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IMPACT ASSESSMENT OF INVERSION OF GROUNDWATER FLOW IN WETLAND ECOSYSTEMS

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In the low holocene parts of The Netherlands the hydrology came to be strongly influenced by human activities after the introduction of dykes and the use of wind power in mills. In the pleistocene part the situation was different. There, the hydrological system was influenced to a relatively small degree until the beginning of this century. From that time on the situation has changed drastically through the use of groundwater for the drinking water supply and later because of pollution of the groundwater.

In this paper the impact is assessed of groundwater withdrawal from pleistocene sandy hills on wetland ecosystems at the hillfoot.

Mesotrophic wetland ecosystems are found in the valley of the River Vecht, north of Utrecht. The nutrient-poor groundwater they depend on is supplied by the flow of effluent seepage water from the adjacent sandy hills (fig. 1). This water comes to the surface as influent seepage water in a belt that runs parallel to the foot of the hill ridge.

The influent seepage belt contains a great variety of aquatic and marshland ecosystems. However their extension and their richness in variety of plant species has strongly decreased in the course of the last decades.

Their survival is endangered by two changes in the hydrological system:

1. Large-scale withdrawal of groundwater from the hill ridge for drinking water supply. This has decreased or even stopped the flow of seepage.
2. Irrigation of the river valley with polluted water from the Vecht which has led to eutrophication of the wetland environment.
   This irrigation takes place in summer to supply water for crop growth. The need to use surface water in this way in the summer is partly the result of the decreased influx of seepage flow. It is also partly a consequence of the greatly increased artificial drainage of the valley during the winter, also done for agricultural reasons. The water thus used cannot be excluded from the natural areas.

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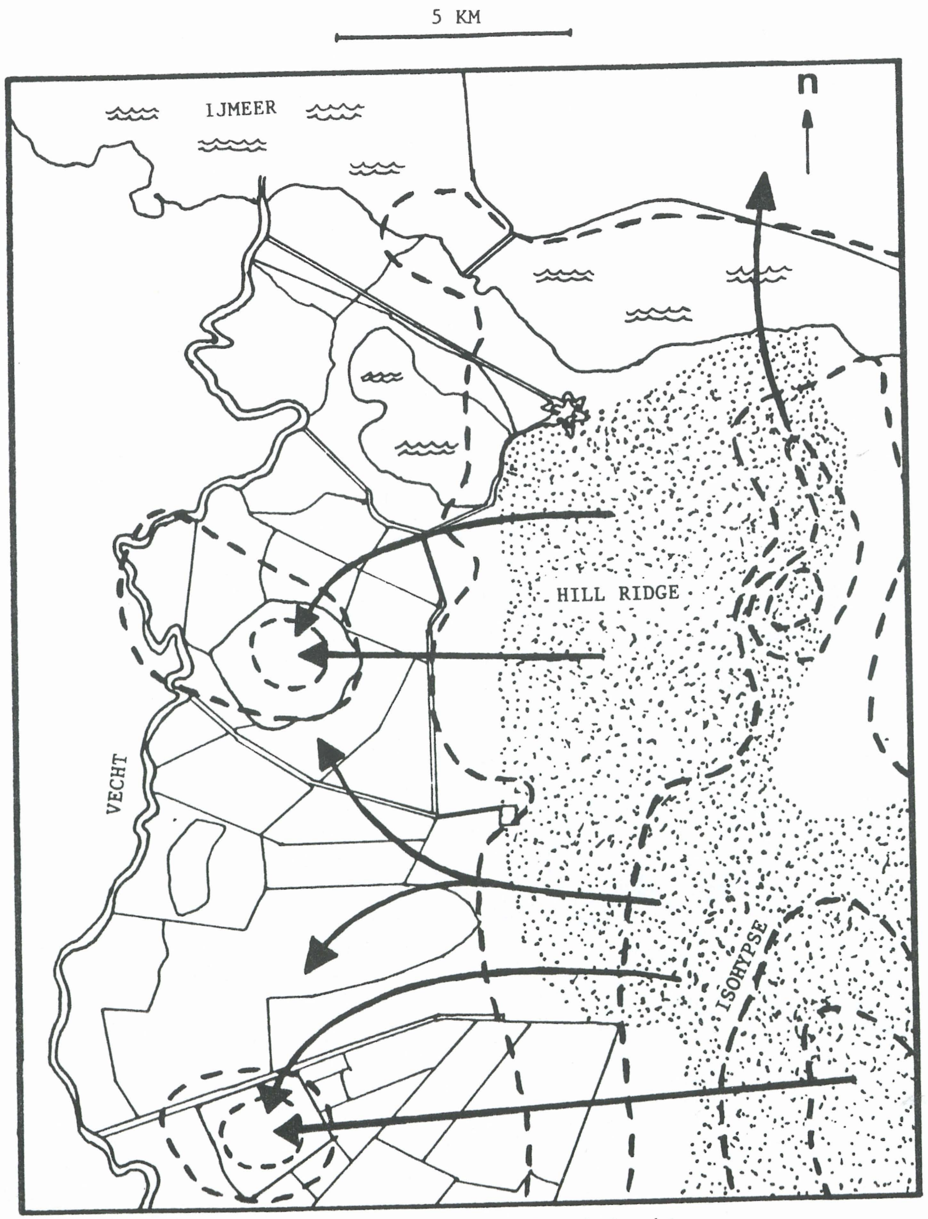

Fig. 1. Valley of river Vecht and sandy hill ridge:
Isohypses and direction of groundwater flow.

Ecologists and conservationists have frequently reported on the decline of mesotrophic ecosystems. Recently, governmental bodies have also become concerned about the situation. The province of North-Holland has initiatied research to solve the problems involved in close collaboration with the Department of Environmental Studies of the University of Utrecht. The area of the Gooi hill ridge and the northern part of the Vecht valley belong in this province. The government of the province is responsible for the management of its fresh water supply (with the exception of large rivers and canals).

Essentially two types of solutions have been designed. One is based on the amelioration of the quality of surface water, the other on the restauration of the groundwater flow from the hills toward the wetland area.

These two approaches correspond to two threats to the environment: the increase in the supply of polluted surface water and the decrease in the influent seepage flow of the groundwater.

In the period from about 1960 to 1980 governmental proposals to solve the problem focused on improving the quality of the surface water. A number of waste water purification plants were constructed in the area. Organic pollutants were eliminated from sewage water. However, this resulted in a high load of inorganic nutrients being released onto the surface water. This did not present problems for ecosystems dependent on eutrophic water, but the mesotrophic ecosystems continued to disappear as they need a nutrient-poor environment.

After 1980 the policy of the authorities has been to concentrate the purification of water in large plants on the edge of the area. The effluent is discharged directly into the River Vecht. An advantage is that eutrophicated effluents are no longer discharged close to mesotrophic areas.

Still, the problem remains of water shortage in summer. Suppletion with Vecht water can not solve it, as heavy loads of nutrients return with the polluted riverwater. However, a promising alternative, in line with the policy of improving surface water quality, seemed to have been found. Water from the lake IJmeer, came into the picture as useful for irrigation. This water has a considerably lower nutrient load than Vecht water has.

The Department of Environmental Studies of the University of Utrecht advocates another type of solution that is based on improving the seepage flow of mesotrophic groundwater from the hills towards the wetland zone.

At this stage, governmental study groups felt the need for a method to evaluate the effects of alternative hydrological solutions on the ecosystems. Policy makers could then make a cost-benefit analysis. For this reason the province of North-Holland asked the Department of Environmental Studies to develop an assessment method.

Methods

A correlative method was used to find the relationship between plant species and the properties of surface water, the hydrology and the soil. Analysis of correlations is far less time-consuming than analysis of causal relations. Findings on correlative relations allow statements to be made on the interaction of environmental factors and species, if they are based on a large number of independent observations. The data-set has to be large in three respects:

- the number of locations
- the number of environmental factors
- the number of different combinations of environmental factors.

The observations used in this study come from 800 locations and include 24 environmental parameters and 200 species (hydrophytes and phreatophytes, that is, species living in surface water or rooting in groundwater). The parameters we examined were surface water level in summer and winter, chemical composition of surface water, piezometric level in summer and winter, direction of vertical groundwater flow (piezometric level minus surface water table) and texture of soil (0-30, 31-60, 61-120 cm). To indicate the range of the environmental factors in the areas we studied, some extremes were as follows:

- salinity :	Cl^- (mg/l)	7.00	-	10266.0
- nutrient load :	PO_4 "	0.00	-	74.24
	NO_3 "	0.00	-	32.63
- surface water table in cm :		-157.	-	+20.
- piezometric level minus surface water table in cm :		-129.	-	+123.
- soil (in general) :		clay / sand / peat		

Of course the greatest accuracy is obtained if a locality is very small. This provides the best conditions to measure the factors that are actually connected to the plants growing on the spot. However, data need not necessarily derive from the same small spot to be useful for correlation calculation. A

larger, but homogenous part of the landscape can also be considered as one observation point. In this case our criterium for homogeneity is that continuous parameters, such as concentration, have no greater variance than 10-20%. Discontinuous parameters, based on a classification, such as soil type, should not vary at all within the area studied.

Use of homogeneous areas has the following advantages:

1. Measurements from locations that are separated in space can be used as long as they derive from the same homogeneous area.
2. Documentation on parameters published on maps can be combined with that from observation points.

In this study the homogeneous areas vary from 0.3 to 30 ha. Most were between 1.5 and 3 ha. Many data were used from existing data systems. Field observations could be restricted to investigation of flora and sampling of surface water.

This combination of data provided us with a data set that could be used for an analysis of correlations. The analysis was done by a step-wise logistic regression analysis. We took the internal correlations of the parameters into account in the calculations. Simply explained, through this mathematical approach a function is sought with ecological variables that gives the possibility of encountering a species. During the calculation the variables that statistically describe the occurrence of the species in the data-set best, are selected step by step. At each step all the variables that are correlated with the variables being dealt with are put aside. The computed function contains a combination of variables that account for the response of the plant species best.

An example of such a function will be given. The probability "p" is defined by a function in which the exponent "q" is essential. Each species has its specific q-value composed of continuous and/or classified environmental variables.

$$p = \frac{e^q}{1 + e^q} \qquad (0 \leqslant p \leqslant 1)$$

$$\begin{aligned} q = &- 2.515 + 2.118 \times (\log Cl) - 0.873 \times (\log Cl)^2 \\ &- 0.769 \times (\log S) - 0.446 \times (\log NH_4) - 0.420 \times (\log NH_4)^2 \\ &+ 0.0 \text{ (if seepage in winter)} - 0.584 \text{ (if infiltration in winter)} + 3.608 \times \text{(level of surface water in winter)} \\ &- 6.815 \times \text{(level op surface water level in winter)}^2 \\ &+ 0.0 \text{ (if soil 31-60 cm is clay)} + 1.436 \text{ (if soil 31-60 cm is sand)} - 2.990 \text{ (if soil 31-60 cm is sandy clay)} \\ &+ 2.099 \text{ (if soil 31-60 cm is peat)} \end{aligned}$$

To illustrate the influence of a certain variable, the values of this variable can be changed while keeping the values of all the others constant. This is done in fig. 2 with the continuous variables chloride and ammonium. Increasing values of these ions are plotted against the probability of a species' occurrence. The curve shows the optimum of a species for the concentrations of these ions.

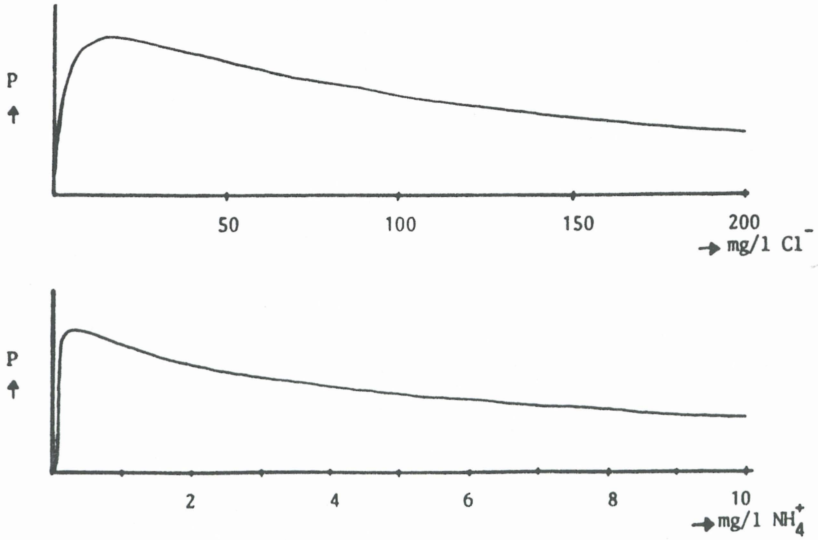

Fig. 2. Influence of variables on the probability, by only changing the values of the variable.

Results

All regression equations that resulted from the logistic regression analysis were incorporated in a computer program called ICHORS. This program produces the probability of encountering 200 plant species with regard to the factors analyzed.

To demonstrate the use of the program we will give an example from the study area. A seepage zone exists alongside the foot of the hill ridge, where seepage water deriving from the hill comes to the surface (fig. 3). If less water is extracted from the hill ridge for the drinking water supply, the seepage zone would become wider. This would be one

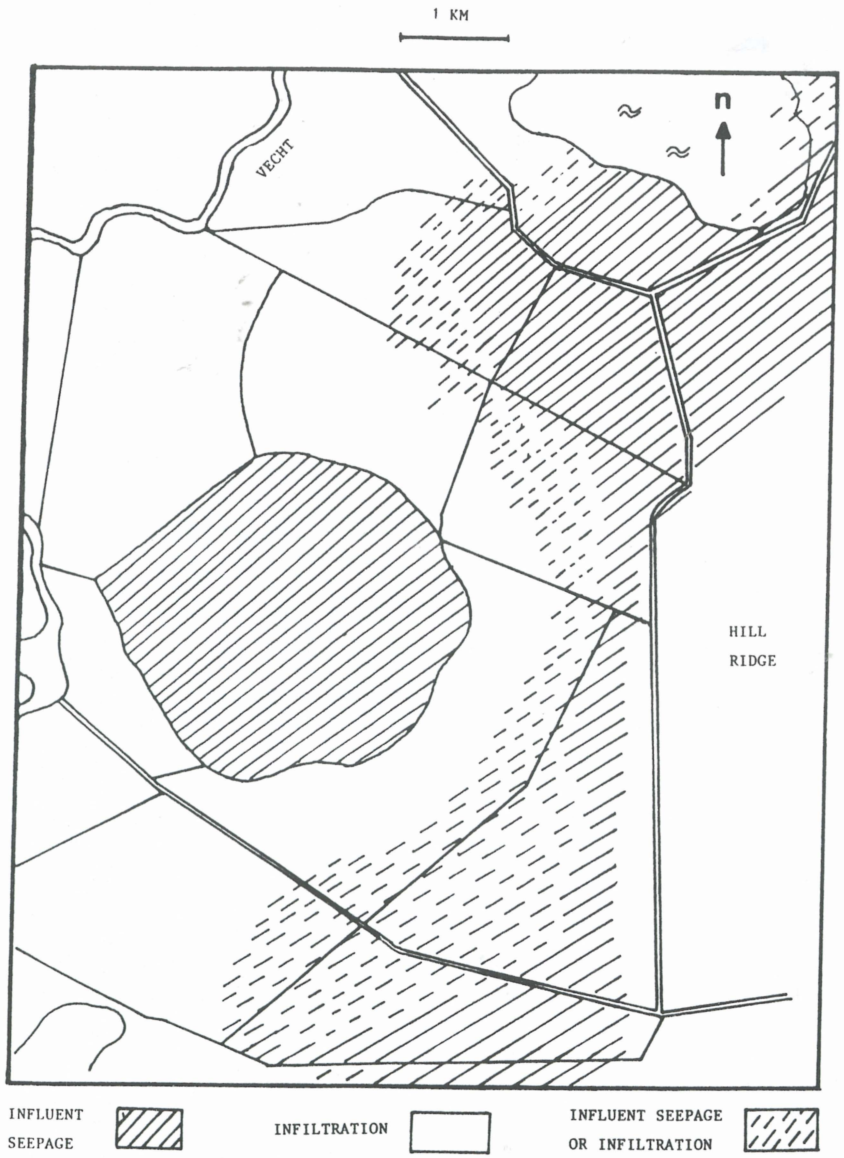

Fig. 3. Map of northern part of the Vecht valley and adjacent part of the hill ridge. Areas with influent seepage in all management variants are hatched with contineous lines. Areas with hydrological alternatives (influent seepage or infiltration) are hatched with broken lines.

management option. If, however, water continues to be withdrawn at the present rate this area will continue to be an infiltration area. In the latter case two types of water could be used as infiltration water: from the River Vecht and from Lake IJmeer.

To assess the effects of each of these 3 options (variants), values of a complete list of variables must be put into the program. In this example there are 3 variants (see fig. 4); water levels and soil type do not vary, while the direction of groundwater flow and the composition of the surface water do (average recent data from the area have been used).

The output of the program gives the probability of encountering 200 species in the case of each of the 3 variants. We can also, as a result, make statements on the reactions of plant communities. As plant communities are characterized by characteristic species groups, the reaction of the community can be described by the reaction of this species group. The characteristic species groups of the aquatic and semi-aquatic communities on the study area are defined by Van den Berg and De Smidt (1985).

An example is given for a wet grassland community on unfertilized peat soil (Caltion palustris).

This community has 10 characteristic species. The reaction of these 10 species on the 3 water management variants is listed in fig. 5. The mean value of the species group gives an indication of the reaction of the community Calthion palustris. In the same way mean values of characteristic species groups of 7 other communities are calculated, to assess the effect of different water regimes on plant communities (fig. 5).

Our conclusions with regard to the 3 variants is that the probability of occurrence in the case of seepage water is 2 to 3 times higher than in that of infiltration water for most communities. If infiltration water is unavoidable then the probability is larger in the case of River Vecht water than of IJmeer water, despite the level of pollution of the former.

The disappointingly low scores of the Lake IJmeer water made the authorities decide to give priority to the search for other variants. Explorations were made to the south of the regio. This was the only direction left which had not yet been explored. The reason for this was that it meant crossing the border of the Province of Utrecht.

In this province are situated the Southern Vecht Lakes, with their good quality water. The water shortage of these lakes during summer has been compensated by dephosphated water

		1	2	3
soil 0 - 30 cm		peat	peat	peat
soil 31 - 60 cm		peat	peat	peat
soil 61 -120 cm		peat	peat	peat
surface water table in summer		-30 cm	-30 cm	-30 cm
surface water table in winter		-30 cm	-30 cm	-30 cm
piezometric level in winter minus level in summer		7 cm	7 cm	7 cm
direction of groundwater flow		seepage	infiltr.	infiltr.
chemical composition (mg/l) and pH of supply water	HCO_3	240.	200.	200.
	Si	7.0	1.0	0.5
	Fe	2.5	0.1	0.1
	NH_4	0.8	1.0	0.75
	NO_3	0.4	10.0	4.0
	PO_4	0.36	1.4	0.5
	Cl	30.	230.	250.
	Na	13.	110.	160.
	Mg	5.5	10.0	21.0
	K	1.9	5.0	9.0
	SO_4	15.	60.	180.
	Ca	40.	70.	75.
	pH	6.9	7.5	7.7

Fig. 4. Values of a complete list of variables as input to the program, to assess the effect of changes in water management. Management changes consist of suppletion with groundwater deriving from the area itself (1), or with surface water from different origin (2 = water from river Vecht, 3 = water from lake IJmeer)

	1	2	3
Caltha palustris	.5502	.0729	.0450
Ranunculus flammula	.4420	.0435	.0391
Carex nigra	.1918	.0033	.0018
Lychnis flos-cuculi	.4990	.1604	.0696
Cirsium palustre	.6854	.1983	.1433
Lotus uliginosus	.8366	.2090	.1588
Agrostis canina	.2138	.1246	.0201
Galium palustre	.7206	.5222	.4319
Iris pseudacorus	.4354	.2938	.2312
Holcus lanatus	.7910	.3672	.4125
Calthion palustris : average (10)	.5366	.1995	.1553
Cirsio-Molinietum (20)	.3796	.1074	.0857
Sphagnetum palustri-papillosi (10)	.1950	.0797	.0712
Caricion curto-nigrae (12)	.4570	.1764	.1402
Hydrocharito-Stratiotetum (10)	.3174	.1454	.1092
Scorpidio-Caricetum diandrae (24)	.2010	.0912	.0751
Cicuto-Caricetum pseudocyperi (20)	.3808	.2863	.2258
Thelypterido-Phragmitetum (21)	.3592	.2218	.1788

Fig. 5. Calculated respons of characteristic species groups on
1. influent seepage water;
2. infiltration water from river Vecht;
3. infiltration water from lake IJmeer.
In brackets the number of characteristic species of each group is given.

from the Amsterdam-Rhine Canal (ARC) since 1985. The dephosphatation plant has a greater capacity than is needed under normal conditions. It was thought that an extra supply of ARC water into the Southern Vecht Lakes could solve the problems of the Northern Vecht Lakes. Indeed, the plant communities that occur in unpolluted wetland have a considerably better reaction to water of the Southern Vecht Lakes than to that from the Vecht and Lake IJmeer.

On the basis of these findings the Province of Noord-Holland may ask the province of Utrecht to agree to supply water for the Northern Lakes in the summer season. The authorities in Utrecht would then be confronted with the question, what the effects could be of an increased supply of dephosphated ARC water on the unpolluted ecosystems in the Southern Vecht Lakes. Assessment of these effects shows that the reaction of the ecosystems on ARC water is not better than on Vecht water.

The conclusion is that the vanishing ecosystems cannot be conserved by surface water management only. Essential to their existence is restauration of the groundwater flow toward the seepage zone.

This solution would require an alternative source of drinking water at an annual rate of 17 million m^3. This presents a financial problem. Drinking water would then have to be transported from a distance, where it is produced from ARC water.

An inversion of the system of water use: groundwater from the tap and surface water to the ecosystems, into: surface water from the tap and groundwater to the ecosystems, would take at least 10 or 20 years to realize. This period might be too long for the ecosystems to survive.

A short-term solution must be found. A possibility lies in the deep polder Horstermeer. Due to its position at 2 m below sea level great quantities of seepage water come to the surface in ditches and canals. A total amount of 10 million m^3 from this polder, and from some smaller ones, could be used for the management of the vulnerable ecosystems. This water almost has the same composition as groundwater. It could be transported to the areas with mesotrophic ecosystems and be infiltrated there.

However, this is not a final solution to the problems of the Vecht Valley. It has two shortcomings:

1. Infiltration water does not have the same effect on ecosystems as does seepage water;
2. Only a part of the natural areas can be supplied with the quantity of good water that is available.

Still, it could help the ecosystems survive at least until the flow of groundwater has regenerated through ending the withdrawal of drinking water from the hills.

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PREDICTION AND ASSESSMENT OF IMPACTS ON THE WATER ENVIRONMENT

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ABSTRACT

The impacts of a project on the water environment may be such that health, economic or ecological consequences are considerable or even unacceptable. Therefore the prediction and assessment of these impacts should be executed in an early stage of the decisionmaking process on the project, to enable the formulation of alternative solutions or mitigating measures. This paper presents a conceptual framework for the conduction of an EIA-study, which has been elaborated for the water environment. The emphasis of this paper is on the crucial element: prediction. For several categories of water impacts available predictive methods are presented. The development in the state-of-the-art of prediction methods in the water environment is reviewed, and the problem of how to select suitable methods is discussed. Some examples of applications of predictive methods illustrate the concepts presented in this paper.

1 INTRODUCTION

It goes without saying that water is one of the most essential elements for everything alive on earth. Man, apart from needing water for drinking, uses water for many purposes. Not only waste removal, but also a lot of economically important