Spatial Prediction and Contract Archaeology: The Benefits of Geostatistics

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Abstract

Contract archaeology has often been viewed by academic archaeology as unable to effectively understand the complex nature of archaeological data. This inability is due to the legislative, temporal, and monetary limitations of contract archaeology investigations. However, with the use of spatial analytical methods contract archaeology can also generate archaeological research questions within their temporal and monetary constraints. This project seeks to use spatial analytical methods, such as geostatistics, within a contract archaeology context to demonstrate the ability of contract archaeology to produce effective spatial predictions and enhance the research potential of contract archaeology.

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Introduction

Contract archaeology and academic archaeology are often viewed on opposite ends of a spectrum, with the latter residing in universities and the former in private cultural resource management firms. While the ultimate approach to archaeological work is very different, the data used by both is the same. Archaeological material consists of the same fundamental components for each side, namely a material, temporal, and spatial component. This project will focus on the spatial component of archaeological data and the attempt to understand it through methods developed within both archaeological contexts.

Analysis of the spatial component of archaeological data has at times been severely limited, even though archaeological data effectively lends itself to such analyses. Contract archaeology can specifically benefit from spatial analysis methods as the current legislation in the United States and the United Kingdom places emphasis on site location and identification. Spatial analytical methods can ultimately help to refine ideas of site distribution and boundaries within project areas and will help to develop more effective research potential for contract archaeology.

The methods used will consist of the use of an effective spatial interpolator, known as geostatistics. Geostatistics is a package of statistical techniques for data that is spatially distributed across a landscape (Ebert 2002) and can help to predict areas of archaeological potential that are difficult or impossible to survey. The proposed method will hopefully be useful in helping contract archaeology incorporate spatial analytical methods that are derived from an academic context into their interpretations and reports while remaining within their temporal and monetary constraints.

Chapter 1 Spatial Prediction and Contract Archaeology

1.1 Spatial Prediction and Current Archaeology Legislation

Spatial prediction and interpolation has been widely ignored by many areas within archaeology, even by areas that could potentially benefit greatly from spatial prediction methods and techniques. The focus within this project is the potential benefits spatial prediction can provide for contract archaeologists. Contract archaeology has changed greatly within the last 20 years, most notably as a result of compliance legislation, such as Section 106 of the National Historic Preservation Act (NHPA, 1966) or Planning Policy Guideline 16 (PPG 16, 1990). These articles of legislation have created a substantial number of archaeological investigations outside of an academic atmosphere, as part of a wider planning process. The inclusion of archaeology into the planning process affected archaeological investigations in a number of different ways, the most important of which has been a strong emphasis on the identification and distribution of sites over a particular landscape.

The compliance legislation mentioned above has placed a priority on the identification and evaluation of archaeological activities (Kolb and Stevenson 1997, 30), and as such contract archaeologists have emphasized broad field methods, such as fieldwalking, test pits, and shovel tests (Kolb and Stevenson 1997, 33). In the planning framework these methods and research goals can be described as Phase I investigations. The major goal of Phase I investigations is the provision of an intensive survey that describes the distribution of prehistoric/historic properties within an area. This includes the documentation of properties, a survey of the boundaries of the area along with the methods used and the identification of all properties including information on the appearance, significance, integrity and boundaries of the property in order to assess its significance (Kolb and Stevenson 1997).

From a spatial analytical perspective, the most important focus is the distribution and boundaries of archaeological properties. The *Guidelines for Public Archaeology in Wisconsin* (Kolb and Stevenson 1997) acknowledges this critical element of site distribution and boundaries in its statement that the recording of site boundaries is "critical in developing predictions about site distributions in various geographic areas and the development of other research questions" (Kolb and Stevenson 1997, 31). The determination of archaeological site boundaries involves a number of different methodologies, including statistical methods of sampling, along with field methods such as field walking and shovel test pitting.

The processes used in the assessment and identification of archaeological site distributions have often relied heavily on sampling designs in order to survey large areas effectively and efficiently. Typically, there are four main reasons for the use of sampling designs in archaeological survey (from Orton 2000, 67): discovery of sites (prospection), estimation of sites, characterization of sites, and hypothesis testing. In achieving the first three goals of sampling design, the most effective field methods are those that can cover large survey areas efficiently. Within the United States, and in particular the Midwest, shovel test pitting at regular intervals such as 10 or 15 meters is often used as the standard field method (Kolb and Stevenson 1997, 33). Where a plowed field exists, field walking can often provide the most beneficial results. However, the use of sampling theory for archaeological work means that only a small section of the proposed project area, typically 2-5% is actually being surveyed. While sampling is critical in developing an effective archaeological survey, the small percentage of surveyed area means a potentially low confidence in the survey results. The idea discussed here that sampled data such as shovel tests and field walking can provide more then simple spatial distributions of sites in an area will be discussed later. The use of the appropriate statistical tools can provide a reliable spatial prediction of sites or artefact boundaries within the survey area, ultimately enhancing the confidence in non-surveyed areas.

It is widely acknowledged that sampled data plays an important role in archaeological survey, but there is often no analysis performed beyond simple intuitive understanding. These intuitive understandings are demonstrated by the simplest visual representations of sampled data, see figure 1, known as symbol maps or data postings (Isaaks and Srivastava 1989), and referred to archaeologically as site distribution or dot density maps. While these maps are effective in providing a basic understanding of the site or artefact distribution over an area, it is important to remember that these maps only show the presence of sites or artefacts at a fixed point or area. Any inference into the values or densities between these fixed points, or unsampled areas, therefore, is purely an intuitive process done by the particular archaeologist. The prediction of the values or densities between these fixed points, known as interpolation, will be addressed in this project. The ability to predict areas of high artefact or site density can ultimately refine and identify the high potential boundaries of a survey area. A clearer and more accurate knowledge of site boundaries and distributions can then fulfill the goals

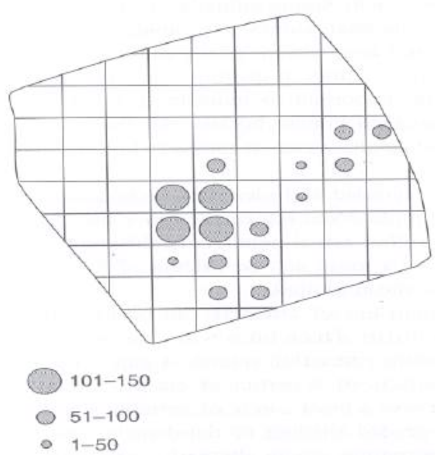


Figure 1 Example of a Symbol Map (Drewett 1999)

of spatial data to contract archaeologists, the development of site prediction with the planning framework.

1.2 *The 'Field' View of Contract Generated Archaeological Data*

This project has identified as its major goal to present a reliable method to predict values for unsampled locations in an archaeological survey. The process of making mathematical guesses about the values of a variable from an incomplete set of values is known as interpolation (Wheatley and Gillings 2002). The decision to use the process of interpolation is by no means straightforward, as there are a number of theoretical and methodological issues that must be understood.

The initial step in the spatial interpolation of a data set is to decide how to 'view' the data. In general, authors (Bailey and Gatrell 1995) have created a dichotomy between types of data: ones that can be considered discrete, and others that are considered continuous. The former assumes a conception of space that is defined by objects, which are considered discrete events in the landscape and are often visualized as points, lines or areas. This conception of space will be discussed as the 'entity' view of space. The latter type of data describes a 'field' view of space, which conceptualizes space as covered with essentially continuous surfaces. This 'field' view assumes that data, such as temperature, atmospheric pressure, or soil characteristics can be recovered at any particular point on the earth's surface. Therefore, recovery of continuous data is done at specific fixed points, typically on a grid or at a predetermined location, leaving us with sampled and unsampled locations.

The determination by the archaeologist of the category to which their data belongs carries with it methodological restrictions, although data can belong to both categories. In the entity view, a pattern of data is most clearly identified by its spatial coordinates within the landscape; these coordinates are the single most defining characteristic of the point, line, or area. Therefore, methods of analyzing point patterns are often concerned with testing the complete spatial randomness of the events or locations. This has typically involved the use of methods such as quadrant analysis, nearest neighbour analysis, and Ripley's K-Function analysis (Bailey and Gatrell 1995, 88). This project will move beyond the testing for spatial randomness and instead attempt to interpolate spatial data. This goal requires adopting the field view of archaeological data as spatially continuous, and the use of associated methods.

The view of archaeological data as spatially continuous is especially important within the field of contract archaeology. Too often, contract archaeology has become too preoccupied with archaeological data only existing in 'sites' (Thomas 1975, 62),. Therefore, the majority of field methods attempt to scour the landscape trying to identify discrete lumps or 'sites' of archaeological value surrounded by a landscape perceived to be otherwise lacking in archaeological importance (Wheatley 1995). The emphasis on sites can clearly be problematic when such a vague definition of a 'site' exists in archaeology, with no specific idea of what exactly is a site, or the spatial properties of it? Most commonly for archaeologists a site consists of any locus of cultural material, thus the possibility of defining a site as either single spearhead, 5 flakes, or 100 pottery sherds, all of which have very different material and spatial components (Thomas 1975). This view of archaeological data has led to project reports (see Hamilton 2004) and maps (see figure 1) that simply graph the presence or absence of archaeological sites on a landscape, with no regard to the density or spatial properties of artefacts over a particular area. By shifting to a view of archaeological data as spatially continuous, we can consider the patterns of the attribute values and densities across the entire landscape, without consistently being constrained by the 'site' mentality.

Contract archaeology holds great potential for the development of the field view of archaeological data, since the sampling techniques and methods are already prevalent in contract archaeology. In essence, the contract archaeology process involves a predefined area, such as a new highway corridor, and involves the decision to sample particular areas and measure the archaeological data within these areas, a process that is very similar to how a geologist would search for different minerals or soil formations. By understanding that the locations are now simply sample sites at which attribute values have been recorded (Bailey and Gatrell 1995, 19), we can begin to use the methods of spatial interpolation in order to further understand the spatial properties and boundaries of our data.

Chapter 2 Choosing a Spatial Interpolator: The Benefits of Geostatistics

2.1 Characteristics of Spatial Interpolators

The choice of spatial interpolator is by no means a straightforward process, since different interpolators have specific advantages depending upon the type of analysis to be performed. This project is concerned with the choice of interpolators based on three characteristics: exact or approximate, constrained or unconstrained, and global or local. The first characteristics to be considered are those concerned with whether or not the interpolated results pass through the observed data points (Wheatley and Gillings 2002); results that pass through the values are referred to as exact, while those in which the interpolated results are different from the observed values are known as approximates. Secondly, interpolators can be defined as either constrained or unconstrained. The difference between the two characteristics relies on the restriction of the range of values to be interpolated. The distinction between the two becomes particularly important in situations in which the predicted values cannot be negative in these situations, unconstrained procedures should be avoided (Wheatley and Gillings 2002). Of particular importance to this project is the third characteristic, global or local procedures. Global procedures map a particular function across an entire region, while a local procedure breaks the surface into smaller surfaces and derives particular functions for specific regions (Wheatley and Gillings 2002).

2.2 Spatial Interpolators

The most common interpolators currently in use within archaeological investigations are kernel density analysis, inverse distance weighting, trend surface analysis, and predictive modeling. These methods are of varying use in current archaeological investigations and all present strengths and weaknesses with archaeological data. Each method will be discussed by a brief summary, with a more in depth discussion of one of the most common methods, trend surface analysis.

Kernel Density Estimation: A method concerned with point data which generates a grid based upon the densities of individual points (Wheatley and Gillings 2002, 185). At the simplest level kernel density estimation (KDE) can be viewed as nothing more then a smoothed form of a histogram laid over a landscape (Baxter and Beardah 1997). KDE often has a tendency to undersmooth higher densities, and oversmooth lower densities and is significantly influenced by grid/kernel size and edge effects. Kernel density estimation has been used archaeology with varying degrees of success (see Baxter, Beardah and Wright 1997; Beardah 1999).

Inverse Distance Weighting: A method which uses numerical approximation procedures in order to interpolate values between known locations. Inverse distance weighting (IDW) are unconstrained procedures that approximate values within the sampled and unsampled locations (Wheatley and Gillings 2002, 193). The procedure is influenced by the number of points used, requiring experimentation with the data to determine the best compromise between the ‘blocky’ results of low values and ‘peaky’ results of high values (Wheatley and Gillings 2002, 195)

Predictive Modeling: A method which seeks to combine a number of different variables into a model that can help predict areas of archaeological potential within the landscape. Often variables that are chosen consist of available environmental data or previous archaeological surveys. Predictive modeling can be an incredibly useful tool in the management of areas with archaeological importance. However, some problems can be that predictive models rely heavily on environmental data, and the creation of an effective model can be a long process producing results that are difficult to understand (Dalla Bona 2000, 97). Predictive modeling has been used with great success in many different archaeological contexts throughout the world including the United States, Canada, and Holland (see Westcott and Brandon 2000; Kammermans 1999; Kohler 1988; Brant, Gronewoudt, and Kvamme 1992).

Trend Surface Analysis: Trend surface analysis is an unconstrained, approximate, global procedure which attempts to model an underlying trend within the data at a global or large scale, through the mean value of spatially continuous variables (Bailey and Gatrell 1995). The basic process involves the fitting of polynomial or algebraic functions of the spatial coordinates by ordinary least squares regression (Bailey and Gatrell 1995). The implicit assumption involved with least squares regression is that the area of study can be represented by a simple function such as a polynomial, plus a random error component (Armstrong 1998). The aim of trend surface analysis is the generation of a smoothed best-fit surface (see figure 2), based upon the polynomial function, that can be used for any kind of archaeological data, such as Romano-British Oxford products, Bagterp spearheads, or even Lowland Classic Mayan sites (see Hodder and Orton 1976; Kvamme 1990).

Trend surface analysis is commonly used due to two basic advantages: its simplistic use of polynomial regression for global analyses and the versatility with various forms of archaeological data. However, when dealing with spatial interpolation within contract archaeology, trend surface analysis becomes less effective. . As discussed earlier, contract archaeology focuses on determining the presence/absence of archaeological sites over a landscape, with emphasis on the distribution and boundaries of sites.

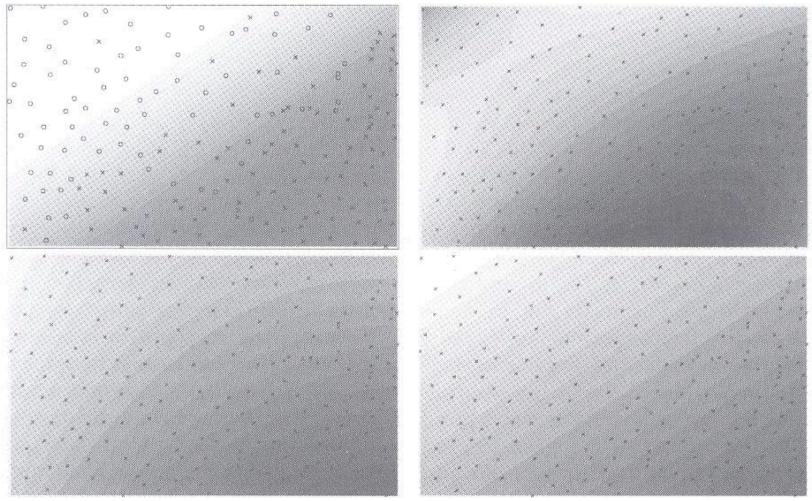


Figure 2 Examples of Trend Surface Analysis (Wheatley and Gillings 2002)

Contract archaeology's focus on site distribution and boundary requires the use of a spatial interpolator with different characteristics, namely, an interpolator that maintains the sampled values over the area and can model localized processes. Since trend surface analysis is unconstrained and approximate, intervening values for some interpolated areas can be very high or very low (Wheatley and Gillings 2002), nor does the interpolated trend surface need to pass through any of the archaeological values. These factors lead to a very broad and locally inaccurate map of the spatial distribution and boundaries of archaeological sites. The characteristics of trend surface analysis and the aims of contract archaeology require an alternate spatial interpolator, such as geostatistics, for more effective results.

2.3 Geostatistics: Theoretical and Statistical Background

Geostatistics is a set of tools used to characterize spatial variation and spatial prediction (Lloyd and Atkinson 2003). Originally developed in the fields of mining and geology, geostatistics can provide a superior method for estimating values of unsampled locations within a landscape. The most common application of geostatistics has been the estimation of natural resource reserves such as precious metals, iron ore and base metals (Armstrong 1998). The archaeological use of geostatistics has been limited (see Lloyd and Atkinson 2003; Ebert 2002), although the theory and method of geostatistics can be easily applied to an archaeological context. Archaeologists, like geologists, are concerned with spatially distributed data and can therefore benefit from a geostatistical approach.

Geostatistics, as well as trend surface analysis, are both based on regionalized variable theory a model where spatial phenomena are modeled as random variables distributed across a surface (Ebert 2002). Understanding spatial phenomena through the use random processes has proved useful in both archaeology and modeling human behavior, as many of observed archaeological patterns have a form that is similar to patterns produced by a non-random process (Hodder and Orton 1976:9). In any spatial analysis based on regionalized variable theory, different components are used, which typically include a deterministic component and a random error component. The key difference between trend surface analysis and geostatistics is that trend surface analysis typically places all spatial randomness into the error component and all structure into the deterministic component (Armstrong 1998). Geostatistics, on the other hand, introduces randomness in terms of fluctuations around a fixed surface, originally termed “drift” by Matheron (1971). These random processes in the spatial data are not considered errors but rather features of the phenomenon with structures of their own (Armstrong 1998). In essence, a geostatistical analysis has three components: a structural component (1), a random spatially correlated component (2), and a random noise element component (3), as seen in figure 3.

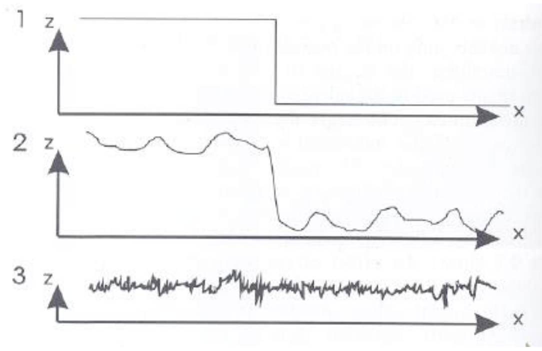


Figure 3 Structural Components of a Geostatistical Analysis (Wheatley and Gillings 2002, 196)

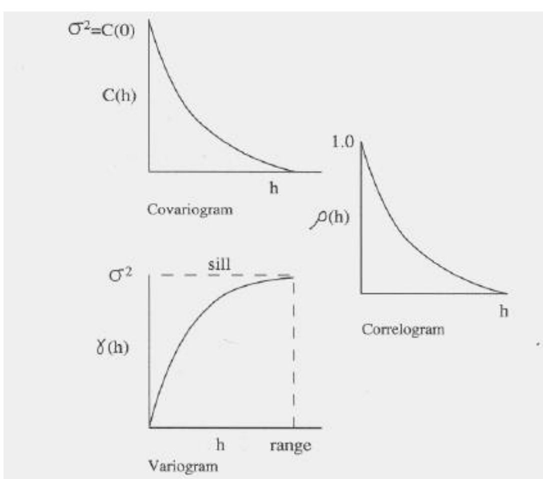
In a statistical sense, the inclusion of a random spatially correlated component changes the simple polynomial regression models used in trend surface analysis. The regression models using ordinary least squares make the simple and possibly unrealistic assumption that only first order effects are involved in spatial phenomena (Bailey and Gatrell 1995). By using the idea of generalized least squares, we can move away from this assumption and attempt to model both first and second order variations within our spatial model by using generalized least squares (see Bailey and Gatrell 1995, 176 for a more detailed statistical discussion). In essence, regionalized variable theory, in combination with generalized least squares statistics, allows geostatistics to model both global (first order) and local (second order) components of our spatial phenomena, depending on the focus of the researcher. The ability to model local components while maintaining its exact and constrained characteristics makes geostatistics the most reliable and effective model available to archaeologists.

Chapter 3 The Geostatistical Method: Visualizing the Variogram

3.1 Understanding the Variogram

With the theoretical and statistical underpinnings established, we can now turn to the processes involved in using geostatistics for spatial data analysis. The core procedure of geostatistics involves the creation of a variogram of the spatial data, or sometimes more formally referred to as a semi-variogram. The variogram seeks to give a graphical representation of spatial variation and does so by plotting a measure of the difference between all points (Ebert 2002, 83), known as the variance ($\gamma(h)$) of the data, versus the distance of these same points (h). Understanding the variance of the data requires an understanding of the idea of the covariance, a factor measuring the extent to which two variables vary together (Bailey and Gatrell 1995). If, for instance, one variable increases along with another variable, we say there is a positive correlation. In general, the same ideas apply in a spatial context, but instead of looking for the covariance or correlation between two independent variables, we are identifying the covariance of the deviations of observations from their mean value at different locations on the map. Typically, we can anticipate spatial data having positive correlation at short distances and lower correlations at greater distances.

Figure 4 Examples of Covariogram, Variogram, and Correlogram (Bailey and Gatrell 1995, 163)



Visualization of the correlation or variance of spatial data can be achieved through a number of different methods, but the most commonly used are through the variogram ($\gamma(h)$) and the covariogram ($C(h)$). These two methods provide similar information on correlation and distance but in slightly different forms (Bailey and Gaterll 1995). The variogram plots variance versus distance, typically creating a concave line starting at $\boldsymbol{h} = 0$ and rising upward towards a maximum, see figure 4. The covariogram has the same general shape as the variogram, but appears as an inverted version of the variogram that starts with a higher variance value and slopes down in a convex manner. The basic relationship between the two can be summed up with the equation:

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

Without discussing the intricacies of these processes it is important to note that both variograms and covariograms can be used and both can be beneficial to specific spatial analyses. The variogram is predominantly used in the geological and earth sciences (Isaaks and Srivastava 1989), and will be used throughout this project since the particular software chosen for analysis provides better results with the variogram.

3.2 Reading and Modeling the Variogram

The variogram has a number of key components which need to be identified for an adequate spatial analysis. A typical variogram consists of two components, the sill and the range, which refer to the point at which the variogram levels out and gains linear stability. The measurement from the point at which this occurs to the variance (y-axis) is known as the sill, while the measurement from the point to the distance (x-axis) is referred to as the range, see figure 5. The distance measurement of the variogram is referred to as the lag ($\boldsymbol{h}$), and is determined by the distance between sampled points, see figure 6. In an idealized variogram, as seen below, the sill and range can be easily identified, and the point of origin always occurs at zero.

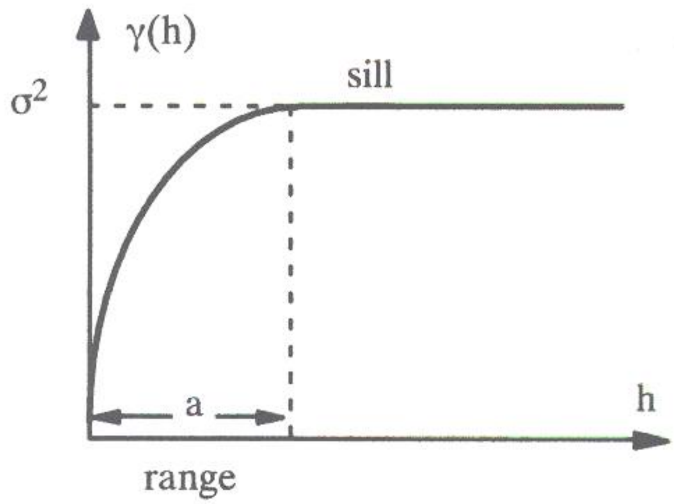


Figure 5 Idealized Variogram showing Range and Sill (Armstrong 1998, 26)

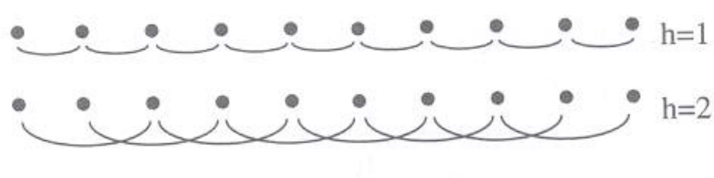


Figure 6 Example of the Lag Distance (Bailey and Gatrell 1995, 164)

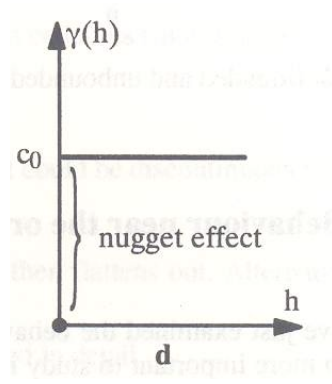


Figure 7 A Pure Nugget Effect (Armstrong 1998, 28)

In actuality, however, sampling error and small scale variability can cause sample values with small separations to be quite different (Isaaks and Srivastava 1989). Within the variogram these different values can be identified by having a point of origin starting at a value higher then zero, which is often referred to as the nugget effect. The nugget effect can be used to determine the level of random noise component within the data; for instance, as if the nugget effect is high, one can infer that the degree of random noise in the data is very high. A completely random data set would therefore have a high nugget effect and no range or sill, resulting in a straight line, seen in figure 7. Ultimately, the creation of an effective variogram is a process involving many different techniques that are used to smooth out sampling and human errors. It is a process that requires experience (see Matheron and Armstrong 1987) in advanced statistical techniques and overall knowledge of the data set, issues that will be discussed below when dealing with the STH 15 Hortonville Bypass data.

The process of creating an effective variogram can be difficult and time consuming, but it is necessary for the second step in the geostatistical process, modeling the variogram, which seeks to fit a standard model to the data to be used as the basis for further interpolation and prediction. The models that are typically used are the spherical, exponential, power, and Gaussian. These dominant models came into existence by mathematically constructing a random function and calculating its variogram (Armstrong 1998). The resulting models for these random constructions were then built up into individual expressions leading to four different models with slightly different characteristics.

The choice of the appropriate model to use with a variogram depends greatly upon the structure of the variogram, as the best fit of model to variogram is desired. Therefore, knowledge of the behavior of these models is beneficial, and described below:

The Spherical Model: The most commonly used model in geostatistics. It has a simple polynomial expression with an almost linear growth up to a certain distance and then a stabilization (Armstong 1998)

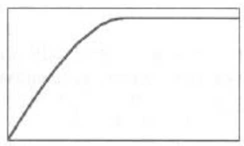


Figure 8 Spherical Model (Armstrong 1998, 37)

The Exponential Model: Similar to the spherical model, but tends to rise more rapidly towards the sill initially and then smoothes out without reaching it

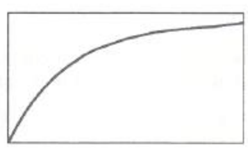


Figure 9 Exponential Model (Armstrong 1998, 37)

The Power Model: Often a special case, it is a linear model starting at the point of origin and increasing straight in a specific direction

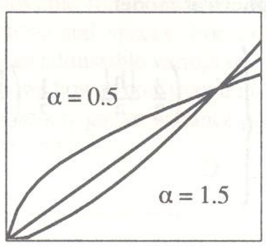


Figure 10 Power Models (Armstrong 1998, 38)

The Gaussian Model: Represents an extremely continuous phenomenon, is characterized by a slight convex beginning transforming into a slight convex ending.

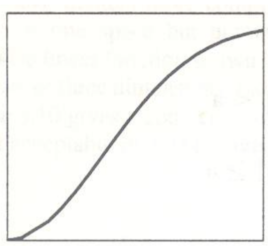


Figure 11 Gaussian Model (Armstrong 1998, 38)

Geostatistics's strength over other methods is its ability to effectively fit these models to the created variogram. These models, along with many lesser known models (see Armstrong 1998) provide the functions upon which later interpolations and predictions will be based. These models help identify the components such as range and sill for use in the prediction and interpolation. Obtaining the best fit of variogram models to be used with kriging interpolation becomes a crucial procedure, since any resulting information is based upon the fit of model to variogram. This is usually done by human experience and by using trial and error techniques within programs such as Variowin 2.2 until the best possible fit is recognized. For a number of different reasons (see Armstrong 1998, 54), these trial and error techniques still provide the most effective results in a geostatistical spatial analysis.

3.3 Interpolating Geostatistics: The Kriging Method

The third step in the geostatistical method is the interpolation or prediction of values for unsampled locations. The interpolation or prediction of values for a particular area based on the use of the geostatistical method of the variogram is known as kriging, named after the South African mining engineer D.G. Krige (Wheatley and Gillings 2000). As discussed earlier, kriging, or optimal interpolation, differs from typical interpolations such as trend surface analysis in its ability to model both first and second order effects of spatial phenomenon. In terms of contract archaeology, this allows for a more precise notion of the regional distribution and boundaries of artefacts from previously identified sites. The main purpose of kriging, then, is to ultimately create a map of kriged values for the project area which can visually show the predicted distribution of artefacts. Mapping these kriged values requires the use of software such as Surfer, Gsharp, or ArcView with kriging extensions (Webster and Oliver 2001). While all forms of kriging are based on the creation of a variogram, for effective results we must still consider two types of kriging techniques along with the structure of our data set. These two main types of kriging methods are known as ordinary kriging and block kriging.

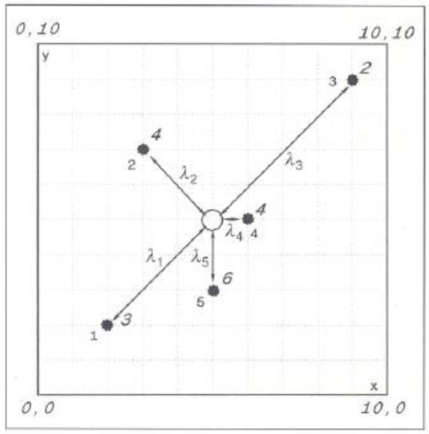


Figure 12 Example illustrating the Prediction of *z* at unsampled locations using ordinary Kriging (Burrough and McDonnell 1998, 139)

Ordinary kriging involves using the chosen variogram model that best fits the data, and interpolating values of unsampled locations based on the chosen model. Ordinary kriging relies purely on the raw data of point location and corresponding z-value of the data to be measured, see figure 12.

Therefore, ordinary kriging works very well when using large, exhaustive, data sets from a grid, since the measurements between points are never extreme. The basic process of ordinary kriging involves choosing a distance from each point, or a maximum number of neighbors, and interpolating values for the distances between them. The search neighbor, if not automatically defined by the software program, can be crudely calculated with the following equation:

Average spacing between data = √ *(Total area covered by samples / Number of samples)*

(Isaaks and Srivastava 1989, 341)

Once an appropriate amount of search neighbours is determined, the kriging procedure can begin. The process itself is similar to a weighted moving average interpolation, however, the weights are now derived from a geostatistical approach, which allows for the random structurally correlated component to be added, improving our weights over the more general approaches, such as trend surface analysis (Burrough and McDonnell 1998, 139). The method of ordinary kriging provides a distinct advantage over previous techniques in that we can also map the estimation error, or kriging variance of the project area. The kriging variance, often mapped as the kriging standard deviation or kriging error, can give valuable information to the reliability of our interpolated values (Burrough and McDonnell 1998, 141).

If such a regular data set is available then ordinary kriging is recommended. However, if the point patterns or sites found in an area tend to be lacking or are irregularly spaced, potential problems can arise. This can be identified most easily in a variogram which demonstrates little spatial continuity see figure 13, and contains a wide array of high and low values within the variogram. A solution to this problem involves overlaying a grid on the project area and assigning point values to particular sections of the grid or blocks, a process known as block kriging.

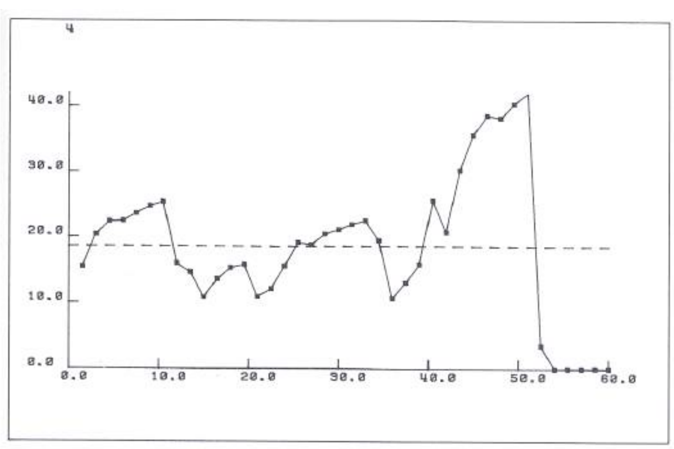


Figure 13 Example of Variogram Demonstrating Low Spatial Continuity (Matheron and Armstrong 1987, 13)

Block kriging relies on the same general principles as any another kriging system: use of the variogram and fitted model to interpolate unsampled locations. However, it differs in terms of the number and location of points in the analysis. In essence, the project area is seen as a large grid, not as individual point locations as in ordinary kriging, and thus each block within the grid is given a value based upon a point within the grid. The location of the point or points within the grid is determined by the researcher; some authors advocate averaging out a number of different points in order to determine a value, or using a different location in the block every time, although the most commonly used point is located as close to the middle of the block as possible.

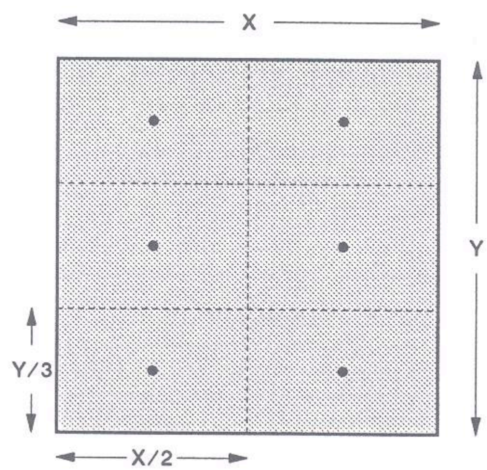


Figure 14 Example Showing the Placement of Point Value inside Block Kriging (Isaaks and Srivastava 1998, 330)

In an archaeological context, block kriging is more effective then ordinary point kriging since archaeological data can be much more scarce and unavailable then the typically used environmental data. Block kriging imposes a sort of spatial continuity upon the data that helps to balance out the irregular patterns produced by the scarcity of archaeological data.

Before this project addresses the use these methods in the real world it is important to note a key issue that may arise in the process of creating variograms and kriging: the idea of spatial continuity in all directions over the entire project area, termed the isotropy or anisotropy of the area (Armstrong 1998). If a variogram is isotropic it is solely dependent upon the magnitude of the distance between the two points, however, if the variogram reacts differently when the angle direction is changed it can be viewed as anisotropic. This is apparent if we look at the graph of the variogram surface, figure 15. We can see that the degree of continuity of the variogram is not evenly distributed, and that in fact we have a strong continuity (red areas) in a 45 degree Northeast-Southwest direction represented by the red areas, and little continuity (blue areas) in the 135 degree Northwest-Southeast.

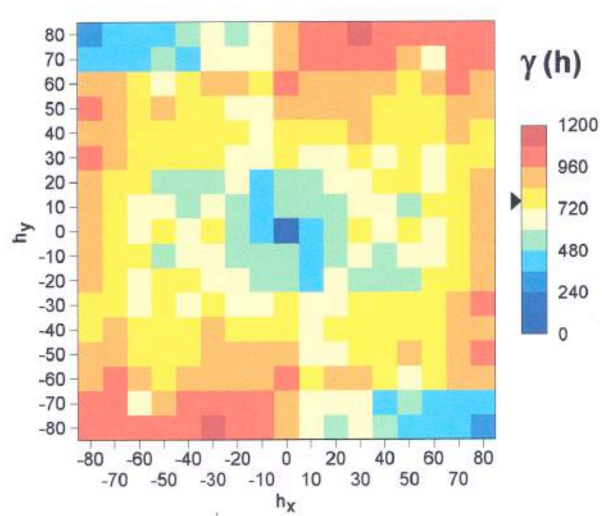


Figure 15 Variogram Surface showing anisotropic Phosphate data produced using Variowin 2.2 (Orton, C. Lecture in G117: Spatial Analysis, 2004)

The implication for our variogram is that it fails to adequately represent the spatial variation of our data. The solution to this problem lies in rotating the direction from which the variogram starts, typically a shift to a 45 degree angle, while keeping the angle tolerance at 90 degrees. This rotation turns the starting angle of the variogram, in order to provide a more adequate identification of the spatial continuity of our data. It is important to note that anisotropy must be checked for by analyzing the variogram surface or comparing directional variograms, and if ignored can result in an inadequate spatial analysis, especially with ordinary point kriging.

This concludes a brief summary of the geostatistical method to be used for this project, although it is by no means an in-depth analysis of the method. A wide range of heavily statistical variogram methods and kriging methods have been developed in the mining and environmental fields that extend far beyond the scope of this project. The preceding section merely covers the theoretical and methodological basics of geostatistics to be used in the case study.

Chapter 4 Case Study: The Hortonville Bypass Archaeological Surveys

4.1 Previous Uses of Geostatistics

The combined use of Geostatistics and archaeological evidence has rarely been attempted, with only two articles having been published (Lloyd and Atkinson (2004) and Ebert (2002)). Both articles highlight the potential of Geostatistics in analyzing spatial phenomenon and predicting unsampled values. This project has similar goals, although the type of data to be used differs, since the data for this project is not derived from a long-term archaeological project or previously known distribution.

4.2 Project Details

The data for this project comes from the ongoing archaeological surveys for the State Trunk Highway 15 Hortonville Bypass, conducted by Norm Meinholz (Meinholz 2004). The contract involves an archaeological survey for a number of proposed new highway corridors that bypass the town of Hortonville, Wisconsin (see figure 16). This project concentrates on the western connection, which consists of two proposed corridors running between New London, WI and Hortonville, WI (see figure 17). The data for this project was collected during the summer of 2004 in conjunction with the archaeological contract being carried out by the Wisconsin Historical Society Museum Archaeological Program and the Wisconsin Department of Transportation. The methods used for collection involve the standard methods for the Wisconsin Historical Society phase I

Figure 16 Map Showing Location of Hortonville, WI (www.mapquest.com 2004)

surveys, including fieldwalking and shovel testing at 10-15 meter intervals (Meinholz, 2004).

The area was chosen for a variety of reasons; first, the data provided comes from within the context of contract archaeology, and as is necessary for bridging the gap between academic methods such as geostatistics and the field methods from contract archaeology discussed earlier. Secondly, the project presents an area in which certain parts of the landscape were not surveyed due to environmental conditions in which some areas were too wet or inaccessible to archaeologists, and laws that limit access to areas outside of highway corridor. These factors are common within contract archaeology and therefore provide a demonstrable need for an overall interpolation and prediction of the area, including locations that could not be surveyed. Third, the author actively worked on the project area, and so possesses an intimate knowledge of the landscape and artefact types.

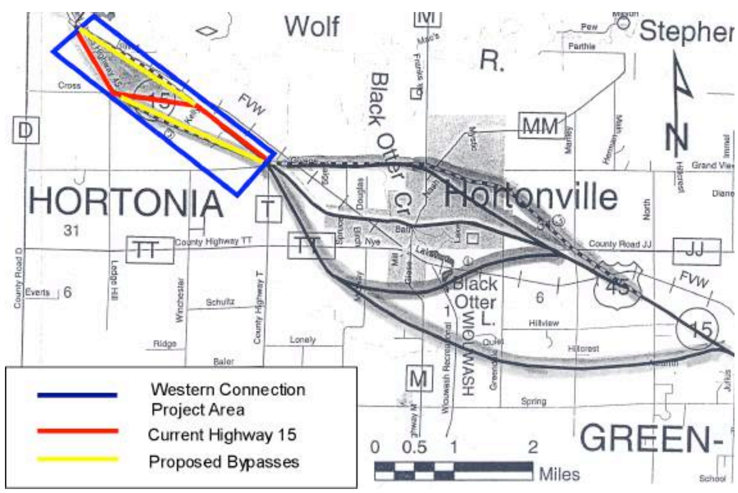


Figure 17 Map Showing the Project Area in Relation to the Entire Hortonville Bypass Project (Meinholz 2004)

The project area itself is larger then the areas surveyed, since the current Highway 15 and the two proposed corridors, marked in red and yellow in figure 17, are irregular in shape. Therefore, in order to interpolate a map through kriging, which only allows for rectangular areas, the area under study in this project must extend beyond the highway corridors to the area seen in figure 18. This area measures approximately 6,100 meters by 1220 metes for a total area of 7,432,000 square meters, with roughly 40 percent or 2,972,800 square meters surveyed. Over two field seasons of archaeological survey in this area, a total of 33 prehistoric archaeological sites were identified along with 15 isolated finds, of which the names and artefact counts can be found in appendix A. The combination of sites and isolated finds made up a total data set of 48 locations to use with our geostatistical methods.

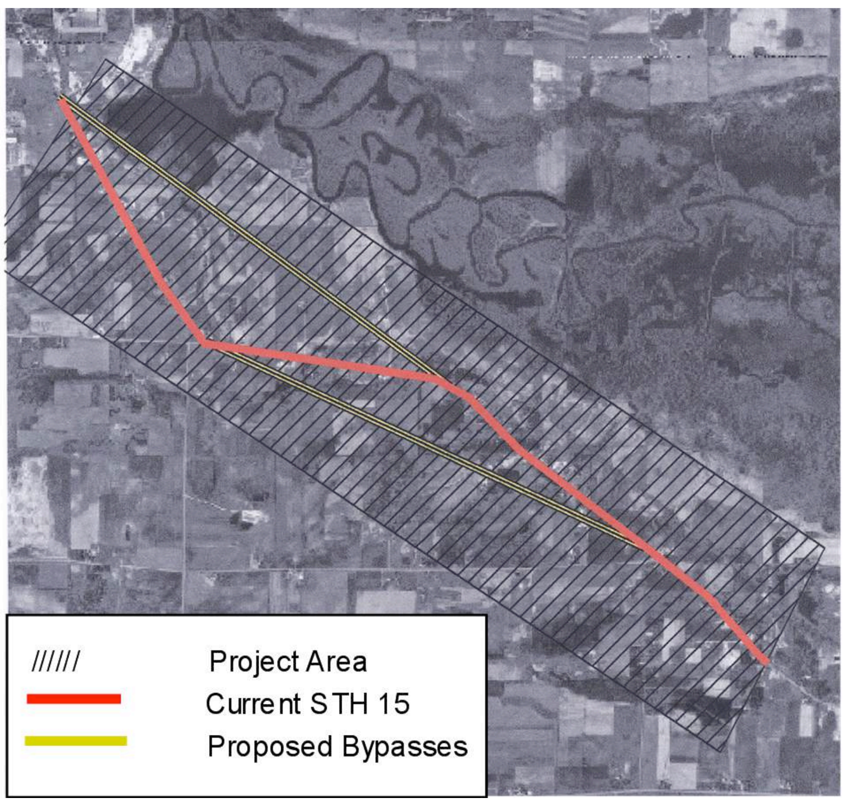


Figure 18 Aerial Photo with Project Area, Current Highway, and Proposed Corridors (Photo from www.mapcard.com, 2004)

4.3 The Geostatistical Analysis

The first step in a geostatistical analysis is the creation of the core tool, the variogram. The variogram was created using a combination of the Variowin 2.2 software along with the geostatistical analyst function in ArcGIS. Initially, two variograms were created: one using the point locations (UTM's) of each particular site along with the total artefact count, and one using the block approach. The block approach assigned each of the 500 squares of the project area grid a value with 48 blocks containing the artefact count values for each site. As mentioned before, scarce amounts of data, such as our 48 sites, can cause a low degree of spatial correlation, thus causing a variogram to produce unstable results, as seen in figure 19 with a high nugget effect and general angularity of the variogram. The instability of this variogram makes adequately fitting a model a difficult and dubious task. Therefore, a second variogram which incorporates the much larger data set of block values will be used, as it provides a much more stable variogram, see figure 20. However, block kriging should be used with caution, as the stability of the variogram is reliant upon the large amount of null values it contains and can produce inaccurate interpolated and predicted surfaces. The curve of the variogram in figure 20 is characterized by two important factors: the high nugget effect and the overall flatness of the curve. The high nugget effect implies that the data with which we are dealing has a limited amount of spatial correlation, because a pure nugget effect

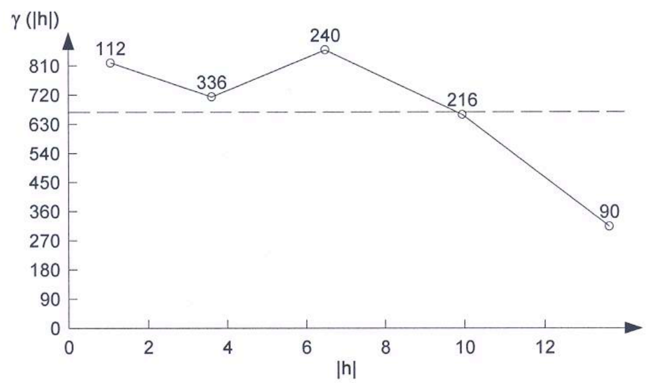


Figure 19 Unstable Variogram Using Ordinary Kriging (Variowin 2.2, 2004)

entails a complete lack of spatial correlation (Isaaks and Srivastava 1989). The second factor, the overall flatness of the curve, demonstrates a generally uniform distribution of sites across the landscape (Ebert 2002), with no strong spatial structure. It is important to acknowledge these two factors as they can have significant effects on the kriged interpolated surface. High nugget effect and curve flatness seem to be characteristic of archaeological data, as seen in previous geostatistics and archaeology examples (Lloyd and Atkinson 2004; Ebert 2002).

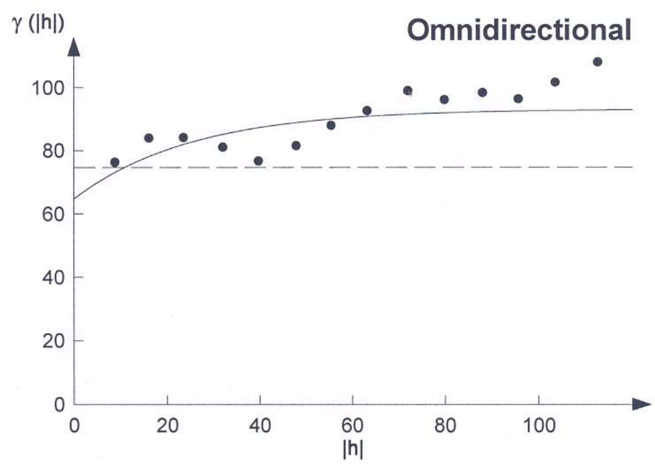


Figure 20 Omnidirectional Variogram of Hortonville Data using Block Values along with Fitted Exponential Model (Variowin 2.2, 2004)

The second step in the geostatistical procedure requires fitting the model to the variogram. The variogram for the Hortonville Bypass data demonstrates a relatively linear pattern, with a gentle sloping towards the y-axis. Often the chosen model is either the spherical or exponential model, with a preference towards exponential for this project, because of the inability of the variogram to reach a specific sill in which the graph levels out. Therefore, an exponential model, which is characterized by a gentle slope towards the sill without ever reaching it, was chosen, and this model showed the highest degree of fit within Variowin 2.2. An attempt to identify anisotropy in the data was also made, but no significant difference appeared in the variogram when the angle direction was changed.

4.4 *Interpolating and Predicting: The Kriged Map*

The final product of all statistical procedures and variograms is a prediction map based on previous analyses. This procedure, known as kriging, can be performed using a variety of programs and software. There are multiple ArcView extensions for kriging interpolation (arcsripts.esri.com), and previous studies have used GSTAT statistical software, or the preferred method for this project will be the Geostatistical Analyst in the ArcGIS software. The Geostatistical Analyst function was used because of its ability to input elements of range, sill, and angle direction from previous variograms into the kriging operation. Unlike many of the ArcView kriging scripts, the geostatistical function allows for operator input of particular values, and has a larger number of available models and kriging methods. Once the appropriate variogram and model were determined through the use of Variowin 2.2 and the Geostatistical Function, the ordinary kriging function was used and a prediction map was developed. This prediction map represents the a predicted value for the entire project area based on the total artefact counts of each block, the distance between the blocks, and the strength of the spatial relationship between them.

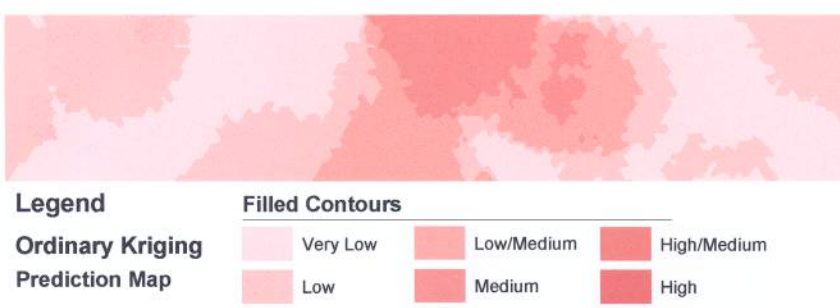


Figure 21 Prediction Map of Hortonville Project Area (Produced using ArcGIS Geostatistical Analyst, 2004)

The prediction map represents the final product of the geostatistical process and has the most potential benefits for contract archaeology, in terms of providing an understanding of overall density and spatial distribution for sites in the entire project area, not just at sampled individual locations. For example, our predictions map (figure 21) shows a medium degree of site potential in the center section, surrounded by low/medium potential and decreasing to very low around this area. The knowledge of these areas of potential high density is crucial to the overall planning process that characterizes contract archaeology. In addition, the prediction map gives a much clearer visual representation of the potential distribution of sites than the symbol maps usually used in project reports (see Hamilton 2004). These overall benefits of geostatistics and kriging make it a much more effective method then any other prediction or interpolation methods.

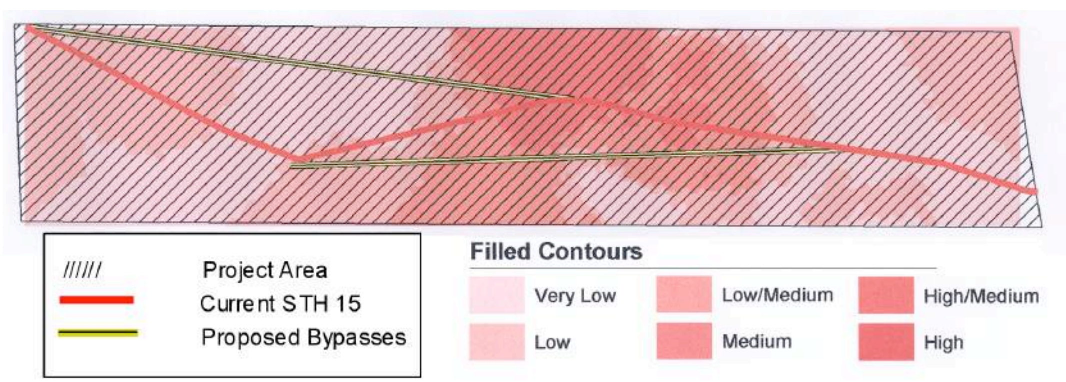


Figure 22 Prediction Map with Sketches of STH 15 and Proposed Corridors (Produced using ArcGIS Geostatistical Analyst, 2004)

In terms of the Hortonville Bypass project, the geostatistics-based prediction map provides important insight for any decisions about future road construction. Figure 22 shows a prediction map with the current State Trunk Highway 15, as well as the two proposed western connection corridors sketched on it. It is apparent that the Northwest highway corridor of the project would potentially affect a significantly small number of archaeological sites than the corridor to the south. The proposed route of the southern corridor stretches through an area of significant archaeological activity, and as predicted by the map, the potential for finding more archaeological sites outside of the sampled locations in this area is very good. The northwest corridor however, tends to run through an area of very low potential and would be preferred choice for construction. The ability to predict with some certainty the archaeological potential of an unsampled area is an aspect that has constantly been sought after by contract archaeology, and this case study shows that it can be achieved with the use of a geostatistical method. It is important to note that no attempt to cross validate the prediction map was done as the kriging or estimation variances for block kriging are substantially less then for ordinary point kriging (Burrough and McDonnell 1998, 143).

4.5 Limitations of the Geostatistical Method

For all the positive benefits that geostatistics brings to archaeology, both academic and contract, it must still be taken with a degree of caution. While these methods fit relatively well with archaeological data, they were not originally developed for archaeology and can have some difficulties in the analysis of archaeological data. One of geostatistics main problems, seen in both the Hortonville Bypass project as well as in Ebert’s (2002) Als archaeological project, is the scarcity of archaeological data. The sparse nature of archaeological data in many parts of the world causes the geostatistical method to create unstable variograms and unreliable interpolations. The interpolated maps based on such data such often fail to provide any valuable information; in areas of sparse observations, it may only interpolate areas of interest in buffers around the sample locations, since other observations may be too distant to affect the predicted value (Ebert 2002). This can result in a map that contains a majority of areas predicted at zero, with small points of predicted values located all around the map, looking much like a typical site distribution or symbol map. In situations where the data set is sparse, some modifications and alternatives may be considered, such as the block kriging approach used here, or the use of a more global interpolator such as trend surface analysis.

Futhermore, most geostatistics programs only have the ability to analyze the spatial patterns of one variable, such as the total artefact count used here. This causes difficulty in the inclusion of alternate forms of data, such as soil type or slope (which can have a significant effect on artefact recovery) in the overall analysis. The procedure incorporating multiple variables into one variogram is known as cokriging, and is considered the natural extension of kriging when multivariate data is available (Wackernagel 1995, 144). However, cokriging is a highly complex statistical procedure and is not easily accessible in much of the software.

Finally, the most common objection to the use geostatistical methods in contract archaeology is its heavily statistical nature, which has been greatly simplified throughout this project, as well as the potential cost of the software used to produce prediction maps. This objection is inadequate, since although geostatistics does rely on a strong statistical approach, only a simple understanding of covariance and the structure of the variogram is needed to begin a basic geostatistical analysis, such as the one produced here. As for the cost of the necessary software, most if it can be obtained as open source software, including Variowin 2.2, which will create a wide variety of variograms and covariograms. The kriging interpolators scripts are also free downloads that work with most versions of ArcView, and the Geostatistical Analyst comes preloaded in the latest ArcGIS. The combinations of these programs were the only tools necessary for completing analysis in this project.

Chapter 5 The Future of Geostatistics and Contract Archaeology

5.1 Enhancing Contract Archaeology

The future of geostatistics in archaeology relies heavily on the incorporation of its theories and methods into the rigid methods of contract archaeologists. The benefits that it offers to contract archaeology are much greater than its potential in an academic context. These benefits include the ability to effectively predict archaeological potential at unsampled locations, and the ability to identify multiple site boundaries and distributions in a regional context, all founded on a strong statistical background that has been proven throughout many various disciplines. The notion of an academically proven prediction method can change the way archaeologists are viewed within the planning process. Archaeology is often merely a data collecting resource for the broader development of an area, but a spatial prediction methodology that goes beyond the current simplistic intuition, will begin to enhance the idea that contract archaeology can also be a data generating process, without heavy additional time or cost to an archaeological firm. The eventual outcome can be a more substantial archaeological role in the planning process and a more active part in the decision process, rather then simply turning over the archaeological data to a non-archaeologist for analysis. As mentioned before in the *Wisconsin Guidelines for Archaeology* (Kolb and Stevenson 1997), the ability to predict the archaeological potential of an area is of utmost importance in helping guide the planning process and enhancing future research goals.

While the future of geostatistics in archaeology will not be known for some time, the benefits that geostatistics can provide are clear. These benefits include a method that has been proven in alternative disciplines and is clearly more accurate then the current prediction techniques of trend surface and inverse distance weighting; a method that can help to refine site boundaries and distributions in a regional context, as well as a method that attempts to bridge the widening gap between contract and academic archaeological methods. Geostatistics shows that an analysis of the spatial component of all archaeological data must be one of the first steps in any archaeological investigation, either contract or academic. A spatial analytical approach such as this can only have positive effects on any future archaeological endeavors.

Appendix A

Site Data Including Site Name, Location, and Total Artefact Count

Spring Ledge Ou-84
UTM: 364620 E 4912780 N
Artefact Count: 35
23 Lithics
12 Ceramics

Bromeland Base Ou-208
UTM: 364174 E 4913234 N
Artefact Count: 2
2 Lithics

Gherhardt Horses Ou-211
UTM: 364350 E 4912970 N
Artefact Count: 16
16 Lithics

Jane’s Spring Ou-212
UTM: 365065 E 4912720 N
Artefact Count: 66
40 Ceramics
26 Lithics

Schiedermayer Ou-213
UTM: 365261 to 364563 E 4912319 to 4912534 N
Artefact Count: 40
28 Ceramics
12 Lithics

Peanut’s Pottery Ou-214
UTM: 364663 E 4912725 N
Artefact Count: 6
6 Ceramics

Ivy Hill Ou-215
UTM: 364900 E 4912755 N
Artefact Count: 76
70 Ceramics
6 Lithics

Medium Pines Ou-216
UTM: 365430 E to 365445 E 4912230 N to 4912250
Artefact Count: 69
49 Lithics
20 Ceramics

Big Pines Ou-217
UTM: 365008 E 4912601 N
Artefact Count: 18
18 Lithics

Blushing Sumac Ou-218
UTM: 366497 E 4911266 N
Artefact Count: 5
3 Ceramics
2 Lithics

Finding Ash Ou-219
UTM: 366624 E 4911234 N
Artefact Count: 4
1 Ceramic
3 Lithics

Korn Ou-220
UTM: 366399 E 4910951 N
Artefact Count: 7
7 Lithics

Spindly Pines Ou-221
UTM: 365000 E 4912825 N
Artefact Count: 98
58 Lithics
40 Ceramics

Elephant Ears Ou-222
UTM: 366309 E 4911317 N
Artefact Count: 7
7 Lithics

Nickel Site Ou-223
UTM: 365565 E 4912162 N
Artefact Count: 2
2 Ceramics

Backyard Ou-224
UTM: 365660 E 4912050 N
Artefact Count: 33
6 Ceramics
27 Lithics

Next to Pines Ou-225
UTM: 365710 E 4912060 N
Artefact Count: 56

53 Lithics
3 Ceramics

Creek View Ou-227
UTM: 364720 E 4912730 N
Artefact Count: 3
3 Lithics

Partika Pond Ou-231
UTM: 367403 E 4911531 N
Artefact Count: 39
39 Lithics

Pumpkin Ridge Ou-236
UTM: 362900 E 4914050 N
Artefact Count: 37
36 Lithics
1 Ceramic

Turtle Back Ou-237
UTM: 362890 E 4913900 N
Artefact Count:13
13 Lithics

Hidden Glen Ou-238
UTM: 362400 E 4912600 N
Artefact Count: 28
9 Lithics
19 Ceramics

Martin's Field Ou-240
UTM: 365792 E 4911850 N
Artefact Count: 1
1 Madison Triangular Point

Old Cat Ou-241
UTM: 365661 E 4911843 N
Artefact Count: 5
5 Lithics

Six Big Horses Ou-242
UTM: 365361 E 4911896 N
Artefact Count: 4
3 Flakes
1 Ceramic

Pasture Fence Ou-243

UTM: 363270 E 4913086 N

Artefact Count: 1

1 St. Charles Point

New Hay Ou-244

UTM: 363331 E 4913162 N

Artefact Count: 1

1 Middle Woodland (Steuben-like) Point

London Mist Ou-245

UTM: 364424 E 4912312

Artefact Count: 61

61 Lithics

Acorn Acres Ou-246

UTM: 365338 E 4911806 N

Artefact Count: 14

12 Ceramics

2 Lithics (FCR)

Soggy Corn Ou-247

UTM: 364424 E 4912312 N

Artefact Count: 2

2 Lithics (1 point and 1 flake)

Pine Row Ou-248

UTM: 363838 E 4912688 N

Artefact Count: 5

2 Lithics

3 Ceramics

Chicakdee Ou-251

UTM: 362277 E 4914198 N

Artefact Count: 25

14 Ceramics

11 Lithics (1 FCR, 1 Cobble, 9 Flakes)

Prairie Ridge Ou-255

UTM: 364215 E 4912447 N

Artefact Count: 10

10 Lithics

Isolated Finds

IF 1 2003
UTM: 363771 E 4913190 N

IF 2 2003
UTM: 363745 E 4913431 N

IF 3 2003
UTM: 362855 E 4913781 N

IF 4 2003
UTM: 362890 E 4913795 N

IF 5 2003
UTM: 365050 E 4912850 N

IF 6 2003
UTM: 365308 E 4912610 N

IF 7 2003
UTM: 367165 E 4911141 N

IF 8 2003
UTM: 367250 E 4911100 N

IF 9 2003
UTM: 366862 E 4911128 N

IF 1 2004
UTM: 362777 E 4914350 N

IF 2 2004
UTM: 363620 E 4912872 N

IF 3 2004
UTM: 363560 E 4912885 N

IF 4 2004
UTM: 363580 E 4912775 N

IF 5 2004
UTM: 365888 E 4911933 N

IF 6 2004
UTM: 364703 E 4912229 N

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