

Wetlands in the Randstad begins

A.J. Gilbert (editor)



April 2000



Wetlands in the Randstad begins

A.J. Gilbert (editor)

W-00/17

May 2000

For further information and distribution, please contact:

Alison Gilbert
Institute for Environmental Studies
Vrije Universiteit
De Boelelaan 1115
1081 HV Amsterdam
Tel. +31-20-4449 555
Fax. +31-20-4449 553
E-mail: secr@ivm.vu.nl

Copyright © 2000, Institute for Environmental Studies

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without the prior written permission.

Table of Contents

Preface	iii
1. Introduction to <i>Wetlands in the Randstad</i>	1
2. Aims and objectives	5
3. Study area – the Vecht	7
4. The individual projects	9
4.1 Project 1: Linking regional and site scales in ecohydrological modelling for integrated water management	9
4.2 Project 2: Remote sensing approach to study scale aspects and functioning of wetland ecosystems	18
4.3 Project 3: Development of chemical indicators to characterise wetland ecosystems	22
4.4 Project 4: Steering of ion channels by metals	27
4.5 Project 5: Effects of changes in hydrology on ecological and chemical characteristics of wetlands	34
4.6 Project 6: Ecological and societal conditions for wetland restoration	39
4.7 Project 7: Performance indicators for co-evolved wetland systems	43
4.8 Project 8: Wetlands in integrated land use models	48
4.9 Project 9: Evaluation of conflict and compromise in wetland management	53
5. Links among projects	57
5.1 Introduction	57
5.2 The links	59
5.2.1 Between the natural and management system	61
5.2.2 Within the natural system	62
5.2.3 Within the management system	64
6. Spatial analysis	65
6.1 Introduction	65
6.2 Space within each project	66
6.3 Possible spatial struggles	68
6.4 Possible solutions	68
6.5 Hardware and Software requirements	69
7. Scenarios	71
7.1 Introduction	71
7.2 The Management Strategy	71
7.3 Exogenous factors	75
7.4 Scenario analysis	76
8. Personnel and organisation	77
References	81

Preface

Wetlands in the Randstad is a research project funded by the Vrije Universiteit under its USF-stimuleringsprogramma 'toponderzoek' (breedtestrategie). This fund aims to stimulate scientific excellence in accordance with the university's research strategy. Members of the Vrije Universiteit who are also members of the SENSE¹ Research School participate in the project. SENSE has developed a research programme with disciplinary inputs involving chemistry, biology, physics, earth sciences and environmental technology on the one hand, and economics, sociology, political science and decision sciences on the other. The main theme of its research programme is the analysis of substance flows through environment and society. SENSE operates in a matrix structure with the above disciplines as the long-term basis. An essential part of this strategy is collaboration with a number of discipline-based research schools, such as the Tinbergen Institute and Functional Ecology. Multidisciplinary research projects addressing a selected number of environmental issues guide the short and medium term research activities. The selection of the issues has been based on environmental and scientific relevance, and clusters of expertise within SENSE.

Wetlands in the Randstad addresses one of the four SENSE core programmes, viz. Core 3 'Climate change, land use and biogeochemical cycles'. Specifically, it addresses spatial interactions between biogeochemical cycles and land use, and focuses on Dutch wetlands as a model system to explore new approaches to the interactions between natural and societal processes in a rapidly developing metropolitan area. This issue is scientifically interesting. It is also highly relevant from an environmental perspective considering the widely recognised need to develop anticipatory approaches that take a comprehensive view of wetlands, the factors impacting them, and means for their protection.

An asset for *Wetlands in the Randstad* is complementarity with other projects. For example the USF-VWK project *Global Change and the Biogeochemistry of Peatlands* (co-ordinated by Prof. R. Aerts, Faculty of Biology) focuses on nitrogen and enhanced CO₂ effects on peatlands (a type of wetlands), whereas the present project focuses on the effects of changes in hydrology. The present project also builds on the results of a case study within the EU-sponsored ECOWET (*Ecological-Economic Analysis Of Wetlands: Functions, Values And Dynamics*, co-coordinated by Prof. J. van den Bergh) project. The results of this project have been reported in Turner *et al.* (1999) and Bergh *et al.* (2000). An additional asset is the established working relationship with the VU Regional Economists of the Tinbergen Institute. Cooperation on this project has the potential of leading to the evolution of a VU-based, internationally recognised centre of excellence regarding wetland dynamics and the spatial interaction of natural and societal processes in highly populated areas.

¹ Socio-Economic and Natural Sciences of the Environment.

1. Introduction to *Wetlands in the Randstad*

Economic activities and demographic processes world-wide have increased significantly over the last 30 years, and are expected to continue in the coming decades. As a result, the quality of nature and landscape is threatened. Different uses can be made of natural areas, for purposes such as agriculture, infrastructure, urban development, as well as nature and landscape conservation. Conflicts of use are common. At least in the Netherlands, a general trend can be recognised of increasing societal value for nature and landscape while that for agricultural production is decreasing. The search for new, sustainable combinations of natural and social processes is attracting the attention of scientists, the public and policy makers alike. However, academic research tends to stay within disciplinary boundaries, and as such is insufficiently equipped to address such broader issues. Ongoing research tends focus on one only one use, such as agriculture, urban development, or nature conservation, or on one set of processes, such as soil ecology or agricultural economics. Increasing our understanding about natural and social processes and their interactions is fundamental to finding a new balance among economic development, nature and landscape in wetland areas. The need for greater knowledge in this field is apparent and is relevant to all wetlands areas, not only those in the Netherlands. Participants in the wetlands project have the opinion that scientific research can only contribute to a sustainable future if it takes a multidisciplinary approach while maintaining the discipline-based requirements of sound scientific work.

Dutch wetlands with their management issues pre-eminently serve this purpose. The biogeochemical processes and substance flows in wetlands are complex and not well understood. The effects of water table changes on substance flows and ecosystem processes can, at best, be predicted in only general terms. Subsequent economic and societal effects, for example changes in recreational or agricultural incomes or in the price of houses, cannot be adequately estimated and so cannot be figured into regional management. Improved wetland management requires advancement in the understanding of the hydrological, chemical and ecological processes and their interactions, and of subsequent societal response. Land use and management interventions have become major determinants of biogeochemical and other natural processes within wetlands. These driving forces are characterised by a wide range of actors (government and private sectors), each trying to optimise their interest in the resources which wetlands deliver as a result of its management regime. Resource supply, resource use and resource allocation are key issues for the economic and ecological functioning of wetlands. Therefore, a full analysis of these driving forces and their capacity to effect changes in ecological processes is required.

Understanding and addressing these topics requires input from a number of disciplines and the development of a multidisciplinary setting. The main disciplines are presented in Figure 1.1, as a visual aid to clarify the relevant disciplines, processes and their interrelationships.

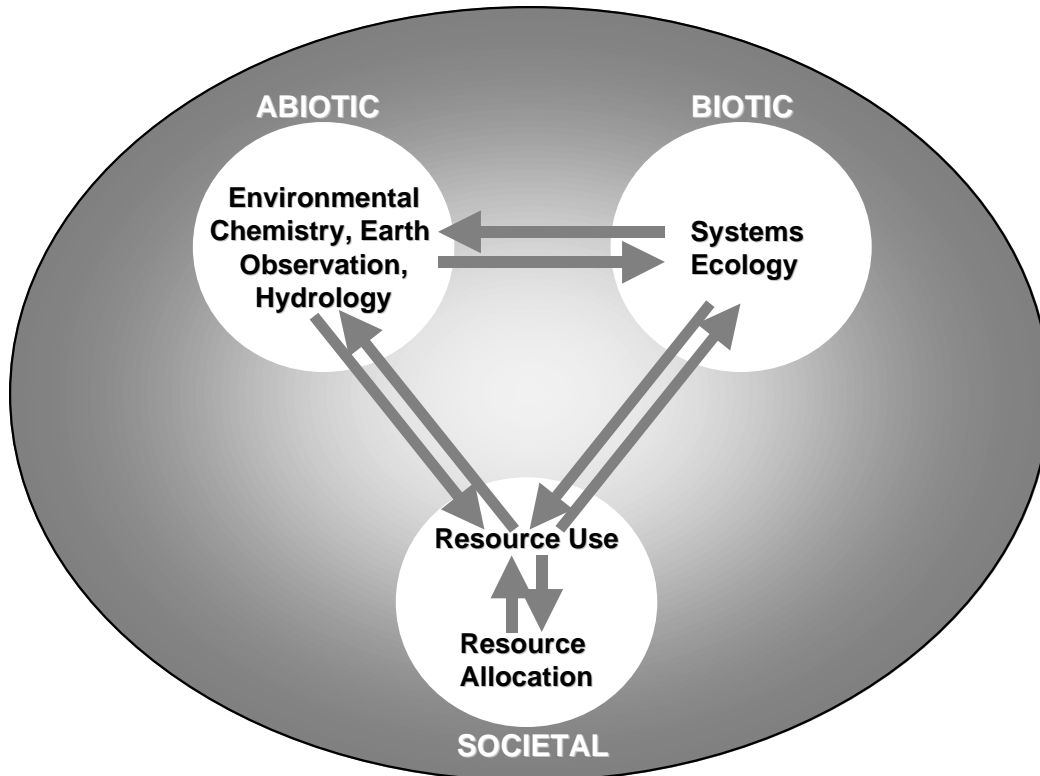


Figure 1.1. Relevant domains of knowledge and their interrelationships.

The overall research goal of *Wetlands in the Randstad* is to enhance the understanding of the spatial interactions between natural and societal processes with the Dutch wetlands as a model system. More particularly, the project will attempt to identify potential scientific benefits presently hidden between traditional disciplinary borders. Progress in gaining understanding of the system as a whole is hampered by the predominance of mono-disciplinary approaches. The SENSE Research School in general, and researchers within this project in particular, aim to overcome these problems. Research questions, projects and their coordination have been specifically defined to meet the challenge of multidisciplinary co-operation within an environment inevitably structured for traditional, mono-disciplinary research. Each individual project will be lead by one discipline (hydrology, chemistry, ecology, economics) but will focus on the gaps in knowledge between this and an adjacent discipline. By focusing on the gaps in knowledge between disciplines new insights will emerge that are relevant both for understanding the system as a whole and for making progress in the disciplinary field itself.

Nine individual research projects have been specified for *Wetlands in the Randstad*. Pairs of key researchers representing the adjacent disciplines will supervise the projects. A mixture of recent graduates undertaking a PhD programme and more experienced researchers will undertake the actual research. The more experienced researchers are placed in crucial areas of cooperation between the natural and social sciences. The Institute for Environmental Studies (IVM) will be responsible for the overall co-ordination of the programme and the development of the joint database and geographic information system.

The latter is needed to resolve incompatibilities among the individual projects in terms of the spatial interactions within the study area as well as the scales at which research will be undertaken. The challenge here is to link the different scales at which each of the individual projects will be operating. Hydrology has a tradition of working at different spatial and temporal scales, and there is experience with the many interactions of hydrologic systems at different scales. Chemistry and parts of ecology tend to focus on process analysis whereby a number of conditions are selected that are not necessarily representative for different scales under changing conditions. Here the challenge is not only to relate chemical and biological parameters to each other, but also to translate findings for a specific set of parameters to a broader area and for a longer time scale. For economics the spatial scale and the range of conditions considered are usually larger than that for ecology and chemistry. It is quite a challenge for economics to link its analysis of land use to analyses from other disciplines providing additional and pertinent information about the land concerned.

Research activities within *Wetlands in the Randstad* are directed towards the hydrological, chemical, and biological changes stemming from human actions in a rapidly developing metropolitan area, as well as towards the relationships between these changes and public welfare. The central option to be addressed is the restoration of wetland ecosystems by raising water levels ('vernatting'). This option represents a structural intervention in the environmental system aimed at the return of certain valued ecosystems and the restoration of the natural capital of wetlands and their resources.

This document presents *Wetlands in the Randstad* as envisaged at its inception. Section 2 details its aims and objectives. Section 3 describes the study area and outlines the reasons for selecting it. Section 4 presents the individual (nine) projects which comprise *Wetlands in the Randstad*. Section 5 discusses interactions among these projects and the multidisciplinary approach within *Wetlands in the Randstad*. Section 6 discusses scales, with an emphasis on spatial scales. Section 7 presents elements to be considered in assessing various paths for regional development. Section 8 lists the people involved in *Wetlands in the Randstad*, their roles, and details how the project is organised to meet this multidisciplinary challenge.

2. Aims and objectives

The text of the Ramsar Convention (Article 1.1) defines wetlands as “*areas of marsh, fen, peatland or water; whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt and including areas of marine water the depth of which at low tide does not exceed six metres*” (Anon, 1994). This definition is driven by water levels and includes human-made systems as well as ecosystems. Under such a definition, all of the western Netherlands may be considered wetlands. The Randstad refers to the area encompassing the cities of Amsterdam, The Hague, and Utrecht. Between these cities lie landscapes comprising (semi-) natural ecosystems, pastures, rivers, lakes, and infrastructure networks (e.g. freeways, train routes).

The restoration of wetlands as part of a larger ecological infrastructure is a goal within various European, national, provincial and local government policies. Examples of national policies include the Nature Policy Plan and the Report on Green Space of the Ministry of Agriculture, Nature and Fisheries (LNV, 1990 and 1996) and the Fourth Report on Spatial Planning (Extra) of the Ministry of Public Housing, Spatial Planning and Environment (VROM, 1990). At the provincial level, examples include the Regional Plan for the Vecht Area (Provincie Noord-Holland, 1995), and the Plan Nominated Areas (Provincie Utrecht, 1989 and 1996). Non-government organisations are also active in wetlands restoration, as indicated by the documents ‘Restoration Plan Naardermeer’ (DHV Water, 1993) and ‘Nature from Cleanest Water’ (Jorna, 1995).

Wetlands in the Randstad aims to develop scientific knowledge which will elucidate the complex interactions between economic and ecological processes for wetlands that are experiencing a transition from mainly monofunctional to multifunctional land use. An essential management question in this transition is to what extent and where water levels should be changed. This question cannot be answered easily. The mixture of agricultural, urban and (semi-) natural elements which comprise the landscape of the western parts of the Netherlands leads to a diversity of spatial scales which are affected by such hydrological changes. Therefore, the analysis of spatial elements and interactions will be dealt with explicitly in the programme by developing a joint database and geographic information system that enables analyses from both natural and social science perspectives.

The programme comprises 9 projects (see Section 4) to address the following questions:

- Discrete increases in water levels up to and including inundation (at least of some areas) would induce what changes in hydrological (Projects 1 and 2), chemical (Projects 3 and 4), and ecological processes (Projects 4 and 5);
- How would these changes affect the natural capital of the wetlands, its resources and the services they are capable of rendering to society (Projects 6 and 7);
- What structural changes within the economic system would allow it to adapt to, and even benefit from, wetland restoration (Projects 8 and 9); and
- How can this information be combined to gain a better understanding of trade-offs inherent in choosing a strategy for wetland restoration (project 7).

The aims and objectives of each of these individual projects are presented in Section 4.

3. Study area – the Vecht

The study area is located between the Amsterdam-Rhine canal in the west, the watershed on a sandy hill-ridge to the east, the IJmeer (part of Lake IJssel which was formerly connected to the sea) to the north, and the city boundary of Utrecht to the south (see Figure 3.1). The area comprises shallow lakes and fens interspersed with agricultural fields and villages. Even where solid soil is present, the groundwater table is close to the surface.

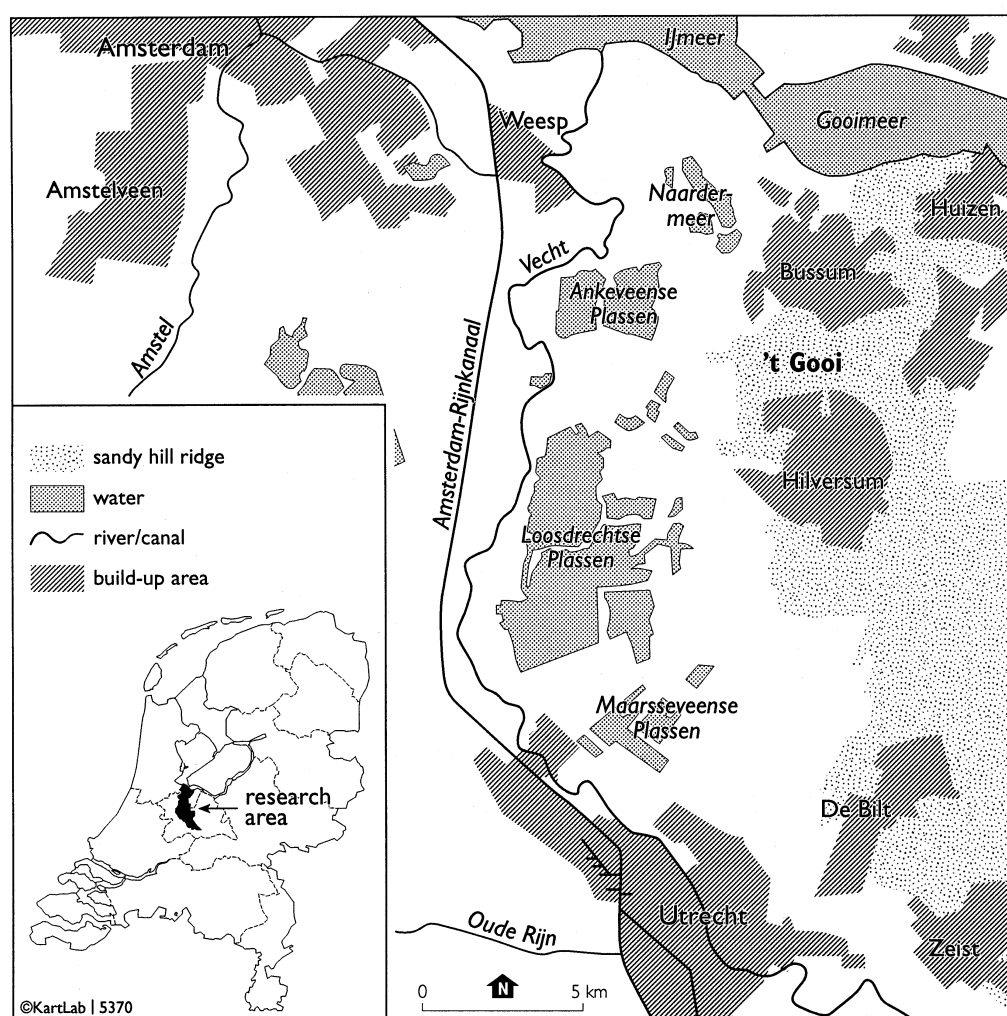


Figure 3.1. The research area and its surroundings (map taken from Van den Bergh et al., 2000).

The area overlaps the provinces of North Holland and Utrecht, and contains 10 municipalities. It comprises some 72 polders. Agriculture is the dominant land use in the area. Agricultural activities consist mainly of dairy farming, with pastures covering about half of the area. It is necessary to drain the land by means of ditches and pumps to keep water levels low. Water management aims at a groundwater level about 40 cm below the sur-

face. Pasturelands also support natural elements such as plant species typical of wetland ecosystems as well as waterfowl and meadow birds. Farmers are given incentives (e.g. the *Relatienota* - Anon, 1975) to maintain such elements on their land.

Nature, varying from open water to wetland ecosystems, covers about a third of the study area. The variety of open water, reedlands, marshes, grasslands and alder forests creates a mixture of different succession phases characteristic of fen wetlands and the transition from aquatic to terrestrial ecosystems. Most nature areas are owned by nature conservation organisations, both governmental (e.g. the National Forestry Service or *Staatsbosbeheer*) and non-governmental (particularly *Natuurmonumenten*). The value of nature in this area is high. The whole area is part of the Dutch Ecological Network and will become part of the European ecological network NATURA 2000; one of its lakes, Naardermeer, is listed as a Ramsar wetland. The study area is also a popular destination for recreation with activities including sailing, camping, walking and cycling. Residents from the component cities of the Randstad are regular visitors to the area.

Human settlement and economic development over some eight centuries have changed the character of these wetlands. The area's hydrology has been affected by groundwater abstraction, the creation of polders, and management of water tables. The last is needed to support agriculture. Ecosystems and lakes are suffering from the adverse effects of nutrient enrichment. This is the product of activities within the study area - agriculture, acid deposition, local sewage treatment plants, and the mineralisation of peat soils with their exposure to the atmosphere – as well as their import from outside the area, largely via the Vecht River. The post WWII landscape, comprising extensive agriculture and relatively undisturbed wetlands, has been replaced by a landscape fragmented by human activities. The area available for nature has decreased with concerns that it is too small or insufficiently connected to support viable plant and animal populations.

Attitudes are changing in the Netherlands. The fragmented state of remaining (semi-) natural areas has given rise to concerns about their future viability. The challenge of climate change (with sea level rise and higher risk of Winter floods) combined with soil subsidence as a result of land drainage begs a different approach to water management than simply continuing with higher dykes and more pumping. Allowing higher water levels (*vernatting*) and, in select areas, restoring wetland ecosystems seems inevitable. A number of restoration projects have already been implemented. However they are relatively small (100-200 hectares) and aim solely at restoring the local hydro-ecological situation. Larger projects with a regional scope seem to be more difficult to implement, perhaps because they are less acceptable to society.

4. The individual projects

4.1 Project 1: Linking regional and site scales in ecohydrological modelling for integrated water management²

Description of the problem

Up till now a large gap remains in the understanding of interactions between regional hydrological conditions, management practices and site scale effects in wetland ecosystems. Wetland flora and fauna depend directly on soil moisture conditions in the root zone. These soil moisture conditions are related to the position of the water table, which in turn depends on local and regional geohydrological structures and water management practices (Hooijer, 1996). Thus the conservation of wetlands should take into account the hydrological processes occurring in surrounding hydrological influence areas. Much attention has been paid to the concept of integrated water management over the last few years. An integrated approach implies several aspects of water management. On one hand it means extrapolating management practices from the past regarding water quality and water quantity of surface water and groundwater to current circumstances. On the other hand it also tends to converge these practices for the different processes to a management strategy, which links the different aspects to an interconnected approach (Liere, 1989). This integrated approach is of great importance for the functioning of wetland ecosystems since different processes and aspects are involved. In particular, complex parcellation, heterogeneities of the (sub-) soil, slight differences in topography and hierarchical non-linear drainage and irrigation systems are factors that need to be taken into account for the management of wetland ecosystems.

When different hydrological processes for integrated water management are being analysed attention has to be paid to a major difficulty. Different hydrological processes operate on different temporal and spatial scales. Unsaturated flow occurs in a 1 m. deep soil profile, while floods occur in river systems of several square kilometres. Flash floods can occur in several minutes while groundwater flow in aquifers may take hundreds of years (Bloschl, 1995). To identify specific management measures for a certain area, computer simulations are often used to study hydrological processes occurring in that particular area. In this hydrological modelling large differences exist between the spatial regional scale of hydrological models (describing flow of groundwater, surface water and/or soil moisture) and the scale of the site, relevant for soil-water-atmosphere processes, agricultural productivity, biodiversity and functioning of wetland ecosystems (Hobma, 1999).

² Prof. I. Simmers, Faculty of Earth Sciences/H&H, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam
Prof. P. Vellinga, Institute for Environmental Studies, Vrije Universiteit Amsterdam, De Boelelaan 1115, 1081 HV Amsterdam.
Dr. T. Hobma Faculty of Earth Sciences/ITC, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam
Drs. Leontien Gorter, Faculty of Earth Sciences, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam.

In the view of integrated water management several model structures have been developed which link the most relevant hydrological processes occurring in the Dutch lowland environment. The most relevant processes are groundwater flow, flow of surface water and flow of soil moisture in the unsaturated zone. In the starting phase of hydrological modelling attention has been only paid to one specific process of the hydrological cycle, while nowadays attention is paid to the interaction between different processes and linkage structures are being developed between the individual model packages. For example, RIZA has developed a linkage structure between NAGROM (a stationary, national groundwater model), DEMGEN* (a semi-stationary, national model package for the unsaturated zone to simulate water use efficiency by agricultural activities and nature areas) and MOLAR (a semi-stationary model package for simulation of evaporation and discharge in the lowland area of the Rhine catchment). This model structure operates on a (sub)fluvial scale and is developed for several purposes (Arnold 1992). It will be used in analyses of current environmental issues regarding eutrophication and desiccation, where information on regional and national scale about seepage and infiltration areas is required. The model package is used by the Rijkswaterstaat (Hoogeveen, 1994). Another example is the regional groundwater model package SIMGRO, which simulates the flow of water in the saturated and unsaturated zone on a regional scale (Querner, 1988). Examples are given of several applications for this model structure. The model structure can be used in surface water management, management of drainage- and collector systems, management of water supply for agricultural purposes, water resources management and analysis of the influence of land use on hydrology (Veldhuizen, 1998). The limitations of these model structures are that they tend to simplify the existing heterogeneities in a particular research area. Heterogeneities in parameters such as land use, soil type, geology, (un-)saturated hydraulic conductivities and resistances as well as heterogeneities in calculated water tables and water fluxes are aggregated to a single value, which are assumed to be valid for a discrete area. Sub-grid variations are neglected in this approach. The results of such an approach are useful for the description of general goals for a management strategy, but do not meet the requirements for practical application. The results will be too general, and specific demands and circumstances of each area will have an influence on the results. This will no doubt cause deviations in the results of the model study (Querner, 1997).

Wetland flora and fauna are adapted to very specific conditions of the water table regimes and inhabit relatively narrow niches. This is indicated by a close correlation between vegetation communities and hydrological patterns. Therefore, differences in water table regime that would be considered insignificant in other areas may be of great importance in wetland ecosystems (Hooijer, 1996). This indicates that discretisation and aggregation for integrated hydrological modelling should be minimised as far as possible when wetland areas are studied. Current available modelling techniques, which incorporate different processes, focus on (sub-) regional scale, while effects on local or site scale are so far most often generalised or ignored. This clarifies the need for an integrated hydrological modelling structure, which links the important processes in wetland areas (saturated groundwater flow and flow of soil moisture in the unsaturated zone) and which is capable of linking the several scale levels of the different hydrological processes. When this modelling technique is available it may be used to study the response of

specific site scale habitats to (sub-) regional changes in hydrology and water management.

Aims and objectives

The aims of the project are:

1. To analyse the interaction between land use and hydrology in the Utrecht / Noord-Holland region of the river Vecht. It should be mentioned that this is not just a one way process. Changes in hydrology can have a significant effect on the suitability of an area for a specific type of land use. On the other hand, changes in land use can have their effect in the hydrological characteristics of the particular area and its surroundings.
2. To develop a model structure that includes a coupling of analytical and numerical simulation for soil moisture and saturated groundwater flow respectively, which enables the ecohydrologist to further zoom on to hydrological doses and effects at the parcel scale of selected wetland ecosystems to investigate the role of the (ground) water regime on biodiversity and ecosystem functioning. In this context the numerical, unsteady, saturated groundwater model package MicroFEM will be linked to the analytical, pseudo-steady, unsaturated soil moisture model package MUST. These two model packages are selected because of their suitability for lowland environments. MicroFEM is known as a powerful tool in simulating saturated groundwater flow and MUST is a tool especially suitable to shallow water table circumstances.
3. To study the effect of regional hydrological changes on water regime at site scale with scenario simulations using the newly constructed model. Some sites will be selected for detailed research (Hostermeerpolder and Naardermeer).

This study will thus provide a powerful tool which can be used for development of an integrated water management strategy. A complete ecohydrological approach to system analysis in wetland areas at regional and local scale will be developed together with a reliable model structure, which makes predictions in regional hydrology and site scale water regime possible. Effects of integrated water management measures can be evaluated before they are put into practice. In this manner better founded decisions can be made about future water management measures.

Research Method

In the research process several detailed steps can be identified.

Inventory

This stage starts with a literature study based on the study area Gooi-/Vechtsteek and on the fundamental problem of scaling in hydrological modelling. An analysis will be made of previous research on scaling and linking problems in hydrology, hydrological modelling and on projects performed in the Gooi-/Vechtstreek.

This will be followed by an analysis of available groundwater models which simulate saturated groundwater flow in the Gooi-/Vechtstreek; several models are available which describe the whole region or just sub-areas in the region. To what extent these models are useful for creating a regional groundwater model will be analysed. From the existing groundwater models the data sets used and the assumptions on which the models are

based will be analysed in order to determine if they are suitable for the purpose of this project.

Data collection

The necessary data will consist of measured water tables, hydraulic heads, amount of groundwater abstraction and groundwater discharge, hydraulic conductivities for water bearing layers and resistances for (semi-) confining layers, meteorological data, data on water quality and information on relief, land use and vegetation. Reliable information on management of water levels at regional and local scales is required for the area as well as a detailed description of the surface water system including existing drainage. Data on supply and discharge of water in polder areas is also required.

From the analyses of existing groundwater models it should be clear which data sets are necessary for further refinement and development of the regional groundwater model. Existing data sets can deliver data in several formats. Digital data sets will preferably be used, since this will enhance the spatial coherence of the area. Furthermore, this format is most suitable for data operation using a Geographical Information System or GIS. These data will first be collated from existing data sets. From this analysis it will be clear in which particular areas further data are required. Additional piezometres will have to be installed whenever and wherever necessary.

Analysis

During the analytical stage extensive fieldwork will be performed at the selected sites, in order to develop a detailed description of the ecohydrological processes and systems present at the particular sites and to supply additional data needed for modelling. For the ecohydrological system analysis sample locations will be selected in close co-operation with the biology faculty, in order to reveal hydrological processes controlling ecologically valuable systems. This implies an extensive analysis of ecohydrological gradients.

Piezometres will be installed in order to measure water levels over a period of at least one year. These piezometres will also be used to sample shallow groundwater quality at selected locations. Cup samplers will be used to sample soil moisture at the same locations. Local geology and soil type will be described. The unsaturated zone modelling simulations require such parameters as depth of the root zone, type of root zone and type of subsoil. In order to establish accurate soil moisture characteristics and hydraulic conductivity relations, samples of the root zone and subsoil will be taken. Together with the 'Staringreeks' series of soil water retention and permeability characteristics of soils in the Netherlands (Wösten *et al.*, 1994), these characteristics and relations will be developed. Soil moisture content in the root zone / sub-soil will also be monitored at the specific sample locations. A detailed description of the micro-relief of the sites will be established by land surveying. A detailed description of existing drainage systems together with water level management practices is also required. The biology faculty will supply detailed descriptions of vegetation communities located at the sample sites. If additional meteorological data are required, appropriate measuring devices will be installed.

Since ecohydrological systems and processes are dynamic in space and time, several sampling locations will be selected and two-weekly or monthly measurements of the hydrological parameters will be continued for at least a year. Fieldwork will preferably be repeated a year later to gain an indication of the behaviour of the systems through time.

An ecohydrological system analysis can be performed using data collected during the fieldwork period. Maps of local geology, soil types, groundwater regime, vegetation and land use will be created and processed in a GIS (ArcView), when possible in combination with high-resolution satellite or aerial surveys. Standard sampling devices, monitoring techniques and classification systems are used as much as possible, in order to enable data analysis and comparison with data from other periods or other areas. This applies, for example, to: the recording of vegetation data using Londo's (1975) decimal scale or the scale of Braun-Blanquet (1964); the taxonomic classification of humus forms in soil data from Klinka *et al.* (1981); the 'Staringreeks' series of soil water retention and permeability characteristics of soils in the Netherlands (Wösten *et al.*, 1994); the hydrochemical classification of water samples in HYFA-parameters (Stuyfzand, 1993).

Regional modelling

Existing and newly created regional and local maps of relevant parameters can be used to modify or create the grid for regional computer modelling. When adequate regional groundwater models are available the grid may need only a refinement at the selected sites. Otherwise, a grid will be created using the relevant maps; this will preferably be achieved using a GIS. The groundwater model should be as physically based as possible. Model schematisations should therefore be based on reliable information and data. Physical boundaries of the regional model area will be the water divide division on the Utrechtse Heuvelrug, the northern border of the city of Utrecht, the river Vecht and the IJsselmeer Lake in the north. These boundaries must be translated into realistic hydrological boundaries. Reliable estimates of groundwater withdrawals and infiltration should be obtained and a good description of the surface water system should be required. The surface water system needs to be incorporated very carefully, since these systems should be modelled as realistically as possible. When the area is schematised, some preliminary simulations will be carried out in order to test the reliability of the model. The results will be used for model calibration and validation; this includes automatic optimisation of the required parameters and a sensitivity analysis of these parameters. Improvement of the model will continue during the stage in which scenario studies are performed. Results can be used to optimise the model, but a validation will need to follow each optimisation step.

Local modelling

The selected sites of Horstermeerpolder and Naardermeer (which have a refined grid in the network of the constructed regional model) will be used to study the effect of regional changes in hydrology and water management at a site scale. A special model structure will be developed to accomplish this, viz.: linkage will be made between the horizontal, saturated, unsteady, groundwater model package MicroFEM and the vertical, unsaturated, pseudo-steady, soil moisture model package MUST. A dynamic interaction between the interdependent saturated groundwater flow and unsaturated soil moisture transport will be thus developed.

The soil moisture transport model MUST needs numerous input parameters in order to be able to calculate the saturation deficit curves and fluxes. Meteorological data are required as well as data on land use / vegetation, type of sub-soil, type of root zone and depth of root zone. Input parameter aggregation should be minimised as far as possible. Information on the distribution of these parameters is gained during the analytical stage.

A file will be created consisting of values for the required parameters for each node / case, which will be used as input data by MUST in order to calculate fluxes and saturation deficit curves.

More detailed information about the modelling procedures is given in Appendix 1.

Scenarios

The developed model structure will be used as a tool to study effects of changes in regional hydrology and water management or a site scale in wetland areas. This will be achieved by studying the results of scenario simulations. Scenarios will be developed in cooperation with other members of the research team. Some comments should be made concerning the scenarios. Scenarios usually comprise two types of elements: management strategies which can be deliberately undertaken to steer the system and exogenous factors which influence the system, but over which regional managers have no influence. The first element comprises actions such as raising water levels, the latter concerns factors like climate and sea level change, or decisions made by the European Community. Several measures in the framework of management strategies could be analysed in this stage. For example, raising water levels in specific areas in several steps (*vernatting*), supplying the study area with *gebiedsvreemd* (atypical for the site) water, eutrophication or water purification, eutrophication or dredging, changes in land use (nature-, recreational-, residential development). In the scope these measures exogenous factors should also be taken into account, as they will be relevant for the whole study area. Exogenous factors which will be taken into account are climate, economic factors and policy. Extreme events, like severe drought or extreme storms, may be studied with the model structure in order to reveal the vulnerability of the system.

In this manner, the effects of several different regional management measures and exogenous factors may be studied at a site scale in the wetland areas. The significance of changes in the water regime at site scale will be tested statistically. This will enhance the understanding of the interaction between hydrological processes at regional, local and site scales.

Workplan

Year 1 (2000)

- December 1999: Selecting sample locations together with biology section; make preliminary agreements on parameters to measure; starting with model and data analysis.
- January-February 2000: Analysis of existing models and data sets used.
- February-March 2000: Analysis of existing data sets; inventory of required additional data; analysis of research area (problems in hydrology and water management at regional and site scale).
- March-April 2000: Preparing fieldwork; continued literature research on study area.
- May-June 2000: Fieldwork period; supervision of fieldwork for environmental science students.
- June-August 2000: Analysing data; using GIS and other classification systems; finishing first analytical stage by development of ecohydrological system analysis of study area.

- September 2000: Starting regional and local computer modelling.

Year 2 (2001)

- Development of the regional groundwater model and a linkage structure between groundwater and soil moisture models, together with additional fieldwork during spring in order to incorporate a time element in the ecohydrological system analysis. Two-weekly or monthly measured hydrological parameters will be used in model simulations in the ecohydrological system analysis.

Year 3 (2002)

- Performing scenario studies to evaluate the effect of regional hydrological changes on the site scale water regime. Make predictions about the effects of management strategies and present an evaluation of the actual state of groundwater dependent ecosystems as well as the impact of change and the potential for future regeneration in wetland areas.

Year 4 (2003)

- Writing and defence of thesis.

Composition of the Research Group

Prof. I. Simmers	flood hydrology (not sure)
Prof. P. Vellinga	coastal zone management
Dr. M. Stam	flood hydrology
Dr. T. Hobma	ecohydrology (ITC)
Dr. C.J. Hemker	groundwater hydrology and modelling
Drs. G. Rot	agricultural hydrology ('Stichting bodemvocht belang')
Drs. L. Gorter	Ph.D. studies (oio)

References:

- Arnold, G. E., de Lange, W.J., Parmet, B.W.A.H., van de Ven, F.H.M. (1992). Schaalproblemen bij het gebruik van modellen op (sub)fluviale schaal; millimeteren op de vierkante kilometer. *Schaalproblemen in de Hydrologie*. Delft, CHO-TNO. 31: 143.
- Bloschl, G., Sivapalan, M. (1995). "Scale issues in hydrological modelling: a review." *Hydrological Processes* 9 (hydrological modelling): 251-290.
- Hobma, T. W. (1999). *Ecohydrological basis for coastal zone management*. Faculteit der Aardwetenschappen. Amsterdam, Vrije Universiteit Amsterdam: 229.
- Hoogeveen, J. (1994). *Koppelingsconcept voor de modellen NAGROM-MOZART-DEMNET-2. Toepassing voor peilbeheer Nederland: Het Gooi en Vechtplangebied*. Lelystad, Wageningen, RIZA, Landbouwniversiteit: 68.
- Hooijer, A. (1996). *Floodplain hydrology; An ecologically oriented study of the Shannon Callows, Ireland*. Faculty of Earth Sciences. Amsterdam, Vrije Universiteit: 221.
- Liere, v. L., Roijackers, R.M.M., Verstraelen, P.J.T. (1989). *Integraal waterbeheer in het Goois/Utrechts stuwwallen- en plangebied*. 's-Gravenhage, TNO.
- Querner, E. P. (1988). "Description of a regional groundwater flow model SIMGRO and some applications." *Agricultural Watermanagement* 14: 209-218.

Querner, E. P., Aarnink, W.H.B. (1997). "Veranderingen in grondwateraanvulling en grondwaterstanden door ingrepen in de waterhuishouding." *H₂O* 30(I): 23-25.

Veldhuizen, A. A., Poelman, A., Stuyt, L.C.P.M., Querner, E.P. (1998). *Software documentation for SIMGRO V3.0; Regional water management simulator*. Wageningen, SC-DLO: 289.

Appendix 1

The selected sites Horstermeerpolder and Naardermeer (which have a refined grid in the network of the constructed regional model) will be used to study the effect of regional changes in hydrology and water management at a site scale. A special model structure will be developed to accomplish this, viz: a linkage will be made between the horizontal, saturated, unsteady, groundwater model MicroFEM and the vertical, unsaturated, pseudo-steady, soil moisture model MUST. A dynamic interaction between the interdependent saturated groundwater flow and unsaturated soil moisture transport will thus be developed. This dynamic interaction will be accomplished by connecting each node in the groundwater model to a specific case in the soil moisture transport model. The groundwater model will calculate a water table for each node. This value is used as input for the soil moisture calculation with the same number as the node. MUST then calculates the flux of soil moisture (upward, capillary rise or downward, infiltration), which depends on the height of the water table. Since the calculated flux from MUST in turn influences the height of the water table, the equilibrium situation between water table and groundwater recharge by a soil moisture flux for each time step has to be derived by iteration. Ideally this procedure will converge the resultant error to a minimum value. Whether this is a realistic goal will need to await development of the linkage structure. It is possible that a maximum number of calculations per time step must be specified or, alternatively, that the first calculated value for the water table is given as input to calculate the soil moisture flux and that subsequently a new time step is calculated.

In this manner aggregation of water tables to calculate soil moisture fluxes and the water regime at site scale are avoided. This will approximate the water regime at site scale more realistically, since groundwater and soil moisture operate in a dynamic, interactive way rather than in a static, separate manner.

The soil moisture transport model MUST needs numerous parameters in order to calculate the saturation deficit curves and fluxes. Meteorological data are required as well as data on land use / vegetation, type of subsoil, type of root zone and depth of root zone. Input parameter aggregation should be minimised as far as possible. Information on the distribution of these parameters is gained during the analytical stage. Ideally these parameters should be determined separately for each soil moisture modelling case (node), but for practical reasons this is impossible. Parameters determined at the sample locations thus form a basis for interpolation techniques to determine a realistic area covering parameter distributions. Statistical interpolation techniques (for example kriging) or discretisation of the area may achieve this. In discretisation procedures the area will be divided into hydrologically homogeneous sub-areas, based on the distribution of the sampled parameters. A representative value of the parameter for each sub-area will be found by aggregation techniques. Which of the available interpolation techniques gives the best results should be tested. The effect of the degree of discretisation on the modelling results should also be tested. A file will be created comprising values for the required pa-

rameters at each node / case, which will then be used as input data by MUST in order to calculate fluxes and saturation deficit curves.

In the modelling procedure two sets of difficulties have to be taken into account.

The first involves problems of scale, which will effect model applicability. The working scale for ecologists and ecological processes is much smaller than that for hydrologists. Groundwater models are generally too coarse for an ecologically significant description of site conditions. Refining the groundwater model network is only acceptable when hydrological data are available on that scale. This is usually not the case, so refining the network only produces apparent accuracy, which is actually not there. This problem should be taken into account when saturated- and unsaturated zone models are coupled and the network at the selected sites is refined. In order to accomplish a regional distribution of required parameters interpolation techniques are to be used. This will make down scaling possible, but uncertainties in interpolation techniques should be taken into account. Since output of the saturated groundwater model will be input for the unsaturated zone model, uncertainties will accumulate. Uncertainties in interpolation of parameters and in modelling techniques will reduce the reliability of the model structure. Results of the modelling and scenario analyses should thus be interpreted appropriately. These results are not fixed values with a 100 % reliability; they should be interpreted as maximum probability with a determined reliability interval. Policy decisions based on the model should also incorporate the reliability interval. Techniques may be analysed or developed to reduce this interval as much as possible, thus enhancing potential use of the model as much as possible.

Some technical problems can also be encountered during computer modelling in the Gooi-Vechtstreek. Modelling of the shallow saturated zone seemed to be particularly difficult in earlier performed studies with many parameters being sensitive to changes in value. Analyses indicated that parameters describing the confining layer in the area appear to be very sensitive; resistance of drainage systems was also defined as a very sensitive parameter. A detailed description and reliable measurements of these parameters are therefore required. A detailed description of the density and dimensions of drainage features (ditches, trenches, etc) is also required from topographic information sources (maps, digital maps) and fieldwork. Another problem encountered during hydrological modelling was schematisation of the boundary condition at the Utrechtse Heuvelrug. Due to long-term groundwater withdrawals, the former water divide on the Utrechtse Heuvelrug no longer exists. A water divide on the Utrechtse Heuvelrug can therefore no longer serve as a Neumann boundary condition. Another boundary condition has to be applied to the region, possibly at a different location. Finally, attention has to be paid to the possible, perhaps temporary, absence of unsaturated conditions in the research areas, specifically when these conditions occur within a grid-cell. The effect of this on evaporation and storage has to be taken into account.

4.2 Project 2: Remote sensing approach to study scale aspects and functioning of wetland ecosystems³

Abstract

In most land or water studies where remote sensing techniques are applied, relatively pure picture elements (pixels) can easily be found, analysed and modelled. (Semi-) natural wetland ecosystems represent the transition between these studies. The understanding (from a remote sensing point of view) of such complex systems requires the integration (by means of data-assimilation) of aquatic-ecological and terrestrial ecohydrological modelling and detailed observation techniques. The degree of observation-detail that is necessary, cannot be provided by traditional (satellite based) optical sensor systems, but the recent development and application of high resolution (spatial and spectral) imaging spectrometers has changed this situation. At present, full spectra can be resolved which should allow providing areal coverage and/or timing series of relevant parameters, including quantitative analyses.

The aim of this project is to understand spectral mixtures of observations of wetland ecosystems and to design methods to derive detailed information on local wetland composition from remote sensing. A secondary aim is to study the amount of information available within a pixel at a certain scale, both by forward and inverse modelling. Ultimately, maps of the state and composition of wetlands at various stages of water level rise will be produced for the overall project team.

Description of the problem

The overall study project will address the analysis of the influences of discrete water level changes on the wetland ecosystem. This will involve mainly the study of increased water levels on hydrological, ecological and chemical characteristics of Dutch wetlands. At various stages (before during and after water level changes) detailed spatial information is required on the physical-ecological status of the wetland. One of the techniques that will be used to obtain this information is remote sensing.

Already in the eighties / early nineties, the potential was demonstrated of high resolution imaging spectroscopy techniques for the determination of a number of aspects of inland water quality (concentrations of suspended sediment, algal pigments and dissolved organic substances) (Dekker *et al.*, 1992, 1993, 1994 and 1999). A number of subsequent

³ Prof. I. Simmers, Faculty of Earth Sciences/H&H, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam.

Prof. P. Vellinga, Institute for Environmental Studies, Vrije Universiteit Amsterdam, De Boelelaan 1115, 1081 HV Amsterdam.

Dr. S. Peters, Institute for Environmental Studies, Vrije Universiteit Amsterdam, De Boelelaan 1115, 1081 HV Amsterdam.

Dr. K. van Huissteden, Faculty of Earth Sciences/K&G, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam.

Dr. T. Hobma, Faculty of Earth Sciences/ITC, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam.

Drs. M.L. Laanen, Institute for Environmental Studies, Vrije Universiteit Amsterdam, De Boelelaan 1115, 1081 HV Amsterdam.

studies have proven the applicability of these techniques for the parameters mentioned. After recent elaboration of inversion techniques such as matrix inversion and neural networks, the inversion of standard bio-optical models and parameter retrieval has become feasible (Hoogenboom *et al.*, 1998). These studies have neglected the influences of bottom reflection and reflection by submerged and emerging macrophytes. Furthermore, the number of parameters retrieved for water composition analyses were limited (Peters *et al.*, 1998), whereby the retrieval of the concentration of CDOM only incidentally succeeded. Evidently, remote observations of wetland systems will contain mixtures of shallow water of various compositions, submerged and emerging vegetation, and mixtures that reflect the transition from water ecosystem to land ecosystem. Existing databases of close range spectral observations and optical water properties is lacking for wetland situations (Rijkeboer *et al.*, 1998, 1999; Pasterkamp *et al.*, 1999).

Aim and objectives

Remote observations of wetland systems will contain mixtures of shallow water of various compositions, submerged and emerging vegetation, and mixtures that reflect the transition from water ecosystem to land ecosystem. The objectives of this study are therefore:

- Build a database of near surface optical spectral observations of homogeneous representatives of all relevant wetland constituents, as well as a documented set of mixtures describing transitions between the former mentioned groups
- By means of integrated modelling (using mainly existing models) understand and describe the optical behaviour of observed groups and mixtures
- Select or design robust inversion techniques that will allow not only to distinguish homogeneous wetland groups, but also to unmix pixels that contain multiple constituents
- Use the selected inversion techniques together with observations from airborne or satellite-borne sensor systems to make quantitative wetland composition maps at the working scale of the overall project.

A database on spectral characteristics of wetland components is non-existent. There is little knowledge on how to interpret composite pixels containing terrestrial vegetation, shallow water of various compositions and water vegetation. By using bio-optical (radiative transfer) models a quantitative basis is formed for general applicable for the monitoring of one of the most vulnerable ecosystem types of the world.

Research method

In order to be able to understand composite wetland remote sensing observations, three phases are foreseen, namely:

4. The study of optical characteristics of wetland ecotypes at close range, and building a spectral database of these observations.
5. To use bio-optical radiative transfer codes such as HYDROLIGHT and SAIL to simulate the optical characteristics of composite pixels at several scales.
6. To design, test and apply adequate inversion methods to derive detailed composition information from inherently mixed wetland pixels at several scales. Probably this

will require some degree of data assimilation, in order to reduce the number of degrees of freedom.

Phase 1 will involve field measurements and laboratory experiments. From selected sites water samples will be collected, of which the inherent and apparent optical properties will be measured using standardised techniques (Rijkeboer, 1999). Coupled close range spectral observations will be performed of the sub-surface irradiance reflectance. Special attention will be given to state of the art methods to determine the absorption characteristics of Coloured Dissolved Organic Matter (CDOM). All observations will be entered into a accessible database.

Phase 2 will involve model simulations using radiative transfer model codes such as HYDROLIGHT and the SAIL model. Composite spectral signatures of mixtures of water (at various compositions) together with aquatic and terrestrial vegetation will be simulated. The simulated studied to determine the potential for inverse retrieval of the constituents. Sensitivity studies will be performed in order to find the influence of model assumptions on retrieval efficiency.

Phase 3 will involve the selection, parameterisation, testing and application of inversion methods (e.g. neural networks) for the retrieval of wetland components concentrations from remote observations. The output of this phase will be a series of maps at various scales of wetland state variables such as type and concentration of CDOM, TSM and algal pigments in water, type and abundance of aquatic and terrestrial vegetation.

The activities will be conducted according to the approximate time schedule given below. During the research, appropriate time will have to be allocated for either the implementation of existing inversion methods such as neural networks or the development of new, simple but dedicated methods.

Field and laboratory studies will be conducted by Drs Laanen, supported by Drs. M. Rijkeboer and Dr. S. Peters.

Temporal and Spatial Scales

The remote sensing study will aim at describing the vegetation growth during a part of the year. Although it would be interesting to study both the variations within one year and the year to year variations in the 4-year period, the study is strongly dependent on available existing remote sensing material. Therefore it is likely that the first aspect will receive more attention than the second will. Most of the existing RS-images are historical (last 7 years) and taken in the summer, which will limit the study of the temporal dynamics.

Available aircraft images are at a spatial scale of 3 - 5 meters. Processes and effects (as function of concentrations) can be studied at this scale. Satellite images with pixel sizes of 15 m and increasing will be used to study general patterns and to upscale the results for the overall study area.

Workplan

Year 1

- Literature study, study of mixing-unmixing models, wetland optical properties, water-land transitions, specific wetland optical properties such as CDOM composition.
- Selection of specific study sites, ecotypes etc.
- Collection of close range spectral data, laboratory determinations of optical properties of aquatic optical active constituents
- Document and make accessible available remote sensing images

Year 2

- Finish database of wetland optical properties
- Analyse close range results: 1st paper on analysis results
- Pre-process remote sensing images
- Set up model simulations with radiative transfer codes

Year 3

- Perform model simulations and sensitivity studies: 2nd paper on results + presentation at a relevant conference
- First selection of inversion methods, test phase, first processing of remote sensing images
- Revisit field sites for extra sampling if necessary

Year 4

- Select, implement and apply optimal inversion techniques and make maps of all retrievable wetland components from selected remote sensing images at various scales
- Analyse the effect of choosing a certain scale level
- Congress visit
- Write remaining papers and PhD thesis. Oral viva.

Composition of the research (sub-) group

Dr. S.W.M. Peters	Remote sensing / hydrology
Dr. K. van Huissteden	Hydrology / remote sensing
Drs. M. Rijkeboer	Ecology / remote sensing
Drs. M. L. Laanen	Ph.D. student (oio)

References

- Dekker, A.G., M. Donze (1994). Imaging spectrometry as a research tool for inland water resources analysis. In: J. Hill (Ed.), Dordrecht, The Netherlands, Kluwer AP,
- Dekker, A.G., H.J. Hoogenboom, S.W.M. Peters, J.P. Moen, E.J. Kootwijk, G. van Rossum (1999). Assessing the quality of inland waters in the Netherlands. *Backscatter*, Vol. 10, No. 1, p. 15-19.
- Dekker, A.G., T.J.M. Malthus, and L.M. Goddijn (1992). Monitoring cyanobacteria in eutrophic waters using airborne imaging spectroscopy and multispectral remote sensing systems. *6th Australasian Remote Sensing Conference, 11 -1992, Wellington, New Zealand*, p. 204-214.

- Dekker, A.G., S.W.M. Peters (1993). The use of the Thematic Mapper for the analysis of eutrophic lakes: A case study in The Netherlands. *Int. J. Remote Sensing*, Vol. 14, No. 5, p. 799-822.
- Hoogenboom, H.J., A.G. Dekker, J.F. de Haan (1998). *InveRSion: assessment of water composition from spectral reflectance: a feasibility study to the use of the matrix inversion method*, NRSP-2 98-15, Netherlands Remote Sensing Board, Programme Bureau, Rijkswaterstaat Survey Department, Delft, The Netherlands, 48 p.
- Hoogenboom, H.J., A.G. Dekker, J.F. de Haan (In Press). Retrieval of chlorophyll and suspended matter in inland waters from CASI data by matrix inversion. *Can. J. Remote Sensing*.
- Pasterkamp, R., M. Rijkeboer, A.G. Dekker (1999). *Specific Inherent Optical Properties of Dutch inland waters and estuaries*, W99/10, IVM/VU, Amsterdam, The Netherlands, 30 p.
- Peters, S.W.M., A.G. Dekker, and P. Keller (1998). From end-user requirements to sensor requirements. In: J.F. Schalles, D. Schlapfer, and K.I. Itten, editors. *1st EARSeL Workshop on Imaging Spectroscopy*, 8 -10 -1998, EARSEL, Zurich, p. 215-220.
- Rijkeboer, M., A.G. Dekker, H.J. Gons, Optical classification of Dutch inland waters [In Press]. *Verh. Internat. Verein. Limnol.*
- Rijkeboer, M., H.J. Gons, A.G. Dekker (1998). Optische teledetectie van waterkwaliteitsparameters: demonstratie voor het waterbeheer. *H₂O*, Vol. 15, p. 19-21.
- Rijkeboer, M., A.G. Dekker, H.J. Gons, (1998) Subsurface irradiance reflectance spectra of inland waters differing in morphometry and hydrology. *Aquat. Ecol.*, Vol. 31, p. 313-323.

4.3 Project 3: Development of chemical indicators to characterise wetland ecosystems⁴

Abstract

There is an obvious need to develop chemical indicators, complementary to biological indicators, to characterise the impact of anthropogenic influences on wetland ecosystems. Chemical indicators are required since structurally similar compounds can exhibit totally different effects. The development of such indicators to characterise the wetland ecosystems is an analytical chemistry challenge, requiring the development of a variety of methods and techniques including sample handling procedures, advanced separation methods and spectroscopic detection techniques. The chemical research will focus on flavonoids, lignins, and tannins especially regarding their presence in the different compartments of the ecosystem (plants, water, soil). Emphasis will be on both analytical chemistry and physical chemistry indicators. Synergy and collaboration with the Faculty of Biology will encourage development, evaluation and eventually use of such indicator system in conjunction with biological indicators. The objective is the ultimate availabil-

⁴ Prof.dr. C. Gooijer, Faculty of Sciences, Division of Chemistry, Vrije Universiteit, De Boelelaan 1083, 1081 HV Amsterdam
 Prof.dr. U.A.Th. Brinkman, Faculty of Sciences, Division of Chemistry, Vrije Universiteit, De Boelelaan 1083, 1081 HV Amsterdam
 Prof.dr. M.A.P.A. Aerts, Faculty of Biology, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam.
 Dr. F. Ariese, Faculty of Sciences, Division of Chemistry, Vrije Universiteit, De Boelelaan 1083, 1081 HV Amsterdam
 Ms. Eva de Rijke, Faculty of Sciences, Division of Chemistry, Vrije Universiteit.

ity of chemical indicators, interrelated with or complementary to biological indicators, that can be used to characterise wetland systems.

Description of the problem

There is an obvious need to develop a system of indicators (biological and chemical) which characterise the impact of anthropogenic influences such as changes in water table on ecosystem stability and ecosystem functioning. This project will concentrate on the development of chemical indicators to characterise the ecosystems concerned; a main analytical chemistry challenge requiring the development of a variety of dedicated methods and techniques including sample handling, separation and spectroscopic identification techniques. There will be a strong synergy and extensive collaboration with the Faculty of Biology to utilise the unique possibility provided by the research programme to develop and eventually use such indicator systems simultaneously with the biological indicators dealt with in project 5. Biological indicators are more general and less selective than chemical ones. Chemical indicators are required since structurally similar compounds can exhibit totally different effects. A close co-operation with the Faculty of Biology is also needed to account for the spatial component of the chemical research. Biology will play the leading role in the sample selection. A diversity of sampling and sample clean-up procedures will be developed to take into account the widely varying concentrations of analytes and dissolved organic matter as well as particulate matter.

The research will focus on lignins, flavonoids and tannins especially regarding their presence in the different compartments of the ecosystem (plants, water, soil), their estrogenic activity, their interaction with organic material (i.e. humic substances) and their potential to be used as stress indicators (i.e. lack of nutrients, UV-radiation). At the moment for these classes of compounds no reliable information is available with respect to the effect and the activity of their (bio)degradation products, (photochemical) decomposition products and metabolites. In order to determine ecotoxicological effects and analyte-matrix interactions, it is important to possess on the one hand reliable and robust quantitative methods and on the other hand techniques allowing the characterisation of (soluble and insoluble) matrix components and analyte-matrix interactions. Therefore, both broad-spectrum biological indicators as well as narrow-spectrum chemical indicators need to be developed. Within this context a very important parameter will be the physical state of the compounds concerned, i.e. free in solution or adsorbed onto particulate (organic) material etc.. Heterogeneous interactions will significantly influence the chemical behaviour.

Concerning *lignins*, including the different type of halogenated and non-halogenated lignosulfonic acids, fulvic and humic acids, and high-molecular-weight humic substances, in particular the composition of both the dissolved (DOM) and non-dissolved (e.g., particulate matter, sediment) organic fraction will be studied. *Flavonoids* are natural compounds, present in a wide variety of plants. The synthesis and degradation of these compounds is strongly influenced by UV-b-radiation (photochemistry), hydrolytic effects and adsorption phenomena. The distribution and behaviour of flavonoids strongly depends on the degree of conjugation with sugar molecules and the type of sugar molecules involved. In this respect mass spectrometry coupled with liquid chromatography (LC-MS), and co-operation with Biology, is important to study the behaviour of the ecosys-

tem in this respect. The *tannin*-type of compounds is not only naturally present in plants, but also the major waste of tannery processes.

From a chemistry point of view the flavonoids, lignins and tannins form classes of compounds that are very complicated as such, i.e. irrespective of matrix effects. Evidently, the best chance of success will be for the compounds that provide the least analytical chemistry / applied spectroscopy problems.

For this reason we will start with the class of flavonoids:

- Contrary to lignins and tannins, these are chemically well-defined compounds.
- Standards are (commercially) available.
- Flavonoids possess chromophoric groups so that they can be studied by UV/Vis spectrometry and furthermore photochemistry experiments (UV-B) can be readily involved.
- Some flavonoids are fluorescent as well; preliminary studies have already been carried out in our department [1].
- Flavonoids give useful MS data. They received extensive attention in the recent literature. They have been studied in various MS modes (Ryan *et al.*, 1999).
- Last but not least, experienced people in this field are available in the Netherlands to become external advisers (Verpoort (RUL), Holman (RIKILT), T. van Beek (LUW).).

Despite the recent attention for flavonoids, also for this class of compounds as well as for lignins and tannins, it is a point of high priority to map out the available analytical chemistry and applied spectroscopy methods with emphasis on robustness and reproducibility in dealing with complex sample matrices of different origins.

Also physical chemistry parameters will be considered. These received extensive attention over many years, as is for instance obvious from the book of G.G. Choudhry, published in 1984 (Choudhry, 1984). Recently they evolved into 'a biogeopolymeric view of human substances' (Cook and Langford, in press).

Aim of project

The aim of the project is to develop chemical indicators that complement biological indicators and can be used to characterise the impact of anthropogenic influences such as changes in water-table on ecosystem stability and ecosystem functioning. In the first place, flavonoid profiles will be chosen for this purpose, especially the profiles obtained by applying on-line liquid chromatography (LC), ultraviolet (UV) absorption spectroscopy and mass spectroscopy (MS) (to be quoted as LC-UV-MS) and the profiles obtained by applying capillary-electrophoresis (CE) coupled to laser-induced fluorescence (LIF). Secondly, physical chemistry indicators will be evaluated. Currently, we are studying (in close collaboration with Prof. Cooper Langford, Calgary Canada) a fluorescent model system that seems to be useful to characterise humic substances; however the research is still in a preliminary stage. Thirdly, lignins and tannins will be considered as alternatives for the indicators developed above.

In view of the chemical structures and compounds dealt with, spectroscopic characterisation even of reference materials is a challenge as such, and a diversity of techniques and methods will be explored. The same holds for the development of sampling and separa-

tion procedures; for the highly complex systems to be studied there is a little chemical expertise available.

The main chemical challenges with respect to compounds of interest are:

- the lack of (ultra-)sensitive selective analytical methods for quantitative determinations;
- the lack of reliable structure elucidation and structure confirmation methods;
- the lack of information on the interaction of these compounds with organic matter (particulate matter);
- the lack of details on the degradation and decomposition behaviour of these compounds.

Also the investigation of analyte-organic matter interactions (adsorption effects) is challenging from an analytical chemistry point of view.

Research method

Three parts in the research method can be distinguished.

I. Method development for standard flavonoids along three main lines;

- LC–UV/Vis-MS (possibly MS/MS); on-line UV/Vis diode array detection will probably be used for quantification and tentative structure assignment; MS for identification purposes.
- CE–LIF /luminescence detection; preliminary experiments indicate the appropriateness of CE (capillary electrophoresis) for quantification of fluorescent flavonoids. For these flavonoids, sufficiently low concentration detection limits will be achievable, if LIF (laser induced fluorescence) detection is involved (Beekman *et al.*, 1999). The technique will be further extended by combining it with other luminescence modes as for instance phosphorescence detection, a technique currently being developed in our group (Kuyt *et al.*, 1999).
- Stand-alone spectroscopic techniques including room temperature synchronous fluorescence spectroscopy, cryogenic high-resolution fluorescence spectroscopy and Raman spectroscopy. If very detailed spectra can be obtained also for complex matrices, stand-alone spectroscopic techniques may ultimately provide the tools to study environmental parameters as well. Currently explorative experiments are performed in our lab.

II. Studying matrix effects including the development of proper sample handling procedures to be combined with LC–UV–MS and CE–LIF– luminescence detection and studying matrix effects

- Development of SPE (solid phase extraction)-based sample handling strategies. SPE-based sampling will enable the detection limits of the target compounds to be attained.
- Selection of optimised detection parameters for all modes of detection. Optimisation of detection parameters will probably most time-consuming, but also most rewarding, in the case of (tandem) MS, where the numbers of experimental variables is by far the largest.
- Miniaturisation of the analytical set-up. Miniaturisation will be of interest for the ‘capillary’ separation techniques, i.e. for CE and for micro/capillary LC (probably

required for some of the MS modes of operation), and if sample size (plants, biota) is limited.

III. Development and evaluation of indicators

- Development of chemical indicators by studying wetland effects on LC–UV–MS and CE–LIF/luminescence profiles of flavonoids.
- Considering alternative indicators, including biological ones and possibly physical chemistry indicators. Currently, we are studying (in close collaboration with Prof. Cooper Langford, Calgary Canada) a fluorescent model system that seems to be useful to characterise humic substances; however the research is still in a preliminary stage.
- If appropriate, considering lignins and tannins as alternatives for the indicators developed above.

Workplan

The elementary steps to be followed were formulated in the section ‘Research Method’. Obviously, prior to these steps an inventory stage can be distinguished, directed on mapping the available chemistry and applied spectroscopy methods for flavonoids, lignins and tannins.

A rough indication for the time schedule can be the following:

Inventory stage	0.5 year
Method development for standard flavonoids	1.5 year
Matrix effects / sample handling procedures	1.5 year
Development and evaluation of indicators	0.5 year

Composition of research group

Prof. C. Gooijer	Applied Laser spectroscopy
Prof. U.A.Th. Brinkman	Analytical Chemistry/Separation Methods
Prof. M.A.P.A. Aerts	System ecology
Prof. H. Irth	Analytical Chemistry/Separation Methods
Prof. W.H.O. Ernst	Botany
Dr. H. Lingeman	Analytical Chemistry/Separation Methods
Dr. H.A. Zappey	Mass Spectrometry
Dr. F. Ariese	Applied Laser spectroscopy
Drs. E. de Rijke	Ph.D. student (oio)

References

- Beekman, M.C., H. Lingeman, U.A.Th. Brinkman and C. Gooijer (1999). Determination of the isoflavone formononin in red clover (*Trifolium pratense* L.) by micellar electrokinetic chromatography combined with deep-UV laser-induced wavelength-resolved fluorescence detection. *J. Microcolumn Separations* 11:347-352.
- Ryan, D., K. Robards, P. Preznler and M. Antolovich (1999). Applications of mass spectrometry to plant phenols *Trends in analytical chemistry* 18:362-372.
- Choudhry, G.G. (1984). *Humic Substances, Structural, Photophysical, Photochemical and Free Radical Aspects and Interactions with Environmental Chemicals*. Gordon.
- Cook, R.L., and C.H. Langford, A Biogeopolymeric View of Humic Substances, in press.

Kuyt, J., U.A.Th. Brinkman and C. Gooijer (1999). Sensitized and quenched phosphorescence as a detection mode in capillary electrophoresis. *Anal. Chem.* 71:1384-1390.

4.4 Project 4: Steering of ion channels by metals^{5,6}

Abstract

Increasing water tables in Wetlands will diminish the availability of micronutrients by an enhance precipitation of metal sulphides. One of the micronutrients with low nutrient availability is zinc. With molecular and genetic approaches the ability of plant species to survive in wetlands, which exhibit strong fluctuations in oxygen concentrations and thus zinc availability, will be studied.

Previous research indicates that at low zinc availability, the expression of the zinc transporter proteins, encoded by genes of the ZIP family (Znt/Irt-like proteins), is enhanced or up regulated. Analysis of the expression of the various ZIP genes may make it possible to unravel the cellular feedback mechanisms between root-specific and leaf-specific signals of zinc supply. At normal to high zinc availability the ZIP genes may be inactivated and transporter proteins encoded by the ZAT (Zinc transporter of *Arabidopsis thaliana*) family may be upregulated or enhanced. These two putative transporter systems are believed to work in tandem and are essential in the uptake and homeostasis of zinc in a variety of species.

Therefore the study of zinc transporter provides us with an opportunity to gain insight in two areas of plant ecology and ecotoxicology. Primarily we wish to review our knowledge regarding the biochemical principles that govern metal uptake and homeostasis in plants. This will provide additional insight into how metals are processed within plants and may give an indication of how readily they move through the food chain. The study will also aid our understanding of interactive regulation of metal transporter proteins in the environment with temporal variation of zinc availability. It will contribute to a rational of understanding biodiversity by identifying fitness differences in wetlands.

Description of the problem

In all ecosystems with partially flooded or water-saturated soils, including wetlands, the occurrence of periodical anaerobiosis is an ecosystem-specific process. It modifies the valencies and the bioavailability of many metals, metalloids and two major nutrients, (i.e. sulphur and nitrogen). Reduced sulphur has a very controlling function during soil anaerobiosis by modifying element speciation and element availability (Ernst, 1990a). As a high radial oxygen loss the element speciation in the rhizosphere is changed from strongly reduced to highly oxidised forms (Armstrong, 1982), thus diminishing the toxicity of sulphides, ammonium and divalent iron and manganese. In the neighbourhood of

⁵ This project is funded separately by the Faculty of Biology.

⁶ Prof.dr. W.H.O. Ernst, Department of Ecology and Ecotoxicology of Plants, Vrije Universiteit, 1087 De Boelelaan, 1801 HV Amsterdam.
Ms Emma Jack, Department of Ecology and Ecotoxicology of Plants, Vrije Universiteit, 1087 De Boelelaan, 1801 HV Amsterdam.

the roots with aerenchyma the elements occur a highly oxidated state (NO_3^- , SO_4^{2-} , Fe^{3+} , Mn^{4+}) whereas in the other part of the soil the elements can be strongly reduced (NH_4^+ , S^0 , H_2S , S_2 , Fe^{2+} , Mn^{2+}). The reduced state of elements and to a lower degree the volatiles such as CH_4 , H_2S and DMS (Schroder, 1993), are important selective factors in most wetlands (Yerly, 1970). In addition plant species with a high oxygen loss can facilitate the growth of other plant species having small aerenchyma resulting in the co-occurrence of very different flooding resistant species in one habitat (Schat, 1982).

Plant species that realise only moderate to low oxygen levels let the rhizosphere in a reduced state with a low availability of micronutrients due to the precipitation of metal sulphides. The variation of the intensity of the radial oxygen loss is the responsible factor for the diversity of plant communities in wetlands (Yerly, 1970). Without human impact, however, the final stages of vegetation development of wetlands are woodlands with a dominance of birches, willows and elders and a low biodiversity (Stortelder *et al.*, 1999).

Zinc (Zn) is one of the micronutrients affected by a reduced environment. During periods of anoxia or partial anaerobiosis the availability of zinc decreases by the precipitation of Zn as ZnS, thus endangering optimal functioning and productivity of plants. Therefore selection may enhance efficiency for Zn (Rengel and Graham, 1996; Hart *et al.*, 1998) or zinc mobilisation via exudation of complexing agents by roots (Von Wiren *et al.*, 1996; Schat, 1999). Plant species growing in habitats with high groundwater levels vary widely in Zn concentration (Ernst, 1978) so that Zn efficiency is a character discriminating plant species and even genotypes of a species (Mathys, 1975; Rengel and Graham, 1996).

Despite the low zinc supply in wetlands it is surprising that during the succession from wetlands with a dominance of sedges and grasses to woodlands, selection has favoured woody species such as willows (*Salix* sp.) and birches (*Betula* sp.) (Ernst, 1990a; Ernst *et al.*, 1996). As a consequence of this Zn in accumulation, the litter layer in these woodlands is very rich in water-soluble ionic Zn (Kuiters and Mulder, 1993a, 1993b) restricting the development of many plant species and diminishing the biodiversity of herbivorous animals. Another aspect of gramineous and herbaceous plants in wetlands and in the final stage of wetland-woodlands is the frequent high concentrations of silica (Ernst *et al.*, 1995; Grootjans *et al.*, 1998) that protect the plants from herbivory and thus reduces animal biodiversity.

Zinc plays a crucial role in the metabolism of each living organism by catalytic, coactive and structural functions (Vallee and Falchuk, 1993). Zinc regulation is strongly controlled by Zn transporter from the ZIP gene family at low Zn supply (Eng *et al.*, 1998; Grotz *et al.*, 1998) and by those from the ZAT genes at moderate to high Zn supply at the plasma membrane level (van der Zaal *et al.*, 1999), the latter perhaps supported by the activation of the genes encoding the cation diffusion facilitator (CDF) metal transporters which may be counteracting high Zn influx by Zn efflux (Paulsen and Saier, 1997). In *Arabidopsis thaliana*, metal transporter proteins encoded by the genes ZIP1, ZIP2 and ZIP3 have different concentration-, time-, temperature-dependent Zn uptake activities in roots with apparent K_m -values of 10-100nM Zn^{2+} (Guerinot and Eide, 1999). These very low Zn concentrations are in the same range of water soluble Zn measured in wet dune slacks in North Holland (Ernst *et al.*, 1996) Thus very efficient Zn uptake is necessary to

avoid Zn deficiency in wetlands. Once in the cell, Zn availability is controlled by its transfer to the site of demand and the sites of storage, i.e. the vacuole (Chardonens *et al.*, 1999). At normal and high Zn supply it looks like the ZIP genes are inactivated and ZAT genes are upregulated (Van der Zaal *et al.*, 1999). Some of the Zn dependent processes are the following:

- Zn as reactive part in the Zn-Cu superoxide dismutase, is involved in the cell integrity. The rapid saturation of Zn-Cu-SOD in *Silene vulgaris* (De Vos, 1991) and the unravelling of a Cu chaperone for Zn-Cu-SOD in *Saccharomyces cerevisiae* (Culotta *et al.*, 1997) are strong indication that this enzyme has a very high priority in the cellular supply with Cu and Zn;
- Plants can only optimally photosynthesise at sufficient Zn supply. As cofactor in the metalloprotein carbohydrase Zn is steering carbon fixation during photosynthesis via the regulation of the equilibrium between atmospheric CO₂ and cellular HCO₃ (Marchner, 1995). The late saturation of this enzyme in ecotypes of plants with a high Zn demand (Mathys, 1977) let expect a low priority of Zn supply to this enzyme.;
- Zn as essential part of zinc fingers, i.e. nucleoproteins directly involved with the regulation and transcription of DNA, is governing protein synthesis and therefore growth (Vallee and Falchuk, 1993).;
- As essential in plants under flooded conditions (Crawford, 1992), Zn is involved in regulating part of flooding resistance in plants. The priority in the regulation of the supply of these enzymes with Zn is not yet fully explored, but it may result in excellent ecophysiological fingerprints.

Aims of project

With the exception of wheat, the Zn supply of higher plants in environments with low Zn supply has not been investigated. The present project will help to understand the interactive regulation of metal transporter proteins in environments with a temporal variation of Zn availability. It will contribute to a rationale of understanding biodiversity by identifying fitness differences in wetlands. The following hypotheses will be tested.

Firstly, plants with low Zn supply obtain the necessary amounts of zinc by high affinity uptake systems encoded by the ZIP gene family.

Secondly, ZIP genes will be down-regulated at sufficient cellular Zn availability. Their function will be replaced by low affinity Zn transporter protein encoded by ZAT genes. Zn efflux from the root to the environment may perhaps be enhanced by CDF proteins.

Thirdly, in the cytosol, Zn-Cu-SOD has the highest priority of Zn supply to ensure a timely removal of oxygen radical and to maintain the integrity of bio-membranes. Zn-Cu-SOD is therefore a signal molecule steering the activity of the Zn uptake systems by means of a feedback mechanism.

Fourthly, the Zn supply to alcohol dehydrogenase to combat damage by oxygen deficiency is of secondary or lower ranking concern and will compete with the zinc supply to carbonic anhydrase, i.e. photosynthesis.

Research method

The research method comprises a number of elements.

Characterisation of Zn uptake and translocation

For the identification of the Zn status of the plants, plants from a normal and a high Zn-demanding genotype will be grown on an either Zn-sufficient or Zn-deficient hydroponic medium. Uptake of Zn will be measured in time series. At harvest the plants will be separated into roots and shoots. Zn adsorbed to the root surface will be exchanged against a lead nitrate solution. The same growth medium will be used in all further studies.

Translocation will be calculated on a whole-plant basis after analysis of Zn and other essential nutrients (AAS, CHNO).

Characterisation of the activity of Zn-enzymes

The activity of enzymes will be measured by standard procedures and will be taken as parameters for internal Zn supply:

Zn-enzymes, i.e. Zn-Cu-SOD (Lolkema 1985), carboanhydrase (Mathys 1977), fructose-1,6-bisphosphatase (Shrotri *et al.* 1983), alcohol dehydrogenase (Moore and Patrick 1988) and RNase (Johnson and Simons 1979).

Peroxidase (Verkleij *et al.* 1987) as a general stress enzyme.

Identification and characterisation of the ZIP gene family

The procedures of identification and characterisation of the Zn transporter genes will follow the methods described by GFrotz *et al.* (1998).

Identification and characterisation of the ZAT gene family

The procedure will follow the methods described by Van der Zaal *et al.* (1999).

Identification and characterisation of the CDF gene family

The procedure will be that described by Paulsen and Saier (1997).

Interaction of silicon with Zn (cell wall precipitation)

If the isolation and characterisation of the zinc transporter from the ZIP family will demand less time than expected, a sensitivity test of the homeostasis of Zn against a surplus of Si may be undertaken to check the impact of withdrawing Zn from the cell metabolism by precipitation of Zn-silicates in the cell walls (Lichtenberger and Neumann, 1997). For this research the facilities are not available in the Netherlands because the preparation of the samples for and the resolution of PIXE (Section Physics, cf. Ernst *et al.* 1995) are not appropriate. Therefore we have to call upon the facilities of our standing cooperation with Dr. D. Neumann (Institute of Plant Biochemistry, Halle) and with Prof. dr. K.J. Dietz (Department of Plant Physiology, University of Bielefeld).

Workplan

Due to the progress in knowledge of metal transporters the schedule, as well as the applied techniques, may be modified during the programme.

October 1999 - December 1999:

- Study the relevant publications, acquaintance of some of the techniques.
- Start of the growth of plants from both ecotypes for the experiments (first time series).

December 1999 - December 2001

- First harvest. Analysis of metals and other nutrients by AAS and CHNO.
- Testing the impact of the Zn supply on the activity of Zn-enzymes and stress enzymes. Elaborating the role of Zn-Cu-superoxide dismutase (Zn-Cu-SOD) as signal molecule for the cytosolic Zn supply.
- Start of second growth experiment.

December 2001-September 2002

- Isolation and characterisation of the ZIP family by Northern, Southern and Western blots of plasma membrane proteins and their mRNA and cDNA.

October 2002 - April 2003

- Start of third growth experiment
- Testing the sensitivity of the Zn transporter(s) in relation
- to the Zn availability and the soil-water-temperature in wetlands.
- Isolation and characterisation of the ZAT gene family and the interaction with the ZIP gene family.

May 2003 - September 2003

- Writing and defence of the thesis.

Composition of the research group

Prof. W.H.O. Ernst	Botany
Dr. J.A.C. Verkleij	Biochemistry
Dr. H. Schat	Ecophysiology
H.W.J. Hakvoort	Biochemical analyst
Drs. E. Jack	Ph.D. student (oio)

Additional cooperation/advice:

Prof. J. Mol, Department of Plant Development Genetics, VU.
 Dr. A.H. de Boer, Department of Plant Development Genetics, VU.
 Dr. B.J. Van der Zaal, Leiden University.
 Prof. M. Koornneef, Agricultural University of Wageningen.
 Dr. J. Coleman, IARC, Rothemsted, England.
 Prof. K.J. Dietz, Universität Bielefeld, Duitsland.
 Dr. D. Neumann, Institut für Pflanzenbiochemie, Halle, Duitsland.

References

Armstrong, W. (1982). Waterlogged soils. In: Etherington, J.R. Environment and Plant Ecology. J. Wiley & Sons, Chichester, pp. 290-330.

- Chardonens, A.N., Koevoets, P.L.M., Van Zanten, A., Schat, H., Verkleij, J.A.C. (1999). Direct evidence for the significance of zinc transport across the tonoplast in naturally selected zinc tolerance. *Plant Physiology* 120, 779-785.
- Crawford, R.M.M. (1992). Oxygen availability as an ecological limit to plant distribution. *Advances in Ecological Research* 23, 93-125.
- Culotta, V.C., Klomp, L.W.J., Strain, J., Casareno, R.L.B., Krems, B., Gitlin, J.D. (1997). The copper chaperone for super-oxide dismutase. *Journal of Biological Chemistry* 272, 23469-23472.
- Eng, B.H., Guerinot, M.L., Eide, D., Saier, M.H. (1998). Sequence analysis and phylogenetic characterization of the ZIP family of metal ion transport proteins. *Journal of Membrane Biology* 166, 1-7.
- Ernst, W.H.O. (1978). Ökophysiologische Bedeutung der Mineralstoffe. In: Baumeister, W., Ernst, W.H.O. *Mineralstoffe und Pflanzenwachstum*. G. Fischer Verlag, Stuttgart, pp. 240-295.
- Ernst, W.H.O. (1990a). Ecophysiology of plants in waterlogged and flooded environments. *Aquatic Botany* 38, 73-90.
- Ernst, W.H.O. (1990b). Element allocation and (re)translocation in plants and its impact on representative sampling. In: Lieth, H., Markert, B. (Eds.), *Element Concentration Cadasters in Ecosystems*. VCH, Weinheim, pp. 17-40.
- Ernst, W.H.O. (1997). Life-history syndromes and the ecology of plants from high sulphur-habitats. In: Cram, W.J., De Kok, L.J., Stulen, I., Brunold, Renneberg, H. (Eds.), *Sulphur Metabolism in Higher Plants. Molecular, Ecophysiological and Nutritional Aspects*. Backhuys Publishers, Leiden, pp. 131-146.
- Ernst, W.H.O., Vis, R.D., Piccoli, F. (1995). Silicon in developing nuts of the sedge *Schoenus nigricans*. *Journal of Plant Physiology* 146, 481-488.
- Ernst, W.H.O., Slings, Q.L., Nelissen, H.J.M. (1996). Pedogenesis in coastal wet duneslacks after sod-cutting in relation to revegetation. *Plant and Soil* 180, 219-230.
- Grootjans, A. P., Ernst, W.H.O., Stuyfzand, P.J. (1998). European dune slacks: strong interactions of biology, pedogenesis and hydrology. *Trends in Ecology and Evolution* 13, 96-100.
- Grotz, N., Fox, T., Conolly, E., Park, W., Guerinot, M.L., Fide, D. (1998). Identification of a family of zinc transporter genes from *Arabidopsis* that respond to zinc deficiency. *Proceedings of the National Academy of Sciences USA* 95, 7220-7224.
- Guerinot, M.L., Eide, D. (1999). Zeroing in on zinc uptake in yeast and plants. *Opinion in Plant Science* 2, 244-249.
- Hart, J.J., Norvell, W.A., Welch, R.M., Sullivan, L.A., Kochian, L.V. (1998). Characterization of zinc uptake, binding, and translocation in intact seedlings of bread and durum wheat cultivars. *Plant Physiology* 118, 219-226.
- Kuiters, A.T., Mulder, W. (1993a). Water-soluble organic matter in forest soils. I. Complexing properties and implications for soil equilibria. *Plant and Soil* 152, 215-224.
- Kuiters, A.T., Mulder, W. (1993b.) Water-soluble organic matter in forest soils. II. Interference with plant cation uptake. *Plant and Soil* 152, 225-235.
- Lichtenberger, O., Neumann, D. (1997). Analytical electron microscopy as a powerful tool in plant cell biology: examples using electron energy loss spectroscopy and X-ray microanalysis. *European Journal of Cell Biology* 73, 378-386.
- Marschner, H. (1995). *Mineral Nutrition of Higher Plants*. 2nd ed. Academic Press, London.

- Mathys, W. (1975). Enzymes of heavy-metal-resistant and non-resistant populations of *Silene cucubalus* and their interaction with some heavy metals in vitro and in vivo. *Physiologia Plantarum* 33, 161-165.
- Mathys, W. (1977). The role of malate, oxalate, and mustard oil glucosides in the evolution of zinc-resistance in herbage plants. *Physiologia Plantarum* 40, 130-136.
- Oberleas, D., 1996. Mechanism of zinc homeostasis. *Journal of Inorganic Biochemistry* 62, 231-241.
- Paulsen, L.T., Sasier, M.H.jr. (1997). A novel family of ubiquitous heavy metal ion transport proteins. *Journal of Membrane Biology* 156, 99-103.
- Rengel, Z., Graham, R.D. (1996). Uptake of zinc from chelate-buffered nutrient solutions by wheat genotypes differing in zinc efficiency. *Journal of Experimental Botany* 47, 217-226.
- Schat, H. (1982). *On the Ecology of Some Dutch Dune Slack Plants*. Dissertation, Vrije Universiteit, Amsterdam.
- Schat, H. (1999). Plant responses to inadequate and toxic micronutrient availability: General and nutrient-specific mechanisms. In: Gissel-Nielsen, G., Jensen, A. (Eds.), *Plant Nutrition - Molecular Biology and Genetics*. Kluwer Academic Publishers, Dordrecht, pp. 311-326.
- Schröder, P. (1993). Plants as sources of atmospheric sulfur. In: De Kok, L.J., Stulen, I., Rennenberg, H., Brunold, C., Rauser, W. (Eds.), *Sulfur Nutrition and Assimilation in Higher Plants. Regulatory, Agricultural and Environmental Aspects*. SPB Academic Publishing, The Hague, pp. 253-270.
- Stortelder, A.F.H., Schaminée, J.H.J., Hommel, P.W.F.M. (1999). *De vegetatie van Nederland*. Vol. 5. Ruigten, struwelen, bossen. Opulus Press, Uppsala, Leiden.
- Stuyfzand, P.J. (1993). *Hydrochemistry and Hydrology of the Coastal Dune Area of the Western Netherlands*. Dissertation Vrije Universiteit, Amsterdam.
- Vallee, B.L., Falchuk, K.H. (1993). The biochemical basis of zinc physiology. *Physiological Reviews* 73, 79-118.
- Van der Zaal, B.J., Neuteboom, L.W., Pinas, J.E., Chardonens, A.N., Schat, H., Verkleij, J.A.C., Hooykaas, P.J.J. (1999). Overexpression of a novel *Arabidopsis* gene related to putative zinc-transporter genes from animals can lead to enhanced zinc resistance and accumulation. *Plant Physiology* 119, 1047-1055.
- Von Wirén, N., Marschner, H., Römheld, V. (1996). Roots of iron-efficient maize also absorb phytosiderophore-chelated zinc. *Plant Physiology* 111, 1119-1125.
- Vos, C.H.R. de (1991). *Copper-induced Oxidative Stress and Free Radical Damage in Roots of Copper Tolerant and Sensitive Silene cucubalus*. Dissertation Vrije Universiteit Amsterdam.
- Yerly, M. (1970). *Écologie comparée des prairies marécageuses dans les Préalpes de la Suisse occidentale*. Veröffentlichungen des Geobotanischen Institutes der ETH Rübel, Zürich, 44, 1-119.

4.5 Project 5: Effects of changes in hydrology on ecological and chemical characteristics of wetlands⁷

Dutch summary

Laagveengebieden in het westelijk veenweidegebied worden veelal gekarakteriseerd door een hoge botanische soorten diversiteit en een hoge natuurbehoudswaarde. Bovendien kunnen zij een belangrijke rol spelen als koofstof 'sinks'. Gedurende de laatste decennia staan deze gebieden onder sterke druk t.g.v. menselijke activiteiten, zoals bijvoorbeeld ontwatering. Recent zijn initiatieven gestart of in voorbereiding om in ontwaterde gebieden de grondwaterstand weer te verhogen teneinde verdroging van natuurgebieden tegen te gaan en de oorspronkelijke natuurwaarden te herstellen. De doelstellingen van het onderhavige project zijn: 1) het analyseren van effecten van menselijke ingrepen in de grondwaterstand op de biodiversiteit en de biogeochemie van laagveengebieden; 2) het onderzoeken van de rol van bovengrondse en ondergrondse diversiteit in het functioneren van laagveengebieden; 3) het identificeren van indicatoren (zowel biologisch als biogeochemisch) voor de effecten van menselijke ingrepen in de grondwaterstand op het functioneren van laagveengebieden.

Hier toe zullen drie lijnen van onderzoek worden gevolgd: 1) een inventariserend veldonderzoek van biogeochemische karakteristieken (boven- en ondergrondse soorten diversiteit, nutriëntenkringloop) van laagveengebieden langs een gradiënt van vernatting (van ontwaterd tot weer vernat); 2) het identificeren van sleutelprocessen in deze gebieden ('ecological fingerprinting'); 3) het verrichten van mesocosmos studies teneinde de bij 1 en 2 gevonden patronen te kunnen verklaren en mogelijk te kunnen voorspellen.

Problem description

The semi-natural wetlands in the western part of the Netherlands, specifically the peatlands, are usually characterised by a high botanical species diversity and a high conservation value (Verhoeven, 1992). They can also play an important role as carbon sinks, because on a yearly basis more carbon is immobilised in organic matter than is lost from these systems through respiration. However, the negative human influence on these areas is severe. The botanical species diversity of these ecosystems is severely threatened by eutrophication, acidification and interference in the hydrology (lowering of groundwater levels) (Aerts *et al.*, 1995; Berendse *et al.*, 1994; Oomes *et al.*, 1996; Beltman *et al.*, 1996a,b). Moreover, these processes have a strong impact on biogeochemical processes in these ecosystems, like nutrient-cycling, the immobilisation of carbon and the emission of greenhouse gasses (Aerts, 1997; Aerts and Toet, 1997; Aerts en Ludwig, 1997; Aerts en De Caluwe, 1999) and also on the species composition and functioning of the soil

⁷ Prof. dr. M.A.P.A. Aerts, Institute of Ecological Sciences, Department of Systems Ecology, Vrije Universiteit Amsterdam, De Boelelaan 1087, 1081 HV Amsterdam.

Prof. dr. ir. P. Vellinga, Institute for Environmental Studies, Vrije Universiteit Amsterdam, De Boelelaan 1115, 1081 HV Amsterdam.

Dr. H.A. Verhoef, Institute of Ecological Sciences, Department of Animal Ecology, Vrije Universiteit Amsterdam, De Boelelaan 1087, 1081 HV Amsterdam.

Drs. J. van Dijk, Institute of Ecological Sciences, Department of Systems Ecology, Faculty of Biology, Vrije Universiteit Amsterdam, De Boelelaan 1087, 1081 HV Amsterdam.

faunal community (Verhoef, 1995, 1996; Berg and Verhoef, 1998; Berg *et al.* 1998). Because the soil community plays an important role in biogeochemical cycles and the availability of nutrients for the vegetation, disturbance of this community will have major consequences for the above-ground part of the ecosystem.

For some years it is tried to enlarge the biodiversity of the Dutch peatlands by restoration projects, in which the original abiotic conditions are restored in order to bring back the original floral and faunal communities (Beltman *et al.*, 1996a,b). Furthermore, nature development projects are carried out in which groundwater levels of former agricultural pastures are raised to develop 'new' nature and to prevent adjacent nature reserves from drying out. For success in these projects, it is necessary to have profound knowledge of underlying processes, knowledge that is far from complete at the moment. Especially knowledge of biogeochemical processes, relations between above and below-ground biotic communities and the resilience of a semi-natural vegetation still has a lot of gaps.

Aims of the project

The aims of the present project are:

7. Analysis of the effects of human interference in the hydrology of peatlands on species diversity and biogeochemistry of these areas.
8. Investigation of the role of and relation between above and below-ground species diversity in the functioning of the peatland ecosystem.
9. Identification of important indicators (both biological and biogeochemical) of the impact of human interference in the hydrology of peatlands on the functioning of these ecosystems.

The innovative aspects of the present research project lie in the integrative nature of the project. Especially the relation between above and below-ground species diversity (plants and soil community), the pathways through which this relation is established and the implications for the ecosystem functioning have hardly been studied.

Furthermore, the policy of *vernatting* is relatively new in The Netherlands. The knowledge gained by the present research project perfectly match the research needs for monitoring the effects of *vernatting* as stated by nature management and conservation organisations (Natuurmonumenten, 1995).

Research method

1) *Gradient analysis in the field.*

The research project will be started with a field survey to identify differences in the species composition of the vegetation between areas in different stages of *vernatting*. Furthermore, the composition of the soil community of these areas, the activity of these soil communities and the relation between above and below-ground species diversity will be studied. The study of soil organisms will concentrate on some major functional groups like enchytraeids, nematodes, earthworms, bacteria and fungi.

2) *'Ecological fingerprinting' in the field*

Vernatting of peatlands will lead to changes in most biogeochemical processes of these areas. Most of these processes are related to nutrient cycling, which means they have a direct or indirect influence on the availability of nutrients for the vegetation. Changes in

these processes may lead to major changes in the development and species composition of the vegetation (Aerts, 1999). Recently, the method of ecological fingerprinting was introduced by Verhoeven et al. (1994, 1996) as a relatively easy method to relate key processes, related to nutrient cycling, and various biotic and abiotic environmental factors. In this method, a standard protocol is used to carry out a number of short-term field surveys to analyse the processes and environmental factors mentioned above. With the outcome of these surveys, processes and environmental factors can be related with a number of multivariate statistical techniques, for instance Principal Component Analysis (PCA) and factor analysis. With this technique, common patterns in the relation between nutrient related processes and abiotic process parameters can be identified. These common patterns can be regarded as an 'ecological fingerprint' of the studied ecosystem. This method proved to serve excellently in a comparative research project on N and P cycling processes and environmental variables in peatlands in Maryland (USA), The Netherlands and Poland (Aerts et al., 1999). This analysis also proved that the species composition of the vegetation had a good correlation with N and P related processes. Therefore we will use the ecological fingerprinting method in the present research project. The availability of data sets with ecological fingerprints of peatlands from various locations enables a good assessment of the effects of *vermatting* on the functioning of these ecosystems.

A similar fingerprint method has recently been developed for the relation between N and C processes and below-ground food web components (Verhoef and Van Dijk, in prep.). Following a sampling protocol, intact soil cores from the field are incubated in the lab. After a specified incubation time, the various variables are analysed and correlated with the use of PCA techniques and a modified GIS-analysis (see also Ettema *et al.*, 1998). From this study it appeared that the composition of the soil community showed clear correlations with N and C mineralisation rates.

The ecological fingerprint method will be additional with a set of chemical fingerprints of the study area, which will be developed in cooperation with the AIO at the Chemistry division.

3) *Mesocosm experiments in experimental garden and climate chambers.*

The research methods mentioned above have a strong correlative character. Furthermore, it is not very likely that we can follow the response of the above and below-ground biota on *vermatting* in very much detail. Therefore an experimental research project will be conducted to investigate the mechanisms that form the basis of the identified patterns. The effects of artificially induced changes in groundwater level on the processes of decomposition, mineralisation and nutrient cycling will be studied in more detail in mesocosms in an experimental garden or climate chamber with strictly controlled environmental conditions.

Study areas

Areas in different stages of *vermatting* will be studied in both the Horstermeerpolder and small polders adjacent to the Naardermeer.

Temporal and spatial scales

Vermatting projects in the study sites have only recently (1997/1998) been implemented. We may expect that no stable state has yet been reached. Therefore we will repeat the

field survey every year, in order to see if variations in processes or environmental factors over time still take place.

The main focus of the field survey will be on the peak of the growth season (which is about the beginning of June according to Den Held & Den Held, 1976). As we also expect seasonal dynamics in these processes and environmental factors, as well as in groundwater level, surveys will also be carried out in other seasons.

Due to its detailed character, the present research project will be conducted on a relatively small spatial scale. Data will be collected from plots up to parcel size, vegetation data up to species level will be collected from smaller subplots (about 10m²). The identification of general patterns in ecological fingerprints, in combination with the hydrological models developed by the faculty of Earth Sciences and remote sensing data generated by the IVM, will enable upscaling of the results up to landscape level.

Workplan

Year 1

- Gradient-analysis, incl. above-n and underground diversity
- Setting up of mesocosms + first measurements

Year 2

- Ecological fingerprinting
- Further work on gradient-analysis, incl. emission measurement
- Mesocosm experiments
- Enrichment experiments with N¹⁵

Year 3

- Further work on emission measurements
- Further work on ecological fingerprinting
- Further work on mesocosm experiments

Year 4

- Analysis of results
- Writing and defence of dissertation

Composition of the research group:

Prof. M.A.P.A. Aerts	Systems ecology
Prof. P. Vellinga	Environmental science
Dr. H.A. Verhoef	Soil ecology
Dr. B. Beltman	Landscape ecology (University of Utrecht)
Dr. M.P. Berg	Soil ecology
Dr. J. van de Staaij	Systems ecology
Drs. J. van Dijk	Ph.D. student

Outside the framework we will cooperate with the department of Landscape Ecology of the faculty of Biology of the University of Utrecht for the gradient analysis. Data sets are already available within this group.

References

- Aerts, R. (1997). Atmospheric nitrogen deposition affects potential denitrification and N₂O emission from peat soils in the Netherlands. *Soil Biology and Biochemistry* 29: 1153-1156.
- Aerts, R., De Caluwe, H. (1999). Nitrogen deposition effects on carbon dioxide and methane emissions from temperate peatland soils. *Oikos* 84: 44-54.
- Aerts, R., Ludwig, F. (1997). Water table changes and nutritional status affect trace gas emissions from laboratory columns of peatland soils. *Soil Biology and Biochemistry* 29: 1691-1698.
- Aerts, R., Toet, S. (1997). Nutritional controls on carbon dioxide and methane efflux from Carex-dominated peat soils. *Soil Biology and Biochemistry* 29: 1683-1690.
- Aerts, R., Van Logtestijn, R., Van Staalduinen, M., Toet, S. (1995). Nitrogen supply effects on productivity and potential leaf litter decay of Carex species from fens differing in nutrient limitation. *Oecologia* 104: 447-453.
- Aerts, R., Verhoeven, J.T.A., Whigham, D.F. (1999). Plant-mediated controls on nutrient cycling in temperate fens and bogs. *Ecology* 80(7): 2170-2181.
- Berendse, F., Oomes, M.J.M., Altena, H.J., De Visser, W. (1994). A comparative study of nitrogen flows in two similar meadows affected by different groundwater levels. *Journal of Applied Ecology* 31: 40-48.
- Beltman, B., Van den Broek, T., Van Maanen, K., Vaneveld, K. (1996a). Measures to develop a rich-fen wetland landscape with a full range of successional stages. *Ecological Engineering* 7: 299-313.
- Beltman, B., Van den Broek, T., Bloemen, S., Witsel, C. (1996b). Effects of restoration measures on nutrient availability in a formerly nutrient-poor floating fen after acidification and eutrophication. *Biological Conservation* 78: 271-277.
- Berg, M.P., Verhoef, H.A. (1998). Ecological characteristics of a nitrogen-saturated coniferous forest in the Netherlands. *Biology and Fertility of Soils* 26: 258-267.
- Berg, M.P., Kniese, J.P., Bedaux, J.J.M., Verhoef, H.A. (1998). Dynamics and stratification of functional groups of micro- and meso-arthropoda in the organic layer of a Scots pine forest. *Biology and Fertility of Soils* 26: 268-284.
- Berg, M.P., Kniese, J.P., Zoomer, H.R., Verhoef, H.A. (1998). Long-term decomposition of successive organic strata in a nitrogen saturated Scots pine forest soil. *Forest Ecological Management* 32: 87-102.
- Den Held, J.J., Den Held, A.J. (1976). *Beknopte handleiding voor vegetatiekundig onderzoek*. Hoogwoud: K.N.N.V., Amsterdam.
- Ettema, C.H., Coleman, D.C., Velledis, G., Lowrance, R., Rathbun, S.L. (1998). Spatiotemporal distributions of bacterivorous nematodes and soil resources in a restored riparian wetland. *Ecology* 79: 2721-2734.
- Natuurmonumenten (1995). *Beheerplan 1995 Naardermeer. Middellange termijnplanning*.
- Oomes, M.J.M., Olf, J., Altena, H.J. (1996). Effects of vegetation management and raising the water table on nutrient dynamics and vegetation change in a wet grassland. *Journal of Applied Ecology* 33: 576-588.
- Verhoef, H.A. (1995). *Soil Ecosystems*. In: *Encyclopedia of Environmental Biology* (editor W.A. Nierenberg) pp. 331-337. Academic Press, New York.
- Verhoef, H.A. (1996). The role of soil microcosms in the study of ecosystem processes. *Ecology* 77(3): 685-690.
- Verhoef, J.A., Brussaard, L. (1990). Decomposition and nitrogen mineralization in natural and agro-ecosystems: the contribution of soil animals. *Biogeochemistry* 11: 175-211.

- Verhoef, H.A., Van Dijk, J. (in prep.). *Spatial heterogeneity of food web structure and ecosystem processes*.
- Verhoeven, J.T.A. (1992). *Fens and bogs in the Netherlands: Vegetation, history, nutrient dynamics and conservation*. Kluwer, Dordrecht.
- Verhoeven, J.T.A., Keuter, A., Van Logtestijn, R., Van Kerkhoven, M.B., Wassen, M. (1996). Control of local nutrient dynamics in mires by regional and climatic factors: a comparison of Dutch and Polish sites. *Journal of Ecology* 84: 647-656.
- Verhoeven, J.T.A., Whigham, D.F., Van Kerkhoven, M.B., O'Neill, J., Maltby, E. (1994). Comparative study of nutrient-related processes in geographically separated wetlands: towards a science base for functional assessment procedures. In: *Global Wetlands: Old World and New* (editor J.W. Mitsch) pp. 91-106. Elsevier Science B.V., Amsterdam.
- Wardle, D.A., Verhoef, H.A., Clarholm, M. (1998). Trophic relationships in the soil micro-foodweb: predicting the responses to a changing global environment. *Global Change Biology* 4: 713-727.

4.6 Project 6: Ecological and societal conditions for wetland restoration⁸

Dutch summary

Wetlands vervullen meerdere maatschappelijke functies en de ontwikkeling van nieuwe wetlands is dan ook niet alleen vanuit een natuurontwikkelingsperspectief aantrekkelijk. Vooral in dichtbevolkte gebieden als de Randstad moet in toenemende mate worden voorzien in natuur- en recreatiegebieden. Klimaatveranderingen, zeespiegelstijging en stedelijke ontwikkeling vragen om een heroverweging van het traditionele beheer van water en ruimte.

Wat betreft de ontwikkeling van wetlands blijkt dat vooralsnog geen grootschalige projecten daadwerkelijk zijn uitgevoerd. Dit terwijl in zowel de wetenschappelijke literatuur als in de beleidsnota's veelvuldig voor de ontwikkeling van natte natuur wordt gepleit.

Deze studie is gericht op het inschatten van de maatschappelijke diensten die wetlands daadwerkelijk kunnen leveren. Hierbij wordt onderscheid gemaakt tussen ecologische waarden, recreatieve mogelijkheden en waterbeheersaspecten. Verschillende wetlands met verschillende vormen en intensiteiten van gebruik zullen onderling worden vergeleken. De informatie over gebruiksmogelijkheden en de (negatieve) consequenties hiervan op de kwaliteit van de wetlands, zal worden geïntegreerd in een ruimtelijk model. Dit model zal worden toegepast op de Vechtstreek.

Problem description

Wetlands perform many functions to society, such as nature, recreation, water purification, flood control and water storage. However, there is a need for better (quantitative) information underpinning this. The study aims to develop an integrated model to quan-

⁸ Prof. dr. ir. P. Vellinga, Institute for Environmental Studies, Vrije Universiteit Amsterdam, De Boelelaan 1115, 1081 HV Amsterdam.
 Prof. dr. M.A.P.A. Aerts, Institute of Ecological Sciences, Department of Systems Ecology, Vrije Universiteit Amsterdam, De Boelelaan 1087, 1081 HV Amsterdam.
 Drs. H. Goosen, Institute for Environmental Studies, Vrije Universiteit Amsterdam, De Boelelaan 1115, 1081 HV Amsterdam.

tify the different wetland goods and services. Information on the total supply of natural resources as a result of wetland development will provide useful input for further socio-economic analysis (projects 8 and 9).

In densely populated metropolitan areas such as the Dutch 'Randstad', the development of new wetlands is not only interesting from a nature restoration point of view. Wetlands can also contribute to the opportunities for recreation, drinking water and flood protection, residential development, water purification and carbon sequestration (Helmer *et al.*, 1996). Most traditional Dutch wetlands have disappeared mainly due to agriculture, which has claimed and managed the land in such a way that most natural dynamics are lost. Peat formation has ceased as a result of continuous drainage of groundwater, which is needed to rehabilitate the land for agriculture. Lowering of the water table (to increase agricultural production) has led to oxidation of the upper peat layers (Schothorst, 1978; Wolf, 1990), which in turn leads to (physical) subsidence of the land. This has caused the land to move slowly but steadily to several meters below sea level. Subsidence in combination with predicted accelerated sea level rise will lead to increased vulnerability to floods (Helmer *et al.*, 1996). Apart from this, through drainage of the land, large areas in the lower parts the Netherlands currently seem to provide a net source of carbon dioxide rather than a net sink. In addition, the inlet of nutrient-rich water from the rivers and the agricultural input of nutrients and pesticides affect water quality negatively.

Aims of the project

This project aims to estimate the opportunities and limits to combined use of wetlands. A better understanding of the potential role of wetlands in urbanised areas, and the boundaries to its sustainable use is necessary. The project will explore the interactions between the natural and societal system and integrate ecological and economic disciplines. Analogue wetland areas with different uses and intensities of uses will be compared. The information will be used to construct an integrated model. This model will be applied to a case-study area, the Vechtstreek. The following most important wetland goods and services will be addressed:

- Ecosystem functions, goods and services: biodiversity (at different scale levels: regional, national, international), ecosystem stability and resilience; carbon and nitrogen balance, spatial interdependence (seed dispersion, island theory);
- Recreation: It is a challenge to estimate the possibilities and carrying capacity of different types of freshwater wetlands with regard to different types of recreation. Also the negative feedbacks of (different types of) recreational use will be determined and incorporated in the model;
- Water management: wetlands are believed to offer freshwater supplies for drinking water, agriculture and nature itself; wetlands could also provide a buffer for excessive water which can help to protect the surrounding land from floods.
- (Residential development: wetlands are attractive areas for urban development projects.)

The contribution of wetlands to these resources will depend on the specific measures taken. Re-wetting of the peat lands can range from temporally waterlogged soils to the development of shallow lakes. Self evidently these different wetland types have different

characteristics and contribute differently to the societal functions. A subdivision into two different types of wetlands can be made (Spieksma, 1998) and will be used in the study:

Aquatic wetlands: stretches of shallow open water (shallow lakes); Paludic wetlands: semi-terrestrial systems (with a groundwater level close to the surface) experiencing periodic inundation.

This research is innovative in a way that it will integrate landscape ecology with economic disciplines and spatial planning, not only on the conceptual level, but also applied to an existing area. Many wetland studies focus on specific wetland functions from a natural science perspective (for instance, biodiversity of wetlands, ecosystem regulation functions) or from an economic perspective (economic valuation of wetlands). This study will explore the complex interactions between the natural and societal system in a spatial context.

Research method

The project deals with estimating the ecological and societal conditions for wetland restoration (re-wetting). First, a comparison will be made of different analogues (existing comparable wetlands) with different types and intensities of use. To study the opportunities for recreation, for example, a number of wetlands (with more or less similar characteristics, geomorphology and hydrology) but with varying recreational intensities will be compared. Comparison of these analogues can yield valuable information on the opportunities and repercussions to the natural system.

A spatial integrated model will be developed to inter-link the different wetland resources. Integrated modelling is a powerful way to analyse and structure complex information. A module describing recreation will be linked to the ecosystem module. Recreational use will affect the ecosystem quality. On the other hand, the ecosystem characteristics are linked to recreation (opportunities for recreation). Also the hydrological module (describing the water storage capacity) will be linked to both the ecological and recreational modules. The water purification function, the ecosystem characteristics and the type of recreation will depend strongly on the hydrology of the wetland. The model will describe different wetland types, based on different water levels (ranging from occasional flooding, to permanently waterlogged soils, to lakes). The model will be created in a GIS environment to capture spatial aspects.

The estimation of the changes in the natural system requires the extrapolation and aggregation of small-scale ecological data to higher spatial scales. Qualitative and quantitative information on different spatial scales have to be combined. One of the ultimate challenges in integrated assessment is to connect higher scale assessments with lower scale ones. To date there has been little, if any, experience with this up- and downscaling in integrated assessments (Rotmans, 1998).

How to deal with (different kinds of) uncertainty in a multidisciplinary context will be another important methodological challenge (Rotmans, 1998). The multidisciplinary setup of the project is innovative and at the same time essential. The project requires a two-way interaction: with systems ecologists to understand the changes in the ecological system parameters used to quantify the changes in natural resource availability; and with economists to provide useful information for socio-economic evaluation.

Temporal and Spatial Scales

The subprojects within the framework program “Wetlands in the Randstad” deal with different spatial scales and time horizons. The chemical and ecological projects will concentrate on the smaller scales, whereas the economic projects will deal with regional scales. The present project can be considered as an intermediate. One of the challenges of this project is to translate specific, detailed and small-scale information to the higher spatial levels. The study will encompass the whole of the study area (the Vechtstreek) and a spatial resolution of 500 m² per grid cell seems reasonable.

Workplan

Year 1: September 1999 – September 2000

- Literature on wetland goods and services and spatial integrated modelling
- Development/further refinement of the framework and method (2 months);
- Analysis of the natural values of wetlands: identification of a reference wetland system; estimating the opportunities for carbon storage; water purification in wetlands

Year 2: September 2000 – September 2001

- Identification of analogue wetlands with recreational use
- Estimation of the opportunities for recreation: recreational use and its ecosystem impacts through a comparison of analogues.

Year 3: September 2001 – September 2002

- Identification of analogues to analyse opportunities for water storage and flood protection
- Estimation of the opportunities for water storage and flood protection

Year 4: September 2002 – September 2003

- Validation, testing and improvement of the integrated model; analysis of the Vechtstreek
- Writing and defence of dissertation

Composition of research group

Prof. P. Vellinga	Environmental science
Prof. M. Aerts	Systems ecology
Drs. A. Gilbert	Ecology and economics
H. Goosen	Researcher

References

- Barbier, E.B., M. Acreman, D. Knowler (1997). *Economic valuation of wetlands: a guide for policy makers and planners*. Ramsar Convention Bureau, Gland, Switzerland.
- Groot, D. de, (1992), *Functions of Nature: evaluation of nature in environmental planning, management and decision making*, Wolters-Noordhoff, 315 p.
- Helmer, W., Vellinga, P., Litjens, G., Goosen, H., Ruijgrok, E.C.M., W. Overmars, 1996. *Growing with the Sea*. View on the Dutch Coastal Zone, World Wildlife Fund for Nature, Zeist.
- Latour, J.B., D. Bal, R. Reiling, G.W. Lammers, R.J. Brink (1993). *Naar een nationale graadmeter voor het natuurlijke milieu*. RIVM/IKC-natuurbeheer.

- RIVM/VROM (1998). *Leefomgevingsbalans: voorzet voor vorm en inhoud*. RIVM Bilthoven.
- Rotmans, J. (1998). *Methods for IA: the challenges and opportunities ahead*. In: Environmental modeling and assessment, Vol 3, No 3, pp. 155-180. Baltzer Science publishers.
- Ruijgrok, E.C.M. (1996). Overview of economic valuation studies. IVM-VU, Amsterdam.
- Schothorst, C.J. (1978), *Drainage and Behavior of Peat Soils*, Wageningen: Institute for Land and Water Management Research (ICW).
- Spieksma, J.F.M. (1998), *Rewetting of damaged peatlands*. Thesis Rijksuniversiteit Groningen.
- Witmer, M.C.H. (1989). *Integral water management at regional level: an environmental study of the Gooi en Vechtstreek*. Thesis Utrecht University.
- Wolf, J. 1990. *Inventory of non-fossil carbon fluxes and stocks in terrestrial ecosystems in the Netherlands* (In Dutch). Theoretical Production Ecology, Agricultural University of Wageningen.

4.7 Project 7: Performance indicators for co-evolved wetland systems⁹

Problem description

The research problem which this project will address stems from three points. The first is the Ramsar Convention's definition of wetlands (Anon, 1994):

wetlands are areas of marsh, fen, peatland or water; whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt and including areas of marine water the depth of which at low tide does not exceed six metres.

Under this definition, all of the western Netherlands may be considered a wetland. The definition is driven by water levels, not by water source or land cover, and includes human-made systems as well as ecosystems. The wetlands of the Vechtstreek are a mixture of palustrine (marshes, swamps and bogs fed by groundwater) wetland ecosystems and pastures supporting extensive grazing, as well as residences and infrastructure for recreation and transport (road, rail and water).

The second relates to the debate around sustainable development and questions regarding the preservation of natural capital (Serageldin and Steer, 1994; Verbruggen, 1995). Lorenz (1999) has developed a framework for assessing the performance of natural capital. Her framework provides the basis for constructing performance indicators which can be used to evaluate natural capital and to identify trade-offs between economic and environmental objectives. The relevance of environmental objectives and nature restoration in the Vechtstreek is given various policy documents such as *Nota Landschap* (LNV, 1992), *Natuurbeleidsplan* (LNV, 1990), *Structuurschema Groene Ruimte* (LNV, 1996), *Vierde Nota over de Ruimtelijke Ordening (Extra)* (VROM, 1990) and *Vierde and Derde Nota Waterhuishouding* (V&W, 1989, 1999). These objectives are repeated, together with economic objectives, within various documents relating to land consolidation, e.g. Provincie Noord-Holland (1997).

⁹ Prof.dr.H. Verbruggen, Institute for Environmental Studies, Vrije Universiteit.
 Prof.dr. N.M. van Straalen, Faculty of Biology, Vrije Universiteit.
 Drs. Alison Gilbert, Institute for Environmental Studies, Vrije Universiteit.

The third considers the *coevolution* of natural and human systems. The term ‘coevolution’ derives from evolutionary biology and was first described by Ehrlich and Raven (1964). Ridley (1996) provides a recent definition of coevolution as the reciprocal selective influence between two parties over a prolonged period. This idea of mutual influence has been taken on board in the relatively new field of coevolutionary economics (Gowdy, 1994). This field explicitly recognises that:

- the economy is a subsystem of the natural environment and co-evolving with that environment; and,
- that, like the natural world, the economy is a living, evolving system.

This project argues that Dutch wetlands are the product of coevolution between human-made and natural systems. Over a period of some eight centuries major changes to wetland ecosystems have been wrought by human activities. For the wetlands of the Vechtstreek, these changes stem from:

- substitution of bogs (oligotrophic, *sphagnum spp*) with fens (mesotrophic);
- formation of lakes as a result of the excavation of peat;
- agricultural development, mainly extensive grazing by cattle;
- water abstraction, land drainage and polder formation.

By the middle of this century, the result of this coevolution was a mixture of agriculture and semi-natural ecosystems which was more biologically diverse than the original bog ecosystem. The mosaic of lakes, marshes, reedbeds, forests, and pastures also catered for a diversity of landscapes. These landscapes also appear to have become part of Dutch culture – ‘typical Dutch landscape’.

This coevolution has reached a crossroads. The incremental nature of many of the processes driving coevolution has resulted in the fragmentation of the remaining semi-natural ecosystems and substantial changes to the region’s hydrology. One particularly adverse effect of the latter is the greater influence of Vecht river water with associated problems of nutrient enrichment, eutrophication of lakes, and accelerated succession within semi-natural remnants or, where Vecht water is kept out of the wetlands, desiccation (*verdroging*). The agricultural partner is also under stress with agricultural incomes in the region being very low, largely as a result of constraints on intensification and requirements for land management. The role of agriculture in wetland landscapes has been long recognised. The *Relatienota*¹⁰ encourages and compensates farmers for managing their land to maintain semi-natural elements. An essential issue for future development in the region revolves around whether agriculture-nature interactions can continue, and how.

The target for nature restoration is not a return to the original bog ecosystem. Apart from the feasibility of reversing eutrophication processes and recreating this ecosystem, the desirability of such a return is questionable given the need to respond to economic and social as well as environmental objectives. Restoration of the typical Dutch landscape, with the mosaic described briefly above, would seem to be not only more feasible but

¹⁰ Nota betreffende de relatie landbouw en natuur- en landschapsbehoud - Gemeenschappelijke uitgangspunten voor het beleid inzake de uit een oogpunt van natuur- en landschapsbehoud waardevolle agrarische cultuurlandschappen. Tweede Kamer, zitting 1974-1975, 13 285, nr. 1-2. Staatsuitgeverij, 'sGravenhage 1975.

also more desirable. Consequently the target of restoration measures is a coevolving system comprising a mixture of semi-natural and human-made capital.

Wetlands in the Randstad focuses on raising water levels as a means of nature restoration in Dutch wetlands. The framework developed by Lorenz (1999) requires the construction of different indicators to capture the performance of human-made and natural capital. The construction of indicators for the latter was based ecological criteria and demonstrated for the Vecht (see also Van den Bergh *et al.* 1999, and Gilbert *et al.*, in prep.).

This project questions whether coevolved capital, whether natural or human-made, is adequately evaluated on the basis of purely ecological or economic criteria. To illustrate, natural capital resulting from wetland restoration could very easily score poorly with regards to ecological criteria. Periodic dredging of lake sediments to remove nutrient stocks, culling of undesirable fish or restocking with desirable fish species hardly suggests that natural capital is performing well ecologically. Its human-made capital could also score poorly with regards to economic criteria, for example if agriculture remained unprofitable or if the costs of human intervention in ecosystems were high. The co-evolved character of capital inherent in the mixture of agriculture and nature may not be captured in these measures, and may very well be more than the 'sum of its parts'.

An extension of this question is how coevolved capital relates to the debate around sustainable development. This debate tends to revolve around how much natural capital can be substituted by human-made capital, how much natural capital is critical for life support, and complementarity among capitals. To some extent the argument from coevolutionary economics is that paths towards sustainable development involve coevolution between human and natural systems. But what about systems which are already the product of coevolution?

Aim(s) of project

The overall goal of this project is to develop performance indicators capable of capturing and evaluating changes in the coevolved capital of Dutch wetlands.

Specific objectives are:

10. To develop these performance measures so that spatial patterns within wetlands can be revealed;
11. To compare these measures with more conventional economic and ecological (as per Lorenz, 1999) measures;
12. To estimate these measures as a result of different strategies for wetland restoration, and in particular as a result of inundation;
13. To use these measures in conjunction with land use allocation (project 8), spatial evaluation (project 9) and quantification of wetland functions (project 6), to identify viable strategies for wetland restoration.

The innovative aspects of this project lie primarily the coevolution of natural and human systems, and developing associated performance indicators which will allow for scenario evaluation. The project takes the recently completed research of Lorenz (1999) a step further. Given that it could be argued that most European ecosystems are the product of coevolution, the approach is relevant to more than the Netherlands. Further, it will con-

tribute to the debate around sustainable development in focusing on the substitutability and complementarity of natural and human-made capitals.

Research method

The research approach will make use of, at least initially, two methods. Firstly, systems analysis will be used to trace the coevolutionary processes which have led to the current state of wetlands in the Vechtstreek. Similar analysis was used in Gilbert and Janssen (1998) to analyse interactions between a mangrove ecosystem and its users. The result was a conceptual model which allowed structured thinking about these interactions and thereby capacity to estimate the effects of different management scenarios. Systems analysis in the context of this project will focus on the interaction between agriculture and wetland ecosystems, and on the role of water levels and water quality on vegetation type. The result of this analysis will be a conceptual model which will provide a template for the models being developed in projects 7 and 10. It will also assist in focusing attention on key processes driving past coevolution and which will be instrumental in future nature and economic development.

The second method will be based on the procedure devised by Lorenz (1999) for indicator development. The focus here is on performance indicators (i.e. for use in scenario evaluation) not on general indicators for environmental management. The following will be undertaken:

- Definition of information need (in conjunction with projects 9 and 10);
- Development of conceptual model (as a result of the systems analysis above);
- Formulation of potential indicators; and,
- Evaluation of potential indicators (the basis for evaluation may differ due to the specific role of these performance indicators).

The remaining steps in Lorenz's procedure deal with data availability and are not relevant in this instance as the indicators must be constructed from model output.

Temporal and Spatial Scales

The model output which this project will use is expected to be at a small spatial scale. Indicators will be developed at a variety of spatial scales depending on the needs of projects 9 and 10. Both the polder and regional levels can be reasonably expected. Spatial aggregation, as shown in the ECOWET project (Van den Bergh *et al.*, 1999), causes a loss of information. Spatial detail in the indicators, with a minimum loss of information, must be maintained to the greatest extent possible.

Both the indicators developed by Lorenz (1999) and within the ECOWET project are based on the output from static equilibrium models. The development of models within this endeavour should be dynamic in time. Indicators will then be constructed at different points in time, in accordance with the needs of projects 9 and 10.

Workplan

Year 1

- Literature
- Publications from ECOWET

- Systems analysis of coevolution
- Preliminary development of indicators
- First draft of literature review chapters
- Use of ECOWET output to test indicators
- Draft of chapters using ECOWET
- Preliminary design of possible indicators within this project

Year 2

- Completion of ECOWET chapters
- Fine-tuning of indicators
- Spatial analysis and indicators
- Preliminary design of indicators for capturing spatial patterns
- Fine-tuning of spatial indicators
- Linkage of indicators with Projects 7 and 10
- Completion of draft dissertation.

Year 3

- Defence

Composition of research group

Prof.dr. H. Verbruggen	Economics
Prof.dr. N. van Straalen	Ecotoxicology
Prof.dr. M. Aerts	Systems ecology
Prof.dr. H. Eijsackers	Systems ecology
Drs. H. Goosen	Ecology
Drs. A. Gilbert	Researcher

References

- Anonymous (1994). *Convention on Wetlands of International Importance especially as Waterfowl Habitat*, Ramsar, Iran, 2 February 1971, as amended by the Protocol of 3 December 1982 and the Amendments of 28 May 1987. United Nations Educational, Scientific and Cultural Organisation (UNESCO), Paris, 13 July 1994.
- Van den Bergh *et al.* (1999). *Integrated analysis of wetlands: the Dutch Vechtstreek case study*. Case study report for the final report of ECOWET project sponsored by EU-DGXII, Environment & Climate.
- Ehrlich, P. and P. Raven (1964). Butterflies and plants: a study in coevolution. *Evolution* 18:586-608.
- Gilbert, A.J. and R. Janssen (1998). Use of environmental functions to communicate the values of a mangrove ecosystem under different management regimes. *Ecological Economics* 25(3):323-346.
- Gilbert, A.J., C.M. Lorenz and M. van Herwijnen (In prep). Evaluation of the wetlands of the Dutch Vechtstreek. To be submitted to *Regional Environmental Change*.
- Gowdy, J. (1994). *Coevolutionary Economics. The Economy, Society and the Environment*. Kluwer Academic publishers, Dordrecht. 286 p.
- Lorenz, C.M. (1999). *Indicators for sustainable management of rivers*. PhD. Dissertation, Faculty of Biology, Vrije Universiteit (forthcoming).

- LNV (1992). *Nota Landschap*. Ministerie Landbouw, Natuur en Visserij, Den Haag.
- LNV (1990). *Natuurbeleidsplan*. Ministerie Landbouw, Natuur en Visserij, Den Haag.
- LNV (1996). *Structuurschema Groene Ruimte*. Ministerie Landbouw, Natuur en Visserij, Den Haag.
- Provincie Noord-Holland (1997). *Gebiedsperspectief voor de Vechtstreek*. Beleidsnota, Provincie Noord-Holland, Haarlem.
- Ridley, M. (1996). *Evolution*. 2nd edition. Blackwell Science, Cambridge Massachusetts.
- Serageldin, I. and A. Steer (1994). Epilogue: expanding the capital stock. IN (eds.). I. Serageldin, and A. Steer. *Making Development Sustainable: from concepts to actions*. Environmentally Sustainable Development Occasional Paper Series no. 2. The World Bank, Washington DC.
- V&W (1989). *Derde Nota Waterhuishouding*. Ministerie van Verkeer en Waterstaat, Den Haag.
- Verbruggen, H. (1995). Modiale duurzame ontwikkeling: efficiëntie en verdeling. *Maandschrift economie* 59:280-297.
- VROM (1990). *Vierde Nota over de Ruimtelijke Ordening (Extra)*. Ministerie Volksgezondheid, Ruimtelijk Ordening en Milieu, Den Haag.

4.8 Project 8: Wetlands in integrated land use models¹¹

Problem description

Wetlands in the Netherlands are subject to pressures from various economic activities. Especially in the Randstad region there is a strong competition for land among residential, industrial, natural and agricultural land use (cf. Dieleman and Musterd, 1993). In this part of the country, where land use is intensive, spatial spill-overs are quite relevant. An example of positive spill-overs is the contribution of wetlands to a high level of attractiveness for residential purposes in nearby areas. Another example concerns the opportunities provided by wetlands for recreational purposes of residents in the region. Negative spill-overs may relate for example to the impact of wetland development on productivity of agricultural activities in nearby zones, for instance, due to the need for high groundwater tables. Another obvious example of a negative spill-over is the impact of urban activities like manufacturing or transport on the quality of wetlands (Turner et al. 1991).

Aims and objectives

The aim of the present project is to focus on two particular aspects of these spatial inter-relationships, i.e. the linkages between wetlands and (1) residential land use as well as (2) recreational activities.

As income levels increase, people are expected to attach more value to the environmental aspects of their residential environment. However, whether this is true in general, and which aspects of environmental quality are most important, are subject to debate.

¹¹ Prof. dr. J.C.J.M. van den Bergh, Dept. of Spatial Economics, Vrije Universiteit.
 Prof. dr. P. Rietveld, Dept. of Spatial Economics, Vrije Universiteit.
 Prof. dr. H. Scholten, Dept. of Spatial Economics, Vrije Universiteit.
 Drs. René van der Kruk, Dept. of Spatial Economics, Vrije Universiteit.

The aim of the project is to analyse the impacts of wetlands on housing markets. This entails a spatial analysis of developments of housing construction and price formation that gives special attention to the role of the presence of wetlands in the regions concerned.

The aim of these approaches is to model the spatial interrelationships between natural and economic phenomena: wetlands and housing markets. These relationships are analysed by means of market outcomes, thus giving the analysis the character of a 'revealed preference' approach. This can lead to an assessment of direct and indirect use values. An alternative approach would have been to use a 'stated preference' approach. A well-known method often used for this purpose is the 'contingent valuation' which can be used to assess non-use values as well. For a detailed account of differences between stated preference and revealed preference approaches see Johansson (1987), Dixon and Hufschmidt (1986), Braden and Kolstad (1991), Freeman (1993), Hanley and Spash (1993) and Rouwendal *et al.* (1999). The main advantage of stated preference is that choice situations are rather easy to construct and control. Nevertheless, the artificial character of the choices presented to respondents casts doubt on the transferability of the outcomes to real choice situations. In wetland related research the market based revealed preference approach has not been often applied. It might be a welcome complement to the stated preference approaches usually applied in this field. Wetlands valuation requires that attention be given to the spatial and ecological characteristics of ecosystems, as well as to different categories of values, such as direct, indirect, option, bequest, primary versus secondary, and non-use value (see Gren *et al.*, 1994, Bingham *et al.*, 1995, Turner *et al.*, 1998). Brouwer *et al.* (1997) bring together a number of wetland contingent valuation studies in a meta-analysis to learn more about the importance of specific functions for total economic values of wetlands. For a variety of approaches to value wetlands see Barbier (1994), Costanza *et al.* (1989), Dixon (1989) and Turner *et al.* (1983).

A difficulty in the analysis of the impact of wetlands on housing markets is that land markets are heavily controlled in The Netherlands. This obviates an immediate link between wetland qualities and the development of residential property in the surrounding areas. Government policies aiming at reducing the supply of housing in wetlands deserve explicit attention in the modelling activities. The research should pay attention to statistical biases due to these institutional features.

A second area where the impacts of wetlands on land use of other sectors take place is in the field of leisure and recreation. Depending on the regime imposed by the government, the existence of wetlands makes certain regions an attractive destination for various recreational activities. In the project we will not aim at a complete analysis of the implications of wetlands for recreation, but will confine ourselves to the implications of wetlands for economic sectors like recreational activities, hotels, restaurants, etc. The presence of wetlands in a region may be expected to have a positive impact on these economic sectors. The question is to what extent this relationship is confirmed by empirical data.

The innovative aspects of this project include:

- The estimation of values of wetlands via a hedonic price approach of dwellings. This is a useful complement to the stated preference approach (contingent valuation) usually adopted in valuation studies of wetlands.

- Explicit attention to the differentiated impacts of regulatory regimes adopted by governments with respect to wetlands (for example, protection versus facilitation of economic activities)
- Integration of wetland analysis in a land use model covering various types of land use, including residential land use, agriculture, manufacturing and other economic activities.

Research Method

The following steps are foreseen in the analysis of the impacts of wetlands on the housing market:

1. Study of literature on theories, models and policies in the field of land use in general and wetlands in particular.
2. Analysis of restrictive land use policies of national, regional and municipal governments in terms of physical planning restrictions on land use. This entails the collection of data on physical planning in a number of regions. The role of wetlands in these restrictive policies will be analysed by linking the physical planning data with GIS based data on various aspects of land use including wetland properties.
3. Analysis of residential development and housing price patterns in various parts of the country. Growth (and decline) in the use of land for residential purposes will be explained in terms of various determinants following the theory of spatial housing markets (accessibility of various amenities, local environmental quality, attractiveness for competing types of land use). Special attention will be given to the role of wetlands in determining local environmental quality. Estimations will be carried out for two regimes (see step 1): one where there are no institutional constraints on land use, and one where constraints are active.
4. Developing indicators of wetland attractiveness for housing and recreation. These would combine ecological data, accessibility data, generalised transport costs and recreation data. GIS systems will be useful in this respect, as they provide an integrated description of the spatial structure and interactions between housing, wetlands, infrastructure and travel. In addition to objective data questionnaires may be used to gather subjective data on (perceptions of) spatial characteristics of recreation and wetland attractiveness.
5. Meta-analysis of the role of environmental quality in the formation of house prices. Several studies have been carried out in various countries on the impacts of environmental quality on house prices. Most of these studies are essentially 'hedonic price studies' (Johansson, 1987) implying an explanation of house prices in terms of house internal and house external features. An example of house external features is given by Schipper *et al.* (1998) who carried out a meta-analysis of the negative impact of airport noise on house prices. In the present study we will focus on the potentially positive effects of a high quality wetland environment on house prices. The results could be compared with those obtained in a study by Brouwer *et al.* (1997), which focused on wetland contingent valuation studies.
6. Analysis of the impacts of wetlands on residential property. This entails the use of micro data on housing prices from real estate agents. Such data concern the demand price of houses as well as the properties of the dwellings. By linking these data with a GIS covering various aspects of environmental quality, it is possible to determine

the size of the impact of environmental quality indicators including variables relating to wetlands. Here again a comparison may be carried out of regions with a strict and regions with a less strict physical planning policy.

7. Analysis of impacts of wetlands on the recreational sector. For this purpose data sets on the locational patterns of this sector will be analysed. The role of wetlands as a location factor will be highlighted. Special attention will be paid to the influence of governmental policies in terms of restricting recreational impacts.
8. Integration of the above analytical results in a land use model. Two models are available: the LAND-USE SCANNER model (see Hilferink and Rietveld, 1999); and the ECOWET model of the Vecht area (van den Bergh et al., 1999). This would lead to an integrated analysis of wetland quality, housing markets and the recreation sector.
9. Policy analysis based on LAND-USE SCANNER or ECOWET model of impact of wetland developments and changes in physical planning regulations on housing markets in terms of increases in housing prices and the construction of housing, as well as the recreation sector.

In most of the research activities mentioned above, some kind of control group approach will be used. This implies that the analysis will not be restricted to the study area in a narrow sense. Instead, the study area will be compared with the developments in other wetlands in the country, as well as with non-wetland areas. By this approach one will be able to determine the differentiated effect in economic terms of what it means to be a wetland region with non-wetland regions. This does not mean to say, that the study area will not receive special attention in this study. In each step special attention will be paid to the position of the study region. The integrative steps 7 and 8 will focus entirely on the study area

Workplan

Year 1

Master's program at the Tinbergen Graduate School
Collection of literature

Year 2

Master's program at the Tinbergen Graduate School
Collection of literature
Writing of Master's thesis
Survey of policies
House construction in wetland analysis

Year 3

Construction of wetland attractiveness indicators
Meta analysis
Hedonic price study

Year 4

Recreational development
Integration land-use scanner

Policy analysis
Writing and defence of dissertation

Composition of research group

Prof.dr. J. van den Bergh	Economics
Prof.dr. P. Rietveld	Economics
Prof.dr. H. Scholten	Economic and spatial analysis
Drs. René van der Kruk	Ph.D. student (oio)

References

- Barbier, E.B. (1994). Valuing Environmental Functions: Tropical Wetlands. *Land Economics*, 70 (2): 155-173.
- Bergh, J.C.J.M., van den, A. Barendregt, A. Gilbert, et al. (1999). *Integrated analysis of wetlands: The Dutch Vechtstreek case study*. Dept. of Spatial Economics and Institute for Environmental Studies, Free University, Amsterdam.
- Bingham, G. et al. (1995). Issues in ecosystem valuation: improving information for decision-making, *Ecological Economics* 14: 73-90.
- Braden, J.B. and Kolstad, C.D. (eds) (1991). *Measuring the demand for environmental quality*. North- Holland, Amsterdam.
- Brouwer, R., Langford, I.H., Bateman, I.J. and Turner, R.K. (1997). *A Meta-Analysis of Wetland Contingent to Valuation Studies*, CSERGE Working Paper, University of East Anglia and University College London.
- Costanza, R., Farber, C.S. and Maxwell, J. (1989). Valuation and Management of Wetland Ecosystems. *Ecological Economics*, 1: 335-361.
- Dieleman and Musterd, 1993
- Dixon, J.A. and Hufschmidt, M.M. (1986). *Economic Valuation Techniques for the Environment*. John Hopkins Press, Baltimore.
- Dixon, J.A. (1989) Valuation of Mangroves. *Tropical Coastal Area Management Manila*, 4(3): 2-6.
- Freeman, A.M.I. (1993). *The Measurement of Environmental Resources Values. Resources For The Future*, Washington D.C.
- Gren, I-M., Folke, C., Turner, R.K. and Bateman, I. (1994). Primary and Secondary Values of Wetland Ecosystems. *Environmental and Resource Economics*. Vol.4: 55-74.
- Hanley, N. and Spash, C.L. (1993). *Cost-Benefit Analysis and the Environment*. Edward Elgar, Vermont.
- Hilferink M. and P. Rietveld (1999). LAND USE SCANNER, an integrated GIS based model for long term projections of land use in urban and rural areas, *Journal of Geographical Systems*, vol 1, pp. 155-177
- Johansson, P-O (1987). *The economic theory and measurement of environmental benefits*, Cambridge University Press, Cambridge
- Rouwendal, J., P.Rietveld and E. Verhoef (1999). *Welvaartsaspecten bij de evaluatie van infrastructuur projecten*. Ministry of Transport, The Hague.
- Schipper, Y., P. Rietveld and P.Nijkamp (1998). Why do aircraft noise estimates differ? A meta analysis, *Journal Of Air Transport Management* 4:117-124.
- Turner, R.K., J.C.J.M. van den Bergh, A. Barendregt and E. Maltby (1998). Ecological-economic analysis of wetlands: Science and social science integration. In: *Wetlands: Landscape and In-*

- stitutional Perspectives*. (ed. T. Söderquist). Beijer Occasional Paper Series, Beijer International Institute of Ecological Economics, Stockholm, Sweden, pp. 293-326.
- Turner, R.K., Dent, D. and Hey, R.D. (1983). Valuation of the environmental impact of wetland flood protection and drainage schemes. *Environment and Planning A*, 15: 871-888.
- Turner, R.K. and Jones, T. (eds.) (1991). *Wetlands, Market and Intervention Failures*. Earthscan, London.

4.9 Project 9: Evaluation of conflict and compromise in wetland management¹²

Problem Description

Wetlands generate multiple services and goods, which are used by different stakeholders. These have interests and actions that can be mutually conflictive. For instance, some uses (supply of drinking water, nutrient run-off caused by agriculture) depend on nutrient uptake by wetland ecosystems, while others (preservation of unique plant species) require nutrient-poor wetland conditions. Public management and policy aim to minimise conflicts and thus search for combinations of activities that satisfy some social objective function. An evaluation of management and policy alternatives requires that criteria are identified. These may include financial benefits, non-monetised benefits, costs of measures, environmental quality impacts, ecological and nature conservation indicators (resilience, productivity, diversity, unique plant and bird species), and spatial and economic distribution aspects. Information about the criteria as well as the relative weights assigned to each of them can be obtained by involving the various stakeholders in the evaluation and decision making processes.

The objective of the project is to develop a structured process to generate compromises among stakeholders for public management and policy of wetland areas. This will include the design of a general framework, the construction of an operational tool, and the application of these to a concrete case. The project will identify stakeholders and their criteria and goals to specify spatial distributions of preferred land use. Analysis of preferences of stakeholders will be used to identify conflicts among stakeholders and to generate alternatives that meet the demands of the stakeholders as well as possible.

The project will make use of previous studies to develop an integrated ecological-economic model. These previous studies have led to experiences with integrated modelling and evaluation in the Vecht region (van den Bergh *et al.* 1999; Rietveld *et al.* 1999). Projects 6, 7 and 8 are expected to provide additional information to develop the model. Previous experience also covers decision support for environmental management (Janssen 1992), and spatial evaluation (Herwijnen, 1999).

Aims and Objectives

This project aims to contribute to two research areas. The first area is integrated assessment and the second area is the formal analysis of institutions.

¹² Prof. dr. J.C.J.M. van den Bergh, Dept. of Spatial Economics, Vrije Universiteit.
 Prof. dr. P. Rietveld, Dept. of Spatial Economics, Vrije Universiteit.
 Dr. R. Janssen, Institute for Environmental Studies, Vrije Universiteit.

Integrated environmental assessment combines the development and use of models, and communication of information and insights with stakeholders in order to solve practical environmental problems. As long as the objectives are clearly formalised, problems, although complex, are suitable for analysis. This changes when the objectives are vague, differ among the stakeholders, and technical facts are surrounded by subjectivity. Problems become then part of a political process. During the past 20 years various approaches have been developed aimed at structuring the decision process in order to improve decision-making. Examples of these approaches are: simulation-gaming, policy exercises, integrated assessment, adaptive management, decision support systems, cost-benefit analysis, multi-criteria analysis, and so on.

In recent years a shift can be observed towards spatial evaluation combining methods from multi-criteria analysis with methods from spatial analysis. In addition, there has been a shift from single user decision to group decision support. This requires aggregation of individual goals, criteria and relative weights. Only limited formal methods have been developed to support the multi-stakeholder processes of spatial environmental management. This project will develop a method to identify potential conflicts between stakeholders. Based on preferences among stakeholders we aim at deriving a spatial picture of areas of conflicts (Cocks and Ive, 1996). Tools from operations research and multi-criteria analysis will be used to identify areas of conflict and generate compromise solutions. The resulting information can be used to improve decision making on spatial planning.

The formal analysis of institutions has a short history. The roots of the formal analysis lay in game theory. Repeated games have been used to study the evolution of cooperation (Axelrod, 1984). Recent studies analyse the stochastic stability of institutions (Young, 1998). These theoretic studies differ from empirical analysis, where distributions of property rights are studied as well as the self-organisation of effective institutions (Ostrom *et al.*, 1999). Moreover, in case of environmental institutions, one needs to include the fundamental characteristics of ecosystems related to scales, multi-stability and resilience (Gunderson *et al.*, 1995, Carpenter *et al.*, 1999).

Characteristic of wetlands is the importance of spatial diversity of consumption of multiple ecological services. Using a simple ecological model of multiple stable states, the evolution of institutions will be analysed. The model follows the tradition of multi-agent modelling in the analysis of ecosystem management (Janssen and Carpenter, 1999; Janssen *et al.*, 1999). More precisely, we will analyse when spatial structures of land use emerge under various assumptions of ecological dynamics. When do agents change their land use, when do resilience structures of land use emerge, and how can governmental policy stimulate desirable evolutionary patterns?

Research Method

The following steps in the research are foreseen:

Design of evaluation framework

Based on a literature study on integrated environmental assessment, an evaluation framework is designed that will be applied in this project.

Selection of stakeholders

This step involves the identification of stakeholders in the wetland area, and selection of the most relevant stakeholder for this project based.

Stakeholder survey

A survey among the selected stakeholders will provide us much information on their objectives and criteria related to their preferred future of the Vecht area. This information is used for the practical implementation of decision support software. This software combines information of the Vecht area, effects of different patterns of land use, and multi-criteria runs for evaluation of scenarios.

Design of the evaluation tool

This tool combines empirical information and the ecological model of project 6 to evaluate effects of different land use scenarios and to generate suitability maps for certain activities. Together with the information derived from the stakeholders a multi-criteria analysis can be performed to identify areas of potential conflicts.

Scenario analysis

Using multi-criteria analysis areas of conflicting interests are identified for alternative scenarios. These scenarios can represent alternative visions on the future of the Vecht area. A heuristic algorithm will be developed that minimise areas of conflicts in order to derive a compromise solution.

Literature study evolution of institutions

Literature on repeated games, common property resource management and institutional economics will be studied.

A Model of evolution of institution in the context of ecosystem management

A multi-agent simulation model is developed to simulate evolution of institutions that manage the use of spatial ecosystems by a heterogeneous set of agents.

Workplan

Year 1

- Development of framework to facilitate multi-stakeholder spatial planning of wetlands
- Selecting stakeholders for participation
- Study of the literature on institutions

Year 2

- Stakeholder survey on their objectives and criteria
- Development of evaluation model
- Model of institutional change and multi-use of ecosystems

Year 3

- Evaluation of plans for the Vecht area and identifying areas of conflicts

- Design of alternative compromise plans
- Study on resilience and institutional design

Year 4

- Evaluation and sensitivity analysis of compromise plan
- Analysis of evolution of institutions for ecosystem management

Composition of research group

Prof.dr. P. Rietveld	Economics
Prof.dr. J. van den Bergh	Economics
Dr. R. Janssen	Economics, decision support, spatial analysis
Dr. M. Janssen	Post-doc

References

- Axelrod, R. (1984). *The Evolution of Cooperation*, Basic Books, New York.
- Bergh, J.C.J.M. van den, et al. (1999). *Integrated analysis of wetlands: The Dutch Vechtstreek case study*. ECOWET final report to the EU. Vrije Universiteit, Amsterdam.
- Carpenter, S., W. Brooke, and P. Hanson (1999). Ecological and social dynamics in simple models of ecosystem management. *Conservation Ecology* 3(2): 4. [online] URL: <http://www.consecol.org/vol3/iss2/art4>
- Cocks, D. and J. Ive (1996). Mediation support for forest land allocation: The SIRO-MED System, *Environmental Management*, Vol. 20, No. 1, pp. 41-52.
- Gunderson, L.H., C.S. Holling, S.S. Light (Editors) (1995). *Barriers & Bridges to the Renewal of Ecosystems and Institutions*, Columbia University Press, New York.
- Herwijnen, M. van (1999). *Spatial decision support for environmental management*, PhD dissertation, Vrije Universiteit, Amsterdam.
- Janssen, M.A. and S.R. Carpenter (1999). Managing the Resilience of Lakes – A multi-agent approach, *Conservation Ecology* 3(2): 15. [online] URL: <http://www.consecol.org/vol3/iss2/art15>
- Janssen, M.A., B.H. Walker, J. Langridge and N. Abel (2000). An adaptive agent model for analysing co-evolution of management and policies in a complex rangeland system, *Ecological Modelling*, in press
- Janssen, R. (1992). *Multiobjective decision support for environmental management*, Kluwer Academic publishers, Dordrecht
- Ostrom, E., J. Burger, C.B. Field, R.B. Norgaard and D. Policansky (1999). Revisiting the Commons: Local Lessons, Global Challenges, *Science*, 284: 278-282.
- Rietveld, P., R. van de Velde and M. Hilferink (1999). *Spatial economic effects of airports, an ex-ante analysis by means of a land use scanner*, Vrije Universiteit.
- Young, H.P. (1998). *Individual Strategy and Social Structure – An Evolutionary Theory of Institutions*, Princeton University Press, Princeton, NJ.

5. Links among projects

5.1 Introduction

As stated in Section 2, *Wetlands in the Randstad* aims to develop scientific knowledge which will elucidate the complex interactions between economic and ecological processes for wetlands that are experiencing a transition from mainly monofunctional to multifunctional land use. Consequently the project is multidisciplinary, as can clearly be seen from the individual project descriptions in the previous section. This section deals with how these different activities will lead to the achievement of the above goal.

Few frameworks exist for the integration of different disciplines. The framework currently being used, largely in the context of indicator development by the OECD, World Bank, Work Resources Institute, EUROSTAT and the European Environmental Agency, is the Driving forces-Pressure-State-Impact-Response or DPSIR framework (e.g. OECD, 1994; Hammond *et al.*, 1995; and see Figure 5.1). This framework was devised to assist environmental research in its analysis of the effects of human activities on natural systems. It is a conceptual and organising framework for the integration of different disciplinary contributions in the analysis and remediation of environmental problems.

The strength of this framework lies in its facilitating disciplinary integration. However, the focus on integration may lead to less attention being paid to a number of crucial, more fundamental, scientific issues, viz.:

- many environmental processes and their interactions with society are stochastic and even non-stochastic (novel events, or surprises);
- many relationships behind the cause-effect chains resulting in environmental problems are non-linear or discontinuous;
- the de-coupling of economic driving forces from their environmental impacts is likely to be needed if societies are to move towards sustainable development; and
- complex interactions among scales, in particular spatial scales, belie the ease with which the DPSIR framework can be applied.

Wetlands in the Randstad, with its individual projects supporting PhD and post-doctoral research, is explicitly directed towards such scientific issues, and most particularly towards the last - interactions among spatial scales. This focus, as well as the practicalities surrounding this type of research, mean that full disciplinary integration will not be attempted by this project. *Wetlands in the Randstad* has a more modest goal than projects typically applying the DPSIR framework. Emphasis is placed on interdisciplinary communication, and on stretching the bounds within each individual project towards a second discipline. The aim is more to contribute to scientific knowledge within and between adjacent disciplines. The disciplines, projects and interactions are shown in Figure 5.2. Project titles and numbers are listed in Table 5.1.

Even though integration will not be attempted, opportunities will be provided within the management structure of *Wetlands in the Randstad* for information to be shared and communicated among projects. The double-headed arrows in Figure 5.2 show where this communication is expected to lie; these links between projects are discussed more fully

in the sections below. In this way it is hoped that partial integration will be possible. This integration will focus on the translation of knowledge about the natural system's responses to *vernatting*, into implications for regional management.

Table 5.1 Projects comprising Wetlands in the Randstad

Project No.	Project Title
1	Linking the regional and site scales in ecohydrological modelling for integrated water management
2	Remote sensing approach to study scale aspects and functioning of wetland ecosystems
3	Development of chemical indicators to characterise wetland ecosystems
4	Steering of ion channels by metals
5	Effects of changes in hydrology on ecological and chemical characteristics of wetlands
6	Ecological and societal conditions for wetland restoration
7	Performance indicators for the co-evolved capital of Dutch wetlands
8	Wetlands in integrated land use models
9	Conflict and compromise in wetland management

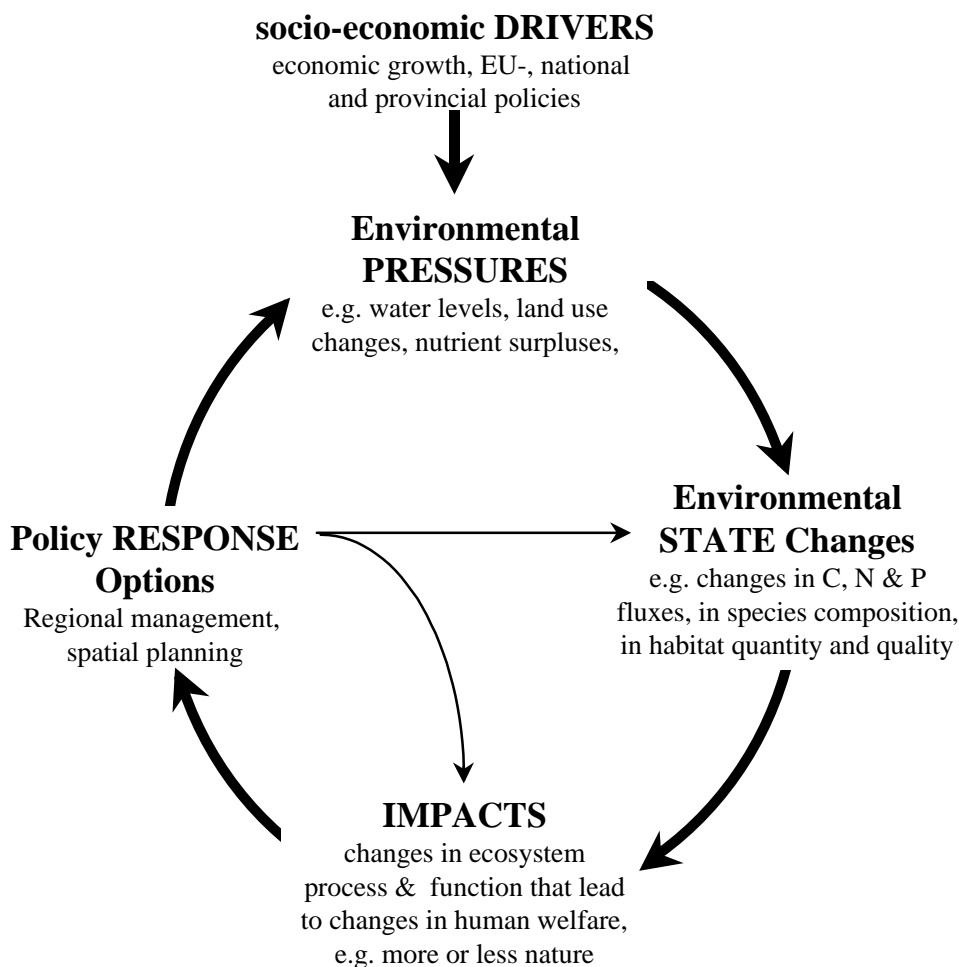


Figure 5.1. The DPSIR framework

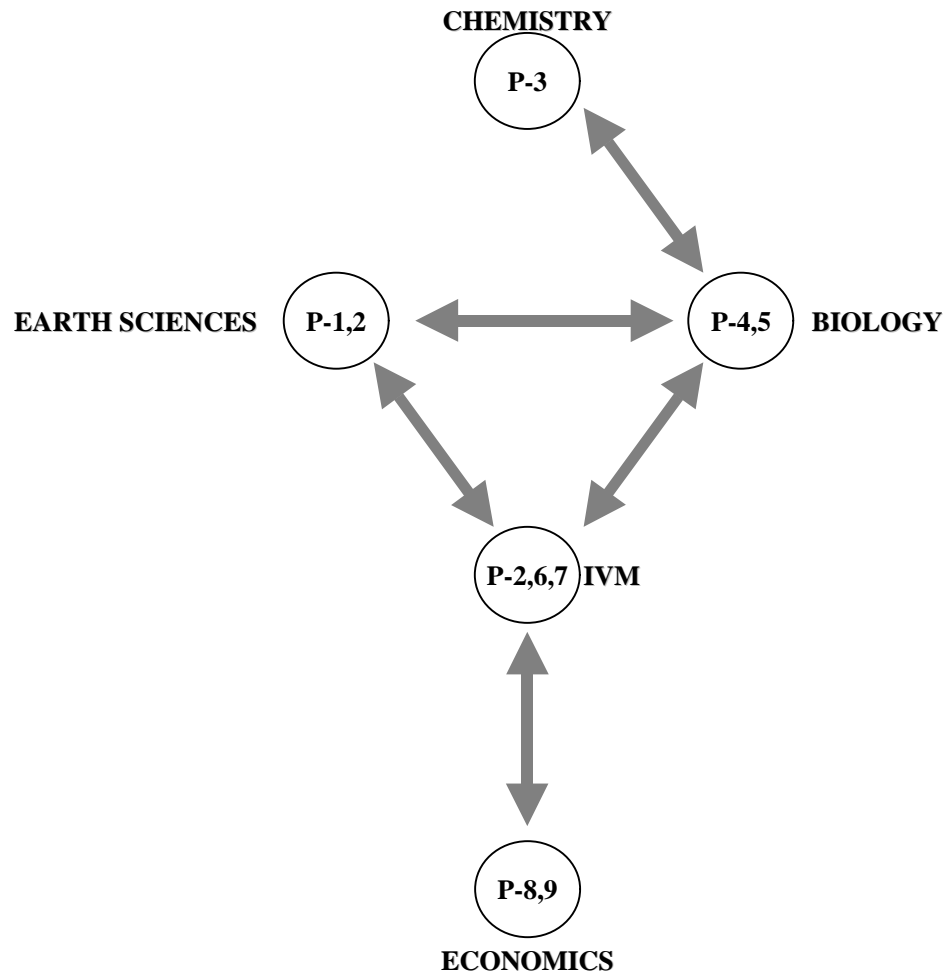


Figure 5.2. Disciplinary overlaps for the nine projects

5.2 The links

The term 'links' is used here to encompass communication between two projects embedded in adjacent disciplines. Figure 5.2 indicates the main aspect of this two-way communication. Links are further specified below.

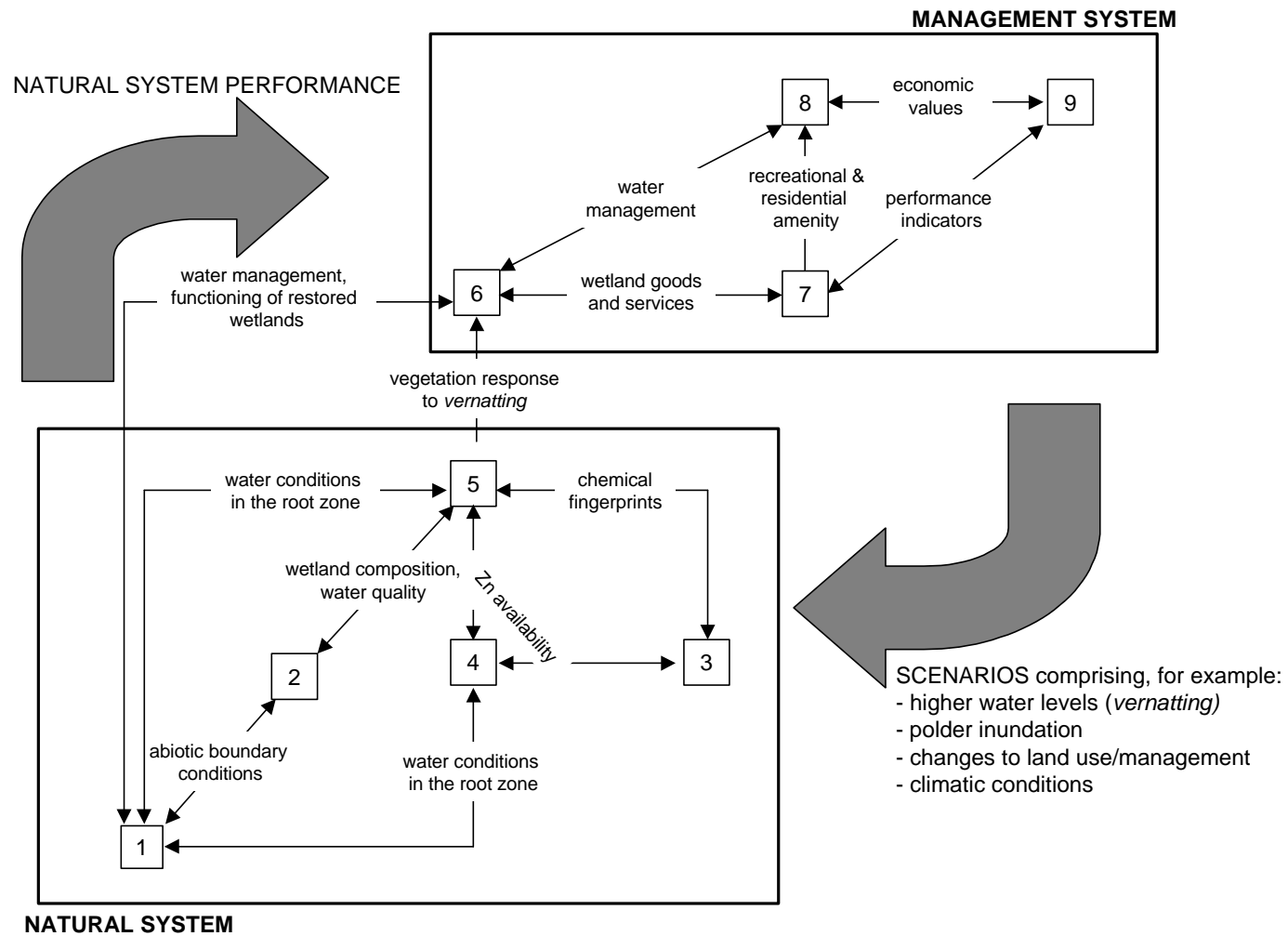


Figure 5.3. Links between the nine projects comprising Wetlands in the Randstad

5.2.1 Between the natural and management system

As indicated by Figure 5.2, the nine projects which comprise *Wetlands in the Randstad* may be grouped into five which deal with the natural system, and four which deal with the management system. Information flows between these two systems tend to be focused on projects 5, 6, and 1:

- Project 1 provides information on hydrological conditions and, to a limited extent, on associated water quality (with ‘vernattig’ as the central management measure being addressed, this project will provide base information for most projects);
- Project 5 captures the natural system’s response to changes in water levels; and
- Project 6 specifies the societal relevance of changes effected on the natural system.

Project 1, modelling the hydrology of the study and experimental areas, is a major source of information for projects addressing the ecological repercussions of hydrological changes. It will develop an hydrological model for the whole study area, with more detailed specification of experimental sites being used by other projects within the natural system. Time series of groundwater heads and fluxes will then be generated for selected sites throughout the study area. Groundwater quality will be described as the product of the mixing of water from different sources. Large-scale maps of groundwater heads (relative to NAP and relative to the soil surface), maps of seepage and infiltration rates and water balances will be provided for the entire model area under a range of scenarios (see Section 7). This information, and particularly its economic consequences, will feed into project 6.

Wetland restoration, specifically addressed in project 6, is expected to contribute to flood control (peak flow discharge), water purification, freshwater storage and to counteract saltwater seepage. Project 6 will estimate the quantities of water that can be stored in the study area and how this can contribute to flood risk management, agricultural and drinking water supplies, water purification and salinisation control. This information will feed back to project 1 via the capacity of wetlands to purify water (water quality), to reduce flood risks (water levels) and to store freshwater (water volumes).

Project 6 also draws on information generated by project 2 (remote sensing). One of the specific objectives of project 2 is the mapping of Coloured Dissolved Organic Matter (CDOM) as an ecological indicator of water quality. Maps of the spatial distribution of this parameter will be generated. Links with project 6 will provide additional input to project 2 on the characterisation of CDOM which may improve the mapping of this parameter. This may lead to more detailed insight into the origin of CDOM as found in various locations, which in turn may lead to the assimilation of remotely detected CDOM into ecological indicator maps. Maps of vegetation, land use and the composition changes at ecological gradients will also be generated by project 2 for used by various projects including project 6.

Project 6 will translate some of the results of project 5 to larger spatial scales and identify their relevance for society as a whole. Project 6 focuses on fen ecosystems, comprising aquatic, semi-aquatic and terrestrial elements, at the landscape level, whereas project 5 focuses on the terrestrial component at much smaller spatial scales (experimental plots

of about 1 m², and gradients across distances of a few hundred metres). Project 5 will focus in more on vegetation response of grasslands to 'vernatting'.

Project 6 will undertake a region-wide assessment of changes effected on the natural system by implementing a selection of scenarios. As discussed in Section 7, 'vernatting' comprises only one element of these scenarios. In undertaking this assessment, project 6 will make extensive use of existing data and expert knowledge. The information from project 5 on grasslands' response to 'vernatting' can be used to validate assumptions used in project 6. This will illustrate the level of uncertainty and the inevitable loss of information as a result of up-scaling local, short term ecological data to higher spatial and temporal scales (see Section 6 and the discussion on spatial scales).

In addition to these links, Projects 7 and 9 will also interact with analyses of the natural system. Project 7 addresses the 'co-evolution' of the natural and social systems present in the study area. Information relevant for the valuation of the natural capital of wetlands and of mixed semi-natural and agricultural landscape will be supported by Project 5. Project 9, in evaluating scenarios, will provide feedback to the natural system with information on the success or otherwise of the nature restoration measures incorporated in the scenarios.

5.2.2 Within the natural system

While project 1 is a central source of information for projects, it also draws information from project 2. This information comprises grid maps of some water quality parameters and of vegetation structure/land use map of the entire study area; these maps will have a spatial resolution of 15-30 meters. The second map will include a classification of wetlands in flooded, moist and relatively dry zones, as well as hydro-logical boundary conditions (hydrological units, exfiltration/infiltration, stagnant water levels etc). The hydro-logical model will use the vegetation and land use map as extra information on, e.g., evapotranspiration. In general, project 2 attempts to contribute to the study of the effects and boundary conditions of spatial information transformation when going from detailed studies to large-scale low- resolution studies. As such it contributes to all projects dealing with spatial issues.

Both projects 1 and 2 will link with project 5 for the spatial description of hydro-ecological zones, land use patterns, typical vegetation types etc. Each of these projects will use a common set of maps of (abiotic) factors such as terrain elevation, soil type etc. Essential information from project 2 to projects 1 and 5 will be the description of spatial extend and spatial variability within and between "eco-hydrological units, zones etc".

Project 1 provides information to the ecological projects 4 and 5. In project 1 a limited version of the Hydrochemical Facies Analysis, adapted for hydroecological studies, will be applied to the selected test sites at both regional and local scales (HYFA; Stuyfzand, 1993). The aim is to unravel and map the hydrochemical evolution of groundwater along the lines of flow discerned by means of the groundwater flow model for the study region, and to link the interdependent changes in groundwater flow, groundwater composition, soil and vegetation. The 'limited version' of HYFA applies to the limited set of chemical parameters that will be used to support the ecological studies. Ecohydrological relationships in the research area that need particular attention by projects 4 and 5:

- Groundwater \Leftrightarrow terrain \Leftrightarrow soil \Leftrightarrow terrestrial plants;
- Groundwater \Leftrightarrow surface water \Leftrightarrow aquatic plants;
- Groundwater flow \Leftrightarrow groundwater composition \Leftrightarrow surface water composition;
- Saturated groundwater \Leftrightarrow unsaturated zone \Leftrightarrow drainage towards surface water systems;
- Evapotranspiration (vegetation structure \Leftrightarrow soil \Leftrightarrow moisture conditions).

More specifically for project 4, project 1 will deliver data on the seasonal and spatial dynamics of aqueous zinc in the various wetland sites so that the steering concentrations for the (de)activation of the various Zn-transporting proteins can be tested. As feedback the outcome of this project can advise the water manager how to select adequate water quality for the development of restored wetlands.

Projects 1 and 5 are strongly interrelated. Project 1 will provide time series of observed groundwater levels and hydrochemical characteristics at experimental sites. Project 5 (together with project 2) will provide detailed vegetation maps of the selected parcels in the test areas. Detailed DEM's and soil maps will be constructed of these 'key-parcels' on the basis of jointly collected field data. The hydrological model will provide time series of groundwater heads and groundwater fluxes at the test sites. Small-scale maps of groundwater heads (relative to NAP and relative to the soil surface), of seepage and infiltration rates, groundwater flow paths and water balances will be provided for relevant water management units around the Horstermeer polder and Naardermeer. Water quality as well as quantity is an important environmental condition for the functioning of the peatland ecosystem. Cooperation between Projects 1, 4 and 5 will attempt to address this relationship. Vegetation data collected by project 5 will be an important input variable for the hydrological model developed.

Projects 3 and 4 both address issues relating to chemical aspects of the natural environment. Metal availability is conditioned by pH, inorganic and organic complexing agents. Inorganic complexes include those formed with sulphates in the case of a sulphur surplus; organic metal complexes are those with phenolic, fulvic and humic acids. The latter are specific for plant species and thus for microsites in the ecosystem. The chemistry of fulvic and humic acids is dependent on plant litter derived from organic matter, and modified by microorganisms.

Project 5 will play the leading role in the site and sample selection for projects 3, 4 and 5. A diversity of sampling and sample clean-up procedures will be developed to take into account the widely varying concentrations of analytes and dissolved organic matter as well as particulate matter. Selection of target compounds and preferred matrices to be studied will also be done in close cooperation. The important question is which matrices are the most interesting from the point of view of biological indicators.

Communication between projects 3 and 5 will be directed towards the development and use of:

- chemical fingerprints as indicators of the functioning of natural wetland systems; and
- biological indicators to characterise the ecosystems concerned.

Biological indicators are more general and less selective than chemical ones. Chemical indicators are required since structurally similar compounds can exhibit totally different effects. Cooperation will be needed to couple these different types of indicators.

Most of the management of Dutch wetlands is directed towards hampering natural succession to maintain a man-made, non-woody ecosystem with a high biodiversity. Project 5 will deliver species-specific ROL. This will enable project 4 to advise on the management of the water table due to the high responsiveness of the Zn transporter proteins to available Zn concentration and of the development of aerenchyma to modify the Zn availability in the rhizosphere.

Project 5 focuses information on the natural system into select ecological consequences. It draws information from all projects within the natural system. Projects 2 and 5, together with project 1, will combine to deliver a spatial description of hydro-ecological zones, land use patterns, and typical vegetation types. Each of these projects will use a common set of maps of (abiotic) factors such as terrain elevation and soil type. Essential information from project 2 will be the description of spatial extent and spatial variability within and between various abiotic and biotic (e.g. ecohydrological) zones.

Outside the framework we will cooperate with the department of Landscape Ecology of the faculty of Biology of the University of Utrecht for the gradient analysis. Within this group, data sets are already available.

5.2.3 Within the management system

Project 6 provides the main communication line between projects in the natural and management systems. It will yield information on the supply of natural resources from the natural system under various scenarios. To achieve this, project 6 will develop an integrated, spatially disaggregated model.

Project 8 will attempt to value wetland environments in terms of their attractiveness for residential and recreational development. Projects 6 and 7 will generate environmental information and indicators to represent this attractiveness on the basis of criteria identified by project 8. Project 8 will generate monetary indicators which will contribute to the multicriteria analysis performed by project 9.

Projects 6, 7 and 9 all develop and make use of a model of the wetlands system. While the form and purpose of these models will differ, cooperation among these projects and agreement as to key variables and processes will be essential. These projects are further linked in that output from the integrated model (project 6) will be processed by projects 7 and 8 into performance indicators for use by project 9 in a multicriteria analysis which will evaluate scenarios. This output will include quantitative (wherever possible) and qualitative information about the volume and characteristics of environmental goods and services which the region is capable of supplying under different scenarios, as well as various economic indicators. This should be available at a variety of spatial scales so that both the spatial character of the indicators, as well as their values for the region as a whole, can be estimated.

6. Spatial analysis¹³

6.1 Introduction

The wetlands project focuses on the Dutch Vechtstreek region. The Vechtstreek region contains peatlands, polders, lakes, a *stuwwal* (glacial hill) and the river Vecht.

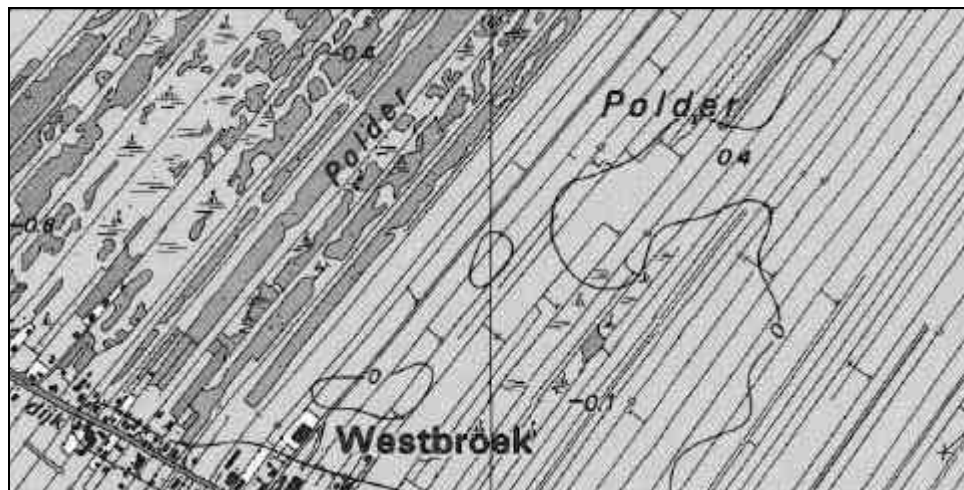


Figure 6.1 A peat landscape is easily recognised on a topographic map because of its characteristic parcelling

Natural and societal processes in wetlands take place on different scales of time and space. Chemical processes can be studied on a very detailed scale, whereas socio-economic systems are studied over larger areas and timeframes. Due to these different scale levels of research, the spatial component of natural and social processes can be an integrating as well as a dividing element in wetlands research. To connect projects with different scale levels with each other, up scaling and down scaling of relevant parameters will be necessary to study the spatial interactions of different processes. The idea of scale, and terms like scaling up and scaling down, are applicable on both spatial data and models that describe spatial processes. For this multi discipline research a common spatial database will be designed and implemented as an integral analytical tool.

Spatial data are distinguished from other data because they have, besides a thematic part, a geographical part. This geographical part describes on one hand the shape and place of a spatial object in an absolute way (metrics). At the other hand, it describes the place in relation to other spatial objects (topology). For both the geographic and thematic part of the spatial data this description of reality is made on a certain time and with a certain quality (modality). The geometrics of an object can have a vector based structure or a

¹³ This section has been written by Nancy Omtzigt.

raster based structure. These properties of spatial data, data about the data, are called meta information or meta data.

6.2 Space within each project

Some spatial information about the projects according to the expectations of the researchers is represented in table 6.1. In the columns are the research scale, the main spatial criteria for the experimental sites, main spatial parameters of the concerning project, availability of spatial data, if the project will work with spatial models and if methods like geo statistics are expected to be needed.

Table 6.1 *Space within each project.*

Project	Indication of scale	Criteria experimental sites	Spatial parameters	Spatial data	Spatial model	Geo statistics
1	region to stand, differences in scale are object of research	gradient groundwater level	ground water level, soil moisture, vegetation, soil, groundwater withdrawal, geohydrological layers, DEM	likely to be available & fieldwork	yes	Interpolation of data
2	region to stand, resolution of several metres	Biotic and abiotic gradients: vegetation, nutrients; accessibility of the area	Water quality parameters, vegetation characteristics	RS data available, fieldwork, input to and from project 1 and 5	yes	yes
3	organism, stand	gradient groundwater level	nutrients, soil moisture, ground water level	input from projects 1 and 5	no	not clear
4	organism	-	-	no need	no	no
5	stand	gradient groundwater level	ground water level, vegetation, soil moisture, meso and micro fauna, nutrients, groundwater quality.	likely to be available & fieldwork, input from project 1	no	Interpolation of data
6	landscape, ecotope	peat area with raising ground water level	recreational pressure, ecotope type	likely to be available & fieldwork, input from project 5	yes	no
7	landscape, regional, ecotope	-	polder (water management system), ecotopes	Likely to be available, input from projects 1, 5 and 6	yes	uncertain
8	region	-	land use parameters	likely to be available	yes	yes
9	whole Vechtstreek (region)	-	depends on criteria stakeholders	likely to be available, depends on stakeholders	yes	no

A region contains different landscapes, like a polder landscape and a peat landscape. A landscape consists of several ecotopes, like reed and open water. A stand is the direct environment of an organism. A stand usually has the dimensions of one or several square metres. But if a 1 m² stand is represented on the scale of a region or landscape, the metric attributes like shape and size seems to disappear and only the location is left. Look at figure 6.1 too see that all canals are represented as lines, where at the scale of a stand they will be represented as areas.

Research takes places on a certain scale, but scale and linking of scales can be a research object themselves like in project 1 “Linking the regional and site scales in ecohydrological modelling for integrated water management”.

If spatial data is likely to be available, it means that data sets with the desired themes are available. If these data sets have the right scale and accuracy is uncertain because the scale and accuracy necessary is not known yet. For project 9, the data need depends mainly on the choices of the stakeholders. Interpolation of data is a way of up scaling of point data to area data.

For project 1, Linking the regional and site scales in ecohydrological modelling for integrated water management, scaling of time and space are part of the research. During the research, the focus will become more and more detailed. On a detailed scale, processes on a greater scale level are assumed to be static. In hydrologic science, zooming out on the research location during the research period is more common then zooming in.

At a detailed scale, other parameters become relevant. Hydrologic conductivities of water bearing layers is are important at the regional level, at the parcel level heterogeneity of local geology and the micro-relief are important.

Gradients from wet to dry are chosen as research locations, in co-operation with project 5.

For project 2, Remote Sensing approach to study scale aspects and functioning of wetland ecosystems, the Vecht area will be studied on different scales. Information captured from remote sensing images will be compared with data from project 1 and 5.

Project 3, Development of chemical indicators to characterise wetland ecosystems, follows project 5 in the location of research areas. The gradient from wet to dry is important, other parameters must be homogeneous. Point measurements are taken at 1000 or 10.000 spots. These point data can be interpolated to make area data.

For research project 5, Effects of changes in hydrology on ecological and chemical characteristics of wetlands, it is necessary to choose the same research locations as project 1, because hydrologic data will flow from project 1 to project 5. The parameter groundwater level can differ in several ways. The groundwater levels in history can be different from the actual groundwater level. There is also a difference in the seasonal groundwater changes. Parameters like pressure of cattle and micro relief must be homogeneous. A small area of about 10 m² is studied in detail, and this “point measurement” is representing the situation of a whole parcel.

Some measurements are very time-consuming, and will only be made on several location. Other types of measurements will be made for a more dense network of locations.

The spatial dimension of the data is not a research topic itself, but can help to provide extra insight in the ecological processes.

For project 6, Ecological and societal conditions for wetland restoration, the research locations are not necessarily all located in the Vecht area. This research is focused on typical Dutch problems like “vernatting” and “waterberging” in peat landscapes. This project is spatially strongly related to project 9 and project 3. With project 3, there is a difference in scale. For upscaling the data of project 3, the data has to be aggregated. Project 3 is focused on one ecotope, where project 6 focuses on several ecotopes. This means that data aggregation is not enough for scaling between projects 3 and 6.

Project 9, Conflict and compromise in wetland management, has the whole Vecht area as the research area. Preferences and processes are studied on a rather detailed scale, probably at the parcel level. This depends on the decision rules of the stakeholders of the Vecht area, and interaction with project 6. The spatial models that will be built for project 9 and project 6 are likely to be linked. The parameters that will be used in the model also depend on the stakeholders, but can be predicted to be attainability, water quality etc. It would be interesting if project 1 could sketch the hydrologic situation in the land use structure suggested by the stakeholders.

6.3 Possible spatial struggles

For data availability, organisations like the National Clearinghouse for Geographic Information (NCGI) offer help on the search for data by acting as a data broker. They represent several main data suppliers.

Beside data availability, data accessibility can be a handicap in spatial analysis. For example the data can be physically available at the computer network of the research group, but not accessible because presence or existence of the data is unknown. Or information about the format, scale and accuracy are absent so utility of the data set is obscure. Data does not always have the correct format, the demanded scale, the desirable accuracy or the desired date. GIS techniques like interpolation and data conversion can solve some of these problems.

Many projects need input from another project, especially from projects 1 and 5. Differences in scale can obstruct data flow through the projects, if the output data of one project cannot be converted to input data for the other project. Study results of one landscape type cannot be upscaled for the whole region, if the region also contains other landscape types. But the results can be upscaled to represent all areas in the region with that specific landscape type.

6.4 Possible solutions

Most projects of *Wetlands in the Randstad* have a strong spatial component. The Vrije Universiteit is establishing a SPIN-lab, for the support of education and research projects with a spatial component. The SPIN lab will help to build a spatial database for the Wetlands projects, and to perform analyses on the spatial data.

This spatial database will contain; topographic data, vegetation, soil, geo hydrological layers, socio-economic data, land use and a DEM (digital elevation model) to start. Re-

sults from each project can be added. For good accessibility of the data in the database, a meta data system will be made. This meta data system will contain information about e.g. maker and quality of the spatial data sets.

National and regional data on geology and hydrology are available at the Netherlands Institute of Applied Geoscience TNO. Digital topographic maps on different scales are distributed by the *Topografische Dienst Nederland* (Topographic Service Netherlands). Alterra-DLO offers for example soil maps, the *Landschapsecologische Kartering Nederland* (Landscape ecological map) and land use maps. The *Centraal Bureau voor de Statistiek* (Central Office for Statistics) has mainly socio-economic data, but also data on e.g. pollution and vegetation. The provincial governments have data of their environmental monitoring network. Organisations like SOVON and FLORON collect data from voluntary researchers about vegetation (FLORON), birds (SOVON) and other animals. Some data sets are rather expensive, other data sets are distributed for free.

A meta data system with information on time and quality of the metric and thematic properties will help find the right data, and to use that data right. A meta data system contains for all the data sets information on the data source, date of data capture, type of data capture (RS, fieldwork), alteration from data capture to map publication (like interpolation, simplification), date of map publication, scale, projection, coordinate system, coverage of the data set, accuracy of metric attributes, accuracy of thematic attributes and references to possible legend files or lookup tables for classification. Such a meta database system can be developed in a common database application like MS Acces. Professional meta data bases like GeoKey have additional skilful features.

The decision in which data format a data set must be available will depend on the data type and the analyses you want to perform on the data set. If the values in the data set are continuous, a raster format is necessary to store these values. Vector data is better for representation of topology and geometry. Conversion of vector data into raster data is easier than conversion of raster data into vector data. If a data set is used for very different type of analyses, it can be necessary to store that data set both as a raster and a vector set.

6.5 Hardware and Software requirements

Geographical Information Systems are developed to store, maintain, analyse and to make output (maps, tables, charts) of spatial data. Hardware requirements to run a desktop GIS like ArcView are a Pentium II or III 300 MHz processor with 128 MB intern memory and a minimum of 8 GB hard disk capacity for storage of the data for the main datastorage system, and 2 GB for other systems. For raster data sets ArcView will be extended with the Spatial Analyst. With the use of the object oriented programming language Avenue, ArcView and the Spatial Analyst can be customised to fit the individual needs of project participants. For processing very complex data sets, Arc/Info on UNIX workstation or Windows NT is needed. Additional software for specific raster analyses is Idrisi.

A meta data system can be bought from a commercial office, or it can be developed using common office software like MS Acces or MS Excel.

7. Scenarios

7.1 Introduction

Various definitions of scenarios exist. An early definition is that of Kahn and Wiener (1967) who define scenarios as hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points. Rienstra (1998) identifies two approaches towards the definition of scenario: the American approach which distinguishes between scenarios and management strategy, and the French approach in which the management strategy is part of the scenario. The IPCC (IPCC, 1994) takes a different approach again, defining a scenario as “a coherent, internally consistent and plausible description of a possible future state of the world”.

For the purposes of *Wetlands in the Randstad*, a distinction is made between ‘scenario’ and ‘vision’. The latter addresses possible future states, as envisaged by stakeholders, and subject to elucidation and analysis by project 9 (see Section 4). This analysis will also include stakeholder assessments of how such futures could be achieved. The former corresponds to a set of conditions which can be specified within models, in an attempt to achieve a particular vision and to deduce its implications. Implications include not only as assessment of how viable a particular vision is, but also its costs and benefits, both monetary and non-monetary. The possibility also exists for back-casting – identifying what settings for selected scenario elements would be needed to create a vision.

From this perspective on scenarios, two different types of elements need to be considered to explore the future of study area:

- The management strategy: actions which can be deliberately undertaken to steer the system towards a particular future; and,
- exogenous factors: events, actions, etc. which influence the system but over which regional managers have no influence, e.g. climate, Brussels.

The following sections briefly discuss a selection of elements from these two categories which could be included in *Wetlands in the Randstad*. At this stage no base year has been identified for application of the scenarios, although a time span of 30 years backwards to 30 years into the future has been recommended by the Steering Committee.

7.2 The Management Strategy

The management strategy comprises a set of actions (or measures) which can be undertaken by regional managers to steer the regional system towards a desired future. A set of different strategies, comprising different measures and/or their specification, will be developed. Each measure is to be specified according to four components:

- the goal of the management measure;
- intensity of measure;
- where the measure is to be applied;
- consistency with other measures; and
- when and over what period the measure is to be applied.

The following illustrates this specification for the key measure being investigated in *Wetlands in the Randstad*, namely ‘vernatting’.

‘Vernatting’

The key management measure being investigated in *Wetlands in the Randstad* is ‘vernatting’ or higher water levels. Much of the study area is subject to water management and drainage of water to 40 cm below ground level. While permitting certain land uses such as agriculture, low water levels create problems for wetlands, both on-site and off-site. On-site, low water levels are directly detrimental to many wetland plant species. Wetland restoration and the maintenance a larger ecological infrastructure (see Section 2) is dependent on releasing these controls. Low water levels may also trigger drainage from adjacent polders where water levels are higher, and so compromise off-site wetland maintenance or restoration. Examples include loss of water from Naardermeer as a result of low water levels in surrounding polders (e.g. DHV Water, 1993), and the reclaimed Horstermeer polder which drains water from adjacent Ankeveense and Kortenhoefse lakes (Van der Klift, pers. comm.).

The goal of this measure is the restoration of boundary conditions (largely water quantity) for the development of wetland plant communities.

Table 7.1 provides a classification according to water levels. The intensity of this measure within *Wetlands in the Randstad* is dependent on its capacity to predict subsequent ecosystem changes. The capacity to predict terrestrial ecosystem responses is linked to research being undertaken and/or culminating in project 5 (see Figure 5.2). These will be (selectively) assessed for water levels varying from their current level through a limited number of intermediate steps to ground level. Water levels at ground level are expected to lead to the development of ‘plas-dras’ communities. The ecological effects of polder inundation (i.e. water levels approximately 1 m above ground level) will not be addressed by project 5, although some information may be gleaned from literature and from experience elsewhere in the Netherlands. Inundation is of interest, particularly to projects 6-9, as it could provide three benefits to the system: the restoration of hydrological gradients; income via recreational use of the artificially-created lake (this aspect determines the depth of water); and increased prices for housing (as a proxy for the societal value place on nature).

Table 7.1 Classification of water levels relative to ground level (Runhaar et al., 1999)

Average Spring Water Level	Average Lowest Water Level	Water Stress	Category
> 50 cm			Deep water
20-50 cm above	> 0		Shallow, permanent water
20-50 cm above	0		Shallow water which may become dry
0-20 cm above			Very wet
0-25 cm below			Wet
25-40 cm below			Very damp
> 40 cm below		None	Damp
> 40 cm below		Limited	Just damp
> 40 cm below		Stress	Dry

Three water level settings, in addition to one in which water levels do not change, will be considered within the measure ‘vernattting’: between 10 and –20 cm below ground level; ground level; inundation. Whether these levels are expressed as average spring levels or average annual levels is not yet clear. If the former, then these levels correspond to the categories wet, very wet and deep water.

Both in practice and in the analysis, water levels cannot be raised uniformly over the study area. ‘Vernattting’ must have a spatial specification. Plans for raising water levels exist or are being implemented for two general areas: Naardermeer and Horstermeer polder. However a region-wide approach is needed which takes on board current hydrological gradients and how they may be restructured to support wetland restoration.

As an illustration, Table 7.2 shows the polders selected for wetland restoration via ‘vernattting’ in the ECOWET project (Van den Bergh *et al.* 1999). Water levels were also raised, although to a lesser extent, in an additional 25, largely agricultural polders which remained under this land use. The goal of ‘vernattting’ in this project was generally to support the nature corridor running north-south through the study area, and in particular where deep polders (notably Horstermeer and Bethune polders) cause drainage which leads to a narrowing of the corridor. The specific reason for raising water levels in each polder is also indicated in Table 7.2. Two polders, Horstermeer polder and Heintjesrak en broeker polder noord were also selected for inundation in one of ECOWET’s scenarios.

ECOWET specified its scenarios at the spatial level of the polder. This level may not be suitable for *Wetland in the Randstad*. Current implementation of ‘vernattting’ make uses of ‘sawas’, in which small dykes or ‘kades’ are constructed around meadows within polders to prevent their higher water levels from having adverse effects on neighbours (Van Brussel, 2000). This implies that scenarios may need to consider a smaller spatial scale than the polder, at least in select instances. Such a small spatial scale will not be relevant for the whole study area, and so the spatial specification within scenarios is likely to consist of a mix of spatial scales.

Table 7.2 Polders selected for ‘vernattting’ in the ECOWET project.

Polder	Goal
Keverdijkse overscheense polder	Support for Naardermeer
Nieuwe keverdijkse polder noord	Support for Naardermeer
Heintjesrak en broeker polder noord	Wider corridor near Horstermeer polder
Heintjesrak en broeker polder zuid	Wider corridor near Horstermeer polder
Hilversumse ondermeent	Wider corridor near Horstermeer polder
Horstermeer polder	Reduce drainage
Het Hol	Support for continuous corridor
Oostelijke binnenpolder van Tienhoven	Wider corridor near Bethune polder
Polder Westbroek west	Wider corridor near Bethune polder
Egelshoek	Wider corridor near Bethune polder
Polder Bethune	Wider corridor near Bethune polder
Molenpolder noord	Wider corridor near Bethune polder
Bethune polder	Reduce drainage

Where ‘vernattig’ will be tested requires first that the measure’s goal acquire a spatial specification. At the very least, *Wetlands in the Randstad* will apply this measure to areas in the vicinity of Hortstermeer polder and Naardermeer. The vicinity of Bethune polder is also likely to be considered. The spatial scale of this specification is still unclear, but will probably vary from the meadow level to groups of polders, as needed.

Measures may be interdependent and checks on the consistency of measures within each management strategy will be needed. Higher water levels conflict with a number of existing land uses, and it may be necessary to change land use or ownership before this measure can be implemented. Higher water levels cannot occur on land with certain uses. Drainage, particularly in early Spring, is undertaken to facilitate agricultural activities, and so this land use conflicts strongly with higher water levels. However it is worth noting that farmers owning land near Naardermeer have made an agreement with Natuurmonumenten to raise water levels on their land (Lemmen, pers. comm.). Conflicts also exist with infrastructure (transport links, sewage treatment plants), with housing and with the a number of country estates located in ‘t Gooi and along the river Vecht itself. Raising water levels will require either changes in its designated use, and/or land acquisition. Natuurmonumenten has acquired land in the vicinity of Naardermeer and in Horstermeer polder where water levels have subsequently been raised.

The polders listed in Table 7.2 and targeted for ‘vernattig’ in the ECOWET project represent 26% of land currently under agricultural use in the study area. A further 33% of agricultural land remained agricultural but with higher water levels, leaving 41% untouched by ‘vernattig’. ECOWET’s analysis included costing acquisition of agricultural land and loss of productivity associated with higher water levels. Table 7.3 lists non-agricultural polders where ‘vernattig’ was not considered. Note that of 72 polders in the region, 33 polders were not targeted for ‘vernattig’, and that 22 of these are largely under agriculture.

Table 7.3 Polders not under agricultural use and also unsuitable for ‘vernattig’ in the ECOWET project

Polder	Land use
Naardermeer	Protected nature
Hilversumse Meent	Urban
Spiegelpolder	Largely open water
Overmeer	Largely urban
Waterleiding plas	Open water
Loenderveense plas	Open water
Loosdrecht	Urban
Tienhovense plassen	Open water
Vliegveld Hilversum	Airport
Utrecht	Urban
Maarsse	Urban

Wetlands in the Randstad will make explicit choices as to where ‘vernattig’ will take place and will also take into account changes to land use and/or productivity as a result of implementing this measure.

The issue of when this measure is to be applied is not one of this year versus next year or in ten years. It is more whether water levels will be raised in one time step, or gradually over several time steps, and the season in which these changes are implemented. It is hoped that project 5, in conjunction with projects 2, 3 and 4, will provide information as to whether the staging of water level rises results in different ecosystem responses.

The need for any further specification of time for management measures in general is somewhat uncertain. The models being developed in projects 6 and 9 are static, and it is not yet clear whether the hydrological model will be temporally dynamic.

A further issue is whether water levels are to be specified in terms of annual or spring average.

The main time component which will require specification is whether water levels are raised in one or a series of steps.

7.3 Exogenous factors

Exogenous factors are events or actions over which regional managers have no influence. They are likely to apply to the whole study area, and so no spatial disaggregation should be needed. Whether a time dimension will need to be specified will depend on the models being developed, and in particular whether they are dynamic and whether they can accommodate seasonal events. Three general categories of exogenous factors are identified and briefly discussed: climate, economic factors, and policy.

Scenarios may take on board extreme climatic events as well as average conditions. Extremely wet conditions, usually during Winter-Spring, are less interesting than extremely dry conditions during Summer. The latter is one source of the environmental issue of 'verdroging' or desiccation, in which the combination of insufficient rain and evapotranspiration in dry periods reduces soil water levels. This has a direct and adverse effect on wetland species through water stress, as well as triggering mineralisation of organic soil and further nutrient enrichment.

Economic growth is a common exogenous factor in scenarios, and the rate is usually fixed as a constant over time. It is as yet uncertain whether models will be dynamic in time. If not, this element may not be relevant as it will not be possible to assess the impact of economic growth.

Agricultural and nature policies at both national and European scales could easily affect activities in the study area. Examples of current policies include:

- Relatie nota which provides incentives for farmers to mow their land at certain times, and so to retard the natural rate of succession in wetlands;
- EU Bird and Habitats Directives, and their combination within Natura 2000
- Common Agricultural Policy
- Natuurbeleidsplan (Nature Management Plan)
- Nota Landschap (Report on Landscape)
- Groene Ruimte (Green Space)
- Vierde Nota Waterhuishouding (Fourth Report on Water Management)
- Vijfde Nota over de Ruimtelijke Ordening (Fifth Report on Spatial Planning)
- Provinciale Waterhuishoudingsplannen (Provincial Water Management Plans)

The scenarios could anticipate future policy developments as well as changes to the relevance of these policies to the study area.

7.4 Scenario analysis

In an integrated project, scenarios would be developed for analysis by a suite of models simulating key processes. While models are being developed within *Wetlands in the Randstad*, it is unlikely that formal scenario analysis will take place. Projects 1 and 6 will develop models of the study area. The model from project 1 will reflect water quantity and, to a lesser extent, quality. It will also include variables representing water management. The model from project 6 will attempt to predict (select) ecosystem changes triggered by the various elements of the scenarios, then estimate the societal significance placed on such changes. The two models from projects 1 and 6 will not be formally linked, and the model from project 6 is likely to be more conceptual than computational. Even so, the scenarios will provide a set of bounds for investigating system behaviour using these models, and the models will generate output to permit evaluation of possible regional futures.

8. Personnel and organisation

Three levels of organisation are evident in *Wetlands in the Randstad*.

Firstly, *Wetlands in the Randstad* will be co-ordinated and supported by IVM staff.

- Prof. P. Vellinga will be responsible for developing and maintaining the strategic coherence of the research programme and will chair meetings of a Steering Committee which overviews the project.
- Ms. A. Gilbert will be responsible for the daily operational co-ordination. The latter includes two crucial activities. Firstly, the co-ordinator will guide the development of the conceptual framework for economic-environmental interactions. Secondly, the co-ordinator will guide the participants in working towards a discrete set of scenarios which will provide common and base conditions for assessing changes in the system.
- Ms. Nancy Omtzigt will have the task of designing and implementing the common spatial data base as an integrating analytical tool among projects.

Secondly, research activities, and in particular interdisciplinary cooperation, will be overviewed by a Steering Committee comprising representatives of the relevant VU faculties and the individual projects. The composition of this group is given in Table 8.1. Secretarial support for the Steering Committee is provided by Ms. D. Smit.

Table 8.1 Composition of the Steering Committee for Wetlands in the Randstad.

Name	Faculty	Task/project responsibility
Prof. P. Vellinga	Institute for Environmental Studies	Chair, Project 6
Ms. A.J. Gilbert		Co-ordinator, Project 7
Ms. A.Q.A. Omtzigt		GIS support
Dr. S.W.M. Peters		Project 2
Prof. I. Simmers	Earth Sciences	Projects 1
Prof. C. Gooijer	Exact Sciences/Chemistry	Project 3
Prof. W.H.O. Ernst	Biology	Project 4
Prof. M.A.P.A. Aerts		Project 5
Prof. P. Rietveld	Economic Sciences and	Project 8
Prof. J.C.J.M. van den Bergh	Econometrics	Project 9

The third level of organisation involves the individual projects and their disciplinary basis. Table 8.2 lists the projects, the researchers and their respective roles. To facilitate quality research which stretches beyond traditional disciplinary boundaries, pairs of the key researchers representing adjacent disciplines will supervise the individual projects. The first supervisor is responsible for the scientific quality within a project's home discipline. The second supervisor is responsible for quality at the interface with an adjacent discipline. A number of projects also have co-supervisors and/or daily supervisors. This allows the inclusion of researchers with specific expertise relevant to the project.

Of these nine projects, six are being undertaken by Ph.D. students (OIO's) and three (projects 6, 7 and 9) by more experienced researchers. These three projects have higher ambitions with regards to disciplinary integration than the other individual projects.

Wetlands in the Randstad officially began on 1 September 1999 and will run until the end of 2003. The first or inception phase is completed with the production of this document.

Table 8.2 *Projects, participants and roles*

No.	Title	PhD Candidate or Post-doctorate	Supervisor from primary discipline	Supervisor from secondary discipline	Other supervision
1	Linking the regional and site scales in ecohydrological modelling for integrated water management	Leontien Gorter	Prof. I. Simmers (Earth Sciences)	Prof. P. Vellinga (IVM)	M. Stam (Earth Sciences) Dr. T. Hobma (ITC)
2	Remote sensing approach to study scale aspects and functioning of wetland ecosystems	Marnix Laanen	Prof. I. Simmers (Earth Sciences)	Prof. P. Vellinga (IVM)	Dr. S Peters, Ms. M. Rijkeboer (IVM) Dr. J. Van Huissteden (Earth Sciences) Dr. T. Hobma (ITC)
3	Development of chemical indicators to characterise wetland ecosystems	Eva de Rijke	Prof. C. Gooijer & Prof. U. Brinkman (Chemistry)	Prof. R. Aerts (Biology)	Dr. F. Ariese (Chemistry)
4	Steering of ion channels by metals	Emma Jack	Prof. W. Ernst (Biology)		Dr. J. Verkleij (Biology) Dr. H. Schat (Biology)
5	Effects of changes in hydrology on ecological and chemical characteristics of wetlands	Jerry van Dijk	Prof. R. Aerts (Biology)	Prof. P. Vellinga (IVM)	Dr. H. Verhoef (Biology)
6	Wetland goods and services as a function of spatial and environmental management strategies	Hasse Goosen	Prof. P. Vellinga (IVM)	Prof. R. Aerts (Biology)	
7	Performance indicators for the co-evolved capital of Dutch wetlands	Alison Gilbert	Prof. H. Verbruggen (IVM)	Prof. N. van Straalen (Biology)	
8	Wetlands in integrated land use models	René van der Kruk	Prof. P. Rietveld & Prof. J. van den Bergh (Economics)	Prof. H. Scholten (Economics)	
9	Conflict and compromise in wetland management	Marco Janssen	Prof. P. Rietveld & Prof. J. van den Bergh (Economics)	Dr. R. Janssen (IVM)	

References

- Anon. (1975). Nota betreffende de relatie landbouw en natuur- en landschapsbehoud - Gemeenschappelijke uitgangspunten voor het beleid inzake de uit een oogpunt van natuur- en landschapsbehoud waardevolle agrarische cultuurlandschappen. (*Report on the relationship between agriculture and the conservation of nature and landscape*). Tweede Kamer, zitting 1974-1975, 13 285, nr. 1-2. Staatsuitgeverij, 'sGravenhage 1975.
- Anon. (1994). *Convention on Wetlands of International Importance especially as Waterfowl Habitat, Ramsar, Iran*, 2 February 1971, as amended by the Protocol of 3 December 1982 and the Amendments of 28 May 1987. United Nations Educational, Scientific and Cultural Organisation (UNESCO), Paris, 13 July 1994.
- Bergh, J.C.J.M. van den, A. Barendregt, A.J. Gilbert, M. van Herwijnen, P van Horssen, P. Kandelars and C. Lorenz (2000). *Spatial economic-hydroecological modelling and evaluation of land use impacts in the Vecht wetlands are*. Discussion paper TI 2000-07/3, Tinbergen Institute, Amsterdam.
- Brussel, J. van (2000). Sawa's in de polder. *De Water - nieuwsbrief over integraal waterbeheer*. pp 9-10, January 2000.
- DHV Water (1993). Herstelplan Naardermeer (*Restoration Lake Naardermeer*). Dossier F1312-10-100, Mei 1993. 198 pp.
- Hammond, A., A. Adriaanse *et al.* (1995). *Environmental indicators: a systematic approach to measuring and reporting on environmental policy performance in the context of sustainable development*. World Resources Institute, Washington DC.
- IPCC (1994). *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*. Prepared by Working Group II [Carter, T.R., M.L. Parry, H. Harasawa and S. Nishioka (eds.)] and WMO/UNEP. CGERIO15-'94. University College London, UK and Center for Global Environmental Research, National Institute for Environmental Studies, Tsukuba, Japan, 59 pp.
- Jorna, F. J. (1995). *Natuur van het zuiverste water*, deel 4: Hydrologisch deelrapport. 's-Graveland, vereniging Natuurmonumenten
- Kahn, H. and A.J. Wiener (1967). *The year 2000: A framework for speculation on the next thirty-three years*. The MacMillan Company, New York.
- LNV (1990). *Natuurbeleidsplan (Nature Policy Plan)*. Ministerie van Landbouw, Natuur en Visserij (Ministry of Agriculture, Nature and Fisheries), Den Haag.
- LNV (1996). *Structuurschema Groene Ruimte (Report on Green Space)*. Ministerie van Landbouw, Natuur en Visserij (Ministry of Agriculture, Nature and Fisheries), Den Haag.
- Organisation for Economic Co-operation and Development (1994). *Environmental indicators: OECD core set*. OECD, Paris, 77p.
- Provincie Noord-Holland (1995). *Gebiedsperspectief voor de Vechtstreek (Regional Plan for the Vecht Area)*. Beleidsnota, Provincie Noord-Holland, Haarlem (Perspective for Vechtstreek Area, Policy Note).
- Provincie Utrecht (1996). *Plan Veiligstelling Gebieden (Plan Nominated Areas)*. Casparie Utrecht, Utrecht.
- Rienstra, S.A. (1998). *Options and barriers for sustainable transport policies: a scenario approach*. Department of Spatial Economics, Vrije Universiteit, Amsterdam. 254 pp.
- Runhaar, J., H.L. Boogaard, S.P.J. van Delft, S. Weghorst (1999). *Natuurgericht Landevaluatie-systeem (NATLES)*. DLO-Staring centrum/Alterra. Rapport 704, Wageningen.

- R. K. Turner, J.C.J.M. Van den Bergh, I. J. Bateman, R. Brouwer, S. Georgiou, I.H.J. Langford, N. Powe, L. Ledoux, S. Crooks, E. Bos, P. Kandelaars, B. Rabeling, M. Green, A. Barendregt, P. Van Horsen, J. van der Straaten, A. Gilbert, C. Lorenz, M. van Herwijnen, M. Skourtos, A. Troumbis, T. Söderqvist, A-S. Crépin, I-M. Gren, Å. Jansson, T. Lindahl, H. Scharin, Dr. O. Byström, J. Lundberg, Dr. G. Destouni, M. Sandström, E. Maltby, M. Blackwell, J. Burgess and J. Clark (1999). *Ecological-Economic Analysis Of Wetlands: Functions, Values And Dynamics (ECOWET)*. Final report of the ECOWET project, ENV4-CT96-0273, sponsored by DG-XII, European Commission, Brussels.
- VROM (1990). *Vierde Nota over de Ruimtelijke Ordening (Extra)*. Ministerie Volksgezondheid, Ruimtelijk Ordening en Milieu (Ministry of Public Housing, Spatial Planning and Environment), Den Haag.