Applications of Archaeological GIS

David Ebert[†]

Abstract. The use of Geographic Information Systems (GIS) in archaeology seems like a perfect match of technology and application. GIS has found its way into many areas of archaeological research, especially in the area of Cultural Resource Management (CRM). While GIS offers many tools for the archaeologist, its full potential has not been realized. This paper offers a conceptual framework in which GIS procedures can be detailed, as well as a description of those procedures. The state of archaeological GIS in Canada is reviewed, with emphasis on both the academic and CRM applications of GIS. Finally, the paper examines the possibilities of archaeological GIS.

Résumé. L´utilisation des systèmes d´information géographiques (SIG) en archéologie représente le mariage parfait de la technologie et de son application. Les SIG sont présentement intégrés dans plusieurs domaines de recherche en archéologie, surtout dans le domaine de la gestion des ressources culturelles. Bien que les SIG offrent plusieurs outils de recherche pour les archéologues, leur potentiel n'a pas encore été exploité. Cet article propose un cadre conceptuel dans lequel les procédures SIG sont décrites. Une mise à jour de l´utilisation des SIG en archéologie au Canada est faite, en mettant l'accent sur les applications académiques ainsi que dans la gestion des ressources culturelles. Finalement, le potentiel futur des SIG en archéologie est exploré.

As a discipline, archaeology has always had a focus on the spatial dimension of human behaviour. As a result, archaeologists tend to interpret human behaviour and material culture in a geographic context. However, the ability to fully realize these interpretations has been hampered by a lack of analytical tools to facilitate them. Fortunately, tools now exist for the collection, storage, retrieval, manipulation, and display of spatial data from the real world for this purpose. These tools are combined in a type of software referred to as a Geographic Information System (GIS), which is also sometimes called a Geographical Information System (Burrough 1986: 6).

A GIS is often defined by a minimum set of subsystems (to differentiate it from other software packages) including those for data input and verification, data storage and database management, data output and display, data conversion, and user control (Burrough 1986: 8; Kvamme 1999: 157). At its simplest level, GIS can be thought of as a spatially referenced database (Maschner 1996a: 2). The spatial data employed describe objects in terms of: 1) a position in some co-ordinate system; 2) non-spatial attributes; and 3) the spatial relations between objects (Burrough 1986: 7).

GIS may be one of the most important technological innovations in archaeology in the past twenty years. It has

[†] Department of Archaeology,
55 Campus Drive, University of Saskatchewan,
Saskatoon, SK S7N 5B1 [David_Ebert@usask.ca]

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made various types of spatial analysis, especially over large regions, possible, practical and potentially sophisticated. GIS has had an impact in the way that archaeology is done, both in the academe and in the Cultural Resource Management (CRM) industry. In fact, skill in the use of GIS has become increasingly important in the consulting world. Perhaps the largest trend in GIS has been the change from doing many of these sorts of analyses in specialized software, separate from a GIS, to having the ability to do them within the GIS.

Two aspects of archaeological GIS are examined and discussed in this paper. Starting with a hierarchical classification of GIS strategies, I introduce and then discuss specific GIS procedures within a variety of archaeological contexts. I then examine the types of GIS projects that have occurred in Canadian archaeology, discuss the implications of the limited availability of GIS instruction in universities, and comment on its potential future contributions.

APPLICATIONS OF GIS IN ARCHAEOLOGY

GIS in archaeology is much more than just the creation of aesthetically pleasing maps. Instead, it has a strong analytical role to offer. Care must be taken, however, that just because we can do something in GIS we do not start letting it define what is done. As Hasenstab (2003) argues, GIS cannot be allowed to be the methodological tail that wags the dog.

A general review of the archaeological GIS literature reveals three main lines of inquiry: 1) site location models, developed mostly for the purpose of cultural resource management; 2) GIS procedure-related studies; and 3) studies relating to larger theoretical issues in landscape archaeology (Savage 1990: 22).

We can further delineate GIS by recognizing a hierarchy of three levels of application in archaeology: 1) visualization; 2) management; and 3) analysis (described below). This ordering does not imply that one is more important than the other, but does indicate differences in GIS analytical capabilities, offering a range of opportunities for the generation of hypotheses and theory.

Visualization is the use of GIS as a map-making center or, more informally, as a "pretty pictures" application. It is the lowest level of GIS use and requires little in the way of analytical capability because it focuses on the graphical functions of GIS. While this can be a vital application of GIS, since effective illustration within archaeological reports is an important task, it does not take advantage of the full capabilities of GIS, nor does it offer much in the way of hypothesis or theory generation. Visualization is essentially the "read-only" mode of GIS.

Management is a step above visualization in terms of complexity, and is widely utilized by those who regulate archaeological resources and those who are involved in the CRM industry. It is essentially the "read-write" mode of GIS since it allows data editing. This level of GIS usage is geared more towards the management of locations, rather than any attempt to do analysis and understand human behaviour, such as looking at settlement patterns. While more complex than visualization, this approach still does not employ the full analytical capabilities of the GIS nor does it offer much possibility of theory generation. It is in this level that most archaeological GIS projects occur.

The highest level of GIS use is that of *analysis*, both in technical terms and as a means of generating or testing theory. Of course, to what extent GIS is ever theory driven is hotly debated. While this level may be the highest level of application, it seems to be less commonly employed than the previous two levels.

Spatial Data

There are two main types of spatial data in archaeology: point data and areal data. *Point data* includes such things as spot locations for artifacts, features, and archaeological excavation units. They are single locations identified by their three-point provenience. *Areal data* includes things such as a surface, landscape, site, or region. Each of these types of data has specific GIS analytical procedures, and these, in turn, offer different possibilities for management and analysis of archaeological data.

Point Procedures

Point procedures focus on point locations, and are often used to analyze trends in data sets or interpolate scattered points to a wider distribution pattern. There are two types of point procedures: density mapping and interpolation. *Density mapping* is the creation of maps showing the distribution of a variable of interest across a surface, such as artifacts in a plowed field or sites in a region. From this sort of mapping, it is possible to analyze locational trends, although these approaches are generally crude (Kvamme 1988: 339). Density mapping tends not to appear as an individual procedure in the archaeological literature, although it is a mainstay of most archaeological reports as part of the overall presentation. Generally speaking, density mapping would fall into the visualization level of GIS use. An example of a simple density map is shown in Figure 1.

It is also possible to use point data to create continuous surface data through

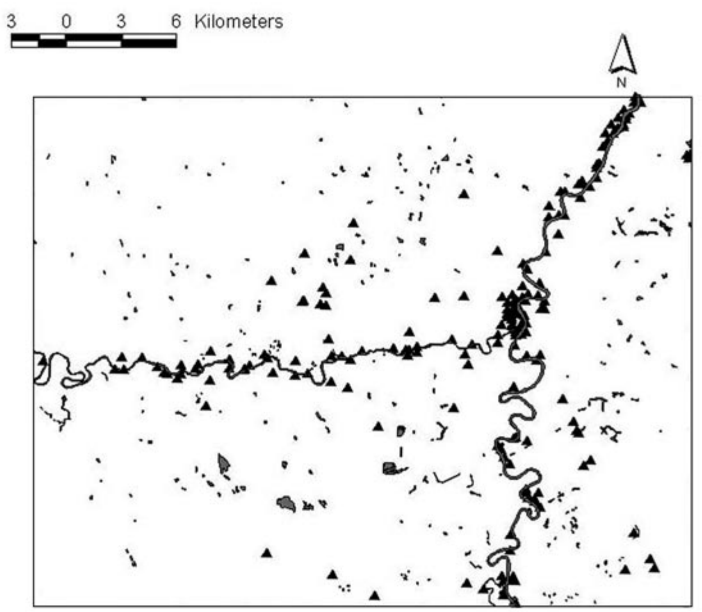

Figure 1. Distributional map of sites (sites are represented by solid triangles).

the use of *interpolation*, which consists of a number of mathematical procedures to convert point distributions to a continuous surface (see Ebert 1998, 2002 for extended discussion). Many of these interpolation techniques are based on theories other than probability theory (Altschul 1988: 69), such as gravity or density models. An example of interpolation is *kriging*, which is based on the premise that things nearby tend to be more alike than those further away (Goodchild 1996: 243); when maps are interpolated, data closer to the spot being interpolated have greater influence than data further away. An example of a map created by interpolation is shown in Figure 2. This map was created from fieldwalking data gathered during the Als Archaeological Project (Ebert 1998). The purpose of this map was to create a distribution map in order to aid in interpretation of surface finds. Patterns are often hard to discern when the data are presented as single points. However, by interpolating the surface finds, a continuous distribution was created, which made it easier to see patterns in certain areas.

The archaeological literature is somewhat scant in terms of GIS projects that employ interpolation types of point procedures. An early study by Zubrow and Harbaugh (1978) employed kriging to determine archaeological site locations using non-GIS methods. While they obtained good results from a synthetic site system, their use of kriging was misguided. Kriging uses the relationship between a continuously distributed variable to make predictions of values where that variable is unknown, such as interpolating soil types, elevation values, or snowfall. However, Zubrow and Harbaugh argue that archaeological sites can be considered as being continuously distributed. To achieve a continuous distribution, they used a binary presence/absence system, meaning a value of zero is assigned to those areas where there are no sites. Other kriging methods, such as co-kriging, would have been more appropriate (Ebert 1998).

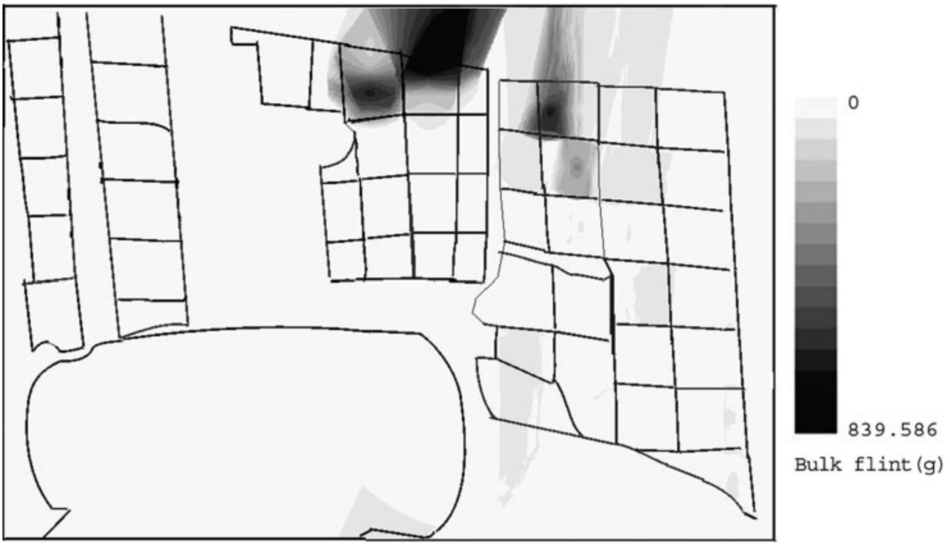

Figure 2. Fieldwalking finds interpolated by Kriging (from Ebert 1998).

An interesting application of interpolation is the use of interpolation and GIS analysis to determine occupation levels in a site (Anderson 2003; Spikins *et al.* 2002). While the rigorousness of these types of applications is still unproven, it shows promise of new possibilities within GIS applications in archaeological research. Nonetheless, there are several problems in using this simple type of analysis. Data of this type are generally cross-sectional, in that they represent snapshots in time, often conflated into a single layer of thematic information (Goodchild 1996: 245). For example, archaeological sites in a region may not be all contemporaneous. This type of spatial analysis is an analysis of form, whereas understanding underlying process is what is really desired (Goodchild 1996: 245).

Areal Procedures

Areal procedures are much more common in archaeological GIS. There can be some overlap with point procedures, such as map interpolation techniques, which treat the site location, or some aspect thereof, as the dependent variable that is being predicted by any number of independent variables (Altschul 1988: 69). Here, even though the input geometry may be on a point-basis, the focus of the procedures is essentially on the landscape or region and on interpreting the sites in that context, rather than on the point-locations themselves. In other words, the unit of analysis is a given area or land parcel, commonly represented by a grid cell in the GIS. The cell holds the value of the point. In the case of archaeological sites, the entire cell would either have a value of site present or absent, even though the cell may be larger than the extents of the site.

GIS-BASED APPLICATIONS OF AREAL PROCEDURES

In archaeological GIS, there are four common applications of areal procedures: 1) predictive modeling; 2) catchment analysis; 3) viewshed analysis; and 4) simulation. These procedures represent only a fraction of the possibilities, and many unexplored areas of GIS are open to investigation by archaeologists. For present purposes, however, each of the four is described here.

Predictive Models

Predictive models attempt to predict the location of sites or materials in a region, based either on a sample of the sites in the region or on theories of human behaviour (Kohler and Parker 1986: 400). They are tools for projecting patterns or known relationships (i.e., areas of known archaeological resources) into related areas of unknown patterns or relationships (i.e., areas of unknown archaeological resources) (Warren and Asch 2000: 6). All predictive models are composed of three elements: 1) available knowledge or body of information from which a model is derived; 2) the method(s) used to transform this information into predictions; and 3) the predictions themselves (Warren 1990a: 91–93). Predictive modeling has been most commonly used in the CRM industry (Carmichael 1990: 216), but has received only limited academic scrutiny, especially in Canada.

Deductive and Inductive Models

There are two general approaches to predictive modeling: deductive and inductive (Kamermans and Wansleeben 1999; Kincaid 1988; Kohler 1999). In practice, these modeling approaches overlap (Kamermans and Wansleeben 1999: 225; Kincaid 1988). The terms themselves are somewhat misleading as neither is purely inductive or deductive in nature (despite this, these are the dominant terms in the literature).

Deductive Modeling

The basis of deductive modeling is a priori archaeological or anthropological knowledge, such as that derived from a theory of general human behaviour (Kamermans and Wansleeben 1999: 225; Kohler 1999: 37). While this is cited as a more powerful method of modeling than inductive modeling, it is less frequently employed (Kamermans and Wansleeben 1999: 225). Deductive models must meet several requirements. They must:

- Possess a decision-making mechanism for location, as well as an understanding of the ends of the decision making process;
- specify variables that affect locational decisions; and
- be capable of being operationalized (Kohler and Parker 1986: 432).

Deductive models can either be based on a theory, such as optimal foraging theory, or on a set of hypothetical criteria for site locations. Deductive models can be applicable to any situation characterized by a specified set of cultural system and ecosystem variables (Sebastian and Judge 1988: 7). The greatest challenge of deductive models is that they are extremely difficult to create and to validate (Sebastian and Judge 1988: 8).

Deductive models are considered more powerful than inductive models because they are explanatory. Nonetheless, they have received little attention in archaeology, something likely due to the difficulty in operationalizing such models (Dalla Bona 1994a), a problem many of these models share. One of the greatest problems is establishing a system of ranking criteria that affect locational decisions. Because it is not possible to access the full range of criteria used in land-use decisions, proxies must used in their place. However, the quality of data utilized for proxy variables is generally quite poor because as our ability to map these data lacks control over time and changing conditions of those proxy variables.

Despite such difficulties, deductive models have been developed for a number of projects. These tend to be based on locational criteria, not theory, as illustrated by Krist and Brown's (1994) prediction of site locations as they relate to the visibility of caribou migration routes. Despite limitations, deductive models hold promise as the increasing sophistication of software and hardware make technical issues less burdensome.

Inductive Models

Inductive models are devices that make use of existing knowledge to forecast spatial patterns (Warren 1990a: 91) and have been the most popular form of predictive modeling (Dalla Bona 1994a). Inductive models have been alternatively termed intuitive or associational (Altschul 1988), empiric-correlative (Kohler and Parker 1986), and correlative (Church *et al.* 2000; Marozas and Zack 1990; Sebastian and Judge 1988: 4). Regardless of the terminology, this approach can be considered analogous to pattern recognition procedures employed in remote sensing image classification (Kvamme 1992: 20), and, in fact, many of the same procedures and statistics are used.

Many of the variables used in inductive predictive models tend to recur from project to project, such as slope, aspect, and distance to water (Kvamme 1985: 218–219; 1992: 25–27; Kvamme and Jochim 1989: 5–6), becoming a "usual suspects" list of predictors. When choosing variables, the preference is for variables that are related to site locations, but not correlated to each other (i.e., relatively independent) (Rose and Altschul 1988: 185). The assumption made in this type of modeling is that non-cultural aspects of environment will correlate and predict site location (Marozas and Zack 1990: 165). However, the tendency of archaeological sites to recur in favourable environmental settings has been the basis of how many archaeologists have found sites through their "archaeological gut instinct" and professional expertise for a long time (Kuna and Adelsbergerova 1995; Warren 1990b: 201; Warren and Asch 2000).

Inductive modeling takes an essentially cultural-ecological view of human settlement systems (Kohler 1999: 32; Wheatley 1993: 133). The unit of analysis is the land parcel, not the site (Warren 1990a: 94). Because sites are compared against the physical environment of the study area as a whole, we must have the ability to be able to analyze environmental units, rather than points representing sites. The identification of correlations between known archaeological sites and certain attributes, usually aspects of the physical environment, is the primary goal (Kamermans and Wansleeben 1999: 225; Kohler 1999: 37).

Inductive models have a number of limitations (Ebert 2000: 129–137), the most significant of which is that (a) their success is unexplainable and (b) we do not know how they work (Sebastian and Judge 1988: 5). Inductive modeling has also been criticized for the methods employed, especially the statistical testing. For example, using linear multiple regression, the most commonly used statistical interpolator, on lithic density data from Stonehenge, Wheatley (1996a: 287) could account for only 25% of the variability within the data. This led him to question whether this method is appropriate as an interpolator for patterned human behaviour.

Inductive Modeling Methods

The weighted map layer approach has been the most popular inductive modeling method and makes use of categorical or class-based map layers, with each category being assigned a weight relative to conditions found at archaeological sites (Brandt *et al.* 1992: 271; Dalla Bona 1994a). This allows specific variables to have more influence over predicted site locations than other variables. One of the ways that weights may be determined is through the use of multivariate statistical procedures, such as logistic regression (Parker 1985). Kvamme (1990) proposes a method of determining the relationship between the distribution of sites and the environment, using statistical methods to elucidate this relationship. Using one-sample statistical tests, the background environment (i.e., all grid cells within a study area) is treated as a control, and statistical deviations from the distribution of environmental features are sought (Kvamme 1990). For such continuous variables as slope, aspect, or distance to water, the Kolmogorov Goodness-of-Fit test is preferable (Kvamme 1990: 370). One of the major weaknesses of this method is that by simply changing weights, exponentially different results may occur (Brandt *et al.* 1992: 271). It is only possible through the use of GIS to quantify the background environment for a large study area in order to compute this test (Kvamme 1990: 370).

Figure 3 illustrates a map created for a project I am currently working on, examining the role of time and predictive modeling. The map shows the basic divisions of high, medium, and low potential. Although not a particularly good predictive model because there are too many cells classified as high and medium potential, having too many cells high and medium potential would also make the predictive model a poor management tool. For example, if all of the cells were high and medium potential, a predictive model would correctly find sites 100% of the time. However, that would not save archaeologists any time or effort, as it would not allow for any focus of a potential archaeological survey.

Inductive Model Testing

Once a model is created, whether by inductive or deductive techniques, testing of the model is paramount. This can be done solely through laboratory methods, such as red flag modeling (Altschul 1990), or through statistical evaluation, such as a gain statistic (Kvamme 1988). In red flag modeling, sites with anomalous settings are examined for possible predictive variables that have been missed (Altschul 1990). The gain statistic quantifies the predictive power of the model, based on a scale of –1 (reverse predictive power) to 1 (very strong predictive power). However, laboratory testing is generally considered to be less effective than field testing predictive models.

Extending Inductive Predictive Modeling

An important question in the analysis of sites concerns how many axes the data may be divided into in order to examine temporal, functional, and spatial differences (Kincaid 1988: 557; Rose and

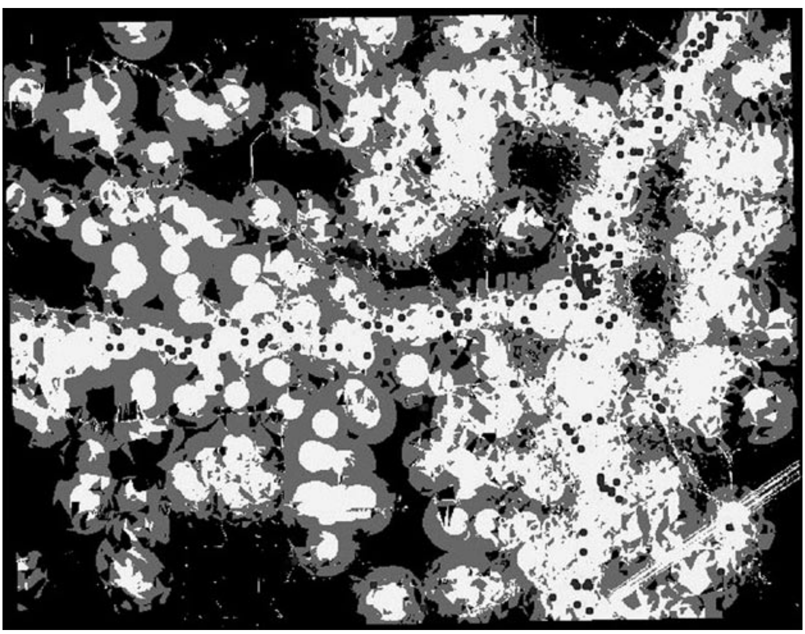

FIGURE 3. Example of a predictive model map (black=low potential, grey=medium potential, white=high potential). Dark circles are known sites from which predictive model was created.

Altschul 1988), given that different types of sites may be associated with different sets of variables (Rose and Altschul 1988: 205). It is unclear if adding this level of detail provides any significant advantages. This question has received little attention and is currently unresolved. This type of approach is illustrated by Robert Hasenstab's (1996: 230) study of Iroquoian villages. His classification of sites was based on three types: 1) functional (villages versus campsites); 2) temporal (five occupation periods); and 3) spatial (three physiographic/cultural zones). These were analyzed on the basis of three classes of environmental data: 1) those related to hunting territories; 2) those related to maize horticulture; and 3) those influencing trade, especially canoe routes (Hasenstab 1996: 230). The results of this study were that the data and methods return only tentative answers, and that it was difficult to evaluate the results because confounding factors, such as autocorrelation and covariance between the variables, may play a role (Hasenstab 1996: 238).

Criticisms of Inductive Modeling

A variety of concerns have been raised regarding predictive modeling. These include questions about the accuracy of site locational data(Dalla Bona 1994a: 29; Duncan and Beckman 2000: 55; Ebert 2000), the accuracy of the environmental data set (Duncan and Beckman 2000: 55; Ebert 2000), and how areas of archaeological potential are defined—something seldom explicitly stated in modeling reports (Dalla Bona 1994a: 15).

One of the greatest failings of traditional inductive modeling projects has been the lack of any non-environmental predictor variables. The focus of predictive modeling has been the correlation of environmental variables, as readily mappable proxies, with archaeological site location. However, the role of social, ideological, and political factors has received little attention in the prediction of site locations (Weimer 1995: 91). While a large body of ethnographic data is available for use in prediction, it has received limited usage despite the potential it has. For example, Dalla Bona and Larcombe (1996) incorporated an ethnographic data in reconstructing the seasonal round of boreal forest hunter-gatherers for a predictive land-use model for northern Ontario (see also Larcombe 1994). One reasons they chose to use to do this was because the ethnographic sources provided information on the social and spiritual significance of natural resources (Dalla Bona and Larcombe 1996: 254).

Stancic and Kvamme (1999) also incorporated what they termed social variables into their analysis of Bronze Age hillforts on the island of Bra in Croatia. These variables included: 1) distance between hillforts; 2) intervisibility; 3) distance from the sea; and 4) location of long barrows (Stancic and Kvamme 1999: 234). While at first glance, distance to the ocean seems no different from an environmental predictive variable, in this case it is the reverse because hillforts were located a considerable distance from the coast (Stancic and Kvamme 1999: 234).

Predictive models based solely on environmental considerations do seem to predict the settlement patterns of hunter-gatherers fairly well (Maschner 1996b: 176). However when the focus is on more "complex" social or political forms, such as the complex hunter-gatherer populations of the Northwest Coast, the predictions do not seem to work as well. This phenomenon is likely due to the fact that in complex social systems, political decisions make more of an impact than does adaptation to the environment (Maschner 1996b: 178). For example, in later periods of Northwest coast prehistory, there is a shift in settlement patterning from one related to the distribution of key resources to one of defensibility and the creation of larger corporate entities (Maschner 1996b: 187). Maschner sees this in evolutionary terms as a shift from economic maximization to political maximization.

Catchment Analysis

A second application of areal procedures in archaeological GIS is site catchment analysis. Site catchment analysis as originally formulated (Vita-Finzi and Higgs 1970) has two major limitations: a lack of complexity and a lack of accuracy (Hunt 1992). GIS offers the possibility to extend the catchment method beyond its initial form to a more sophisticated level of analysis.

The issue of accuracy relates to the identification of appropriate ecosystems and the arbitrariness of catchment analysis (i.e., whether it represents the true pattern of cultural practice) (Hunt 1992). GIS can overcome both of these problems (Hunt 1992) since it can not only maintain multiple original categories of data, thus allowing greater complexity in the analysis, but facilitate the addition of more complex catchment areas instead of the geometric shapes (i.e., circles) currently employed in catchment analysis. Site catchment can also be done through the use of Thiessen polygons, whose edges are half the distance to the next nearest site (Kvamme 1999: 175). Since the polygons partition the entire region into non-overlapping territories that are assigned to a specific locus (Kvamme 1999: 175), every point inside a Thiessen polygon is closer to the centre of that polygon than the centre of the adjacent polygon(s).

Site catchment analysis was one of the methods employed in the Danebury study of Iron Age settlements in England (Lock and Harris 1996). Here, the spatial relationships between farmsteads were examined through the use of 400- and 1000-m buffers around each of the settlements. The 400-m buffer simulates an infield system under the control of a single farmstead, whereas the 1000-m buffer represents overlapping spheres of influence (Lock and Harris 1996: 235–236). This overlap may be explained through the suggestion of sharing of communal grazing resources (Lock and Harris 1996: 236). The authors concluded that Iron Age settlements reflect an inherent competition for resources, resulting in a regularly spaced settlement pattern (Lock and Harris 1996: 237).

One way of making improving site catchment analysis is through the introduction of *cost surfaces*. A cost surface acknowledges the fact that movement through space does not entail equal costs energetically (Kvamme 1999: 175). To create a cost surface, a cost map is produced that represents impedances to movement imposed by the natural environment (Madry and Rakos 1996: 113), such as slope, vegetative cover, natural barriers, or other factors (Kvamme 1999: 175–176). Most studies using cost surfaces have relied heavily on slope to determine the cost of movement (van Leusen 1999: 217). The simple use of slope as the determinant of cost requires that isotropy, or variation based on direction, is considered. For example, travel up a slope is much more difficult energetically than travel down a slope (van Leusen 1999:

217), so isotropic cost involved. If a cost surface is created that indicates slope cost as being all downhill, the resulting map will not be a realistic. Because cost varies according to the direction of travel or other factors (e.g., vegetation), cost surfaces must be made isotropic.

Cost surfaces can be used in a number of different ways to enhance site catchment analysis more or to determine optimum paths. An example of the latter is found in Madry and Rakos' (1996) study of Celtic Iron Age pathways. The paths were thought to be placed on the ridge top simply as a preference (Madry and Rakos 1996: 115). What they found after examining the location of the actual paths with the least-cost pathways was that the paths were ultimately placed based on a combination of cultural (visibility from the hillforts) and environmental (least-cost paths) factors (Madry and Rakos 1996: 117).

Viewshed Analysis

The study of visibility can take one of a number of forms. The simplest form of analysis is a *line of sight* analysis, which considers whether one point is visible from another (Kvamme 1999: 177). A more complex type of visibility analysis is the calculation of a *viewshed* (a map of locations that are visible/not visible from a given location, derived from a digital elevation model). A viewshed is simply the calculation of multiple lines of sight in a 360-degree circle from a single location, specifying_all the areas that are visible from a single location (Kvamme 1999: 177). An example of a viewshed is provided in Figure 4, where visible areas from the white dot (the location of the viewer) are shown in black and non-visible areas are shown in grey. Viewsheds can be used to understand aspects of location, such as whether a site location was chosen to optimize what could be seen from that point. Additional com-

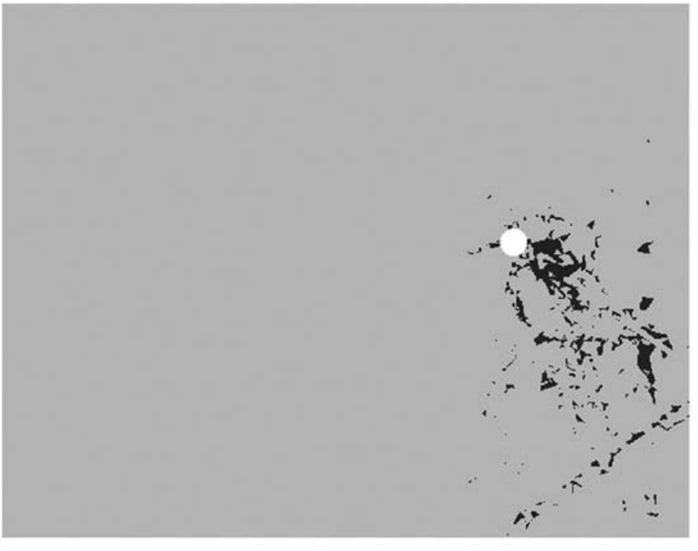

FIGURE 4. A sample viewshed (white dot = observer location, grey = non-visible areas, black = visible areas).

plexity can be added by calculating a multiple viewshed, which is calculated from the Boolean union of viewsheds from a number of individual locations (Kvamme 1999: 178).

One way that a multiple viewshed could be applied would be the calculation of all of the areas visible from a series of hilltops. Cumulative viewsheds are the sum of those taken from a number of individual locations (Kvamme 1999: 178; Wheatley 1995). The result of a cumulative viewshed is that each cell in the map holds a value of locations from which the point is visible. Visibility analysis has been proposed as a method of bridging the gap between current data and social and cognitive landscapes (Lock 1995: 16).

Viewsheds have been employed to understand the social landscape, including such aspects of it as the relationship between visual dominance and territoriality (Lock and Harris 1996: 224). For example, one of the goals of Danebury project mentioned previously was to determine whether the hillforts were located were they were to provide visual dominance that could be exerted over a territory, or for purely defensive purposes. Lock and Harris (1996: 232–233) found that the maximum defensive protection was waived in order to obtain maximum visibility over the local populace of lower-order farmsteads. Visibility was also one of the factors evaluated by Madry and Rakos (1996) in their study of Celtic roads and hillforts in the Arroux River valley in Burgundy, France. One of the hypotheses examined was that forts had a view over the roads, perhaps for sentries to observe the road network (Madry and Rakos 1996: 111). They found that 86.31% of all the Celtic roads were in view of one of the hillforts. This is greater than the 68.37% of the total study area, which is visible from the hillforts (Madry and Rakos 1996: 111), and indicates that roads were built specifically to be in view of one of the hillforts, rather than randomly. Moreover, 59.85% of the roads were visible from the two main hillforts in the region, suggesting that roads were built to be observed from the hillforts (Madry and Rakos 1996: 111).

In addition to these applications, viewsheds have been used with a predictive capacity. For the Great Lakes area, for example, Krist and Brown (1994: 1130) employed viewsheds to evaluate the degree to which precontact hunters situated themselves to observe the predictable caribou migrations. A cost surface was thus created by them to simulate possible caribou migrations paths, with hunters situating themselves in sheltered areas or near look-out points to observe migration (Krist and Brown 1994: 1133). Although this model provided important information about Paleoindian and Early Archaic sites in the region, the authors concluded that better data regarding caribou migration were necessary to fully evaluate the predictive power of this model (Krist and Brown 1994: 1135).

Methodological Problems with Viewsheds

There are several methodological problems with viewshed analysis. First, there is the difference between the calculated viewshed and what can actually be seen by the observer (van Leusen 1999: 218); what can be seen, according to the viewshed, might not be perceived by the viewer. A related problem to this question is the “tree-problem” (Maschner 1996a: 8; Wheatley 1996b: 97)—viewsheds tend to be created as if the landscape was flat, and trees or other vegetation are not factored in. This problem can be alleviated by raising or lowering the height of the observer to simulate the average tree height in the region (Maschner 1996a: 8; Wheatley 1996b: 97). Second, there is an edge-effect problem, where viewsheds might extend further than the edges of a study area (van Leusen 1999: 218). Third, there is the question of significance (van Leusen 1999: 219), which considers whether there is any appreciable difference between visibility from archaeological sites and that from any other point (van Leusen 1999: 219). In other words, while it is assumed that the degree of visibility from an archaeological site is high, there may be other areas where the visibility is greater, and therefore more significant. Fourth, there is the decrease of visual impact with distance (Wheatley 1996b: 98), especially of such monumental sites as long barrows or hillforts. Finally, viewshed also suffers from certain technical and data quality errors (Wheatley 1995: 182).

Some of these issues noted here are evident in the viewshed depicted in Figure 4. For example, one common technical problem in viewshed analysis is that the curvature of the earth, which affects how far one can see, is not taken into account. In Figure 4, some of the areas that are shown as visible are some 14 km from the viewing location.

One solution to the failings of viewshed analysis has been the introduction a more complex form known as fuzzy viewsheds (Maschner 1996a: 9). Traditional viewshed analysis evaluates locations as being visible or not visible from a given location. Fuzzy viewsheds add a distance decay function, which models the degree to which distant objects may be visible (Maschner 1996a: 9). Instead of being a *visible/not-visible* dichotomy, fuzzy viewsheds introduce an uncertainty, consisting of *visible/not-visible/possibly visible* distinctions. This addition addresses both the problems of differences in calculated versus perceived viewsheds and the technical problem of curvature of the earth.

Simulation

A simulation model is a simplified representation of reality (Chadwick 1979: 237). It is not a snapshot of reality, but a depiction that aids in identifying and understanding the processes involved in its evolution, either through description or explanation (Chadwick 1979: 237). While much of the history of simulation modeling relates to the development of specialized software outside the realm of GIS, its inclusion within GIS has now become more common.

A simulation seeks to model a phenomenon by identifying key variables and examining their interactions. This can be done with computer applications that allow the analyst to run multiple iterations with the key variables being modified to examine their impact on the outcome (Aldenderfer 1991: 196). The idea of using simulations in archaeology is not new. David Clarke introduced computer simulation as a tool for archaeological research in his 1968 book, *Analytical Archaeology* (Aldenderfer 1991: 208).

Simulation has generally been employed in three ways by archaeologists: 1) as a tool to force clear thinking in the formulation of a problem; 2) as an experimental laboratory; and 3) as a means to generate data (Aldenderfer 1991: 211). The advantage of simulation is that the models emphasize dynamic processes, distributed processes, and relationships among agents, none of which are present in traditional analyses (Kohler 1999: 2). Although simulation cannot give researchers access to the entire human experience, it does allow researchers access to portions (Kohler 1999: 3).

A specialized form of simulation that has received considerable attention of late is *agent-based simulation*. This method allows the creation of landscapes that can be wholly imaginary or representative of real-world situations (or aspects thereof), and agents can be modified to represent important features of individuals or social units, such as households (Dean *et al.* 1999: 179). The way that agents behave in relation to each other or to the environment can then be governed by anthropologically validated rules (Dean *et al.* 1999: 180).

Lake (1999) demonstrates the use of an agent-based module for the GRASS GIS system, called MAGICAL (Multi-Agent Geographically Informed Computer Analysis). This system was specifically designed for hunter-gatherer studies so it reflects an emphasis on mobility, subsistence, and rational decision making. Each agent in MAGICAL has its own set of variables, which is affected by its own life history (Lake 1999: 110). This means that this system is basically an adaptive system in which the agent can learn from its actions and change its strategy in response to previous successful actions (Gilbert 1999: 364). Using an evolutionary-ecological paradigm, agents have the ability to have a user-specified genotype (Lake 1999: 111). The core of MAGICAL is an event scheduler, which receives requests from agents to perform certain actions and grants permission at appropriate times (Lake 1999: 111). What distinguishes MAGICAL from many other simulators is the spatial database that allows all actions to be spatially referenced (Lake 1999: 112). In Lake's study, which employed optimal foraging theory, the foragers were sent out foraging for hazelnuts on the island of Islay in Scotland. The simulation gave the archaeologists insights into colonization from the sea, foraging patterns, and settlement patterns. The results were somewhat problematic, however, because artifact discard patterns and the settlement patterns did not mesh well with the known archaeological record, perhaps indicating that foraging for hazelnuts was not a major determinant of Mesolithic land use on Islay (Lake 1999: 137).

Simulation holds much promise in archaeological research, and perhaps addresses the problems of operationalizing deductive predictive models. Agents could be programmed with behaviour rules derived from theories, as is done in MAGICAL, and site locations could be simulated based on those behaviour rules. However, the creation of simulations usually requires a high degree of computer skills, including knowledge of programming languages, and may thus remain impractical for most archaeologists.

ARCHAEOLOGICAL GIS IN CANADA

Archaeological GIS has been widely adopted in European and American archaeology, but far less so in Canada. Where is has been employed in Canada, the majority of applications have been in CRM and government-based archaeology rather than in academic archaeology. Compounding this problem is that much of what has been written about or derived from the limited number of archaeological GIS projects conducted exists only in the grey literature of CRM-based and academic archaeology.

That most GIS projects have been conducted for or by the CRM industry, (and to a certain extent its governmental counterparts) is likely driven likely by the desires of its clients. Many of the sectors with whom CRM companies hold contracts have already adopted GIS and thus are comfortable with its use and understand its capabilities. Forestry companies are accustomed to the use of GIS models to delin eate wildlife habitat, for example. As a result, in working with forestry companies, I have found first-hand that having forestry GIS specialists and archaeological GIS specialist speaking a common language enabled them to translate the concerns of the various stakeholders to their forestry and archaeology colleagues, respectively.

It is unfortunate for Canadian archaeologists that so much of the CRM-oriented GIS work remains poorly known. Failure to publish the results of such projects is one reason. In addition, since much of it contains proprietary information, access to these reports is very limited. However, some consulting archaeologists have presented their work at conferences (e.g., the CRIMP models of Western Heritage).

The situation in academic archaeology is also problematic. There, the literature on archaeological GIS has been limited to unpublished theses and dissertations. Furthermore, there are currently few professors at Canadian universities and colleges that list GIS as a research interest. In my experience as a member of the graduate admissions committee at the University of Manitoba (1998–2002), increasing numbers of graduate students expressed interest in doing a research project involving GIS. There are, however, few supervisors in Canada who are trained in GIS. A review I conducted of Canadian university websites revealed that only four archaeology professors in Canada list GIS as an interest: James Conolly (Trent University), Scott Hamilton (Lakehead University), Quentin Mackie (University of Victoria), and myself. A slightly larger number list "computer applications" as an interest. Compounding this problem is that the departments of the four individuals listed above have either terminal Masters' programs or no graduate program at all.

Given the paucity of academics with interest in this area, few classes in archaeological GIS are offered in archaeology programs across Canada. This apparent lack of interest has important implications for the archaeology departments who are training the students, many of whom go on to careers in consulting archaeology, where they may find themselves in a job where it is helpful to have experience in GIS. It is certainly possible to obtain training in GIS through other departments, primarily geography, but these programs do not provide information about archaeological applications. How then do our students get the training in something that is highly marketable in the CRM industry? Clearly, more expertise is needed, but that will only come with time as more faculty with an interest in, and training in, archaeological GIS are hired by academic departments.

Archaeological GIS Projects in Canada

To date, there have been only two major academic GIS projects in Canada, both of which were concerned with predictive modeling and forestry. The CARP project (Dalla Bona 1994a, b; Hamilton *et al.* 1994; Hamilton and Larcombe 1994; Larcombe 1994), based at Lakehead University, was a pioneering examination of predictive modeling projects. It remains a widely cited project in the archaeological GIS literature, widely used in many other projects as a primer in predictive modeling, and has influenced how inductive, weighted-layer modeling is done.

A second, more recent predictive modeling project is the Manitoba Model

Forest Archaeological Predictive Modeling Project (MbMF APMP) (Ebert 2003; Petch *et al.* 2000a, b). This project has examined the feasibility of doing this type of predictive modeling in the boreal forests of Manitoba with a great deal of success. Like the CARP project, this project also employed an inductive weighted-layer approach to modeling.

CONCLUSIONS

GIS provides archaeologists with a series of methods that can be employed to pursue various lines of inquiry with archaeological data in a single digital environment (Lock and Harris 1996: 216). For example, since human settlement pattern choices are based on a multiplicity of factors, employing a number of different research techniques facilitates the development of better model human settlement pattern choices.

By sheer weight of use, predictive modeling has received the majority of attention of all GIS applications. Predictive modeling has shown that there are important regularities that can be examined with regards to settlement in relation to the physical environment, but more work needs to be done to include cultural information, such as ethnographic land-use data, especially in the context of the Aboriginal peoples of North America. However, archaeologists must remember that predictive modeling is only one of many applications that can help to understand human behaviour. Site catchment analysis gives a glimpse into the relationship between the landscape and the site, and can extend the knowledge of why people settle in one location and not another. Visibility and viewshed studies may also give us an idea of preferential use of the landscape. Finally, simulation provides an area of exciting possibility in settlement pattern analysis in allowing archaeologists to recreate on their desktops what may never be seen again–past societies and civilizations. While these constructs are purely theoretical, they allow testing of empirically collected data to see if patterns in the simulation match patterns in the data. If so, the result would tend to support explanatory hypotheses. However, empirical data are sometimes scanty and commonly biased towards '"conventional wisdom," something archaeologists engaging in simulation must keep in mind.

Many European archaeologists have raised concerns that GIS re-introduces environmental determinism to archaeology but most believe that this problem can be overcome because GIS can be extended to include non-environmental data, and therefore move beyond simple culture-environmental relationships to more complex understandings of culture (Gaffney *et al.* 1996; Gaffney and van Leusen 1995). The cognitive information relating to how communities perceive and interpret the environment around them is patterned, and therefore should be measurable and mappable (Gaffney *et al.* 1996: 134), and therefore available for use in a GIS.

Much remains to be done with GIS to improve our ability to model and analyze settlement patterns from precontact times. For example, one of the greatest concerns that archaeologists have about GIS is that it is currently atemporal, with spatial phenomena being handled as a slice of time (Castleford 1992: 25). This approach uses snapshots of particular periods to show change over time. Castleford (1992: 103) proposes that the solution to this problem may be as simple as tagging spatial data with both a temporal and spatial identifier. Although this solution is somewhat simplistic and might create more problems that it solves, the addition of a temporal dimension will revolutionize the use of GIS in archaeology and the many other fields that are concerned with temporal aspects of spatial distributions. Finally, with a temporally oriented GIS, archaeologists will be able to look at cultural change, culture process, and cultural evolution, as time is one of the key variables of interests to archaeologist, often even more so than space.

Similarly, GIS must be made to be truly three-dimensional. GIS currently supports primarily a two-dimensional map, to which a third dimension is appendedmaking it what some refer to as 2.5 dimensional. For archaeologists who work with sites that are three dimensional, this makes the representation of things like stratigraphy and cultural levels very difficult, if not impossible.

Furthermore, the underlying theoretical basis of GIS applications in archaeology needs to be examined. Some (e.g., Church *et al.* 2000) have argued that GIS is a method in search of a theory. While this argument may be somewhat of a red herring, since other methodologies (e.g., zooarchaeology) are not attacked for being atheoretical, itis clear that those involved in using GIS in archaeology must take a step back and consider both how we are using GIS and how we are applying it within a theoretical framework with a rigourous research design. It is likely that as GIS applications mature and as more GIS-trained archaeologists work the methods will find their theoretical place within established general theories in archaeology.

Even without many of these changes, GIS has evolved from earlier archaeological applications to new and innovative uses at a variety of scales. For example, most of the examples discussed above are regionally-based applications of GIS. Recently there has been more attention paid to other scales of analysis, such as the site itself (e.g., Quesada *et al.* 1995) or even levels within the site (e.g., Abe *et al.* 2002; Marean *et al.* 2001). While such scale of sites, level, and artifact analyses are not new, the addition of archaeological GIS methods to address these holds much promise.

GIS clearly provides a powerful set of tools for the analysis and exploration of settlement patterns of past peoples. It is reaching greater levels of acceptance in many fields, especially as hardware becomes more powerful and affordable, as the software more sophisticated and user-friendly, and as more digital datasets come online. The future of GIS in archaeology will be one of growth as more academics adopt it for their own research, more departments offer training, and more CRM companies delve deeper into its applications GIS. While some aspects of archaeological GIS in Canada remain underdeveloped, there remains much reason for optimism for its future here. This is especially true if more students seek training in GIS techniques, for their knowledge and skills will have substantial long-term benefits for the practice of archaeology in Canada.

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