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A model to predict and assess the impacts of hydrologic changes on terrestrial ecosystems in The Netherlands, and its use in a climate scenario

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Abstract

Current water management policy in The Netherlands aims to serve a multitude of land use functions, such as agriculture, industry, shipping, and drinking water supply. To attune this policy to the diversity of functions, computer models are used to predict the consequences of various policy options as a part of PAWN: the government's Policy Analysis of Water management for The Netherlands.

Nature conservation and development is a relatively new aspect of water management policy. This article describes the PAWN model DEMNAT, which is designed to predict the impact of hydrologic changes on terrestrial ecosystems in The Netherlands. The main components of the model are explained and the predicted effects of an assumed climatic change are discussed.

1. Introduction

In the Netherlands the overall responsibility for water management lies with the Public Works Department (Rijkswaterstaat) of the Ministry of Transport and Public Works. Rijkswaterstaat performs various studies as a part of PAWN (the Policy Analysis of Water management for The Netherlands). The results of these studies are used when deciding on water management policy for the near future. About 40 prediction models have been developed within PAWN, e.g. for calculating groundwater levels or for estimating the quality of surface water. The models are used to analyze the consequences of a large number of interventions in water management for various land use functions, such as agriculture, industry, shipping and drinking water supply.

Recently, nature has come to be regarded as an important land use function that needs to be incorporated into integrated water management. Groundwater tables are very shallow in the Netherlands – in 90% of the country the water table is less than 1 m below surface in winter and less than 2.5 m below surface in summer – so more than half of the vegetation types are exclusively or largely phreatophytic (Colenbrander *et al.* 1989), and hence are vulnerable to hydrologic changes. Rijkswaterstaat, in cooperation with a number of research institutes, developed the national hydro-ecological prediction model DEMNAT (Dose Effect Model for terrestrial NATure; Witte 1990) to include the nature function explicitly in PAWN. DEMNAT enables the impacts of hydrologic changes on plant species richness of several terrestrial ecosystems to be predicted. In addition, DEMNAT evaluates these impacts in terms of nature conservation.

DEMNAT was used in policy analysis to prepare an important document on national water management (Ministry of Transport and Public

Works 1989). It can also be used in analyzing the effects of climatic change. It is expected that in central and northern Europe, 'greenhouse warming' will result in drier summers and moister winters. In summer, this climatic change will reduce river discharges, lower the groundwater level, and change upward seepage. To counteract the negative effects of lower groundwater levels, surface water may be distributed artificially over large areas (see also Fiselier and Klijn 1991). Ecosystems of wet and moist sites will be affected by these changes.

Most of this paper is devoted to a description of DEMNAT, emphasizing ecological aspects (section 2). To illustrate DEMNAT's usefulness we have applied the model to a climate scenario (section 3). Finally some obvious shortcomings of the model and prospects for its improvement are discussed (section 4).

2. Description of DEMNAT

DEMNAT had to be used to prepare a national policy document (Ministry of Transport and Public Works 1989), and therefore only two years of development time were available. This influenced the approach adopted; for practical reasons it was decided to: (a) use the results of the existing hydrologic PAWN models as input; (b) use existing geographic data only; and (c) only consider vegetation as representative for the biotic part of ecosystems. The latter restriction is commonly accepted in The Netherlands for hydro-ecological studies, for two reasons: first, the relationship between the abiotic environment and plant life is considered to be rather straightforward, whereas the relationship between the abiotic environment and fauna is more indirect; secondly, the value (expressed as a number) of an area for nature protection is usually deduced from the vegetation (Van Wirdum 1986).

DEMNAT is designed to predict the effects of hydrologic changes on the vegetation of terrestrial ecosystems. Three modules can be distinguished within DEMNAT: (a) a Geographic Information System (GIS); (b) a system for valuating nature; and (c) a calculation module. The GIS module comprises geographic data on hydrology and ecosystems. In it, overlays are constructed to retain units (*ecoplots*) that can be regarded as homogeneous in their reactions to hydrologic changes (*doses*). In the nature valuation system, each ecosystem type is valued in terms of its merit for nature conservation. Finally, the calculation module uses *dose-effect functions* to predict the effect of hydrologic changes on the plant species richness of ecosystems and the associated nature values, per ecoplot.

The three modules will be described in detail below.

2.1. Geographic information used in DEMNAT

Various geographic data are required on the predicted hydrologic change and on variables that determine the consequences of such a change on the vegetation. They are: (a) hydrologic data; (b) site condition data, which determine what effects hydrologic change will have on vegetation; and (c) vegetation data.

We obtained geographic information on site conditions and vegetation using an existing ecosystem typology for The Netherlands (Stevers *et al.* 1987), adjusted for our purposes (Klijn 1988; Witte and Van der Meijden 1990). This typology describes vegetation in relation to operational, *i.e.* directly active, site factors. Within the area involved in the PAWN study (see Figure 1), the following site factors are assumed to be decisive in explaining the spatial variation of ecosystems, as reflected by plant species composition:

- abiotic: soil moisture regime, nutrient availability and acidity;
- biotic: structure of the vegetation.

All site factors are classified separately in ranges relevant to plant species composition. Figure 2 distinguishes the classes; each vegetation structure class is indicated by a capital letter, each abiotic site factor class by a number. The combinations of classes encountered in reality are distinguished as *ecotope* types. Each ecotope type is coded by its classes, for instance: 'H27' stands for a herbaceous vegetation (H) on a wet (2) and moderately nutrient-rich (7) site. Each realistic combination of

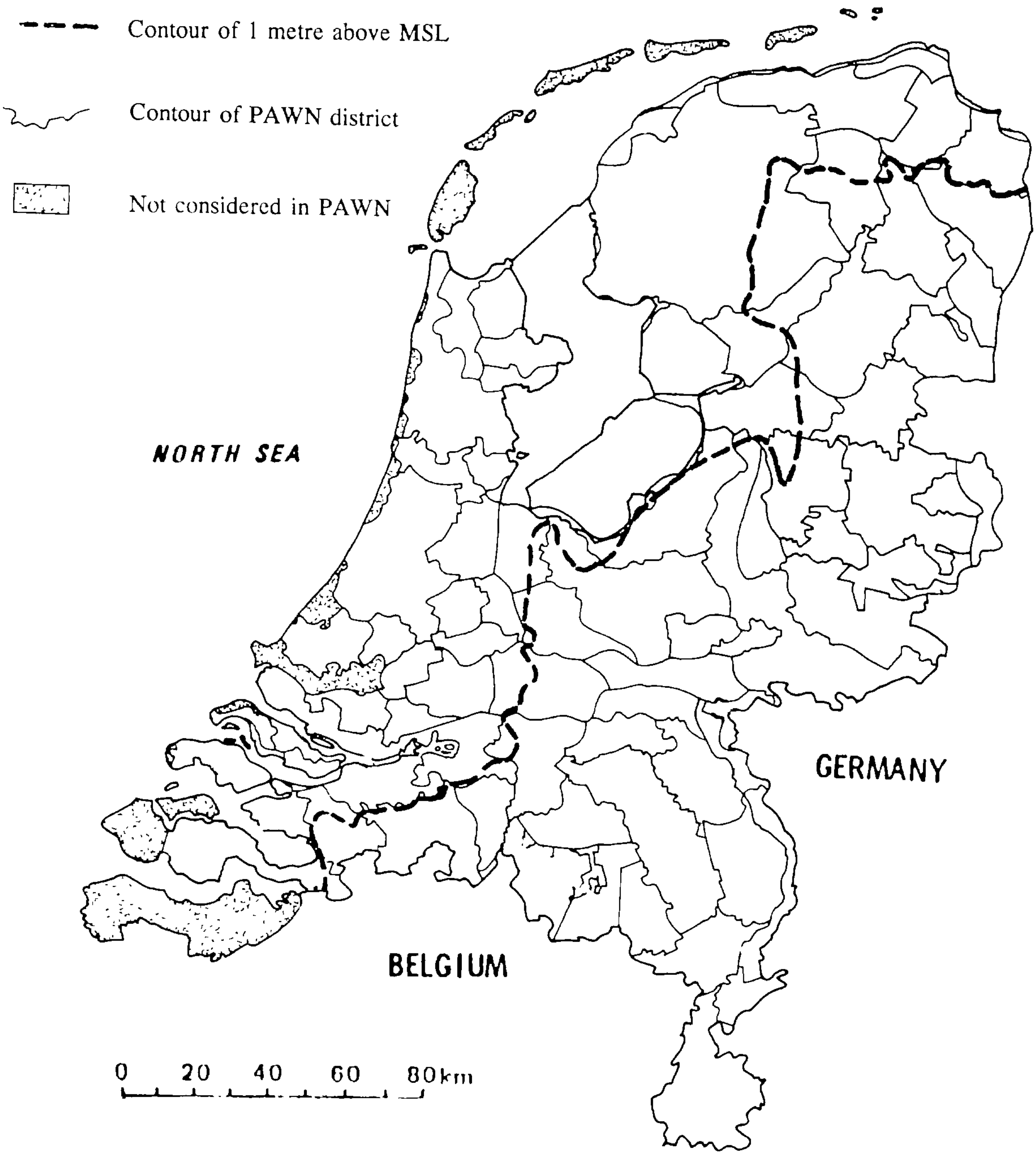

Fig. 1 Map of the Netherlands showing the PAWN districts and the division in a western and northern low-lying area, and an eastern and southern high-lying area. The boundary between these areas has been arbitrarily chosen to be 1 m above mean sea level (MSL) contour.

abiotic classes results in an *abiotic site* type, indicated by the capital 'S' (site), followed by the numbers for the abiotic classes. An abiotic site type may carry different vegetation structures; *e.g.*, S27 may carry herbaceous vegetation (H27) or a woodland (W27).

We subdivided each abiotic site type into *relational* site types to take account of differences in how vegetation reacts to changes in hydrology.

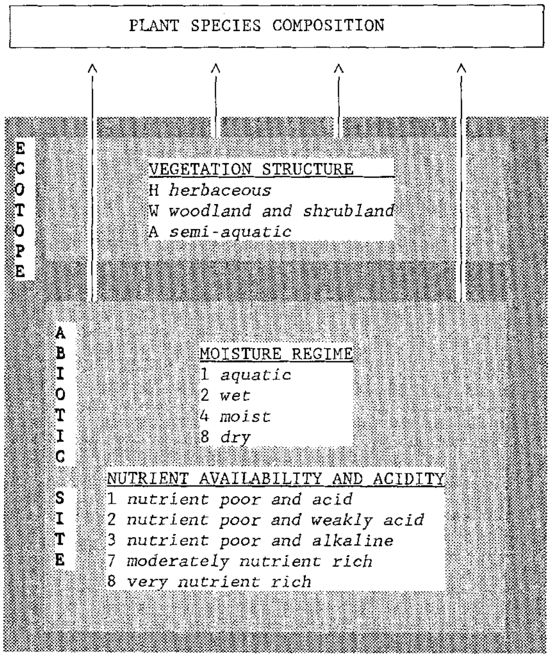

Fig. 2. Schematic presentation of an ecotope and its abiotic site. The differentiating characteristics (all relevant to plant species composition) are in underlined capitals; the classes that determine the ecotope type/abiotic site type are italicized and coded with a capital letter or a number.

This reaction is controlled by processes such as mineralization, eutrophication and acidification, which depend on soil properties such as 'parent material' and 'organic matter content'. The classes 'peat', 'clay', 'humic sand', and 'non-humic sand' were distinguished for subdivision of abiotic site types. For instance, 'S21' comprises 'S21 peat' and 'S21 non-humic sand'. Each relational site type relates to one specific dose-effect function; hence the adjective 'relational'.

The following geographic information is used in DEMNAT:

a. Maps of hydrologic information to locate hydrologic changes, calculated with PAWN models;
b. Maps showing the presence of several ecotope types and their relative plant species richness (*completeness*) on a 5× 5km grid;
c. Maps showing the distribution of abiotic site types on a 250× 250m grid to specify the location of each ecotope type within its 5×5km cell;
d. Distribution maps of relational site types to determine the impact of a hydrologic change on the vegetation.

We will describe these maps in more detail, including their construction and use in DEMNAT, below.

2.1.1. Hydrologic data

For modelling purposes the Netherlands are divided into water management units, referred to as *districts* (there are 77 districts in the Netherlands; see Figure 1) and *subdistricts* (144 subdistricts). The existing hydrologic PAWN models generate results in terms of changes in water quality for each district and in groundwater level for each subdistrict. To use these outcomes as input to DEMNAT, we transformed the districts and subdistricts to grid cells of 250× 250m.

Podzol soils having a perched water table may carry vegetation of wet/moist, nutrient-poor, acid sites. Because these soils cannot be influenced by water management, they must be considered separately when analyzing water management policies. Therefore we mapped the probable occurrence of perched watertables.

For every 5× 5km grid cell we investigated the possibility of surface water flowing in from the main rivers and channels.

2.1.2. Ecotope types

On the major problems we faced was the absence of suitable information on ecotopes in the Netherlands. We derived this information from a national floristic data base (Mennema *et al.* 1980, 1985; Van der Meijden *et al.* 1989), which contains data on the presence of all indigenous vascular plant species in grid cells of 5×5km for two inventory periods (1902–1950 and 1950–1980).

We used the floristic data of the second inventory period to determine approximately the actual distribution and relative plant species richness (completeness) of ecotope types (Witte and Van der Meijden 1990). Table 1 describes the 12 ecotope types taken into account which we considered all worthy of nature conservation. Ecotope types of semi-aquatic sites (terrestrializing sites and small water bodies, such as ditches) and wet sites were selected because they can be affected by water management. Only two ecotope types of moist sites were considered; the other types often occur on clay and loam soils having much available soil moisture but a deep groundwater level. These soils are hardly susceptible to changes in groundwater level.

We obtained geographic information on the presence and completeness of the ecotope types involved as follows. First, indicator species were selected for each ecotope type, by applying an established division of plant species into ecological groups (Runhaar *et al.* 1987). Using this division, each plant species was ascribed to the ecotope types it prefers. Then, the number of indicator species for an ecotope type found within a grid cell, the score, was used as an index of presence. It was decided that the score should exceed a certain threshold value before presence could be assumed. Finally, beyond this threshold value the score was interpreted as a measure of completeness. Because every ecotope type has its own number of indicator species, the scores of different types are not directly comparable. Therefore scores were normalized to a *completeness factor* F_c proportional to the relative species richness.

The distribution of ecotope types has been published in maps in which the completeness factor is ascribed to three floristic quality classes, qualified as 'moderate', 'good', or 'very good' (Witte and Van der Meijden 1990). As an example, Figure 3 shows the distribution map of H21 (herbaceous vegetation on wet, nutrient-poor and acid soils), one of the 12 ecotope types selected.

2.1.3. Abiotic and relational site types

The Soil Map of The Netherlands (scale 1: 250,000) is stored in grid cells of 250× 250 m (Steurs *et al.* 1985). We used this data base to estimate the spatial distribution of abiotic and relational site types, corresponding to the selected ecotope types.

Table 1 includes a description of the abiotic site types concerned. First, each abiotic site type was ascribed to units from the soil map (Klijn 1988). This enabled maps of the 250× 250 m cells of abiotic site types to be obtained by graphically presenting all the soil map units corresponding to an abiotic site type (Witte and Van der Meijden 1990). Because of the geographic imprecision of the floristic data (5 × 5 km cells), the abiotic site maps are used in DEMNAT to specify the location of ecotope types within their grid cells. As an example, Figure 4 shows the probable distribution of abiotic

Table 1. Ecotope types and abiotic site types used in DEMNAT.

Code	Ecotope type	
	Abiotic site type	Vegetation
H21	Wet, nutrient-poor, acid soils	pioneer vegetations and grasslands
H41	Moist, nutrient-poor, acid soils	as H21
H22	Wet, nutrient-poor, weakly acid soils	as H21
H42	Wet, nutrient-poor, weakly acid soils	as H21
H23	Wet, nutrient-poor, alkaline soils	as H21
H27	Wet, moderate nutrient-rich soils	as H21 and tall herb vegetations
H28	Wet, very nutrient-rich soils	as H27
W27	Wet, moderately nutrient-rich soils	woodlands and shrublands
W28	Wet, very nutrient-rich soils	as W27
A11–A12	Nutrient-poor, acid and neutral waters	semi-aquatic and helophytic vegetations
A17	Moderately nutrient-rich waters	as A11–A12
A18	Very nutrient-rich waters	as A11–A12

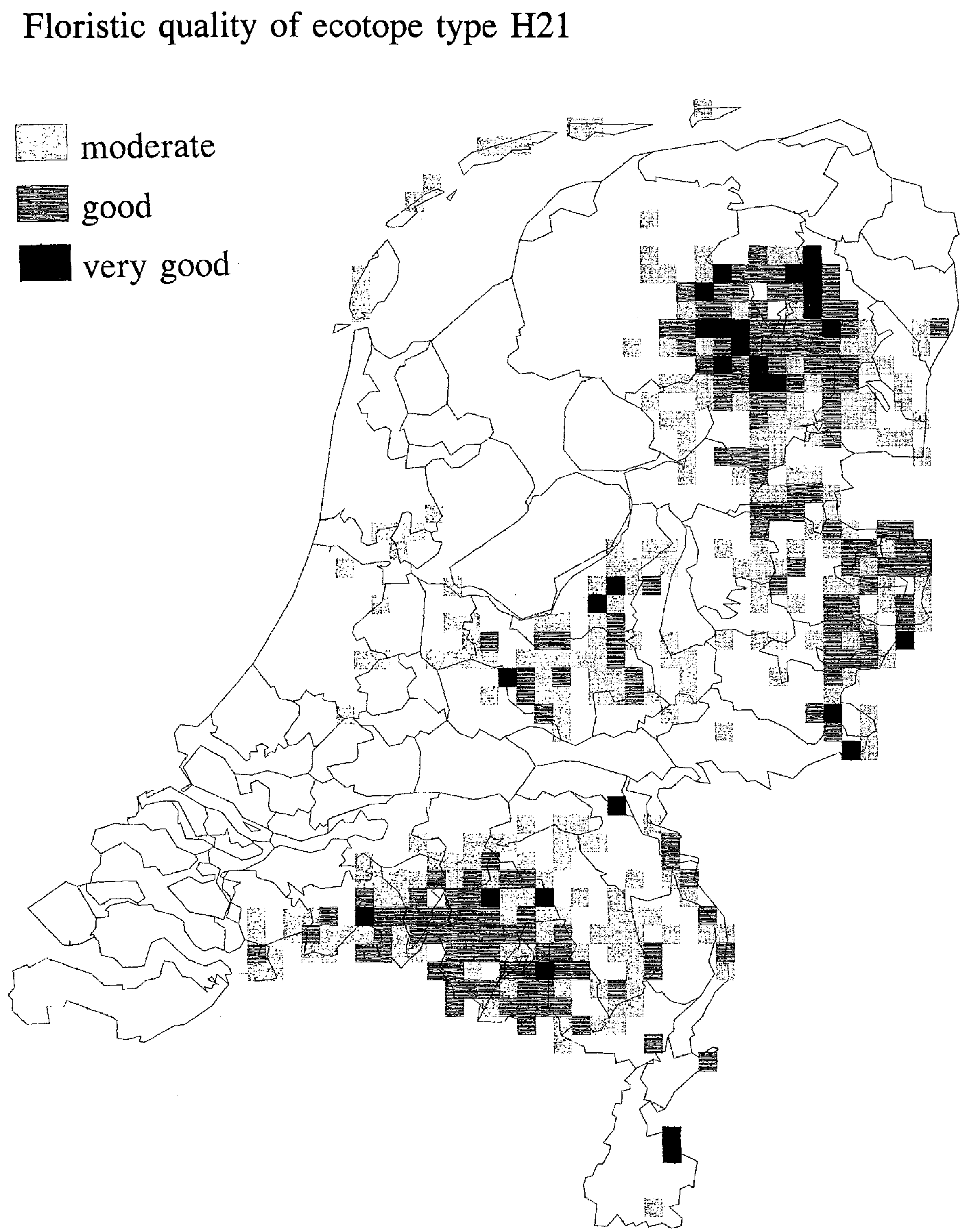

Fig. 3. Distribution and completeness of ecotope type H21: pioneer vegetations and grasslands on wet, nutrient-poor, acid soils. As a background, the contours of the PAWN districts are shown.

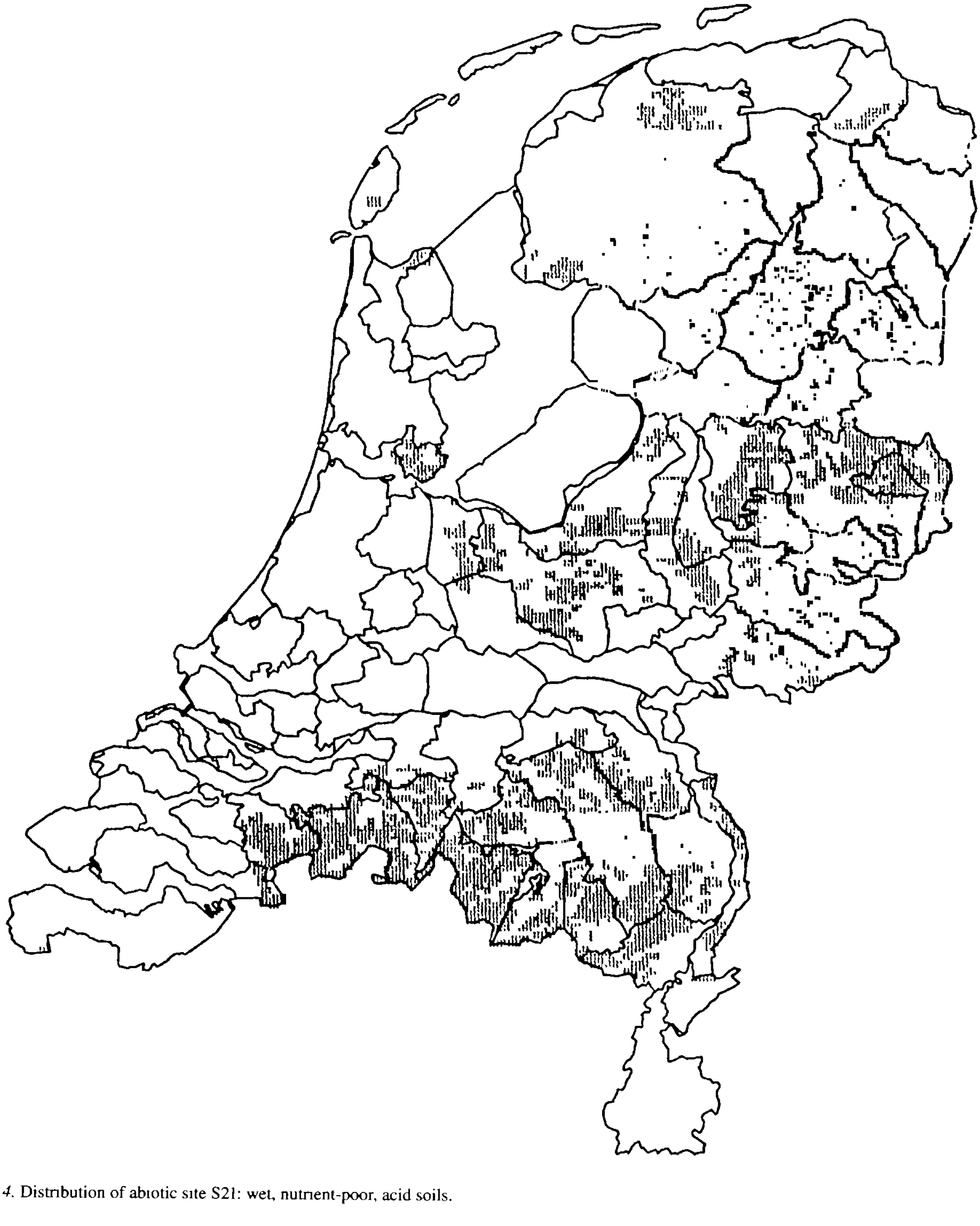

Fig. 4. Distribution of abiotic site S21: wet, nutrient-poor, acid soils.

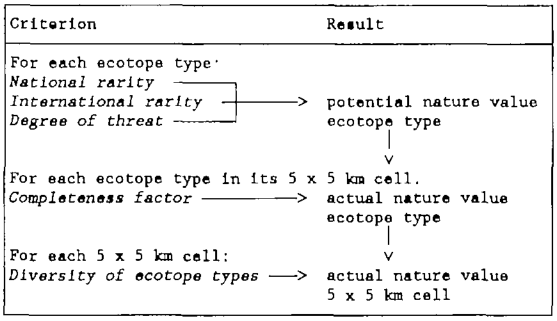

Fig. 5. The nature valuation criteria used in this study.

site type S21; Figure 4 corresponds to the map of ecotope type H21 (Figure 3).

We investigated the distribution of relational site types in a similar way. In DEMNAT, the relational site type is used as an interface between hydrology and vegetation: as will be explained in section 2.3.2., it determines the impact of a hydrologic change (dose) on the completeness factor of the associated ecotope, type. In total, 28 relational site types are distinguished.

2.1.4. Combining geographic information: the ecoplot

For the calculation module we combined the maps of subdistricts, relational site types and the 5×5 km cells to make one map, in order to achieve calculation units called *ecoplots.* An ecoplot is the basic element for which calculations are carried out. The use of these primary geographic units provides readily accessible information for the calculations, and hence limits the computation time for a DEMNAT run.

Each ecoplot is described by number codes for its 5× 5 km cell, its subdistrict, and its relational site type. Moreover, the following information – to be used in the calculation module (section 2.3) – is attributed to each ecoplot:

a. The area of the ecoplot as a fraction of its associated abiotic site type (AF_{PLT}). As mentioned above, we used the abiotic site map to specify the location of an ecotope type within its 5× 5 km cell. The map area of the abiotic site is in turn subdivided into ecoplots of different sizes. We assumed that each ecotope type is distributed over its associated ecoplots, in proportion to their area. On the basis of this assumption, the results per ecoplot have to be multiplied by AF_{PLT}.
b. The areal fraction of Dutch territory within the 5× 5 km cell (AF_{NL}). On the border with Germany and Belgium, grid cells do not lie wholly within Dutch territory. Hence, the ecoplot results also have to be multiplied by AF_{NL}.
c. Weighting factors to scale down the hydrologic change per district or subdistrict to the ecoplot. These weighting factors are based on assumptions about the relative hydrologic change in various soil units (for more information on this, see Witte 1990).

2.2 Nature valuation

A nature valuation is need to compare the impacts of hydrologic changes on different ecotope types with respect to nature conservation. Moreover, nature valuation enables the outcomes for the different ecotope types to be combined, thus yielding comprehensive results that are useful for policy makers. Because the valuation of nature is rather subjective, we separated strictly the prediction of effects on the completeness factor from the assessment of these effects in terms of nature conservation.

The criteria we used in the nature valuation are

Table 2. Potential nature values (V_{Pnt}) for the selected ecotope types.

Code ecotope type	V_{Pnt}
H21	2.4
H41	2.6
H22	3.7
H42	3.8
H23	5.0
H27	1.7
H28	1.0
W27	1.9
W28	2.0
A11–A12	3.9
A17	2.2
A18	1.4

shown in Figure 5. The potential nature value for each ecotope type, V_{Pot} was determined from the criteria 'national rarity', 'international rarity', and 'degree of threat'. The potential nature value refers to floristically well-developed representatives of the ecotope type in question. For each ecotope type, national rarity was deduced from its ecotope map, by summing the completeness factors of all the cells on a map (ΣF_c). This was done for both inventory periods (1902–1950 and 1950–1980), thus revealing the recent decline of each ecotope type. This was assumed to be a good measure of the degree of threat. International rarity was determined on the basis of literature. Finally, the three criteria, national rarity, international rarity and degree of threat, were combined to yield potential nature values on a 5-point scale. These values are shown in Table 2.

The nature value in the 5×5 km grid cell of ecotope types that are not floristically well-developed, the *actual nature value* (V_{Act}), is determined from the completeness factor and from the potential nature value, by multiplying these factors.

Adding all the actual nature values of the ecotope types within a grid cell yields the actual nature value of groundwater-dependent ecotope types per cell. Through this process the diversity in ecotope types is automatically introduced as an additional criterion for nature value.

2.3. The calculation module

2.3.1. Hydrologic doses

In the calculation module, the hydrologic changes calculated with the PAWN models per district or subdistrict are attributed to ecoplots by means of the weighting factors mentioned in section 2.1.4. After this down-scaling, the hydrologic changes are used as doses for calculating effects on the ecotope types. The following types of dose are considered:

a. *Change in mean Spring Groundwater Level (dSGL)*
In the Netherlands, variety in plant species composition is usually highly correlated with the SGL (Runhaar 1989). The SGL is a measure for site factors that influence vegetation more directly, such as soil temperature and the availability of moisture and oxygen.

b. *Change in intensity of upward seepage*
Many highly valued plant species are found in areas with upwelling lithotrophic water (see *e.g.* Both and Van Wirdum 1981; Dijkema *et al.* 1985; Beltman and Grootjans 1986). Upwelling mitigates fluctuations in groundwater level and supplies groundwater rich in calcium, *i.e.* alkaline, but relatively poor in nitrogen and phosphorus. In the Dutch climate – which has an annual precipitation surplus – seepage and slight changes in relief can promote site heterogeneity in wet terrains, with an influence of rainwater in the relatively elevated sites, and of groundwater in the lower sites (Van Wirdum 1991).

c. *Change in surface water quality*
An influx of water with a chemical composition alien to the local surface water can affect the chemical conditions of a site and hence the plant species composition. Concentrations of N, P, Ca and Cl are the parameters used to assess water quality, in combination with the relative volume of water supplied to a PAWN district.

2.3.2. Dose-effect functions

DEMNAT uses dose-effect functions to predict, per ecoplot, the impact of the hydrological doses on the completeness factor (dFc) and the associated actual nature value ($dV_{Act} = dF_c \times V_{Pot}$) of each ecotope type.

Unfortunately, no systematic descriptions of the response of plant species and vegetation to changes in the water regime were available. It was impossible to incorporate existing hydro-ecological models such as ICHORS (a multidimensional response model for individual plant species; Barendregt and Wassen 1989), or WAFLO (a model based on assumptions concerning the reactions of operational site factors and corresponding plant species; Gremmen *et al.* 1990) into DEMNAT, because these models require too much detailed input data for application to the whole of the Netherlands.

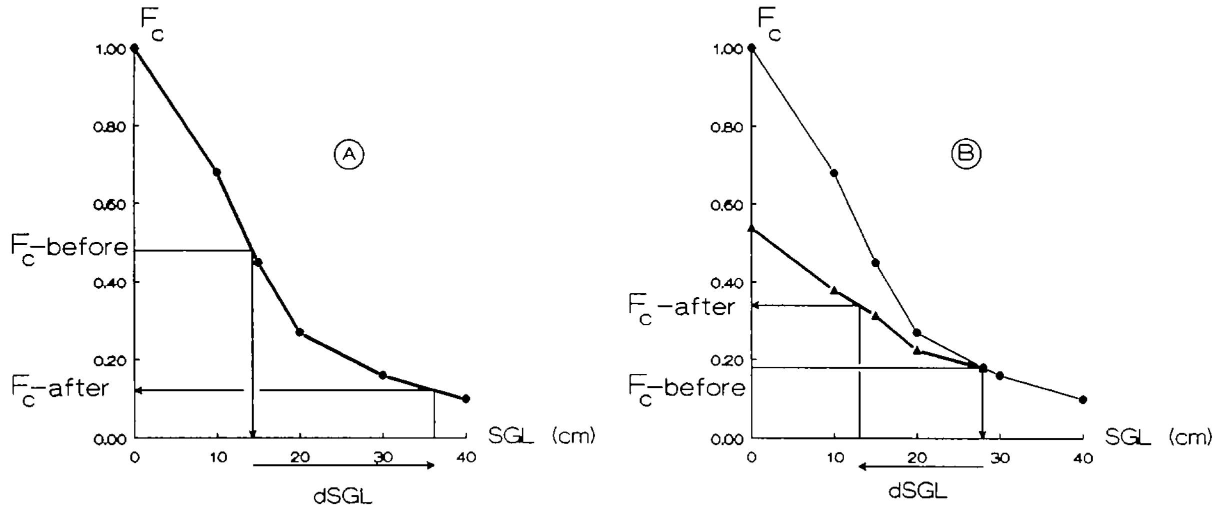

Fig. 6. Example of a dose-effect function for a change in the mean Spring Groundwater Level (dSGL) and its use (viz. ecotope type H21 on relational site type 'S21 peat').
A: with a fall in the SGL; B: with a rise in the SGL.

In DEMNAT we considered the relational site as a black box that directly controls the effect of a dose on the completeness factor. In brief, the dose-effect functions were established as follows, using a data base of vegetation relevées in combination with observations on site characteristics (Groen 1989). First, frequency distributions of ecological groups versus site factors were constructed. Then, several dose values were interpreted in terms of changes in site factors for each relational site type. Finally, the effect of these changes on the ecological groups was calculated, using the frequency distributions as response curves.

The dose-effect functions relate to the medium term (about 10 years), which was considered to be relevant to policy making. Figure 6a illustrates a dose-effect function for a lowering of the spring groundwater level (dSGL< O). We compared some of the functions for a lowering of the SGL with predictions made by a number of experts on the subject (Hochstenbach and Gremmen 1989), and found an apparent agreement.

Of course Rijkswaterstaat's policy makers also wanted to be able to predict the effects of ecotope types recovering as a result of a rise of the SGL (dSGL> O). Predicting a recovery, however, requires a more complex model and additional geographic information, *e.g.* on vegetation management and the supply of nutrients through artificial fertilizers and manure. As a temporary solution, we introduced a hysteresis factor by expert judgement (Figure 6b).

We established similar dose-effect functions for the hydrologic doses 'change in seepage intensity' and 'change in water quality'. However, we consider these functions to be less reliable.

2.3.3. Working up ecoplot results

Calculations for each ecoplot result in a change in the completeness factor, dF_c, and a change in the actual nature value, dV_{Act}. These results are multiplied by the surface fractions AF_{PLT} and AF_{NL} and, if relevant, corrected for the occurrence of perched water tables. After this operation, the results are recorded in various ways, for instance per ecotope type, per grid cell, and per PAWN district. At the end of each DEMNAT-run the totals are written to files that are input to other programs (*e.g.* graphic ones), or that can be printed directly.

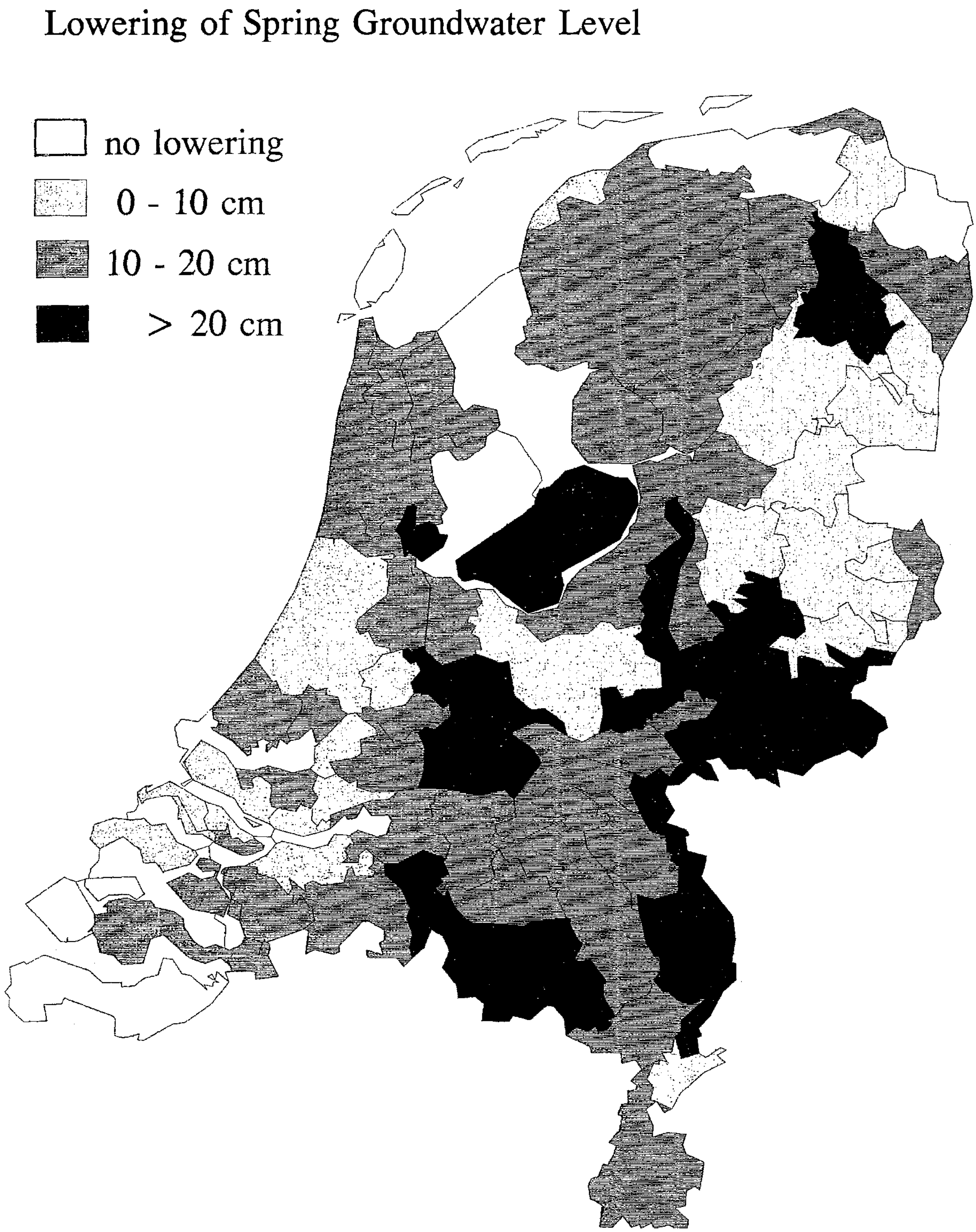

Fig. 7. Predicted change in the mean Spring Groundwater Level per PAWN district.

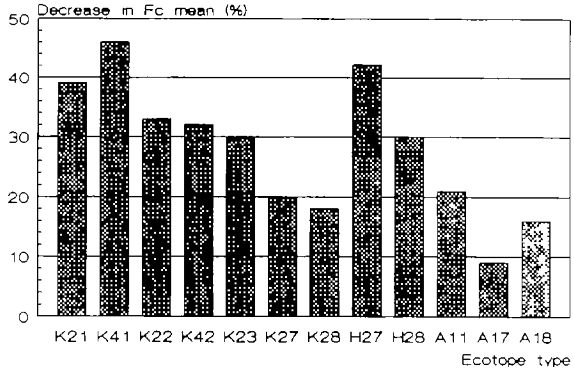

Fig. 8. Predicted decrease in the mean completeness factor of the ecotope types in the PAWN districts.

3. Predicting the effects of climatic change

3.1. The climatic scenario

To illustrate how DEMNAT can be used to predict the ecological effects of climatic change, we first postulated the following climate scenario for the Netherlands:

a. 1% increase of precipitation in winter, 9% decrease in summer;
b. an increase of the potential evapotranspiration by 47% in winter and 24% in summer;
c. sea level rise of 85 cm.

The changes in climate (a and b) are based on a study by Parmet (1991) who compared eleven years of meteorological data from two stations, one located in the Netherlands and the other in Brittany (France). Parmet assumed that the future climate in the Netherlands will resemble the present climate in Brittany, and hence data from Brittany can be used as if recorded in the Netherlands.

The assumed sea level rise of 85 cm (c) is based on a study on the effects of sea level rise on Dutch society (Rijkswaterstaat and Delft Hydraulics 1990). In that study a rise of 85 cm within the next hundred years was considered the worst-case scenario.

3.2. Hydrologic and ecological effects

We used a hydrologic PAWN model to predict the effect of this climate scenario on the SGL and the seepage intensity. We did not consider the effects of a changed water distribution on surface water quality, because no data on water quality were available. However, these effects are assumed to be of minor importance for the selected ecotope types, because they mainly affect aquatic ecosystems.

Figure 7 shows the predicted effects on the SGL per PAWN district. Obviously, considerable changes in the groundwater level may be expected throughout the Netherlands, especially in the relatively higher-lying east and south (*cf.* Figure 1), where drainage is mainly by gravity rather than by pumping. These areas are of special interest in terms of nature conservation because of the presence of nutrient-poor sites (S11-S12, S21, S22, S41, S42). In the lower-lying areas in the west and north, which mainly consist of polders (*i.e.* land reclaimed from marshes or the sea), the effect on the SGL seems less. This can be ascribed to the possibility of controlling surface water levels in the polders and to an increased upward seepage caused by sea level rise.

The ecological impacts of changes in SGL and in upward seepage were predicted with DEMNAT. For this application, the occurrence of perched water tables was disregarded. Figure 8 shows the effect on the mean completeness factor in the PAWN districts for all the ecotope types selected. As expected, the ecotope types of nutrient-poor sites show an especially substantial decline. The mean decline in nature value per PAWN district is presented in Figure 9; this figure roughly coincides with Figure 7.

4. Discussion

As stated in the introduction, DEMNAT was developed as a decision-supporting prediction model for Dutch national water management policy, within the framework of PAWN. Therefore, it was designed primarily to examine hydrologic changes

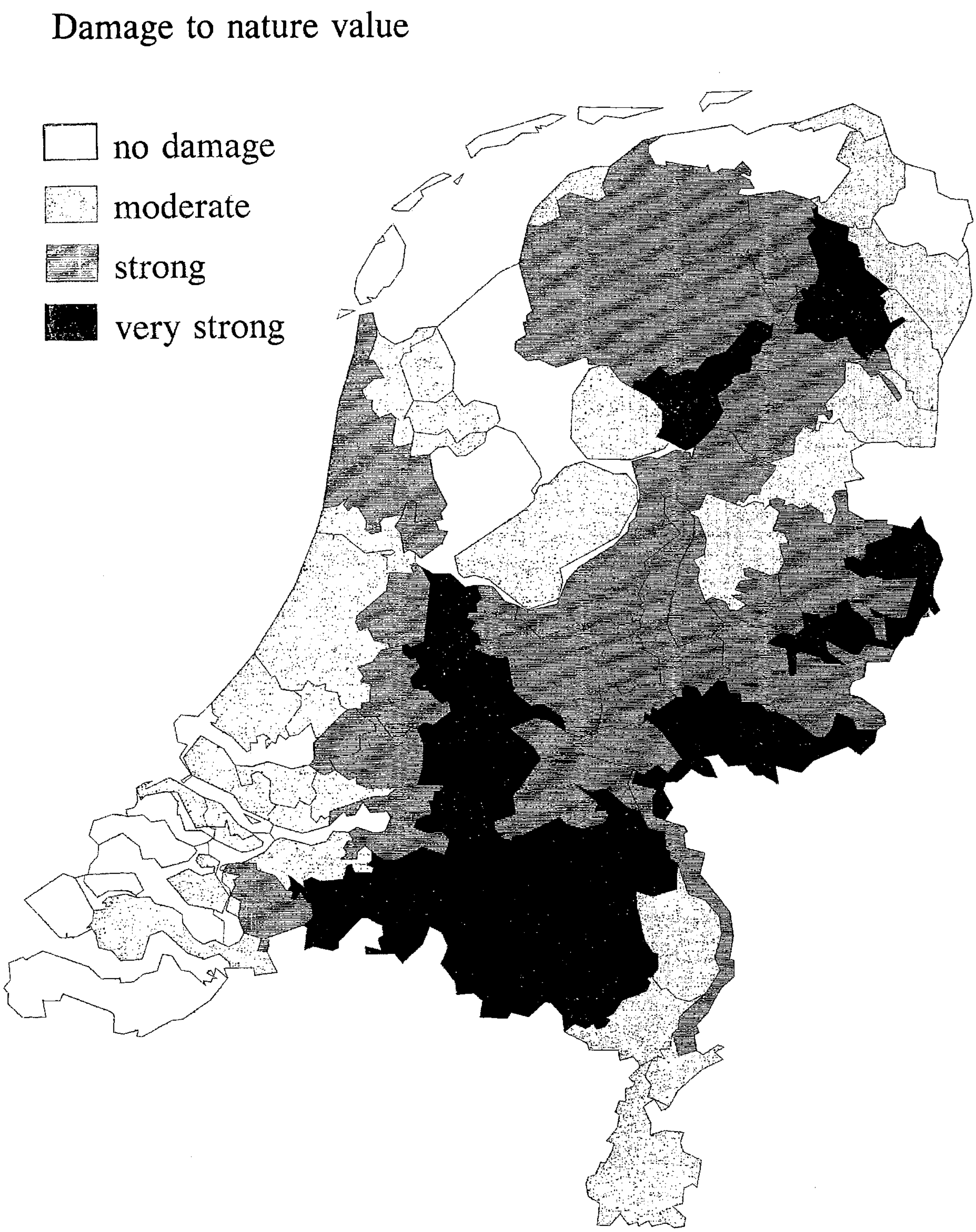

Fig. 9. Predicted decrease in the mean nature value per PAWN district.

anticipated within the next decades as caused by human intervention. The question therefore arises whether DEMNAT can be applied to climate scenarios. The dose-effect functions used in DEMNAT were designed for predictions over the medium term. Consequently, DEMNAT may be the wrong tool to use in climate scenarios, because climatic change takes place on a much longer time scale. Moreover, DEMNAT does not take account of the effect of temperature rise on ecotope types. On the other hand, as Figure 7 shows, the hydrologic change induced by the greenhouse warming could be substantial, and this may overshadow the effect of a temperature rise.

All in all, DEMNAT's application to a climate scenario is to some extent questionable. We postulate nevertheless that DEMNAT may be useful for indicating trends in ecological changes and changes in nature conservation values resulting from climatic change.

5. Shortcomings of DEMNAT and prospects for improvements

In the most recent policy analyses of Rijkswaterstaat, DEMNAT proved to be a helpful tool in assessing the influence of water management measures on the natural environment (Claessen and Witte 1991). However, the outcomes required careful interpretation by experts, partly because of shortcomings in the geographic data and the dose-effect functions used.

As far as the geographic data are concerned, we must stress that the hydrologic changes were predicted for entire PAWN subdistricts, which vary in size from dozens to hundreds of km^2. Though these hydrologic changes are scaled down in DEMNAT, hydrologic predictions for smaller calculation units would be a far better basis.

Additionally, the completeness of ecotope types had to be derived from the occurrences of plant species in 5×5 km grid cells, recorded during an inventory period of several decades. This implies imprecision on location of a species, no information on its abundance, and lack of knowledge on the combined occurrence in both space and time of species from the same ecological group. Furthermore, there appeared to be regional differences in the intensity with which the floristic inventory was carried out, depending on, for instance, the industriousness of the provincial governments.

Finally, the abiotic site maps were derived from soil maps, which do not contain information on nutrient availability, which is affected by the supply of nutrients through artificial fertilizers and manure. Nor is the information entirely up-to-date because soil mapping takes dozens of years and meanwhile some factors (notably groundwater level) may change dramatically.

Because DEMNAT had to be developed so quickly, there was not enough time to gather the best existing field data for deriving dose-effect functions. Moreover, the assumptions made when inferring the functions were necessarily rather rough. For instance, the capacity of plant species to migrate to new sites in response to hydrologic change was not taken into account. And a disputable hysteresis factor was introduced for the recovery of the vegetation.

Clearly, DEMNAT is not yet a finished turn-key prediction model. However, we believe its basic physiology is healthy and that it deserves further development.

In cooperation with the National Research Institute of Public Health and Environmental Hygiene (in Dutch: RIVM), we plan to achieve improvements by upgrading the geographic data. First, hydrologic changes need to be predicted more accurately. This is outside the scope of DEMNAT, but falls within the task of Rijkswaterstaat. Hydrologic models that generate more accurate changes in groundwater levels and seepage intensity will be adapted, for instance, for calculation units of 1×1 km. Next, the data on ecotopes will be updated and geographically refined. Using existing floristic data, we will construct ecotope maps for the period 1980–1990 with grid cells of 1×1 km as a basis. Finally, we intend to achieve more accurate site mapping by using a more detailed soil map and additional data, *e.g.* on nutrient supply.

The dose-effect functions also need improvement. We plan to revise these functions, using more field data and better-founded assumptions.

We may also look at long-term changes; this may mean considering the possibility of one ecotope type changing into another. Further improvement can only be established over the long-term, if more systematic descriptions of vegetation and site characteristics become available. At present there are not enough reliable data to validate the dose-effect functions (Gremmen *et al.* 1990), and therefore a systematic monitoring program during a period of many years in carefully selected sites is urgently needed. This, however, is outside the scope of DEMNAT.

When upgraded, DEMNAT may become a useful tool for deciding which water management strategy is least harmful to nature values confronted with changing climatic conditions.

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