DEMNAT-2.1, latest innovations on a national dose-effect model for the analysis of dehydration of wetlands in The Netherlands.

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ABSTRACT

In the past 10 years there is a growing concern in the Netherlands on problems related to dehydration of wetlands. Several causes like e.g. high levels of groundwater withdrawal for drinking water and industrial water supply, and extensive lowering of drainage levels for agricultural purposes have caused a structural lowering of groundwater tables and a loss of upward seepage in many parts of the country. As a consequence, most groundwater dependent ecosystems now lack their specific needs in terms of water quantity and quality. This environmental stress forms a serious threat for the existence of many rare plants and animals.

In order to develop optimal abatement strategies the Dutch government has developed a dose-effect model which is used for scenario analyses of dehydration on a national scale. This model DEMNAT, makes extensive use of spatial data and is imbedded in a GIS with a user-interface. During the past two years several improvements have been made on the model.This paper discusses the major innovations carried out on the model concept of DEMNAT.

INTRODUCTION

In the densely populated Netherlands groundwater tables are generally low. For instance, during the winter more than 70% of the country has mean groundwater tables less than 1 meter below surface. As a consequence, more than half of the vegetation types are exclusively or largely phreatophytic (Colenbrander et al., 1989), and hence are funerable to hydrologic changes.

During the past 10 years there is a growing awareness in the Netherlands on problems related to dehydration of wetlands. Several causes are responsible for the large scale structural lowering of groundwater tables and decrease in upward seepage. Main causes are considered to be extensive drainage in agricultural areas and continuing groundwater withdrawal for drinking and industrial water supply. Based on an inventory conducted in the late eighties it was concluded that approximately 75% of the Dutch groundwater dependent nature reserves were adversely affected by dehydration (Braat et al., 1989). Outside nature reserves the loss of biodiversity due to dehydration may expected to be even worse. Since the inventory dehydration was recognized as a national environmental problem. In order to analyze the problem and to develop sound abatement strategies models are developed by the national authority. These models should help in estimating the economical and ecological consequences of different water management scenario's. DEMNAT is used to determine the ecological effects of long term the changes in hydrology on a national scale.

The first version of DEMNAT (Witte, 1990; Witte et al., 1992) was used for a policy document on national water management (Claessen, 1990). A second version of the model, named DEMNAT-2.0, was used in the impact assessment for the National Policy Plan on Drinking Water and Industrial Water Supply (Beugelink et al., 1992). The changes between the first and the second version of DEMNAT were large due to differences in the input data (e.g. floristic data used in DEMNAT-2.0 is known per 1 km^2 compared to 5 km^2 in the older version). The present version of the model, DEMNAT-2.1, resembles the former version although several essential changes have been made. This version will be used for the Watersystem Reconnoitring which will be conducted in 1996 by institutes of the Ministry of Transport, Public Works and Water Management.

This paper discusses the model concept of DEMNAT and the major changes made in DEMNAT-2.0 to establish the present version DEMNAT-2.1.

MODEL CONCEPT

In order to predict ecological effects of changes in hydrology the complete cause-effect chain needs to be simulated from changes in hydrology via changes in operational site factors (depending on soil characteristics) to changes in the vegetation (depending on the site preference of plant species). Operational site factors are factors which directly affect plant growth (e.g. moisture regime, nutrient-availability, acidity, salinity). A model needs to combine information on the different soil types with information on the different vegetation types. In addition, dose-effect relations are needed for all possible combinations of soil and vegetation. The

DEMNAT model contains all these elements. Basically, DEMNAT consists of three modules: (1) a geographical schematization of ecosystems, (2) a set of dose-effect functions, and (3) a nature valuation module.

geographical schematization of ecosystems
DEMNAT-2.0 combines information from the 1 : 50.000 soil map of the Netherlands and the national data bank on the distribution of plant species (FLORBASE) in order to derive the type and location of ecosystems present in the Netherlands.
The 1 : 50.000 soil map of the Netherlands contains more than 2000 units. This information has been aggregated into 52 ecological relevant soil units and 6 groundwater classes. The combination of soil units and groundwater classes form the abiotic units of DEMNAT-2.0 and are called ecoseries (Klijn et al., 1992). Within each 1 by 1 km gridcell several ecoseries can be distinguished. For each ecoserie a site-matrix is defined in which for each site the chance on occurrence is estimated. The site-matrix contains a certain hierarchy in which some operational site factors are more dominant than others. For instance, at nutrient poor sites acidity is a differentiating site factor in contrast to nutrient rich sites where acidity is not differentiating. In table 1 the site-matrix used in DEMNAT is shown.

Table 1 ***The site-matrix of operational site factors used in DEMNAT. The asterisks indicates a wet, weakly acid, nutrient poor site.***

	fresh water					brackish	saline
	nutrient poor			moderately nutrient rich	very nutrient rich		
	acid	weakly acid	basic				
aquatic							
wet		*					
moist							
dry							

The occurrence of vegetation types is derived from FLORBASE (Witte & Van der Meijden, 1995; Van der Meijden et al., 1995). This data bank contains information on the presence of vascular plants per 1 km^2 for the period between 1975 and 1990. Plant species were aggregated per gridcell into ecological species groups reflecting a certain ecosystem type. Aggregation of plant species was based on common occurrence in the field derived from vegetation surveys and common site preference based on indication values like e.g. Ellenberg (Runhaar et al., 1989). Each individual plant species was given a weight factor indicating how characteristic a plant species is for a given ecosystem type. For instance, a plant species with a weight factor of 1.0 is unique for a specified ecosystem type whereas a plant species with a weight factor of 0.5 indicates that it occurs in two ecosystem types. In fact, the weight factor is a measure for the ecological amplitude of the plant species. By adding the weight factors of the characteristic plant species for a given ecosystem type a score is obtained. As species diversity differs per ecosystem the score of each ecosystem type is normalized to a value between 0 and 1 using ecosystem type specific threshold values (Witte et al., 1993). The resulting value is called `completeness' and is a measure for the floristic development of the ecosystem. By using this method vegetation maps can be made of ecological species groups based on FLORBASE.
The ecosystem types make use of the same site-matrix as the ecoseries. One consistent system to classify plant species and soil types into ecologically relevant groups is crucial in order to link the vegetation units known per 1 km^2 gridcell to the different soil units present within the same gridcell. The combination of an ecological species group and an ecoserie is called ecoplot and represents an ecosystem unit within the gridcell. The ecological effects are computed at the level of ecoplots but results are always aggregated to the level of a gridcell using the size of each ecoplot as a weighing factor. Defining small scale units like ecoplots is essential as most nature reserves occur as small spatial units in the fragmented landscape of the Netherlands.

dose-effect functions

DEMNAT-2.0 can predict the ecological effect of changes in spring groundwater level, upward seepage, water level of small surface waters and inlet of river water into local systems. For each separate ecoplot a dose-effect function is needed per dose (i.e. hydrologic change) in order to translate the changes in hydrology into local ecological effects. The dose-effect functions are computed in two steps (Van der Linden et al., 1994; Runhaar & Van der Linden, 1995). First, it is determined which changes in operational site factors can be expected for different soil types given a certain hydrologic dose. Second, empirical relationships between species composition and operational site factors are used to predict how these changes will affect the vegetation. Thus, a dose-effect function which indicates the effects of a structural lowering in groundwater table does not only take moisture regime into account, but also the effects on nutrient availability (due to increased mineralization) and acidity (due to the increase in the amount of rainwater in the root zone). The advantage of using dose-effect functions is that calculations are relatively rapid and robust. These are important advantages as a rapid calculation allows small spatial units to be preserved in the model without needing to be eliminated e.g. by aggregation. Furthermore, the calculations are robust as the dose effect relations for the soils are based on small scale studies with dynamic process-models in which input data is more reliable than for national scale studies.

nature valuation module

A nature valuation module is used in order to translate the ecological changes into its relevance for nature conservation. The use of nature values also makes it possible to aggregate ecological effects of a hydrologic scenario into one single number as nature values of separate ecosystem types can be added into one total. This facilitates the interpretation of a large number of scenario's and allows a cost-(nature)benefit analysis.

The actual nature value of an ecosystem type in a certain gridcell depends on its potential nature value, the size of the ecoplots within the gridcell on which the ecological species group occurs and the relative species richnes (i.e. completeness) of the ecosystem type. The potential nature value per ecosystem type is based on national and international rarity (Witte et al., 1993). This corresponds with the general opinion that items which are rare are more valuable than common items. Biodiversity is accounted for by using the relative species richness of an ecosystem type. The advantage of using a normalized term for biodiversity per ecosystem type is that ecosystems with a low species diversity do not automatically get low nature values. Several ecosystems in the Netherlands have a naturally low biodiversity but are nevertheless highly appreciated due to the rare plant these systems harbour. With this approach an ecosystem also does not get higher nature values when ruderal herbs enter the system (e.g. nettle *Urtica dioica*). Finally, it is important to notice that the nature values are only meaningful on a relative scale and should not be used in absolute terms.

INNOVATIONS IN THE MODEL CONCEPT

connection with hydrologic models

Ecohydrologic models which operate on national scale are confronted with scale problems. The actual hydrologic changes and ecological effects mostly occur on local scale. DEMNAT-2.0 was coupled to LGM a groundwater model for national scale (Pastoors, 1992) and DEMGEN a national model for the unsaturated zone and small surface waters (Abrahamse et al, 1982). LGM has an output resolution of 1 km^2 for upward seepage. For changes in groundwater levels the information per 1 km^2 was divided into groundwater classes. The inlet of river water was simulated by DEMGEN for relatively large geographical districts (80 in total). The limited resolution of these hydrologic models hamper the possibilities for a meaningful ecohydrologic analysis.

In the case of DEMNAT-2.1 recent developed hydrologic instruments like NAGROM and MOZART will be used. The topsystem of NAGROM a national groundwater model (De Lange, 1992) has been spatially differentiated using detailed information on ditch density, topography and soil types (Vermulst et al., 1996). Furthermore, a newly developed hydrologic model for the unsaturated zone MOZART (Arnold, 1995) has been coupled to NAGROM. With this approach upward seepage can be modelled per 500 x 500 m grid on a national scale. Also stream valley systems situated in the pleistocene sandy region of the Netherlands with valuable wet meadows are now accounted for in these hydrologic models.

The hydrologic changes modelled by NAGROM and MOZART are input for DEMNAT-2.1. By using a special coupling-programme the most likely combination is made between the output of the hydrologic models and the ecoseries of DEMNAT-2.1. The coupling mechanism is based on the similarity between soil physical units used in MOZART and ecoserie soil units used in DEMNAT. Furthermore, coupling is based on groundwater classes *modelled* by MOZART and groundwater classes used in DEMNAT based on the Dutch soil map 1:50.000, and on *modelled* values for salinity and the code for brackish or saline upward seepage from the ecoserie-typology.

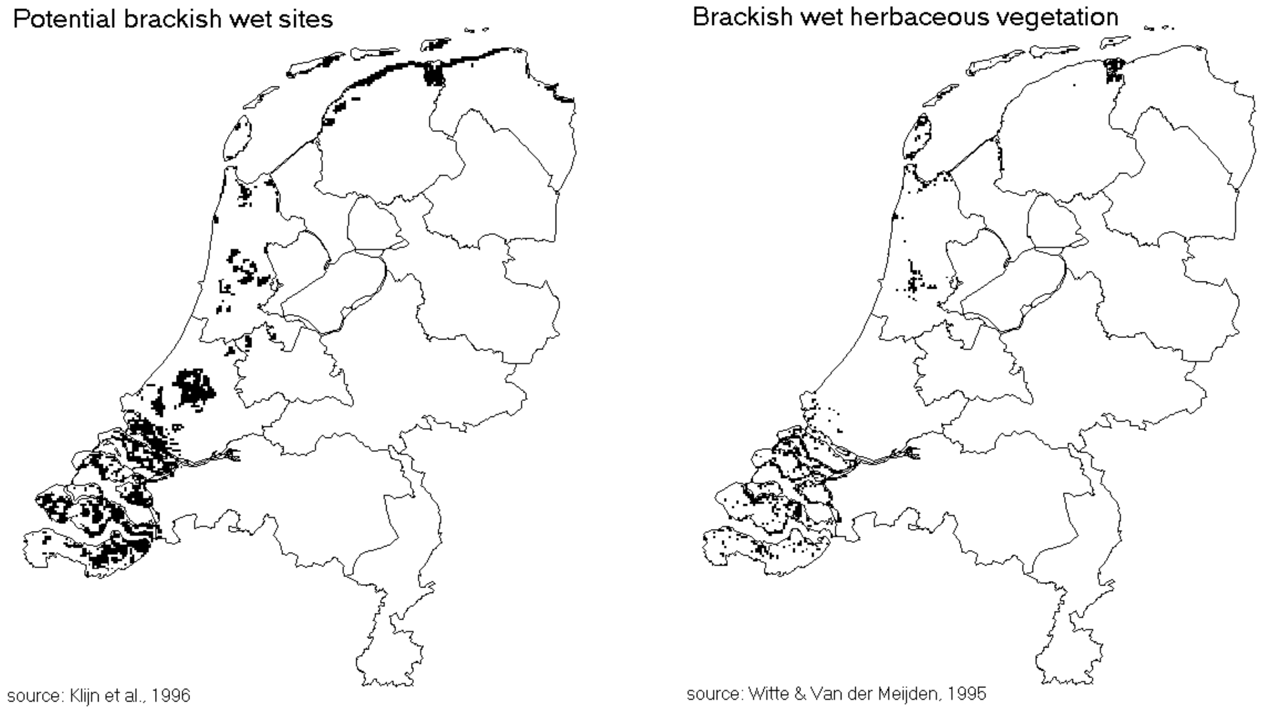
ecoseries-2.1

The ecoserie-typology used in DEMNAT-2.1 has been expanded compared to the one used in DEMNAT-2.0. First, all ecoseries are now all derived from the Dutch soil map 1:50.000. For DEMNAT-2.0 this was not the case as the Dutch soil map 1:50.000 was not available yet for all parts of the Netherlands. Second, the former ecoserie-typology which was only based on information of soil types and groundwater classes has been expanded with information on upward seepage. As source for the type of upward seepage the LKN-groundwater relation map is used (Klijn,1989). This map which is based on a wide variety of sources indicates the chance on occurrence and type (i.e. lithocline, brackish, saline or a mixture) of upward seepage. Based on a regression between ecoserie-soil units and codes for upward seepage as well as on expert judgement the most likely combinations are made between codes for upward seepage and ecoserie-soil units (Klijn et al., 1996). There are two main purposes for the expansion of the ecoserie-typology with information on upward seepage. First, a better definition of ecoseries contributes to a better coupling between hydrologic dose and ecoserie. This is important as the present hydrologic models for national scale fail to model the hydrologic doses on a scale level sufficiently detailed for ecohydrologic models. Second, also the coupling between ecoserie and ecotope group has improved as better defined ecoseries improve the prediction of operational site factors. An optimal estimation of operational site factors occurring on ecoseries is important as information on the ecological species groups is only available per km^2.

inlet of river water

The way in which effects of inlet of river water into local surface waters are modelled has also been improved in DEMNAT-2.1. In the former version of DEMNAT the change in the percentage of inlet water was translated within the model to a change in nutrient status of the surface waters. Although this is the case in large parts of the country this is certainly not always true. In several parts of the country the surface waters also receive large amounts of nutrients from so-called diffuse sources, like manuring practices in agricultural areas, sewage cleaning installations and industrial installations. In these cases inlet of river water can be used to lower the nutrient status in surface waters. As changes in water quantity are not directly ecologically relevant DEMNAT was adapted to parameters which reflect water quality changes. The effect of inlet of river water was split up into a salinity and a nutrient effect. As a measure for salinity chloride concentration in the local surface waters was taken. As a measure of the nutrient status ortho-phosphate concentration was taken. Dose effect functions for salinity were incorporated into DEMNAT because several valuable fresh water ecosystems appear to be highly sensitive for chloride changes (Barendregt, 1993). These new dose effect function also give opportunity to model effects in brackish ecosystems. Brackish polder ecosystems are situated in the western part of the Netherlands and depend on brackish upward seepage (figure 1). Due to continuing inlet of fresh water into these systems the salinity of surface waters is decreasing and consequently also the highly appreciated brackish vegetation.

The ecological effects of changes in phosphate concentrations and chloride concentrations are not independent of each other. Plant species which are sensitive to high phosphate concentrations also appear to be sensitive to high chloride concentrations. Therefore a multiple-stress function has been designed in order to combine the changes of both chloride and phosphate concentrations into one ecological response. The dose-effect functions become less sensitive for changes in chloride if higher levels of phosphate occur. The reason for this is that at higher phosphate concentration levels a certain proportion of the plant species disappears which are also sensitive for changes in chloride concentrations. For pure brackish aquatic ecosystems the effects of water inlet are solely expressed in changes of chloride concentration. An important difference with the former dose-effect functions is that positive as well as negative effects can be modelled as a consequence of increased chloride concentrations.



Potential brackish wet sites

Brackish wet herbaceous vegetation

source: Klijn et al., 1996

source: Witte & Van der Meijden, 1995

Figure 1 ***The potential distribution of brackish wet sites on the basis of soil and hydrology and the actual ocurrence brackish wet herbaceous vegetation in DEMNAT-2.1.***

For the aquatic brackish ecosystem type the relative species richnes increases up to a certain optimum located near a chloride concentration of approximately 4000 mg per l ([Cl^-] = $10^{3.6}$ mg/l). Beyond that concentration level salinity becomes to high to support optimal development of the brackish ecosystem type. The multiple-stress function and the dose-effect function for brackish aquatic ecosystem types are shown in figure 2.

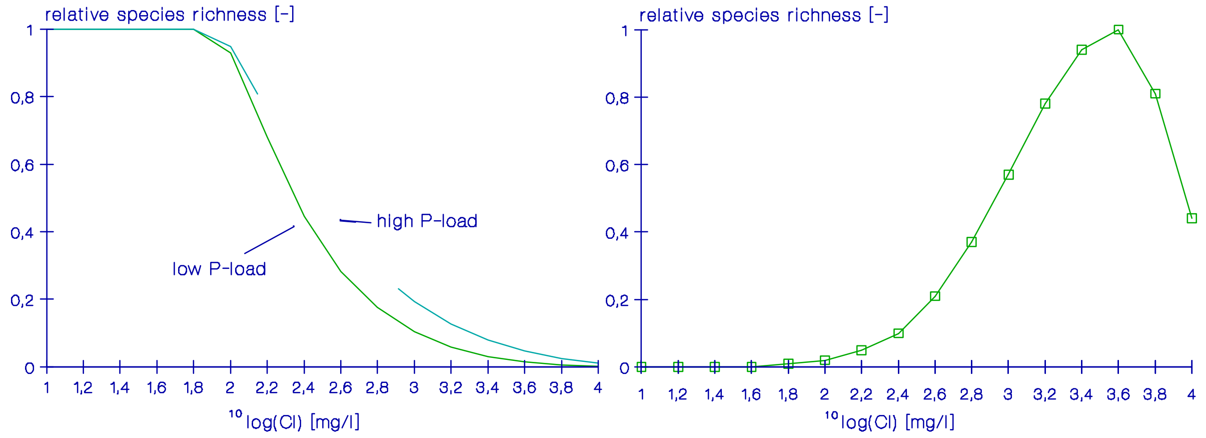


Figure 2 ***The relationship between completeness and chloride concentration for a nutrient rich aquatic vegetation (left) and a brackish aquatic vegetation (right). In the left figure the effect of the reduction of plant species due to high phosphate concentrations in the surface water is shown on the dose-effect function for chloride concentration changes in nutrient rich aquatic vegetation.***

combining separate effects

A relatively large change in the model concept of DEMNAT is the way in which separate effects of hydrologic doses are combined into one single effect. In DEMNAT-2.0 separate effects were calculated by dividing computed effects into degradation and restoration. The degradation effect was substracted from the relative species richness whereas the restoration effect was added to the relative species richness. Unsatisfying aspect of this approach is that hydrologic measures which result in restoration can completely counteract degrading effects of other hydrologic measures even if the degrading measures are still present. In DEMNAT-2.1 another approach is followed in order to combine separate effects. First, separate effects are calculated based on the different dose-effect functions. Second, the sequence in which the dose-effect are to calculate the ecological effects is sorted based on the separate effects. Dose-effect functions which are responsible for the largest degradation are functions which should be used first in a second round of the determination of ecological effects. Functions which are responsible for the largest restoration are last in the calculation sequence. Finally, separated effects are calculated for a second time but this time the completeness fraction which results from the first dose-effect function is input for the second dose-effect function, and so on. The procedure is illustrated in figure 3. The argument for this approach is that full restoration of a wetland ecosystem is not possible if not all essential hydrologic conditions are met.

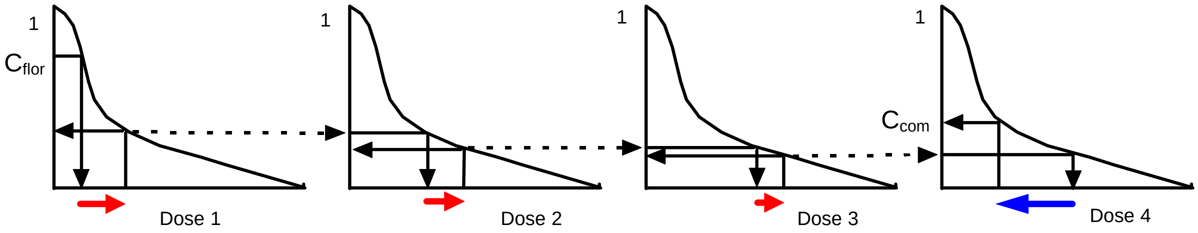


Figure 3 ***Separate effects of dose-effect functions are combined into one overall effect by computing the effects in series. Dose effect functions which cause the largest degradation are used first. The last dose effect function in this example resulted in some restoration but the overall effect was degradation (C_{flor} = relative species richness derived from FLORBASE, C_{com} = relative species diversity after combining all doses).***

Apart from the procedure how separate effects are combined most dosis-effect functions are also extended in range. For instance, the effects of lowering of the spring groundwater level in DEMNAT-2.0 was only possible for the range between 0 and 80 cm below surface level. In DEMNAT-2.1 this has been extended to 150 cm below surface level.

aggregating results for larger districts

When the results of ecological effect models are used to compare different districts or regions in the Netherlands there can be a systematical bias due to differences in the degree by which the flora has been investigated. These differences are apparent as the flora inventory in the eastern part of the Netherlands is less thoroughly compared to the western part of the Netherlands. Results from DEMNAT aggregated for districts should therefore be corrected in order to limit this systematical bias in results.

DEMNAT-2.1 is provided with a standard method to correct aggregated results for districts (Bleij & Witte, 1994). The method is mainly based on the comparison of flora input used by DEMNAT and another more complete flora data bank. This flora data bank does not only include all FLORBASE observations but also observations present in the ATLAS-1 flora data bank made after 1975. The ATLAS-1 data bank as a lower spatial resolution (5 x 5 km gridcells) but as the information is used to correct aggregated results for districts this is not a problem. For each district a score is calculated for the presence of each ecosystem type based on FLORBASE-1 (S_{25}) and FLORBASE-1 supplemented with data from ATLAS-1 (S_{opt}). The results per district and ecosystem type are consequently multiplied with the corresponding ratio of S_{opt} / S_{25}.

FLORBASE-1

Apart from changes in the model concept also the input data of DEMNAT has been improved. This accounts for the hydrologic input, the input on the soil units (ecoseries) but also for the flora input. In DEMNAT-2.0 the flora data bank FLORBASE-0 was used. This large data bank was realized in a relatively sort time period but a controle on possible errors had not yet been taken place. DEMNAT-2.1 makes use of FLORBASE-1 which was subjected to an extensive error controle. In addition, also floristic information was included from most nature reserves in the Netherlands. From this data base (more than 3 million observations!) the occurrence of ecosystem types has been derived. The number of ecosystem types has been expanded from 15 to 18 due to the inclusion of three brackish ecosystem types (brackish wet herbeceous vegetation, brackish moist herbeceous vegetation and brackish aquatic vegetation) in DEMNAT-2.1.

EXPECTATIONS

The above described innovations are expected to improve the overall performance of DEMNAT. As the number of ecosystem has been expanded with three brackish types DEMNAT may also be more applicable for estimating ecological effects of climatic change. In the Netherlands increase of brackish upward seepage in the western part of the country may be expected due to sea level rise caused by global warming. Although the way in which effects of inlet water are modelled has been improved in DEMNAT still much effort is needed to improve the modelling of changes in inlet water itself. MOZART offers good opportunities but more data needs to be coupled to MOZART before modelling of water quality changes in local surface waters significantly improves.

One major issue is not yet dealt with thoroughly. The method to model recovery of ecosystems has undergone only minor changes in DEMNAT. The recovery of the ecosystem does not only depend on the hydrology but also on vegetation management and the availability of diaspores. Modelling recovery of ecosystems should be improved as most policy analyses in the Netherlands on water management, environment and nature now focuss on the retreival of nature values.

In the first part of 1996 activities are planned to improve the modelling of recovery with DEMNAT. To estimate the conditions for biotic recovery information will be used on the dispersion of plant seeds and persistence of seed banks. Furthermore, the type of vegetation management should be included in the model as this affects abiotic as well as biotic conditions (for example, possibilities for germination of seeds and settlement of plant species). At this moment especially the lack of detailed geographical information on the type of nature reserves and vegetation management in these reserves hampers the possibilities to improve the modelling of recovery.

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