RIC Report 016
Discussion Document

ARCHAEOLOGICAL PREDICTIVE MODELLING: AN ASSESSMENT

Report prepared for

The Earth Sciences Task Force
Resources Inventory Committee

Heather Moon
Archaeology Branch
Ministry of Tourism and
Ministry Responsible for Culture

April 30, 1993

Preamble

This report is submitted to the Resources Inventory Committee (RIC) by the Archaeology Task Group of the Earth Sciences Task Force.

The Resources Inventory Committee consists of representatives from various ministries and agencies of the Canadian and the British Columbia governments. First Nations peoples are represented in the Committee. RIC objectives are to develop a common set of standards and procedures for the provincial resources inventories, as recommended by the Forest Resources commission in its report *The Future of Our Forests*.

Funding of the Resources Inventory Committee work, including the preparation of this report, is provided by the Canada-British Columbia Partnership Agreement on Forest Resources Development: FRDA II – a four year (1991-1995) $200 million program cost-shared equally by the federal and provincial governments.

Contents of this report are presented for discussion purposes only. A formal technical review of this document has not yet been undertaken. Funding from the partnership agreement does not imply acceptance or approval of any statements or information contained herein by either government. This document is not official policy of Forestry Canada nor of any British Columbia Government Ministry or Agency.

For additional copies, and/or further information about the Resources Inventory Committee and its various Task Forces, please contact:

The Executive Secretariat
Resources Inventory Committee
840 Cormorant Street
Victoria, BC V8W 1R1

FAX: (604) 384-1841

Abstract

Through the Resources Inventory Committee, the Archaeology Branch is currently involved in an inter-ministerial initiative designed to coordinate their inventory with other provincial inventories. As part of this project, the Branch is investigating the application of Geographical Information Systems (GIS) to archaeological predictive modelling.

As analytic tools, archaeological predictive models are well-suited to applications in land management. Among other things, they identify patterns in spatial relationships between archaeological sites and their physical locations and thus indicate potential relationships between the natural or social environment and the locations of past human activities.

In general, the use of predictive models based on sampling is a good way of obtaining a general impression of an area, of being able to tell with a certain degree of precision and reliability what is "out there". As such, they are of value to planners and developers in choosing among possible alternatives and in helping minimize damage, delays, and expense.

By focusing research on the location of sites, as well as on the types of sites expected to occur in specific locations, the modelling process can help to define major similarities and differences among sites, and reflects the information potential for both identified and "projected" sites within an area. GIS provides an environment in which sophisticated modelling can be undertaken.

It is apparent that model-building is a very complex and time-consuming process. To develop a set of standards for the archaeological and environmental data required to prepare predictive models, is somewhat difficult to evaluate. There is no set of standards or "cookbook" to follow because of the variety and variability in modelling approaches and management objectives, as well as regional physiographic and cultural differences.

,Predictive modelling holds much promise for cultural resource management in land-managing agencies, even though it is currently in a highly experimental and rapidly changing state.

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1.0 Introduction

The Archaeology Branch, as part of the Resources Inventory Committee (RIC), is currently involved in an inter-ministerial initiative designed to coordinate their inventory with other provincial inventories. one aspect of this involves the investigation of the application Geographical Information Systems (GIS) to archaeological predictive modelling. This report was prepared by the Archaeology Task Group for the Earth Sciences Task Force and outlines the issues involved specific to the Branch.

In the last 20 years thousands of archaeological sites have been identified in British Columbia and hundreds of site reports have recorded an enormous amount of valuable archaeological information. During this time, however, there has been little attention paid to the development of techniques that would enable archaeologists to utilize all the accumulated data on cultural resources in a strategic planning process. To help address these issues, the Archaeology Branch is interested in predictive modelling, both as a method for integrating existing data as well as for the potential for effective and efficient management of cultural resources on a long term basis.

The value of predictive modelling as a method to help resolve the problems inherent in the management of cultural materials is obvious. The ability to determine the relative probability of site location without continuous and expensive field survey is without question beneficial to the administration of any resource inventory. However, within the parameters of a scientifically based field like archaeology, any procedure that affects the well established and generally accepted conventional methodological approach must be subject to rigorous evaluation by those who will employ it before it will be accepted.

As a first step, this paper examines existing archaeological predictive modelling studies to determine if this is an appropriate methodology to assist in regional planning and resource management of archaeological resources.

To begin, it will be necessary to briefly describe and define archaeological predictive modelling. Sections two and three describe the development of models in general and the types of models most commonly used. Section four summarizes archaeological applications of GIS. Sections five and six discuss the problems and advantages of archaeological predictive modelling as developed over the last decade. Sections seven and eight summarize the difficulties in evaluating variety and variability in modelling approaches. Section nine outlines the necessary conditions for the development of an archaeological predictive model (or models) for British Columbia.

2.0 Predictive Modelling

As it has matured, archaeology has moved from a descriptive, documentary discipline to one that attempts to explain certain aspects of human behaviour with reference to independent events and variables known to have occurred in the past (Sebastian/Judge 1988:3). For some time archaeologists have examined environmental patterns exhibited by sites or other archaeological features in regional location analyses (e.g., Green 1973; Judge 1973; Kellog 1987; Roper 1979; Shermer and Tiffany 1985; Thomas and Bettinger 1976).

A predictive location model may be defined as "a simplified set of testable hypotheses, based either on behavioural assumptions or on empirical correlations, which at a minimum attempts to predict loci of past human activities resulting in the deposition of artifacts or alteration of the landscape" (Kohler 1988:33). As analytic tools, archaeological predictive models are well-suited to applications in land management. Among other things, they identify patterns in spatial relationships between sites and their physical locations and thus indicate potential relationships between the natural or social environment and the locations of past human activities.

Models are simplified constructs of a complex universe. Predictions about that universe made on the basis of a model are constrained by two specific relationships: (1) the relationship of the internal components of the model to each other, or the coherence of the model as a whole; and (2) the relation of the universe the model is based upon to the actual universe it is to represent.

In archaeology predictive modelling is considered to be a method for estimating the probability of archaeological site occurrence within a specific geography. Predictions about the likelihood of site occurrence on the basis of a model refer to the accuracy of that model to the universe it represents and the degree of probability that the model universe represents the actual universe. When there are models that generate data, the expectations are that the generated data will correspond with the real world in some way (Wood 1978:246).

Archaeology is still very much in the initial stages of learning how to go about using predictive modelling. Models are selective abstractions, which of necessity omit a great deal of the complexity of the real world. Those aspects of the real world selected for inclusion in a model are assumed to be significant with respect to the interests and problem orientation of the person constructing the model (Sebastian/Judge 1988:1).

The archaeologists' goal is to correctly identify important aspects of the natural or social environment that influenced the location of human activities, and to interpret the archaeological record as the result of a set of functional, temporal, spatial, and behavioural responses to a varied environment (Kincaid 1988:550).

One hallmark of contemporary attempts at archaeological prediction is the explicit or implicit assumption that environmental factors are major, exclusive, determinants of much of human behaviour (site location, subsistence strategies, etc.). Environmental variables, such a ' s distance to water, distance to resources, shelter, and available lookouts, are compared with the location of archaeological materials to determine whether there are correlations between these landscape characteristics and such cultural variables as the location of sites. "The causal link between site locations and natural, independent variables is usually considered to be multivariate – that is, people positioned their sites with respect to an optimal combination of all resources in which they were interested" (Altschul 1988:61).

Predictive location models attempt to predict, at a minimum, the location of archaeological sites or materials in a region, based on a sample of that region (Kohler/Parker 1986:399). In the past, formal sampling has frequently been confused with, and at times even identified with, predictive modelling. In some cases the implementation of a sampling design is considered as predictive modelling. It should be emphasized that sampling and predictive modelling are not the same thing. Verification of formal predictive statements (hypotheses) through empirical testing against the archaeological record frequently involves techniques of sampling. Modelling can be based upon sampling, and sampling strategies can be designed based upon predictive models. Models can be built from small or large (100%) samples and sampling can be used to test models. Realizing the distinction between sampling and prediction is a valuable first step in understanding how very complex the process of predictive modelling really is (Sebastian/Judge 1988:2).

The development of predictive models of site distribution has both practical and theoretical importance. Models can improve our definition of important types of sites and our understanding of their distribution across the landscape. Models can clarify processes of culture change and interaction and provide a regional framework for understanding the development and evolution of human systems. They can permit us to understand cultural adaptation to differing environments and provide insight into the nature and origin of social, political, and economic processes (Kincaid 1988:549).

Equally important, however, is the increased ability to predict site locations, which implies an increased understanding of the site settlement system which produced a particular site location pattern in an area. Better predictive models are of value in developing a body of theory which attempts to explain the relationships between human groups and their environments (Parker 1985:174). "The danger of building inconsistent theory for explaining phenomena as complex as human location behaviour is very high; the advantages of predictive approaches are correspondingly great" (Kohler/Parker 1986:398).

3.0 Development of the Model

The development of models centers around three main tasks: 1) classification of independent variables; 2) classification of dependent variables; and 3) expression of the relationship between them. For example, the dependent variable could be site presence/absence and the independent variables the environmental variables. In an archaeologically unknown region, selection of variables for a model predicting settlement locations is based on a consideration of which characteristics of the environment might have been important to the people using that environment. Such evaluations may be based on known relationships between site locations and environmental variables in ethnographic or archaeological contexts thought to be similar to the area of study (Parker 1985:184).

Since different cultural groups interact with each other and their environment in different ways, the critical independent and dependent variables and their relationship can vary widely from cultural system to cultural system. The goal of predictive modelling is to produce reasonably accurate representations of selected interrelationships for particular cultural systems. A successful model, or series of models, organizes information about archaeological sites – their function, location, and cultural affiliation – into a series of statements about human behaviour. Under controlled conditions, these statements can be applied to unknown areas to provide predictions concerning archaeological resources located in these areas.

The goal is to correctly identify important aspects of the natural or social environment that had influenced the location of human activities, and to interpret the archaeological record as the result of a set of functional, temporal, spatial, and behavioral responses to a varied environment. "Although governed to some extent by the demonstrably regular and consistent rules that apply to all living systems, human behaviour is organized into cultural systems, which exert additional influences on that behaviour beyond those of natural forces. There is good reason to believe that site locations cannot, in general, be fully predicted from environmental variables alone" (Kincaid 1988:551).

The first step in developing a predictive model of archaeological site location for a specific region is to amass the available data. Four basic sources of data are commonly used: historical documents, ethnographic documents/research, archaeological data, and environmental data (Altschul 1988:78). The quality of data on previously recorded archaeological sites must be carefully reviewed for location accuracy and completeness (Kincaid 1988:556).

To formulate a good initial model, the ethnohistory of the study area needs to be summarized. This will provide information on important site settlement modelling criteria, such as average settlement size and population by season, average length of settlement stay by season and site settlement selection by season.

once the available data have been gathered, they must be evaluated in terms of their applicability for predicting site location. one of the first tasks is to identify general trends of cultural change and stability and trends in the distribution of known sites. One result of this type of background research must be the identification of known sites or at least of the types of sites crucial to understanding regional settlement systems (Altschul 1988:80).

It is important at the data-evaluation stage to determine (or hypothesize) the types of sites expected to be found for each culture period and their probable locations. The definition of site types reflecting temporal, functional, and cultural differences is perhaps one of the most useful tasks that can be performed to prepare for model building. Environmental data are also needed for model building. To be useful, however, environmental data should be of consistent quality and scale throughout the study area (Altschul 1988:81).

All previously archaeologically surveyed areas should be mapped on base maps. The type and completeness of survey coverage must be carefully examined. Using information provided in project reports, the archaeologist should separate projects in which coverage appears to have been biased, incomplete, or otherwise suspect from those in which survey and recording practices conform to acceptable standards.

The plan should next address the second step of the project – the fieldwork phase. The formulation of a trial model for the study area must include detailed information about proposed field methods, rates of inventory, recording standards, and collection strategies as well as detail concerning the rationale for selection of sample inventory units. All this information must be collected and evaluated prior to initiation of fieldwork (Kincaid 1988:559).

> Statistically representative data are not necessary to develop a model; if new data collection is planned for purposes of model development, however, these are certainly the most effective data to collect. Model testing, on the other hand, does depend on the availability of unbiased data that are representative of the study area, most often data that were collected using some form of random sampling. Until a representative sample of data is obtained through a carefully designed inventory project, any model developed for the area must remain essentially untested and should be used accordingly (Kincaid 1988:558).

In many cases, the value of the results depends on the detail of the environmental data recorded for each sample unit and the levels and types of measurement used in recording the data. The results of a model are only as good as the data on which the model is based (Kincaid 1988:561).

Previous archaeological analyses of the distribution of sites have often focused on the distinction between a settlement pattern and a settlement system; "the pattern being the empirical evidence of site distribution while the system is the behavioral abstraction of regularities in the processes which generated the pattern" (Parker 1985:174). This analysis proposes that the generating process is one of location assessment and choice, which in itself is sufficient to characterize the settlement system. The regularities defining a settlement pattern are seen as a reflection of underlying regularities in the settlement system.

A good location model does not focus on the archaeological site as the unit of analysis. It recognizes all possible site location choices; those without sites as well as those with. It predicts where sites are unlikely to occur as well as where they are likely to occur. If environmental information is known only for locations where sites are found, then it is impossible to use the proposed methodology. Locations where sites are not expected to be found cannot be predicted. An effective predictive model must focus on any potential site location, not simply the locations where sites are known to exist.

If site locations only are examined for some variable, such as distance to nearest water, interpretations could be in error if comparisons are made to the distribution of this variable for the total area with no consideration of the non-site locations in the sample (Parker 1985:175).

Undoubtedly there were some differences in site location selection throughout the entire prehistoric period. Hunting and gathering, as well as agricultural subsistence patterns, are probably represented in any sample of prehistoric sites. It is assumed, however, "that there may be enough similarities in the environmental characteristics of the chosen site locations to allow the derivation of a significant predictive model for prehistoric site location. Such similarities would represent fundamental physical properties of locations necessary for survival. The set of site locations used in building the predictive model, therefore, is concordant with the list of variables chosen" (Parker 1985:187).

Trial models developed in early stages are not unusable, but their use is limited, and they should be used with caution. Trial models can, however, provide a check on the adequacy of field recording procedures (Kincaid 1988:557).

3.1.1 Types of Models

> The models of interest here are simplified sets of testable hypotheses, based either on behavioral assumptions, or on empirical correlations, which at a minimum attempt to predict locations of past human activities resulting in the deposition of artifacts or alteration of the landscape. First, the fact that such models are simplifications of reality means that they are fallible; no model that is simple enough to be useful can possibly anticipate all the contingencies that might result in the deposition of cultural materials. Second, by virtue of making predictions, such models are, or should be, testable (Kohler 1985:13).

Model development is a repetitive process of inventory and analysis that is most effective as a long-term strategy. In general, the quality of the model depends on the quality of the data; better data yield more precise and accurate models (Kincaid 1988:556). Location modelling normally assumes that certain environmental variables strongly influence archaeological site location (Kohler 1988:28).

There is good reason to consider intuitive thought in a discussion of predictive modelling. Many models for site location or settlement behaviour are intuitive or not fully operationalized. If a model can be objectively replicated and mapped, it is operationalized; a model consisting of the statement that "sites are located near rivers on dry, level ground," for example, is not mappable until site, near, river, dry, level, and ground have been rigorously defined (Kohler 1988:35).

Much of the recorded archaeological data base in British Columbia is due to *intuitive models*. Archaeologists have only recently concerned themselves with formalizing their notions about site location into research designs. Many archaeologists have surveyed and continue to survey land based on their ideas about where they will find sites. Moreover, these intuitive models are often the basis for more intensive research projects (Altschul 1988:65).

The most important characteristic of intuitive models from a scientific standpoint is that the components are not fully conceptualized. While everyone may understand the statement "sites will be found on high ground and near water", there will not necessarily be agreement on what is high ground or what "near water" means. The relationship(s) among landform, distance to water and archaeological sites is only partially established. Until everyone can agree on what the terms mean they cannot be operationalized in a way that can be replicated (Altschul 1988:64).

Many predictive models developed in Cultural Resource Management (CRM) studies take the form of relatively simple pattern-recognition or *associational models*. Associational models are among the most commonly used predictive models in cultural resource management (Altschul 1988:66). They are attractive primarily because of their simplicity; they are easy to construct and relatively straightforward to understand.

Associational models provide a means of operationalizing the environmental variables that may be related to site location. In this sense they are a tremendous improvement over intuitive models. Associational models can be used to provide a first guess about site location and as a basis for future research; they can, for instance, define environmental parameters that will be useful in stratifying a region for an archaeological survey.

Areal models are those that predict certain characteristics of sites or cultural resources, such as density or frequency, per a specified unit of land. For the most part, areal models are more attractive than associational models because the latter only produce relative statements about site location, such as "more sites will be found in this area than in that one" or "more sites found in this zone than would be expected by chance alone," and these statements are often inadequate for research or management needs. In many instances researchers and managers want to know more than the fact that one zone will contain more sites than another; they want to know how many sites each zone will contain and what site density in each zone will be (Altschul 1988:68).

One of the more popular types of predictive models used in CRM is an areal-based *pattern-recognition model*. Most of these models utilize sample data to compute a mathematical function, which is then used to predict some aspect of site location (ie., presence/absence or site density) for unsurveyed units (Altschul 1988:69).

Some models are deductively derived and attempt to predict how particular patterns of human land use will be reflected in the archaeological record while others work with inductively derived models that identify and quantify relationships between archaeological site locations and environmental variables. The latter models are termed *correlative*, and are by far the most common in current archaeological modelling practice.

If a research project requires information about the general nature of human use of a landscape, correlative models provide invaluable data. For example, it is clear from the ethnographic record, that human groups employing different subsistence strategies make use of their environments in very different ways. The nature and strength of correlations between cultural remains and features of the environment will be strongly affected by differences in prehistoric resource selection (Sebastian/Judge 1988:4).

Correlative models work by comparing the locations of a sample of sites with environmental features and forecasting the locations of other, unknown sites in areas that are similar environmentally. Consequently, we move from a total mapping of the environment and a partial mapping of archaeological resources to a total predicted mapping of archaeological resources (Kohler/Parker 1986:401).

As stated previously, any predictive model constructed inductively can be only as accurate as the survey data on which it is based. If models must be built without the benefit of a probabilistic sample, they should not be used for serious planning purposes until they have been validated or revised according to rigorous sampling procedures. In correlative models, the bridge between the sample and the target population is built with formal statistical inference. For example, a common procedure for building predictive models begins with a small probabilistic sample of a region using relatively large independently selected survey units (quadrats) stratified by some environmental variable (Kohler/Parker 1986:404).

Inductive (or correlative) models have limited explanatory value because they do not account for observed correlations between independent and dependent variables. For example, empirical analysis may demonstrate that a certain type of site in a sample is always located within a limited distance of outcrops of a particular geologic formation. While this information may be very useful in certain contexts, it has not been demonstrated that the presence of outcrops actually influenced site locations (Kincaid 1988:567).

Correlative models are not immediately "transferable," that is, when developed for one geographical location, they do not necessarily work in another; there is no logical reason why they should. "The question then is whether it is more cost-effective to redevelop the correlative model for use in a new area or to develop the explanatory model in the first place, since the latter would be applicable in a variety of areas and would address other management needs (interpretation, evaluation) at the same time" (judge/Martin 1988:578).

There is a second theoretical approach, the *deductive* approach, that is sometimes used in archaeological predictive modelling. Briefly, a deductive approach or *explanatory model* (ie., one proceeding from theory to data) often explains why a model works. This is important, especially if the model is to be successfully applied to other settings. The major drawback of deductive models is the difficulty in making them operational. In contrast, inductive models proceed from data to theory; observed correlations in the data are used to formulate general hypotheses. If, for example, several major village sites in a particular area are located near or on one particular soil type, one might hypothesize that large habitation sites tend to be located close to this particular soil type.

From a research perspective, explanation is our ultimate goal. Deductively derived models are also superior from a management point of view. If we do not understand why patterns occur, we cannot be confident they will reoccur in the future. Pattern-recognition models often show that settlement distributions are highly patterned, but without some sort of explanatory framework, management decisions based on these patterns are unsupported (Altschul 1988:67).

Theory-based, deductive areal models have not received much attention in cultural resource management studies, for three reasons. First, theoretically based models require more time to create. The internal connections between variables must be explicitly stated, as well as the logical arguments supporting those relationships. Second, validation procedures are more complex. Deductive models must demonstrate that they are not only consistent with the data but also more sound than any alternative. In contrast, inductive models are judged primarily on the accuracy of their predictions. No statement is necessary about how the population was formed in these models, only that the dependent variable interacts with one or more independent variables. Thirdly, the predictive statements derived from some types of deductive models are not always useful for management purposes (Altschul 1988:72).

In reality, in the long-term time frame of cultural resource management programs, the distinction between deductive and inductive approaches becomes blurred. The model building and refinement process is based on a continuous cycle of data collection, analysis, and model refinement. The results of one cycle of field testing and analysis are used to refine the model, which then guides the next phase of data collection (Kincaid 1988:555).

3.1.2 How Location Models are used in Cultural Resource Management

The foregoing discussion has reviewed several kinds of predictive models of site location. Some are largely or wholly operationalized, others are intuitive; some are based on deductive arguments, others are inductive.

In a cultural resource management context, predictive models and sampling have been used in the formulation of planning documents. One of the best such studies was performed in central Colorado by Nickens and Associates (Kvamme 1980). A random sample inventory survey was performed, for use in generating a predictive model of site location. Previous work in the region guided researchers, in terms of which data were to be collected for the model.

Once the data were collected and analyzed, a model was constructed which compared the environmental qualities of site and non-site areas. Environmental factors crucial to site location included vertical distance to water, view, shelter, low slope, and forested resources (Kvamme 1980:96-103). These were combined and weighted in a discriminant function analysis. Any given plot of ground could then be rated by this analysis as to its likelihood for containing a site. This model was tested against independent data gathered later from within the project area (Klesert 1987:230).

In at least two Pacific Northwest Forests, rather informal location models based on a small amount of data, are being used to determine sampling proportion (but not intensity) in future survey. Areas similar to those where few resources were located in past surveys are sampled at very low rates, with survey effort concentrated in areas similar to those which, in the past, evidenced high densities of cultural resources (Kohler 1985:15).

In the Southwest, attention has focused upon "complete" surveys, not samples, in a preliminary effort to determine the potential for building predictive models. "The question asked of each project was: would it have been possible, given these data, to design a survey strategy that would have resulted in the location of most of the sites by examining only one part of the area? Where the answer was yes, one looked for environmental characteristics that could be used to define areas containing sites" (DeBloois 1985:8).

In Ontario and Saskatchewan archaeologists are working with foresters "to investigate the feasibility of using predictive models to anticipate the spatial distribution of heritage resources" in boreal forest environments (Dalla Bona/Larcombe 1992:36).

Location models are currently employed primarily to focus survey efforts on areas with probable dense distributions of archaeological resources. "This may be good for archaeology, in the limited sense that it builds up the site inventory relatively rapidly, but it is a strategy that may miss important segments of adaptations from some time periods, while missing other periods entirely". Moreover, this approach may be neither cost-effective nor good management (Kohler 1985:18).

The location selection decision-making process involves three basic components: 1) the biophysical properties of location, 2) the social subsystem; and 3) the "cultural" information. Ideally, all three of these components should be built into a location choice model. The most readily available information for an archaeological context is data regarding the biophysical properties of locations, the social and cultural components of the location choice being largely unknown except for well understood archaeological situations (Parker 1985:174).

If it is not understood why a model works in one study area, there can be no way of knowing whether it will work in a new study area. In order for a cultural resource manager to use information derived from models, even for the most general planning purposes, he or she must know that the model works within specified levels of confidence and precision (Sebastian/Judge 1988:6).

With explanatory models on the other hand, eventually it may be possible to offer general models that can be demonstrated to be applicable in any situation characterized by a specified set of cultural system and ecosystem variables (Sebastian/Judge 1988:7).

4.0 Archaeological Applications of Geographical Information Systems in Cultural Resource Management

Geographic Information Systems (GIS) are computer-based systems designed to input, store, transform, manipulate, analyze and display spatial data traditionally represented in the form of maps or plans. These systems are characterized by their ability to store many sets of location data, usually representing a series of map layers. The power of GIS lies in their ability to store not only location and attribute data for each spatial entity but also the topological relationships between them. This permits the different spatial features making up each map layer to be integrated with those of other map coverages, examined in the same analysis, and new component maps or information produced.

"It is this ability to handle spatially disparate data from several map layers, to seek relationships, to produce composite variables and maps, and to model the information, which makes GIS so potentially important to archaeology" (Lock/Harris 1992:90). GIS is well suited for "what if" types of queries encouraging an explanatory approach to data analysis.

A primary feature of GIS is the ability to select, integrate and analyze features from a combination of map coverages and to construct new composite variables or maps from these sources. GIS also possess operations which enable the "buffering" of either point, line or polygonal map features or the generation of separate overlay features. "The use of such operations for neighbourhood analysis and site catchment analysis of archaeological sites, along with the buffering of environmental or archaeological features which enable the exploration of various hypothesised relationships, provide a very powerful and useful tool to the archaeologist" (Lock/Harris 1992:91).

Finally, GIS provide an environment in which sophisticated modelling can be undertaken. Specifically, archaeological data often suffer from the problem of "white areas" in which no data is known to-exist, although it may not be clear whether this is due to some bias or represents a true absence of data. GIS offers a powerful modelling environment within which it is possible to generate models to predict and extrapolate beyond the available data and into these "white areas". "If, for example, multivariate relationships are known to exist which help explain the location of certain archaeological sites to a high degree, then the ability exists to use these relationships within a GIS to predict and map the location of possible, as yet unknown, sites" (Lock/Harris 1992:92).

In many ways GIS are similar to traditional database-management systems, but with the distinction that the data possess a spatial or mappable component. This characteristic of GIS provides a number of capabilities not found in traditional database-management systems. "Foremost among these is the ease with which maps of data can be produced, thereby offering a ready means to portray complex spatial relations and patterns. It is the ability of GIS to handle, generate, manipulate, and analyze spatial data types that is of importance for archaeological predictive modelling" (Kvamme 1990a:370).

There are three main areas of research currently conducted in CRM utilizing GIS:

1. Site location models developed primarily for cultural resource management purposes;

2. GIS procedure related studies;

3. Studies that address larger theoretical concerns related to landscape archaeology through GIS methods (Savage 1990:25).

The goal of an approach that utilizes a GIS as a cultural resource management tool is to locate areas that are sensitive to the presence of archaeological sites in advance of development. This would enable the plan of the development phase of a terrain altering project to incorporate and avoid sensitive archaeological areas. The majority of initial work with GIS in archaeology has centered on location analysis and predictive modelling. This is probably due to the emphasis on GIS as a management support tool, and the fact that many of the current GIS available have been developed by various government agencies (Savage 1990a:26).

In the absence of truly uniform data quality standards the results of current location models represent hypotheses to be tested in archaeological survey, not the end product of a process that creates archaeological "facts". "Many of the location analyses using GIS have been undertaken precisely to avoid a large survey, so it appears that the use of GIS in a CRM context may result in more harm than good if compliance is assumed on the end product of such analyses" (Savage 1990a:28).

The fundamental role that GIS plays in regional archaeological analysis is to provide the researcher with a means to obtain large amounts of environmental data in an easy and rapid manner (Kvamme 1990a:371). GIS technology easily and rapidly allows characterization of the nature of the distribution of a continuous variable across entire regions of study, with generally much greater accuracy than can be obtained by manual methods.

Finally, it should be emphasized that the region that is encoded within a GIS database can bias the results of analyses if it is not representative of some actual area of interest. For example, the region of interest ideally should correspond with the general area where habitation sites are located (Kvamme 1990a:379).

5.0 Problems with Archaeological Predictive Model Applications

Should managers select a correlative (inductive) model, which is easier to design, takes less time to develop, and is initially more accurate, or should they plan to use an explanatory (deductive) model, which is more complex and difficult to develop and may not be as accurate a predictor? (Judge/Martin 1988:577)

Cultural resource managers and archaeologists are less concerned with the overall predictive success rate of a model than with the likelihood of an inaccurate prediction. There are two types of predictive errors: a prediction can be made that a location (or area) contains a site when in fact it does not, and a prediction can be made that a location does not contain a site when in fact it does. The first type of error may lead to increased costs or to inefficient use of resources and is a wasteful error. Errors of the second type lead to the destruction of cultural resources and are gross errors.

In a hypothesis-testing framework there are always two potential errors: rejection of the null hypothesis when it is in fact true (wasteful error) or acceptance the null hypothesis when it is false (gross error). An ideal predictive model minimizes both types of errors: it makes accurate predictions. In practice, however, models do make inaccurate predictions. Generally, it is much more costly in cultural resource management to make a gross error than a wasteful one, and the likelihood of making a gross error is inversely related to the likelihood of making a wasteful error (Altschul 1988:62).

The choice between two models, then, has less to do with overall success than with minimizing errors, especially gross errors. "In general, a more powerful predictive model is one that for a specific proportion of gross errors to total predictions also minimized the area predicted to contain cultural resources" (Altschul 1988:63).

Predictive models are probability statements; they are not "facts," and cannot substitute for facts in any application requiring the use of hard data about specific areas containing archaeological resources.

> The problem is that some archaeologists have told some planners that our predictive models can be used as hard data, when in fact, it is our hard data on site location and significance that must be figured into the planner's cost-effective ratio. To substitute a scientific hypothesis (our predictive model) for scientific fact (actual site location) as a criterion for a planning decision is to court disaster. There is only one way for us to get the hard data for use in such decisions: by an intensive ground-reconnaissance of the entire area to be affected by a proposed project (Kohler 1988:24).

The specific failings of past modelling efforts have included:

> failure to address management needs, lack of specificity, poor use of existing data, ineffective or biased sampling designs, inappropriate statistical analysis techniques, failure to collect inventory data suitable for the development of a predictive model, development of models using non-replicable techniques, lack of comparability of and inappropriate use of environmental variables, lack of phasing to allow for model testing and refinement, and failure to use

such technical aids as remote sensing and geographic information systems (GIS) to streamline model development (Sebastian/Judge 1988:10).

Resource managers have found that predictive modelling is being employed in a wide variety of ways and that there is little . mutually agreed-upon theory, method, or policy to guide the use of this technique (Judge/Martin 1988:571). Issues of primary concern are:

1. Areas designated "low probability" are frequently given "administrative clearances" based on model predictions, with no field inspection;

2. There is no universally followed policy regarding how, or whether, such clearances should in fact be made;

3. The models are also commonly consulted for information needed to prepare environmental assessments and statements, and in formulating cultural resource management plans.

In order for a cultural resource manager to use information derived from models, even for the most general planning purposes, he or she must know that the model works within specified levels of confidence and precision (Sebastian/Judge 1988:6).

Too frequently, a good fit between model predictions and observations is taken as a confirmation of the model. It appears that the dominant goal of location models in archaeology is to get the facts and the model to fit. However, no model can account for all the facts, and several contradictory models can predict the same set of facts. Too often neither the model nor the facts are properly theorized, and therefore alternative explanations are not rigorously considered (Keene 1988:242).

Land managers should take care against the improper use of intuitively derived models in influencing inventory efforts.

Archaeologists who work frequently in an area often develop a "feel" for where sites should be found. occasionally, these intuitions have been used as a basis for limiting inventory to certain areas without testing others (Kincaid 1988: 561). A danger in this approach is that if sites are sought only where they are thought to exist, the prediction becomes a self-fulfilling prophecy. Potential results can include destruction of significant resources or introduction of a strong bias into the data base.

Intuitions should not be dismissed, but they should not be equated with scientifically verified information. Intuitions must be formalized, expressed in terms that can be measured and applied in the inventory process, and subjected to a rigorous testing program. In this way they can be of vital importance in effective model development (Kincaid 1988:562).

Models of site location based on existing data can lead to predictions with very high accuracy rates. After all, if people have only looked for sites in certain types of places, then it is inevitable that site locations will be highly correlated with specific environmental attributes.

The problem is that many archaeologists stop there and never formalize their answer. Thus, no matter how brilliant their insight or how many sites they find, no one can objectively evaluate how well their model works (Altschul 1988:65).

> The development of model components and the definition of their interrelationships should be the areas in which archaeologists make their greatest contribution to the predictive modelling process. This, however, has not been the case. Instead, there has been a tendency among archaeologists producing predictive models to concentrate on the sophisticated multivariate mathematical techniques and to give only casual attention to the predictive variables. In most cases, methodological discussions focus on the inner workings of the statistical procedures with only passing references to the reasons why specific variables are theoretically related to site location. Indeed it appears that investigators are assuming that the relationship(s) between the environment and site location cannot be specified, other than that there is one, and that if only enough environmental variables are put to the equations something useful will come out (Altschul 1988:84).

The task of location modelling is to isolate those aspects of the environment that do influence settlement behaviour and place them into perspective with non-environmental factors that also influence settlement behaviour (Kohler 1988:25).

This is a crucial observation for the task of location modelling. Many valid criticisms can be made of naive environmental determinism for its suggestions of large-scale, simplistic correlations between environmental and cultural features. Correlation is not explanation and does not tell us anything about causality.

Because correlative models are designed to tell us where sites are located (relative to various environmental variables) and not why they are located as they are with respect to those variables, even when they work exceedingly well, it is not known why they work. To the manager who only needs to know where archaeological sites are this may not immediately appear to be a major limitation. But if it is not known why a model works in one particular study area, it cannot be explained whether it is expected to work in the next valley or watershed or in a similar but distant environment. Thus correlative models are not truly predictive, but consist of projections of an observed pattern from a sample to the whole universe.

Another limitation arises because correlative models require measurable, mappable data. For this reason, they depend heavily on environmental factors to provide their independent variables, and because of this they are most successful when applied to societies whose movements, group size, and activities are highly regulated by aspects of their environment – generally hunters and gatherers (Sebastian/Judge 1988:5).

Because correlative models are relatively straightforward to develop and because simple environmental variables are relatively easy to measure, these models are viewed as cost-effective and objective. And in the short run they often provide the kinds of information needed (Sebastian/judge 1988:8).

Although there may be arguments about how to test for correlation or how to measure the strength of a correlation or assign confidence limits to it, once those are resolved the only question that remains is whether a correlation exists or not (Sebastian/Judge 1988:10).

A major problem with associational models is generalization. They are usually not derived from probabilistic sample surveys and thus may contain biases that will be magnified if the model ,is generalized (ie. extended to areas that have not been surveyed) (Altschul 1988:66).

There is no question that controlled probabilistic sampling is an efficient way to learn various things about a population without having to examine every member of that population. "Except in the few cases where there is essentially no environmental variation within the area to be sampled, one of the things we obviously want to find out is what kinds and numbers of sites might be located in which types of environments" (Ambler 1984:140).

In principle, a perspective is gained concerning what kinds and densities of sites are found in what kinds of locations, and from this sample projected to the subject area as a whole. However, "no matter how rigorous our sampling design, how thorough our sample, or how complex our statistics, we have not learned anything about the area as a whole, we have only learned about our sample; all else is projection, within certain limits of probability. We can predict likely locations for sites, but cannot predict locations where sites are absent" (Ambler 1984:141).

If one cannot rely on the results of probability sampling due to gross errors in application, then predictive models built into these data are equally unreliable. Here we have the focus of the current controversy over predictive modelling. It is not the modelling and it is not the sampling that makes archaeologists uncomfortable, it is the substitution for verification. Previous work has demonstrated that prehistoric sites are distributed differently across the landscape from one area to another and their relationship to existing environmental variables is neither obvious nor simple. Data available for analysis is often unreliable due to uncontrolled biases through probabilistic samples and incompatible methods of observation.

One reason is that most models are constructed inferentially, starting from a sample of archaeological sites in a region and generalizing to an unknown population of sites in that same region (Kohler 1988:19). Environmental variables are often not used in most predictive location models because archaeologists simply do not know how to use them (Kohler 1988:20).

The model must be subjected to rigorous testing to confirm its accuracy. This demonstrates a major limitation on any predictive model: predictions are based on known data and are incapable of dealing with unique or extraordinary occurrences. By basing the model on sample data we only intensify the problem (Klesert 1987:230).

Two methodological issues arise from the foregoing: how to characterize the nature of the background environment on variables under examination, and how to compare archaeological samples against the background environment.

Aside from relevant statistical literature regarding sample size and the power of tests, there has been little study or guidance in the archaeological literature regarding the nature or size of samples needed to adequately characterize the often considerable variation present in the background of regions, particularly when they are large.

One-sample testing strategy for regional archaeological analysis avoid many difficulties by treating the background environment (on any variable) as a constant. Archaeological samples then may be compared against this background referent to determine whether they are unusual or deviate in some way from this norm. Stated differently, the background environment of a defined region of study is the same population of interest. One-sample tests examine whether characteristics of an archaeological sample depart significantly from the population.

Two-sample tests can only represent the background environment imperfectly through random sampling. This introduces additional variance to an analysis because sampling variation in both the archaeological class as well as the background class must be dealt with by the statistical test. Less powerful conclusions must result when compared with one-sample-testing approaches, to the same problems, that focus only on variation in a single archaeological sample (Kvamme 1990a:368).

For continuous environmental variables such as elevation, slope, aspect, distance to water, and local relief, a one-sample chi-square test is possible, but it is undesirable because the continuous variables must be categorized into relatively few classes whose areas in the region of study can be determined on maps (ie., area of level ground vs. area of steep ground; area within one kilometre of water vs. area within two kilometres of water vs. area beyond two kilometres of water). "This amounts to the re-scaling of interval-level concepts to a lower level resulting in the throwing away of information that can lead to less-powerful inferences" (Kvamme 1990a:369).

Predictive modelling as employed by most archaeologists, until recently, looked for sites in likely locations and ignored places not considered to be likely for sites. Archaeologists are now beginning to realize that the "modelling" which has been advocated in the past has a surprisingly, and perhaps dangerously, simplistic foundation beneath all of the mathematical discussions.

How are models evaluated? The answer often depends on the questions asked. For example, "successful modelling" for the archaeologist who wishes to predict location of sites to minimize construction impact may appear as a "failure" to the archaeologist attempting to interpret the processes that drive humans to select past settlement locations.

An important consideration for evaluating models is their ability to take into account rare sites. These sites constitute a very small portion of the site population either by virtue of their own characteristics or their location in relation to the environment. A site type can be rare without being impossible to model, but most models do not address these sites, because their low numbers make most statistical techniques unusable. The rare site problem increases when sample inventories at low sampling rates are used to generate the data base for model development.

Models should be evaluated for their completeness. Did they address changes in the environment through time? Are there biases in the' sample design that might affect the reliability of the data? Also, the resolution of the model is important. If the management need is for statements specific to linear corridors for example, broad zonal models may not be useful (Kincaid 1988:566).

On-site characteristics (such as slope) and resources, distances of sites to environmental features or resources, and characteristics of catchments surrounding sites, all share the feature that they are site focused. "To be measured, such variables demand identification of a specific location. By contrast, most predictive models focus on characteristics of the quadrats used for survey or for prediction" (Kohler/Parker 1986:408).

Few predictive models use immediate location characteristics of sites (such as aspect, view, and on-site vegetation), because of the high spatial resolution for prediction these require. Nonetheless, settlement-pattern analyses have repeatedly demonstrated that sites may be non-randomly located in relation to very local features. More intuitively, locations for rockshelters, quarries, petroglyphs, weirs, and other specialized site types readily demonstrate the potential importance of very local environmental features to site location (Kohler/Parker 1986:409).

Research questions are often changed or refined as knowledge increases. "We need a lot more basic data before attempting to satisfactorily answer many of the research questions posed today, and we cannot hope to anticipate all the types of questions that might and should be asked once an area has been surveyed" (Ambler 1984:142).

If theory establishes the rules for the relationships among variables, models enable us to view the implications of changing the rules, to view the outcome of assigning specific values or conditions to those variables. Thus, models are not only manifestations of theory; they actually allow us to probe the limitations and sensitivities of theories.

Models are frequently criticized for ignoring variables, or for oversimplifications. Such criticism overlooks the paradox of models: their greatest strength, the ability to simplify reality and make problems tractable, is also a weakness. Such simplification sacrifices some aspects of reality. Any individual modelling effort, therefore, is incomplete.

Successful model applications generally result from approaching a problem with several different models or with several variations of a single model. Models can be viewed as heuristic devices, as a means for examining the implications of theory (Keene 1985:241).

With the ability to create potentially powerful archaeological resource models through a GIS, discipline wide attention must be given to how these models are employed by officials in government agencies responsible for the protection of irreplaceable resources. There is natural concern that agencies will use such models to form decisions resulting in a loss of resources in predicted low site probability regions. This perception tends to misplace blame on models, or model makers, rather than on decision makers.

Land managers may make unreliable decisions with regard to the resource base with or without the use of location models of any kind. It is hoped that managers will choose from among the responsible decision alternatives. If they have not always done so, this should not be seen as the fault of the methodology on which they based their information. If managers are making unreliable decisions with regard to the archaeological resource base, then attention should be paid to defining the responsibility. The question becomes whether (GIS based) site location models can be designed to give better site location predictions than would be possible without the use of such models.

Several archaeological GIS studies already have appeared that contain more computer generated "gloss" than substance. The lure of producing beautiful maps and data models is great, but some thought and concern must be given to the quality of the data and nature of the assumptions used to produce them. Without careful consideration these models will contribute to unreliable land use decisions.

This potential problem area will become more severe as sophisticated, non-archaeological computer consultants, who do not understand the nature of the archaeological data, processes, and needs, become increasingly involved in complex database, analysis, and modelling situations on a contractual basis (largely in cultural resource management contexts). In these cases archaeologists must play a large role and provide informed guidance; to be informed, however, requires some knowledge of GIS technology, the computational procedures that go into them, and analysis and modelling procedures. Consultants are usually hired because archaeologists lack the technical knowledge (Kvamme 1989:188-189).

The use of inappropriate sampling techniques, failure to differentiate significant temporal and functional subsets of sites, failure to consider how representative variables really contribute to location decisions, low spatial resolution, inappropriate statistical tests, and little consideration for model validation have often weakened the usefulness of these models for both management and research. All of these weaknesses may not be found in any one model, but at this stage in the development of predictive modelling, it can hardly be expected that any model would be entirely free from these difficulties (Kohler/Parker 1986:440).

Finally, the interpretability of the model is important. Is the model simple enough to be understood and explained in anthropological terms? Does it relate environmental and site variables to the everyday world? If not, it may not be usable by future researchers in a cultural resource management environment (Kincaid 1988:567).

6.0 Advantages of Predictive Modelling

By focusing research on the location of sites, as well as on the types of sites expected to occur in specific locations, the modelling process can help to increase the accuracy and precision of functional, temporal, and spatial qualifiers. Modelling helps to define major similarities and differences among sites and reflects the information potential for both identified and projected sites within an area. In evaluating whether a particular site is potentially significant, the archaeologist often relies on previous experience with other sites of the same type.

The importance of a site cannot be equated solely with its membership in a particular site type or class. However, the rare or unique site, which fails to appear as a separate type during statistical analyses, may be the most significant site in an area. "These sites are often not amenable to identification through sample inventory, but they can be successfully integrated into predictive models if sufficient information is known about them. It is important to consider the physical characteristics of a site as well as its class membership" (Kincaid 1988:562).

Often the nature of the archaeological record itself can indicate that special strategies will be needed for modelling efforts. Sometimes the environment determines whether modelling will be easy or difficult. The most usable environmental variables for predicting site locations are "those that monitor spatial availability of resources (ie. degree of patchiness) and temporal availability of resources (ie. degree of constancy, contingency, and predictability)" (Kincaid 1988:552).

Modelling is useful as a long-term technique for organizing and structuring data and data collection priorities. It is less useful under a short time frame that does not allow for testing and refinement phases.

Perhaps the most valuable applications of modelling, however, is in the area of planning. Planning for the management of cultural resources can take place during the development of land-use plans, environmental assessments, province-wide or area-wide program plans, or site-specific plans. Models are especially suited to planning applications, because they focus on broad scale, generalized trends, actions, or information. The main weakness of models, the inability to consistently produce detailed site-level specific statements, is usually not critical in a regional planning situation (Kincaid 1998:563).

"Are we only interested in predicting general site densities and locations for management purposes, or do we also want to learn about cultural processes and human behaviour? Both of these objectives must be approached from a theoretical standpoint starting with the consideration of how we believe systems of human adaptation operated in the past and evaluating how the ways we discover, collect, and analyze our data are compatible with what we need to know" (Ebert/Kohler 1988:98). The answer may be both, but management decisions are often limited by the amount of money available.

Archaeologists do not know all about the complex systemic behaviour that must be the basis of archaeological predictive modelling. While there may be more than one way to do predictive modelling once archaeologists know how to do it, there is only one way to learn how to do it: by doing it! Developing predictive modelling as a tool to aid both archaeologists and cultural resource managers must proceed from a consideration of the wants and needs of both.

The size of the potential modelling project area is important. Models are most easily interpreted and understood if they relate in a defined way to cultural boundaries or to major environmental zones. When ' only a small portion of a cultural area or environmental zone can be analyzed, only a portion of a cultural system might be examined. In designing small modelling projects, difficulties often occur in meeting minimum sample-size requirements for statistical analyses (Kincaid 1988:551).

The configuration of the modelling project area is also important. Linear as compared to areal projects are generally more difficult to model because linear projects tend to cross-cut several environmental and cultural zones, each of which may be poorly represented regarding the total subject area.

Perhaps the most cost-effective context for model development is within the framework of general planning by a land-managing agency or a local government. These programs (such as the Resource Inventory Committee and the Corporate Resource Inventory Initiative) can develop and sustain long-term approaches that are funded on an incremental basis and result in cumulative and refined data bases. Such data bases, and the models based on them, may take years to develop and test. The end result, however, is a powerful and effective management tool (Kincaid 1988:554).

A common problem encountered by archaeologists is that it can be an extremely difficult task to organize and efficiently manage the large bodies of important data that might exist in a region, let alone the amount of data that occurs on a state/province-wide level. The retrieval of particular kinds of information, for example, about a specific archaeological project, can be exceedingly troublesome when some of the data might exist on one or more maps, while other information might occur on sight forms, project reports, published articles, or even in notes associated with museum collections. The effective value of our recording efforts is thus severely compromised (Kvamme 1989:141).

Since data in GIS have a spatial component, GIS are distinct from traditional database management systems. It is the geographical structure that give GIS added capabilities over traditional database management systems (Kvamme 1989:139).

Maps portraying the geographic arrangement of information are easily produced through a GIS. The visual display of mappable data may be one of the most important features of this technology to the archaeologist, because archaeologists are used to working with maps, and maps convey large quantities of information in an easily understandable and recognizable way. Moreover multiple kinds of information can be displayed simultaneously (Kvamme 1989:162).

Modelling of the regional distribution of archaeological sites is another area of interest to archaeologists and has constituted the largest area of application of GIS technology. "Through GIS a parallel strategy can be employed to yield a regional model of archaeological site location. A variety of terrain, soils, vegetation, hydrological, and other biophysical data, which have been shown by previous work or theory to be related to regional archaeological distributions, are encoded for an area of study within a GIS" (Kvamme 1989:178).

Finally, to evaluate model performance or accuracy, the GIS is used to compare model predictions against test locations of known archaeological class membership. A classification model developed by this strategy can then be regarded as a regional predictive model-when locations of unknown archaeological class membership are classified.

The short-comings of some pre-GIS studies are that they were unable to assess model performance in terms of its application to the entire region of study. For example, "it could be the case that about 97% of all locations (regardless of site presence or absence) in the study area meet 5 of the 7 criteria, the fact that 97% of the known site locations are correctly indicated by the model would not, in this case, be significant. On the other hand, if only 20% of the entire region happened to meet 5 of the 7 criteria, while 97% of the sites did at the same time, then some predictive power would be suggested" (Kvamme 1989:181).

The benefits of archaeological location modelling in GIS contexts are potentially large. Through GIS a wide variety of alternative modelling strategies can rapidly be implemented allowing simultaneous pursuit of a number of different approaches and ideas. Good regional models can help to characterize patterns of prehistoric land use in a more understandable way, often conveying the essence of spatial pattern better than the original site location data. Coupled with their analytic capabilities, GIS potential for advances in understanding of prehistoric cultural processes can be large. Good location models can suggest likely locations where as yet undiscovered archaeological sites might be found. Such models could be extremely useful to archaeologists wishing to discover new sites or to government agencies responsible for the management and protection of archaeological resources on large tracts of public lands.

Parker (1986) argues that GIS-built archaeological models can positively contribute to resource management by increasing the efficiency and quality of management and by reducing costs. Moving a proposed road alignment from a predicted archaeologically sensitive region to an area of low predicted sensitivity, for example, can help to minimize costs for mitigation of impacts. The need for survey and mitigation in these regions is stressed by Parker (1986); however, she emphasizes that the amount of required work would be less because there generally would be fewer cultural resources than in high sensitivity areas (Kvamme 1989:187).

7.0 Summary

In general, the use of predictive models based on sampling is a good way of obtaining a general impression of an area, of being able to tell with a certain degree of precision and reliability what is "out there". As such, they are of value to planners and developers in choosing among possible alternatives and to help minimize damage, delays, and expense (Klesert 1987:231).

> Many archaeologists and managers consider predictive modelling to be a practical reality at the methodological level. On the basis of archaeological surface survey or previously recorded data taken from site files, the occurrence of sites correlated with environmental variables, most of which can be derived from topographic or other maps or from such data sources as remote sensing: elevation, slope angle and direction, different types of landform, (assumed to be good defensively, for lookouts, or for shelter), vegetation and soil types, and distance to water sources. The "best" indicators are those that correlate with occurrences of sites that are already found, and these are used to predict where sites will or will not be discovered, at least potentially, in unsurveyed areas (Ebert 1988a:3)..

"Surely there was more to prehistoric human behaviour than this implies," said one colleague, himself a Native American trained as an archaeologist, and geographic information system researcher. "This is what we do to map fox or squirrel habitats: look for water and shelter and food and then draw polygons and isopleths around them. Do these archaeologists think they know all about how complex past peoples' seasonal rounds were, why they went where they did?" We as archaeologists do not know all about the complex systemic behaviour that must be the basis of archaeological predictive modelling (Ebert/Kohler 1988:98).

It seems clear that the use of predictive models has basic limitations: models are nothing more nor less than simplified abstractions of a variable and complex reality. Archaeologists have always employed predictive models, in all situations, whether they have been explicit about that use or not. over the years archaeologists have become more sophisticated in their approach towards sampling and modelling, but it has been a matter of progressive refinements rather than anything approaching a paradigm shift or conceptual revolution. With the introduction of sampling as a replacement for intensive surveys, it is essential that the sampler demonstrate that the model has been adequately tested prior to its implementation, and that the sample does supply the researcher with what is required: either a representative picture of the whole, or labour-saving approximation of an entire population (Klesert 1987:234).

Since it is not the primary objective of the predictive modelling effort now underway to achieve any reduction in the amount of survey required, the way surveys are currently performed will likely not be affected at all. That is assuming that surveys currently being conducted are appropriate, technically sound, and in conformance with existing standards and guidelines. In cases where this is not true, the increased control required of surveys providing data for model development should improve survey techniques and increase the value of the data produced (DeBloois 1985:10).

Archaeologists with management responsibilities fear that the current/suggested potential of predictive modelling is too limiting. They are looking for practical methods to provide better information about cultural resources in order to make realistic recommendations to management. Archaeologists without management responsibilities fear that the technology, if allowed to go unchecked, would be applied by land management in an irresponsible manner.

Archaeologists are concerned about the explanation of past human behaviour, and there is general agreement that they should not be satisfied with only the demonstration of correlations, but that they must also provide explanations for those correlations.

Management objectives are sometimes thought to be limited to a narrow concern over "how many sites are where", and indeed, models can suggest what types of sites are in a specific area and where in that area they might occur. Some models can also be used to generate population estimates and statements concerning the probability of site occurrence in a particular location. These classes of information are important in management decisions about possible surface-disturbing actions. But the more research-oriented objectives of modelling are also important because such models can help to indicate data gaps and highlight research issues needing additional work. Such models can assist in understanding existing data and, in some cases, can expedite and streamline inventory programs (Kincaid 1988:549).

Archaeological sites in a region are not only non-randomly distributed, but often exhibit pronounced patterns with respect to landform, soils, vegetation, hydrology, and other features. Explanations of archaeological distributions or prehistoric landscape uses have centered around these environmental characteristics. It has been variously argued, depending op cultural context and geographical region, that in placing their activities prehistoric peoples selected such environmental features as level ground, proximity to water sources, good views, good soil conditions, south-facing slopes, and a host of other factors. Many regional analyses that have attempted to demonstrate these tendencies have not been very convincing or successful, however, at least until the advent of GIS Kvamme 1989:168).

There is good reason to believe that site locations cannot, in general, be fully predicted from environmental variables alone. In land management applications, therefore, models of natural phenomena and models of cultural phenomena should not be considered equivalent. Managers need to have a realistic understanding of what models can and cannot do in order to use them effectively (Kincaid 1988:551).

From a management perspective, the most important issue facing land managers is not whether to invest in predictive models but whether the modelling process should be an integral part of the overall cultural resource management program. It can be argued that managers should utilize models and the modelling process because it is in their best interest to do so. In the short run, the first few predictive models will probably not be very powerful. They will not be substitutes for inventory surveys, and perhaps they will not even be very good planning tools. Moreover, a commitment to the model-building process may require the restructuring of the cultural resource management program to ensure that projects are designed to meet specific objectives and their results are cumulative. Standardization will have to give way to flexibility in research design, and the agencies may have to be prepared for larger rather than smaller sampling fractions. In the long run, however, a commitment to modelling may be the land managing agencies' best hope for the creation of useful tools to guide future development and management of this country's cultural resources (Altschul 1988:88).

Predictive modelling can be a worthwhile component of cultural resource management, if for no other reason than that it injects rigor into the management process and serves to integrate management with archaeological research. The process of modelling and the preparation and development of models are extremely valuable assets to management, regardless of their ultimate "success" of the models (Judge/Martin 1988:579).

However, the Archaeology Branch feels at present that archaeologists do not know as much as they should about how to do predictive modelling. Through the proper combination of rigor and research, they can probably learn to do such modelling in the near future, but at "this stage in our understanding of the modelling process, it would be premature to produce a guidebook or manual" (Ebert/Kohler 1988:97).

Modelling is a cyclical process of ongoing refinement, rather than a one-time event, and thus models cannot be developed by archaeologists and then simply "turned over" to land managers for "application". Predictive modelling is potentially the most cost-effective way to combine sound management practices with valuable research programs (Judge/Martin 1988:580).

Undoubtedly the most important criterion to consider in evaluating a model is whether or not it has been tested. Without testing or evaluation, a model is little more than a guess. Another reason for model testing is to determine the nature and strength of relationships that may have been discovered (Kincaid 1988:565).

Are logistic models with a significant "fit" sufficient to allow interpretations of site probability for areas as yet unsurveyed? If predictive models are to contribute to a greater understanding of human settlement patterns and to the land-use decision-making process, it is imperative that a validation methodology be developed to allow for more rigorous model testing. Such procedures should allow the incorporation of further field tests (Parker 1985:189).

8.0 Conclusions

It is apparent that model-building is a complex and time-consuming process. There is no set of standards to follow because of the variety and variability in modelling approaches and management objectives, as well as regional physiographic and cultural differences (Judge/Martin 1988:573).

The first issue is that of the complexity of the process, modelling past human behaviour/activities, is not an easy task. Humans do not behave mechanistically, and thus generalizations about their behaviour are difficult to derive and can never be completely accurate. The relationships among humans, their activities, and past landscapes are very complex to begin with, and this complexity is compounded by subsequent changes in these landscapes, and by the difficulty of the quantitative methods that one must employ to model these relationships: methods that are frequently beyond the expertise of those who wish to use them. Modelling is a tool, but it is by no means (Judge/Martin 1988:574) a simple tool and not a panacea. As a complex tool, its uses are limited, and it requires expertise to implement correctly. As with any tool, modelling can be abused, and the value of the results diminishes accordingly. Used properly, however, modelling can be of inestimable value to both the manager and the research archaeologists.

Predictive modelling of archaeological site locations can never be a complete substitute for actual field inventory (intensive survey). Human behaviour is too complex to permit this kind of modelling accuracy, and too many variables have intervened between the time the behaviour took place and the present to achieve, through modelling, the accuracy available with field inventory. For this reason, it is unlikely that predictive modelling could, in the foreseeable future, be sufficiently accurate to satisfy the identification requirements (Judge/Martin 1988:575) in an area. By the same token predictive modelling is unlikely to satisfy the needs of a research archaeologist whose research design requires accuracy at a similar level.

Modelling can, however, provide research archaeologists with estimates of probable site densities in unsurveyed areas, and this same capability is of great potential benefit to the manager. In the short term, for example, the ability of models to project areas of low site density or to indicate probable locations of sites for data recovery can be extremely helpful to the manager, not as a substitute for inventory but as an aid in designing cost-effective inventory.

Modelling's greatest strengths, however, lie in its contributions to the long-term planning process. It is here that models developed with resource planning, interpretation, and evaluation in mind can be of tremendous value to the establishment of management priorities and to the integration of cultural resource management with other resource management responsibilities.

Further, such model-based management can facilitate research, quite apart from the preservation and protective responsibilities of the manager. Since a fundamental purpose of cultural resource preservation is to maintain the scientific potential of the resource, that is, to preserve its information content, modelling as a component of long-range planning is of particular value to managers and researchers alike (Judge/Martin 1988:576).

As a planning tool, predictive models should permit the projection of resource potential, scaling of inventory effort to meet expectations, estimating resource values, projecting project costs, and checking on the validity and reliability of surveys conducted. Models will allow managers to project expectations onto project area maps, or to display expectations graphically. Job costing, time estimations, and other project planning activities will be facilitated. Survey efforts can be concentrated in areas of highest expectations and reduced in areas of low expectation. Sampling strategies demonstrated by predictive modelling to be most effective and efficient could be designed to maximize the amount of information collected for the effort expended (Kohler 1985:15).

9.0 Recommendations

Predictive modelling holds much promise for cultural resource management in land-managing agencies, even though it is currently in a highly experimental and rapidly changing state. Current efforts are seen as diffuse and lacking in momentum and direction. Rather than working toward refining existing models or developing new types of information or methods, agencies sometimes develop new models that suffer from the same limitations as previous ones (Kincaid 1988:567).

Predictive models should be developed when an adequate (tested or replicated) data base is available or when anthropological/archaeological models are available which are specific enough to guide the planning of surveys. They should be developed in a situation that will engender resource responsibility. Predictive models should be developed by the Archaeologist(s) involved, in concert with other resource professionals working in and/or knowledgeable about the area.

Predictive models should produce relevant anthropological and distributional information and be used to guide cultural resource inventory, rather than being used to "clear" large areas without field survey and verification.

Predictive models should be developed at a regional level, based on broad environmental-geographic boundaries, such as drainage basins. Such models should contribute to regional plans and be subject to professional peer reviews.

Predictive models ideally need explicit "causal" mechanisms rather than correlative ones. They should distinguish between behavioral and natural factors, and should attempt to recreate and explain original site distribution patterns as well as take into account site variables, and refine site "discovery" strategies. In short, they should be scientifically based on the widest variety of evidence relating to the distribution of discoverable sites across the landscape. They also need to be testable and flexible (Kohler/Parker 1986:447).

10.0 Bibliography

Aldenderfer, Mark S. 1992. The Role of Geographic Information Systems in Quantitative Anthropology. *The Anthropology of Human Behaviour Through Geographic information and Analysis*, February 1-2, 1992, UC Santa Barbara, edited by Herbert D.G. Maschner and Mark S. Aldenderfer (in press). Oxford University Press, Oxford.

Allen, Kathleen M. S. 1990a. Manipulating Space. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 197-200. Taylor and Francis, London.

Allen, Kathleen M. S. 1990b. Modelling Early Historic Trade in Eastern Great Lakes Using GIS. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 319-329. Taylor and Francis, London.

Allen, Kathleen M.S., Stanton W. Green and Ezra B.W. Zubrow. 1990. *Interpreting Space: GIS and Archaeology*. Taylor and Francis, London.

Allen, K.M.S., S. Green and E. Zubrow. 1990. *Interpreting Space. In Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 383-386. Taylor and Francis, London.

Altschul, Jeffery. 1988. Models and the Modeling Process. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 61-96. U.S. Government Printing Office, Washington.

Altschul, Jeffrey. 1990. Red Flag Models: the Use of Modelling in management Contexts. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 226-238. Taylor and Francis, London.

Altschul, Jeffrey H. and C.L. Nagle. 1988. Collecting New Data for the Purpose of Model Development. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 257-299. U.S. Government Printing Office, Washington.

Ambler, J.R. 1984. The Use and Abuse of Predictive Modeling in Cultural Resource Management. *American Archaeology* 14 (2) :140-146.

Attwell, M.R. and M. Fletcher. 1987 An Analytical Technique for Investigating Spatial Relationships. *The Journal of Archaeological Science* 14:1-11.

Baily, R., D. Howes, S. Hackenberger and D. Wherry. 1985. *Geographic Information Processing in Land Use Modeling and Testing in the Columbia River Basin*. Paper presented at the 50th Annual Meeting of the Society for American Archaeology, Denver.

Berry, Michael S. 1984. Sampling and Predictive Modeling on Federal lands in the West. *American Antiquity* 49:842-853.

Bettinger, Robert. 1977. Predicting the Archaeological Potential of the Inyo-Mono Region of Eastern California. In *Conservation Archaeology*, edited by Michael Schiffer, pp. 217-225. Academic Press, New York.

Blankholm, H.P. 1989. ARCOSPACE: A Package for Spatial Analysis of Archaeological Data. *Archaeological Computing Newsletter* 19:3.

Bradley, John E. and W.R. Killam, G.R. Burns, M.A. Martorano Goodson and Associates Inc. 1986. An Archaeological Survey and Predictive Model of Selected Areas of Utah's Cisco Desert. *Cultural Resource Series No. 18*. Utah State Office, Bureau of Land Management, Salt Lake City.

Brose, David S. 1984. The Modern Modal Model Muddle, or, Some Comments on the King and Plog Explication in Predictive Modeling and the McKinley Mine Dilemma. *American Archaeology* 4(2):96-97.

Brown, Margaret K. 1978. *Predictive Models in Archaeological Resource Management*. Illinois Archaeological Survey.

Burrough, P.A. 1986. *Principles of Geographical Information Systems for Land Resources Assessment*. Clarendon Press, Oxford.

Carmichael, David L. 1990. GIS Predictive Modelling of Prehistoric Site Distributions in Central Montana. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 216-225. Taylor and Francis, London.

Carr, Christopher 1984 The Nature of Organization of Intrasite Archaeological Records and Spatial Analytical Approaches to Their Investigation. In *Advances in Archaeological Method and Theory*, Volume 7, edited by Michael Schiffer, pp. 103-222. Academic Press, New York.

Carr, Christopher. 1985. *For Concordance in Archaeological Analysis: Bridging Data Structure, Quantitative Technique and Theory*. Waveland Press Inc., Illinois.

Clark, D.L., (editor). 1977. *Spatial Archaeology*. Academic Press, London.

Cribb, R. 1986. Introducing the Concept of a Dedicated Spatial Analysis Package for Archaeology. *Archaeological Computing Newsletter* 9:5-12.

Cribb, R. 1987. Some Spatial Analysis Application Programs. *Archaeological Computing Newsletter* 9:5-12.

Cribb, R. and M. Minnegal. 1989. Spatial Analysis on a Dugong Consumption Site at Princess Charlotte Bay, North Queensland. *Archaeology in Oceania* 24(l):1-12.

Condie, Carol J., M. Glassow, H.B. Holt. 1984. Comments on King and Plog in Predictive Modeling and the McKinley Mine Dilemma. *American Archaeology* 4(2):98-101.

Crumley, Carole L. and W. H. Marquardt. 1990. Landscape: a Unifying Concept in Regional Analysis. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 73-79. Taylor and Francis, London.

Dalla Bona, Luke and Linda Larcombe. 1992. *Determining Archaeological Potential*. Centre for Archaeological Resource Prediction, Thunder Bay, Ontario.

DeBloois, Evan I. 1985. Predictive Modeling in the Forest Service. In *Archaeological Inventory and Predictive Modeling in the Pacific Northwest*, edited by R.F. Darsie, J.D. Keyser and S. Hackenberger in proceedings of a conference sponsored by the USDA-Forest Service.

Ebert, James I. 1988a. Modeling Human Systems and "Predicting" the Archeological Record: The Unavoidable Relationship of Theory and Method. *American Archaeology* 7(l):3-8.

Ebert, James I. 1988b. Remote Sensing in Archaeological Projection and Prediction. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 429-492. U.S. Government Printing Office, Washington.

Ebert, James, I. and T.A. Kohler. 1988. The Theoretical Basis of Archaeological Predictive Modeling and a Consideration of Appropriate Data-Collection Methods. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 97-171. U.S. Government Printing Office, Washington.

Farley, James and W. F. Limp, J. Lockhart. 1990. The Archaeologist's Workbench: Integrating GIS, Remote Sensing,EDA and Database Management. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow. Taylor and Francis, London.

Ferguson, T.A. 1985. *Use of Geographic Information Systems to Recognize Patterns of Prehistoric Cultural Adaptation*. Paper presented at the 50th Annual Meeting of the Society of American Archaeology, Denver.

Ferguson, T.A. 1986. *The Professional Map Analysis Package (pMAP) and its Archaeological Application*. Workshop proceedings of Microcomputers in Archaeology. Society of American Archaeology, New Orleans.

Gaffney, Vincent and Zoran Stancic. 1991. Predicting the Past: GIS and Archaeology. *Geo-Informations Systems* 4(4):27-32.

Grant, E. (editor). 1986. Central Places. Archaeology and History. *Department of Prehistory and Archaeology*, University of Sheffield.

Green, Stanton. 1990a. Approaching Archaeological Space. *In Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow. Taylor and Francis, London.

Green, Stanton. 1990b. Sorting Out Settlement in Southeastern Ireland: Landscape Archaeology and Geographic Information Systems. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 356-363. Taylor and Francis, London.

Gumerman, George J. 1971. The Distribution of Prehistoric Population Aggregates. *Anthropological Reports No. 1*. Prescott College Press, Prescott.

Harris, Trevor M. and G.R. Lock. 1990. The Diffusion of a New Technology: a Perspective on the Adoption of Geographic Information Systems within UK Technology. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green & E. Zubrow, pp. 33-53. Taylor and Francis, London.

Hasenstab, Robert. 1990. *Agriculture, Warfare, and Tribalization in the Iroquois Homeland of New York: A GIS Analysis of Late Woodland Settlement*. Ph.D. Dissertation. University of Massachusetts, Amherst.

Hasenstab, Robert J. and B. Resnick. 1990. GIS in Historical Predictive Modelling: the Fort Drum Project. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 284-306. Taylor and Francis, London.

Hietala, H. (editor). 1984. Intrasite Spatial Analysis in Archaeology. *New Directions in Archaeology*. Cambridge University Press, Cambridge.

Hodder, Ian R. and C.R. Orton. 1976. Spatial Analysis in Archaeology. *New Studies in Archaeology 1*. Cambridge University Press, Cambridge.

Jackson, Jack M. 1990. Building an Historic Settlement Database with GIS. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 274-283 Taylor and Francis, London.

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

Judge, James W. and D.W. Martin. 1988. An Appraisal. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 571-580. U.S. Government Printing Office, Washington.

Kincaid, Chris. 1988. Predictive Modeling and its Relationship to Cultural Resource Management Applications. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 549-569. U.S. Government Printing Office, Washington.

King, Thomas F. 1984a. The OSMPMOA is Coming, in Predictive Modeling and the McKinley Mine Dilemma. *American Archaeology* 4(2):83-88.

King, Thomas F. 1984b. One More Time Around: Responses to Comments. In Predictive Modeling and the McKinley Mine Dilemma, *American Archaeology* 4(2):107-109.

Klesert, Anthony L. 1984. Federal Coal Mine Archaeology and the Radicalization of a Moderate: A Reply to Plog and King. In Predictive Modeling and the McKinley Mine Dilemma, *American Archaeology* 4(2):102-104.

Klesert, Anthony. 1987. The Essential Role of Context in the Use of Sampling and Modeling. *American Archaeology* 6(3):228-235.

Kohler, Timothy A. 1988 Predictive Locational Modelling: History and Current Practice. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 19-59. U.S. Government Printing Office, Washington.

Kohler, Timothy A. and Sandra C. Parker. 1986. Predictive Models for Archaeological Resource Location. In *Advances in Archaeological Method and Theory*, Volume 9, edited by Michael Schiffer, pp. 397-453. Academic Press, New York.

Kvamme, Kenneth .1985a. *Fundamentals and Potential of Geographic Information System Techniques for Archaeological Spatial Research.* Paper presented at the 50th Annual Meeting of the Society for American Archaeology, Denver.

Kvamme, Kenneth. 1985b. Determining Empirical Relationships Between the Natural Environment and Prehistoric site Locations: A Hunter-Gatherer Example. In *For Concordance in Archaeological Analysis*, edited by Christopher Carr, pp. 208-237. Westport Publishers, University of Arkansas.

Kvamme, Kenneth. 1986a. *ARGIS: an Archaeological Geographic Information System.* Workshop proceedings of Microcomputers in Archaeology. Society for American Archaeology, New Orleans.

Kvamme, Kenneth. 1986b. *An Overview of Geographic Information Systems*. Workshop proceedings of Microcomputers in Archaeology. Society for American Archaeology, Mew Orleans.

Kvamme, Kenneth. 1988a. Using Existing Archaeological Survey Data for Model Building. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 301-323. U.S. Government Printing Office, Washington.

Kvamme, Kenneth. 1988b. Development and Testing of Quantitative Models. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 325-428. U.S. Government Printing Office, Washington.

Kvamme, Kenneth. 1989. Geographic Information Systems in Regional Archeological Research and Data Management. In *Archaeological Method and Theory,* Volume 9, edited by Michael Schiffer, pp. 139-204. University of Arizona Press, Tuscon.

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

Kvamme, Kenneth. 1990b. GIS Algorithms and Their Effects on Regional Archaeological Analysis. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 112-126. Taylor and Francis, London.

Kvamme, Kenneth and T.A. Kohler. 1988. Geographical Information Systems: Technical Aids for Data Collection, Analysis and Display. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 493-547. U.S. Government Printing Office, Washington.

Larralde, Signa L. and S.M. Chandler. 1981. *Archaeological Inventory in the Seep Ridge Cultural Study Tract, Uintah County, Northeastern Utah, with a Regional Predictive Model for Site Location*. Report prepared for the Bureau of Land Management, Colorado.

Limp, W.F. and J.A. Farley. 1986. *Utilizing Computerized Mapping and Geographic Information Systems for Exploratory Data Analysis of Geobased Archaeological Data*. Workshop proceedings of Microcomputers in Archaeology. Society for American Archaeology, New Orleans.

Lock, Gary and Trevor Harris. 1992. visualizing spatial Data: the Importance of Geographic Information Systems. In *Archaeology and the Information Age*: A Global Perspective, edited by P. Reilly and S. Rahtz, pp. 81-96. Routledge, London and New York.

Lockyear, K. and S.P.Q. Rahtz (editors). 1991. Computer Applications and Quantitative Methods in Archaeology 1990. *BAR International Series* 565. British Archaeological Reports, Oxford.

Madry, Scott L.H. 1990. The Realities of Hardware. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and ,E. Zubrow, pp. 173-183. Taylor and Francis, London.

Madry, S.L.H. and C.L. Crumley. 1990. An Application of Remote Sensing and GIS in a Regional Archaeological Settlement Pattern Analysis: The Arroux River Valley, Burgundy. In *Interpreting Space: GIS and Archaeology,* edited by K. Allen, S. Green and E. Zubrow, pp. 364-380. Taylor and Francis, London.

Marble, Duane F. 1990. The Potential Methodological Impact of Geographic Information Systems on the Social Sciences. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green, and E. Zubrow, pp. 9-21. Taylor and Francis, London.

Marozas, Bryan A. and J.A. Zack. 1990. GIS and Archaeological Site Location. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 165-172. Taylor and Francis, London.

Maschner, Herbert D.G. n.d. Geographic Information Systems in Archaeological Research. In *The Oxford Companion of Archaeology,* edited by Brian Fagan. Oxford.

Maschner, Herbert D.G. and Mark S. Aldenderfer (editors). n.d. *Anthropology Through Geographic Information and Analysis*. Oxford University Press, Oxford (in press).

Maschner, Herbert D.G. and Jeffrey W. Stein. 1991. *Multivariate Approaches to Site Location on the Northwest Coast: Log-linear Modelling, Logistic Regression, and Geographic Information Systems*. Southern Illinois University at Carbondale, Illinois (in press).

Nelson, Ben A. 1984. Disputable Progress in Predictive Modeling and the McKinley mine Dilemma. *American Archaeology* 4 (2):105-106.

Oliver, S.G. and E.K. Schroeder. 1986. *Archaeological Applications of ARCINFO: a Geographic information System*. Workshop proceedings of Microcomputers in Archaeology. Society for American Archaeology, New Orleans.

Parker, Sandra. 1985. Predictive Modelling of Site Settlement Systems Using Multivariate Logistics. In *For Concordance in Archaeological Analysis: Bridging Data Structure, Quantitative Technique and Theory*, edited by Christopher Carr, pp. 173-205. Waveland Press Inc., Illinois.

Pilgram, Tom. 1987. Predicting Archaeological Sites from Environmental Variables, A Mathematical Model for the Sierra Nevada Foothills, California. *BAR International Series* 320. British Archaeological Reports, Oxford.

Plog, Fred. 1984.a The McKinley Mine and the Predictive Model, Limited Survey Approach: The Archaeology of Red Herrings in Predictive Modeling and the McKinley Mine Dilemma. *American Archaeology* 4(2):89-97.

Plog, Fred. 1984b. Response to Comments in Predictive Modeling and the McKinley Mine Dilemma. *American Archaeology* 4(2):110-113.

Rahtz, S.P.Q. (editor). 1988. Computer and Quantitative Methods in Archaeology 1988. *BAR International Series* 446. British Archaeological Reports, Oxford.

Rose, Martin R. and J. H. Altschul. 1988. An Overview of Statistical Method and Theory for Quantitative Model Building. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 173-255. U.S. Government Printing Office, Washington.

Savage, Stephen, H. 1990a. GIS in Archaeological Research. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green, and E. Zubrow, pp. 22-32. Taylor and Francis, London.

Savage, Stephen H. 1990b. Modelling the Late Archaic Social Landscape. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 330-335. Taylor and Francis, London.

Sebastian, Lynee and W.J. Judge. 1988. Predicting the Past, Correlation, Explanation, and the Use of Archaeological Models. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 1-18. U.S. Government Printing office, Washington.

Stine, Linda and Roy S. Stine. 1990. GIS, Archaeology and Freedom of Information. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 54-64. Taylor and Francis, London.

Stine, R.S. and D.P. Lanter. 1990. Considerations for Archaeology Database Design. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 80-89, Taylor and Francis, London.

Stine, R.S. and T. D. Decker. 1990. Archaeology Data Integration and GIS. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 134-140. Taylor and Francis, London.

Sydoriak Allen, Kathleen M. 1990. Modelling Early Historic Trade in the Eastern Great Lakes Using Geographic Information Systems. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 319-329. Taylor and Francis, London.

Tainter, Joseph A. 1984. Introduction to Predictive Modeling and the McKinley Mine Dilemma. *American Archaeology* 4(2):82.

Thomas, Alston V. 1988. A Survey of Predictive Locational Models: Examples from the Late 1970's and Early 1980's. In *Quantifying the Present and Predicting the Past*, edited by W. Judge and L. Sebastian, pp. 581-645. U.S. Government Printing Office, Washington.

Tipps, Betsey. 1988. The Tar Sands Project: An Inventory and Predictive Model for Central and Southern Utah. *Cultural Resources Series No. 22*, Utah State Office. Bureau of Land Management, Salt Lake City.

Tomlin, C.D. 1990. *Geographic Information Systems and Cartographic Modeling*. Prentice Hall, Englewood Cliffs, New Jersey.

Tomlinson, R.F. 1987. Current and Potential Uses of Geographical Information Systems: the North American Experience. *International Journal of Geographic Information Systems* 1:203-218.

Wansleeben, M. 1988. Applications of Geographical Information Systems in Archaeological Research. In *Computer and Quantitative Methods in Archaeology*, edited by S.P.Q. Rahtz, pp. 435-451. BAR International Series 446(ii). British Archaeological Reports, Oxford.

Warren, Robert E. 1990a. Predictive Modeling in Archaeology: A Primer. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 90-111. Taylor and Francis, London.

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

Williams, I. and W.F. Limp and F.L. Bruier. 1990. Using Geographic Information Systems and Exploratory Data Analysis for Archaeological Site Classification and Analysis. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 239-273. Taylor and Francis, London.

Wilson, Samuel M. and D. J. Melnick. 1990. Modeling Randomness in Locational Archaeology. *Journal of Field Archaeology* 17:403-412.

Wood, John J. 1978. optimal Location in Settlement Space: A Model for Describing Location Strategies. *American Antiquity* 43(2):258-270.

Zubrow, Ezra. 1971. Adequacy Criteria and Prediction in Archaeological Models. In *Research and Theory in Current Archaeology*, edited by Charles Redman, pp. 239-255. John Wiley & Sons, New York.

Zubrow, Ezra. 1990a. Contemplating Space: A Commentary on Theory. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 67-72. Taylor and Francis, London.

Zubrow, Ezra. 1990b. Modelling and Prediction with Geographic Information Systems: a Demographic Example from Prehistoric and Historic New York. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 307-318. Taylor and Francis, London.

Zubrow, Ezra and Stanton Green. 1990. Coping with Space: Commentary on Data Sources, Hardware and Software. In *Interpreting Space: GIS and Archaeology*, edited by K. Allen, S. Green and E. Zubrow, pp. 129-133. Taylor and Francis, London.

Appendix: Implementing a Predictive Modelling Program

1. Collect ethnographic, informant and existing site location data.

To formulate a good initial model the ethnohistory of the study' area must be summarized. This provides information on important site settlement modelling criteria, such as average settlement size and population by season, average length of settlement stay by season and site settlement selection by season.

As part of this process, informants from local communities should be sought out whenever possible. Often local informants have a strong understanding of what sites were historically important, where they are located and in what condition they are now in. Using topographic maps and tape recorders, informant data can be collected at specially convened community meetings, band offices and in private homes.

Since there are classes of sites that are difficult to predict because they represent individual rather than group decisions, information about them might be obtained from discussions with First Nations peoples. This process also provides an opportunity to bring the native community into the integrated resource management process.

All known archaeological data should be incorporated into the database. Information from the provincial database can be directly down loaded and checked for errors.

All of these kinds of data are very difficult to use for interpretive purposes because they are not amenable to the inevitable reorganization that is necessary in order to pursue specific resource management problems or answer specific questions. Structuring this data to a usable format involves entering the data into a GIS.

2. Select Modelling Areas.

Ecological and ethnological factors form the basis for dividing the study area into smaller units. Each of these subdivisions represents areas where historical cultures had common settlement patterns and lifestyles. This process enables the task of modelling large areas manageable.

3. Build Stage One Model.

Once the site data is compiled, key geographic variables must be derived. The exact techniques used depends on the diversity of the collected data. Usually, the dominant predictive variables become apparent. Lesser trends may require the use of multivariate statistical analysis for clarification.

Derived information is then codified into a set of site location rules. The predictive rules identified in stage one may indicate, for example that certain types of sites are located near streams of a certain size. Based on the best available data, terms such as "near" are statistically quantified, enabling, for example the definition of appropriate buffer zones.

The site prediction rules should be tested periodically against actual site data as it is recovered and the model should be revised accordingly. Also, the priorities and strengths (weighing) of those rules must be re-evaluated periodically. It is likely that numerous changes to the modelling criteria will take place as hypothesis testing is undertaken and better information becomes available.

The classes of geographic data to be used in model building are usually hydrology, drainage, slope, aspect, landforms and vegetation. Much of this information is available from a variety of maps at different scales. other environmental variables must also be considered in order to look for trends which may improve the precision of the model estimates. Some work is usually necessary to structure the existing forms of digital data in order to make it compatible with a mainstream GIS platform.

One hallmark of contemporary attempts at archaeological prediction, and indeed much modern archaeology in general, is the explicit or implicit assumption that environmental factors are major, even exclusive, determinants of much of human behaviour (site location, subsistence strategies, etc.). Environmental variables, such as distance to water, distance to resources assumed to have been important, shelter, and available lookouts, are compared with the location of archaeological materials to determine whether there are correlations between these landscape characteristics and such cultural variables as the location of sites. The causal link between site locations and natural, independent variables is usually considered to be multivariate -that is, people positioned their sites with respect to an optimal combination of all resources in which they were interested.

Environmental factors deemed crucial to site placement usually include vertical distance to water, view, shelter, low slope, and forested resources (Kvamme 1980:96-103). These factors are combined and weighted in a discriminant function analysis. Any given plot of ground can then be rated by this analysis as to its likelihood for containing an archaeological site. This type of model can then be tested against independent data gathered at a later date from within a project area (Klesert 1987:230).

NTS Maps can provide information on topography, altitude range, slope, aspect, and water resources. Geologic maps provide information on the underlying rock formations. Vegetation maps provide information on present vegetation types.

Topographic information may include: crest slope, midslope, bench, foot slope and stream terrace. Two aspects of topography seem important: landform and slope. There appears to be a relationship between water resources and site occurrence, but it is not as clear-cut as for slope or landform. In many cases, sites are located in areas with no water at all, and even the most reliable water resources are not utilized to the same degree as very flat land.

Vegetation is commonly thought to be an important factor for two reasons. First, the vegetation type is important because different types contain different kinds of useful plants in different quantities. Second, borders or ecotones between two types are thought to be especially good locations for sites because they permit use of two vegetation types and therefore a greater variety of useful plants.

However, there is no guarantee that modern vegetation provides an accurate approximation of situations existing thousands of years ago. Much of British Columbia has been subject to logging, mining, grazing and other vegetation-altering activities, and this, in combination with introduced plant species, has altered vegetation patterns.

Finally, it is always important to remember that many sites may have escaped discovery in the course of archaeological survey because of vegetation cover. It is more difficult to discover some types of archaeological sites in some types of vegetation than others. Therefore, the correlation between current vegetation and site location may be due partly to the ease of discovery rather than to prehistoric use patterns.

The representativeness of modern geology is much more certain, but geology has less value for predicting sites. Favourable water resources appear to have increased the toleration for steep slope. Mildly sloping land is often used to its greatest extent near the confluence of streams containing at least one perennial. Landform has the greatest effect, followed by slope, water, and vegetation. The preeminence of landform is natural, since in some categories it combines other factors.

4. Testing and Revising.

The first testing operations may involve applying regional models against the provincial site inventory. In many areas there may be insufficient number of recorded sites to undertake this kind of test. In areas where this is feasible, testing will be implemented. This is a straightforward process that involves determining the number of sites that are located within or outside the model's predicted areas of high potential or whether sites straddle both high and low potential zones. Testing will also involve making model predictions in areas that are easily accessible (cutovers, road right-of-ways) followed by field assessment of the results. Testing should include some attempt to assess the reliability of informant-collected data by applying model segments which are working well. As more and more data is acquired, the testing cycle will be repeated until an acceptable level of precision and accuracy are obtained.