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WATER RELATED IMPACTS ON NATURE PROTECTION SITES

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ABSTRACT

Models for the prediction of impacts of water-related projects on nature protection areas are often based on the assumption that the involved sites are homogeneous with respect to the operational environment of spontaneously settled plant species. This is shown to be a false assumption. As a consequence, the site requirements for nature protection cannot be immediately derived from autecological records, as it is done in agricultural impact models. Both types of impact models are compared. In this contribution, the nature site is conceived as an ecological device, which itself requires a singular environment in order to safeguard the requisite internal variety. Impact models for nature protection should be based on the environmental requirements of such ecodevices, rather than those of the individual species. Current Dutch models are compared with regard to the description and the role of the sites.

1 INTRODUCTION

Some statistical figures about the development of The Netherlands (Table 1, Centraal Bureau voor de Statistiek, 1979, 1985) can illustrate how much the Dutch must have modified their land to relieve the needs of the human society. Most of the surface area, 96% of 41473 km^2 in 1983, is directly used for this purpose, and the total land area is even continuously being enlarged by land reclamations. Much of the remaining 'waste land' is reserved for nature protection: 2.9% of The Netherlands. The society needs include drinking and industrial water use, and these have disproportionally grown because of the increasing standard of living. The industrial use of water is estimated to be about twice as large as the public water use. Several hundreds of land-improvement plans for large areas were realized after 1950, including an often radical revision of the water management. Especially the animal productivity grew enormously.

Table 1 Statistics of the population density, the drinking water withdrawal, the production of milk, meat, and dung, and the use of fertilizers in The Netherlands

Year	1950	1983
Population density (people per km^2)	309	423
Public drinking water supply (x 10^6 m^3)	317	1072
viz., groundwater	239	738
surface water	78	334
Milk production (x 10^6 l)	5771	13207
Meat production (x 10^6 kg)	400	2468
Dung production (x 10^6 kg)	ca 20000	51682
i.e., P as P_2O_5	70	179
N	117	290
K as K_2O	124	277
Use of fertilizers (x 10^6 kg):		
P as P_2O_5	120	87
N	156	478
K as K_2O	155	117

These numbers tell how important water-related engineering projects in The Netherlands are, and how severely they almost must interfere with nature protection, both in the 'waste land' area, including the nature reserves, and in the corners of the cultivated land area.

In order to take account of the needs of nature protection in forthcoming water-related projects, and to possibly stop the harmful effects of historical and ongoing projects, it is desired to state these needs in a formal and quantitative way which should also allow for impact assessment. The SWNBL study (Oosterbaan, 1986) sped up studies in this field in order to make a general impact model available.

This contribution focuses on the impact on the spontaneous vegetation, since the vegetation is often used to determine the value of an area for nature protection, and since the impact on the vegetation seems to be somewhat more straightforward than it is on the fauna. A comparison is made with current approaches in agriculture to show the large differences. Mentioning of less representative cases, such as reed cropping as an agricultural item, or salt marshes for nature protection, is avoided. These are not the main problem areas for the present study. The discussion is extended to some of the logic which is being used in nature protection models. A general scheme which covers both types of applied ecological models serves as a starting point. Individual parts of the present reasoning have been presented in earlier publications (van Wirdum, 1979, 1981, 1982a,b, 1985a).

2 THE PROBLEM

In order to state the impacts of water-related projects on nature protection it is tried to answer the question:

What relates the objets d'art of the water engineers to wild plants?

An analogous problem has been solved for agriculture by primarily considering the physiological **requirements of the species** (crops) involved. Here, a rationale will be developed which highlights the requirements for the processes in the various environments of nature, i.e., the **requirements of the sites** of the species. Although crops and wild plants all belong to the Regnum Vegetabile, it will be seen that the models which are profitably being used in agriculture are not readily applicable to the impact problems of nature protection. The reasons for this point are:

Table 2 Comparison of features of water-impact models for agriculture and for nature protection, respectively. Critical requirements have been printed in bold face

	Agriculture	**Nature protection**
1. Object features		
1a. Site	homogeneous operational environment	various operational environments
1b. Vegetation	few species of plants	many species of plants
1c. Description	site average	frequency distribution
2. Criterion	productivity of crop	capacity to fit spontaneously settled threatened species
3. Water quantity parameters		
3a. Water use by the vegetation	**minimum groundwater level (critical)**	minimal groundwater level (mostly not critical)
3b. Soil aeration	maximum groundwater level to prevent anoxia (rarely critical in impact studies)	**minimum groundwater level to prevent change of redox conditions and decomposition of organic soil components (highly critical)**
3c. Accessibility for cattle and vehicles	maximum groundwater level (rarely critical in impact studies)	of secundary importance (not critical)
4. Water quality parameters		
4a. Salt damage	fresh water required	**various requirements**
4b. Ionic composition	rarely considered	**especially litho-atmocline gradient critical**
5. Adjustment time	years	centuries
6. Relation with nutrient status via 3b and 4b	only weak, since external supply to excess status	**strong, since maximum tolerated nutrient status low**

- The objects are different: the Dutch meadows and arable fields are different from natural sites;
- Nature protection has different criteria for the evaluation of sites, i.e., the variate to be explained is different;
- The critical causative parameters appear to be different for conservational land use as compared to agriculture, and as far as the same parameters play a key role, they are often critical in a different range.

Some of the arguments for these statements are summarized in Table 2. Of course this detracts nothing from the usefulness of the results of agricultural science, even for the present purpose.

3 THE MODEL: GENERAL CHARACTERISTICS AND A FIRST APPROXIMATION

3.1 The model set-up

The following compartments are distinguished in the causal chain between a water-related project and plant performance (Fig. 1):

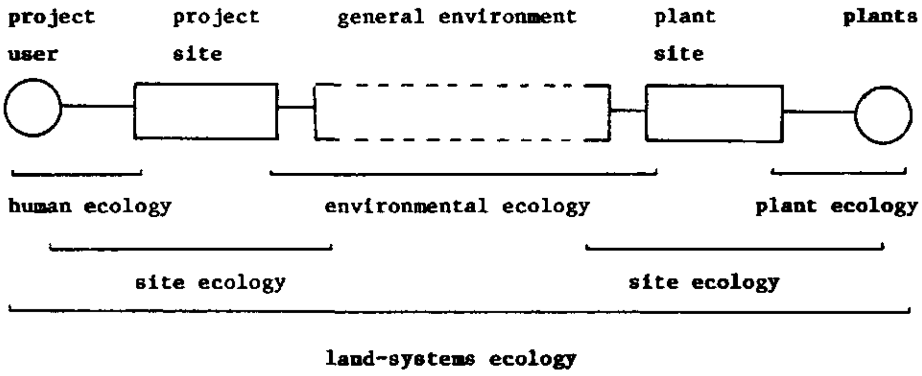

Figure 1 The causal chain of impacts; the relevant branches of applied ecology have been indicated

The **project user** has requirements, e.g., **p** m^3 of drinking and industrial water per year, or a water table not more than a cm below the soil surface in the summer, and not less than **b** cm in the winter. The **project site** is used to meet these requirements, e.g., by groundwater withdrawal, or water supply and drainage. The **general environment** dynamically sustains both the project and the plant site. Ideally, it should not be considerably changed by the work involved: the inexhaustible-resources scenario. It has appeared, however, that the general environment is most often changed a lot near the project site, though the effect decreases as the distance from the project site increases. In a model, this is formally represented by some transfer logic, including loss functions. In the case of water-related projects such logic is often based on the Darcy and continuity equations for water flow. The relevant aspects of the state of the general environment near the **plant site** can thus be determined. The latter may be an arable field, or a nature reserve, etc. It should fulfil the requirements of the **plants**.

Sites, in turn, transfer the information from the general environment to the **operational environment** of the plants, especially to the root zone. The properties of the site determine how this information is modified during transfer and thus constitute **conditional factors**. Since the site is the last compartment through which the information is passed to the plant it is imperative to have a reliable model for site processes. Details which may be neglected in the model of the general environment must often be considered in the model of the site. This will be shown to be the bottleneck in studies of the causal chain of impacts on spontaneous vegetation.

The aim of nature protection is commonly related to the protection of threatened species, the threats being caused by human impacts on the environment of wild organisms. One must be aware, however, that the interest is not the individual species, but the construct 'nature', which enables the spontaneous coexistence of so many different forms of life. The threatened species are indicators of the state of nature, they indicate the Achilles' heel of the natural construct. According to this concept of nature protection, the threatened organisms in a nature reserve might themselves be regarded the end users of the plant site. We still need people to formulate their requirements, however, using **criteria** and **targets** for the value of the site. Both are related to the presence of specified organisms, the indicator organisms and goal organisms of nature protection, respectively. The goal organisms are the threatened organisms themselves. The indicator organisms inform about the goodness of the protection that the goal organisms receive, and about the chance that they will appear or disappear. In agriculture, humans are obviously the end users of the site, and they also have criteria and target values, e.g., crop, milk, or meat production in kg/ha (2 in Table 2). Note that the present author is convinced that there are objective criteria for the comparison of the value of sites for nature protection. When such criteria are properly derived from the general aim stated above, there should be no objection against incorporating them in a model. The weighting of the interest of nature protection, as compared to, e.g., agriculture, in contrast, is a matter of concern at the social and political level of decision. At that level, humans consider themselves the end users of the whole of all sites, and nature protection is recognized at human will.

3.2 The varying model entities: ecological field, ecodevices, and operational environment

The sites as conceived in the above-mentioned fashion are called **ecodevices**: devices that process inputs from the general environment into the required products. **Humecs** (human ecodevices) are ecodevices which are installed to relieve immediate needs of humans. They may be related to urban and industrial functions (urban ecodvices, or **urbecs**), such as a groundwater-withdrawal station, or to rural, especially agrarian functions (agrarian ecodevices, or **agrecs**), such as an arable field. **Natecs** (natural ecodevices) are ecodevices which should safeguard the spontaneous occurrence of wild organisms. They may be deliberately installed and used for this purpose by humans: nature reserves. Ecodevices may also be used to undo or diminish the effects of other ecodevices on the general environment. Such **envecs** (environmental ecodevices: water-purification plants, buffer zones, etc.) thus limit or nullify the transfer in the general environment.

The general environment as conceived here is called **ecological field: An ecological field is an area within which the ecological properties orderly depend on space, and possibly time, coordinates.** Consequently, those ecological properties which do not do so are excluded from the field description and have to be coped with in the ecodevice one. The field factors are called **positional factors** since they explain the capacity of the ecological field to sustain ecodevices according to the place in the field.

An ecodevice is the conceptual aggregate of land components which is capable of in situ processing the ecological field properties into a user-required operational environment. The preservation of natecs thus signifies that nature protection preserves natural processes in support of the existence of wild organisms, rather than artificially preserving their operational environments, as in pot cultivation. Wild organisms are indicators of the state of health of nature, rather than themselves individually being the motives for nature protection. The main types of ecodevices are listed with their shorthand names in Table 3.

Table 3 The main types of ecodevices

ECODEVICES	- for humans:	- as to urban functions:	**URBECS**
in situ processing	**HUMECS**	- as to agrarian functions:	**AGRECS**
of ecological	- for nature:		**NATECS**
field properties	- for field stability:		**ENVECS**

Individual plants respond to their immediate environment. The immediate environment which comprises the **operational** factors is called the **operational environment** or **milieu sensu stricto:**
The operational environment of organisms is the part of their environment which immediately determines their biological performance. This notion covers the range from physiology to population dynamics. Strictly spoken the response is solely determined by the biological properties of the plants (their **biological program**).

The rightmost part of the general scheme of Fig. 1 is dealt with here, including, (1), the plants (crops or wild ones), (2), the plant sites (agrecs or natecs), and, (3), the varying properties of the ecological field at the location of agrecs and natecs, i.e., where these devices happen to be 'plugged in'.

3.3 Modelling conventions

The distinction between the ecodevices and the ecological field is a starting point for further formal restrictions in the modelling process. By way of agreement, the general environment is only capable of direct transfer of information: when the input is water, the output is not heat or birds. This is different from ecodevices. In the present systems concept, ecodevices may process a volume of water and yield a concentration of phosphate, or, indeed, even plants, birds, and humans, and anything which can have a part in the composition of the environment which the goal organisms will meet. It will be shown that even the current agricultural models formally let biomass be produced out of water. This allowance may bring about great difficulties for a physically realistic description of even only some of the complex transfers within an ecodevice. It is therefore compulsory to arrest that troublesome 'virus' within the ecodevices. The ecological field is used to derive the values of the variables which explain the possible excitation of the virus.

Accordingly, the ecological field may mostly be described by a deterministic model, while one often must resort to more or less stochastic models in order to capture what is going on in ecodevices, especially in complex natecs. In the model representation by Kemmers (1986, Figure 1), the same increase in complexity can be recognized from the ecological field towards the operational environment. It may be noted, however, that Kemmers still pinpoints the deterministically explainable functions of supposedly homogeneous ecodevices in this first-level approach.

3.4 A model for agricultural ecodevices

Several models for agrarian ecodevices which have been developed in the last decade start with the hydraulic head in the ecological field as a positional factor, measured below the lowest groundwater level observed at the plant site, i.e., in the ecodevice. The unsaturated water flow and evapotranspiration problem in the conditionally active ecodevice is then simultaneously solved to determine the flow of water through the crop (operational factor). To arrive at the end result, an empirical formula is implemented which relates this water use to biomass production and compares it to a target value for similar weather conditions (de Laat et al., 1981). This is a model of applied ecology, rather than a scientific model, since many ecodevice processes which are controlled by the same positional factor, and which have an impact on biomass production, are not being taken into account. Since J.B. van Helmont (1577-1644, cited from Russell, 1973) concluded from experiments that plant production was entirely determined by water use, agricultural science has been able to reveal the shortcomings of such a simple model. Because the other aspects of plant nutrition, especially soil fertility, are separately controlled in modern agriculture, however, the modern version of the facts which van Helmont found is sufficient in the applied agricultural model of the impact of water-related projects (3a in Table 2). In this case it is therefore not necessary for the impact model to let the ecodevice transfer anything else than water. Such a **direct-chain model** (only water transfer) is conceptually simple and can be realized on the basis of physics, although the very making is still quite an achievement (de Laat, 1980). As a device, the agrec is only weakly developed or open in the sense of van Leeuwen (1966). It is taken apart in this model, (1), to enable a more detailed description of vertical water transfer, and, (2), to let the water be processed into biomass.

Another point to be stressed is that the ecodevice in this model may be considered homogeneous (1a,b,c in Table 2). Although there may exist differences in water use at different places within the ecodevice, the average value is enough to know, provided that the differences are not extreme. This is characteristic of open devices. The operational environment is everywhere the same within such an ecodevice. Of course this is partially the effect of such human device functions as tillage measures and land improvement. In modern agriculture, agrarian ecodevices in gradients of the ecological field are designed so as to break the gradient up in discrete homogeneous parts. Such agrecs are therefore **convergent** (van Leeuwen, 1966) ecodevices.

A third reason for the relative simplicity of this agricultural model is that the relation between the hydraulic head and water use mostly shows a relatively wide optimum range: as the hydraulic head rises above a critical level, the water use is increased until it is at the maximum. A further increase of the hydraulic head has no further effects until the root zone becomes anoxic and production drops sharply. Most agricultural ecodevices in The Netherlands are provided with a drainage system which is able of preventing such a situation. This is therefore not a critical part of the range for impact models (3b,c in Table 2).

3.5 Further reflections on the agricultural model

Model parameters adapt the model to a singular case: crop parameters, soil parameters, and weather parameters. The crop parameters follow from the species and variety of crop. For some crops, additional research must be done in order to get precise results. The soil parameters can be determined by physical analysis of the soil, or they are estimated from the soil type represented on soil maps (Bouma et al., 1981). For any historical period, the recorded weather parameters can be used; otherwise they have to be inferred from the known climate. It is an important feature of the model that the soil parameters are supposed to form a rigid structure of fixed properties, i.e., properties which do not change in the long run. In other words: the device as such is invariable. This is often only justified because of tillage measures: the state of the device is frequently redressed by sawing, planting, ploughing, manuring, etc.

According to the Relations Theory by van Leeuwen (1966) it appears anomalous that open and convergent devices exhibit a deterministic behaviour. This is largely due to the choice of the variate to be explained: crop production. The crop species, however, can only grow in such devices as a result of the intensive human care. With regard to the spontaneous vegetation, open and convergent devices are characterized by a small number of species which may or may not occur, and even become dominant weeds, according to coincidences which are difficult to predict. None of them has a fixed long-term niche in the ecodevices under discussion. The pair 'large natural uncertainty - small agricultural uncertainty' symbolizes the dominance of human control functions over natural ones in agriculture. Where the human control fails, the natural uncertainty can take over, and even become a lethal factor for the users under the form of droughts and plagues. The stochastic approach of complex natecs, on the other hand, is a consequence of the processes in such natecs being determined to such a degree of precision as is beyond the human faculties of independent measuring and modelling.

Shortly, in an agricultural water-impact model for The Netherlands:
- the ecodevice may be considered homogeneous and invariable;
- a direct causal chain of water is considered;
- the model may be largely deterministic;
- the range of sensitivity should be the range of variation of crop water use under the influence of a varying suction head in the root zone.

3.6 Existing natec models

Until recently, natec water-impact reasoning was not really different from the main lines of the agricultural model. Londo (1975) uses 'groundwater influence in the root zone' as an explaining variable, which suggests that a calculation of vertical water transfer in the ecodevice might be a useful component of a natec impact model. The natec hydraulic head is mostly translated into groundwater levels, and, instead of the calculation of water use, informal knowledge or look-up tables are used to check which of the species might probably be able to survive. With this input, a formula for the evaluation usually accounts

Table 4 Summary of current water-impact models for natecs. Legend: (A) highly demanding, (B) trained personnel required, (C) formal desk study, (D) current hydrological models, (0) no prescribed procedures, expert judgment acceptable, (*) computer procedures provided

ICHORS	
Learning phase	
Field assessment of species composition of sites	(B)
Field and laboratory assessment of site characteristics	(A)
Derivation of response model for each species separately	(*)
Application phase	
Definition of site characteristics	(0)
Computation of probability of occurrence of each species separately	(*)
VEDES	
Learning phase (not always necessary?)	
Field assessment of site characteristics, inclusive of the vegetation	(B)
Classification of ecotopes	(*)
Definition of ongoing activities	(0)
Derivation of transition matrices for ecotope classes	(0)
Application phase	
Field assessment of site characteristics, inclusive of the vegetation	(B)
Classification of ecotopes	(*)
Definition of proposed activities which may have an impact	(0)
Derivation of predicted ecotope class (via transition matrix)	(*)
Evaluation of ecotope for nature protection (look-up table)	(*)
WAFLO	
No learning phase needed	
Application phase	
Field assessment of species composition	(B)
Assessment of site characteristics (from existing Dutch soil maps)	(C)
Definition of new average groundwater table in spring	(D)
Derivation of new site state (fixed models and rules)	(*)
Matching with old species list (look-up tables)	(*)
Evaluation for nature protection (formula)	(*)

Table 5 Description and use of site properties in impact models for natecs. In brackets: units of expression, or number of classes

ICHORS	**VEDES**	**WAFLO**
initial state a–c nearest open water level; summer, winter, and difference (cm) d difference of hydraulic head, summer-winter (cm) e–f upward or downward groundwater flow; summer and winter (+/-) g–t open water composition (pH, Cl, Na, Mg, Ca, K, HCO_3, NO_3, NH_4, PO_4, P-tot, S-tot, Fe-tot, Si-tot) (mg/l) u–x principal soil component; 0-30 cm, 30-60 cm, 60-120 cm; secundary component 0-30 cm (7)	**initial state** a vegetation structure (8) b succession stage (2) c substratum (2) d stability of substratum when pioneer stage (3) e soil moisture (4) f salinity (3) g nutrient level (4) h chalk/pH (2) i facultative additional quality indication (3) (all derived from a vegetation description in the standard procedure; at least a species list)	**initial state** a species list b soil type c ASG = average spring groundwater level (a can be derived from vegetation maps; b and c from standard Dutch soil maps)
cause of change (similarly defined new state)	**cause of change** j activity names, such as groundwater-withdrawal, grazing, manuring, eutrophication, etc.	**cause of change** d change of ASG (cm) e expected new ASG (cm)
		intermediate result 1 watersupply according to agricultural model (9) 2 increase of instability of environment (+/-) 3 nitrogen mobilization (empirical formula)(+/-) 4 degree of aeration (empirical formula) (10) 5 depth of ditches (3)
result probability of occurrence of 209 species according to response model from general statistics	**result** new ecotope type according to transition matrix (empirical, literature, or expert judgment) (ca 100)	**result** new species list = initial list minus species whose milieu will disappear (chance 0, 0.5, or 1) according to formalized correspondence of new state to Ellenberg and Londo milieus
evaluation suggested procedure: percentage change of probability per species respective to computed probability in initial state; weighting optional	**evaluation** attached value of ecotope type (under development)	**evaluation** according to rareness of species in The Netherlands

for species diversity and rareness of individual species. In order to cope with the many-species problem, variants of this type of model condense the species information into phytosociological groups. Others have extended such procedures to the classification of **ecotopes** (see 4.1) on the basis of both phytosociological and general ecological information. Van Gijsen (1979) discussed five then existing methods for the assessment of impacts. Her conclusion with regard to these methods is that the probably best ones yield results which are difficult to be reproduced, since they include a lot of informal 'best professional judgment'.

The formalization of water-impact models for natecs has since followed three slightly diverging lines of development in The Netherlands, yielding the models ICHORS, WAFLO, and VEDES, summarized in Tables 4 and 5.

1) The ICHORS model (Barendregt et al., 1985, 1986) consists of an entirely statistical correlative approach. Strictly, ICHORS is a matching model, rather than an impact model. Values of several parameters are measured in sites and used to derive a multidimensional response model for individual species. The 24 input parameter values for the new state, including a complete chemical analysis of the water, are derived from external sources. In the present state, the model 'knows' the response of 135 phreatophytes (see 4.3) and includes a less reliable model for a further 75 species, which are too rare to allow for an accurate calculation of the probability of their occurrence. In the sample applications provided, only the occurrence of few, more common species reaches an appreciable probability at the 95% level of significance, even in the environments that fit them best.

2) The WAFLO model (Gremmen et al., 1985) was developed to be linked with current hydrological models for the ecological field. The strict modular construction of WAFLO enables the replacement of individual modules when better alternatives become available. The input is the new groundwater level and the draw-down. It contains some logic to derive the availability of water and nutrients, the degree of aeration in land sites, and the depth of open-water sites, and uses these parameters to

predict which of the presently occurring species will formally disappear. The species are matched to the site parameters by means of the Ellenberg indicator lists (see 4.3). An additional feature is the formal reaction of 'midy-haters' according to Londo (mostly threatened species, see 4.3) to a slight change of the average depth of the water table. Kemmers (1986) explains the present efforts to improve the non-biological parts of this type of models. In the present form, the model has been calibrated and tested for the Pleistocene part of The Netherlands. The evaluation for nature protection is separately carried out. A validation has been attempted, but was not very successful. The simulation was correct for about one half of the species involved.

3) The VEDES model (Udo de Haes et al., 1985) is based on a typology of 'ecotopes'. The major, and most mature, part of the model concerns the classification of ecotopes. The assessment of impacts is realized on the basis of empirical transition matrices which are provided for some activities and ecotope types. The activities are only weakly quantified. Each ecotope type has been given a fixed base value in order to evaluate the impacts. This base value can be supplemented with a quality indication for each individual ecotope. In the present state, 78 ecotopes have been defined, of which 28 unsufficiently (Runhaar et al., 1985, p.41). Several threatened species are unknown to the model, e.g., 8 of the 20 species which are listed in Table 7. The method includes a great amount of expert judgment. Hence, the reproducibility of results is uncertain. A related model at a further level of abstraction has been presented by Canters & Udo de Haes (1986).

Stimulated by contract research and marketing perspectives the different lines of development each go their own way, and a clear comparison of the pros and cons, of the similarities and dissimilarities, and of the actual stage of development and testing is not available at present. As far as the present author knows, the WAFLO model is the only one for which all fundamental information has been published until now, inclusive of a sensitivity analysis and validity testing. In the following an attempt is made to discuss some of the different elements of the models.

4 SITES IN THE CURRENT MODELS

4.1 Milieu, ecotope, and ecodevice: different ways to look at a site

Although it may be possible to study the operational environment of a free-floating alga in nature, it is unpracticable to separate the operational environment of a rooting plant at a natural site. In order to gain information on this point, the **site which contains the operational environment** is sampled:

Depending on the study objectives, a site in ecology is the smallest separately considered environmental envelope comprising and sustaining the operational environment of the organisms of interest. A dynamic relation exists between the milieu, the plant of interest, and the other components of the site.

In planning and impact studies to a mapping scale of, e.g., 1:50 000 the lower limit for site size is approximately 250 x 250 m^2. Such large sites may obviously accomodate several different operational environments at once. The ecodevice concept stresses the possible non-equivalence of sites to operational environments.

The following situations can occur:
1) the site is rather homogeneous: the same operational environment and one plant species are dominant all-over, as in many agrarian ecodevices;
2) the site is slightly inhomogeneous. Yet the different operational environments have much in common, and the different plant species may be considered as one ecological group. Their distribution over the site is more or less random;
3) the site is definitely inhomogeneous. The average value for any of the operational factors in the different milieus is not representative of what the goal organisms of nature protection require.

All three natec models summarized in Table 4 are based on a case-2 site concept. The actual sites investigated meet several requirements of which the ecotope concept in the VEDES model may be considered representative (Runhaar et al., 1985). Udo de Haes et al. (1985)

specify:

'An ecotope is an area which is homogeneous with respect to its vegetation structure, its succession stage, and a number of abiotic factors', and list the homogeneity criteria used. The authors of the ICHORS and WAFLO models used similar criteria to define the reacting sites in an equally reproducible fashion, but they do not require them to be classed under discrete types of supposedly universal validity. In WAFLO, the initial state of a site may well be derived from maps which represent classed sites, however (Gremmen et al., 1983). Ecotopes are visible real-world sites, primarily distinguished on the basis of morphological characteristics. VEDES ecotopes are just classed sites. The morphological homogeneity is different from functional homogeneity with regard to plant species, however. Opposite the claim by Runhaar et al. (1985), ecotopes, like other sites, may comprise different operational environments (cases 1-3 above). In advance of checking the possible importance of case-3 sites, the role of the sites in the different models is exposed below. Attention has been given to the reasons why different authors preferred different concepts. A thorough discussion on these choices is really needed. The following is just a first attempt, based on the published information.

4.2 The role of sites in the current models

In all three models under discussion, sites have characteristic properties (Table 5). In the ICHORS model, most of the abiotic properties have to be specified precisely according to a continuous cardinal scale of expression, e.g., 'p mg Cl$^-$ per dm^3 of water'. VEDES uses a smaller amount of abiotic parameters, and these are classified according to a low-resolution ordinal scale, e.g., 'eutrophic'. WAFLO uses soil and groundwater information as available on standard Dutch soil maps. The cause of change is also formulated differently in the three models. It is very uncertain whether the ICHORS input requirements can be reliably met in real-world applications. Yet, they make the model a potentially useful instrument for the answering of 'what, if' questions, i.e., to check the variance which remains uncovered after the application of less accurate models. The importance of the water-quality parameters (see below) is being given attention in the WAFLO and SWNBL studies too (Kemmers, 1986, Waterloopkundig Laboratorium, 1985).

VEDES and WAFLO require a description of the vegetation, which is rather similar in both cases. The models differ, however, in the way these descriptions are used. In VEDES, this is to derive the abiotic properties of the site and some general characteristics of the vegetation (structure, succession stage), in order to class it as an ecotope. The properties of the ecotope which react in the model, are average properties assigned to the type of ecotope. The original species lists are preserved for the purpose of attaching an additional quality indication to individual ecotopes. When this is not desired, a less precise description of the vegetation in the field work stage will suffice. Udo de Haes et al. (1985) even reject the species level as it is used in WAFLO for reasons which are hard to accept. The ecotope system is itself largely based on the species level of indication. The loss of resolution, which is caused by the removal of detailed information with regard to species′leads to trivial impact statements, such as 'drainage, manuring, and grazing of bogs will change them into manured grasslands, which are less rare, and less unique, and need a shorter time of development than bogs'. Runhaar et al. (1985) reveal an increased interest in the species level in order to, (1), improve the ecotope classification, and, (2), enable a more useful impact evaluation. As emerging properties of ecodevices, species are especially indicative of the functioning and the overall value of such devices.

ICHORS, and less strictly VEDES, are different from WAFLO in requiring freshly derived matching logic, prompted by the desire (Barendregt et al., 1986) for continuous response curves, rather than indications of the optimum. Runhaar et al. (1985) also stress the need to take account of the range of tolerance of species, but they overlook (p. 38) the possible occurrence of case-3 sites, and use phytosociological criteria to derive the required information (see 4.4). Apart from conceptual errors, it must be doubted whether it is still possible in The Netherlands to find enough steady-state sites for the fresh development of response models, especially with regard to rare species (van Wirdum &

van Dam, 1984). In the framework of the WAFLO model, and of the SWNBL study, statistical response models have been thoroughly tried out (Looman, 1985, van Wirdum, 1985b). It was decided to prefer the compiled experience of earlier workers, such as Ellenberg (1978) and Londo (1975). There data were proven to be consistent with records by Kruijne et al. (1967), who did a statistical survey under more favourable circumstances than the natural environment presently provides. Dijkema et al. (1985) attempted to correlate the characteristics of the most threatened operational environments in nature reserves to requirements of the relevant natecs. In the long run, a combination of such investigations with more advanced statistical techniques may yield interesting results. For the time being, however, the approaches of the environment in ICHORS and in VEDES will probably decrease the precision of predictions to a level which is appropriate to case-2 sites (4.1). They certainly do not enable good explanations of the occurrence of many rare species, such as those bound to the 'gradient belts' mapped by van Leeuwen (1966, 1967).

An interesting point of difference between the models is that WAFLO uses the matching logic to predict which of the initial state species **will not** be able to survive, while ICHORS predicts the probability of species to **be able** to occur in the new state, disregarding the possibility that some of the factors are out of their required range. Likewise, VEDES implicitly stresses the positive probability of occurrence attached to the new ecotope. Both WAFLO and VEDES recognize the importance of initial state information. The WAFLO procedure comes in the place of the notably difficult prediction of circumstances which are supposedly not influenced by the change which causes an impact on the site. The neglect of possible new species to appear is accepted by reasoning that the experience has taught that most newly appearing species, in the cases for which the model was made, are not indicative of an increased protective value of the ecodevices. In the present form, the model is therefore unsuited for predicting the course of development of natecs as a result of purposeful management. It remains to be seen whether the procedures used in VEDES and ICHORS render these models any better for that situations, however. The missing of the initial state, and thus of change as such, in ICHORS is at least a very severe drawback here.

4.3 A survey of the milieu of threatened phreatophytes

Especially valuable natecs may loose some of their value. Since this study emphasizes situations which might be threatened by becoming dryer, the presentation is restricted to hydrophytes and phreatophytes according to Londo (1975):

Hydrophytes are species with submerged or floating vegetative parts.

Phreatophytes are species which are mainly confined to the sphere of influence of the phreatic surface in the area considered. Hydrophytes are also phreatophytes. The latter collective name will be used here.

Table 6 The number of threatened phreatophytes and hydrophytes in each Ellenberg milieu (bold face), comparative to the sum total of Dutch species. Species which have not been assigned to any singular milieu by Ellenberg (1978) have been omitted from the counts. The Ellenberg moisture (F), nitrogen (N), and acidity (A) figures appropriate to each milieu have been indicated

Nutrient status	**Acidity**		Dry F1-3		**Moist** F4-6		**Wet** F7-9		**Very wet** F10-12	
Rich	**Alkaline**	**R7-9**	3	**0**	54	**6**	29	**8**	19	**5**
N7-9	**Intermediate**	**R4-6**	0	**0**	13	**0**	4	**1**	3	**2**
	Acid	**R1-3**	0	**0**	2	**0**	0	**0**	0	**0**
Intermediate	**Alkaline**	**R7-9**	14	**0**	69	**7**	29	**7**	19	**4**
N4-6	**Intermediate**	**R4-6**	4	**0**	32	**4**	27	**12**	8	**1**
	Acid	**R1-3**	0	**0**	13	**2**	3	**1**	0	**0**
Poor	**Alkaline**	**R7-9**	51	**0**	36	**2**	17	**16**	4	**4**
N1-3	**Intermediate**	**R4-6**	10	**0**	16	**3**	15	**12**	2	**2**
	Acid	**R1-3**	11	**0**	31	**3**	35	**23**	9	**6**

Table 7 Some threatened phreatophytes of the poor & wet Ellenberg milieus and the appropriate F, R, and N figures according to Ellenberg (1978). English and Dutch names are provided

	F	R	N
Species of acid milieu			
Drosera rotundifolia L. - Sundew (ronde zonnedauw)	9	1	1
Carex echinata Murray - Star Sedge (sterzegge)	8	3	2
Cirsium dissectum (L.) Hill - Marsh Plume Thistle (spaanse ruiter)	8	3	2
Myrica gale L. - Bog Myrtle (gagel)	9	3	2
Species of intermediate milieu			
Carex lasiocarpa Ehrh. - Slender Sedge (draadzegge)	9	4	3
Eriophorum gracile Roth - Slender Cotton-grass (slank wollegras)	9	5	2
Carex diandra Schrank - Lesser Tussock Sedge (ronde zegge)	9	6	3
Carex hostiana DC. - Tawny Sedge (blonde zegge)	9	6	2
Species of alkaline milieu			
Dactylorhiza incarnata (L.) Soő - Meadow Orchid (vleeskleurige orchis)	8	7	2
Parnassia palustris L. - Grass of Parnassus (parnassia)	8	7	2
Epipactis palustris (L.) Crantz - Marsh Helleborine (moeraswespenorchis)	8	8	2
Liparis loeselii (L.) Rich. - Fen Orchid (sturmia)	9	9	2
Species which have been classified indifferent with regard to acidity			
Carex dioica L. - Dioecious Sedge (tweehuizige zegge)	9	x	2
Calamagrostis stricta (Timm) Koeler - Narrow Smallreed (stijf struisgras)	9	x	2
Sanguisorba officinalis L. - Salad Burnet (grote pimpernel)	7	x	3
Oxycoccus palustris L. - Cranberry (veenbes)	9	x	2
Menyanthes trifoliata L. - Buckbean (waterdrieblad)	9	x	2
Valeriana dioica L. - Marsh Valerian (kleine valeriaan)	8	x	2
Succisa pratensis Moench - Devil's-bit Scabious (blauwe knoop)	7	x	2
Pedicularis palustris L. - Red-rattle (moeraskartelblad)	9	x	2

As a first approximation, Ellenberg's ranking of species for the water, nutrient, and acidity factors has been analysed (van Wirdum & van Dam 1984, Looman, unpublished). The resolution of this ranking (Ellenberg, 1978) is diminished here to a 4x3x3 matrix of 'scaled-down Ellenberg milieus', as in Table 6. Londo lists which phreatophytes 'are characteristic of the relatively constant (less dynamic) and/or relatively oligotrophic and/or vulnerable habitats, or are (relatively) rare species of more dynamic and/or eutrophic habitats'. This phrase obviously signifies threatened species, which are indicative of highly protective ecodevices, i.e., very valuable natecs. They are called 'midy-haters' for reasons which are not explained here. Table 6 presents the numbers of Dutch midy-haters according to Londo in the 4x3x3 matrix of Ellenberg milieus, together with the sum total of Dutch species in each class. Species which Ellenberg has not classed under any singular milieu have been disregarded, however. Thus, one third of the Dutch flora is covered.

There is an obvious clustering of midy-haters in the 'poor & wet' classes. When it would be possible to classify any real site (of ca 250 x 250 m^2) in any singular one of these classes, there would at least be a basis for a physically realistic impact model for natecs according to a case-1 or case-2 approach (4.1). In such a model, one could treat all species which are classed under the same Ellenberg milieu as one biologically homogeneous group, as in the WAFLO model.

Checking the list of midy-haters for each of the three 'poor & wet' classes, it appears that this is correct for the water and nutrient factors, but not for the acidity factor. A more or less representative sample of the species involved is given in Table 7, which includes some species that are considered indifferent with regard to the acidity factor. These species can be found together at 30 x 30 m^2 sites! They are even more often found together than alone: 'Rare species never come singly'. As far as such sites have not yet gone lost, they belong to the most valuable ones for nature protection in The Netherlands. The involved species are indicative of species-rich sites which exhibit a great variety of operational environments with respect to acidity.

Meanwhile, Tables 6 and 7 confirm the statements under items 3 and 4 in Table 2 with regard to nature protection. The wet and very wet milieus are all characteristic of an excess water supply. Table 7 reveals a dominance of F9 species, which is also reported for actual nature reserves by Dijkema et al. (1985). According to Ellenberg, F9 species are 'wetness indicators, especially on badly aerated soils'. The water use by the vegetation is apparently not a critical factor here. With regard to the N figure, N2 species are most frequent in Table 6, forming a category in between N1 ('only on soils, very poor in mineral nitrogen'), and N3 ('mostly on poor soils'). Since the majority of the involved soils in natecs are rich in humus or peat, i.e., organic nitrogen compounds, the poor aeration apparently controls the mobilization of nitrogen, as acknowledged in item 3b of Table 2. The recognition of such indirect controls is formalized in the WAFLO model. In VEDES, it relies on the contents of the transition matrices, which are rather informally derived.

With regard to water-quantity parameters, it may be concluded that a case-2 approach (4.1) is probably allowed, justifying the treatment of these parameters in the WAFLO model, and the ongoing modelling efforts discussed by Kemmers (1986). A body of knowledge, acquired by the agricultural sciences can thus be profitably used. The wide span of the R! acidity figure, F1 ('only on very acid soils') to F9 ('alkalinity and chalk indicators'), reflected by item 4b (Table 2), will be a subject of further discussion here (see 5).

4.4 Phytosociological homogeneity is different from milieu homogeneity

With regard to the sites in the current models, the homogeneity concept, as relevant to the operational environment of plants, will now be compared with the homogeneity concept in phytosociology, which is used to limit sites, especially in the VEDES ecotope system. Most of the species in Table 7 can be met with in, or are even characteristic of, syntaxa which belong to the Parvocaricetea class of rich-fen communities and the Molinietalia order of species-rich meadow communities, respectively (Westhoff & den Held, 1969, Oberdorfer, 1979, van der

Meijden, 1983). The involved syntaxa (classes which comprise all more or less similar arrangements of species found in nature) are in fact nodums in a phytosociological continuum, as is expressed by Westhoff & den Held (1969, p. 178). As far as the species show a syntaxonomically different range, stands of the relevant syntaxa are often found together in a fine-grained pattern. Accordingly, it is often possible to select such a level of phytosociological classification that sites appear homogeneous with respect to the vegetation, as is in fact done in the VEDES ecotope classification system. Several problems are attached to the implementation of this idea, however, of which two are mentioned here:

1) The syntaxon is not always easy to assess and the environmental data with respect to its preferred environment include several individual stands which may especially differ with regard to the presence or absence of threatened, but phytosociologically often **characteristic** species. It has thus been falsely suggested (see van Gijsen, 1979) that the value of a site for nature protection would not change if the environmental state would only stay within the range of tolerance of the relevant syntaxon as a whole, or of its **dominant** species. This point still plays a role in the VEDES ecotope system.
2) Opposite to what most standard texts (e.g. Westhoff & den Held, 1969, p. 25) suggest, the milieu of a syntaxon is fundamentally different from the milieu of a taxon (i.c., a species). The well-developed presence of a syntaxon is indicative of a particular spatial pattern of different species-milieus. The extreme milieus represent requirements, rather than being indicative of tolerance. This is especially well demonstrated by the natural association of slightly acid hummocks and alkaline hollows in several base-rich fen sites with covers of the mentioned Parvocaricetea vegetation.

It is obvious that the best solution to both problems is to take account of each individual species, or of ecological species groups, and to describe the sites by characteristic frequency distributions, rather than average values (Table 2, item 1c). This would acknowledge the awareness of the **requisite variety** of a site in order to have rare species.

5 THE ECODEVICE AS A VARIETY GUARD

Any species which is bound to a narrow range of states of the environmental complex can only exist there in the long run, when this range is guaranteed for a long time. Allthough it can not be concluded that threatened phreatophytes are bound to sites which belong to any singular Ellenberg milieu, it appears that many of them require 'poor & wet' sites with an internal variety of alkaline to acid types of operational environments. The impact problem for such a site is thus moved to the problem of safeguarding the dynamic equilibrium which controls the inhomogeneity of the site, rather than only safeguarding the operational environment of any of the individual species.

The stable, fine-grained gradient-zone between acid and alkaline circumstances within an ecodevice is basically supported by microrelief, and possibly reinforced by the response of the vegetation, as discussed for mires by van Wirdum (1979). In order to solve the impact problem, it is necessary to find out which of the hydrology-related ecological field properties is a necessity for the ecodevice to guard the existence of this so-called **poikilotrophic** (variegated) zone. When the soil, the relief, and the vegetation may be considered fixed initial state characteristics of the natec, the remaining causative variates are the amount and chemical composition of the rainwater, the hydraulic head and composition of the groundwater, and the composition and level of the surface water. From several investigations (Dijkema et al., 1985, Grootjans, 1985, Kemmers, 1985, van Wirdum, 1979, 1981), it has appeared that the frequency distribution of the hydraulic head of a singular type of alkaline, **lithotrophic** groundwater (van Wirdum, 1980, 1982a), and of surface water are controllable positional factors which determine the distribution of chemical types of water within the ecodevice. A change of these parameters will, after some time, cause the vegetation, and even the soil, to be altered. This is preliminary recognized in WAFLO by the 'instability of the environment' (Table 5), and by inferences from an 'ecohydrological map' (Reijnen et al., 1981).

The internal drainage structure of the ecodevice is a conditional factor in the variety control mechanism. It is sometimes possible to partially compensate the change of positional factors by an adjustment of the drainage system.

Several device properties, such as the relief, the soil type, and the vegetation structure are regarded fixed properties in the equilibrium state of an ecodevice. These properties play an important role, both physically and chemically, unless the device is of an open type (3.4). If the ecological-field 'tension' is changed, however, the fixed properties may also become altered. This is often a slow process. Initially, it may even appear that the ecodevice continues to work normally. The apparent stability of an ecodevice, as judged from the stable vegetation pattern, is caused by the same protective capacity which enables complex ecodevices to bridge natural periods of less favourable ecological-field properties.

The time needed to acquire a new steady state, in equilibrium with a changed positional environment, is probably of the order of magnitude of several centuries in many natecs (5 in Table 2). The disappearance of certain rare plant species may consequently lag behind a long time. It must be emphasized that the protective power which is responsible for the occurrence of such species is also responsible for their very slow reaction. The ecodevice, as it were, has a memory of the original equilibrium state. This is a major reason why validity testing of impact models which do not emphasize the kinetics of the change process is a very delicate matter, especially while several other influences may interfere during the equilibration phase. Such influences may comprise the atmospheric pollution and the presently severe problems of eutrophication and dung disposal in The Netherlands (cf. Table 1).

Many of the most important natecs in The Netherlands are rich in species which indicate that the ecodevice is in part fed with lithotrophic water, which is supposed to be derived from groundwater inflow, as in seepage areas (Dijkema et al., 1985). It is indeed uncertain whether these natecs still exist in a steady state.

6 CONCLUSIONS AND RECOMMENDATIONS

1) Impact modelling for nature conservation is more difficult than it is for agriculture. The ecodevice concept facilitates a separation of deterministic and stochastic aspects of the involved models. This has only been done in the WAFLO model.

2) The impact models WAFLO, VEDES, and ICHORS differ with respect to modular structure, accuracy, completeness, stage of development, and documentation. They are similar in the site concept. Further differences are not backed by convincing arguments. In the cases of ICHORS and VEDES sensitivity analyses are badly missed. The further stage of development of WAFLO is balanced by a pragmatic incorporation of modules which are possibly not very precise. The other models can hardly be judged at this point.

3) Natecs can be characterized by a requisite variety, which is partially supported by the water quality in the ecological field. It is recommended that systems for the description and classification of sites are checked with regard to their possible incorporation in models which emphasize these points. The development of such models requires more, and more cooperative, efforts than have apparently been given to the currently available models.

4) Validation of natec impact models is very difficult. In all conclusions, one must check for possible lagging of the ecodevice characteristics.

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