Deconstructing the crystal ball: the state of the art in predictive modelling for archaeological heritage management in the Netherlands

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Abstract: This paper presents the first results of a three-year study into the application of predictive modelling techniques in archaeological heritage management in the Netherlands. Predictive maps play an increasingly important role in the decision making process for planning schemes on a municipal, provincial and national level but at the same time the validity and reliability of the models that form the basis of predictive modelling have been questioned internationally. In the Netherlands a national research team recently started a project called “Strategic research into, and development of best practice for, predictive modelling on behalf of Dutch Cultural Resource Management”.

The goal of the project, which runs until the beginning of 2005, is a thorough analysis of the various models and methods used in current predictive modelling practice, the exploration of possibilities for methodological improvement and greater efficiency, and the formulation of recommendations for the Dutch Handbook of Archaeological Quality Norms (http://www.cvak.org/).

The first phase of the project is now completed. This paper presents a review of the current practice of both commercial and governmental predictive modelling in the Netherlands. In some ways the conclusions are remarkable.

Key words: predictive modelling, archaeological heritage management, GIS.

Background: the BBO research programme

The Netherlands is one of the most densely populated countries in Europe. More than 16 million people live and work in an area of just over 40,000 square kilometres. Urban and infrastructural developments continuously change the Dutch landscape. Nowadays the rate of change is so rapid that in many areas the archaeological record is under heavy threat. It has been estimated by Groenewoudt et al. (1994) that, since the 1950s, approximately one third of all the archaeological information in the Dutch soil has been lost without any form of archaeological intervention.

As a consequence of the 1992 Valletta Convention the protection of both the recorded and the as yet unrecorded archaeological heritage is now an important topic (fig. 1). The aim of the Valletta Convention is to protect the archaeological heritage as a source of the European collective memory and as an instrument for historical and scientific study. Archaeology has now become part of the spatial planning process. An extra research effort is needed in order to develop new tools to meet the demands society poses on Dutch archaeology.

figure 1 - Valletta, Malta.

In 2001, the ministry of Education, Culture and Science with participation of the ministries of Housing and Planning, Agriculture and Nature, and of Transport and Public Works initiated a national research programme “Protecting and Developing the Dutch Archaeological-Historical Landscape” (Stimuleringsprogramma Bodemarchief in Behoud en Ontwikkeling, BBO). This programme, managed by the Netherlands Organisation for Scientific Research (NWO), aims to make a scientific contribution to the actual policy of integrating archaeological and historical values into spatial planning (Bloemers 2001, Bloemers et al. 2001, Bloemers 2002). It focuses on establishing a meaningful link between scientific knowledge, archaeological-historical heritage management and applied planning policy in the Netherlands.

The fundamental appreciation of cultural historical resources as meaningful elements for the quality of the human environment is an important topic within the programme. Research goals are:

- An operational definition for the concept of sustainability of archaeological-historical resources;
- Well-founded and effective methods for non-destructive survey, evaluation, selection, protection, development, design and management of these resources;
- Concepts and instruments to integrate these recourses with historical landscape and buildings in environmental and spatial planning based on the temporal and spatial characteristics of evolution, transformation and region; and
- A philosophy of justification towards present and future human generations for the way a society manages its heritage.

Two concepts were selected as guiding principles for the programme because of their potential for internal and external integration of projects: “cultural biography of landscape” and “action research” (Bloemers 2002).

Kolen (1993,1995) was the first to introduce the concept of cultural biography of the landscape in Dutch archaeology. In the same way as the biography of an individual or a biography of things, one can think of the cultural biography of the landscape as the life history of a landscape. The cultural connotation of a landscape often shifts through time, and Kolen considered this concept to be theoretically and practically useful for the contemporary appreciation of the historical landscape (see also Hidding et al. 2001, Kolen and Lemaire 1999).

The second concept, action research, integrates scientific knowledge with applied cultural and environmental politics. ‘Action’ points to the process of decision making, ‘research’ to the knowledge needed for the decision making process, and developed during this process. Action research can help archaeologists with the sustainable development of the cultural landscape within the framework of environmental planning policy.

The BBO programme is divided into three types of research, allowing both short and long-term studies:

- Conceptual studies to formulate explicitly the fundamental lines of research (short term, published in Bloemers et al. 2001);
- Strategic inter- and multidisciplinary research to establish a structural integrated relationship between cultural heritage management and environmental planning; and
- Fundamental and applied research to develop and test methods, techniques, procedures and results in the real world of environmental planning and dealing with specific types of problems like linear infrastructural constructions, urban and industrial development, the rural landscape and water management and mineral exploitation.

Problem Orientation

There is a growing awareness, both among urban planners and archaeologists, that archaeology should be included in the process of planning and development from an early stage (Groenewoudt 1994). Increasingly, the contemporary design of the future landscape is making use of and incorporating the historical and archaeological values of the past. In this process the efforts of archaeologists are directed at preserving the archaeological heritage as our source of information and inspiration for future generations.

In order to reach these goals heritage managers, planners and designers need (among other instruments) cartographic tools: not just maps showing the locations of currently known archaeological sites and monuments, but also maps indicating where to *expect* archaeological material. Since the 1980s, in some countries, archaeologists, working in Archaeological Heritage Management (AHM), have been producing such maps by means of predictive modelling, but no general agreement exists regarding either the theoretical basis for, or the methods of, predictive modelling. In practice, different researchers use different modelling methods and techniques. Moreover, the use to which predictive modelling is put varies; usually it is an instrument in advising for archaeological heritage management, but sometimes it may also be used as a tool for academic research.

Predictive modelling is a technique used to predict archaeological site locations on the basis of observed patterns and/or assumptions about human behaviour (Kohler and Parker 1986; Kvamme 1988, 1990). It was initially developed in the USA in the late 1970s and early 1980s, where it evolved from governmental land management projects and gave rise to considerable academic debate (e.g. Carr 1985; Savage 1990). At first, the emphasis of research and development was on the statistical methods used to evaluate the correlation between archaeological parameters and the physical landscape (e.g. Parker 1985, Kvamme 1985). Recently, European researchers have also tried to incorporate social variables into their models (e.g. Wheatley 1996, Stančič and Kvamme 1999, Lock 2000, Golan 2003). Some researchers reject the use of predictive modelling in archaeological heritage management completely (e.g. Wheatley 2001). They think this type of modelling is a waste of time and suggest that the money should be used for other types of archaeological prospection by means of field walking, augering and excavating trial trenches.

There are various ways to categorise approaches to predictive modelling (Van Leusen 2002). The dominant one makes a distinction between an inductive (inferential) and a deductive approach. Within the inductive approach, a model is constructed on the basis of correlations between known archaeological sites and attributes that are predominantly taken from the current physical landscape. This type of statistical analysis is regularly applied for all kinds of site location studies. We only speak of a *predictive* model when the observed correlations are extrapolated. These extrapolation models are most commonly used in AHM, but may also have their use in scientific research, e.g. to analyse anomalies in the observed settlement pattern. Inductive (or data dependent) models lack an external testing mechanism, and often rely on expert knowledge for their evaluation and adjustment (Deeben et al. 1997, Deeben et al. 2002). The alternative approach is the deductive one, in which the predictive model is constructed on the basis of prior anthropological and archaeological knowledge, and the known sites are only used to evaluate the model (Kamermans 2000, Whitley 2001, Deeben et al. 2002).

Inductive modelling has been the dominant methodology, especially in American AHM practice. Recently however, deductive modelling seems to regain interest as it offers a better opportunity for incorporating theoretical considerations on human behaviour (Ebert 2000). This became especially clear during a recent conference in Argonne (Illinois, USA; March 2001), and points to a reconsideration of the archaeological theory behind predictive modelling. However, very few (e.g. Whitley 2000) applications try to incorporate both lines of modelling. Whitley recently pointed out (this volume) that archaeologists use the words deductive and inductive in connection with predictive modelling in a different manner from their original philosophical meanings. He prefers the terms correlative and cognitive instead of the often incorrectly used terms inductive and deductive.

Another widely used distinction is by theoretical stance, between ecological determinism and various post-modernist approaches (Gaffney and Van Leusen 1995, Kvamme 1997, Wheatley 1999). An important criticism directed towards current predictive models is that most of them are constructed from an ecological "deterministic" point of view. Nearly all the variables used to build such models are characteristics of the modern physical environment. It is as if social variables play no role in human behaviour.
A third distinction looks at the aims of the models (Sebastian and Judge 1988:4). Are they correlative or explanatory? Is the ultimate goal to understand human behaviour in the past, or is it simply to predict the presence of archaeological material in the present? A final distinction is between possibilistic and probabilistic models. Nearly all archaeological predictive models have been possibilistic, that is, they indicate how suitable an area was for a specific activity rather than how probable it is that that area was in fact used for that activity.

The Dutch practice of predictive modelling has been heavily influenced by the American tradition. Predictive modelling was first introduced in the Netherlands around 1990 by Kvamme (Brandt et al. 1992), and has since been used widely for AHM purposes (Verhagen 1995, Deeben et al. 1997). Over the years, a number of papers have appeared that criticise the inductive, AHM oriented approach then common in Dutch predictive modelling (van Leusen 1995, 1996, Kamermans and Rensink 1998, Kamermans and Wansleeben 1999), while others have experimented with and applied alternative methods and techniques (Wansleeben and Verhart 1992, 1997, 1998, Kamermans 2000, Verhagen and Berger 2001, Deeben et al. 2002).

This vigorous debate has led to the establishment in 1998 of a group of Dutch predictive modelling practitioners (informally known as the Badhuis group, after one of its meeting places in Amsterdam). The members of this group joined forces to investigate the procedures and problems in predictive modelling in the Netherlands and to suggest improvements to current practice. The group consisted of researchers from the State Service for Archaeological Heritage Management (ROB), RAAP Archeologisch Adviesbureau BV (Archaeological Consultancy), and the Universities of Groningen and Leiden. As a result of its discussions, six major problem areas were identified that need to be better understood in order to guide the future development of predictive modelling in the Netherlands (see also Verhagen et al. 2000). These problems all have implications for the quality, applicability and reliability of the current predictive maps:

- Quality and quantity of archaeological input data;

- Relevance of the environmental input data;
- Need to incorporate social and cultural input data;
- Lack of temporal and/or spatial resolution;
- Use of spatial statistics; and
- Testing of predictive models.

In early 2002 various members of the Badhuis group formed a research team to start a project as part of the BBO programme called: "Strategic research into, and development of best practice for, predictive modelling on behalf of Dutch Cultural Resource Management". For this project the above-mentioned problems were translated into research themes (see below). The project consists of a thorough analysis of the currently used prediction methods and models, both in the Netherlands and internationally. The insight gained through this analysis may be expected to lead to a qualitative improvement to the present generation of archaeological predictive maps. The project fits into the third BBO research theme of fundamental and applied research to develop and test methods, techniques and procedures.

Research phases and themes

Phase 1. Procedural analysis

The predictive modelling project proceeds in three phases, the first of which was finished in December 2002. It was directed at establishing a 'baseline' by reviewing relevant international literature on the theory and methodology of predictive modelling, and by conducting a formal, or 'process', analysis of current modelling practice at the State Service for Archaeological Heritage Management (ROB) and RAAP Archeologisch Adviesbureau BV, which at the moment are the most important producers of predictive maps for AHM purposes in the Netherlands. The results are published in an internal report (Van Leusen et al. 2002), which serves two purposes. Firstly, it was used to set priorities and establish the detailed work programme for phase II of the project. Secondly it will be used to measure the progress made by the project by comparison to its final report.

Phase 2. Research into specific themes of predictive modelling

The next project phase consists of research into the six specific problem areas listed above. Details of this phase are given below in the section on future work.

Phase 3. Preparation of project report

The final project phase consists of the writing of a summary report. The aim is to produce a set of reasoned guidelines for AHM-oriented predictive modelling in the Netherlands. A major part of the report will consist of the case studies produced under each of the six research themes of phase 2. The report will also contain suggestions for further work based on the process analysis, and recommendations for best practice in the context of the quality norms for Dutch archaeology (Kwaliteitsnorm Nederlandse Archeologie) (College voor de Archeologische Kwaliteit 2001).

The baseline report

The product of the first phase, the baseline report (Van Leusen et al. 2002), contains an overview of the current practice of predictive modelling in the Netherlands, and is briefly reviewed here.

The use of predictive maps in Dutch archaeological heritage management

Archaeological involvement in the process of planning and development in the Netherlands starts with a desktop assessment of the archaeological implications of specific plans (fig. 2 and 3).

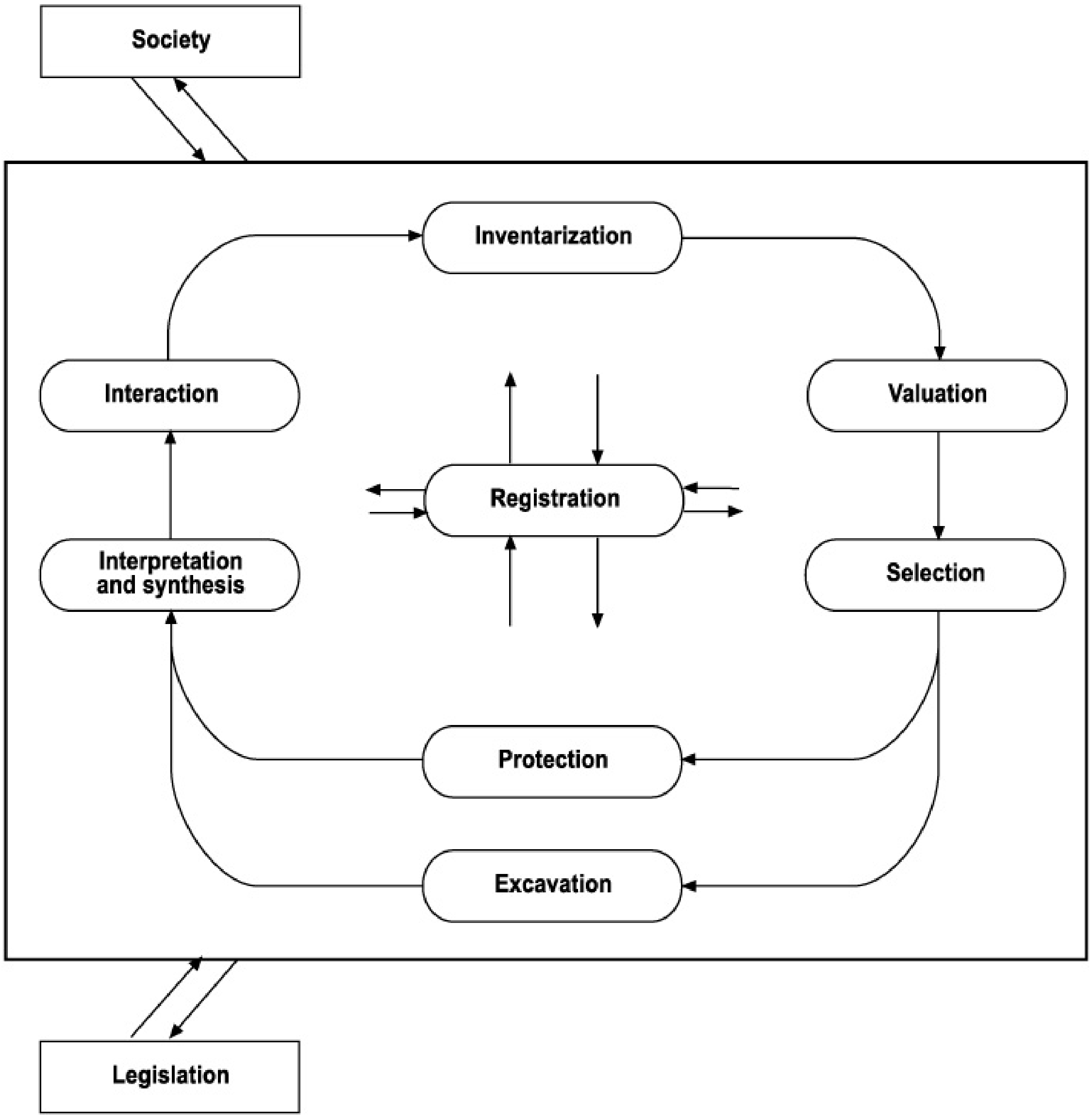

figure 2 - the Dutch AHM cycle (Deeben et al. 1999).

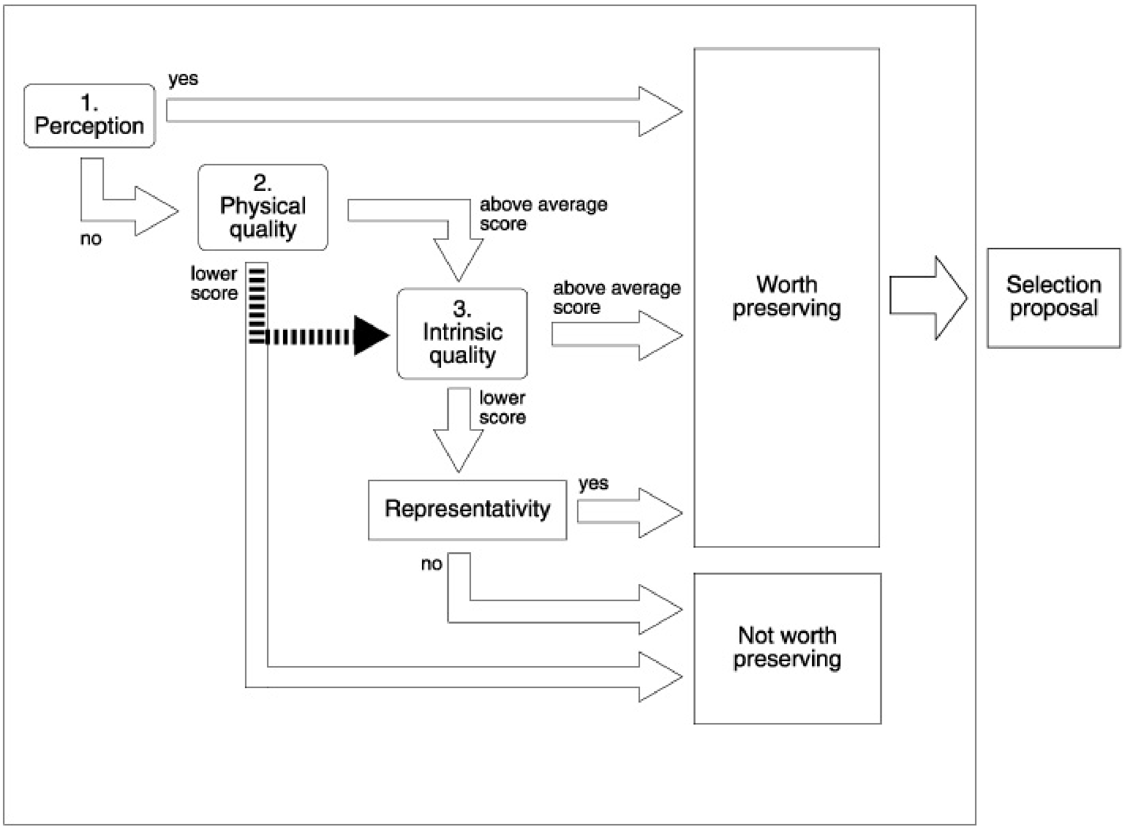

figure 3 – the stages in the process of valuation in the Dutch AHM cycle (Deeben et al. 1999).

In this context, predictive modelling is just one of several tools; the main one consists of maps presenting the known archaeological values that also have a formal status as monument, such as the Dutch Archaeological Monuments Map (AMK). This is a joint product of the State Service for the Archaeological Heritage and the provincial authorities. Because of the invisibility of most of the Dutch archaeology, these maps are at best a rather shadowy reflection of what is actually present in the soil. So any effort to produce a more complete picture of the archaeological potential of the soil is welcome. Predictive modelling is such an effort.

The following brief introduction to the role of predictive models in the Dutch planning process is based on Witbreuk and Kruijsen (2003).

Spatial planning in the Netherlands is co-ordinated by the provincial authorities. They act as an intermediary between the national government that decides on the national planning policies, and the municipalities, that carry out these policies. Dutch legislation obliges the provincial authorities to make an inventory of the existing situation and the possible and desired developments in their province. The results of this inventory are incorporated into a regional plan. This plan describes the desired future developments in the province in very general terms, but provincial or municipal authorities and individuals are not legally bound to follow these guidelines. Municipal authorities

therefore have the opportunity to make local plans that may deviate from the regional plan, but these are subject to an examination by the provincial authorities, who may pass or reject the local plan. One of the tools currently employed by some (but not all) provincial authorities to perform this check is a Map of Cultural Historical Values, which combines an archaeological predictive map with maps of (built) monuments and other elements of cultural historical interest (e.g. AMK).
In the Netherlands predictive maps are produced on two scales: national and regional. The State Service for the Archaeological Heritage (ROB) produces the Indicative Map of Archaeological Values of the Netherlands (IKAW). Commercial parties, notably RAAP Archeologisch Adviesbureau BV, produce predictive maps on a regional or local scale, sometimes in the course of planned developments, but also for use in regional and local spatial planning policy. Were the Map of Cultural Historical Values has been integrated in the regional plan, it can become a powerful instrument in forcing municipalities to take cultural historical values into account in their local plans.
However, provincial predictive maps are not in all cases sufficiently specific to allow the formulation of local plans: especially when a municipality contains a high proportion of 'high indicative value' areas, they may be advised to commission a more detailed and (for them hopefully) less restrictive local predictive map.
In such cases, these local maps must again be examined and accepted by the provincial authorities before they are allowed to replace the provincial predictive map. Some provincial authorities, such as those of Friesland and Gelderland, feel that an improvement in the quality of available predictive maps is necessary in order to incorporate the interests of archaeology in spatial planning, and are actively stimulating their municipal authorities to follow this path.

The national map

The first version of the Indicative Map of Archaeological Values of the Netherlands was completed in 1997 (Deeben et al. 1997); a second version became available in 2001 (Deeben et al. 2002) (fig. 3). The basic assumption underlying this map is that a relationship exists between the distribution of archaeological material on the one hand, and aspects of the modern landscape on the other. The purpose of the map is to specify these relationships and to visualise them in map form, using four classes or values referring solely to the relative likelihood of coming across archaeological artefacts during the implementation of plans. No information is given as to the absolute density, age or type of sites.

The Netherlands has been subdivided into three geological or geomorphological zones each treated differently:

1. The relatively high sandy areas in the east with deposits dating from the end of the Pleistocene. The majority of finds from this area date from the late Palaeolithic onwards and can be found at or near the present surface.
2. The lower lying area in the west in which sediments and peat accumulated as a result of sea level rise during the Holocene. In this zone, archaeological remains deposited on top of the Pleistocene sediments can be covered by many metres of sediment. More recent remains can also be buried deeply under sediment and peat.
3. The area presently under water. The North Sea, inland seas and estuaries are adjacent to the land formed in the Holocene. The Dutch part of the continental shelf in the North Sea also contains some of our archaeological heritage.

The data sources for constructing the predictive map are: the national digital archaeological sites and monuments record ARCHIS, the digital version of the soil map and in some cases the geological map, both scaled 1:50,000, and a map of the palaeo-geography of the central river area at a scale of 1:100,000.

The method used for the Pleistocene zone is mainly inductive and quantitative (or correlative). Because of the low visibility of archaeology in the Holocene and underwater zones, a deductive (or cognitive) approach based on palaeo-geography was applied there. The result is a map with four qualitative classes, or indicative values: a high risk for archaeology, a medium risk, a low risk, and no risk of finding *in situ* sites predating the year 1500 AD.

figure 4 - the Indicative Map of Archaeological Values of the Netherlands (IKAW, 2nd generation). In this map the land area as well as the underwater areas are rated. Dark green – high-value area under water, green – middle value area under water, light green – low-value area under water, red – high-value area on land, orange – middle-value area on land and yellow – low-value area on land. (Deeben et al. 2002).

Only parts of the map has been tested. In the Northern province of Drente an unused, independent data set from the provincial museum was used to perform a test (Deeben and Hallewas in press) (fig. 5). The first version of that part of the IKAW was based on 2231 sites; in the meantime, 3945 new sites have become available from the archives. Adding the two data sets together caused an increase in the percentage of find spots in the zone with a low indicative value from 11.6 to 17.0. The proportion in the medium value zone remained nearly the same, while it decreased slightly in the zone with a high indicative value. In total, 83% of the additional find spots were located in zones with a medium or high indicative value; when the modelling procedure was repeated for the second-version IKAW this figure rose to 88.4%. These results were said to be ‘encouraging’. However, adding the two samples together is not a correct procedure for carrying out an independent test. Furthermore, the statistical significance of the reported figures is not very high as 72 % of the province has either a medium or a high indicative value, implying a gain of about 16%.

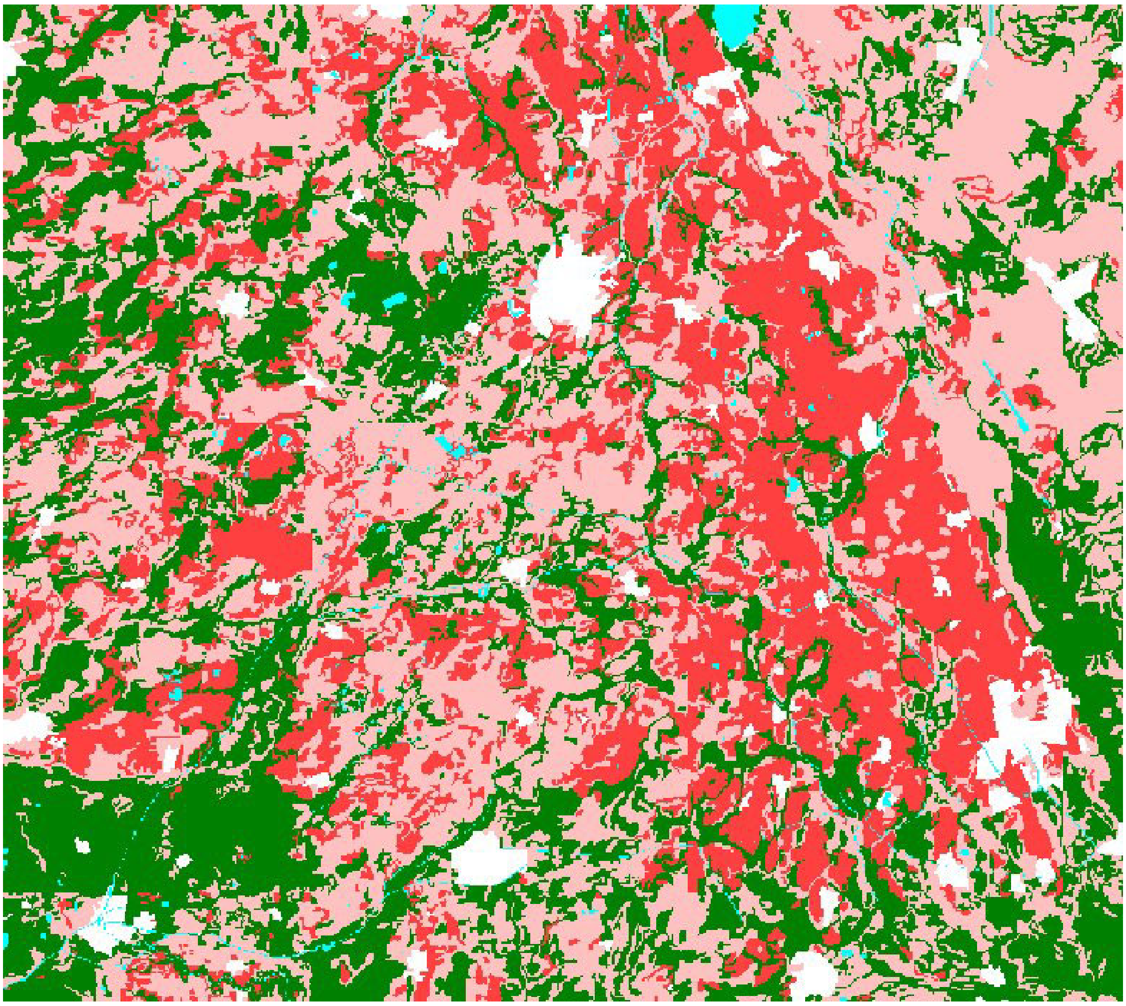

figure 5 – the IKAW for Drente, red – high-value area, pink – middle-value area and green – low-value area.

In the western Holocene part of the country, the IKAW resulting from the deductive procedure, is tested by comparing the values on the predictive map with the distribution of sites obtained from ARCHIS (Deeben et al. 2002: 26). This test is carried out per period (Neolithic, Bronze age, Iron Age, Roman Period and Early Middle Ages). The distribution of sites is in general in agreement with the values allotted, especially in the case of settlements.

In summary we can say that the national predictive map is:

- Partly correlative, and partly cognitive;
- Ecologically “deterministic”, based on the soil map or on palaeo-geographical reconstructions;
- Possibilistic;
- No independent tests for the correlative part.

The regional maps

RAAP Archeologisch Adviesbureau BV has been the initiator of predictive modelling in Dutch archaeological heritage management. Initially the American inductive method using multivariate statistics was followed (Brandt et al. 1992). Nowadays predictive maps are mainly constructed in a deductive way, based on expert judgement using characteristics of the physical landscape (fig. 6). Quantitative analysis hardly plays a role any more. No rigorous tests of the predictive maps were ever conducted or even proposed. Hence RAAP models are:

- Mainly cognitive;
- Mainly ecologically “deterministic”;
- Possibilistic;
- No tests.

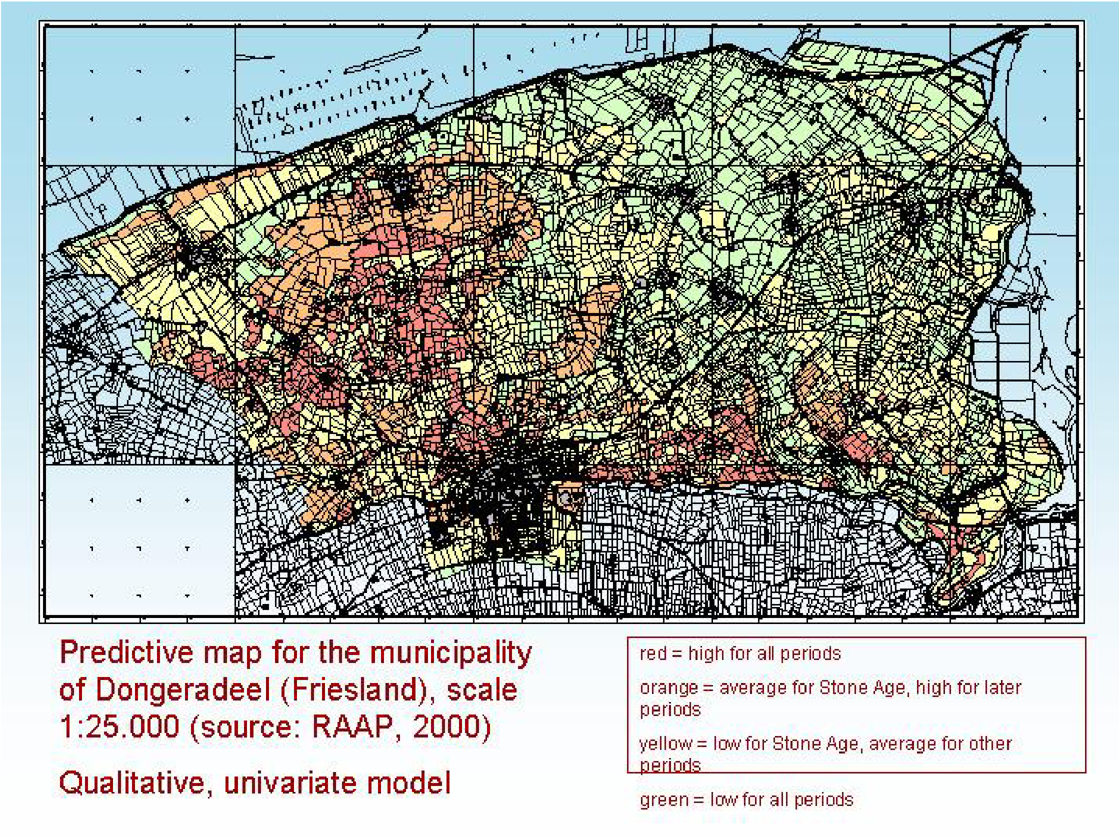

figure 6 - an example of a predictive map made by RAAP.

In the Netherlands a development can be observed from the pure 'American-style' inductive maps to, on a national level, a combination of deductive and inductive models and, on a local and regional level, deductive models. The models are mainly ecologically "deterministic" and possibilistic, and aim to establish and exploit correlations between human behaviour and the physical landscape. It is striking that, in contrast with North American practice, the Dutch models are not adequately tested before or after they are used to produce a predictive map.

The reception of predictive maps in Dutch AHM

Martijn van Leusen interviewed three provincial and two municipal archaeologists about their use of predictive maps (Van Leusen et al. 2002). The results are in some ways remarkable.
Three out of twelve provinces do not use the Indicative Map of Archaeological Values to co-ordinate their policies. Some provinces produce their own more detailed predictive maps and some only use the national map in cases where it does not conflict with their own predictive maps. One provincial respondent specifically advises lower authorities, in accordance with the instructions for use of the IKAW, to create maps on a more detailed scale.
In the spatial planning process, predictive models are used by the provincial and local services when judging urban plans and when issuing construction permits.
Provincial archaeologists in general advise as follows on the basis of indicative maps: low, no action need be taken outside areas with known finds; medium, contact the provincial archaeologist for advice regarding additional studies to be conducted; high, closer study including field research is mandated, plus avoidance of sensitive areas. Very similar advice is given by municipal archaeologists. Zones of low indicative value are sometimes investigated on an incidental basis, by coring or observation during works. In general, medium and high zones tend to carry similar advice; the dominant opinion among the five respondents is that two zones would therefore suffice as well.
It is also remarkable that the interviewed archaeologists say that public demand for predictive maps is still very low: the general public, developers, and amateur archaeologists have not yet expressed any interest in them.
The general feeling among those interviewed is that the Indicative Map of Archaeological Values has played an important role in getting archaeology on the political agenda, but that more detailed local versions are now needed to achieve full integration into the planning process.
One of the data sources, the archaeological data in the national database ARCHIS, is criticised for being too limited in quantity and quality. This, however, is partly due to the fact that lower authorities, non-governmental bodies, but also universities, do not always pass the archaeological data they generate along to ARCHIS. For this reason the creation of local predictive maps often involves visits to local archives and amateur archaeologists to update and augment the input data set. More broadly, provincial and municipal archaeologists responsible for heritage management do feel the need for more, and more detailed, background information about:

- The nature and quality of the expected remains;
- Classification of archaeological remains;
- The rarity of site types;

- Landscape genetic maps;
- The depth and thickness of the deposits containing the remains;
- Post-depositional and soil disturbing processes.

Conclusions

Implementation of the 1992 Valetta treaty requires significant adaptations to the processes and procedures of Archaeological Heritage Management. After a lengthy process of ratification and legal consultation, it is now becoming a reality in many countries of Europe including the Netherlands. To help along the process of adaptation in the Netherlands, the twin concepts of ‘cultural biography of the landscape’ and ‘action research’ have been made central to the national research programme *Protecting and Developing the Dutch Archaeological-Historical Landscape* (BBO).

Predictive modelling has been recognised as an integral and indispensable part of the BBO programme. The research project presented here will evaluate and improve existing methods and techniques for the prediction of archaeological site location and will contribute to a firmer embedding of archaeology in planning schemes. Predictive modelling is already an important tool for archaeological heritage management but is not without criticism. The project has identified six areas in which improvement may be possible: quality and quantity of archaeological input data, quality and relevance of environmental input data, incorporation of social and cultural input data, increasing the temporal and spatial resolution of models, better use of spatial statistical techniques, and establishing a proper testing cycle.

The reception of the national Indicative Map of Archaeological Values was generally favourable, although its practical use is obviously limited, mainly by its scale factor. The limited utility of the national map on a detailed scale has led to the production of many regional, large scaled predictive maps. This is in accordance with the recommendations accompanying the IKAW. In general, the policy advice attached to these maps is being followed by the authorities, and in that sense the system functions well. It looks as if a map with only two categories (No/Further archaeological assessment required) would suffice. The fact that testing these maps is not part of the standard procedure is worrying. Finally, we see it as an excellent development that there is a great demand for more information by the provincial and municipal archaeologists, who want to be able to make a well balanced decision on the basis of as much information as possible.

Future work

The project is now well in its second phase. The work plan for this phase consists of a series of overlapping sub-projects, each of which is aimed at analysing and/or developing a particular theme in predictive modelling. Themes 1, 3, 5 and 6 below are 'academic' themes and are aimed at analysing and developing modelling techniques for the generation of archaeological base data, dealing with cultural variables, spatial statistics and reasoning, and procedures for testing predictive models. Themes 2 and 4 are aimed at the development and implementation of planned improvements to the current generation of predictive models, and concern the inclusion of historic/palaeo-geographic (stratigraphic) data and increasing the spatio-temporal resolution.

Theme 1. Analysis and assessment of the archaeological input data layer.

Archaeological observations and find records as present in the national database ARCHIS have been collected from different sources over many years. They are by their nature prone to qualitative and quantitative biases and deficiencies, and therefore should not be used directly as an input data layer in a predictive model. The aim of this study is to propose ways of avoiding or correcting for these biases. Predictive models must be based on meaningful archaeological entities, and we therefore propose to study methods of aggregating archaeological observations or records into complexes. In all types of models, the influence of 'formation' processes on the archaeological input data layer requires the development and application of corrections to the simple density transfer methods currently used.

Theme 2. Extension of environmentally-based models by incorporation of historic and palaeo-geographic map data.

Historic and palaeo-geographic data are needed when models cannot be based on representations of the current landscape, as is most clearly the case in the Holocene part of the Netherlands. The aim is to follow and evaluate current practice in this respect.

Theme 3. Analysis and development of the potential of social and cultural variables.

Cultural and social variables have been largely ignored in predictive models because of the practical problems involved in mapping such variables. The aim of this study is to assess available approaches and to determine their applicability to the Dutch situation. The work will consist mainly of an inventory of current approaches (see also papers in Lock and Stančič 1995; Wescott and Brandon 2000; papers presented recent GIS conferences in Argonne (Illinois, USA, March 2001) and Wünsdorf (Land Brandenburg, Germany, October 2001)) and a proposal for future approaches. These approaches can be based upon ideas such as the use of earlier periods to model the period under study, the use of 'behavioural' models from human geography (e.g., the typical distance between parent and child settlements) or ideas from landscape architecture (see also papers in Lock 2000).

Theme 4. Increasing the spatial and chronological resolution of predictive models.

Lumping together archaeological input data from several periods and/or socio-economic systems across large areas degrades the results of current predictive models, because induction and prediction are being based on *aggregate* properties of the archaeological input data set. Problems of scale also affect both the input data and the resulting predictive models. For example, landscape variables may only be available at a scale of 1:50,000, with much detail suppressed by map generalisation or unrecorded because it would require too intensive a level of field survey. Conversely, archaeological patterning at local and sub-regional scales cannot be expressed by models based on larger units such as archaeo-regions. The aim of this study is to reconsider current approaches, including the concept of the 'archaeo-region' which lies at the basis of large parts of the IKAW.

Theme 5. Research into spatial statistics.

Three problems in statistical analysis in particular require closer study – the problem of auto-correlation in landscape variables, the provision of error and uncertainty estimates when giving predictions, and the correct application of Bayesian inference techniques (Verhagen 2001). The aim of this study is to improve standards of statistical analysis in predictive modelling. The work for this theme will consist of the preparation of case studies demonstrating these problems.

Theme 6. Model testing.

The question to find out whether a model is any good needs further study. The aim of this study is to define what constitutes a good test and to apply such tests in one or more case studies. The work for this theme will consist of the preparation of a report about best practice in model verification and extrapolation, and the execution of tests of predictive models, using current field research projects.

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