HABITAT, A SPATIAL ANALYSIS TOOL FOR ENVIRONMENTAL IMPACT AND DAMAGE ASSESSMENT

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ABSTRACT
Water resources management involves impact assessment of measures in order to determine whether objectives will be achieved and which unwanted side effects may occur. Objectives are often described in terms of effects on safety, nature and agriculture. In addition to hydrological, hydraulic and water quality models to examine the environmental state, models are needed to assess these effects on water related functions. Deltares | Delft Hydraulics developed the HABITAT spatial analysis tool for this purpose. HABITAT allows for an assessment of effects of changes in water management by applying cause-effect relations on grid-maps. These cause-effect relations may, for example, describe the ecological response of vegetation on different flood regimes, the effect of water management on soil subsidence or the effects on potential flood damage. Results can be visualised in maps, figures or tables. The HABITAT tool can be used as post-processing tool on results of the water state models or be connected in case of feedback mechanisms. In this way it translates results, like discharge or phosphorous contents, into something more meaningful for policy makers like flood risk maps or ecological quality maps. Within HABITAT, knowledge rules that describe cause-effect relations and were developed in specific studies, can be stored in a database. They may consequently be re-used and adapted for other studies possibly in other areas. For further development of HABITAT and the WIKI-based knowledge base, Deltares has adopted the principle 'Dare to Share'. HABITAT is freely available for users that are willing to share the knowledge rules they developed.

Keywords: Spatial analysis tool, habitat, damage assessment, environmental impact assessment

INTRODUCTION

Integrated Water Resources Management (IWRM) involves assessing effectiveness of measures in achieving the defined objectives. This implies that not only the effects on the water state but also effects on water related functions need to be determined. After all, water management is just a means to enable societies and ecosystems to function well. Therefore, the effects of strategies and measures on economic, social and natural systems should be assessed (De Bruijn, 2005). In Europe this is amplified by EU directives like the Birds Directive (EU, 1979), Habitat Directive (EU, 1992) and the Water Framework Directive (EU, 2000). For these Directives, Member States have to take measures to achieve pre-defined ecological objectives, while taking into account autonomous developments and social and economic requirements. The Flood Risk Directive (EU, 2007) aims to map and subsequently reduce flood risk, which is defined as 'the combination of the probability of a flood event and of the potential adverse consequences for human health, environment, cultural heritage and economic activity associated with a flood event'.

Effects of water management strategies are often estimated with support of hydrological or hydraulic computer models. The results of these models need to be interpreted in terms of their effects on water related functions, as these are often the real objectives of a measure. Only then does the effectiveness of measures become clear and can be determined whether additional or other measures are needed. Moreover, it may result in an adjustment of the objectives, when for example even with all thinkable measures the objectives appeared not to be realistic.

While for the water state many comprehensive computer tools exist, this is not the case for ecological impact, damage and flood risk assessment. Several tools exist but they are often case specific, difficult to adapt and/or only usable by the developer (Hooijer & De Bruijn, 2005; De Bruijn, 2008a). This is partly due to the fact that physical rules or cause-effect relations are not as generic as hydrological issues. For example, habitat requirements of a certain species and the amount of flood damage to residential property may differ from region to region.

The above indicates that from both a technical and a policy perspective there is a need for a tool that is able to translate results of hydrological, hydraulic and water quality models into effects on the natural environment and human society. Further requirements are that the tool must be easy to setup and adapt, transparent and reusable. HABITAT is such a tool.

This paper describes HABITAT and shows how HABITAT may be used for two quite different issues: environmental impact and damage assessment.

HABITAT

HABITAT is a spatial analysis tool that provides a platform for model development without the need for highly advanced programming skills. A user can easily build an application in HABITAT, using different functions or so-called knowledge rules. The functions often describe cause-effect relations, which can be combined or linked by using each the output of one knowledge rule for an other. In this way, the cause-effect chain (or parts of it) can be simulated from pressures, like climate or land use changes and measures, via state describing the water quantity and quality, to impact on the environment, society and economics and response (management) (after the PSIR framework from Hoekstra 1998).

Essentially, HABITAT is a geographic information system (GIS). In fact it is an extensive user interface built around PCRaster, a software package that is used for map-calculations (PCRaster, 1987). The tool applies the knowledge rules on maps (grid cells), using data of different map layers, and/or adjoining cells. To set-up an application in HABITAT, the user implements knowledge rules either by importing them from the ecological knowledge base (we call it a Toolbox), or by making his/her own knowledge rules. Knowledge rules can be implemented by adding one of the five different grid processing tools, including a broken linear function, a table reclassification with a single grid, a table reclassification with multiple grids, a formula based function and the spatial statistics function. The formula based function allows to operate arithmetic, logical and neighbourhood functions on one or multiple grids. It is also possible to make queries (using the 'if-then-else' functions). The spatial statistics function converts spatial information from one or two maps to a table presenting, for example, the surface area of specified ranges or values, the average, median, minimum, maximum and standard deviation. It can also present these values for a particular nature area or dike ring indicated in another map.

The results of HABITAT are presented in maps or in tables. Results can be analysed by requesting cell values of a cell or cross-section, by a visual inspection of maps, by calculating difference maps with the formula based function or by performing the spatial statistics function to convert the map information into a table.

An important characteristic of HABITAT is the Knowledge Base. It is a toolbox with knowledge rules and consists of a web-based database and a set of knowledge rules in the software. It can be used to store knowledge rules and groups of knowledge rules as a template, in order to re-use them in other projects or other areas. The knowledge rules can be based on measurements or on expert knowledge. For each knowledge rule or group of knowledge rules it is possible to enter meta-information like the creator, implementation date or references to documentation. Each knowledge rule can be visualised in the user interface (see for example Figure 1).

The web-based version of the knowledge base presently contains ecological knowledge rules only, but it can be easily expanded for other subjects. The current knowledge base on internet presents different fact sheets of species and groups of species in a WIKI, which makes it possible for every person to update the knowledge base. Each fact sheet gives general information like name, water system, occurrence and the ecological quality element of one of the EU Directives. Furthermore, a description of the habitat use, environmental requirements and reproduction strategy is given. The effect relations indicating the boundaries of environmental conditions for the presence of species are presented either in formulas, tables or graphs. The application area and information on validation and uncertainties of the knowledge rules are given as well. Each fact sheet finishes with information on sample applications and references.

The use and development of both HABITAT and the Knowledge Base is based on the ‘Dare to share’ principle (Soekijad. 2005). Knowledge rules are exchanged through dedicated WIKI pages, thereby improving the quality of knowledge rules and stimulating the sharing of software maintenance costs. HABITAT is freely available for users who are willing to share their developed knowledge rules with the ‘HABITAT community’ as part of the ‘Dare to Share’ principle.

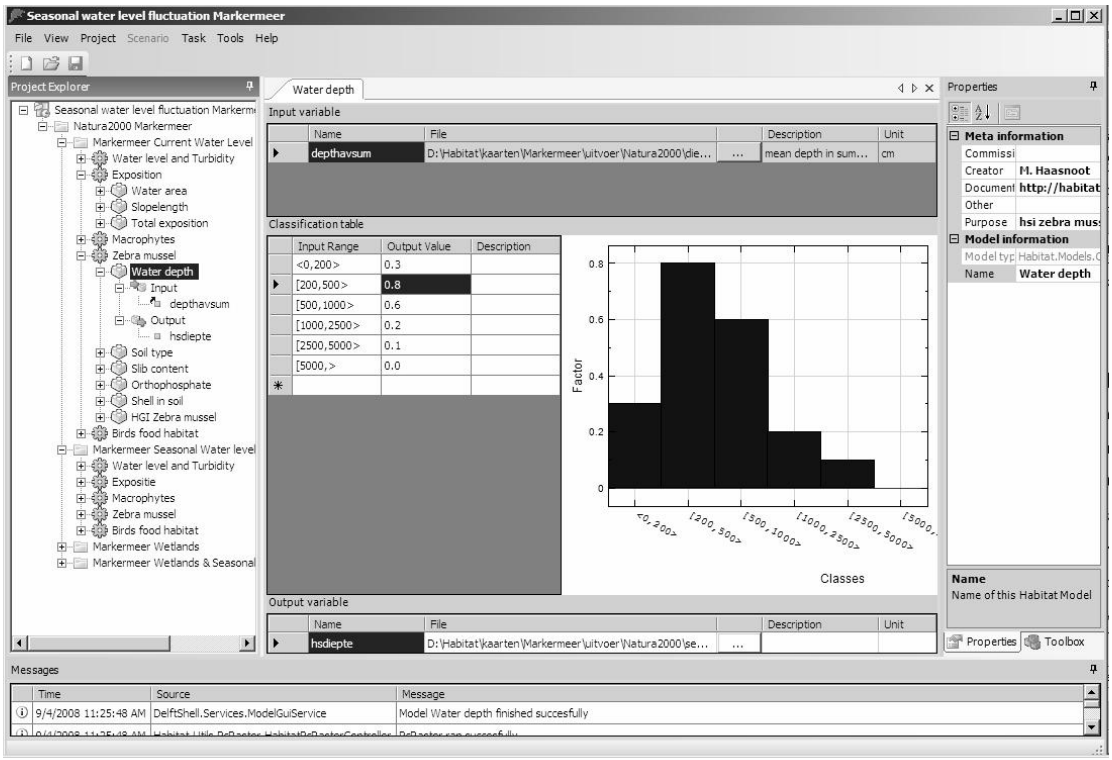


Figure 1. Example of the User Interface of HABITAT. The left pane (Project Explorer) presents the knowledge rules (indicated with bricks) grouped by task (indicated by a cogwheel) for four water management strategies in different folders. In the centre pane, a knowledge rule for the habitat suitability for the zebra mussel in relation to the water depth is presented. The input map for the highlighted knowledge rule is derived from one of the knowledge rules previously applied in the Project Explorer, indicated with a little arrow at the input map. The right pane shows the meta-data of this knowledge rule. Behind the meta-data is the Toolbox.

APPLICATION 1: ENVIRONMENTAL IMPACT ASSESSMENT

HABITAT has been used for several studies to assess the impact of autonomous developments or water management strategies on ecology. We will illustrate this with a case study for Lake Markermeer. The reason for this study was the wish of the Dutch government to improve the ecological state of the Lake IJsselmeer area, in part resulting from the requirements of the EU Directives related to ecology. Currently, the water level fluctuation is unnatural with a higher water level in summer and a lower water level in winter. The reason for this is the need for a water level which is low enough in winter to ensure safety and high enough in summer for navigation and water conservation. The Dutch government wanted to test the hypothesis that a more natural water level fluctuation would help to achieve the defined ecological objectives.

HABITAT was used to analyse the effects of different scenarios of water level fluctuations on the ecological objectives in terms of macrophytes, fish species, birds, bivalves and different habitat types. The implemented effect-chain in HABITAT can be shortly described as follows: The water level has an effect on the water depth and flood duration, which were calculated from a bathymetry map for each month. The water level influences the wind fetch, which was calculated as a weighted average of the fetch of eight directions and their relative occurrence. Water depth, wind fetch and flood duration together with input maps indicating the transparency, algae concentration, orthophosphate concentration, soil type, silt content, shell cover form the environmental state which is used to determine the suitability of the area for the identified indicator species corresponding with the ecological objectives. These (groups of) species are: macrophytes, habitattype Eu-code 3140 Chara spp., common pochard (*Aythya ferina*) representing macrophyte-feeding birds, tufted duck (*Aythya fuligula*) representing benthos-feeding birds and spined loach (*Cobitis taenia*). Zebra mussels (*Dreissena polymorpha*) were also taken into account as they are the main food source for tufted ducks.

The ecological impact part is based on the principle that each species has its own preferred environmental conditions and requirements to live, breed, grow and/or reproduce. This is based on the habitat method by developed by the US Fish and Wild Life Service (1980) and has been used since to determine the quantity and quality of habitats for organisms (see for example Duel et al. 1995, Guisan & Zimmermann 2000, Tomsic et al. 2007). Habitat models calculate the potential occurrence of species with a set of functions describing the response of species to environmental conditions limiting the density and fitness of these species. The results present the habitat suitability, which has values between 0 and 1 indicating a respectively low and high quality. A high habitat suitability value can be interpreted as a higher probability of the occurrence of species.

The ecological knowledge rules are based on literature and expert knowledge. An example is given in figure 2. They are described in more detail by Haasnoot and Van de Wolfshaar (in press.) and Haasnoot et al. (2005).

The accuracy of the ecological knowledge rules was assessed by comparing the results for the current situation with monitoring results using the Signal Detection Theory (Zweig et al. 1993, Fielding et al. 1997). The input data consists of a bathymetry map and soil map, both with a cell size of 25x25 m, whereas for the other parameters the input maps were derived from time series of observed water quality parameters. The amount of correct predictions by the ecological knowledge rules, taking 0.7 as a threshold for the predicted presence of species, range from 72% for the zebra mussel to 88% for the submerged macrophytes (Haasnoot & Van de Wolfshaar, in press.).

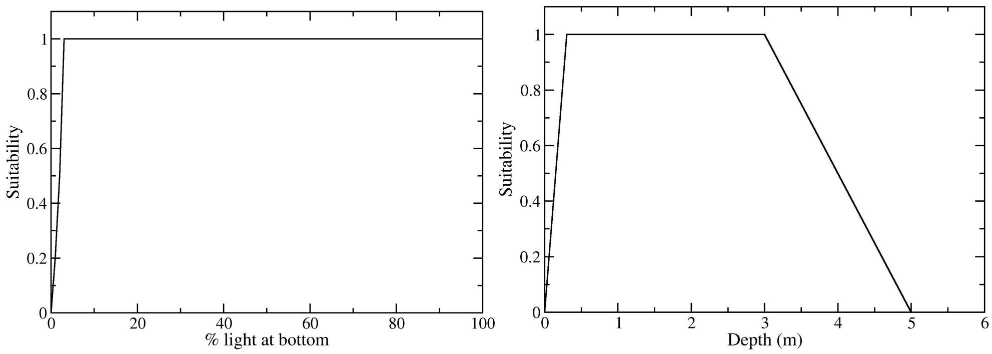


Figure 2. Response curve for the availability of light at the bottom of the lake and water depth and Habitattype 3140, Chara spp. (based on Van den Berg et al. 2003). The total habitat suitability is the minimum of the result of these knowledge rules.

The results of the scenario analysis were disappointing in the sense that the suggested water level fluctuations did not result in a considerable improvement of the habitat quality for the species mentioned in the ecological objectives (Haasnoot and Van de Wolfshaar, acc.). The average increase in suitable habitat was 6% in the most favourable scenario. Only for the spined loach the increase was 25%. For Chara species the amount of suitable area increased with 8%. Crucial water levels appeared to be the mean and minimum water level during summer. Because of the steep slope of the lake (much like a bathtub) the projected change in water management did not result in the increase of shallow parts, while exactly these areas provide a suitable habitat for a lot of species. A fluctuation at a lower level would improve the results, but this was not possible considering the boundaries given by other functions. Therefore, an extra measure was investigated, namely the construction of an island with shallow banks in combination with water dams to reduce wind impacts. This resulted in a considerably larger increase of the desired suitable habitat. An example of the results is given in Figure 3.

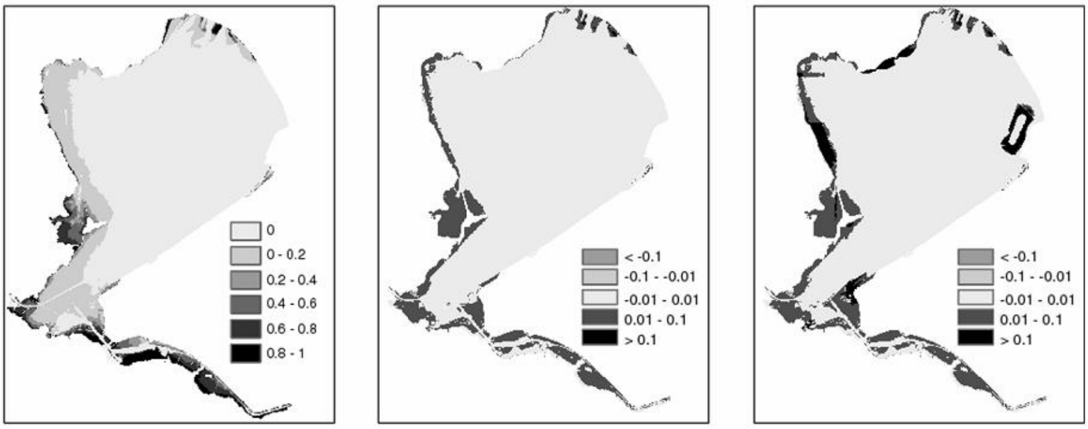
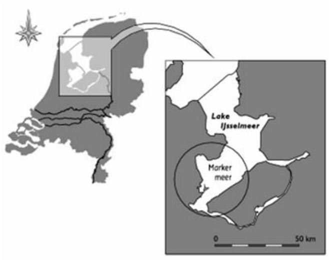


Figure 3. Example of result of HABITAT. The figures present the habitat suitability for chara species in the Lake Markermeer in the current situation (left) and the change in habitat suitability for the most favourable scenario with a seasonal water level fluctuation (middle) and with this water level fluctuation in combination with the construction of an island and under water dams (right).



APPLICATION2 : FLOOD DAMAGE ASSESSMENT

In flood damage assessments, inundation maps from hydraulic models, satellite images or other sources are combined with data on land use and the corresponding depth-damage relationship to estimate flood damage. By combining this damage estimate with the probability of occurrence of the event, risk maps may be produced.

In the Netherlands, damage and casualties resulting from floods are usually assessed with the Standard Dutch Damage and Casualty Model (HISSM) (Kok et al., 2005). As this model requires a lot of input e.g. on type of industries, business and number of employees, it is mostly not feasible to use the HISSM for other situations than for the current situation. To estimate future flood impacts corresponding with future scenarios or alternative flood risk management strategies a simplified damage model was developed. This model, called the ‘damage-scanner’, is less detailed and less accurate than the HISSM but it allows fast explorative calculations of future flood damage (Klijn et al., 2007; De Bruijn, 2008).

For each land use type, the damage-scanner calculates the flood impacts per ha and is based on the following equation:

$$D_{cell} = f * D_{\max}$$

With:
D_{cell} = Estimated flood damage in the raster cell under consideration
f = Damage factor (value between 0 and 1)
D_{max}= Maximum potential flood damage in the cell under consideration

The maximum potential flood damage depends on the land use type of the cell. The damage factor varies between zero and one. It equals zero if the cell is dry and one if the water depth equals or exceeds 5m. For water depths larger than zero and smaller than 5 m, the factor gradually increases with water depth from zero to one.

The maximum potential damage and the shape of the damage curves were derived from the HISSM model (Figure 4). The damage-scanner was used for nationwide flood damage assessment in the Netherlands for two nation-wide studies: Second Sustainability Outlook and Attention for security (Klijn et al., 2007; De Bruijn, 2008b). It was reused for the Scheldt Estuary (De Bruijn et al., 2008a), while similar procedures have been used for the Mekong and Meuse Rivers (De Bruijn, 2005). The damage-scanner was originally programmed in PCRaster (PCRaster, 1987). Every time it was used, it took some time to reorganize all files and to remember the exact procedures. As it is expected that the damage-scanner will be used for other projects as well, it was recently updated and reprogrammed in HABITAT.

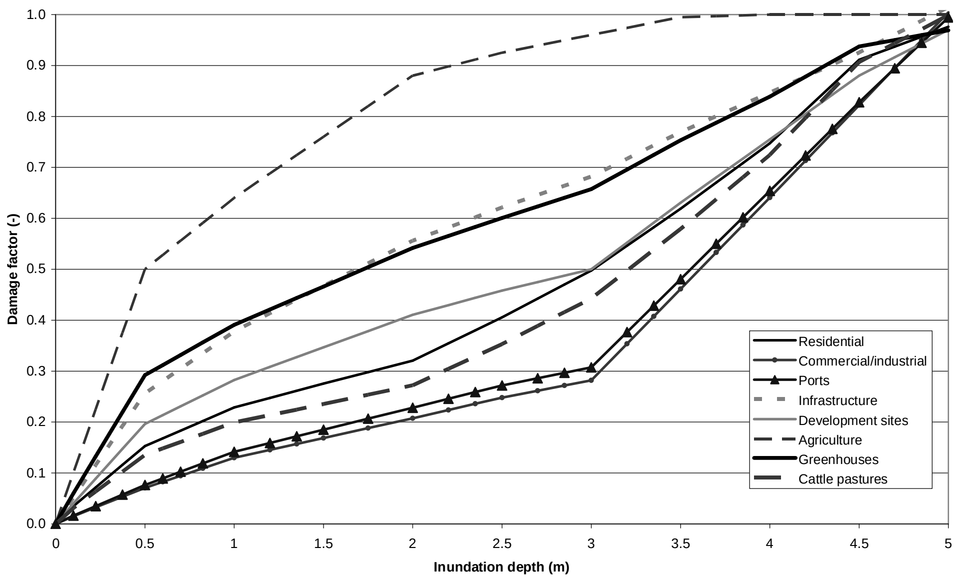


Figure 4. Example of damage functions for a few land use types.

To give an idea of the possibilities of HABITAT for damage assessment, the results of the application for the Second Sustainability Outlook are presented here. In the Outlook several future socio-economic and climate change scenarios were considered and combined with spatial planning and flood risk management policies (Kuijpers, 2007). The resulting images of the Netherlands were assessed on many criteria which, when combined, gave insight into the well-being of the country. Water-related parameters were not the most relevant ones. Mainly the impact of those parameters on society and ecosystems were considered. Deltares studied the impact of the spatial planning policies and flood risk management measures on flood risks (Klijn et al., 2007). Flood risks were determined by combining flood probabilities and flood impacts including both flood damage and flood related casualties, using the damage functions presented in Figure 4.

In future, it is expected that not land use will change, but so will maximum potential flood damage. Production capacity, the number of valuable possessions of households and yields per hectare may all increase. To incorporate these changes, the resulting flood damages were increased with a factor which represents all aspects of economic growth that are not visible in the new land use map.

The result showed that potential flood impacts in 2040 increase with about 70-90 % due to socio-economic developments. Climate change impacts have little effect on flood impacts until 2040 (but they do affect flood probabilities of course). Potential flood damage in the densely populated areas in the coastal zone is expected to increase more than anywhere else, but potential flood damage in the areas along the tidal rivers increases fast as well. These areas are going to be hit significantly by climate change effects and need to receive due attention in future flood risk management policies. Figure 5 shows current and future damage maps. The results can be combined with current and future flood probabilities to establish current and future flood risks.

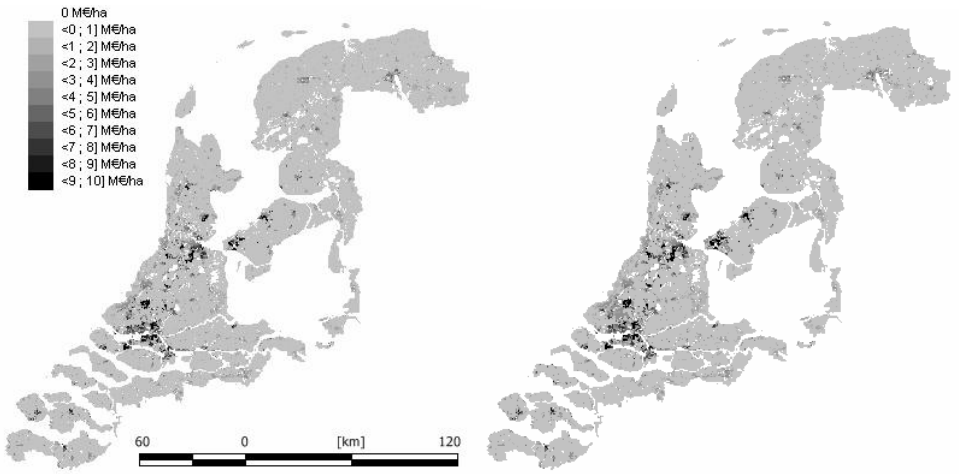


Figure 5. Current (left) and future (right damage maps.

CONCLUSIONS AND DISCUSSION

Currently, HABITAT is used a as a spatial analysis tool for (1) ecological impact assessment to analyse the availability and quality of habitats for individual or groups of species, resulting in a prediction of the suitability of the faunal and floral habitats and for (2) flood damage and risk assessment to analyse the presence and extent of flood damage to different land use types (residential, agriculture), resulting in a prediction of the potential damage and/or flood risk. In these applications, HABITAT is used as a post-processing tool, using results from hydrological, hydraulic or water quality models. Other applications involve the analysis of the whole cause-effect chain, like the effects of water management strategies on soil subsidence and CO_2 emissions in peatlands by using knowledge rules based on expert knowledge and measurements (Haasnoot and Hooijer, unpublished).

The concept of using knowledge rules to simulate the cause-effect chain helps to understand the system in terms of relevant steering variables and effectiveness measures. It also allows for making expert knowledge explicit and re-usable. Consequently, gaps in knowledge or uncertainties become clear as well. However, it is not always possible to describe a cause-effect relation in a knowledge rule due to complexity of the relation.

The knowledge base has proven to be a valuable part of HABITAT. It allows for an effective and clear storage of expertise such as that incorporated in the damage-scanner and the Lake Markermeer study. Often, the central question in new studies is (slightly) different, but basic principles can be used. The knowledge base makes it much easier to re-use the same or similar procedures again, enabling others to use the same procedures without the need for advanced programming skills. The possibility of viewing the knowledge rules in combination with a description on the background makes the tool transparent, also for others. The challenge for the knowledge base is to validate the knowledge rules and to ensure the proper application and purposes. In addition, users need to be prepared to describe the knowledge rules and share these with the HABITAT community through the web-based knowledge base.

Taking the uncertainty of expert knowledge into account would be a valuable improvement for the tool, especially when an application results in intermediate habitat suitability values (Van der Lee et al. 2006). A spatial analysis tool is not always needed, for example in water distribution studies. Moreover, spatial information is not always available.

The results presented in this paper show that HABITAT can assist in ecological impact and flood damage assessment studies by analysing the effectiveness of measures or effects of autonomous developments, which is needed for IWRM studies. Presenting the effects on the real objectives and the visualisation of maps and the summary of results in tables support the communication with policy makers.

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