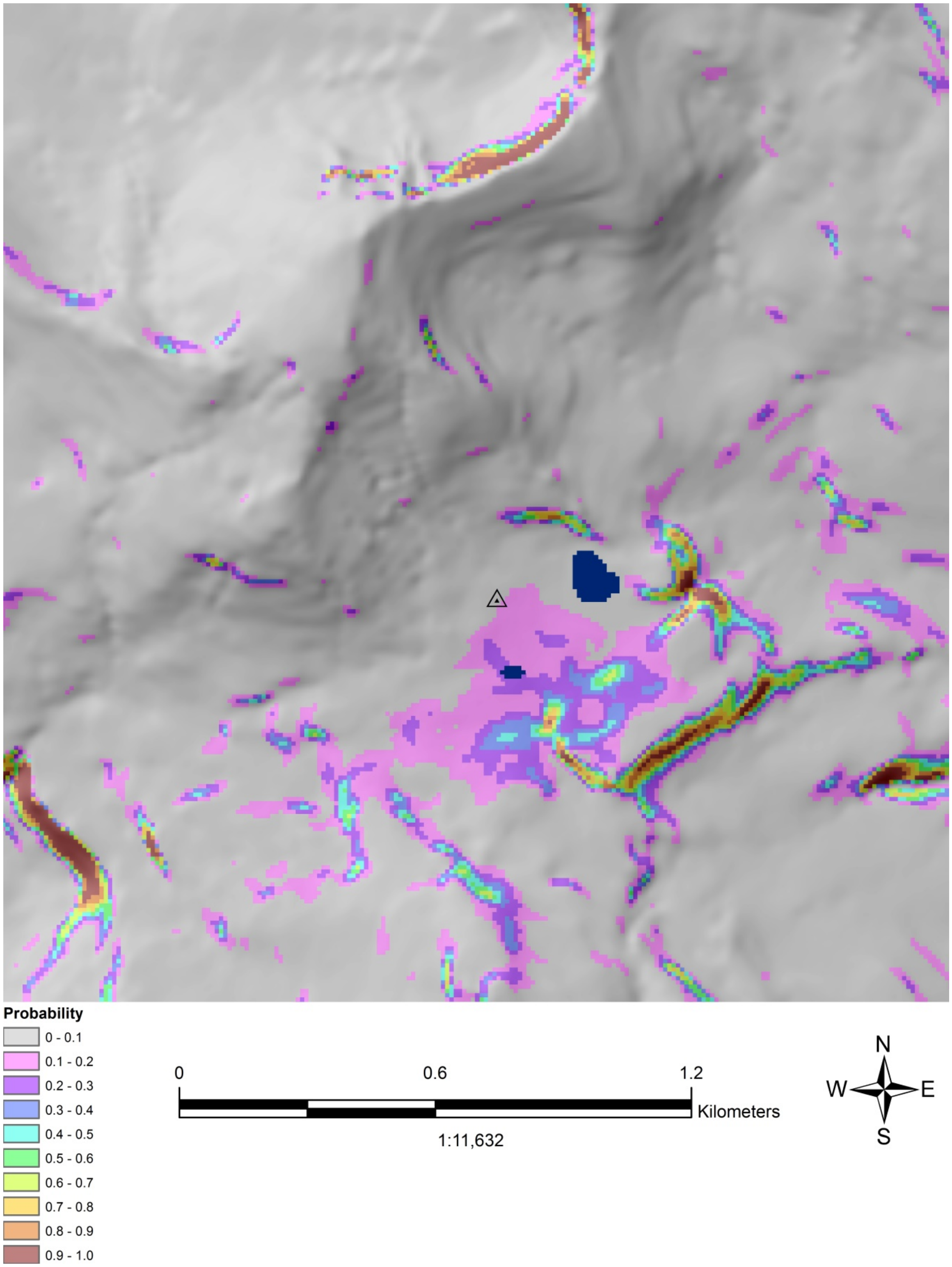

Figure 29. Displays the estimated location of an isolated Paleoindian point near Fawn Pass in conjunction with the probability surface. The estimated location has a very low probability score, which is likely due to the lack of details regarding its location.

Chapter 6

Conclusion

The model assessment results indicate that the predictive model can be considered a successful model. The results represent a significant increase from a random classification, and thus meet the standard set forth by Kvamme. Improvements that could be employed to improve the model's accuracy include the increasing the number of sites for the development of the model, separating the region into different regions that have been surveyed and drawing site absent samples from those, and collecting new sites from surface surveys and test excavations that are located away from the major rivers and roads. The model output identifies high probability areas where Paleoindian artifacts are likely to be found on the surface. The reason for specifying its accuracy in regard to surface artifacts is based on the fact that the majority of the Paleoindian locations used to develop and test the model were found on the surface. However, the model did produce high probability areas at each of the excavated Paleoindian sites.

Thus, another model could be produced using just the excavated Paleoindian sites or a process that weights those sites characteristics higher. But, due to the lack of subsurface data used to generate this model no statements or conclusions about buried sites can be reliably derived from this model. A number of the high probability areas appear to be located on steeper slopes than one would normally expect. This is likely attributed to the high percentage of surface artifacts used to construct the model and their tendency to be located on or near eroding landforms.

This model is an attempt to quantify the cultural-ecological relationship for Yellowstone National Park. The model was created in hopes that it would be aid for future field surveys and research designs that desire to expand our knowledge of Paleoindians use of Yellowstone National Park. Also that the data used to create this model would aid in the creation of more accurate and methodologically sound models with even more predictive power.

In regard to the critiques of archaeological predictive modeling it should be noted that this model was developed using modern ecological and environmental variables and does not aim to make inferences about Paleoindian socio-cultural traditions. Although, should it lead to more Paleoindian sites being found the knowledge from those new developments could provide the building blocks necessary to begin a more in-depth and holistic investigation of the Paleoindian cultures that utilized the Greater Yellowstone Ecosystem and surrounding regions.

Without the use of Geographic Information Systems (GIS) the development of this model could not have been produced in a timely manner. The calculations required for over 88 million cells for one layer alone seems be unfathomable, without the use of GIS. For the sixteen variables created 1,422,427,040 values for the environmental variables alone. The analytical and storage properties of GIS mentioned above combined with the visualization capabilities make it a fundamental tool for all archaeologists.

It’s hard to fully determine the accuracy of the model without a proper testing sample, but all results predict that this model will produce better than chance results at minimum and substantial improvements over the chance probability at best. Having surveyed a number of regions inside YNP the model appears to accurately model aspects of the environment that are common where Paleoindian artifacts are found. But, it must be mentioned that the model does appear to be biased towards the areas similar to where the major surveys have taken place and therefore the majority for the recorded Paleoindian sites. That is, very few surveys have been conducted on high-ridgelines or higher elevation meadows where some Paleoindian artifacts have been found in other regions and just outside the northern boundary of the park (Haines 1963; Lee 2011). One other motivation for the creation of this model was the increasing number of tourists and the ever-changing landscape of Yellowstone, both of which pose threats to the archaeological record of Paleoindians in Yellowstone. It is hoped that this model or one similar would give researchers the tools to identify, record and learn from these sites before they are taken from history.

The relationship between Paleoindian sites and moderate values of slope was surprising initially, however, realizing that a majority of the Paleoindian artifacts I have discovered and seen discovered are typically very near eroding terraces or embankments; which the GIS cannot discern without more accurate elevation datasets. Therefore it is more likely that these terrace edges, combined with the other variables are more likely to yield Paleoindian artifacts then pure chance alone. The model also shows that Paleoindian sites are more closely associated with lower values in the variables: relief 600m, 300m, and 150m, as well as, stream and river confluences, confluences with lakes, streams and rivers, distance to perennial streams, distance from glaciofluvial terraces and plains, glaciated rolling uplands. These all seem relatively obvious, but if one was to look at the landscape of all of Yellowstone National Park, it is clear that areas with these types values coincide only over a fraction of the Park. Not surprisingly the lower the values in distance to shrub and herbaceous vegetation, and distance to forests were more associated with Paleoindian sites. The use of these variables in a distance from manner was an attempt to represent the ecotone between grassland and forest and appears to have succeeded. Although as mentioned in chapter 4 this could possibly be refined further by also doing an internal distance from the edge of the polygons, therefore providing multiple measures of Paleoindian sites distance from grassland and forest boundaries.

The patterns exhibited visually show a tendency for large river valleys and lakeshores, but interestingly the sites along the major river valleys appear more dispersed. Except for in the northern area where we see a higher concentration then a gradually widening dispersion of sites up the Lamar and Yellowstone River valleys. Another pattern to note was that although the distance between sites varies the general distance between sites is very near ten kilometers suggesting a pattern that might be explored further in future research. There are fluctuations in this particularly in the more concentrated sites around Yellowstone Lake and near the North Entrance of YNP where the average distances from site to site is between five to ten kilometers. No quantitative analyses were conducted in regards to this aspect of site distribution, but could be incorporated in further research. The settlement patterns in regard to environmental variables as mentioned previously could be the result of biases in the locations of the research projects, but do provide a subtle idea of how Paleoindian artifacts are distributed across Yellowstone.

The results show generally what was already assumed about Paleoindian site locations in YNP, but the ability to visually display these areas that meet the selected environmental criteria is valuable, particularly to resource managers and researchers in planning future projects.

Works Cited:

Adams, J. S.
2011 Crescent Hill Chert: A Geological and Cultural Study of a Raw Material Procurement Area in Yellowstone National Park, Wyoming, Anthropology, University of Montana, Missoula, MT.

Adams, J. S. and D. H. MacDonald
2015 Differential Selection of Lithic Raw Materials by Prehistoric Hunter-Gatherers in the Upper Yellowstone River Valley, Montana/Wyoming. In *Toolstone Geography of the Pacific Northwest*, edited by Terry L. Ozbun and R. L. Adams, pp. 208-217. Archaeology Press, Simon Fraser University.

Andrefsky, W. J.
1994 Raw Material Availability and the Organization of Technology. *American Antiquity* 59:21-34.

Berry, K. J., K. L. Kvamme and P. W. Mielke, Jr.
1983 Improvements in the Permutation Test for the Spatial Analysis of the Distribution of Artifacts into Classes. *American Antiquity* 48(3):547-553.

Butzer, K. W.
1982 *Archaeology as Human Ecology*. Cambridge University Press, Cambridge.

Cable, N. and A. Standley
2012 *Archaeological Prediction for Road Asset Management: State Highway 11 Northland*. NZ Transport Agency Waka Kotahi, OPUS International Consultants Limited.

Campbell, J. S.
2006 Archaeological Predictive Model of Southwestern Kansas, Department of Geography, University of Kansas, Ann Arbor.

Cannon, K. P.
1992 *A Preliminary Appraisal of Archaeological Resources Along Yellowstone Lake, Yellowstone National Park, Wyoming*. U.S. Dept of the Interior, National Park Service, Midwest Archaeological Center, Lincoln, NE.-Draft Version.

Cannon, K. P., George M. Crothers and K. L. Pierce
1996 *Archaeological Investigations Along the Arnica Creek to Little Thumb Creek Section of the Grand Loop Road, Yellowstone National Park, Wyoming*. Branch of Cultural Resources, Yellowstone National Park, Wyoming: National Park Service.

Cannon, K. P. and R. E. Hughes

1997 Provenience Analysis of Obsidian Paleoindian Projectile Points from Yellowstone National Park. In *Current Research in the Pliestocene*.

Cannon, K. P., S. H. Hughes and C. Simpson
2010 The Ecology of Early-Holocene Bison in the Greater Yellowstone Ecosystem, Wyoming : Preliminary Results from the Horner Site. *Current Research in the Pleistocene* 27:161-163.

Carr, C. (editor) 1985 *For Concordance in Archaeological Analysis: Bridging Data Structure, Quantitative Technique and Theory*. Westport Publishers, Kansas City.

Chandler, S. M. and P. R. Nickens
1983 Regional Sampling and Predictive Modeling in CRM: Some Examples from the Northern Colorado Plateau. Paper presented at the 48th annual meeting for the Society for American Archaeology, Pittsburgh.

Clark, W. A. V. and P. L. Hosking
1986 *Statistical Methods for Geographers*. John Wiley & Sons, New York.

Dalla Bona, L.
1994 *Ontario Ministry of National Resources Archaeological Predictive Modelling Project*. Thunder Bay: Center for Archaeological Resource Prediction, Lakehead University.

Davis, L. B.
1993 Paleo-Indian Archaeology in the High Plains and Rocky Mountains of Montana. In *From Kostenki to Clovis*, edited by O. Soffer and N. Praslov, pp. 263-277. Interdisciplinary Contributions to Archaeology. Springer US.

Davis, L. B.
1997 Extinct Faunas in Northern Rockies and Plains Archaeological Contexts. In *Partners in Paleontology: Proceedings of the Fourth Conference on Fossil Resources*, edited by J. Johnston and J. McChristal, pp. 53-55. Natural Resources Report NPS/NRFLFO/NRR97/01. U.S. Department of the Interior, National Park Service, Florissant Fossil Beds National Monument.

Davis, L. B. and S. T. Greiser
1992 Indian Creek Paleoindians: Early Occupations of the Elkhorn Mountains' Southeast Flake, West-Central Montana. In *Ice Age Hunters of the Rockies*, edited by D. J. Stanford and J. S. Day, pp. 225-283. Denver Museum of Natural History and University Press of Colorado, Niwot.

Davis, L. B., Stephen A. Aaberg, James G. Schmitt and A. M. Johnson
1995 *The Obsidian Cliff Plateau Prehistoric Lithic Source, Yellowstone National Park, Wyoming*. U.S. Department of the Interior, National Park Service, Rocky Mountain Region, Division of Cultural Resouces. Denver, Colorado.

Douglas H. MacDonald and E. S. Hale (editors)
2011 *Yellowstone Archaeology: Northern Yellowstone*. University of Montana Contributions to Anthropology Volume 13 (1). University of Montana Office of Printing and Graphics, Missoula.

Duke, P. and M. C. Wilson (editors)
1995 *Beyond Subsistence: Plains Archaeology and the Postprocessual Critique*. University of Alabama Press, Tuscaloosa.

Duncan, R. B. and K. A. Beckman
2000 The Application of GIS Predictive Site Location Models within Pennsylvania and West Virginia. In *Practical Applications of GIS for Archaeologists: A Predictive Model Kit*, edited by K. L. Wescott and R. J. Brandon, pp. 33-58. Taylor & Francis, Philadelphia, PA.

Ebert, J. J.
2000 The State of the Art in "Inductive" Predictive Modeling: Seven Big Mistakes (and Lots of Smaller Ones). In *Practical Applications of GIS for Archaeologists: A Predictive Model Kit*, edited by K. L. Wescott and R. J. Brandon, pp. 129-134. Taylor & Francis, Philadelphia, PA.

Elston, R. G.
1992 Modeling the Economics and Organization of Lithic Procurement. In *Archaeological Investigations at Tosawihi, A Great Basin Quarry, Part 1: The Periphery, Volume 1*, edited by R.G. Elston and C. Raven. Inter-mountain Research and Bureau of Land Management, Silver City, Nevada.

Frison, G. C.
1987 The University of Wyoming Investigations at the Horner Site. In *The Horner Site: The Type Site of the Cody Cultural Complex*, edited by G. C. F. a. L. Todd, pp. 93-106. Academic Press, New York.

1990 The North American High Plains Paleoindian: An Overview. *Revista de Arqueologica Americana* (2):9-54.

1991 *Prehistoric Hunters of the High Plains*. 2nd ed. Academic Press, New York.

2007 Paleoindian Occupations. In *Medicine Lodge Creek*, edited by G. C. F. a. D. W. Walker, pp. 69-90. Clovis Press, Albuquerque, New Mexico.

Frison, G. C. and D. J. Stanford
1982 *The Agate Basin Site: A Record of the Paleoindian Occupation of the Northwestern Plains*. Academic Press, New York.

Frison, G. C., D. L. Toom and R. C. Mainfort
1996 Adaptations in the Northern Plains. In *Archaeological and Bioarchaeological Resources of the Northern Plains*, edited by G.C. Frison and R. C. Mainfort. vol. Arkansas Archaeological Survey Research Series No. 47. Arkansas Archaeological Survey, Fayetteville, Arkansas.

Gaffney, V. and P. M. V. Leusen
1995 Postscript - GIS, Environmental Determinism and Archaeology: A Parallel Text. In *Archaeology and Geographical Information Systems: A European Perspective*, edited by G. Lock and Z. Standic, London.

Greiser, S. T.
1985 Memoir 20: Predictive Models of Hunter-Gatherer Subsistence and Settlement Strategies on the Central High Plains. *The Plains Anthropologist* 30(110):i-134.

Greiser, S. T.
1985 Predictive Models of Hunter-Gatherer Subsistence and Settlement Strategies on the Central High Plains. *Plains Anthropologist* 30:1-134.

Haines, A. L.
1963 A Preliminary Report on High-Altitude Indian Occupation sites Near the North Boundary of Yellowstone National Park, Manuscript on file, Yellowstone National Park, Mammoth.

Hale, Elaine Skinner and M. Livers
2013 Prehistoric Culture History and Prior Archaeological Research in Southern Yellowstone. In *Yellowstone Archaeology: Southern Yellowstone*, edited by D. H. M. a. E. S. Hale, pp. 2-21. The University of Montana, Missoula, Montana.

Hill, M. E. J.
2007 A Moveable Feast: Variation in Faunal Resource Use Among Central and Western North American Paleoindian Sites. *American Antiquity* 72(3):417-438.

Hodder, I.
1987 The Contribution of the Long Term. In *Archaeology as Long Term History*, edited by I. Hodder, pp. 1-8. Cambridge University Press, Cambridge, England.

1990 *The Domestication of Europe: Structure and Contingency in Neolithic Societies*. Blackwell, Cambridge.

1991 Interpretative Archaeology and It's Role. *American Antiquity* 56:7-18.

Hofman, J. L. and R. W. Graham
1998 The Paleo-Indian Cultures of the Great Plains. In *Archaeology of the Great Plains*, edited by W. R. Wood, pp. 87-139. University Press of Kansas, Lawrence.

Hughes, R. E. and K. P. Cannon
1997 The Continuing Obsidian Studies in the Greater Yellowstone Area. Paper presented at the 62nd Annual SAA Conference, Nashville, Tennessee.

Janetski, J. C.
2002 *Indians of Yellowstone Park*. revised edition, University of Utah Press, Salt Lake City.

Jochim, M.
1976 *Hunter-Gatherer Subsistence and Settlement: A Predictive Model*. Academic Press, New York.

Johnson, A. M., B. O. K. Reeves, M. W. Shortt, R. Yellowstone Center for and F. Yellowstone Park
2004 *Osprey Beach (Site 48YE409/410), Yellowstone National Park, Wyoming*. Lifeways of Canada Limited, Calgary, Alta.

Judge, W. J. and L. Sebastian
1988 *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling*. U.S. Government Printing Office, Washington, D.C.

Knell, E. J.
2007 The Organization of Late Paleoindian Cody Complex Land-use on the North American Great Plains, Anthropology, Washington State University.

Knell, E. J. and M. G. Hill, Jr.
2012 Linking Bones and Stones: Regional Variation in Late Paleoindian Cody Complex Land Use and Foraging Strategies. *American Antiquity* 77(1):40-70.

Kohler, T. A. and S. C. Parker
1986 Predictive Models for Archaeological Resource Location. In *Advances in Archaeological Method and Theory: Volume 9*, edited by M. B. Schiffer, pp. 397-452. the University of Arizone Press, Tucson.

Kvamme, K. L.
1979 Settlement Variability on the High Plains of Northeastern Colorado: The South Platte River. *Southwestern Lore* 45:18-28.

1983 Computer Processing Techniques for Regional Modeling of Archaeological Site Locations. *Advances in Computer Archaeology* 1:26-52.

1988 Development and Testing of Quantitative Models. In *Quantifying the Present and Predicting the Past: Theory, Methods, and Application of Archaeological*

Predictive Modeling, edited by W.J. Judge and L. Sebastian, pp. 325-428. US Department of the Interior, Bureau of Land Management Service Center, Denver.

1989 Geographic Information Systems in Regional Archaeological Research, Data Management. In *Archaeological Method and Theory*, edited by M. B. Schiffer, pp. 139-203. University of Arizona Press, Tucson.

1990a The Fundamental Principles and Practice of Predictive Archaeological Modeling. In *Mathematics and Information Science in Archaeology: A Flexible Framework*, edited by A. Voorips, pp. 257-295, Bonn: Holos.

1990b One-Sample Tests in Regional Archaeological Analysis: New Possibilities through Computer Technology. *American Antiquity* 55(2):367-381.

1992 A Predictive Site Location Model on the High Plains: An Example with an Independent Test. *Plains Anthropologist* 37(138):19-40.

2006 Integrating multidimensional geophysical data. *Archaeological Prospection* 13(1):57-72.

Kvamme, K. L. and T. A. Kohler
1988 Geographic Information Systems: Technical Aids for Data Collection, Analysis, and Display. In *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling*, edited by W.J. Judge and L. Sebastian, pp. 493-547. U.S. Government Printing Office, Washington, D.C.

Lahren, L. and R. Bonnichsen
1974 Bone Foreshafts from a Clovis Burial in Southwestern Montana. *Science* 186(4159):147-150.

Lee, C. M.
2011 Ice Patch Archaeology in Yellowstone's Northern Ranges. In *Yellowstone Archaeology: Northern Yellowstone*, edited by D. H. MacDonald and E. Hale. vol. 13(1). University of Montana Office of Printing and Grahpics, Missoula.

Lock, G. and Z. Stancic (editors)
1995 *Archaeology and Geographic Information Systems*. Taylor and Francis Inc., London.

Maas, L. E., Michael C. Livers, S. H. Elaine and D. H. MacDonald
2011 Prehistory and Archaeology within the Gardiner Basin, Yellowstone National Park, Montana/Wyoming. In *Yellowstone Archaeology: Northern Yellowstone*, edited by Douglas H. MacDonald and E. S. Hale, pp. 41-55. vol. 13 (1). The University of Montana Department of Anthropology Contributions to Anthropology. The University of Montana Office of Printing and Graphics, Missoula.

MacDonald, D. H.
1999 Modeling Folsom Mobility, Mating Strategies, and Technological Organization in the Northern Plains. *Plains Anthropologist* 44(168):141-161.

2012a Fishing Bridge Point (48YE381): A Stratified Prehistoric Site at Yellowstone Lake, Wyoming. *Plains Anthropologist*.

2012b *Montana Before History: 11,000 Years of Hunter-Gatherers in the Rockies and Plains*. Mountain Press Pubishing Company, Misoula, Montana.

MacDonald, D. H. and E. Hale (editors)
2011 *Yellowstone Archaeology: Northern Yellowstone*. 13(1). University of Montana Contributions to Anthropology.

MacDonald, D. H. and E. Hale (editors)
2013 *Yellowstone Archaeology: Southern Yellowstone*. University of Montana Contributions to Anthropology 13(2), University of Montana, Missoula.

MacDonald, D. H., Jordan C. McIntyre and M. C. Livers
2012 Understanding the Role of Yellowstone Lake in the Prehistory of Interior Northwestern North America. *North American Archaeologist* 33(3):251-289.

MacDonald, D. H., E. M. Lester and J. Hardes
2010 The Yellowstone Bank Cache Site (24YE355): A Late Archaic Pelican Lake Occupation on the Upper Yellowstone River, Montana. *Archaeology of Montana*:1-24.

MacDonald, D. H. and M. C. Livers
2010 *Interim Report of the 2009 Montana Yellowstone Archaeological Project, Yellowstone Lake, Yellowstone National Park, Wyoming*. National Park Service.

Maschner, H. D. G. and J. Stein
1995 Multivariate Approaches to Site Location on the Northwest Coast of North America. *Antiquity* 69:1-73.

McLeod, C. M. and D. Melton
1986 *The Prehistory of the Lolo and Bitterroot National Forest: An Overview*. USDA Forest Service, Northern Region, Lolo and Bitterroot National Forests, Missoula, MT.

Meyer, D.
2004 *Yellowstone National Park Archaeological Site Assessment: 2001 Field Season Final Report*. Museum of the Rockies, Montana State University. Submitted to and on file at National Park Service, Branch of Cultural Resources, Yellowstone National Park, Mammoth, Wyoming

Nelson, M. C.
1991 The Study of Technological Organization. In *Archaeological Method and Theory*, edited by M. B. Schiffer, pp. 57-100. University of Arizona Press, Tucson.

NPS
2011 Facts About Yellowstone. Yellowstone National Park. YELL 176.

Park, R. J.
2010 A Culture of Convenience? Obsidian Source Selection in Yellowstone National Park, Department of Archaeology and Anthropology, University of Saskatchewan Saskatoon, Sakatoon.

Peterson, M. R.
2008 Prehistoric Settlement Patterns on the High Plains of Western Nebraska and the Use of Geographic Information Systems for Landscape Analyses. In *Archaeological Landscapes on the High Plains*, edited by L. L. Scheiber and B. J., pp. 237-276. University Press of Colorado, Boulder, CO, USA.

Pilgrim, T.
1987 *Predicting Archaeological Sites from Environmental Variables: A Mathematical Model for the Sierra Nevada Foothills, California*. BAR International Series 320, Oxford.

Reeve, S. A.
1989 Prehistoric Settlements at the Yellowstone Lake Outlet, Yellowstone National Park, Wyoming. Manuscript on file at the Midwest Archaeological Center, Lincoln, NE.

Reeves, B. O. K.
2006 *1999-2001 Archaeological Inventory Yellowstone River Tower Falls-Gardiner and Hellroaring Creek, Wyoming and Montana*. Yellowstone National Park, Mammoth Hot Springs, Wyoming.

Roll, T. E. and S. Hackenberger
1998 Prehistory of the Eastern Plateau. *Handbook of North American Indians* 12:120-137.

Sanders, P.
2013 Prehistoric Land-Use Patterns Within the Yellowstone Lake Basin and Hayden Valley Region, Yellowstone National Park: A Reassessment. In *Yellowstone Archaeology: Southern Yellowstone*, edited by D. H. M. a. E. S. Hale, pp. 22-39. vol. 2. 2 vols. The University of Montana, Missoula, Montana.

Sanders, P. H.

2000 *Archaeological Test Excavations of 12 Sites Along the Canyon to Lake Junction Highway, Yellowstone National Park, Wyoming, Project 7851*. Office of Wyoming State Archaeologist, Laramie, Wyoming.

Shortt, M. W.
1999 *Yellowstone National Park FHWA Archaeological SIte Inventory East Side of the Canyon to Fishing Bridge Segment of the Grand Loop Road: 1998 Field Season Final Report*. Museum of the Rockies.

2002 *The Archaeological Inventory of Portions of the South Shore of West Thumb and Testing of the Osprey Beach Locality, Yellowstone National Park: The 2000 Field Season Final report*. Yellowstone Center for Resources, Yellowstone National Park.

Shortt, M. W. and L. B. Davis (editors)
1998 *Yellowstone National Park Archaeological Site Inventory - Black Canyon of the Yellowstone and its Tributary Streams: 1996 Field Season Final Report*. Museum of the Rockies, Bozeman, Montana.

Taylor, D. C., K. Wood and J. J. Hoffman
1964 Preliminary Archaeological Investigations in Yellowstone National Park, Manuscript on file at the Midwest Archaeological Center, Lincoln, NE.

Van Leusen, M., A. R. Millard and B. Ducke
2009 Dealing with Uncertainty in Archaeological Prediction. In *Archaeological Prediction and Risk Management*, edited by H. Kamermans, M. Van Leusen and P. Verhagen. University Press, Leiden.

Veljanovski, T. and Z. Stancic
2006 Predictive Modeling in Archaeological Location Analysis and Archaeological Resource Management: Principles and Applications. In *GIS and Archaeological Site Location Modeling*, edited by M. W. Mehrer and K. L. Westcott, pp. 393-412. Taylor & Francis Group, New York.

Verhagen, P.
2006 Quantifying the Qualified: The use of Multicriteria Methods and Bayesian Statistics for the Development of Archaeological Predictive Models. In *GIS and Archaeological Site Location Modeling*, edited by M. Merher and K. Wescott. CRC Press, Boca Ranton.

2007 *Case Studies in Archaeological Predictive Modeling*. Amsterdam University Press, Amsterdam, NLD.

Verhagen, P. and T. Whitley
2012 Integrating Archaeological Theory and Predictive Modeling: a Live Report from the Scene. *Journal of Archaeological Method and Theory* 19(1):49-100.

Vivian, B. C.
2005 Identifying a Cody Component at the Malin Fish Hole Site (24YE353) in Yellowstone National Park. Paper presented at the Paper presented at the 63rd Annual Plains Anthropological Conference, Edmonton, Alberta.

Vivian, B. C., Brian O.K. Reeves and A. M. Johnson
2008 *Historical Resources Mitigative Excavations at site 24YE353: Malin Creek Site: Final Report*. Report on file, Branch of Cultural Resources, Yellowstone National Park, Mammoth Hot Springs, Wyoming
.

Vivian, B. C., Doug Mitchell, Kevin Thorson and A. M. Johnson
2007 *Archaeological Inventory of Yellowstone Lake Shoreline Survey Solution Creek to Southeast Arm, Volumes 1 and 2*. Yellowstone Center for Resources, Mammoth Hot Springs, WY.

Warren, R. E.
1990 Predictive Modeling of Archaeological Site Location: A Case Study in the Midwest. In *Interpreting Space: GIS and Archaeology*, edited by K.M. Allen, S. Green and E. Zubrow, pp. 201-215. Taylor and Francis Inc., London.

Warren, R. E. and D. L. Asch
2000 A Predictive Model of Archaeological Site Location in the Eastern Prairie Peninsula. In *Practical Applications of GIS For Archaeologists: A Predictive Modeling Kit*, edited by K. L. Wescott and R. J. Brandon, pp. 5-32. Taylor & Francis, Philadelphia, PA.

Wheatley, D.
2000 Spatial technology and archaeological theory revisited. *BAR INTERNATIONAL SERIES* 845:123-132.

Wheatley, D. and M. Gillings
2002 *Spatial Technology and Archaeology*. Taylor & Francis, New York.

Whitley, T. G.
2000 Dynamical systems modeling in archaeology: A GIS approach to site selection processes in the Greater Yellowstone Region. Ph.D., University of Pittsburgh, Ann Arbor.

Whitlock, C.
1993 Postglacial Vegetation and Climate of Grand Teton and Southern Yellowstone National Parks. *Ecological Monographs* 63(2):173-198.

Wilson, M. C.

1995 The Household as a Portable Mnemonic Landscape: Archaeological Implications for Plains Stone Circle Sites. In *Beyond Subsistence: Plains Archaeology and the Postprocessual Critique*, edited by Phillip Duke and M. C. WIlson. University of Alabama Press, Tuscaloosa.

Zubrow, E. B. W.
1994 Knowledge Representation and Archaeology: A Cognitive Example Using GIS. In *The Ancient Mind: Elements of a Cognitive Archaeology*, edited by C. Renfew and E. Zubrow, pp. 107-118. Cambridge University Press, Cambridge.

Appendix A: SPSS Output Table

Logistic Regression

Notes

Output Created		25-JAN-2015 20:54:16
Comments		
Input	Active Dataset	DataSet6
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	26285
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing
Syntax		LOGISTIC REGRESSION VARIABLES SiteScore /METHOD=BSTEP(LR) Relief1000_CircleMap Relief600_CircleMap Relief300_2CircleMap Relief150_2CircleMap YNPSlope_MosDEM2Resmp SpringsMtr_MaskExtGOOD SwmpMrsh_DstFrm_MaskExt IntStreams_YNPDstFrmIntg_ReClip StrmRvrDstFrm_MaskExt LkRvrStrmDstFrm_MaskExt DistFrmPrnlStrm2Int_Clip1 Shrub_HerbDistFromIntgr_Mask Forests_DistFromIntgr_Mask GlacioFluvialTerracePlns_DstFrmInt_Mask GlaciatedRollingUplandsDstFrmInt_Mask AlluvialLndFrm_DistFromIntg_Mask /PRINT=GOODFIT CORR ITER(1) CI(95) /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(900) CUT(0.5).
Resources	Processor Time	00:00:05.74
	Elapsed Time	00:00:05.75

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	26285	100.0
	Missing Cases	0	.0
	Total	26285	100.0
Unselected Cases		0	.0
Total		26285	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
0	0
1	1

Block 0: Beginning Block

Iteration History[a,b,c]

Iteration		-2 Log likelihood	Coefficients
			Constant
Step 0	1	36121.461	-.220
	2	36121.455	-.220

a. Constant is included in the model.

b. Initial -2 Log Likelihood: 36121.455

c. Estimation terminated at iteration number 2 because parameter estimates changed by less than .001.

Classification Table[a,b]

	Observed		Predicted		
			SiteScore		Percentage Correct
			0	1	
Step 0	SiteScore	0	14585	0	100.0
		1	11700	0	.0
	Overall Percentage				55.5

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	-.220	.012	315.374	1	.000	.802

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	Relief1000_CircleMap	7898.342	1	.000
		Relief600_CircleMap	7862.748	1	.000
		Relief300_2CircleMap	7252.531	1	.000
		Relief150_2CircleMap	6543.343	1	.000
		YNPSlope_MosDEM2Resmp	3480.015	1	.000
		SpringsMtr_MaskExtGOOD	1174.006	1	.000
		SwmpMrsh_DstFrm_MaskExt	265.857	1	.000
		IntStreams_YNPDstFrmIntg_ReClip	1549.733	1	.000
		StrmRvrDstFrm_MaskExt	41.504	1	.000
		LkRvrStrmDstFrm_MaskExt	6997.247	1	.000
		DistFrmPrnlStrm2Int_Clip1	1115.944	1	.000
		Shrub_HerbDistFromIntgr_Mask	274.159	1	.000
		Forests_DistFromIntgr_Mask	347.583	1	.000
		GlacioFluvialTerracePlns_DstFrmInt_Mask	7536.378	1	.000
		GlaciatedRollingUplandsDstFrmInt_Mask	1107.352	1	.000
		AlluvialLndFrm_DistFromIntg_Mask	1480.591	1	.000
	Overall Statistics		14156.678	16	.000

Block 1: Method = Backward Stepwise (Likelihood Ratio)

Iteration History[a,b,c,d]

Iteration		-2 Log likelihood	Coefficients																	
			Constant	Relief1000_CircleMap	Relief600_CircleMap	Relief300_2CircleMap	Relief150_2CircleMap	YNPSlope_MosDEM2Resmp	SpringsMtr_MaskExtGOOD	SwmpMrsh_DstFrm_MaskExt	IntStreams_YNPDstFrmIntg_ReClip	StrmRvrDstFrm_MaskExt	LkRvrStrmDstFrm_MaskExt	DistFrmPrnlStrm2Int_Clip1	Shrub_HerbDistFromIntgr_Mask	Forests_DistFromIntgr_Mask	GlacioFluvialTerracePlns_DstFrmInt_Mask	GlaciatedRollingUplandsDstFrmInt_Mask	AlluvialLndFrm_DistFromIntg_Mask
Step 1	1	19834.183	.450	-.001	-.002	.000	-.014	.030	.000	.000	.000	.000	.000	.000	-.001	-.001	.000	.000	.000
	2	16038.800	1.122	.000	-.005	-.003	-.023	.056	.000	.000	.001	.000	.000	.000	-.001	-.001	.000	.000	.000
	3	14616.186	1.880	.001	-.007	-.009	-.030	.082	.000	.000	.001	.000	-.001	.000	-.001	-.002	.000	.000	.000
	4	14312.462	2.355	.002	-.009	-.014	-.033	.100	.000	.000	.001	.000	-.001	.000	-.001	-.002	.000	.000	.000
	5	14294.284	2.490	.003	-.009	-.017	-.034	.106	.000	.000	.001	.000	-.001	.000	-.001	-.002	-.001	.000	.000
	6	14294.202	2.499	.003	-.009	-.017	-.034	.106	.000	.000	.001	.000	-.001	.000	-.001	-.002	-.001	.000	.000
	7	14294.202	2.499	.003	-.009	-.017	-.034	.106	.000	.000	.001	.000	-.001	.000	-.001	-.002	-.001	.000	.000
Step 2	1	19867.977	.500	-.001	-.002	.000	-.014	.030		.000	.000	.000	.000	.000	-.001	-.001	.000	.000	.000
	2	16040.405	1.169	.000	-.005	-.003	-.023	.055		.000	.001	.000	.000	.000	-.001	-.001	.000	.000	.000
	3	14616.030	1.891	.001	-.007	-.009	-.030	.082		.000	.001	.000	-.001	.000	-.001	-.002	.000	.000	.000
	4	14312.609	2.353	.002	-.009	-.014	-.033	.100		.000	.001	.000	-.001	.000	-.001	-.002	.000	.000	.000
	5	14294.298	2.488	.003	-.009	-.017	-.034	.106		.000	.001	.000	-.001	.000	-.001	-.002	-.001	.000	.000
	6	14294.214	2.497	.003	-.009	-.017	-.034	.106		.000	.001	.000	-.001	.000	-.001	-.002	-.001	.000	.000
	7	14294.214	2.497	.003	-.009	-.017	-.034	.106		.000	.001	.000	-.001	.000	-.001	-.002	-.001	.000	.000
Step 3	1	19878.966	.499	-.001	-.002	.000	-.014	.030		.000	.000	.000	.000	.000	-.001	-.001	.000	.000	
	2	16035.787	1.181	.000	-.005	-.003	-.023	.055		.000	.001	.000	.000	.000	-.001	-.001	.000	.000	
	3	14615.153	1.896	.001	-.007	-.009	-.030	.082		.000	.001	.000	-.001	.000	-.001	-.002	.000	.000	
	4	14313.551	2.345	.002	-.009	-.014	-.033	.100		.000	.001	.000	-.001	.000	-.001	-.002	.000	.000	
	5	14295.431	2.476	.003	-.009	-.017	-.034	.106		.000	.001	.000	-.001	.000	-.001	-.002	-.001	.000	
	6	14295.349	2.484	.003	-.009	-.017	-.034	.106		.000	.001	.000	-.001	.000	-.001	-.002	-.001	.000	
	7	14295.349	2.484	.003	-.009	-.017	-.034	.106		.000	.001	.000	-.001	.000	-.001	-.002	-.001	.000	

a. Method: Backward Stepwise (Likelihood Ratio)

b. Constant is included in the model.

c. Initial -2 Log Likelihood: 36121.455

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	21827.253	16	.000
	Block	21827.253	16	.000
	Model	21827.253	16	.000
Step 2[a]	Step	-.012	1	.911
	Block	21827.241	15	.000
	Model	21827.241	15	.000
Step 3[a]	Step	-1.135	1	.287
	Block	21826.107	14	.000
	Model	21826.107	14	.000

a. A negative Chi-squares value indicates that the Chi-squares value has decreased from the previous step.

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	14294.202[a]	.564	.755
2	14294.214[a]	.564	.755
3	14295.349[a]	.564	.755

a. Estimation terminated at iteration number 7 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	4133.234	8	.000
2	4132.412	8	.000
3	4109.181	8	.000

Contingency Table for Hosmer and Lemeshow Test

		SiteScore = 0		SiteScore = 1		Total
		Observed	Expected	Observed	Expected	
Step 1	1	2597	2628.643	32	.357	2629
	2	2601	2622.415	28	6.585	2629
	3	2600	2586.489	29	42.511	2629
	4	2398	2438.526	231	190.474	2629
	5	1786	2066.823	843	562.177	2629
	6	1975	1247.986	654	1381.014	2629
	7	435	446.438	2194	2182.562	2629
	8	94	240.464	2535	2388.536	2629
	9	33	174.540	2596	2454.460	2629
	10	66	132.676	2558	2491.324	2624
Step 2	1	2597	2628.643	32	.357	2629
	2	2601	2622.415	28	6.585	2629
	3	2600	2586.493	29	42.507	2629
	4	2398	2438.524	231	190.476	2629
	5	1787	2066.873	842	562.127	2629
	6	1976	1247.940	653	1381.060	2629
	7	431	446.286	2198	2182.714	2629
	8	96	240.601	2533	2388.399	2629
	9	33	174.548	2596	2454.452	2629
	10	66	132.677	2558	2491.323	2624
Step 3	1	2597	2628.644	32	.356	2629
	2	2601	2622.402	28	6.598	2629
	3	2600	2586.471	29	42.529	2629
	4	2404	2438.915	225	190.085	2629
	5	1787	2065.627	842	563.373	2629
	6	1968	1248.721	661	1380.279	2629
	7	430	446.418	2199	2182.582	2629
	8	99	241.269	2530	2387.731	2629
	9	31	173.972	2598	2455.028	2629
	10	68	132.561	2556	2491.439	2624

Classification Table[a]

	Observed		Predicted		
			SiteScore		Percentage Correct
			0	1	
Step 1	SiteScore	0	13000	1585	89.1
		1	1293	10407	88.9
	Overall Percentage				89.1
Step 2	SiteScore	0	13001	1584	89.1
		1	1292	10408	89.0
	Overall Percentage				89.1
Step 3	SiteScore	0	13003	1582	89.2
		1	1296	10404	88.9
	Overall Percentage				89.1

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Relief1000_CircleMap	.003	.001	18.121	1	.000	1.003	1.001	1.004
	Relief600_CircleMap	-.009	.001	50.184	1	.000	.991	.988	.993
	Relief300_2CircleMap	-.017	.002	48.536	1	.000	.983	.979	.988
	Relief150_2CircleMap	-.034	.003	105.844	1	.000	.966	.960	.973
	YNPSlope_MosDEM2Resmp	.106	.003	1033.695	1	.000	1.112	1.105	1.119
	SpringsMtr_MaskExtGOOD	.000	.000	.012	1	.911	1.000	1.000	1.000
	SwmpMrsh_DstFrm_MaskExt	.000	.000	245.553	1	.000	1.000	1.000	1.000
	IntStreams_YNPDstFrmIntg_ReClip	.001	.000	453.337	1	.000	1.001	1.001	1.001
	StrmRvrDstFrm_MaskExt	.000	.000	51.439	1	.000	1.000	1.000	1.000
	LkRvrStrmDstFrm_MaskExt	-.001	.000	1229.874	1	.000	.999	.999	.999
	DistFrmPrnlStrm2Int_Clip1	.000	.000	107.900	1	.000	1.000	1.000	1.000
	Shrub_HerbDistFromIntgr_Mask	-.001	.000	192.846	1	.000	.999	.999	.999
	Forests_DistFromIntgr_Mask	-.002	.000	189.707	1	.000	.998	.997	.998

	GlacioFluvialTerracePlns_DstFrmInt_Mask	-.001	.000	1132.968	1	.000	.999	.999	1.000
	GlaciatedRollingUplandsDstFrmInt_Mask	.000	.000	55.586	1	.000	1.000	1.000	1.000
	AlluvialLndFrm_DistFromIntg_Mask	.000	.000	1.151	1	.283	1.000	1.000	1.000
	Constant	2.499	.074	1136.302	1	.000	12.167		
Step 2[a]	Relief1000_CircleMap	.003	.001	18.108	1	.000	1.003	1.001	1.004
	Relief600_CircleMap	-.009	.001	50.279	1	.000	.991	.988	.993
	Relief300_2CircleMap	-.017	.002	48.575	1	.000	.983	.979	.988
	Relief150_2CircleMap	-.034	.003	106.300	1	.000	.966	.960	.973
	YNPSlope_MosDEM2Resmp	.106	.003	1039.852	1	.000	1.112	1.105	1.119
	SwmpMrsh_DstFrm_MaskExt	.000	.000	247.439	1	.000	1.000	1.000	1.000
	IntStreams_YNPDstFrmIntg_ReClip	.001	.000	454.314	1	.000	1.001	1.001	1.001
	StrmRvrDstFrm_MaskExt	.000	.000	52.360	1	.000	1.000	1.000	1.000
	LkRvrStrmDstFrm_MaskExt	-.001	.000	1249.090	1	.000	.999	.999	.999
	DistFrmPrnlStrm2Int_Clip1	.000	.000	114.469	1	.000	1.000	1.000	1.000
	Shrub_HerbDistFromIntgr_Mask	-.001	.000	194.838	1	.000	.999	.999	.999
	Forests_DistFromIntgr_Mask	-.002	.000	192.489	1	.000	.998	.997	.998
	GlacioFluvialTerracePlns_DstFrmInt_Mask	-.001	.000	1145.872	1	.000	.999	.999	1.000
	GlaciatedRollingUplandsDstFrmInt_Mask	.000	.000	59.097	1	.000	1.000	1.000	1.000
	AlluvialLndFrm_DistFromIntg_Mask	.000	.000	1.140	1	.286	1.000	1.000	1.000
	Constant	2.497	.073	1183.071	1	.000	12.147		
Step 3[a]	Relief1000_CircleMap	.00265	.001	18.422	1	.000	1.003	1.001	1.004
	Relief600_CircleMap	-.00919	.001	50.187	1	.000	.991	.988	.993
	Relief300_2CircleMap	-.01674	.002	48.442	1	.000	.983	.979	.988
	Relief150_2CircleMap	-.03408	.003	106.219	1	.000	.966	.960	.973
	YNPSlope_MosDEM2Resmp	.10620	.003	1039.385	1	.000	1.112	1.105	1.119
	SwmpMrsh_DstFrm_MaskExt	.00023	.000	275.874	1	.000	1.000	1.000	1.000
	IntStreams_YNPDstFrmIntg_ReClip	.00073	.000	479.235	1	.000	1.001	1.001	1.001
	StrmRvrDstFrm_MaskExt	-.00003	.000	51.327	1	.000	1.000	1.000	1.000
	LkRvrStrmDstFrm_MaskExt	-.00090	.000	1248.522	1	.000	.999	.999	.999
	DistFrmPrnlStrm2Int_Clip1	-.00035	.000	141.994	1	.000	1.000	1.000	1.000
	Shrub_HerbDistFromIntgr_Mask	-.00130	.000	193.341	1	.000	.999	.999	.999
	Forests_DistFromIntgr_Mask	-.00225	.000	191.525	1	.000	.998	.997	.998
	GlacioFluvialTerracePlns_DstFrmInt_Mask	-.00051	.000	1146.269	1	.000	.999	.999	1.000
	GlaciatedRollingUplandsDstFrmInt_Mask	-.00018	.000	58.513	1	.000	1.000	1.000	1.000
	Constant	2.48446	.072	1203.390	1	.000	11.995		

a. Variable(s) entered on step 1: Relief1000_CircleMap, Relief600_CircleMap, Relief300_2CircleMap, Relief150_2CircleMap, YNPSlope_MosDEM2Resmp, SpringsMtr_MaskExtGOOD, SwmpMrsh_DstFrm_MaskExt, IntStreams_YNPDstFrmIntg_ReClip, StrmRvrDstFrm_MaskExt, LkRvrStrmDstFrm_MaskExt, DistFrmPrnlStrm2Int_Clip1, Shrub_HerbDistFromIntgr_Mask, Forests_DistFromIntgr_Mask, GlacioFluvialTerracePlns_DstFrmInt_Mask, GlaciatedRollingUplandsDstFrmInt_Mask, AlluvialLndFrm_DistFromIntg_Mask.

Correlation Matrix

		Constant	Relief1000_CircleMap	Relief600_CircleMap	Relief300_2CircleMap	Relief150_2CircleMap	YNPSlope_MosDEM2Resmp	SpringsMtr_MaskExtGOOD	SwmpMrsh_DstFrm_MaskExt	IntStreams_YNPDstFrmIntg_ReClip	StrmRvrDstFrm_MaskExt	LkRvrStrmDstFrm_MaskExt	DistFrmPrnlStrm2Int_Clip1	Shrub_HerbDistFromIntgr_Mask	Forests_DistFromIntgr_Mask	GlacioFluvialTerracePlns_DstFrmInt_Mask	GlaciatedRollingUplandsDstFrmInt_Mask	AlluvialLndFrm_DistFromIntg_Mask
	Constant	1.000	-.172	.036	-.053	-.015	.030	-.202	-.492	-.223	-.261	-.158	-.042	-.130	-.180	-.257	-.233	.188
	Relief1000_CircleMap	-.172	1.000	-.762	.128	-.046	.098	-.024	.050	.039	.029	-.131	.013	.033	-.045	-.067	.107	-.024
	Relief600_CircleMap	.036	-.762	1.000	-.563	.213	-.091	-.030	-.036	.021	.036	.008	.040	-.006	.031	-.023	-.024	-.007
	Relief300_2CircleMap	-.053	.128	-.563	1.000	-.746	.153	.047	.006	-.082	-.033	.030	-.043	.004	.044	.109	.079	-.021
	Relief150_2CircleMap	-.015	-.046	.213	-.746	1.000	-.567	-.055	.021	.050	.024	.047	.023	-.016	.000	-.046	-.042	-.001
	YNPSlope_MosDEM2Resmp	.030	.098	-.091	.153	-.567	1.000	.074	-.030	.083	-.138	-.206	-.003	.030	-.052	-.212	.041	.007
S	SpringsMtr_MaskExtGOOD	-.202	-.024	-.030	.047	-.055	.074	1.000	.082	-.056	-.119	-.121	-.230	-.094	-.112	.110	-.231	-.142
t	SwmpMrsh_DstFrm_MaskExt	-.492	.050	-.036	.006	.021	-.030	.082	1.000	.078	.234	-.073	.037	.020	.112	.178	-.254	-.272
e	IntStreams_YNPDstFrmIntg_ReClip	-.223	.039	.021	-.082	.050	.083	-.056	.078	1.000	-.311	-.118	.185	-.008	-.170	.023	.004	-.176
p	StrmRvrDstFrm_MaskExt	-.261	.029	.036	-.033	.024	-.138	-.119	.234	-.311	1.000	.112	-.187	.013	.040	.146	-.111	-.154
	LkRvrStrmDstFrm_MaskExt	-.158	-.131	.008	.030	.047	-.206	-.121	-.073	-.118	.112	1.000	-.034	-.035	-.046	-.099	.049	-.036
1	DistFrmPrnlStrm2Int_Clip1	-.042	.013	.040	-.043	.023	-.003	-.230	.037	.185	-.187	-.034	1.000	-.032	-.019	-.001	.037	-.469
	Shrub_HerbDistFromIntgr_Mask	-.130	.033	-.006	.004	-.016	.030	-.094	.020	-.008	.013	-.035	-.032	1.000	.310	-.026	-.076	-.064
	Forests_DistFromIntgr_Mask	-.180	-.045	.031	.044	.000	-.052	-.112	.112	-.170	.040	-.046	-.019	.310	1.000	.054	-.001	-.042
	GlacioFluvialTerracePlns_DstFrmInt_Mask	-.257	-.067	-.023	.109	-.046	-.212	.110	.178	.023	.146	-.099	-.001	-.026	.054	1.000	.057	-.073
	GlaciatedRollingUplandsDstFrmInt_Mask	-.233	.107	-.024	.079	-.042	.041	-.231	-.254	.004	-.111	.049	.037	-.076	-.001	.057	1.000	-.005
	AlluvialLndFrm_DistFromIntg_Mask	.188	-.024	-.007	-.021	-.001	.007	-.142	-.272	-.176	-.154	-.036	-.469	-.064	-.042	-.073	-.005	1.000
S	Constant	1.000	-.181	.031	-.044	-.027	.046		-.487	-.240	-.293	-.188	-.093	-.153	-.208	-.241	-.294	.165
t	Relief1000_CircleMap	-.181	1.000	-.763	.130	-.047	.100		.052	.038	.026	-.135	.007	.031	-.048	-.065	.104	-.028
e	Relief600_CircleMap	.031	-.763	1.000	-.562	.212	-.089		-.034	.019	.033	.004	.034	-.009	.027	-.020	-.031	-.011

p	Relief300_2CircleMap	-.044	.130	-.562	1.000	-.745	.150	.002	-.079	-.028	.035	-.033	.009	.050	.104	.092	-.014
	Relief150_2CircleMap	-.027	-.047	.212	-.745	1.000	-.566	.026	.047	.017	.040	.010	-.021	-.006	-.040	-.057	-.009
2	YNPSlope_MosDEM2Resmp	.046	.100	-.089	.150	-.566	1.000	-.036	.088	-.131	-.200	.014	.037	-.044	-.222	.059	.017
	SwmpMrsh_DstFrm_MaskExt	-.487	.052	-.034	.002	.026	-.036	1.000	.083	.247	-.063	.057	.028	.123	.170	-.242	-.263
	IntStreams_YNPDstFrmIntg_ReClip	-.240	.038	.019	-.079	.047	.088	.083	1.000	-.321	-.126	.178	-.013	-.178	.029	-.010	-.186
	StrmRvrDstFrm_MaskExt	-.293	.026	.033	-.028	.017	-.131	.247	-.321	1.000	.099	-.222	.002	.027	.161	-.143	-.174
	LkRvrStrmDstFrm_MaskExt	-.188	-.135	.004	.035	.040	-.200	-.063	-.126	.099	1.000	-.064	-.047	-.061	-.087	.022	-.054
	DistFrmPrnlStrm2Int_Clip1	-.093	.007	.034	-.033	.010	.014	.057	.178	-.222	-.064	1.000	-.055	-.047	.025	-.017	-.520
	Shrub_HerbDistFromIntgr_Mask	-.153	.031	-.009	.009	-.021	.037	.028	-.013	.002	-.047	-.055	1.000	.303	-.016	-.101	-.078
	Forests_DistFromIntgr_Mask	-.208	-.048	.027	.050	-.006	-.044	.123	-.178	.027	-.061	-.047	.303	1.000	.067	-.028	-.059
	GlacioFluvialTerracePlns_DstFrmInt_Mask	-.241	-.065	-.020	.104	-.040	-.222	.170	.029	.161	-.087	.025	-.016	.067	1.000	.085	-.058
	GlaciatedRollingUplandsDstFrmInt_Mask	-.294	.104	-.031	.092	-.057	.059	-.242	-.010	-.143	.022	-.017	-.101	-.028	.085	1.000	-.039
	AlluvialLndFrm_DistFromIntg_Mask	.165	-.028	-.011	-.014	-.009	.017	-.263	-.186	-.174	-.054	-.520	-.078	-.059	-.058	-.039	1.000
	Constant	1.000	-.179	.032	-.042	-.026	.043	-.465	-.217	-.272	-.181	-.009	-.143	-.202	-.236	-.293	
	Relief1000_CircleMap	-.179	1.000	-.763	.129	-.048	.101	.047	.034	.022	-.138	-.008	.029	-.049	-.066	.103	
	Relief600_CircleMap	.032	-.763	1.000	-.563	.212	-.089	-.038	.018	.031	.004	.033	-.010	.027	-.021	-.032	
	Relief300_2CircleMap	-.042	.129	-.563	1.000	-.745	.150	-.002	-.084	-.031	.035	-.048	.008	.048	.104	.092	
	Relief150_2CircleMap	-.026	-.048	.212	-.745	1.000	-.565	.025	.047	.016	.040	.007	-.022	-.006	-.041	-.057	
S	YNPSlope_MosDEM2Resmp	.043	.101	-.089	.150	-.565	1.000	-.033	.093	-.129	-.200	.028	.039	-.044	-.221	.060	
t	SwmpMrsh_DstFrm_MaskExt	-.465	.047	-.038	-.002	.025	-.033	1.000	.036	.211	-.081	-.096	.006	.112	.161	-.261	
e	IntStreams_YNPDstFrmIntg_ReClip	-.217	.034	.018	-.084	.047	.093	.036	1.000	-.365	-.138	.098	-.028	-.191	.018	-.016	
p	StrmRvrDstFrm_MaskExt	-.272	.022	.031	-.031	.016	-.129	.211	-.365	1.000	.091	-.372	-.012	.016	.154	-.150	
	LkRvrStrmDstFrm_MaskExt	-.181	-.138	.004	.035	.040	-.200	-.081	-.138	.091	1.000	-.108	-.051	-.065	-.090	.019	
3	DistFrmPrnlStrm2Int_Clip1	-.009	-.008	.033	-.048	.007	.028	-.096	.098	-.372	-.108	1.000	-.112	-.090	-.007	-.044	
	Shrub_HerbDistFromIntgr_Mask	-.143	.029	-.010	.008	-.022	.039	.006	-.028	-.012	-.051	-.112	1.000	.300	-.020	-.103	
	Forests_DistFromIntgr_Mask	-.202	-.049	.027	.048	-.006	-.044	.112	-.191	.016	-.065	-.090	.300	1.000	.064	-.030	
	GlacioFluvialTerracePlns_DstFrmInt_Mask	-.236	-.066	-.021	.104	-.041	-.221	.161	.018	.154	-.090	-.007	-.020	.064	1.000	.084	
	GlaciatedRollingUplandsDstFrmInt_Mask	-.293	.103	-.032	.092	-.057	.060	-.261	-.016	-.150	.019	-.044	-.103	-.030	.084	1.000	

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	Relief1000_CircleMap	-7156.047	17.892	1	.000
	Relief600_CircleMap	-7172.502	50.802	1	.000

	Relief300_2CircleMap	-7171.904	49.605	1	.000
	Relief150_2CircleMap	-7200.835	107.467	1	.000
	YNPSlope_MosDEM2Resmp	-7733.212	1172.222	1	.000
	SpringsMtr_MaskExtGOOD	-7147.107	.012	1	.911
	SwmpMrsh_DstFrm_MaskExt	-7269.345	244.488	1	.000
	IntStreams_YNPDstFrmIntg_ReClip	-7379.871	465.539	1	.000
	StrmRvrDstFrm_MaskExt	-7173.188	52.174	1	.000
	LkRvrStrmDstFrm_MaskExt	-8035.587	1776.972	1	.000
	DistFrmPrnlStrm2Int_Clip1	-7205.292	116.382	1	.000
	Shrub_HerbDistFromIntgr_Mask	-7254.539	214.876	1	.000
	Forests_DistFromIntgr_Mask	-7249.590	204.978	1	.000
	GlacioFluvialTerracePlns_DstFrmInt_Mask	-7924.474	1554.746	1	.000
	GlaciatedRollingUplandsDstFrmInt_Mask	-7175.135	56.068	1	.000
	AlluvialLndFrm_DistFromIntg_Mask	-7147.674	1.145	1	.285
Step 2	Relief1000_CircleMap	-7156.047	17.880	1	.000
	Relief600_CircleMap	-7172.557	50.900	1	.000
	Relief300_2CircleMap	-7171.925	49.636	1	.000
	Relief150_2CircleMap	-7201.085	107.955	1	.000
	YNPSlope_MosDEM2Resmp	-7736.535	1178.855	1	.000
	SwmpMrsh_DstFrm_MaskExt	-7269.882	245.549	1	.000
	IntStreams_YNPDstFrmIntg_ReClip	-7381.452	468.691	1	.000
	StrmRvrDstFrm_MaskExt	-7173.645	53.076	1	.000
	LkRvrStrmDstFrm_MaskExt	-8070.401	1846.588	1	.000
	DistFrmPrnlStrm2Int_Clip1	-7208.877	123.539	1	.000
	Shrub_HerbDistFromIntgr_Mask	-7255.623	217.032	1	.000
	Forests_DistFromIntgr_Mask	-7251.420	208.627	1	.000
	GlacioFluvialTerracePlns_DstFrmInt_Mask	-7941.077	1587.939	1	.000
	GlaciatedRollingUplandsDstFrmInt_Mask	-7176.836	59.458	1	.000

Step 3	AlluvialLndFrm_DistFromIntg_Mask	-7147.674	1.135	1	.287
	Relief1000_CircleMap	-7156.771	18.194	1	.000
	Relief600_CircleMap	-7173.080	50.811	1	.000
	Relief300_2CircleMap	-7172.419	49.489	1	.000
	Relief150_2CircleMap	-7201.611	107.873	1	.000
	YNPSlope_MosDEM2Resmp	-7736.988	1178.628	1	.000
	SwmpMrsh_DstFrm_MaskExt	-7285.183	275.017	1	.000
	IntStreams_YNPDstFrmIntg_ReClip	-7393.805	492.261	1	.000
	StrmRvrDstFrm_MaskExt	-7173.664	51.979	1	.000
	LkRvrStrmDstFrm_MaskExt	-8071.433	1847.517	1	.000
	DistFrmPrnlStrm2Int_Clip1	-7223.813	152.277	1	.000
	Shrub_HerbDistFromIntgr_Mask	-7255.695	216.040	1	.000
	Forests_DistFromIntgr_Mask	-7251.432	207.516	1	.000
	GlacioFluvialTerracePlns_DstFrmInt_Mask	-7942.086	1588.823	1	.000
	GlaciatedRollingUplandsDstFrmInt_Mask	-7177.113	58.878	1	.000

Variables not in the Equation

			Score	df	Sig.
Step 2[a]	Variables	SpringsMtr_MaskExtGOOD	.012	1	.911
	Overall Statistics		.012	1	.911
Step 3[b]	Variables	SpringsMtr_MaskExtGOOD	.002	1	.967
		AlluvialLndFrm_DistFromIntg_Mask	1.140	1	.286
	Overall Statistics		1.153	2	.562

a. Variable(s) removed on step 2: SpringsMtr_MaskExtGOOD.

b. Variable(s) removed on step 3: AlluvialLndFrm_DistFromIntg_Mask.