ArcGIS tools for the prediction and evaluation of terrestrial ecosystems

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Abstract

This paper presents the use of ArcGIS in ecological modeling by Kiwa Water Research and Dutch Water companies. The ability to predict the effects of water management measures on wet terrestrial ecosystems is essential in environmental impact assessment and sustainable water resources management. Knowledge about steering natural processes, plant communities, and site conditions is used in various (GIS) models that we have developed in the past (in AML and Avenue). These models have recently been redesigned and developed for ArcGIS mainly using raster-modeling techniques and VBA. This paper elaborates on both ecological and GIS backgrounds and methods.

Introduction

Kiwa Research and Consultancy is a knowledge center for drinking water issues, and the associated ecological and environmental questions, in The Netherlands. Kiwa is responsible for scheduling and conducting joint research between Dutch water companies. Over the last 30 years expertise has been acquired in various areas including: hydrology; ecology; process technology and distribution technology. GIS-technology has been used since 1989 to support our core competence: integration of the aforementioned fields of knowledge for the development of innovative tools and concepts to effectively support our customers.

Modeling terrestrial ecosystems

Purpose - Ecological impact assessment

In Europe, wet and moist terrestrial ecosystems ('wetlands') have become threatened. The deterioration of these wetlands is mainly due to the lowering of groundwater levels (desiccation); a process that persists as a result of groundwater abstraction and drainage of the surroundings. To prevent further deterioration, and to restore the natural environment and related biodiversity, nature conservation and restoration of wet and moist terrestrial ecosystems has become an important aspect of the water management policy of the European Community. Predicting the effects of water management measures on wet and moist terrestrial ecosystems is an essential element in environmental impact assessment studies. Nowadays, governmental organizations, water utility companies and water authorities throughout Europe need instruments that can predict the effects of their activities on the natural environment, and give information about measures that may compensate or mitigate the negative effects of these activities.

Scientific Knowledge – site conditions related to plants

One branch of eco-hydrological research deals with relationships of hydrology and bio-diversity**;** particularly the relation between hydrology and the occurrence of individual plant species and plant communities.
Every plant has specific environmental demands, such as temperature, light and the availability of water, oxygen and nutrients. These demands are called the 'environmental site conditions' of species and they have been studied for decades. Many problems have been encountered in these studies.
Some of these problems are caused by the natural competition between wild plant species and the fact that site factors may strongly affect each other. For example, the groundwater level not only influences water supply, but also acidity and (the) availability of oxygen and nutrients. The possibilities for laboratory based experimental research are limited by these natural processes. These and other problems are discussed in detail by Witte et al. (2004).
Despite of all of these problems**,** researchers compile databases linking measurements of site conditions (e.g. groundwater levels, nutrient availability, pH) to the occurrence of plant species or vegetation types. These databases are often used to predict what will happen to the vegetation when certain site conditions are altered by various activities. The model NICHE® (see appendix I) is based on one such principle.

Expert judgment – using indicator values of plant species

Eco-hydrologists often use indicator values to avoid the aforementioned problems. Based on knowledge gained in the field, measurements and literature, several experts have compiled lists of their indicator value estimates for plant species in relation to site factors on an ordinal scale. Such lists are useful in that they facilitate corrections which compensate for selective sampling, apparent correlations and discrepancies resulting from differences between measuring methods. From a scientific viewpoint, however, it is of course unsatisfactory that such lists are based on expert judgment alone.

The list of indicator values for plant species in Central Western Europe, compiled by Ellenberg (1992), is widely known. This list describes the ecological optimum levels for various site factors, on a 9- to 12-piece ordinal scale, for a range of species. Examples of such site factors include: 'salinity'; 'nitrogen richness'; 'acidity' and 'moisture regime'. These factors have a rather direct, causal relationship with the functioning of plant species. Ellenberg's list can, for example, be used to qualitatively establish spatial or temporal changes in site factors. Many researchers have made more detailed lists for the Netherlands (Witte 2002) and for specific types of landscapes. INDICA® (Aggenbach 2002) is a software tool based on such indicator values. If provided with an appropriate list of field observations, including the abundance of plant species in a particular type of landscape (e.g. dry dunes, dune-valleys, brook valleys, bogs), INDICA® can estimate the likelihood of particular site conditions (moisture, pH and nutrient availability).

Table 1. Moisture figures F, taken from Ellenberg (1992).

F	Description
1	Indicator of extreme dryness, restricted to soils which often dry out for some time
2	Between 1 and 3
3	dry-site indicator, more often found on dry ground than on moist places, never on damp soil
4	Between 3 and 5
5	Moist-site indicator, mainly on fresh soils of average dampness, absent form both wet and dry ground
6	Between 5 and 7
7	Dampness indicator, mainly on constantly moist or damp, but not on wet soils
8	Between 7 and 9
9	wet-site indicator, often on water-saturated, badly aerated soils
10	Indicator of sites occasionally flooded, but free from flooding for long periods
11	Plant rooting under water, but at least for a time exposed above, or plant floating on the surface
12	Submerged plant, permanently or almost constantly under water

The eco-hydrological model chain

The eco-hydrological models for bio-diversity form an information chain; where the output of one model is the input of the next (Figure 1). This chain starts with a groundwater model that is used to compute a spatial picture of the depth of the groundwater table**,** as well as the intensity of upward and downward seepage (e.g. MODFLOW; Hill 2003). Such computations may, of course, be done for various hydrological situations, i.e. the current situation, a situation with a new groundwater extraction, or a situation with a climate that has changed due to global warming. The second model is one-dimensional and it calculates water flow in the unsaturated zone, such as SWAP (Van Dam *et al.* 1997). It computes, for instance on a daily basis, the depth of the groundwater table and the soil moisture deficit, - factors that are relevant to the species composition of the vegetation and which we will therefore call ‘site variables’. Outputs from this model are used as an input to a one-dimensional soil chemical model, such as ANIMO (Kroes and Roelsma 1998), NICHE® (Koerselman et al. 1998) or SMART (Kros et al. 1995), which compute other variables that are important for the vegetation, such as soil-pH and N-mineralization. The effect of the resultant site variables on the vegetation may then be computed in a direct manner, e.g. with probability functions which predict the occurrence of plant species, or with the aid of groundwater duration lines that are associated with each specific vegetation type. However, such direct relationships are usually rather weak because of the poor availability of the field data, which describes the soil’s physical and chemical properties, upon which they are based.

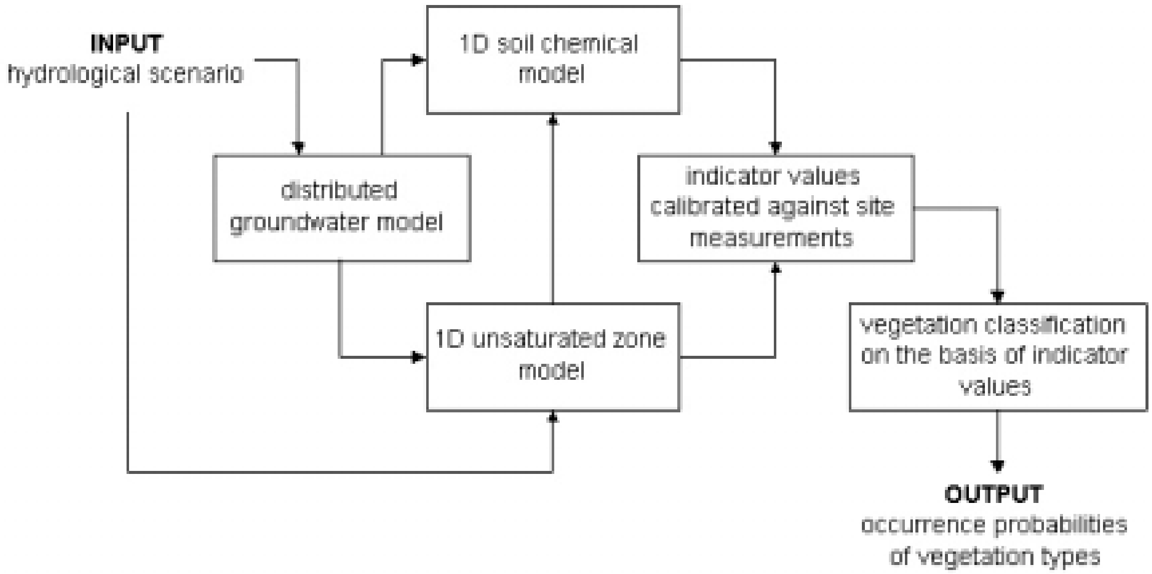

Figure 1. General process chain of our eco-hydrological model for bio-diversity.

Moreover, to avoid statistical nonsense, we feel that correlative relations between site and vegetation should be based as much as possible on ecological knowledge. In practice, this means two things. Firstly, one should use those site variables which are known to have a strong influence on the species composition of vegetation via water management. In the Netherlands, such variables are for instance: Chlorine content (as a measure for the site factor ‘salinity’); spring groundwater level and soil moisture deficit (for ‘moisture regime’); N-mineralization (‘nutrient availability’) and soil-pH (‘acidity’). Secondly, one should correlate these variables with parameters of the vegetation that are believed to have a causal relationship with these site factors. An example of one such meaningful correlation would be to relate the average indicator value for acidity with the soil pH-H_2O (as a measure of acidity’). Most eco-hydrological models use calibration curves established from well-investigated relevés (vegetation sample) to translate computed site variables into indicator values.

A new method to modeling of biodiversity

Indicator values can be successfully applied to the eco-hydrological modeling of bio-diversity (Witte 2004). In one of KIWA’s new models, we add a final link to the model chain (Figure 1): we use indicator values**,** established in the previous step, to compute the occurrence probabilities of vegetation types. To do so, we describe each vegetation type as a function of indicator values with the aid of Kernel fitting (i.e. using probability densities that are constructed by weighted sum of Gaussians) (Wand and Jones 1995). Data for the statistical functions come from a database with relevés[1].

[1] A vegetation relevé is the result of a sampling carried out in a plant cover. At a chosen location an area of a prescribed size is marked out (in grassland often approximately 10 m^2). Next, it is noted, amongst other relevant information, which species occur within the area and to what extent each species covers it.

The functions are made in the following three steps:

- Each relevé in the database is assigned to a vegetation type on the basis of its species composition;
- Species compositions are used to calculate average indicator values for each relevé;
- Each relevé is a point in an n-dimensional space that is formed by n indicator value axes. Species of the same vegetation type form a cluster in this space. This cluster is described by Kernel functions. It may be interpreted as the ecological NICHE® of the vegetation type.

An example of the three-dimensional space of indicator values for moisture regime, nutrient richness and acidity is shown in figure 2. A relevé is depicted as a ball and a vegetation type is indicated by a color. The position of vegetation types in this space is described by Kernel functions, using the statistical program PARDENS® (Torfs et al. 2002; Wójcik and Torfs 2003).

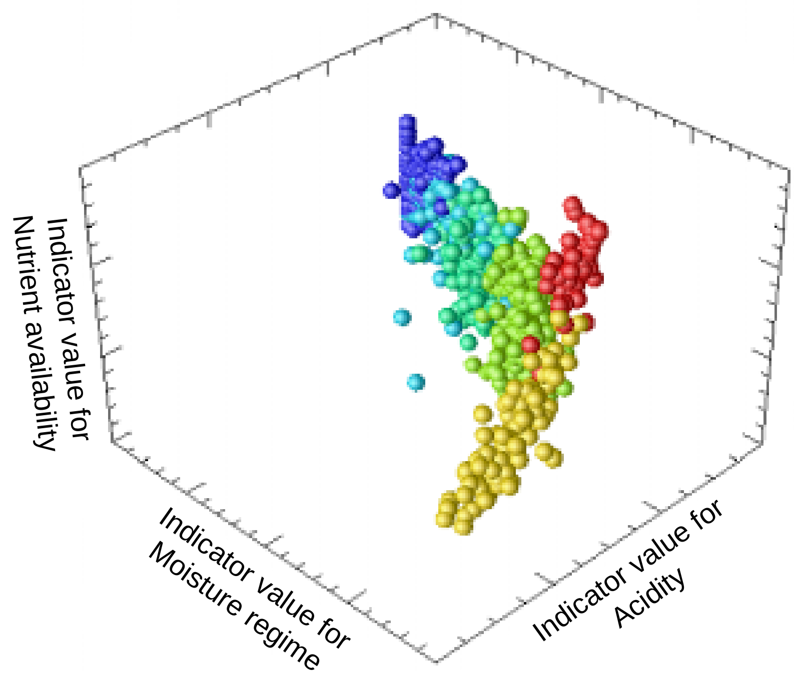

Figure 2. Classified vegetation samples (balls) plotted in relation to their average indicator values. Colors correspond to different vegetation types. Each vegetation type in this 3D-space is described by Kernel functions.

It should be noted that in The Netherlands more than 400,000 relevés are available (www.synbiosys.alterra.nl) for use in building Kernel functions of vegetation types. The geographical position of most of these relevés is well known. This enables us to derive regional functions for specific landscapes, such as dunes or brook valleys. Moreover, our method does not depend on a particular division of vegetation into types: any division can be used, provided, of course, that the division makes ecological sense. Each Kernel function attributes relevés to vegetation types on the basis of habitat factors and not, as regular vegetation classification systems do, on the basis of their species composition. This feature makes our method especially suitable for application in environmental impact assessment studies.

Figure 3 shows an example of the predicted occurrence probability of a vegetation type in the province of Gelderland, The Netherlands. Distribution maps of different vegetation types can be combined into one map, showing vegetation types with the highest occurrence probabilities. This is demonstrated in Figure 4 for a small region in the province of Gelderland. It shows the potential distribution of vegetation types of woods that are most likely to occur before (Figure 4A1) and after (Figure 4B1) a groundwater level fall of 25 cm. The corresponding occurrence probability of these predictions is given in Figure 4A2 and Figure 4B2, respectively.

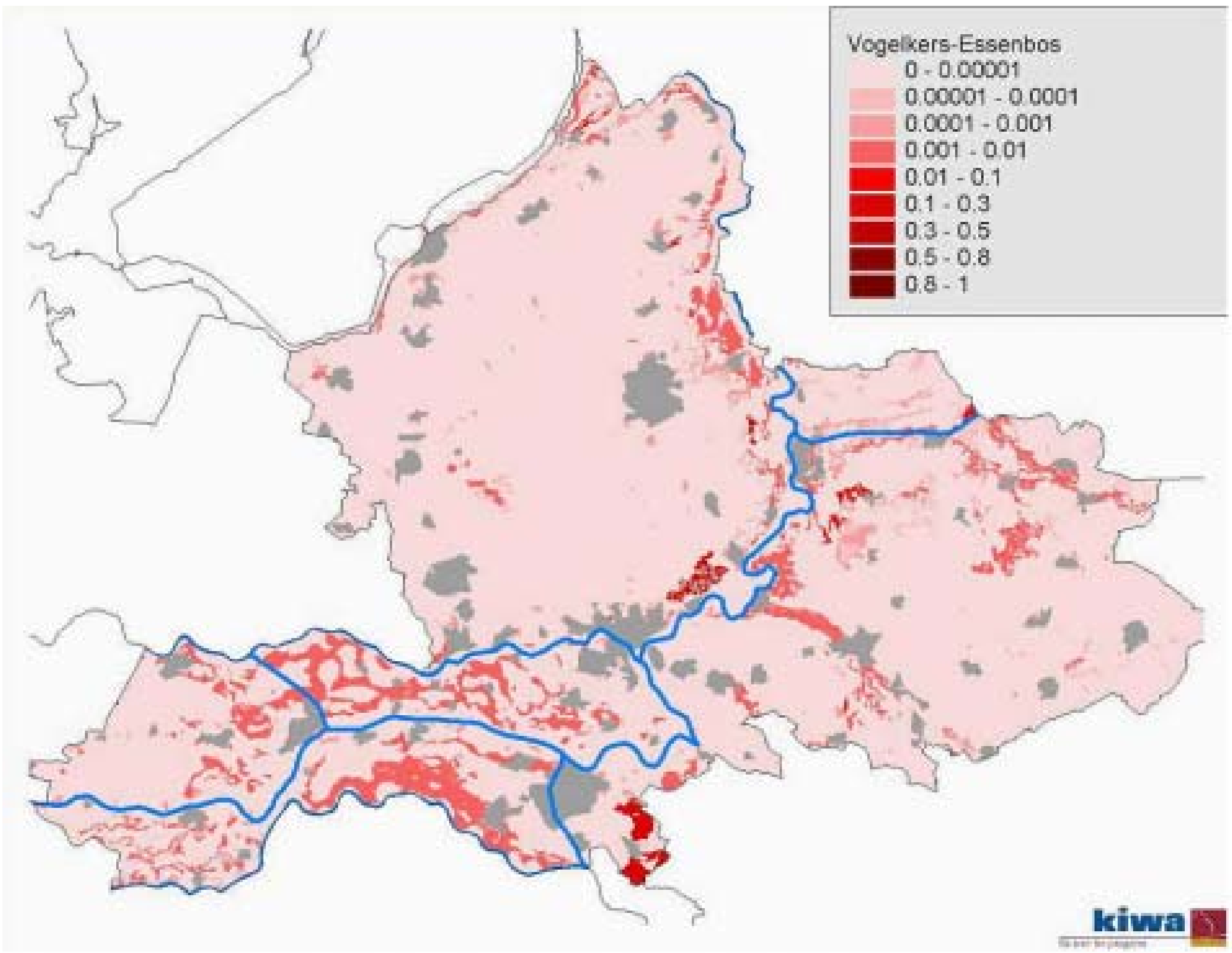

Figure 3. Occurrence probability in the Province of Gelderland (The Netherlands) of the *Pruno Fraxinetum* association (defined by Stortelder *et al.* 1999). Since land-use and atmospheric deposition of nitrogen has not been taken into account, this map shows the potential distribution.

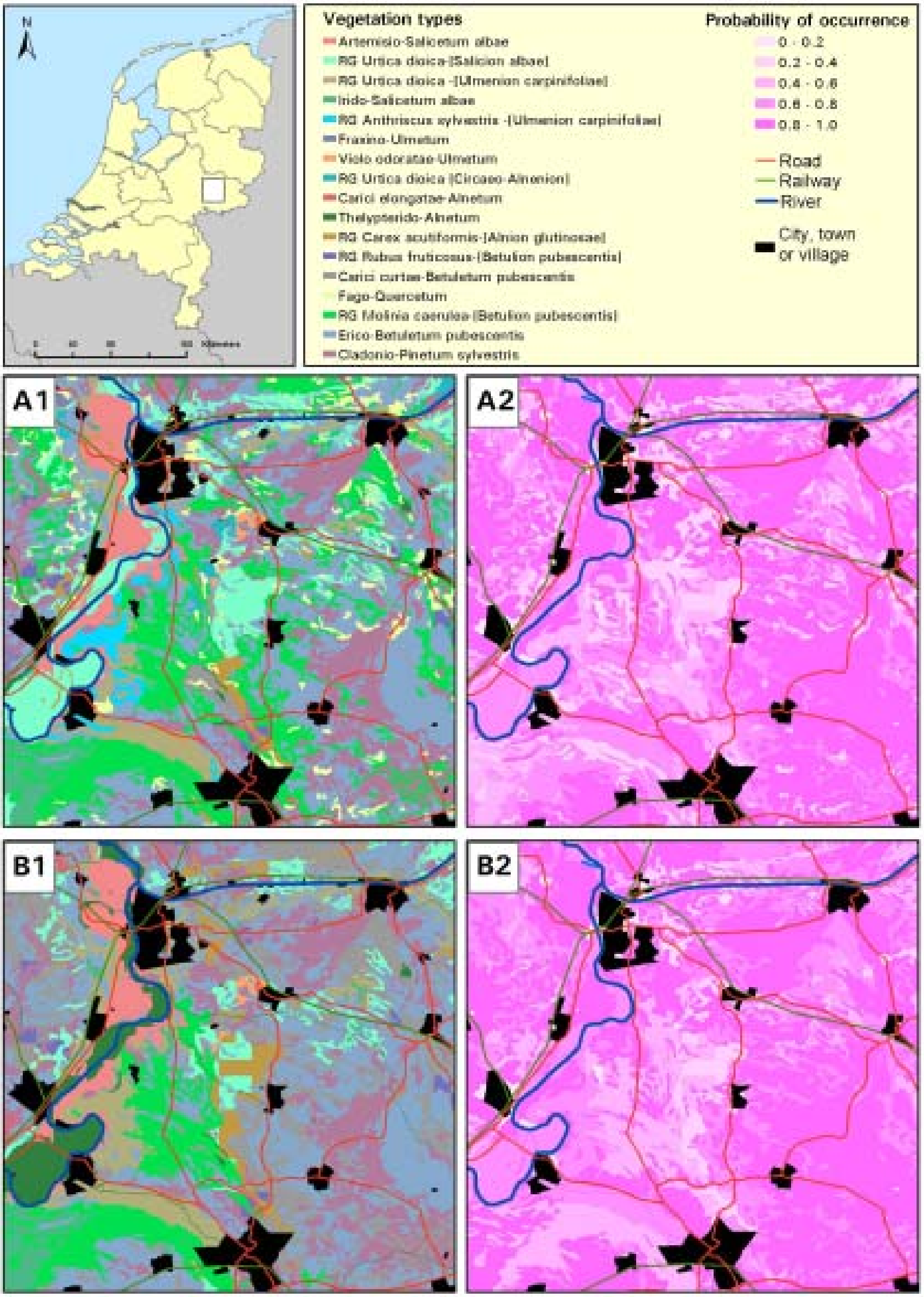

Figure 4. Vegetation maps, showing the potential distribution of vegetation types that are most likely to occur before (A1) and after (B1) a 25 cm fall of the groundwater table. Figures on the right (A2 and B2) show the occurrence probability of the predictions. Vegetation types are associations of woods according to Stortelder *et al.* (1999).

The model has been tested using a database of 35,000 relevés that had already been classified by experts. One-half of the database was used to calibrate Kernel functions, the other half to validate them. It appeared that 86% of the relevés are classified correctly on the basis of three indicators (moisture, nutrient availability and acidity). This implies that the indicator values we employed must have been quite good, and that the division of the vegetation into associations makes ecological sense.

Development of ArcGIS tools

Development strategy – a modular approach

In the past we have developed a number of tools using both ArcInfo (using AML) and ArcView 3.* (using Avenue). With the introduction of ArcGIS in 2001 we decided to stick to our existing tools in ArcInfo and ArcView 3.* for as long as is feasible. However, we wanted to build new tools directly into ArcGIS. The complexity of the ArcObjects model became a major hurdle for taking the right steps within a short period. In our line of research work the development of software**,** as such**,** is rarely a separate goal. New software has to prove its benefits immediately. This means also that the capacity for software development is rather limited.

In 2002 we started a number of new projects in the field of ecological impact assessment. We wanted to incorporate new knowledge/decision rules in our existing model (NICHE®). Besides the prediction of vegetation**,** there was also a requirement for the prediction of bird habitats using the method developed by SOVON Dutch Centre for Field Ornithology (Sierdsema 1998), see appendix II for a comprehensive explanation of this method. Most of our existing GIS tools proved to be too complex and ill-documented to be understood by our end-users, who were not able to read and interpret the AML scripts. Preparing data for NICHE®, and doing test-runs and calibration could take as long as 3 weeks for both the ecologist and the GIS specialist; we found this unacceptable. To be more flexible in the future we have decided to redevelop and extend NICHE®, based on ArcObjects.

Like most organizations working with ESRI GIS products we foresee the gradual shift from ArcView 3.* towards the use of ArcMap and ArcCatalog. Thus the decision to use ArcMap as our application framework was easily made.

Our strategy in developing tools has always been to extend, and not to limit, the functionality of the ‘out of the box’ software. Protecting the user from GIS functionality in order to prevent problems in your own software is bad practice; especially if end-users are highly qualified and are always requiring more functionality. Of course the computer skills of the end-user play a mayor role. For this reason some of our ecologists had to follow introductory courses in ArcGIS.

Learning from the past**,** we wanted to guarantee the involvement of the end-user, by ensuring that they directly benefited from the tools, even as they were still “under construction”. The ecologists using the tools must be able to modify certain decision rules based on new insights or site specific conditions.

Our challenge was limit the number of simple steps we could take in facilitating the implementation of the NICHE® modules in ArcGIS. This involved a phase of completely rethinking the methods and technology used.

We realized that we had to look further than the current scope of NICHE®, and our other concepts and models. We wanted to follow a modular approach to the design and development of our tools. First we looked at the current state of the GIS related ecological models we use. In figure 5 an attempt has been made to visually depict the major characteristics and functionality of these models.

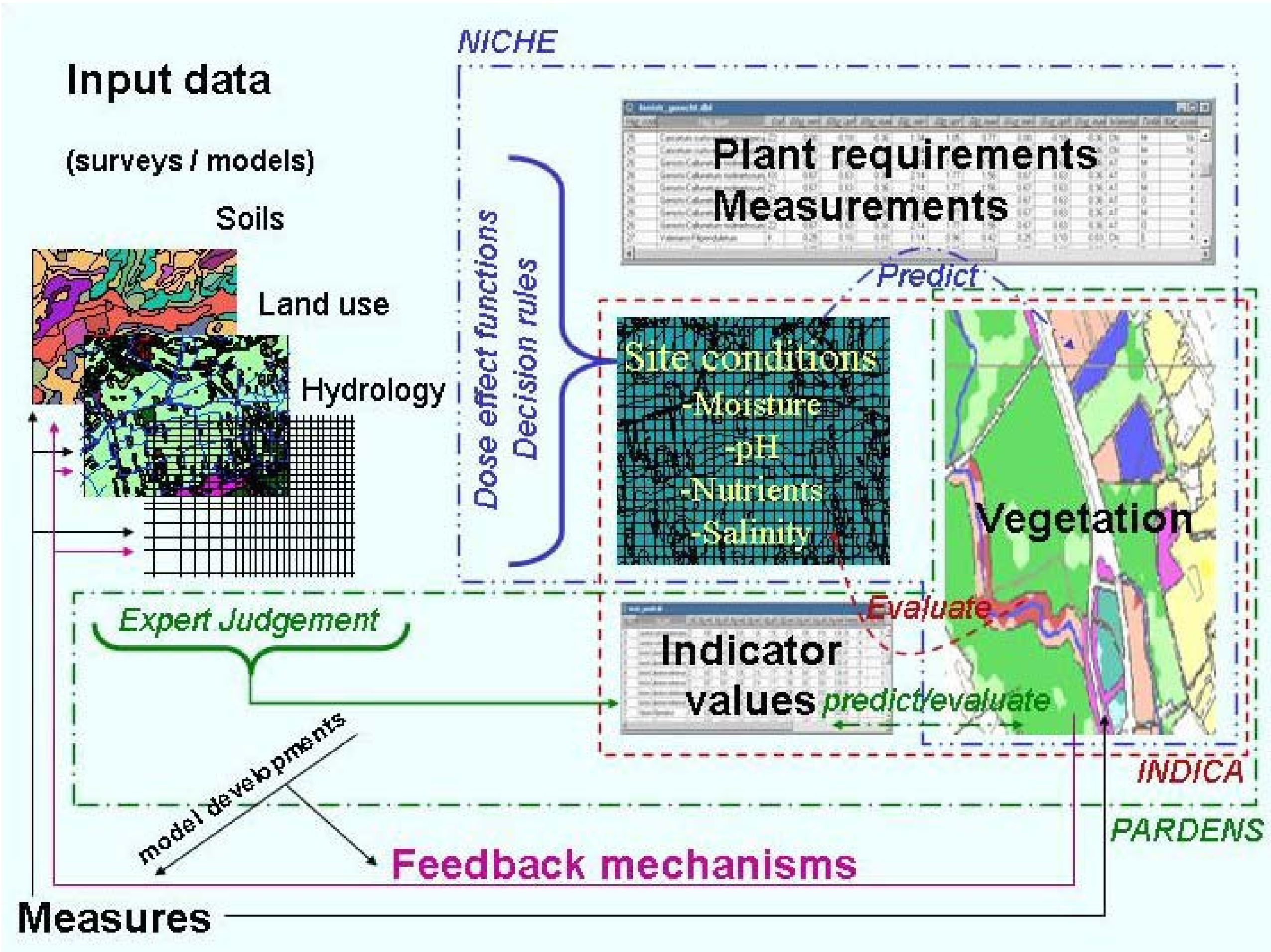

Figure 5 Major functionality of three models NICHE®, INDICA® and PARDENS®.

NICHE® uses dose-effect functions and decision rules to derive site conditions from input data. NICHE® then predicts plant communities based on a database with selection criteria based on available field measurements. INDICA® evaluates vegetation field surveys to derive site conditions (quantitatively) on the basis of indicator values for plant species in specific landscape types. Expert judgment is used with the PARDENS® model to derive indicator values from environmental parameters. PARDENS® can be used to both predict vegetation, and evaluate the environmental conditions in a qualitative manner. Future model developments will incorporate the effects of measures and feedback mechanisms.

It is useful to consider how far to pursue the (GIS) integration of the existing models. Heinzer et al. (1999) distinguish three levels of integration, ranging from model centric to GIS centric approaches. Partial integration uses GIS only for certain aspects of model parameter input. Encapsulated Integration is when GIS 'wraps' around a model and a GIS user and data-interface for the model exists. Embedded integration is when the solution algorithms are programmed within the GIS language.

We have used the embedded form in the case of our hydro-ecological model NICHE® (Raterman 2002). Actually this embedded integration was a logical step because no technical model and software implementation existed at the time we started developing it in 1994. Other models which have been developed more recently are based on Excel, Access, Matlab (see also Raterman 2001) or are developed as a stand-alone tool with C++ . These models are partially integrated with GIS, and exchange data in the form of ASCII files. In most cases this works well, and there is no real need to automate the processing involved - as long as the processes occur less frequently. On the other hand, automating these processes may have positive effects on the quality and replicability of the results. Experts are often reluctant to allow GIS specialists to 'take over' their tools. The goal of the GIS specialist should not be to put everything in the GIS, but rather to make work easier and more fun for all experts involved in the project.

So how is modularity achieved? Reynolds et al. (1997) give some important definitions and guidelines.

There are five criteria for a good modular design:

1) Decomposability. A good modular design should decompose the problem into smaller, independent sub problems. With plant and ecosystem models this is not easy because the processes show more interaction and happen simultaneously.

2) Composability. This means that the modules created may be reused and recombined to create new models. This should be easy.

3) Understandability. Modules should be separately comprehensible without the need to refer to other modules. Understandability and decomposability are closely linked. If the correct functioning of a set of modules depends on their activation in a certain order, they will not be separately understandable.

4) Continuity. A small change in the problem specification should not require changes in the basic structure of the model. It should be necessary to modify only a few (preferably one) modules.

5) Protection. This means that the effect of run-time errors should not propagate to other modules. Each module should validate its own input data to avoid these problems.

The following are some useful guidelines for modular design. Modules have to be implemented with a language that can be understood by the end-users. Modules should only have a few small interfaces to other modules. The interface from one to the other must be explicit, not hiding any part of the communication. This implies that the use of global variables must be avoided. All information about a module has to be private.

Taking into account al the requirements mentioned above we may characterize our development strategy as follows; design and develop a number of flexible and interoperable model tools based on separate user-friendly modules; involve the end-user as much as possible in the development process to guarantee the efficient use of the tools.

Proposed modules

Looking at our existing model chain, and taking into account future integration needs, we have concluded that we need a wide range of modules. Modules for data preprocessing and post processing are necessary in order to encapsulate the models INDICA® and PARDENS®. A number of analytical modules have to be developed to implement the NICHE® model in ArcGIS.

We can distinguish the following main modules:

1) Preprocessing

a) Conversion of various output files from groundwater models

b) Input generation for PARDENS® Kernel fitting

2) Analysis and model calculations

a) Site characterization: nutrient availability from various input data

b) Site characterization: pH (base saturation) from various input data

c) Site characterization: indicator values for moisture, Nutrient availability and pH

d) Suitability analysis for plant communities

e) Calculation of buffer zones for bird habitats

f) Selection of open areas for bird habitats

g) Suitability analysis for bird habitats

3) Post processing

a) Assign proper legends to output layers

b) Statistical module to determine bio-diversity / nature values

c) Linking results of PARDENS® to a source map with indicator values

d) Linking results of INDICA® to vegetation map

e) Grouping of predicted plant communities for input in 2g

f) Comparing results of 2 models (e.g. INDICA® and NICHE®) or 2 model scenarios from a single model

We have chosen to start developing separate macros with VBA. Each macro contains one module only. These macros could be combined and linked to a simple user form with only a few buttons, at a later stage. Following this approach, a certain combination of modules presented on one form (user interface) results in a complete evaluation or prediction tool, e.g. NICHE®, INDICA® or PARDENS®.

Obviously we have prioritized the development of the modules that contribute to the core of the model NICHE® (i.e. 2a-d and 3a). Module 2g is at the core of the prediction of bird habitats, and was also assigned a high priority. These choices leave most of the necessary pre- and post processing to the end-user, - for the time being of course. The prioritized modules have been developed simultaneously to a number of projects (EIA studies) in 2003 and 2004. In the following paragraphs different aspects of the results will be illustrated.

Using ArcMap

How can we organize our work within an ArcMap session in such a way that it facilitates the operation of the modules? The modules should fit in to the basic structure of ArcMap as much as possible because the user may need all GIS functionality and extensions. The most logical way seemed to use the concept of **data frames** to organize input and output to the modules. The appropriate data frames for input and output have to exist in the current ArcMap document (mxd) before modules can be executed. Figure 6 illustrates how the model NICHE® is set up within an ArcMap document.

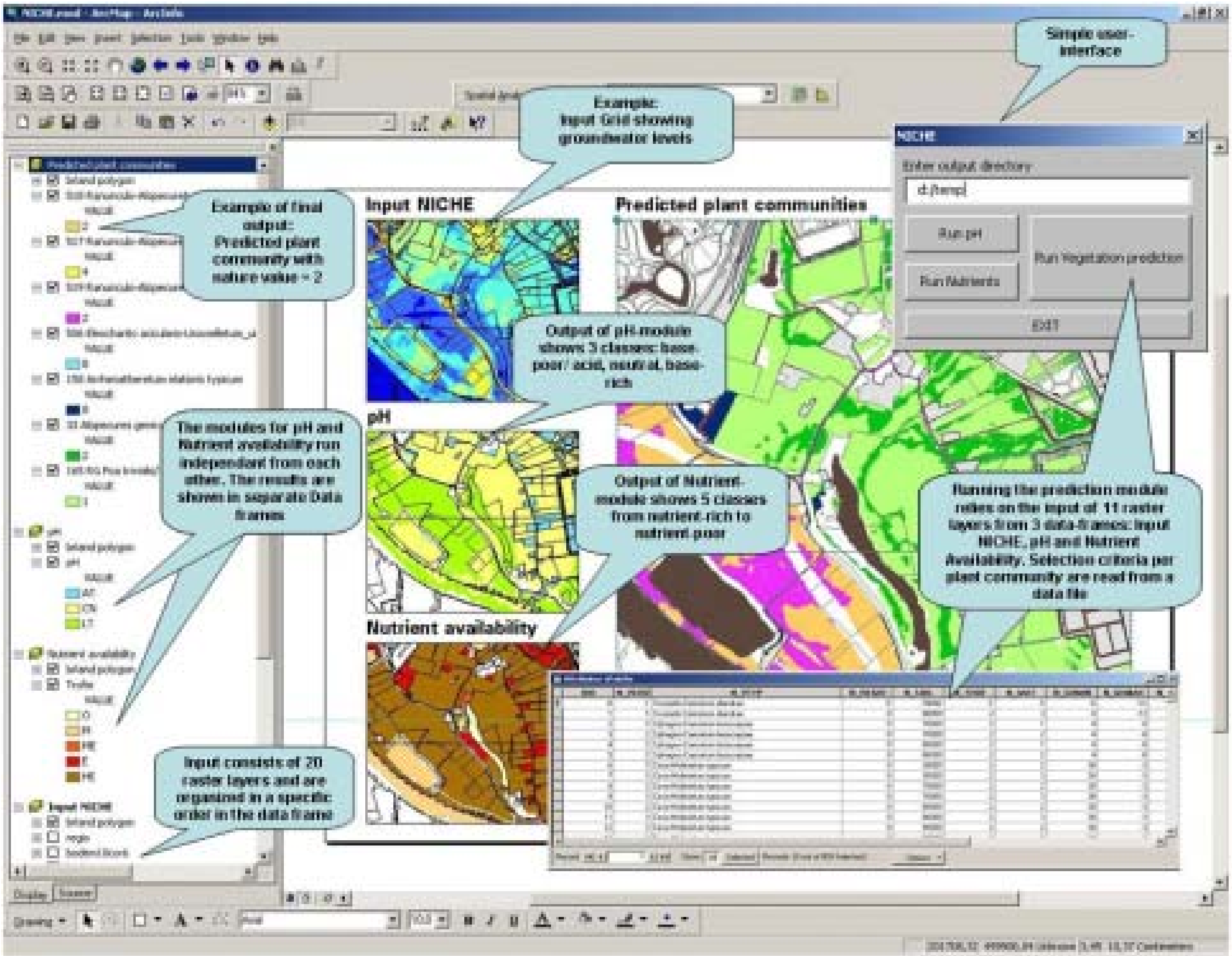

Figure 6 NICHE® for ArcMap consists of three modules combined on a simple user form. The data shown are from the EIA study around 'Engelse Werk' a groundwater extraction exploited by the Dutch water company 'Vitens'.

The ArcMap document will contain the input and output of one scenario. A new scenario can be generated on the basis of a previous ArcMap document. We have chosen to store the VBA macro's in the mxd. Of course this may have some disadvantages; if a decision-rule in a module has to be adapted all mxd's need to be updated. However, the general approach in our studies is such that adaptations are made in a calibration phase, before scenario calculations. Thus the disadvantage as mentioned will hardly occur.

Structure within a single module

The general structure of a single module is simple:

1) Read input data (raster layers, tables) from input data frame
2) Data analysis (combine, select, reclassify, calculate, aggregate etc.)
3) Write output to permanent raster on disk and show in dedicated data frame

This simple structure has been used in case of the modules for site characterization of pH and nutrient availability (2a and 2b). In case of the suitability/prediction modules for plant communities (2d) and bird habitats (2g), however, this structure requires ‘looping’ through a set of selection criteria in a table:

1) Read input data (raster layers) from multiple data frames
2) Start loop at first row of the table
    a. Read input from table (selection criteria)
    b. Data analysis (combine, select)
    c. Write and show output
3) End loop at end of table

The modules which have not been developed yet may require a different structure. To improve the quality and reliability of the modules also data verification steps and error handling need to be built in, this will be dealt with in the near future.

Using the right ArcObjects

The possibilities for implementing modules, i.e. which ArcObjects to use, seem almost endless. Finding a suitable combination of objects to tackle the problem is quite a challenge. In this section we have made an attempt to describe how and why we have used the selected objects. More detailed information about the ArcObjects may be found online, or in the ArcObjects Developer help system that comes with the ArcGIS software.

We found the easiest way to perform the calculations within a module was to use the **RasterModel** object because it is easy to understand and maintain. This object works like the Raster Calculator. The ***script*** property of the **RasterModel** object holds a string with the expression. A major benefit is that every user is able to understand the expressions within this “calculator”. A number of ‘supporting’ objects have to be created before the **RasterModel** may be ***executed***. The order in which objects were set also seemed to be important (**IRasterAnalysisEnvironment , Iworkspace and IWorkspaceFactory**). With the ***bindraster*** method, the input rasters are connected to the ***script***, but this can only be done after defining the script. The **boundraster** method allows access to the results after execution of the script. Within the script of the RasterModel reclassify commands may be applied - using so called ‘remap’ tables stored on disk. This provides a very fast method for deriving results from relationship ‘curves’. This method is used to relate spring ground water levels, for each soil type, to Nitrogen availability. In figure 7 some of the methods discussed above are illustrated.

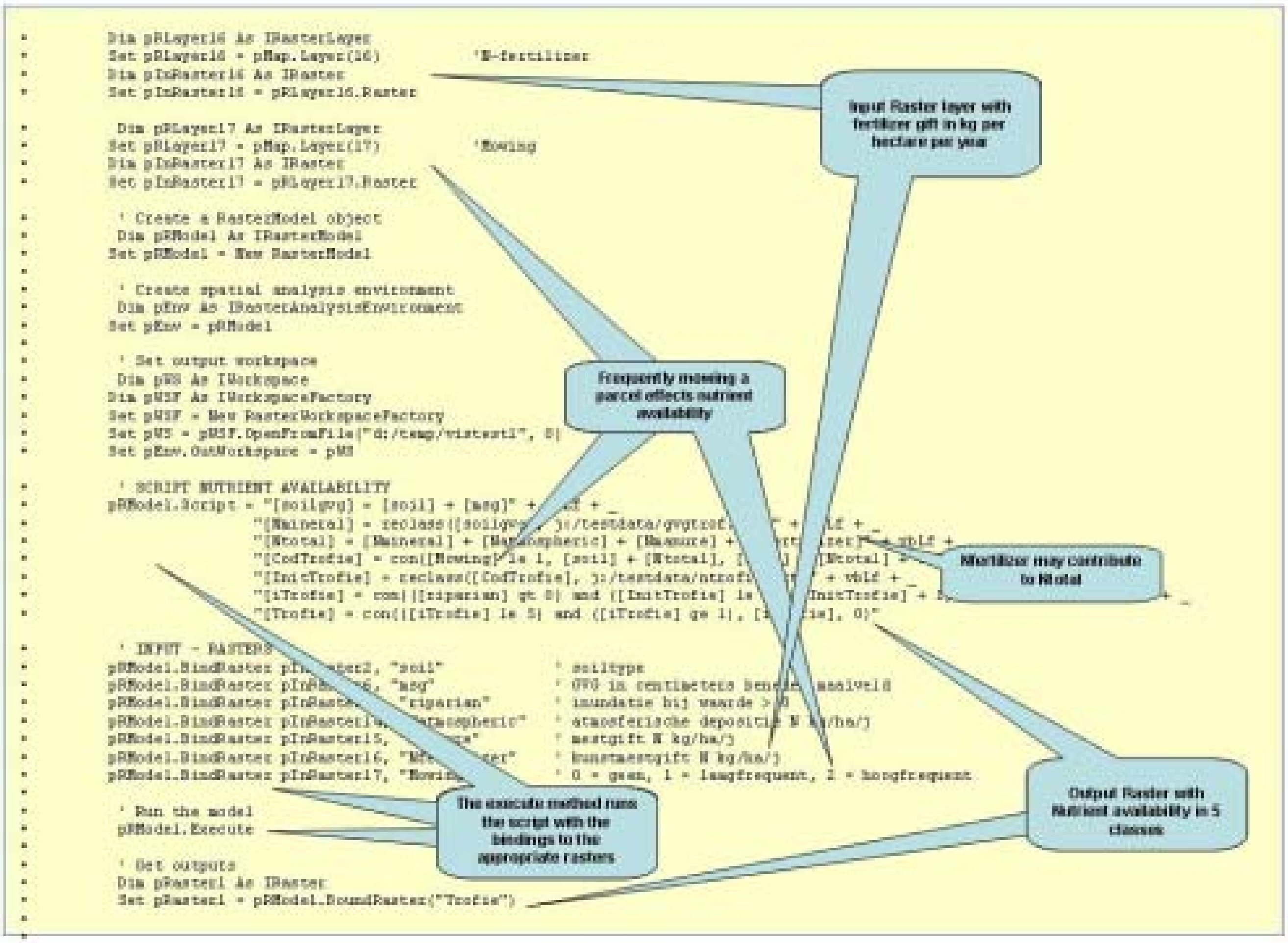

Figure 7. The VBA code of the core-part of module 2a ‘Nutrient availability’.

Some of the ArcObjects are obviously indispensable starting points for any task in ArcMap; **MxDocument** and **Map.** Another useful object is **Maps**. The Imaps interface can be used to change the active data-frame from where to get or put raster or feature layers. The Imap interface gives access to the separate raster, or feature, layers in the data frame. We often use these techniques in our modules. With **RasterLayer** and **Raster** the input data for the modules are accessed. To physically write the output raster of the modules a number of other objects had to be used: **RasterBandCollection, RasterDataset and TemporaryDataset**.

The prediction module of NICHE® uses a **StandaloneTable** from a **StandaloneTableCollection**. This facilitates the input of selection criteria from a dbf file which has been added to the data frame. Each row in the dbf file contains a set of criteria which have to be compared to the input rasters. Each plant community has ranges for: minimum and maximum ground water level; soil type; pH; Nutrient availability; flooding duration; flooding depth and other (optional) parameters. Within a ‘Do Until’ loop the values from the rows and fields are read and the **RasterModel.execute** request is called. The same approach has been used for the prediction of bird habitats. In this case the table contains values for minimum distances to disturbing elements (buildings, roads), and minimum values for territory (continuous areas).

Once a module has been finished it may be easily adapted to develop another module, assuming that it is bbased on the same principles. The NICHE® module for prediction of plant communities was developed in several weeks: the module for bird prediction in several days.

Conclusions

Modeling terrestrial ecosystems

Governmental organizations, water utility companies and water authorities throughout Europe need instruments that can predict the effects of their activities on the natural environment, and give information about measures that may compensate or mitigate the negative effects of these activities.

Every plant has specific environmental demands ('site conditions'), such as temperature, light and the availability of water, oxygen and nutrients. Despite of all kind of research problems**,** ecologists compile databases linking measurements of site conditions to the occurrence of plant species or vegetation types for use in ecological modeling.

To overcome research problems several experts have compiled lists of indicator values estimates for plant species in relation to site factors on an ordinal scale.

Indicator values can be successfully applied to the eco-hydrological modelling of bio-diversity. In one of KIWA's new models indicator values are used to compute the occurrence probabilities of vegetation types.

Development of GIS tools

To support the ecologists in combining different model results in a GIS a number of flexible and interoperable model tools are required.

A modular design has been followed to ensure continuity and the ability to compose ecological models on the basis of a combination of separate modules.

The end-user has to be involved as much as possible in the design and development of the modules to guarantee understandability and efficient use of the tools.

ArcObjects, ArcMap and VBA may be used efficiently to achieve a good modular design and implementation of the required modules and user interfaces.

Appendix I

NICHE®

General concept

Knowledge about steering natural processes is used in the expert system NICHE® (Nature Impact Assessment of Changes in Hydro-Ecological Systems). An example of such an expert system is the model NICHE® (Nature Impact assessment of Changes in Hydro-Ecological systems). NICHE® uses easily obtainable GIS-data to predict effects on plant communities caused by changes in hydrology, land use or management.

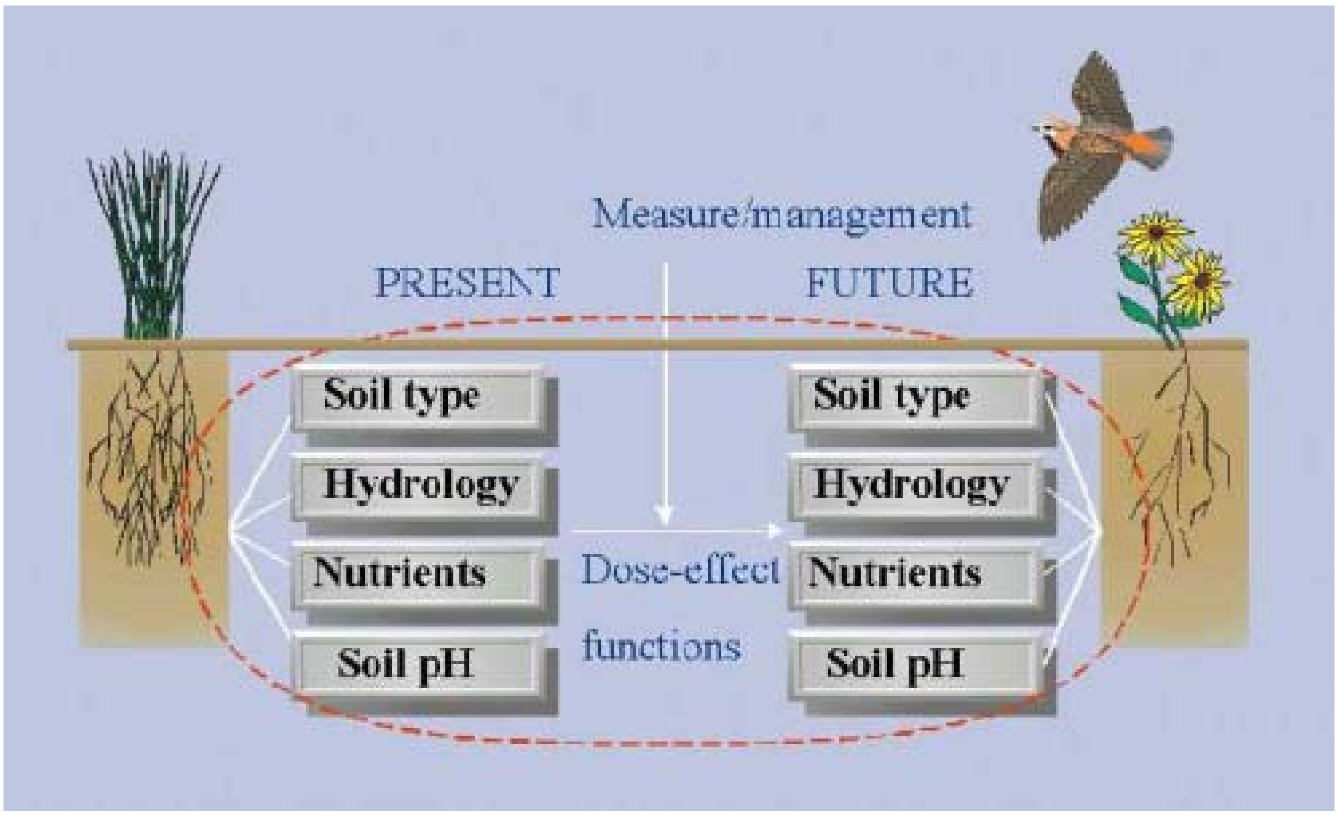

Figure 1: Ecological concept of NICHE®®

Figure 1 illustrates the ecological concept. NICHE® determines site conditions (nutrients availability, pH, ground water level) using dose-effect functions. These functions are based on field observations and expert judgment. Predicted site conditions are compared with a database that contains site requirements of plant communities. If predicted site conditions fall outside the range of site requirements for the current vegetation, it is expected that the vegetation will be replaced by vegetation that is adapted to the predicted site conditions.

To enable the comparison of different measures or scenarios, effects are also expressed in 'nature value scores'. Nature value scores are a function of the nature value of the plant community involved and the area that is affected.

Examples of questions that can be answered using the output of NICHE® are:

1. Will ground water extraction adversely affect the species composition of plant communities in wet ecosystems? Do alternative scenarios have less adverse effects?
2. Which restoration measures are most effective in restoring certain 'desired' plant communities?
3. Where do we find promising locations for restoration projects?

Optional input to NICHE® includes; riparian zones; Nitrogen deposition values (atmospheric, manure and fertilizer) linked to specific land-use categories; ground water flux-type, base-rich (deep ground water) or base-poor (shallow ground water).

Figure 2 shows a way to present the output. Here nature-goals in terms of different groups of plant communities are compared with NICHE® predictions.

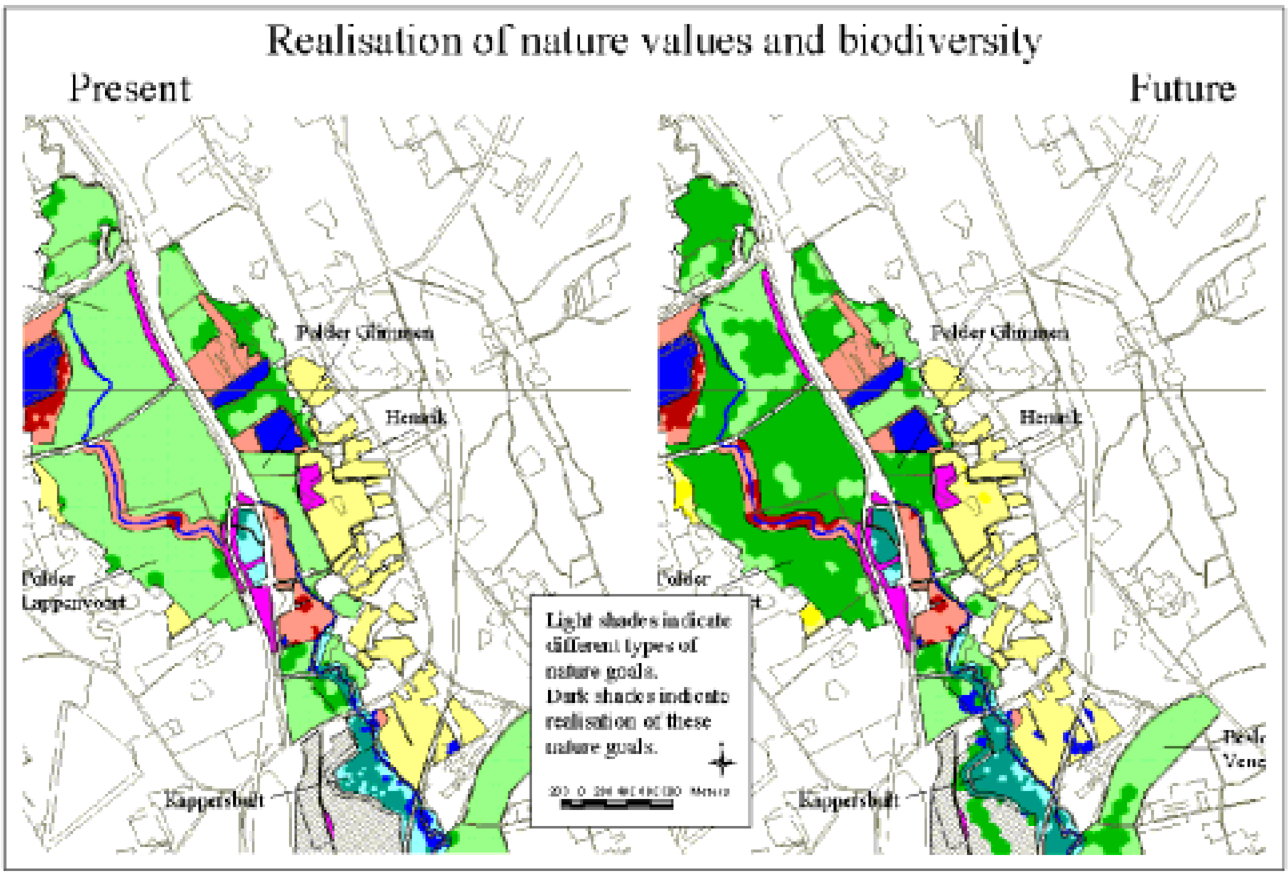

Figure2: Example of how NICHE® output is used in an EIA report.

Appendix II

NICHE® Prediction of birds

The avifauna is predicted by a) assigning ecological species groups to vegetation types and b) a number of additional habitat demands.

a) Assignment of species groups to vegetation types.
Based on best professional judgment a list is made of vegetation types that can be inhabited by a certain species group. For this purpose a difference is made between vegetations that can hold complete species groups in average densities and vegetations that can hold only a limited number of species and lower densities of the more critical species. The latter are so-called rump-groups, equivalent to rump-vegetation types.

b) Additional parameters
Next to vegetation type there are many more parameters that can influence the presence of breeding birds. Some examples are:
- vegetation structure*
- total amount of suitable vegetation types*
- presence of foraging areas in the case of commuting birds like colony breeders, marsh harriers or meadow birds
- amount of suitable habitat in the vicinity
The presence and densities are higher when there is more suitable habitat in the vicinity
- size of open areas*
In meadow birds the size of open areas is important. Despite the presence of suitable vegetation types small grassland areas within forest of built-up areas will not be inhabited by meadow birds.
- Disturbing factors like the presence of roads*, trees*, buildings* and recreational activities
the presence of disturbing factors can make a suitable vegetation partly or entirely unsuitable as breeding habitat. Within 200 meters of a highway for example only rump groups of meadow birds are to be expected.
Factors marked with (*) are currently incorporated in the bird prediction module of NICHE®.

The expected number of breeding pairs of each species is calculated by dividing the total amount of suitable habitat by the average territory size. Eventually a map is produced with the expected number of breeding pairs per ecological group. By giving each species a different weight the model can generate nature values for a quick comparison of scenarios.

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